PREDICTING HEAT LOAD INSIDE THE CATTLE SHELTER BY ANALYZING BIOTIC AND ABIOTIC FACTORS IN TROPICAL HUMID ZONE

by

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(2015 – 20 - 015)

THESIS

Submitted in partial fulfilment of the

requirements for the degree of

B.Sc. – M.Sc. (Integrated) Climate Change Adaptation

Faculty of Agriculture

Kerala Agricultural University

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH
VELLANIKKARA, THRISSUR – 680 656

KERALA, INDIA

2020

DECLARATION

I, hereby declare that the thesis entitled "**PREDICTING HEAT LOAD INSIDE THE CATTLE SHELTER BY ANALYZING BIOTIC AND ABIOTIC FACTORS IN TROPICAL HUMID ZONE**" is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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<u>CERTIFICATE</u>

Certified that the thesis entitled "**PREDICTING HEAT LOAD INSIDE THE CATTLE SHELTER BY ANALYZING BIOTIC AND ABIOTIC FACTORS IN TROPICAL HUMID ZONE**" is a record of research work done independently by **Ms. Divya Sasi** under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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ACKNOWLEDGEMENT

I would like to extend my sincere thanks to all people who have contributed to the successfulness of this thesis.

Heartily, I would like to express my sincere gratitude and a deep sense of obligation to the Chairman of the Advisory Committee **Dr. S. Harikumar**, Assistant professor, Department of Livestock Production Management, CVAS, Mannuthy, for his persuasive, inspirational and impeccable guidance. His valuable advice, insightful comments, and encouragement keep me in tract and creative suggestions to improve the quality of research.

I express my thanks to **Dr. P.O Nameer**, Special officer, Academy of Climate Change Education and Research, KAU, Vellanikkara for his suggestions, inspiring comments and moral support for the accomplishment of this thesis.

I feel obliged to **Dr. V. Beena**, Associate Professor and Implementing Officer CAADECCS, KVASU, Mannuthy and member of my advisory committee for her constant encouragement, warm support and valuable advices. And also providing me facilities during the course of my studies as well as motivated me to embark on this academic journey.

I express my heartfelt gratitude to **Dr. A. Prasad**, Assistant Professor, Dept. of Livestock Production Management, CVAS, Mannuthy, and member of my advisory committee for his scrupulous guidance, advices, valuable and timely suggestions given during my study.

Words are not enough to express my sincere gratitude to **Dr. Gleeja V. L**, Assistant Professor, Dept. of Statistics, CVAS, Mannuthy for her supporting attitude and pleasant co-operation rendered to me as a member of the Advisory committee in the pursuit of this work. Her valuable help and suggestions in analysing the data helped to improve the quality of thesis.

I respectfully thank **Dr. Gopakumar C.S**, Scientific officer, Academy of Climate Change Education and Research, KAU, for his invaluable blessings and comments regarding my research work. The useful discussions I had with him, both inside and outside the college, were always a source of inspiration to me.

I owe my sincere gratitude to **Smt. Famey V Mathew**, Assistant director, Dairy development board for the cooperation and help rendered during the research work.

I would like to extend my sincere gratitude to the Dairy Extension Officers **Sri. Rajesh Kumar** (Nedumkandam Block), **Smt. Jasmine.S** (Pattambi Block) and Secretaries of Dairy Cooperative Societies **Sri. Sudeeran** (Chirakkekode), **Sri. Krishnan** (Valakkavu), **Sri. Vishnu Ramachandran** (Cumbummedu), **Sri. Somanath A.K** (Veliyanadu), for their will full cooperation, timely assistance and enlightened response in carrying out the survey work.

I extend my sincere gratitude to **Mr. Afsal Ayoob**, former Research Fellow, CAADECCS, Mannuthy for his support, suggestions and immense help from the framing till the end of the work.

I wish to express my heartfelt thanks to **Mr. Adharsh C.J** for his valuable help in field visits.

I sincerely thank **Sri. Sibi Mathai, Sri. Kannan, Sri. Muralidharan, Sri. Abin Philip, Sri. Manoj Kumar** for their valuable help in field visits and safeguarding transportation facilities to remote areas.

I express my sincere gratitude and thanks to the **dairy farmers of Chirakkekode**, **Valakkavu, Muthuthala, Pattambi, Moncombu, Chambakulam, Veliyanad, Cumbummedu**, blocks for giving me all support and cooperation without which this work could not have been completed.

I respectfully thank **Kerala Agricultural University and Academy of Climate Change Education and Research** authorities for providing all the support to complete this work. I am greatly indebted to the **Centre for Animal Adaptation to Environment and Climate Change Studies (CAADECCS), KVASU** and **Implementing officer** for providing all the amenities for the research programme. I am happy to thank all the **faculties, staff and workers of College of Veterinary and Animal Sciences, Mannuthy** for their support and help.

__Meenakshi Priyadharshini and Swathy. S__ deserves a special mention for her invaluable help and constant support till the last minute of the work.

My heartfelt thanks and love to all my classmates of __Exemiers-2015__, for their support given to me during the whole college days.

I am sincerely thankful to all the __teachers, students and staff of Academy of Climate Change Education and Research__ for their support. I express my sincere gratitude to __my parents and other family members__ for their support during my research program.

Above all, I gratefully bow my head before the Almighty, for the blessings showered upon me in completing the thesis successfully.

Lastly I offer my regards to all of those who supported me in any respect during the completion of the project.

Divya Sasi

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ABBREVATION

BGHI	Black Globe Humidity Index
CCI	Comprehensive Climate Index
DESU	Dairy Extension Service Units
ERHL	Effective Radiant Heat Load
ESI	Environmental Stress Index
ETI	Equivalent Temperature Index
GI	Galvanized Iron
HLI	Heat Load Index
ITSC	Index of Thermal Stress for Cows
LPHSI	Livestock and Poultry Heat Stress Index
LWSI	Livestock Weather Safety Index
RCC	Reinforced Cement Concrete
RH	Relative Humidity
SR	Solar Radiation
Ta	Air temperature
T_{bg}	Black globe temperature
T_{db}	Dry bulb temperature
T_{dp}	Dew point temperature
THI	Temperature Humidity Index
THI_{adj}	adjusted THI
T_{wb}	Wet bulb temperature
VP	Partial vapour pressure
WBGT	Wet Blub Globe Temperature
WS	Wind speed

CHAPTER 1

INTRODUCTION

Direct and indirect impacts of climate change, a global phenomenon, is bringing about serious consequences on the biophysical, economic, and social systems of life on earth (Nash *et al*., 2019). Scientific research over the past few decades has implicated the fingerprint of human activities on extreme weather events that happens from regional to the global scale (Hulme, 2014). Its repercussions and perturbations are not limited to a single nation or region of the world, or to a single generation. It sways throughout the globe down through the ages creating huge uncertainties (Rothman and Chapman, 1993). The Intergovernmental Panel on Climate Change (IPCC) through its fifth assessment report clarifies the anthropogenic influence on climate systems, as well as provides an ordered documentation for the trends and causes of climate change. We learn from the report the potential risks to human and natural systems. Two passwords to unlock this impasse are adaptation and mitigation (IPCC, 2013). The main sources of global climate change are the pollutions associated with energy use on local and regional scales, land-use change and urbanization (Karl and Trenberth, 2003). It is projected that the average temperature of the earth will be raised by an additional 2.0–4.9°C compared to the pre-industrial level, indicating about 100 times faster rise in temperature than what happened during the last 20,000 years (Raftery *et al.*, 2017).

National economies of many developing countries are very sensitive to climate change because large percentage of their population derives their livelihood from agriculture and allied sectors which lack the adaptive capacity to cope with uncertainties of climate (Ludwig *et al.,* 2007). Economy of a developing country like India crucially depends on the performance of this sector. More than 50 per cent of the population depends on agriculture for livelihood, employment in India and hence it is crucial in national food security (Madhusudhan, 2015). Livestock sector is the major sub-sector of agriculture and accordant with National Accounts Statistics (GOI, 2019a) its GVA (Gross Value Added) was 4.9 per cent for the year 2017-2018. Climate change is becoming a petrifying challenge to the progress and even the sustenance of the livestock sector in India because of its far-reaching consequences on the production of milk, meat, and wool (Kumar *et al*., 2015). Milk being the single largest agricultural produce, dairy farming is the largest component of livestock sector. Responses of dairy animals to their thermal environment are extremely varied, and managing them to reduce the negative impact of hot climatic conditions remains somewhat challenging to small and marginal farmers of the country. Only under a thermo neutral condition the dairy cattle can maintain its core body temperature between 38 °C and 38.5 °C (Lees *et al.,* 2019). During summer months, combination of environmental factors in particular the above normal atmospheric temperature, relative humidity, and solar radiation induces thermal stress resulting in reduced reproductive performance, milk production, reduced animal comfort, and even death rendering dairy industry less profitable (Hammami *et al.,* 2013).

Naturally, regions located close to equator (tropics) feel the heat of climate change utmost. Thermal stress is the major climatic constraint for livestock production in hot humid tropical environment. Kerala is located in south-western India, between 8°17′30′′ and 12°47′40′′ latitudes. It has an undulating terrain ranging from 0 to 2400m above sea level. This results in a wide range of climatic condition to exist in Kerala from a cooler climate of the high ranges to the hot and humid extreme of the plains.

The low yielding, dwarf, nondescript and Vechur breeds native to Kerala are hardy, resistant and adapted to the hot and humid environment. But they barely produce 793 kg milk per lactation even under well-managed condition. The evolution of Sunandini cattle from a group of cross-bred animals through selection as part of the Key Village Scheme under the five-year plan of government of India and later the Indo Swiss Project have greatly influenced the dairy economy of the state of Kerala by enhancing the productivity of the animal (Chacko, 2005). As per

Basic Animal Husbandry Statistics (2012), 93 per cent of the cattle population are crossbred in Kerala (GOI, 2012)

Several meteorological models have been established to foresee the magnitude of thermal stress in dairy animals. Majority of the heat stress studies in livestock are mainly focused on the effects of temperature and humidity on animal health. Temperature Humidity Index (THI) (Thom, 1959) has been generally acknowledged as a golden standard for quantifying the thermal status of the animal (Hahn *et al*., 2009). Later on, numerous other models have been established that had widespread application in livestock production and management, predominantly in the dairy sector. Feasibility of THI in computing the thermal stress has been questioned by many scientists (Mader and Davis, (2002), Eigenberg *et al*., 2005, Brown-Brandl *et al*., 2005, Gaughan *et al*., 2008) by raising the importance of wind speed and solar radiation, which are also identified as the main drivers of heat exchange. Furthermore, Gaughan *et al*., 2008, Eigenberg *et al*., 2005, Brown-Brandl *et al*., 2005 advocates that in conjunction with ambient thermal condition, indicators of animal thermal comfort should also be incorporated into the predictive models in order to develop a holistic model for representation of animal discomfort. Combination of immediate climatic condition and animal responses to changed environment will enable farmers to implement strategies to thwart severe impact hot weather conditions.

In addition to the external climatic condition, a variety of factors both biotic and abiotic including animal number and density, its physiological responses, influence of shade, the number and size of fans and sprinklers, and facilities designed to minimize the entry of solar radiation, orientation of shed all influence the environmental conditions inside the barn (Stowel *et al.,* 2003). Present study envisaged to develop a location specific meteorological model suitable to Kerala condition considering onsite measurement of climate data and animal responses. So location-specific thermal stress evaluation studies in cattle with respect to different agro-climatic zones of Kerala, evaluation of microclimate, and structural characteristics of the shelter are decisive for analysis and extremely relevant in today's context. Hence the objectives of the study within this thesis were conducted to;

- Assess the relationship between various meteorological, structural parameters and micro environment of cattle shed.
- Analyse housing designs and its impact on microclimate of cattle shed.
- Develop a meteorological model for scientific and reliable prediction of the microenvironment for constructing cattle shelter.

CHAPTER 2
REVIEW OF LITERATURE

2.1. GENERAL OVERVIEW

Livestock is a major factor in the growth of world agriculture. The demands for livestock products are increasing at a global level in order to satisfy the needs of a growing population. Globally, the human population is expected to increase by 2 billion persons in the next 30 years, from 7.7 billion today to 9.7 billion in 2050 for which food production will need to increase by 70 per cent (UN, 2019). Meanwhile, total global cultivated land area has not changed since 1991 (Rojas-Downing *et al.*, 2017). It was also estimated that in developing countries approximately annually 56 billion animals were reared and slaughtered for human consumption (FAO, 2008). In general it was approximated that, nearly one-third of global human protein consumption are animal products. In developing nations over the period 2008–2017 per capita requirement of meat is expected to increase by almost 13 per cent (Godber and Wall, 2014) and also it is estimated that global milk production will rise up to 1070 million tons by 2050 (Alexandratos and Bruinsma, 2012). But, sustainability of the livestock production system is seriously affected by climate change, especially when crosses of high yielding exotic dairy breeds were reared in a tropical environment (Das *et al.*, 2016). Accumulation and dissipation of heat energy from the animal body are seriously influenced by combination of above-normal environmental conditions and animal factors. It encompasses a significant challenge for the scientific community dealing with the livestock population in a tropical environment for enhancing its sustainability, reliability, profitability, and milk production (Das *et al.*, 2016). Microclimatic conditions significantly influence the productive performance and welfare of animals housed within the animal shelter. A range of factors in addition to climatological parameters such as structural specifications, stocking density, ameliorative intervention adopted to alleviate environmental stressors found to have decisive influence on microclimate, physiological indices as well as productive performance of the animals (Shock *et al*., 2016).

2.2. CLIMATE CHANGE

Climate change is arguably the most severe challenge facing our planet during the 21st century, is threatening the well-being of the next generation. According to UNFCC (1992), "a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods of time". Natural and anthropogenic parameters which alters the Earth's energy budget are key drivers of climate change. But modern climate change is caused by human activities which are now large enough to surpass the borders of natural variability. Alarming rise in the concentration of greenhouse gases in the atmosphere and positive radiative forcing, fluctuations in the global water cycle, reductions in snow and ice cover, sea level rise, and increased incidence of extreme weather events manifest the anthropogenic influence on climate system. Furthermore, various climate models projected that global average surface temperature will significantly rises between 2.6 and 4.8°C by 2100 and was predicted to continue into the future (IPCC, 2014). Instrumental observations of air samples since 1958 reveals that, greenhouse gases such as carbon dioxide, methane and nitrous oxide have long atmospheric lifetimes extending from decades to centuries and results in its accumulation and build up in concentration in the atmosphere. These gases are well distributed in the atmosphere across the globe and continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system (Karl and Trenberth, 2003).

2.2. CLIMATE CHANGE AND ANIMAL AGRICULTURE

Climate change is putting dire pressure on the ability of humanity to feed itself under the unprecedented rate in the exploitation of land and water resources (Flavelle, 2019). Rapid urbanization and improved standard of living in developing nations have created repercussions in the demand for livestock products, which will continue to increase in the coming decades and leads to the livestock revolution (Thornton *et al.*, 2009). The livestock sector is one of the fastest-growing segments of the agricultural economy, predominantly in the developing world, providing livelihood to the poor and weaker sections of the society and employs about 1.1 billion peoples across the globe (Rojas-Downing *et al.,* 2017).

Negative environmental implications resulting from greenhouse gas emission act as a deterrent for global livestock production (Baumgard *et al*., 2012). Both direct and indirect impacts of climate change poses greatest threat to the sustainability of livestock system (Faurès *et al*., 2013). Although, the livestock sector is the biggest sufferer of climate change and contribute to 14.5 per cent of human-induced GHG emissions (Gerber *et al.,* 2013a). Mitigation measures to attenuate emissions from this sector have some limits since it is imperative to ensure sufficient food supply for a growing world population (Baumgard *et al*., 2012).

2.2.1 Contribution of livestock sector to climate change

Livestock sector plays an important role in climate change by generating significant amount of greenhouse gas to the atmosphere such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Faurès *et al.,* 2013). These gases are either released directly from enteric fermentation, respiration, excretion and manure management or indirectly from feed production, processing and transport of animal products, and land use changes (Rojas-Downing *et al.,* 2017). Methane and nitrous oxide are the most notorious among them, in which CH_4 has a global warming potential 28 times higher than CO_2, produced mainly through enteric fermentation and manure storage comprising 44 per cent of anthropogenic CH_4 emission. Whereas nitrous oxide the most potent GHG which has a global warming potential 265 times higher than carbon dioxide generated mainly through manure storage and fertilizer application (Grossi *et al.*, 2019).

Methane is the by-product of enteric fermentation as part of the digestive process of ruminant animals such as cattle, buffalo, small ruminants and pigs (Gerber *et al*., 2013a). This methane emission is a part of evolutionary adaptation that enables the rumen ecosystem to dispose hydrogen which otherwise hampers carbohydrate fermentation and fiber degradation (Grossi *et al.,* 2019). The rate of enteric methane emission depends upon various factors such as type of digestive tract, age and weight of the animal, quantity and quality of feed consumed, feed digestibility and fermentation intensity. That is higher the feed digestibility, lesser the amount of methane emitted per unit of caloric energy consumed than those with lower digestibility (Popa *et al*., 2016). Organic matter content in the excreta is partially decomposed by bacteria in anaerobic condition produces methane and carbon dioxide (Rojas-Downing *et al*., 2017). Storage and treatment of liquid manure under anaerobic condition in closed tanks supplemented with warm and humid conditions can also results in the increase of methane production (Grossi *et al.,* 2019).

Composition of waste materials, the type of bacteria involved, and conditions after excretion determines the rate of production of N_2O from managed livestock waste. Nitrous oxide is produced through microbial process of both nitrification and denitrification, often related to the level of soil nitrate and soil aeration in gazing system. Nitrogen oxide emissions could be lowered by enhancing the aeration of the soil and by adopting techniques for improving nitrogen cycling in the production systems itself (Henry and Eckard, 2009). Storage, application and deposition of manure account for 0.8 gigatonnes CO_2 eq. per year from methane and nitrous oxide (Faurès *et al*., 2013).

According to Gerber *et al*. (2013b), agriculture land that recently converted to grazed land act as net sinks for CO2 by storing atmospheric CO2 in the form of organic carbon. However, after soil carbon reaches its saturation level, they revert their state of being acting as a sink to being a source of CO_2 owing to its sensitivity to climate change. Globally livestock contribute to five per cent of anthropogenic CO_2 emission, which mainly occurs from production, processing and transport of animal products, feed materials, energy consumption from animal production unit (heating, ventilation, etc.) as well as emissions from the expansion of pasture, expansion of crop land for feed production (Gerber *et al*., 2013a).

2.2.2. Impact of climate change on livestock

Climate is a crucial factor which plays a decisive role in determining the growth, development, and productivity of domestic animals (Collier *et al*., 2019). Any change from the expected climate will lead to an overwhelmingly undesirable consequence on the health and welfare of livestock (Lacetera, 2019). Increased air temperature, relative humidity, solar radiation, wind speed, uncertainties in occurrence as well as increased magnitude and frequency of extreme weather events adversely affect livestock production and productivity all-round the globe both directly and indirectly (Faurès *et al*., (2013), Lacetera, (2019)).

Amidst, these intervening factors, the temperature is considered to be the most critical parameter determining livestock production by affecting animal production, reproduction, and health, the incidence of diseases, forage production, and water availability etc. (Rojas-Downing *et al*., 2017). According to (Nardone *et al*., 2010) climate change, specifically global warming and its subsequent thermal stress significantly influence the productive function of livestock, especially as and when adaptive responses take the charge over productive responses. The vulnerability of livestock species to thermal stress depends on the intensity, magnitude and duration heat stress (Thornton *et al.,* 2010 and Lacetera, 2019) together with the influence of phenotypic and genotypic characters that impart the adaptive potential to animals (Renaudeau *et al*, 2012). And also, severe impacts are anticipated in grazing systems involved in lower latitudinal areas such as arid and semi-arid regions experiencing higher temperature and scanty rainfall, because of their dependence on climatic conditions for natural resource base and limited adaptation opportunities (Faurès *et al*., 2013). Meanwhile, positive effects are expected in temperate and higher latitudes, due to the advantage of increasing temperature on promoting livestock and forage production (Herrero *et al*., 2012).

In hot humid climate, heat stress induces behavioural and metabolic changes, suppress immune function, create oxidative stresses and reduces the feed intake resulting in decline in productivity and in certain occasions substantial mortality in livestock may also occurs (Thornton *et al.,* 2010). 3 to 4 °C rise in body temperature above normal leads to heat induced complications such as heat stroke, heat exhaustion, heat syncope, heat cramps will occur and ultimately organ dysfunction and greater risk of mortality during the hottest months (Lacetera, 2019). Higher temperature and changing precipitation pattern makes the condition conducive for the transmission of existing vector-borne diseases, the evolution of new strains of pathogens and infectious diseases, and also generate new disease transmission models (Faurès *et al*., 2013; Rojas-Downing *et al.*, 2017 and Lacetera, 2019).

Continued exposure to environmental stressors evokes certain biological adjustments in animals thereby enabling them to survive in those harsh conditions (Lees *et al*., 2019). Acclimatization response to a particular environmental stressor will occur in two phase such as acute (short term) phase, and chronic (long term) phase and will decay itself whenever the stressors are removed (Collier *et al*., 2019). Adaptation to biological changes over several generations will become genetically fixed and the animal will be adapted to the environment (Lees *et al*., 2019).

Forage production in several regions of the world is seriously impacted by wide fluctuations in distribution of rainfall during growing seasons, warmer temperature and elevated concentration of CO_2 in the atmosphere (Giridhar and Samireddypalle, 2015). Quantity and quality of fodder produced depend on the region and duration of growing seasons. The decline in forage quality may lead to increase in methane emission, reduce the digestibility and degradability due to the deposition of lignin in cell walls of the plant. This necessitates the need to offset the methane emission by replacing forage intake with grain feeding (Joyce *et al*., 2013). Furthermore, dwindled supply of water for animal drinking, feed production, and processing of animal products traumatize livestock production (Thornton *et al*., 2010; Rojas-Downing *et al*., 2017 and Nardone *et al*., 2010).

2.3. HEAT STRESS

Heat stress is a physiological response that negatively affects overall animal welfare and productive capacity. It is a major limiting factor that affects livestock production in tropical humid climate. It was defined as the sum total of external forces acting on an animal that causes an increase in body temperature above the thermoneutral zone as well as evokes some physiological response, caused by the combined effect of dry bulb temperature, humidity, solar radiation, and wind speed (Dikmen and Hansen 2009).

Temperature fluctuating between − 0.5 to 20.0 °C and 60–80 per cent relative humidity is generally accepted as the thermoneutral zone of cattle by which animal welfare is protected. But when air temperature surpasses 25.0–26.0 °C, disturbs the thermoneutral zones and induces some negative physiological and behavioural changes among cows (Herbut *et al*, 2018). In tropical humid regions, effective temperature is the combined effect of ambient temperature and humidity. During summer months when air temperature rises above the upper critical temperature, health and biological functions of the animal get impairing through reduced milk yield and reproductive performance (Prasad *et al.,* 2016). In hot humid climate, extended period of high temperature coupled with high humidity compromises heat dissipation to outside (evaporative cooling) leading to impaired thermoregulatory mechanisms, raises the body temperature and leads to thermal stress.

Thermal stress adversely affects endocrine function and fertility of animal (Herbut and Angrecka, 2013). Along with this, reduced dry matter intake results in poor quality and quantity milk yield, hence reducing the profitability of dairy farms (West, 2003,). Studies revealed that 35 per cent decline in milk yield was due to reduced feed intake and the remaining 65 per cent reduction was due to direct physiological effect of thermal stress (Rhoads *et al*., 2009). Crossbred Jersey cows effectively reduce 170 gm milk per cow per day in the herd during high thermal stress conditions under tropical environment (Mandal *et al*., 2016).

2.4. ECONOMIC CONSEQUENCES OF HEAT STRESS ON LIVESTOCK PRODUCTION

The traditions of domesticating livestock for economic benefits have been practising in many developing countries all over the world. The innate benefits of livestock sector significantly contribute to the rural economy and socio-economic development of these countries (Hegde, 2019) .In low income agrarian developing countries habituated predominantly with rural communities under poverty, most of them pursue their livelihood in smallholder diversified crop-livestock farming systems (Otte *et al.,* 2012). Livestock's share out of total agricultural output is nearly 40 and 20 per cent in developed and developing countries respectively. And globally livestock sector provide employment to at least 1.3 billion people as well as ensures livelihood for about 600 million poor smallholder farmers in developing countries (FAO, 2018a). Cattle is the most popular among the ruminant species in more than 100 countries, where the population is over one million (Hegde, 2019).

It has been observed that the livestock industry confronts a drastic reduction in milk yield when dairy animals are reared in places and seasons where environmental conditions venture outside the thermoneutral zone of animals (St-Pierre *et al*., 2003). Thus, heat stress has become a major concern among livestock farmers all around the world because of its associated reduction in milk yield and huge economic losses (Polsky and von Keyserlingk, 2017). Heat abatement strategies and other proactive management methods to counterbalance the consequences of heat stress are often too expensive and beyond the reach of the small and marginal farmers of India (Sirohi and Michaelowa, 2007). It has been observed that 30-40% reduction in milk yield is recorded during heat stress (Habeeb *et al*., 2018), resulting to a loss of $897 to $1500 million to U.S dairy industry, adding up to $2.36 billion loss to the entire livestock industry (St-Pierre et al., 2003). Adding to this, more than 50% of the global bovine population is occupying in the tropical region causing economic loss to 60% of dairy farmers around the world (Nardone *et al*., 2010). Therefore livestock farmers should be well acquainted about management strategies necessary to be implemented prior to the incidence of heat stress before making a serious economic loss (Habeeb *et al.*, 2018).

2.5. FACTORS REGULATING THE MICROCLIMATIC CONDITIONS INSIDE CATTLE SHELTER.

Milk productivity and welfare of the animals inside the free-stalls are largely influenced by barns microclimate (Herbut *et al.*, 2013). Diverse factors such as air temperature, humidity (Kučević *et al.*, 2013; Schüller *et al.*, 2013 and Collier *et al.*, 2006), solar radiation, wind speed, precipitation influence the environmental conditions interior to the cattle shed (Hill and Wall, 2015). In addition to these external climatic conditions, a variety of in-barn parameters like animal number, shade properties, nearness to vegetation, the number and size of fans and sprinklers and other ameliorating techniques, orientation of shed etc. significantly influences the microclimate inside the shelter (Shock *et al.,* 2016). The improved microenvironment of the shed helps to maintain normal physiological indices such as body temperature, respiratory rate, and hormone concentrations and thereby showing more milk yield per cow per day and reduced heat load (Sahu *et al.*, 2018). Currently, an intensive system of rearing cattle is widely practiced and thus cows spend the majority of their productive life inside the barn necessitating the need for suitable microclimatic conditions. The upper limit of ambient temperatures at which Holstein cattle may maintain the stable body temperature is 25 to 26°C, thus above 25°C heat abatement measures need to be adopted. With increasing ambient temperature there is a shift in non-evaporative cooling to evaporative cooling, but under hot humid condition, high relative humidity obstructs evaporative cooling mechanisms (West, 2003). In addition to this, higher relative humidity makes a situation conducive to bacteria development and increases the concentration of noxious gases produced as a result of animal waste decomposition (Herbut *et al.*, 2013). Also reported that when air temperature exceeds 20 °C and humidity reaches the unsatisfactory level, cow begins to show signs of heat stress by moving slowly, breathe out heavily to get rid of the heat, and reducing the feed intake. A considerable drop of 3-4 litres of milk per day is recorded for every 1.5 kg reduction of feed intake when the temperature rises to 30°C from 20°C (Herbut *et al.,* 2013).

As far as tropical regions are concerned, solar radiation is of greater magnitude by which mean radiant temperature is usually higher than the air temperature. Changes in wind velocity along with solar radiation have a profound influence on convective heat exchange (Da Silva *et al*., 2010). Moreover direct and indirect solar radiation affects bedding temperature as well as sidewall temperature of stall barns, which depends directly on orientation of the shed (Angrecka *et al*., 2017).

In order to make microclimate more hospitable for cows by reducing exposure of radiation and decline in ambient temperature, diverse methods such as planting tree near the shed, bush belts, growing creepers over the roof, extensions of eaves and the installation of sunlight-reducing mesh, low-pressure sprinklers and fans, ventilation systems can be provided. (Herbut *et al.,* (2013); Angrecka *et al*., (2017) and Herbut *et al*., (2018)).

Microclimate modification by means of providing different roofing materials, fans, sprinklers, misters, foggers, etc. are some effective methods commonly employed to reduce the minimum and maximum temperature and heat load in diary animals (Narwaria *et al*., 2017). Air cooling by means of well-designed evaporative coolers reduces ambient temperatures inside the shelters. It works efficiently during the hottest period of the day. It is also reported that cooling cows by means of fans and sprinklers yield 11.6 per cent more milk than control cows under the same shelter (Da Silva, 2006).

The selection and use of microclimate modifying technique need to be evaluated carefully to ensure that those practices might improve health and performance of the cow without hampering ambient conditions. Since effects may differ from one place to another depending upon the climate regime of that particular region. Hence in regions where environmental relative humidity reaches above 75 per cent installation of evaporative cooling systems such as cooling pads, misters, and sprinklers were not recommended due to the further intensification of humidity associated with these systems (Fournel *et al*., 2017).

Weather data obtained from the nearest meteorological stations are often used to quantify thermal stress in cattle in most of the studies. But Schüller *et al.* (2013) reported that on-farm measures of temperature and humidity differ significantly from those of weather stations located near the study sites and confirms that on-farm measures are more likely to better gauge conditions experienced by the cows.

2.5.1. Climatological variables influencing microclimate

Climatic environment surrounding the animal are extremely complex. It was apparent that health, performance and welfare of the dairy animals are largely influenced by numerous biometeorological elements like ambient temperature, relative humidity, solar radiation etc. (Brouček *et al*., 2006).

Among these climatological factors, temperature was considered to be an overriding factor affecting the physiological functions of domestic animals. In thermoneutral condition no additional energy was required to heat or cool the body. Heat exchange occurs solely by physical means such as the constricting and dilating blood vessels of the skin, ruffling up the fur and evaporation from lungs or skin. Despite the wide variations in the external environment, these homeotherms maintains relatively constant core body temperature by adopting these thermoregulatory mechanisms (Renaudeau *et al.*, 2012).

Daily mean temperature of 10-20 °C is generally considered as 'comfort zone' for most of the farm animals (FAO, 2011). Also, it is generally accepted that dry bulb temperature of 28°C is the upper critical temperature that does not significantly induce physiological or behavioural changes among cows (Dikmen and Hansen, 2009). In an attempt to reduce hyperthermia, homeotherms responds to elevated temperature by increasing heat dissipation and lowering heat production (Lacetera, 2019).

Hajizadeh *et al.*, 2017 found that black globe temperature have significant relation with ambient temperature less than 35°C, because there were changes in black globe and dry-bulb temperatures at lower ranges. But at temperature above 35°C, significant relation was not evident because variations of the black globe temperature was considerably higher than dry-bulb temperature.

But with rising temperature, non-evaporative cooling mechanism such as conduction, convection, and radiation will become less effective and the cow become increasingly reliant upon evaporative cooling mechanism such as sweating and panting (West, 2003). According to Dikmen and Hansen (2009) dry bulb temperature acts as a good predictor of rectal temperatures of lactating Holsteins in a subtropical environment as well as effectively predicts magnitude of hyperthermia experienced by heat-stressed cows.

In addition to this, higher relative humidity and solar radiation further worsens the effect of high air temperature. Higher relative humidity impedes the evaporative potential of the skin and respiratory system of the animal, while solar radiation adds heat gained from metabolic processes which must be dissipated to maintain normal body temperature (Da Silva, 2006). Radiant heat load reduces the heat dissipation capacity of the animal. Thus, increased heat input from the environment reduces metabolic heat production and thereby restraining animal productivity (Berman and Horovitz, 2012).

Davis and Mader (2003) claimed that changes in wind velocity together with solar radiation significantly influence the capacity of animal to maintain thermal balance by altering convective cooling mechanisms by wind speed and adding up heat load by solar radiation. Wind flow helps to keep animal cool during extreme hot conditions of summer. Hence this should also be considered while deciding the type and location of shelter (Herbut *et al.,* 2013).

If ambient temperature is lower than body temperature of the animal, increased air movement over the body surface disrupt the layer of warm air and replace with cool air. However, the effect of wind speed is uncertain if ambient temperature exceeds body temperature. Bolton (2018) referred that as wind helps to reduce humidity of the area as it sweeps away airborne water particles in the air.

Mader *et al*. (2006) advocated that, under high relative humidity evaporative cooling mechanisms will limit and wind speed raises the body temperature at a faster rate. However in low humid condition effect of wind speed will be positive.

Air movement is driven by thermal gradient, it varies with distance (Brouček *et al.* (2006), and such that a significant variation in wind speed was recorded at different levels of the barn (Herbut *et al.,* 2013). In a free-stall barn, the performance of ventilation system is largely influenced by power and direction of wind. Moreover fan can be effectively used to provide air movement by forced ventilation in a well-designed barn. If the air is hotter, the cattle gets heat rather than losing it which necessitates the need of natural or mechanical ventilation during hot summer conditions (Brouček *et al.*, 2006).

Study conducted by Prasad (2014) at University Livestock Farm, Mannuthy, Thrissur, analysed ambient temperature, relative humidity and THI both interior and exterior to the cattle shed over 24 hour period and observed that the temperature outside the cattle shed was lower than interior between the time points 5:41 PM and 7:48 AM, were as relative humidity on the other hand was found to be higher. And the converse was found to be true between time points other than above said time. Another study by Harikumar (2017) at Cattle Breeding Farm (CBF), Thumburmuzhy, Thrissur found that ambient temperature interior was lower than the exterior but relative humidity interior was 2- 3 per cent higher than exterior. He also advocates that the rise in relative humidity interior may be due to regular cleaning of floor with water as a routine practice.

According to Berman and Horovitz (2012) influence of air temperature, relative humidity and wind velocity on thermal stress is widely studied, mainly due to its simplicity of measurements, rather than radiant heat load, since it is measured infrequently. Solar radiation includes both direct as well as diffused radiation, which is a major determinant of environment condition around the cow especially in pasture and a leading overriding factor contributing to thermal stress (Herbut *et al.,* 2018). It is found that cows that are exposed to direct sunlight had higher marked increases in average body temperature when compared to protected cows on days with higher solar radiation (Tucker *et al.*, 2008). Radiant heat load on a sun exposed dairy cattle is about three times of its metabolic heat production and consequently reducing its productivity and comfort (Da Silva *et al.*, 2010).

2.5.2. Influence of structural characters on microclimate

2.5.2.1. Importance of housing

Appropriate animal housing is salutary for better health and comfort, protection from predators, harsh weather and moderate the range of animal's microclimate, which would enable the animals to utilize their genetic ability and feed for optimal production. Thus serious considerations are required for site selection, shelter design, and future requirements of the animals to be reared, as it is difficult to frequently construct animal houses according to climatic needs (Sejian *et al.*, 2012). The quality of shade environment decides the microclimate inside the shelter and protects the animal from harsh stressful environment (Kamal *et al.*, 2013).

Since Kerala comes under tropical humid zone, cow shelter in the country should be designed to reduce the heat load because heat stress cause more damage to animals. Theoretically it is stated that best type of animal shelter should maintain the microclimatic temperature within 15 to 25° and humidity around 10-12 mm Hg (Belsare and Pandey, 2008). Physical modification of the microenvironment is the primary means to temper the impact of a hot climate on animal production and increase dairy profitability (Fournel *et al.*, 2017). It was based on the concept of protecting the animals from the factors causing heat stress as well as enhancing evaporative heat loss by animals (Sejian *et al.*, 2012). In the changing climatic condition where the weather is increasingly unpredictable, defective shelter design and wrong choice of material for housing will result in cumulative lose in production as it is evident from change in milk yield in different climatic condition (Ambazamkandi *et al.*, 2015).

2.5.2.2. Shades and its orientation

Shades for dairy cows are mainly used to alleviate the harmful effects of hot climate and to protect the animal from incident solar radiation. It helps to minimize loss in milk yield and reproductive efficiency. Nearly 30 to 50 per cent reduction in total heat load could be obtained in a well- designed shading structure (Collier *et al*., 2006). Increased rectal temperature, respiration, and pulse rate, excessive water loss through evaporation, dryness of skin etc. are caused by heat gain by direct and indirect means. It will affect the overall growth rate and productivity of animals and even lead to mortality. Thus shades can be provided to protect the animal from direct and indirect solar radiation (Kamal *et al*., 2018). Shading systems can be either natural or artificial, but both of this doesn't alter the air temperature and relative humidity around cows but can be easily implemented and economical (Renaudeau *et al*., 2012).

Tree shades are efficient to provide protection from direct solar radiation and are effective in providing shelter to the animals. Certain studies reveals that dry bulb temperature, black globe temperature, wind speed along with animal factors such as rectal temperature, respiration rates of animal kept under tree shades are significantly lower than that compared to unshaded animals (Fournel *et al*., 2017). Because of high shadow uniformity, good resistance to ponding, simple management and immediate availability per animal artificial shades are more preferred over natural shades (Sejian *et al*., 2012. Thermal load of cow can be reduced by 30 per cent by providing appropriate shade (Brown-Brandl *et al.*, 2005).

Studies conducted by Abdel-Aziz *et al*. (2015) found that shade trees with large canopy such as Mimosa (Albiziajulibrissin), Royal Poinciana (Delonixregia), and Common Fig (Ficuscarica) effectively reduces solar incidence on building facades and significantly reduces the electricity consumption for cooling during summer times. Besides the energy conservation benefits shade trees will improve air quality and lowers ambient temperature. This study was conducted for human dwellings in Amman, the capital of Jordan, representing a Mediterranean climate. However, these findings can also be effectively used for animal studies also.

Height and orientation of animal shelter has a significant influence on the microclimate inside the barn. Studies conducted by Angrecka and Herbut (2016) concluded that precise selection of orientation of building in accordant with the prevailing wind direction and angles of solar incidence during different times of the year improves the living condition inside the barn.

Martin (1998) cited by Hatem *et al.* (2006) mentioned that cattle shelters are traditionally oriented in north-south for cold climates which helps to encourage solar intrusion under the shade to enhance soil drying. And for hot climate sheds are oriented with long axis of the building runs in east-west direction which helps to reduce the encroachment of direct solar radiation on the side walls or entering the shelter (Schultz *et al*., 2010 and Das *et al*., 2015). In regions where average temperature rises above 30°C the east-west orientation was more beneficial (Haque and Hussain, 2011). Das *et al*. (2015) reported that orientation of cattle shed had a significant effect on air temperature, relative humidity, THI and daily average milk yield. Significantly higher daily average milk yield of 9.720 ± 0.093 kg in east west oriented farms compared to 9.470 ± 0.085 kg in north - south orientated sheds.

Increasing shed height enhances aeration under shed by allowing higher air velocity compared to low shed, which results in decreasing of maximum temperatures measured under shed consequently, milk production also increases (Hatem *et al*., 2004). Dairy cattle are enthused to use shade in hot weather and its usage increases with insolation and HLI (Tucker *et al*., 2008). Albeit, under larger shade area animals shows greater lying time, cows are able to share the resource rather than compete for it moreover 70 per cent reduction in aggressive interactions are recorded when the size of the area was taken into account.

2.5.2.3. Roofing material and thermal conductivity

Conduction, convection and radiation are the different ways by which animal gain heat from the environment. Radiation may be either direct solar radiation or reflected radiation from surrounding structures (indirect). Both are the major cause of heat stress in animals and 45 per cent cut in radiant heat load can be obtained by providing shades (Narwaria *et al*., 2017). During summer prolonged exposure to direct sunlight result in increased loss of water from body through evaporation.

Type of roofing material determines the microclimate underneath the covered area. It should be made of strong and durable weather proof light weight material which poorly conducts heat as well as devoid of affinity to condense moisture inside. Wide varies of material such as thatch, clay tiles, Wood, Sun screen, RCC, Galvanized sheet, Asbestos, Plastic sheets (Haque and Hussain, 2011) which should be either of having properties such as high reflectivity, low thermal conductivity, low under-surface emissivity, correct roof profile (slope) and maximum practical height (Kamal *et al*., 2014). Prasad, (2014) observed that that majority of cattle sheds in Kerala had tiled roofing (32 per cent) followed by tin sheet (22 per cent), asbestos (19 per cent), palm leaves (12 per cent), aluminium (7 per cent) and concrete (3 per cent).

Lower thermal conductivity allows only less heat to be transferred within and ensuring better microclimate inside the barn thus thermal conductivity is the important criterion for selecting roofing material (Narwaria *et al*., 2017). Based on lower thermal conductivity thatched, asbestos, and plastic are found to be good. But due to high thermal conductivity asbestos does not protect the animal from negative effect of environmental variable compared to thatch and agro-net in hot humid climate. Inner side roof surface temperature was lower in thatch ceiling roof during both morning and afternoon (30.60±1.52 and 33.25±1.68ºC respectively) when compared to asbestos roof 39.76±3.00 and 44.20±2.78 ºC respectively). Thatched roof act as a good insulator and also cheap as compared to asbestos, however its durability is no longer. Provision of thatched ceiling under asbestos roof provide favourable environment for cross breed jersey cattle (Sahu *et al*., 2018).

Agro-net which is commonly used in green houses can also be used as an effective roof modification during summer months by reducing the influence of solar radiation on THI (Herbut and Angrecka, 2013) as well as it is comparatively cheaper and modifiable as per needs (Narwaria *et al*., 2017). During summer season provision of agro net followed by thatch as shade materials in an open paddock provide favourable micro-environment to the crossbred cattle during summer season. It helps to keep their physiological responses in a normal range (Kamal *et* al., 2014). He also found that surface temperature of asbestos roof is significantly higher than thatched ($p < 0.05$) and the lowest for agro net. Kamal *et al.* (2016) observed that calves grouped under agro net have more feeding time, and less time spent around water trough when compared to those under asbestos and thatch.

A study conducted in North East Zone of Tamil Nadu, India indicated that thatched roof, followed by tile and metal roofing are suitable with respect to the microclimate (Sivakumar *et al.*, 2017). The animal kept under a tiled roof and having no walls had lesser stress levels than those kept under the Galvanized Iron sheet (Roy and Chatterjee, 2010). However, its thermal conductivity was higher than thatched but it was widely used in rural areas. Lowest dry bulb temperature was recorded for shelters having reinforced cement concrete (RCC) as compared to asbestos and conventional tree shelters (Kaur and Singh, 2004). Bhattacharyya and Bordoloi, (2015) found that during summer season thatched roofs provides a suitable micro environment for dairy cows (Jersey grade cows) and yield apparently more milk compared to other roofing materials like GI and asbestos. And also advocates that GI and asbestos can be used along with provision of false ceiling, fan, wet curtains etc.

The greater thickness of the RCC roof maintains a cooler environment than the asbestos sheet even though its (RCC) thermal conductivity is slightly higher than asbestos. Galvanized iron (GI) and asbestos sheet are widely used in organized farms because it is cheaper than RCC and highly durable, but higher thermal conductivity outweighs its merits (Sastry and Thomos, 2012). Asbestos roofs are unable to cut down the heat load during afternoon because of its complete heat absorption and dissipation but helps to reduce the temperature before noon (Kamal *et al.*, 2016). Polythene sheets are generally used in temporary sheds as it is economical and easily adjustable as per needs. Even though, it's extreme thinness make it ineffective in protection from insolation. Hence it is commonly used to make thatch waterproof (Sastry and Thomos, 2012).

Table 1. Thermal conductivity of different roofing materials

Roofing material	Thermal conductivity	Range
Thatch	Very low	0.05 Kcal/ mh °C
Polythene sheets	Very low	0.04-0.05 Kcal/ mh °C
Reinforced Cement Concrete (RCC)	Low	0.53-1.50 Kcal/ mh °C
Asbestos sheets	Intermediate	0.4 Kcal/mh °C
clay tiles	High	2.2 Kcal/ mh °C
Galvanized Iron	Higher	175 Kcal/ mh °C

Source: (Narwaria *et al.*, 2017)

Roof insulation is an important technique that physically modifies the microenvironment and reduces the heat load on the cow but it prevents the heat loss from the cow itself during night time (Liberati, 2008). Absorption of sunlight by roof surface could be reduced by painting the roof white (Bryant *et al.,* 2007). Fournel *et al*., (2017) cited that false ceiling beneath the metal roofing of an open shelter helps to reduce dry-bulb and black globe temperature by 1.2 and 2ºC respectively contributing 1.3 and 2.2 units drop in THI and BGHI. Thus animals in the insulated area consume more feed and give better milk yield. Thermal insulating material like thermocol placed under the asbestos roof, fastening bamboo mat below GI and asbestos, application of mud plaster over existing structure of thatch or asbestos sheet, either agro net or paddy straw bedding with bamboo structure over asbestos roof, wet gunny bags laid over roof tops are certain roof modification practiced in extreme hot regions (Narwaria *et al.,* 2017). Studies conducted by Das *et al*. (2015) in northern and southern district of Goa found that besides manual and mechanical cooling, false ceiling made inside the cattle shed will provide extra comfort and result in higher milk yield.

2.5.2.4. Floor material and lying comfort

As an effort to improve cooling animals changes their behavior pattern, it has been reported that heat stressed cows increase their standing time as an effort to bring more body surface area to air which helps to relieve thermal stress. In thermo neutral zone cows have 11-14 hours of lying time, with 30 per cent reduction when temperature increases (Polsky and von Keyserlingk, 2017). Excess insolation results in increased heating of wall and stall materials, which may get reflected in cows lying time and resting comfort. Lying surface should drain excess heat and sweat from body and makes them cool by allowing conductive cooling. Since abdominal temperature of HF cattle is about 35°C coupled with higher ambient temperature (around 38°C), heat transfer from animal to environment and thus cooling become difficult (Herbut and Angrecka, 2013). Thus flooring material used for rest areas is very important for cow comfort. Because while lying nearly 20 per cent of body surface comes in contact with stall (Aguilar, 2013). Hence in large commercial farms bedding materials are selected based on its economic feasibility, udder health, lying and thermal comfort and is a part of heat abatement strategies (Fournel *et al*., 2017).

Concrete floor is commonly used in dairy farms because of its high durability, thermal conductivity and strength. But slippery nature and hardness leads to conformational defects causing injuries to hoof such as laminitis (Vanegas *et al*., 2006). Platz *et al*. (2008) reported that covering concrete floor with perforated rubber mats provide grip and improves the ability of animal to express normal behavior by offering relatively less challenging environment. However, long term effect of use of rubber mat as flooring material was not proven scientifically for tropical humid climate.

Studies carried out by Prasad *et al*. (2013) at University Livestock Farm, Kerala Veterinary and Animal Sciences found that rubber mat flooring had significantly ($P<0.05$) higher temperature than concrete flooring during 11.40 AM, 3.00 PM, 5.10 PM and 10.00 PM with maximum temperature difference of 0.95°C recorded at 11.40 AM. Another study conducted by Sahu *et al*. (2018) found that asbestos sheet and concrete floor provide only lesser comfort to cows whereas shelter improvement techniques providing thatched celling below asbestos and soft flooring by sand reduces thermal stress and enhance staying comfort of dairy cows

Clean sand bed act as an excellent flooring material for cattle barn as it reduces the growth of bacteria causing environmental mastitis and cohesion less nature helps to move the soil readily (Haque and Hussain, 2011).

2.5.2.4. **Cooling mechanisms**

In addition to providing adequate shade, heat stress can also be reduced by adopting different cooling strategies which helps to reduce in-house ambient temperature well below outside air temperature and to keep cow's body temperature as close as possible to normal (38.5 -39.3°C) (Brouček *et al*., 2006). Practically, this can be accomplished by increasing the rate of evaporative cooling either by direct evaporation from the skin surface by means of wetting or cooling the microenvironment of the animal using cooling pads, sprinklers, misters, etc. and increasing convective heat transfer rate by increasing air speed over cow in an enclosed shed (Fournel *et al*., 2017).

Among various cooling methods evaluated, air conditioning was found to be the most efficient method to modify a warm environment. This method effectively reduces air temperature and relative humidity by lowering the THI of the environment. But the expense of such types of mechanical air cooling make it impractical for cooling livestock on a commercial basis (West,2003).

Direct wetting or misting of skin and hair of animal during periods of higher temperature is found to be effective in relieving thermal stress as it increases heat dissipation because of large surface area of the hair allowing for greater vaporization of the water (Brouk *et al*., 2003). It is reported that a seven per cent increase in milk yield is obtained when cows are sprinkled between 12h and 13h under shade in sub-humid tropical climate (Sejian *et al*., 2012). And also under gazing system, single use of sprinklers and fan system for 30 minutes prior to milking is proved to be effective to reduce the impact of heat wave providing relief to heat stress (Valtorta *et al*., 2002). Showering cattle and then evaporating the water from skin was highly effective in reducing respiration rates and skin temperature. This helps to allow sufficient heat to dissipate from the skin via evaporation rather than exchange through convection (Brouk *et al*., 2003).

Combined use of fan and sprinkler system is the most economical method of cooling in dairy farms already having a closed holding pen by which fans mechanically ventilate the area and sprinkler system enhances evaporative cooling (VanDevender, K., 2013). Large droplets of water was used to wet the skin of the cow and cooling is achieved when water evaporates from the hair and skin. This method of cooling allows more efficient heat lose than by sweating. But this accumulates water in the hair may increase the humidity around the animal and reduce effective heat loss (Sejian *et al*., 2012). Evaporation of water helps to reduce temperature by absorbing heat but as a matter of fact it also increases the relative humidity due to the increased level of water vapour present (Renaudeau *et al*., 2002). Also water evaporated from atomizing nozzles such as foggers, misters, and cooling pads are also found to be effective in reducing heat stress (Fournel *et al*., 2017). When relative humidity exceeds 80 per cent animal overlay comfort (Ward and Eng, 2013). Also, cooled animals reduce their capability to cope with warmer condition and become more reliant to cooling even in milder temperature (Gaughan *et al*., 2008). Besides this avoid moisture build-up on udder and in the cows lying area is important to be considered while wetting the animal.

Evaporative cooling strategies may produce negative results by further increasing the humidity and thereby reducing heat dissipation from the body in hot humid environment, which can be effectively nullified by supplementing adequate ventilation as it helps to increase heat lose via convection (Sejian *et al*., 2012). While air temperature is well below cow's body temperature, increasing air movement effectively provide relief from heat stress, in fact animal will still be under stress when air temperature rises from 21 to 27°C (Brouček *et al*., 2006).

Proper ventilation systems helps to pull out stale air and bring in fresh air into barn, improves air quality by removing poisonous ammonia and moisture and also helps in heat reduction by cooling cow through high velocity air movement. Also, cows will need a higher ventilation rate, when the external temperature is high. Conversely, when the temperature is mild or cool, cows will need a lower ventilation rate (Eckelkamp *et al*., 2019). Wetting combined with forced ventilation is proved to be effective in hot and humid climate, which permits high speed air movement preventing air saturation and represent a heat loss of 560 kcal/h (Sejian *et al*., 2012).

Natural ventilation together with fans, either high speed axial or high volume low speed fans, installed interior to the confined facilities is the most prevalent ventilation system in dairy barns to supplement cooling (Tyson, 2010). Albeit, position of natural ventilation and direction of prevailing wind must be considered wisely while placing fan in order to increase the effectiveness of cooling (VanDevender, 2013). However, fans placed along feed barriers and resting areas merely moves air only within the barn but they do not provide air exchange. Hence, tunnel ventilation which provides air movement as well as promote air exchange simultaneously can be used effectively as a special and simple summer-time ventilation system. In a tunnel ventilated barn, fresh air enters through a gable end opening, which travel longitudinally inside the barn by creating a negative pressure and is exhausted by tunnel fans installed at opposite end (Gooch and Timmons, 2000).

2.6. TOPOGRAPHICAL INFLUENCE ON HEAT STRESS

The topography of an area has a significant influence on climate, distribution of vegetation, and species richness of an area (Moura *et al*., 2016). Environmental lapse rate, decrease in temperature with increasing altitude, make land at higher elevation cooler than low lying areas (Becerra *et al.,* 2016). And also, the orientation of slope of the land with respect to the sun has a profound effect on climate such that south-facing slopes in the northern hemisphere receive abundant sun rays and support entirely different ecological communities than north-facing slopes (Janet, 2019). Latitude, the direction of the prevailing wind, evaporative conditions, altitude above the mean sea level, availability of water, proximity to mountains and water resources, and other factors define the climate of an area (West, 2003). Each individual climatic variable is analyzed separately and integrated by using available climate classifications which corresponds to distribution of flora in the sense that each climate type is dominated by particular vegetation zone or eco-region. More than 100 years ago first quantitative classification of Earth's climate was developed by Wladimir Köppen in 1900 and further modified by his collaborators and successors is still in widespread use by researchers across a range of disciplines (Peel *et al*., 2007 and Belda *et al*., 2014). The range and extent of ambient temperature are principally reliant on latitude, with latitudes closer to the equator suffer conditions increasingly conducive to heat stress (West, 2003). Thermoregulation constraints are imposed by the interaction between climate and topography due to climate change (Moura *et al*., 2016). Livestock community inhabiting in higher latitudes are hardly hit by the rise in ambient temperature than those at lower latitudes since local livestock breeds are often already quite well-adapted to heat stress and drought (Thronton *et al*., 2009). Prasad (2014) found that altitude had a significant negative relationship with THI.

2.7 INFLUENCE OF LIGHTING

Solar radiation in the form of visible light have profound influence on animal behavior by governing diurnal and seasonal activity patterns of the animals (Shinde and Gupta, 2016). During evolutionary development, many animal species have become capable to detect and react to changes in light intensity and photoperiod duration which (Penev *et al*., 2014) varies with latitude and season and has a direct influence on animal performance (FAO, 2011). Henceforth it is not a matter of surprise that most terrestrial animals have been adapted to recurring cycle of light and darkness within a 24-h period (Collier *et al*., 2006).

Light is one of principal component that influences the microclimate of farm animal and is essential for maintaining animal welfare (Penev *et al*., 2014). Since dairy cattle are not seasonal breeders, the influence of photoperiod was largely ignored relative to other domestic species, with more substantial effect on reproduction (Collier *et al*., 2006). Dahl *et al*. (2000) reported that through photoperiod manipulation, the production potential of dairy cattle can be improved and can be used as a management tool for dairy farmers to enhance productivity and profitability. Prolonged photoperiod increases dry matter intake which supply extra nutrients (Shinde and Gupta, 2016), secretion of insulin-like growth factor (IGF-1) and prolactin concentration which increases the milk yield (Dahl, 2008) with little or no effect on milk fat composition (Dahl *et al.*, 2000).

Researches have showed that 8 to 10 per cent increase milk yield was obtained when milking cows were exposed to 16–18 hr. of light followed by 6–8 hours of darkness. It was also found that there was no benefit in providing 24 hr. continuous lighting without darkness, since dairy cows requires 6–8 hr. of uninterrupted darkness each day to detect light increase (House, 2016).

2.7 ANIMAL RESPONSE TO HEAT LOAD

Animal's climatic environment is very complex, several combinations of temperature, relative humidity, radiant energy, and animal factors increase heat load beyond the normal physiological range in the cow and act as limiting factors for production in tropical and subtropical areas (West, 2003, Renaudeau *et al.*, 2012). Animal integrates these environmental conditions and responds to it adaptively by evoking certain physiological, behavioural, and immunological responses. Intergovernmental Panel for Climate Change (IPCC, 2007) reported that under hot climatic conditions animals may suffer from an increase in body surface temperature, rectal temperature, respiration rate, and pulse rate, and decrease in feed intake, production, and reproductive efficiency. In addition to heat load, cattle in tropical and subtropical regions are often exposed to multiple stressors such as incidence of pest and pest-borne diseases, seasonal variations in nutrition and housing management, high daily fluctuation in temperature and relative humidity with negative stimuli such as hunger, thirst, and frustration, induced by heat stress, adversely affect the animal's affective states (Polsky and von Keyserlingk, 2017). Owing to the duration of exposure to these stressors, dairy cattle may suffer from acute stress response which lasts from a few minutes after the beginning of the stress to a few days to chronic heat stress which lasts from a few weeks to months (Collier *et al*., 2017and Lees, 2018).

Furthermore, breed of the cow, its coat color and age, lactation phase, milk production level, feed, and water intake levels, feed composition, and body condition score risk the occurrence of heat stress (Herbut *et al*., 2018). The magnitude of the adverse impact of heat stress is determined by the adaptive potential of the animal. To re-establish homeotherms and homeostasis animals initiate certain compensatory and adaptive strategies such as physiological and behavioural changes which may lead to production loss when the stress extends for a prolonged period (Rashamol et al, 2018). However, adaptive mechanisms of cows fail to remove excess heat, whenever the upper critical temperature rises above the permissible limits (Herbut *et al*., 2018).

2.7.1. Physiological Responses to Heat Load

The long lasting adverse physiological effect of thermal stress results in a tremendous economic loss for the dairy industry (Perano *et al*., 2015). Animals physiologically adapt to thermal stress by adopting mechanisms to reduce their heat production and enhance heat dissipation (Collier *et al*., 2017). High respiration rate, sweating, increased core body temperature, skin temperature, reduced dry matter intake and metabolism, vasodilation with increased blood flow to the skin surface, altered efficiency of feed utilization and water metabolism are the physiologic responses associated thermal stress and subsequently determines the level of discomfort/comfort of dairy animals (Ganaie *et al*., 2013). Energy requirement increases by 20 per cent when the temperature rises above 35° C, compared to the energy requirements at thermoneutral conditions of 16°C or lower (Schüller *et al*., 2013) and also, the substantial increase in respiration rate results in increasing energy expenditure by 11 to 25 per cent (Lees, 2018). Animal reduces its dry matter intake as an effort to bring metabolic heat production in line with its heat dissipation capabilities which resulted in 35- 50 per cent reduction in milk yield (Lees *et al*., 2019). Usually, cows fail to resume their original milk yield before heat stress even after resumption of favourable environmental conditions (Stull *et al*., 2008).

2.7.1.1. Body temperature.

Body temperature was considered as an important physiological parameter and is act as a good indicator of thermal stress in dairy animals (Brown-Brandl *et al*., 2001). It could be measured in terms of rectal temperature, vaginal temperature, skin temperature, rumen temperature, subcutaneous tissue temperature, and tympanic temperature measured through ear canal (Liu *et al*., 2019). Animal's body temperature increase when environmental temperature approaches its body temperature along with high relative humidity of atmosphere impedes the evaporation and cooling capacity of the animal (Ganaie *et al*., 2013). Changes in rectal temperature indicates the corresponding changes in magnitude of core body temperature and was generally considered to be a useful measure of body temperature to evaluate the adversity of thermal environment, which affected the growth, milk yield and reproductive ability of dairy animals (Ganaie *et al*., 2013, Patel *et al*., 2016). Nevertheless, rectal temperature was not constant because of diurnal variations which may peaks after hottest period of the day, when heat energy produced through metabolic processes and heat energy dissipated to the environment are imbalanced (Gaughan *et al*., 2002).

Various field studies revealed that when lactating cow subjected to temperature higher than its thermoneutral zone, rectal temperature increases significantly. And rise in rectal temperature less than 1ºC was enough to reduce dry matter intake and production (Rejeb *et al*., 2016).

Collier and Zimbelman (2007) stated that rectal temperature predict heat stress better than THI. And also reported that considerable reduction in milk yield occurs when rectal temperatures reached 39°C (Collier and Zimbelman, 2007).

Milk yield decreases by 1.8 kg/day per cow for every 0.55 °C (1 °F) increase above a daily rectal temperature of 38.6°C (Allen *et al*., 2013). Higher producing cattle with large body size confronts greater thermal stress than its counterpart because of its greater metabolic heat production associated with its milk yield (West, 2003). In other words, 10 per cent more metabolic heat is generated by higher producing cows compared to lower producing one (Tapkı and Şahin, (2006) and Liu *et al*., 2019).

Generally, core body temperature which reveals the internal body temperature was measured using rectal, vaginal, tympanic, vascular, intra-peritoneal, or digestive tract sensors. Whereas mid-peripheral temperature is measured by microchips implanted intramuscularly, or at a depth of more than two centimeters from the skin. And peripheral or surface temperature measurements are obtained from the animal's skin, coat, eyes, udder, legs, ears, and by implanting microchips at a depth of less than two centimeters from the skin. Perhaps may of the aforesaid methods are invasive and may restrains the animal further (Vickers *et al*., 2010).

Recent development in technologies like telemetry (Vickers *et al*., 2010) and infrared thermography (Yadav *et al*., 2017) provide least stress to the animal as there is no restraining because of limited contact with the animal and, therefore it is well suited for assessment of animal stress and welfare. Studies conducted by Chaudhari and Singh (2015) in lactating Murrah buffaloes, found that higher humidity and ambient temperature significantly affects its skin temperature. Bland *et al*., 2013 demonstrated that dietary manipulation can be adopted as an important strategy to reduce heat load of dairy cattle as wheat-fed cows showed a significantly higher flank temperature compared to maize-fed cows ($p<0.01$).

2.7.1.2. Respiration Rate

Respiration rate is a sensitive indicator of heat stress which is influenced by age, performance, growth stage, genotype, and time of feeding, health and nutritional status of the animal as well as previous exposure to hot conditions, housing design, cooling strategies imposed, and other environmental factors (Gaughan *et al*., 2000). Increase in respiration rate is the initial response shown by the animal when environmental temperature surpasses thermoneutral zone (Ganaie *et al*., 2013). An increase in respiratory frequency consequently increase daily maintenance energy requirements by 7-25 per cent (Aggarwal *et al*., 2012). It is one of the primary mechanisms for maintaining heat balance by dissipating extra heat by respiratory cooling mechanism which vaporize more moisture to the environment (Rashamol *et al*., 2018). In addition to strong positive correlation between higher ambient temperature and respiration rate, other environmental factors such as increased solar radiation and relative humidity, decreased wind velocity also contribute to heat load and subsequently influence respiration rate (Eigenberg *et al*., 2005).

Respiratory evaporative lose increases by 55 per cent when cows acclimated to 21.1° C exposed to 32.2° C for two weeks (Aggarwal *et al*., 2012). Practical assessment of thermal stress by measuring respiration rate can be done non-invasively by counting flank movement per minute using stopwatch (Shilja *et al*., 2016). Studied conducted by Gaughan et al. (2000) concluded that, changes in respiration rate lags behind dry bulb temperature by 2-4 hours, therefore respiration rate observations should be made at least two to three hours prior to the hottest part of the day in conjunction with panting observations. Panting scores were assigned based on visual observation of behavior, not on the estimation of respiration rates and offers a quick assessment of thermal stress without the need to count for a specified period of time (Brown-Brandl *et al*., 2006).

When cow pants in hot climatic condition, respiratory alkalosis occurs, bicarbonate (HCO_3–) is converted to carbonic acid which is broken down to CO_2 and water for expiration and excretion (West, 2003). Moreover, because of accumulated heat load cattle continued to show an elevated panting score even if heat load index drops below threshold value (Gaughan *et al*., 2008). Sometimes a fall in respiration rate occurs even though ambient temperature is increasing which may indicates that the animal failing to cope because of its inability to dissipate the extra heat load through respiratory evaporating cooling mechanism (Rashamol *et al*., 2018).

2.7.1.3. Sweating rate

In addition to evaporative heat lose through respiratory tract, vaporization of water from skin surface by active sweating is one of the most effective means of thermoregulation and heat loss mechanisms of crossbreed cattle (Aggarwal *et al*., 2012). Weather factors such as air temperature, relative humidity, wind speed and solar radiation significantly influence the sweating rate. Along with these, certain physical and optical properties of hair-coat and fur such as hair-coat density and thickness, length and color of hair and skin influence the efficiency of sweating rate (Gebremedhin *et al*., 2008). Sweating accounts for 16-26 per cent of heat dissipation at an air temperature of 10 °C, 40-60 per cent at 27 °C, and about 80 per cent at temperature above 38 °C (Aggarwal *et al*., 2012). Higher ambient temperature increases the potential for evaporative heat lose through skin while high relative humidity lessen that potential. Result of studies conducted by Maia *et al*. (2008) in black and white HF cattle reveals that sweating rate is significantly higher in black areas of the skin compared to white areas because of the absorption characters of black color. Besides this, Gebremedhin et al. (2008) demonstrated that sweating rate can also defined be by breed differences with Jersey cows are considered to be more heat tolerant than Holstein cows.

2.7.1.4. Dry matter intake

In addition to thermoregulatory mechanisms such as sweating and panting, cattle dissipate extra heat energy by decreasing heat generating from rumen fermentation and metabolism by reducing dry matter intake, which also helps to maintain homeostasis (Beatty *et al*., 2008). Hence by reducing dry matter intake, animal attempts to bring metabolic heat production in line with its heat dissipation capabilities (Gaughan *et al*., 2002).

Rejeb *et al*. (2016) demonstrated that reduction in appetite during thermal stress is associated with increase in body temperature, consequently reduces dry matter intake which may help to maintain homeothermy through reduced metabolic heat production. Henceforth, under high ambient temperatures diary animals are expected to decrease dry matter intake in order to reduce their metabolic heat production (Hill and Wall, 2017). Feed intake starts declining when ambient temperature approaches 25-26°C, and reduces rapidly above 30°C resulting in 40% reduction in dry matter intake at 40°C (Kadzere *et al*., 2002). Under heat stress efficiency of energy utilization for milk production get reduced due to reduced feed intake (West, 2003). When a lactating HF cattle is transferred from an air temperature of 18 to 30°C, milk production declines by 15 per cent accompanied by 35 per cent reduction in energy utilization efficiency (Kadzere *et al*., 2002) since they reallocate energy for maintaining thermoregulation (Renaudeau *et al*., 2012).

West *et al*. (2003) demonstrated that dry matter intake and milk yield declined linearly with respective increases in air temperature or THI during the hot climate. Milk production decreases by 5.59 kg when THI value increases from 65.62 to 83.27 resulting in 2.31 kg drop in dry matter intake (Rejeb *et al*., 2016). Metabolic heat production increases with the productive capacity of the animal which is a major challenge for high producing cows in hot climate. This can be overcome by modifying the environment at critical times (West *et al*., 2003), as well as changing the feeding pattern by providing feed at cooler hours of the day (Kadzere *et al*., 2002). Furthermore, energy density of the diet, animal condition, previous exposure to hot conditions and days on feed will changes the dry matter intake (Gaughan *et al*., 2002).

2.7.1.5. Pulse Rate

There exists an inconsistency in the variation of pulse rate with various environmental conditions. Both increase and decrease in pulse rate with increase in environmental temperature has been reported until now (Ganaie *et al*., 2013). Dalcin *et al*. (2016) demonstrated that heart rate of thermally stressed *Bos taurus* cattle increases linearly with BGHI together with rectal temperature and respiration rate. This increasing trend in pulse rate was continued even after decline of ambient temperature indicating that the physiological responses of animals returns to its normal range only after a definite period when animals were brought to comfort zone (Ganaie *et al*., 2013).. On contrary to this, certain other studies show that pulse rate of *Bos taurus* cattle decreases when they are subjected to severe thermal stress (Kadzere *et al*., 2002). Also, it has been reported that changes in food consumption and metabolic rate will also contribute to changes in pulse rate (Rashamol *et al*., 2018). Heart rate increases with short term exposure and decreases with long term exposure to tropical climate. This is because of the fact that the cows are not acclimatized to tropical climate initially (Kadzere *et al*., 2002)

2.7.2 Behavioral response to thermal stress

Along with several physiological rearrangement adopted by cattle as an attempt to facilitate heat dissipation and to reduce metabolic heat production, cows in tropical humid climate manifest certain behavioral responses that can be used as a reliable indicator of heat stress (Brown-Brandl *et al*., (2006); Gaughan *et al*., (2008); Castaneda *et al*. (2012) and Kamal *et al*., 2018). Variations in behavioral responses should not be overlooked as they are directly linked to the production performance of cattle (Allen *et al*., 2013). It is also worth mentioning that the early diagnosis of heat load increases the efficiency of heat load alleviating strategies used and improves animal welfare during periods of hot weather (Castaneda *et al*., 2012). Thus, behavioral responses provides an insight into which how the animal responds and cope to stressful environmental conditions before production is being compromised (Schütz *et al*., 2010). It is the first response of animal to increasing heat load, if the behavioral responses are not sufficient to nullify the adverse effect of heat load and to maintain homeostasis animal will adopt physiological and hematological coping strategies (Lees, 2018).

Brown-Brandl *et al*., 2006 demonstrated that due thermal stress, eating, lying and agonistic behavior of cattle decreases as well as drinking and lying behavior increases compared to thermoneutral condition. And also it is evident that dairy cattle are highly motivated to use shade in warm weather condition when temperature and solar radiation is kept increasing (Tucker *et al*., 2009). It was also found that shifts in behavior along with elevated body temperature, respiration rate and thereby higher stress level is more pronounced in dark hided cattle compared to light hided cattle (Brown-Brandl *et al*., 2006).

2.7.2.1 Shade seeking behavior

Shade structures are effective in providing protection from solar radiation which helps to minimize loss in milk production and reproductive capacity and is estimated to reduce heat load from 30 to 50 per cent with a well-designed shade structure (Collier *et al.*, 2006). Dairy cattle with access to adequate shade have significantly lower rectal temperature, respiration rates and about 10 per cent more milk production compared to unshaded cattle (Fournel *et al.*, 2017). With increasing ambient temperature and solar radiation, cattle readily use shade when given access to it (Tucker *et al.*, 2008). Hence access to adequate shade is a valuable resource for dairy cattle in summer that can alleviate the negative effects of increased heat load (Kamal *et al.*, 2018,).

Availability of shade influences other behavior such as lying, standing, gazing and rumination (Stivanin *et al.*, 2019). Unshaded cows respond to heavy heat load by adopting other behavior strategies such as crowding around water trough and increasing standing time (Kendall *et al.*, 2006). Moreover, there is also evidence that cattle will engage in aggressive behavior to gain access to adequate shade especially when heat load increases (Tucker *et al.*, 2008). If more spade per cow is given, cows will simultaneously use shade and are able to share recourses rather than compete for it (Schütz *et al.*, 2010). Indeed, it is also found that combination of shade and sprinklers can effectively reduce heat load (Tucker et al., 2008). Schütz *et al.* (2010) compared the behavior of gazing cattle without shade or with access to 2.4 or 9.6 m^2 per cow and observed that cows with access 9.6 m^2 shade/cow spent a higher proportion of their lying time in the shade (36%) than cows with 2.4 m^2 shade (10 per cent) with 70 per cent fewer aggressive interactions. In addition to this, it is also observed that cow that had only 2.4 m^2 shade congregate around the water trough for longer period and has higher respiration rate.

2.7.2.2. Standing and lying behavior

Dairy cattle lie down approximately 8 to 16 h/d processing feed into milk and stands about 35 to 175 min/day in free stall barns (Tucker and Weary, 2004). Following thermal stress a reduction in the lying time may lead to physiological changes which may eventually led to negative impact on animal welfare (Ratnakaran *et al*., 2017). Regardless of the environment, even a mild increase in ambient temperature may evoke an increase in standing behavior (Smith *et al*., 2016). While standing portion of the animal body surface exposed to air flow increases allowing for considerable amount of heat lose through the underside of the cow (Tucker *et al*., 2009). This behavior acts as an adaptive mechanism to avoid the additional heat load from the ground as and to favor easy heat dissipation form the body (Ratnakaran *et al*., 2017). According to Tucker *et al*. (2009), time spent for standing increases by 10 per cent when heat load increased by 15 per cent. Core body temperature of dairy cattle is positively correlated to standing behavior, which are more likely to stand when core body temperature rises above 39.2 °C (Allen *et al*., 2013). Brown-Brandl *et al*. (2006) demonstrated that standing behavior increased by 6.1 per cent and lying behavior decreases by 3.2 per cent during thermal stress compared to thermoneutral condition. Also, it is found that heat abatement strategies such as wetting and forced ventilation significantly reduce thermal stress in dairy cattle allowing them to spend more time in lying posture (Gaughan *et al*., (2008a) and Harikumar *et al*., 2017).

2.7.2.3. Rumination and feeding behavior

Reduced feed intake is one of the most predominant behavior response of dairy cattle to reduce their metabolic heat production under thermal stress (Dalcin *et al*., 2016). West (2003) reported that for every 1 °C increase in ambient temperature above a cow's thermal neutral zone, dry matter intake decreases by 0.85 kg. It was evident from the results obtained by Ominski *et al*. (2002) that rate of feed intake decreased considerably during hotter periods of the day, while a sharp increase in intake occurred as the temperatures cooled. Hence, shifting the major part of feed intake to night hours, when non evaporative heat loss from the animal to the environment is more is efficient to lower energy expenditure during the daytime (Aharoni *et al*., 2005). Typically, lactating dairy cows spends about 4.5 h/day eating and 7 h/day ruminating (Beauchemin *et al*., 2018). Ruminating time is negatively affected by heat stress leading to a 2.2 minute reduction in time spent ruminating with every unit increase of THI above 76 (Soriani *et al*., 2013). Rise in THI depress rumination time, which subsequently led to a decline in DMI followed by reduction in milk production (Moallem *et al*., 2010). However, if comfortable microclimatic conditions are provided through heat ameliorative measures, a significant improvement in feeding and rumination time can be achieved (Vijayakumar *et al*., 2009). It was also reported rumination time for calves grouped under thatched roof was higher than those under asbestos sheet (79±1.79 and 74±1.55 min respectively). Although, if adequate access to shade per cow was provided, higher feed intake than cattle with less access to shade was also reported (Kamal *et al*., 2018).

2.8. BREED DIFFERENCES IN PHYSIOLOGICAL ADAPTABILITY TO THERMAL STRESS

Higher producing dairy breeds are more sensitive to heat stress compared to beef cattle, because of higher metabolic energy production (Das *et al*., 2016). The genetic ability of the animal to survive in a stressful environment is also a key component of adaptation. Therefore along with heat stress mitigation strategies focusing on housing management, variations in feeding, reduction in stocking density, etc., genetic variation among the animals both within and between breeds is important to be considered (Osei-Amponsah et al., 2019). The ability of an animal to face the adverse effect of solar radiation mainly depends upon the several characteristics features of skin and hair coat (Da Silva, 2006). Different breeds respond differently to heat stress.

Cattle from zebu breeds (Bos indicus) are native to warm-climate and are well adapted to cope with continuous high temperature and humidity than *Bos taurus* breeds of European origin (Hansen, 2004). European cattle are evolved in a more temperate environment. They perform well at temperatures ranging from 5°C to 25°C (Hernández-Rivera *et al.,* 2019), even at high humidity. But when temperatures exceed 25°C, drop in milk production occurs and nearly 50 per cent reduction at the temperature of 32°C or above, In contrast, genetic adaptations that have developed in zebu cattle during its evolution have acquired genes for thermotolerance. Comfort zone of zebu breeds lies between 15–27 °C and milk production begins to drop only after the temperature exceeds 35 °C (FAO, 2011). Evolutionary coping mechanisms that enhance the thermoregulatory ability of *Bos indicus* breeds include, hump with large ears and loose, thin skin with a prominent dewlap, greater skin surface to mass ratio, greater skin pigmentation, short sleek and shiny hair, lighter-colored coats, higher density sweat glands, and increased skin vascularity (Hansen, 2004). These special features promote heat dissipation by convection and evaporation and helps for maintaining animal comfort under hot conditions. The modern *Bos taurus* dairy cow differs greatly in her adaptations and ability to cope under heat stress conditions compared with her predecessors. They had thick skin held tightly to the body, long hair and a large amount of fat, which serve as insulators that reduce heat flow via conduction and convection and exacerbate effects of heat stress and are desirable traits for cold or temperate climates and thus, when subjected to high environmental temperatures, may lack adequate heat coping mechanisms (Polsky and von Keyserlingk, 2017).

The basal metabolic rate of *Bos indicus* is lower than for *Bos taurus*. Lower metabolic rate and milk yield of zebu breeds are the major contributing factor for its thermotolerance. The light-colored smooth and shiny hairs of zebu cattle reflect a large amount of incident solar radiation and thereby reduces heat exchange by radiation. Moreover properties of skin and less subcutaneous fat facilitate increased blood flow to the skin during heat stress reduces resistance to heat transfer from the body core to the skin (Hansen, 2004).

Cattle reduce their feed intake in response to heat stress, followed by reduced metabolic heat production. The reduction is more pronounced in *Bos taurus*, a 20 per cent decrease in feed consumption in Holstein cow at 30°C and consumption virtually stops when the temperature approaches 40°C in both

Holstein and Jersey. Associated with this certain clinical signs viz. open-mouthed panting, drooling, reluctance or inability to rise, increased licking of coat, and neurological signs of dullness such as staring and glazed eyes, etc. are expressed (Beatty *et al*., 2006).

Dikmen *et al.* (2009b) stated Holstein cow when subjected to warm-climate couldn't express their production potential in terms of milk production and compromises their reproductive efficiency. Studies conducted by Dikmen *et al.* (2014) confirms that slick haplotype which is responsible for short and sleek hair coats in Senepol cattle when introduced into Holsteins reported superior thermoregulatory ability compared to non-slick animals and experience a less drastic depression in milk yield during the summer. Hence it can be concluded that when one such thermotolerent genes are isolated from zebu cattle and further exploit them by using appropriate breeding strategies for climate-smart animal production (Osei-Amponsah *et al*., 2019).

Therefore crossbreeding programs involving the transfer of thermotolerent genes from cattle adapted to warm climate to less heat-tolerant breeds are gaining interest in the past few decades (Hernández-Rivera *et al*., 2019). Heat shock proteins (HSPs) are identified to be associated with heat tolerance and production performance in dairy cattle, they are synthesized during heat stress. It is reported that HSP70 is an ideal molecular marker for quantifying heat stress response in ruminant livestock (Sejian *et al*., 2018). Since cattle in the tropical and subtropical environments are subjected to various types of stress factors, mechanical inventions to alleviate thermal stress may not be practically feasible and expensive to implement particularly in poorly adapted cattle. Therefore along with proper managerial interventions, selecting and breeding cattle that are adapted to these stress factors are the best methods to ameliorating the effects of thermal stress to improve productivity and animal welfare (Dalcin *et al*., 2016).

2.9. HEAT STRESS INDICES

2.9.1. Temperature Humidity Index (THI)

Many indices have been developed for assessing animals' reaction to changing environmental conditions by combining various stress factors (Herbut *et al.*, 2018). Majority of studies on heat stress in livestock are mainly focused on temperature and humidity, since these data are easily available from nearby meteorological stations, whereas information about amount of radiation received by animal, wind speed, rainfall are not publically accessible (Bohmanova *et al.*, 2007 and Habeeb *et al.*, 2018).

In hot humid condition, temperature and humidity significantly influence heat transfer between animal body and external environment, and hence adequately representing overall impact of heat stress on livestock (Brown-Brandl *et al.*, 2005).The environmental conditions leading to heat stress in diary animals are generally represented using the temperature-humidity index (THI), the common empirical discomfort index, which is originally developed to indicate human discomfort by accounting the effect of air temperature and humidity first introduced by Thom of U.S. Weather Bureau (Thom, 1959) which has been adopted to show animal stress levels (Li *et al.*, 2009). Until now the THI which incorporates dry bulb and wet bulb temperature is remained as the most common indicator of heat stress in different animal species (Hammami *et al.*, 2013). Nascimento *et al.* (2019) proposed that strong interaction between temperature and humidity should be considered in order to illustrate the potential impact of these variables on bovine thermoregulation. Different animal species and humans have different sensitivities to ambient temperature and the amount of moisture in the air. Thus, a range of equations with different weightages for dry bulb temperature and relative humidity have been proposed for computing THI.

$THI = [0.4 \times (T_{db} + T_{wb})] \times 1.8 + 32 + 15$ (Thom, 1959)

$THI = (0.15 \times T_{db} + 0.85 \times T_{wb}) \times 1.8 + 32$ (Bianca, 1962),

$THI = (0.35 \times T_{db} + 0.65 \times T_{wb}) \times 1.8 + 32$ (Bianca, 1962)

THI = .8× T_{db} + ((RH/100) × (T_{db} - 14.3)) + 46.4 (LWSI; LCI, 1970)

THI = (0.55 × T_{db} + 0.2 × T_{dp}) × 1.8 + 32 + 17.5 (National Research Council, 1971)

THI = 0.72 (T_{db} + T_{wb}) + 40.610. (McDowell *et al*., 1976)

THI = T_{db} + 0.36 × T_{dp}) + 41.2 (Yousef, 1985)

THI = db°F–[(0.55 -0.55 x RH) (db°F–58)] (LPHSI, 1990)

T_{db} – Dry bulb temperature (°C); T_{wb} – Wet bulb temperature; T_{dp} - Dew point temperature. ; RH- Relative Humidity (%); db°F- bulb temperature (in Fahrenheit).

Integrating environmental factors to index, THI is divided into categories that potentially indicate the level of heat stress that varies by definition between researchers and conditions (Polsky *et al*., 2017). The Livestock Weather Safety Index (LWSI) (LCI, 1970) is the commonly used benchmark to quantify heat stress associated with hot-weather climate for livestock exposed to extreme conditions and determine the susceptibility of animal by assigning potentially heat stressed animals into normal, alert, danger and emergency categories by quantifying environmental using a combination of temperature (Ta) and per cent relative humidity into temperature humidity index (Davis and Mader (2003) and Hahn *et al*. (2009).

According to (McDowell *et al*., 1976) THI values 70 or less was comfortable, 75-78 stressful, and values above 78 caused extreme discomfort and animals may not be able to sustain normal core body temperature.

In 1990, Livestock and Poultry Heat Stress Indices was developed from Clemson University by incorporating the effects of both air temperature and relative humidity, which can be applicable to both small and large animals with different THI thresholds. LPHSI is calculated as THI=db°F–[(0.55 -0.55 x RH) (db°F–58)] where db°F = dry bulb temperature (in Fahrenheit) and RH = relative humidity percentage (RH %). THI thresholds less than 72 units indicates absence of heat stress while 72 to <74= Moderate heat stress, 74 to <78= severe heat stress and 78 and more = very severe heat stress in case of large animals. While, for small animals these thresholds values were highly varied and THI of 82 units relates to absence of heat stress, 82 to <84 = moderate heat stress, 84 to <86 = severe heat stress and 86 and more = very severe heat stress (Habeeb *et al.*, 2018).

Also, Armstrong (1994) stated that Temperature humidity index value less than 71 was considered as comfort zone, 72-79 as mild heat stress, 80 to 90 as moderate heat stress, and when values exceeds 90, it caused extreme distress and animals were unable to maintain thermoregulatory mechanisms. Generally, mild heat stress was considered to begin in cattle when THI approaches 72 with stress increasing to moderate level at 79 and severe stress at 89.Therefore, farmers should take measure to alleviate heat stress in summer months when THI approaches 72 in order to prevent loss in milk production and changes in milk composition somatic cell counts (SCC) and mastitis frequencies (Akyuz *et al.*, 2010).

Milk yield decreased by 0.2 Kg per unit increase in THI above 72 (West, 2003). In Mediterranean climate, Holstein-Friesian cows exhibited reduced milk productivity and DMI when THI values exceeds 68, and consequentially reduces milk yield by 0.41 kg per cow per day for every point increase in THI beyond 69 (Gantner *et al.* (2012) and Pragna *et al.* (2017)). It is evident from various studies that, maximum temperature and minimum relative humidity were the most critical variables to quantify heat stress, and both variables are easily combined into a THI (Ravagnolo *et al.*, 2000).

However THI indices differ in their ability to detect heat stress, in humid environment indices with larger weights on humidity seems to be more preferable whereas in arid and semiarid regime indices with emphasis on ambient temperature is found to be more appropriate (Bohmanova *et al.*, 2007). Nonetheless, it applies only to air temperature and relative humidity, without taking into account other relevant microclimate factors, such as air movement, solar radiation which in the summer affects the thermal comfort, cooling and milk productivity of the cows (Herbut (2013) and Herbut *et al.,* 2018).

Solar radiation and wind speed alter the ability of animal to remain in thermal equilibrium by influencing heat load and convective cooling respectively. Hence, adjustment to the THI equation based on solar radiation and wind speed are essential in determining level of heat stress (Davis and Mader, 2003).

Accordingly, in order to overcome the limitation of conventional THI Buffington *et al*. (1981) proposed a Black Globe Humidity Index (BGHI) which replaces dry bulb temperature with a black-globe temperature (Sejian *et al*., 2017). Black globe temperature was measured using a black globe thermometer made of a black copper ball which integrates the effects of air temperature, solar radiation and convective cooling due to wind into a temperature value with the help of temperature sensor fitted inside the ball (Li *et al*., 2009). The effect of radiant heat load can be evaluated by the equation

$$\text{BGHI:} = T_{bg} + .36T_{dp} + 41.5$$

Where T_{bg} = black globe temperature ° C and T_{dp} = dew point temperature, °C)

Under conditions of high solar radiation BGHI had shown a positive linear relationship with rectal temperature as well as negative relationship with milk yield compared to cows kept in areas lacking shade (Zimbelman *et al*., 2009, Herbut et al, 2018). BGHI values of 70 or below will not possess threat to dairy cattle exposed to solar radiation but when the index value crosses 75 points animal welfare is impaired with marked reduction in feed intake (Hahn *et al*., 2009 and Sejian *et al*., 2017). It also shows greater correlation with skin surface temperature and respiration rate (Collier *et al*., 2011). Studies show that BGHI is a better environmental indicator of comfort as well as respiratory frequency is the best physiological indicator of thermal stress in dairy cattle (Dalcin *et al*., 2016). Buffington *et al*. (1981) demonstrated that BGHI had greater correlation with rectal temperature and milk yield under conditions of high solar radiation (r^2 =0.36) without the influence of shade than under a shade structure (r^2 =0.23). Perhaps, BGHI showed limited applicability in determining heat stress in areas with a tropical climate (Da Silva *et al*., 2007).

Wet Blub Globe Temperature (WBGT) is the most widely used heat stress index. It was considered as a common index for quantifying environmental heat stress, and was simpler and most convenient to use. This index was based on black globe temperature (T_{bg}) which accounts for solar radiation, wet bulb temperature (T_{wb}), and dry bulb temperature (T_{db}) (Li *et al.*, 2009).

$$WBGT = 0.7\ T_{wb} + 0.2\ T_{bg} + 0.1\ T_{db}$$

However, regardless of its high correlation with physiological responses to work in hot, humid environments, inherent limitations of WBGT in terms of its inconvenience in routinely assessing heat stress in dairy farm due its difficulty in measuring black globe temperature (Kumar *et al.*, 2018). As it requires about 30 mints for the instrument to reach initial equilibrium, as well as the blackened sphere is often too large rendering measurement of black globe temperature impractical (Moran *et al.*, 2001). Furthermore, measuring wet bulb temperature requires a ventilated wet-bulb thermometer needs to be kept wet all the time (Li *et al.*, 2009).

Hence, Moran *et al.* (2001) introduced a new a novel environmental stress index (ESI), which is based on dry bulb temperature (T_{db}), relative humidity (RH), and solar radiation (SR).

$$ESI = (0.63 \times T_{db}) - (0.03 \times RH) + (0.02 \times SR) + [0.0045 \times (T_{db} \times RH)] - [0.073 \times (0.1 + SR) - 1].$$

These three commonly used variables are simple to measure and fast responders showing greater correlation with WBGT index. One of the earlier method that have been applied to the assess microclimatic conditions inside animal shelter is proposed by Baeta *et al.*, (1987) named Equivalent Temperature Index (ETI) for dairy cattle in above-thermoneutral conditions by combining the effects of dry bulb temperature and relative humidity with wind speed to evaluate the impacts on heat dissipation and milk production (Li *et al.*, 2009; Herbut *et al.*, 2018 and Hahn *et al.*, 2009)

$$ETI = 27.88 - 0.456T_{db} + 0.010754T_{db2} - 0.4905RH + 0.00088RH2 + 1.15WS - 0.12644WS2 + 0.019876\ Tdb\ RH - 0.046313\ T_{db}\ WS$$

Where, Tdb – Dry bulb temperature, RH – Relative humidity, WS – Wind speed

Since this index doesn't account to solar radiation which has a significant influence on microclimate inside the barn as well as on the occurrence of heat stress and is based results obtained in climate chambers that does not reflect the real production conditions, this formulae has not been widely accepted and is inefficient in temperate climate (Herbut *et al.,* 2018 and Hahn *et al.,* 2009).

Animals have the ability to integrate environmental changes and respond to it by adopting a variety of measures to indicate heat stress such as evoking certain physiological changes such as elevated body temperature, increased respiration rate, altered behavioral and immune responses. Furthermore, respiration rate have a positive correlation with dry bulb temperature and is also associated with increased solar radiation, relative humidity and decreased wind speed (Eigenberg *et al*., 2005).

In order to overcome the limitations of THI, new thermal indices have been developed by incorporating various environmental and physiological parameters (Hammami *et al*., 2013 and Gaughan *et al*., 2008). Adjustments to THI by accounting solar radiation and wind speed based on panting score have been proposed by Mader and Davis (2002) which allows the producers to more accurately predict heat stress (Mader and Davis, 2002). The adjusted THI is expressed as:

$$THI_{adj} = 4.51 + THI - 1.992\ WS + 0.0068\ SR;$$

Where WS = wind speed, m/s, SR = solar radiation, W/m^2.

THI is reduced by 3.14 units for each 1m/s increase in windspeed and for each 100 W/m^2 decrease in SR it was reduced by 1.49 units. The negative relationship between wind speed and panting score illustrates the ability of the animals to utilize convective heat exchange, which reaches its maximum when wind speed approaches 2 m/s, beyond which ability of the animal to dissipate heat is not apparent. Besides this solar radiation can contribute 1000 W/m^2 to the overall heat load of the animal which is further exacerbated by the dark color of hair, whereas presence of shade structures limited the adverse effect of radiation particularly in black hided cattle (Mader and Davis, 2002; Mader *et al.*, 2006 and Herbut *et al.*, 2018).

It was recommended that stress alleviating strategies should be initiated when THI value exceeds 70 units, prior to peak incidence of thermal stress. Hence, THI equation adjusted for radiation and wind speed helps to initiate ameliorative interventions as well as helps to predict future heat stress levels associated with changing weather patterns (Mader *et al.*, 2006).

Eigenberg *et al.* (2005) evaluated respiration rates (RR) of unshaded cattle exposed to daylight during summer months when temperature exceeds 25°C and compared with dry bulb temperature (T_{db}, °C), dew point (T_{dp},°C) or relative humidity (RH, %), solar radiation (SR, W/m^2), wind speed (WS, m/s) as independent variables. $RR = 2.8T_{db} + 2.4T_{dp} - 1.5WS + 0.038SR - 52.8$ (Based on dew point temperature)

$RR = 5.1T_{db} + 0.58RH - 1.7WS + 0.039SR - 105.7$ (Based on relative humidity)

Gaughan *et al.* (2003) developed a Heat Load Index (HLI) that predicts heat stress by overcoming unreliability in measurement of dry bulb temperature based on panting score. The HLI is based on black-globe temperature (T_{bg}, °C), relative humidity (RH, %), wind speed (WS, m/s), where black globe temperature is not measured directly, instead it is calculated by using dry bulb temperature and solar radiation. The HLI uses two separate equations, one for when the black globe temperature is greater than 25°C, and one for when it is less than 25°C

$HLI\ T_{bg}>25 = 8.62 + (0.38\ RH) + (1.55\ TG) - (0.5\ WS) + e^{[2.4 - WS]}$

$HLI\ T_{bg}<25 = 10.66 + (0.28\ RH) + (1.3\ TG) - WS$

Where, e = the base of the natural logarithm (approximate value of e = 2.71828).

The thermoneutral condition of HLI is ≤ 70 units, above this range heat stress of varying degrees of severity occurs will from 70.1 to 77 as warm, 77.1 to 86 as hot and above 86 very hot. The critical threshold value of 86 was developed for unshaded Angus steers based on changes in panting score. Later on adjustments to reference threshold are made subsequently on the basis of genotype (*Bos taurus*, *Bos indicus*, and crossbred cattle), coat color (black, red, and white), health status , degree of acclimatization, and access to shade, days on feed and manure management, and water trough temperature (Gaughan *et al.,* 2008). HLI is a better predictor of heat load than a spot measure THI as it provides real time heat load values with added advantage of including accumulated heat load to which the animals are exposed to previous climate (Lees, 2018).

Apart from heat load index, Mader *et al*. 2010 developed a Comprehensive Climate Index (CCI) with comparable thresholds. It was based on numerous environmental parameters that adjusts temperature for the combined effects of relative humidity, wind speed, and solar radiation. This index act as a holistic method to predict heat load in which all other previous indices fails to provide. It can be applied in a wide range of temperature from -30 to + 40 °C and can be used to determine temperature stress among cows both in very hot and very cold conditions (Mader *et al*., 2010; Herbut *et al*., 2018 and Lees, 2018).

Recently, Da Silva *et al*. (2015) proposed a new thermal index for dairy cattle in tropical environment, especially for the semi-arid regions. The effective radiant heat load (ERHL) which permits adequate estimates of the solar radiation in tropical regions by accounting transmittance from surrounding objects is also incorporated into the model. The Index of thermal stress for cows (ITSC) is calculated as,

$$ITSC = 77.1747 + 4.8327\ T_{db} - 34.8189\ WS + 1.111\ WS + 118.6981 VP - 14.7956\ VP - 0.1059\ ERHL$$

Where, T_{db} – Dry bulb temperature (°C), WS – Wind speed, m/s, ERHL - Effective radiation heat load, W/m^2, VP - Partial vapour pressure, kPa.

2.10. SPATIAL AND TEMPORAL CLASSIFICATION OF KERALA BASED ON TEMPERATURE HUMIDITY INDEX (THI)

Kerala is located in south-western India confronting hot and humid climate in the plains, while cool and bracing climate throughout the year in the high altitudes. According to THI based zonation of India by NICRA (2012), Kerala lies in the high-stress zone experiencing high THI. Adaptability and stress evaluation studies in dairy cattle with respect to thermal comfort delineates Kerala into seven THI zones. Extreme high-stress zone H4 are the pockets of severe stress having mean THI as 93.40. H1, H2, H3 are the high-stress zones in the coastal and midland of the state of Kerala with 89.87, 90.66, 91.07 respectively as mean THI, were as L1 and L2 zones are low THI zones with mean THI 75.52 and 78.73 respectively form the comfortable and moderately comfortable zones of Kerala (Prasad, 2014).

2.11 MODELS PREDICTING HEAT LOAD IN CATTLE SHELTER

Several metrological models have been developed to predict the magnitude of thermal stress in dairy animals. Majority of the heat stress studies in livestock are mainly focused on the effects temperature and humidity on animal health. According to Schüller *et al*. (2013) climate data obtained from meteorological stations underestimate heat stress in both the magnitude and duration. Therefore, he advocates that onsite measurement of climate data is mandatory for evaluating thermal stress.

Building characteristics (Haque and Hussain, 2011) and its orientation (Hatem *et al*., 2004), presence of shade trees (Abdel-Aziz *et al*., 2015), animal management practices (Harikumar, 2017 and Brouček *et al*., 2006), as well as the physiological and behavioral characteristics of animal (Herbut *et al*., 2018) also influences the thermal balance of the animals.

Studies conducted by Mader *et al.* (2006) in order to determine the environmental parameters contributing to heat stress in cattle and found that wind velocity and solar radiation significantly influence the heat load and adjustments were made to the THI equations. Adjusted THI equations showed a higher correlation with panting score and proved its appropriateness in predicting THI during hot hours of the day.

Lees (2018) developed a Dairy Heat Load Index (DHLI) based on panting score, black globe temperature and relative humidity to predict the impact of heat load and thermal comfort of dairy cattle in sub-tropical and tropical dairy regions of Australia.

CHAPTER 3

MATERIALS AND METHODS

3.1 STUDY PERIOD

The study was carried out in summer period extended for two months in February and March of 2020.

3.2 STUDY AREA

The selection of study areas was based on the LPHSI (THI = db°F–[(0.55 - 0.55 x RH) (db°F–58)] (LPHSI, 1990) where, RH-Relative Humidity (%), db°F-bulb temperature in degree Fahrenheit). A detailed field study was conducted in four THI zones of Kerala (Prasad, 2014) including three higher zones such as H1, H2, H3 and one lower zone L1. The zone H1, with a mean THI of 89.8 included Moncombu in Alappuzha district. The zone H2 included Vellanikkara in Thrissur district, with a mean THI of 90.66. The zone H3, having a mean THI of 91.07 included Pattambi in Palakkad district. These zones belonged to the coastal and midland of Kerala and recorded higher THI values during the study period. The lower THI zone L1 located in the high range areas of Idukki district at Pambadumpara with a mean THI of 75.52.

3.3 SELECTION OF FARMS

The study was carried out in different dairy farms from the respective zones and the selection of farms was based on the primary data of dairy farmers collected from the Dairy Extension Service Units (DESU) of Department of Dairy Development. The area of study was restricted to 10km geographical radius from the centre of zone since these zones were delineated based on meteorological data collected from the centre of the zone. Twenty five farms were selected from each zone which was further grouped into three classes based on the number of animals (Sabin, 2016) viz. small farms (1-2 animals), medium farms (3-10 animals) and large farms (more than 10 animals). Field visits were arranged and data collected directly from farms.

3.4 METEOROLOGICAL DATA COLLECTION

Macroclimatic and microclimatic data from exterior and interior of the cattle shelter were collected using electronic loggers.

3.4.1 Ambient temperature (°C)

Interior ambient temperature (°C) was measured at a height of 1.2m from the floor at the centre of the shelter. Exterior reading was taken at a distance of 5m from animal facing side of the shelter and at a height of 1.2m from ground (standard height of Stevenson's Screen). Electronic digital heat stress meter (HT30, Extech Instruments Corporation, USA) was used to record the ambient temperature.

3.4.2 Relative humidity (%)

Interior relative humidity (%) was measured at a height of 1.2m from the floor at the centre of the shelter. Exterior reading was taken at a distance of 5m from animal facing side of the shelter and at a height of 1.2m from ground (standard height of Stevenson's Screen). Electronic digital heat stress meter (HT30, Extech Instruments Corporation, USA) was used to record the relative humidity.

3.4.3 Solar radiation (°C)

The effect of exterior non shaded solar radiation (°C) at a height of 1.2 m from the ground was measured by digital heat stress meter (HT30, Extech Instruments Corporation, USA), at a distance of five metre away from animal facing side. Intensity of solar radiation inside the shelter was also measured at the same height from the ground at the centre of the shelter.

3.4.4 Wet bulb temperature (°C)

The wet bulb temperature (°C) was recorded at a height of 1.2 m from the ground by using digital heat stress meter (HT30, Extech Instruments Corporation, USA. Exterior and interior readings were taken five metre distance away from animal facing side of the shelter and at the centre respectively.

3.4.5 Wind velocity (m/s)

Wind velocity (m/s) was measured at height of 10 feet from ground using digital anemometer (Lutron AM-4201 digital anemometer, Taiwan) both inside and outside the shelter.

3.4.6 Light intensity (lux)

Intensity of light at the eye level of animal was recorded using digital lux meter (HTC LX-10A Mini Lux Meter, Range: 0-199999 Lux, HTC, China). Readings were recorded randomly from different areas inside the shelter and the mean value was taken in order to get a representative value of light inside the shelter.

3.5 TOPOGRAPHICAL INFORMATION

Latitude, longitude and altitude of each farm was recorded using GPS Tracker GARMIN Etrex 20x, Garmin, USA

3.6 STRUCTURAL PARAMETERS (ABIOTIC FACTORS)

3.6.1 Facilities, Housing and Infrastructure

Information regarding the structural characteristics of the shelter such as type of shade structure, roof type and roofing material, flooring material were recorded. Dimensions of the shelters were also recorded in terms of length(m), width (m), height (m) and total air volume (m^3) contained inside the shelter was calculated. Total length and width of the shelter was measured inside and the width of manger was not considered for total width calculation. Total height of the shelter from floor level was measured at the centre. The height of the eves, sidewalls and grilled area were also recorded. Length, width and height were measured using digital distance meter (Bosch GLM 40, Bosch, Germany).

Heat abatement strategies adopted in the shelters along with its proximity to vegetation and other shade structures were documented. In addition to this, temperature of floor and roof is randomly taken from six different locations inside the barn and its mean value was calculated. It was measured using infrared thermometer (EXTECH HD500: Extech Instruments Corporation, USA)

3.7 MEASUREMENT OF BIOTIC FACTORS

3.7.1 Animal details

Total number of animals in the farm was counted and categorised as small farms (1-2 animals), medium farms (3-10 animals) and large farms (more than 10 animals) (Sabin, 2016). Animal details such as breed, skin colour, length, and girth were also recorded. Length from point of shoulder to pin bone and girth at chest level of animals was measured using standard measuring tape.

3.7.2 Metabolic body size

Metabolic body weight is defined as 3/4th power of body weight. Live body weight of cattle was estimated using Shaeffer's formula (Khan *et al*., 2003):

Live weight (kg) = $(L \times G^2) / 660$

Where, L= Length of the body (inches)

G = Chest Girth (inches)

Metabolic body weight (kg) = $(\text{Live weight})^{3/4}$

3.7.3 Work rest cycle

Work rest patterns such as lying and standing positions, feeding and rumination were recorded from a distance without disturbing the animal at the point of observation. Numbers of animals in work rest positions were counted in all the farms.

3.7.4 Production details

Production details in terms of average milk yield (Kg /day) were collected from each farm on the basis of farmer response and the mean value was calculated.

3.7.5 Physiological Parameters

3.7.5.1 Body temperature (°C)

Skin temperature was taken from fore head, left flank and udder by using infrared thermometer (Extech HD 500, Extech Instruments Corporation, USA). Readings were taken from all the animals when the total number of animals was less than six and when the total number was more than six, randomly six animals from the group were selected. The mean skin temperature was calculated from each farm.

3.7.5.2 Respiration rate (bpm)

The respiration rate was recorded by observing the flank movements of animals for one minute from a distance without disturbing the animal. The mean respiration rate of six or all the animals was recorded when the number of total animals were above six or below six respectively.

3.7.5.3 Panting score

Panting scores were assigned based on their respiration rate (Gaughan *et al.*, 2008). Cattle having a normal respiration rate not more than 40 breaths/min (bpm) was categorised as panting score 0, respiration rate between 40 and 70 bpm expressing slight panting with visible chest movements as panting score 1, moderate panting having respiration rate between 70 and 120 also with presence of drool as panting score 2. Panting score 3 was given when the animal showed respiration rate between 120 and 160 also with experiencing heavy open mouth panting with drooling and extended neck. In addition to respiration rate between 120 and 160 bpm, if the animal shows excessive salivation and occasional protruding tongue, a panting score 3.5 was given whereas if respiration rate rises beyond 160 bpm with protruding tongue for extended period with excessive drooling, panting score 4 was given.

3.8 HEAT LOAD INDEX

Heat load index (HLI) that predicts thermal stress on the basis of black-globe temperature (TG, °C), relative humidity (RH, %), wind speed (WS, m/s) was calculated both inside and outside the animal shelter (Gaughan *et al.,* 2008). The HLI used two separate equations, one when the black globe temperature (T_{bg}) was greater than 25°C, and the other when temperature was less than 25°C.

$$HLI_{T\ bg>25} = 8.62 + (0.38\ RH) + (1.55\ TG) - (0.5\ WS) + [e^{2.4-WS}]$$

$$HLI_{T<25} = 10.66 + (0.28\ RH) + (1.3\ TG) - WS$$

Where e = the base of the natural logarithm (approximate value of e = 2.71828).

3.10 STATISTICAL ANALYSIS

The data obtained on various parameters were statistically analysed using various methods. Karl Pearson's correlation coefficient was used to ascertain linear relationship between various parameters. Regression model which defines the relation between Heat Load Index inside the shelter and other predictor variables were developed using the stepwise regression method. Analysis of variance (ANOVA) followed by Duncan's Multiple Range Test was also used in the study. The data were analysed using IBM SPSS Statistics Version 24.0.

CHAPTER 4

RESULTS

4.1. Geographical details of the study area

The study was conducted in the four selected THI zones of Kerala viz HI (Moncombu), H2 (Vellanikkara), H3 (Pattambi) and L1 (Pampadumpara). Geographical details such as latitude, longitude and the mean altitude of location of farms studied are given in Table 2.

Table 2. Geographical details of the study area

THI Zone	Name of the zone	Latitude	Longitude	Altitude (m) (Mean ± SE)	Mean THI (Mean ± SE)
HI	Moncombu	9.49 º N	76.33º E	9.72 ± 0.82	84.21 ± 0.49
H2	Vellanikkara	10.54 º N	76.28º E	46.60 ± 7.86	81.77 ± 0.27
H3	Pattambi	10.80 º N	76.18º E	39.04 ±1.82	84.85 ± 0.38
L1	Pampadumpara	9.79º N	77.15 º E	1031.52± 8.55	77.10 ± 0.39

4.2. Classifications of dairy farms

The dairy farms were classified into three groups based on the number of animals and showed in Table 3. In all the zones, number of large farms was less than small and medium farms. It was observed that 50 per cent were medium farms with 3-10 animals among the overall farms studied.

Table 3. Classification of dairy farms

THI Zone	Small farms (1-2 animals)	Medium farms (3-10 animals)	Large farms (>10 animals)
H1	8	15	2
H2	8	15	2
H3	13	8	4
L1	7	15	3
Overall	**36**	**50**	**14**

4.3. Breed wise classification of cattle

Cattle of Kerala are mainly classified as crossbreds and indigenous. The crossbreds constitute 95.2 per cent of the total cattle studied across the four THI zones of Kerala, are having exotic inheritance of Holstein Friesian (HF) or Jersey. Among these crossbred cattle, HF forms the major category whereas non-descript cattle forms the least category (Fig. 1).

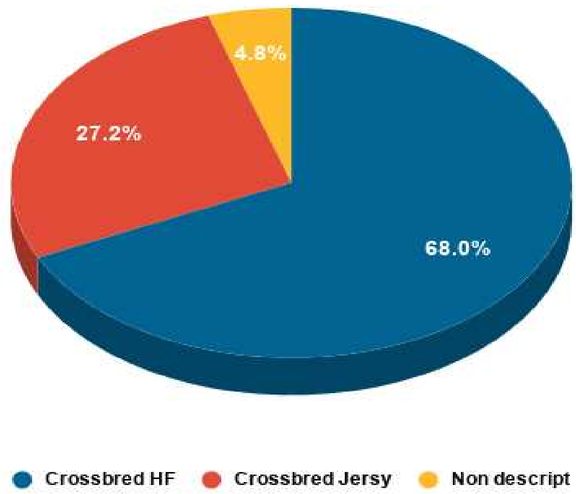

Figure 1. Breed wise distribution of cattle in different zones

4.4. Classification of cattle based on skin colour

Fig. 2 showed the overall classification of cattle based on their skin color. Cattle having black coat color forms the major class followed by the fawn, black and white, white, fawn and white respectively.

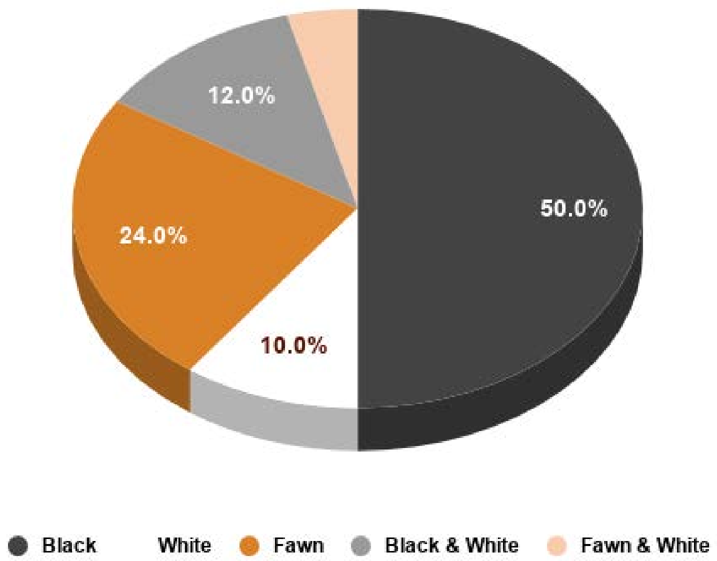

Figure 2. Classification of cattle based on skin colour

4.5. Distribution of different roofing materials for cattle shelter.

In Kerala, a wide variety of materials are being used for roofing cattle shelters. Different roofing materials used in the farms are given in Fig.3. In the present study Galvanised Iron (GI) sheet was found to be the most preferred material followed by asbestos, tin sheets and clay tiles. However, temporary roofing such as tarpaulins and thatching together constituted less than 10 per cent of the total cattle shelters studied.

Distribution of roof materials in different categories of farms viz small (Fig.4) medium (Fig.5), and large(Fig.6). Among the total farms surveyed, 36 per cent were small farms (Table 4). Almost all types of materials found to be used as roofing materials (Fig.3) were seen in small farms (Fig.4). It was also evident that in 93 per cent of large farms surveyed, GI sheets were used predominantly. Materials other than GI and asbestoses were not used in large farms as a roofing material. Thatched, tarpaulins and false ceiling roof materials were found only in small and medium farms. There was a sigificant assosiation between roof materials and categories of farms using Fisher's Exact Test ($p<0.05$).

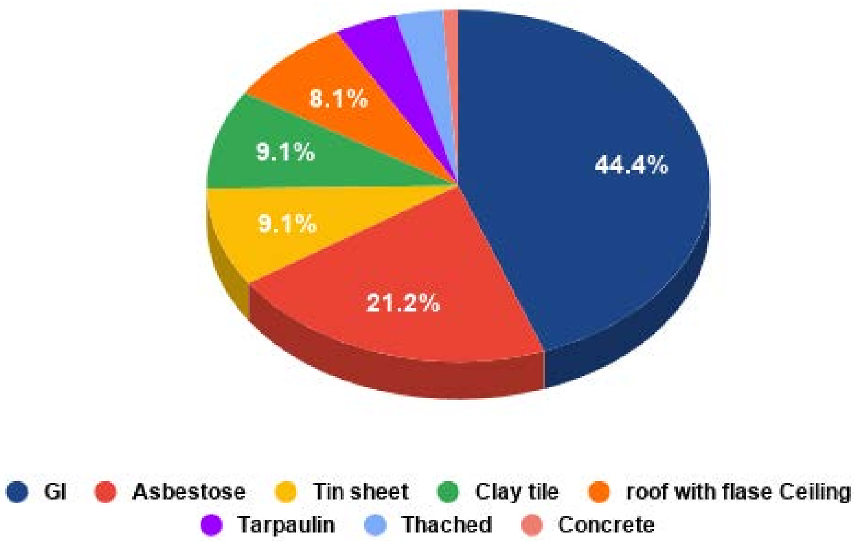

Figure 3. Roofing Materials Used in Cattle Shelters in Kerala

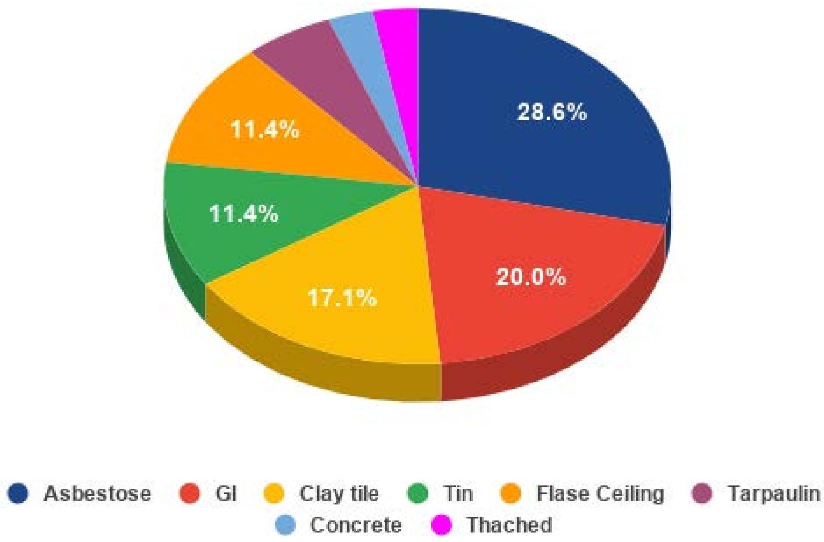

Figure 4. Distribution of roof materials in small size farm

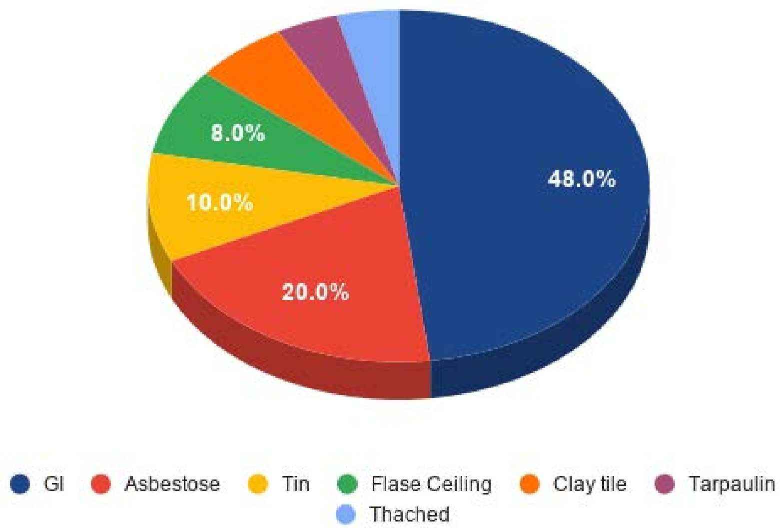

Figure 5. Distribution of roof materials in medium size farms

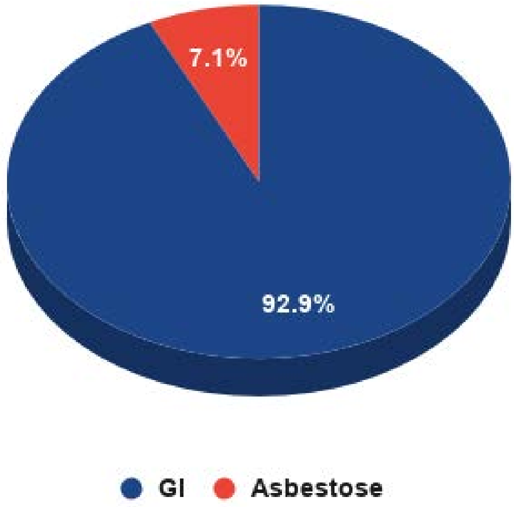

Figure 6. Distribution of roof materials in large size farms

4.6. Flooring materials used in cattle shelter

In 99 per cent of the dairy farms studied, solid concrete floor was a common feature. Rubber mats were provided as an additional flooring material over the concrete floor in 63 per cent of the farms. Wood as flooring material was observed only in one per cent farms (Fig.7).

Rubber mat as an additional flooring material was found predominately in large and medium-size farms, but in small farms, rubber mats were rarely used (36.1 per cent). The detailed distribution of floor materials in different categories of farms viz small, medium and large is depicted in Fig.8, Fig.9, and Fig.10 respectively. There was a significant association between floor material used and categories of farm using Fisher's Exact Test ($p < 0.01$).

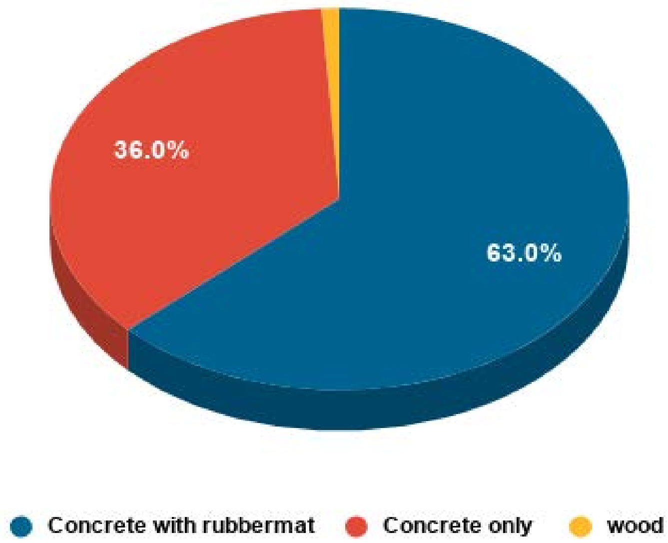

Figure 7. Flooring materials used in cattle shelter of Kerala

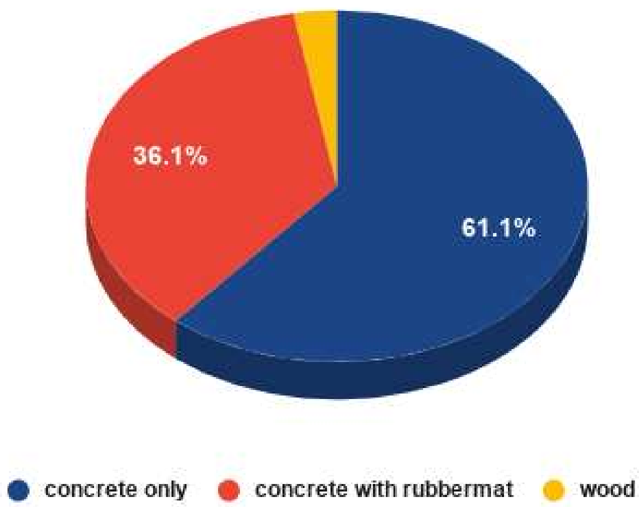

Figure 8. Distribution of floor materials in small size farms

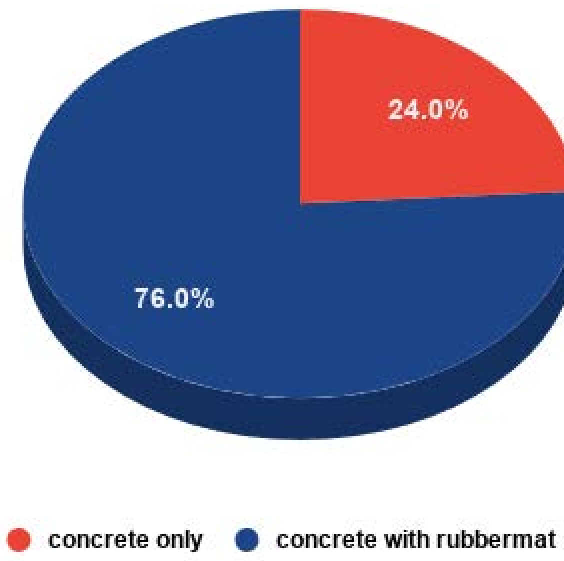

Figure 9. Distribution of floor materials in medium size farms

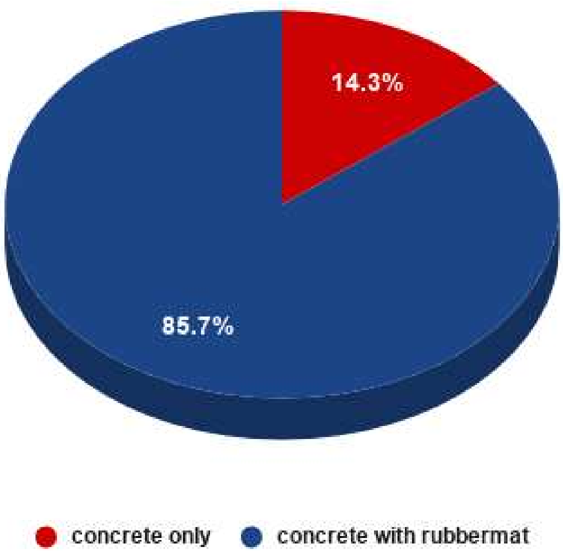

Figure 10. Distribution of floor materials in large size farms

4.7. Orientation of cattle shelters

The direction of long axis of the cattle shelter was observed. The North-South orientation of shelters was predominantly seen in all the zones. East-West orientation was observed in 36 per cent of farms (Fig.11).

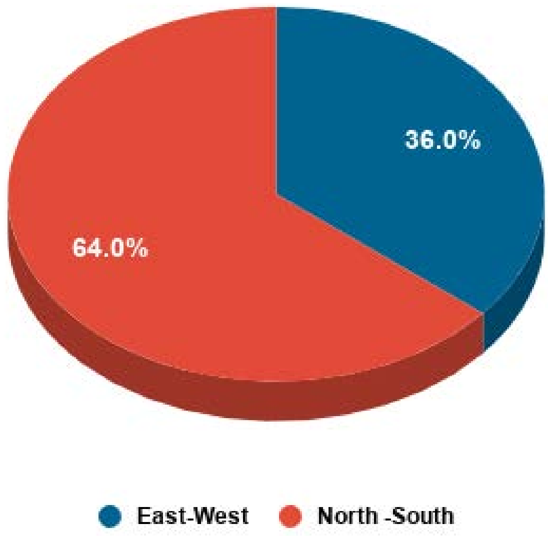

Figure 11. Orientation of cattle shelters

4.8. Orientation of animals inside the cattle shelters

Inside the shelter, cows were aligned in such a way that they were facing either north, south, east or west depending on the orientation and structural peculiarities of the building. No specific trend was noticed in this study as given in Fig.12. In tail to tail or face to face housing systems, cows were facing in two directions and therefore it was not accounted in this study

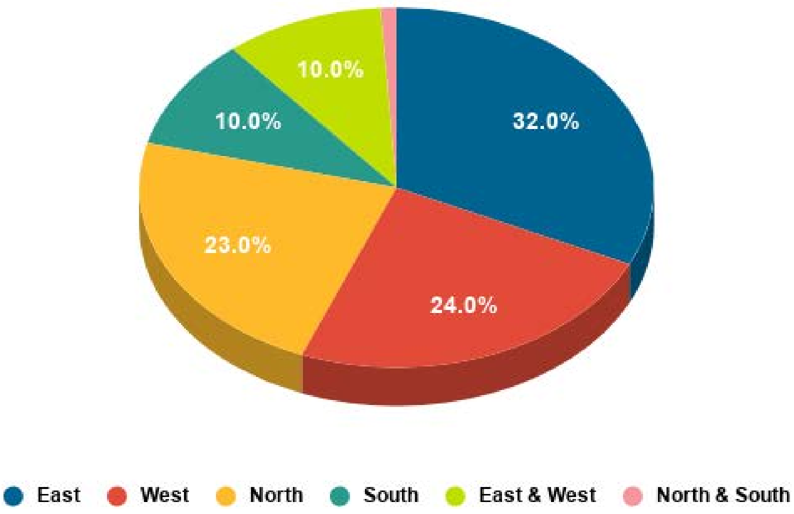

Figure 12. Orientation of animals inside the cattle shelters

4.9. Presence of shade over the farms

Fig.13 showed the availability of shade over the shelters from vegetation and shade trees in different farms. It was noticed that 75 per cent of farms were under the shadow of vegetation with shade varying from 25 per cent to 100 per cent and the rest of the farms were directly exposed to the sun.

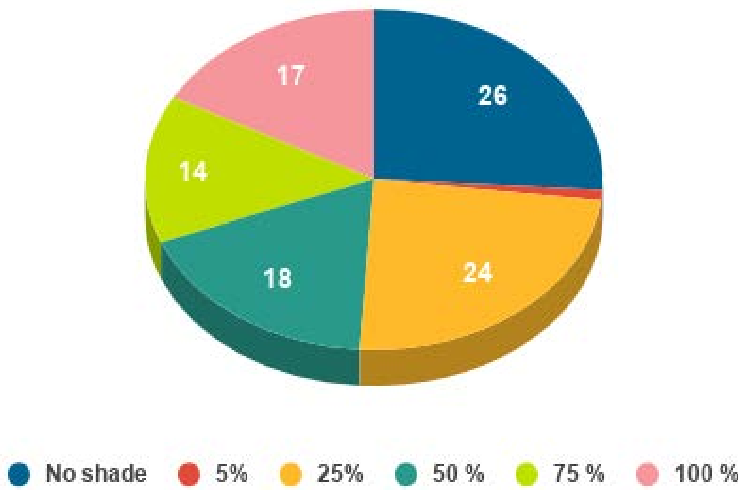

Figure 13. Presence of shade over the farms

4.10. Roof and floor temperature of cattle shelters

The mean roof and floor temperature of cattle shelters in different THI zones were illustrated in the Table 4. Highest roof temperature was measured at the H1 zone which was no significantly different from mean roof temperature measured at the zones H2 and H3. At the same time, highest mean floor temperature was recorded at the zone H3 not significantly different from H1. Lowest value of both was recorded at the zone L1.

Table 4. Roof and floor temperature of cattle shelters

THI Zone	Roof temperature (°C) Mean ± SE	Floor temperature (°C) Mean ± SE
H1	$43.63^{a} \pm 1.93$	$27.99^{a} \pm 0.40$
H2	$39.62^{a,b} \pm 1.80$	$26.48^{b} \pm 0.49$
H3	$42.51^{a,b} \pm 1.81$	$28.92^{a} \pm 0.50$
L1	$37.41^{b} \pm 1.48$	$23.83^{c} \pm 0.43$

Means with different superscripts differ significantly at $p<0.05$

4.11. Roof temperature for different roofing materials

The comparison of roof temperature with different roofing materials is illustrated in Table 5. It was evident from the table that there was a significant difference in temperature of thatched roof with the temperature of other roofing materials except the temperature of roof with false ceiling. No significant differences in temperature was observed for Galvanised Iron (GI), tarpaulin, tin sheet, clay tile, asbestoses and roof with false ceiling. The highest temperature was observed for GI (44.08 ± 1.46) followed by tarpaulin (41.33 ± 5.99), tin sheet (41.20 ± 2.61), clay tile (39.75 ± 2.30), asbestoses (38.90 ± 1.37), roof with the false ceiling (34.32 ± 2.14), and thatched (29.20 ± 2.08).

Table 5. Comparison of roof temperature for different roof materials

Roofing materials	Mean temperature (°C) (Mean ± SE)
GI	$44.08^{a} \pm 1.46$
Tarpaulin	$41.33^{a} \pm 5.99$
Tin sheet	$41.20^{a} \pm 2.62$
Clay tile	$39.75^{a} \pm 2.3$
Asbestoses	$38.90^{a} \pm 1.37$
Roof with false ceiling	$34.32^{ab} \pm 0.9$
Thatched	$29.20^{b} \pm 2.14$

Means with different superscripts differ significantly at $p<0.05$

4.12. Mean temperature for different flooring materials

Table 6 shows the mean temperature of different floors in cattle shelter. Either concrete slatted floor alone or concrete slatted floor covered with perforated rubber sheet was used in almost all farms. It was noticed that there was no significant difference in temperature of both, but a small drop in temperature (approximately 1°C) was observed on the floor covered with a rubber mat.

Table 6. Mean temperature of different floors in cattle shelters

Floor material	Mean temperature (°C) (Mean ± SE)
Concrete	$27.28^{a} \pm 0.46$
Rubber mat	$26.43^{a} \pm 0.37$

Means with different superscripts differ significantly at $p<0.05$

4.13. Body weight and metabolic body weight of cows

The mean body weight of all the cattle studied was 438.22 ± 6.33 Kg and the mean metabolic body weight was 95.61 ± 1.03 Kg. No specific trend in the distribution of body weight was observed, however, cows in the L1 zone recorded the highest body weight and metabolic body weight compared to other zones (Table 7)

Table 7. Body weight and the metabolic bodyweight of cattle

Zone	Body weight (Kg) (Mean ± SE)	Metabolic body weight (Kg) (Mean ± SE)
H1	417.33 ± 11.48	92.20^{b} ± 1.92
H2	406.47 ± 9.71	90.41^{b} ± 1.66
H3	456.63 ± 8.83	98.72^{a} ± 1.40
L1	471.54 ± 13.93	100.99^{a} ± 2.25
Overall	438.22 ± 6.33	95.61 ± 1.03

4.14. Behaviour response of cattle in different THI zones

Table 8 shows the behaviour responses of cattle in different THI zones. It was recorded that at the time of observation overall 62 per cent of cattle were standing and 31 per cent were ruminating. Similar behaviour was observed in all the zones without much variation.

Table 8. Behaviour responses of cattle in different zones

	THI Zones					
Behaviour response (%)		**H1**	**H2**	**H3**	**L1**	**Overall**
	Standing	58.76	74.68	55.66	60.80	62.47
	Lying	41.24	25.32	44.34	39.20	37.53
	Ruminating	36.08	30.52	32.08	27.20	31.12
	Feeding	15.46	25.32	19.81	12.80	18.88

Table 9. Climatic variables recorded exterior and interior of animal shelter (Mean ± SE)

	H1		H2		H3		L1		Overall	
	Exterior	**Interior**	**Exterior**	**Interior**	**Exterior**	**Interior**	**Exterior**	**Interior**	**Exterior**	**Interior**
Ambient Temperature (°C)	34.28± 0.49	33.34 ± 0.38	35.06 ± 0.29	34.30 ± 0.39	36.23 ± 0.35	35.13 ± 0.28	30.0 ± 0.40	29.44 ± 0.32	33.91 ± 0.30	33.05 ± 0.28
Black globe Temperature (°C)	38.62± 0.99	35.70 ± 0.73	39.63 ± 0.89	36.38 ± 0.73	40.21 ± 0.75	37.39 ± 0.66	39.22 ± 1.32	31.08 ± 0.57	39.42 ± 0.50	35.14 ± 0.41
Relative humidity (%)	52.30± 1.47	53.90± 1.41	34.98 ± 1.63	36.86 ± 1.70	45.76 ± 0.88	47.85 ± 0.90	42.29 ± 1.10	44.14 ± 0.90	43.83 ± 0.90	45.69 ± 0.89
Wet bulb temperature (°C)	29.01± 0.36	28.12 ± 0.24	27.60 ± 0.30	26.80 ± 0.29	30.01 ± 0.31	28.70 ± 0.26	25.10 ± 0.33	23.33 ± 0.18	27.93 ± 0.25	26.74 ± 0.24
Wind speed (m/s)	0.25± 0.10	0.15 ± 0.08	1.65 ± 0.49	1.39 ± 0.37	0.48 ± 0.24	0.35 ± 0.23	1.77 ± 0.52	0.30 ± 0.15	1.03 ± 0.20	0.54 ± 0.12

All climatic variables recorded exterior to the shelter have a strong significant positive correlation ($p < 0.01$) with same variables recorded interior in all zones.

4.15. Climatic variables recorded exterior and interior of animal shelter

Climatic variables such as ambient temperature (°C), black globe temperature (°C) relative humidity (%), wet bulb temperature (°C), and wind speed (m/s) both exterior and interior to the shelter were recorded as shown in Table 9. It was found that, climatic variables recorded exterior to the shelter have a strong significant positive correlation ($p< 0.01$) with the same variable recorded interior in all zones.

4.15.1. Ambient temperature (°C)

Mean ambient temperature both exterior and interior to the shelter showed an increasing trend from zone H1 to H3. The highest value of exterior and the interior temperature was recorded in zone H3 (36.23 ± 0.35 and 35.13 ± 0.28°C respectively) and the lowest value was recorded in zone L1 (30.0 ± 0.40 and 29.44 ± 0.32°C respectively). In all THI zones significant positive linear relation ($r=0.941$, $p<0.01$) between exterior and interior temperature was observed as well as a small drop in temperature was found at interior condition in all THI zones.

4.15.2. Black globe temperature (°C)

Black globe temperature recorded exterior and interior to the shelter in different THI zones showed in Table 9. Mean black globe temperature exterior and interior is increasing from H1 to H3. The highest value of black globe temperature both exterior and interior (36.23 ± 0.35 and 35.13 ± 0.28°C respectively) was recorded in zone H3. And the lowest exterior black globe temperature was observed in zone H1 while the lowest interior was in zone L1.

4.15.3.. Wet bulb temperature (°C)

Distribution of wet bulb temperature both exterior and interior of cattle shelters along with dry-bulb (ambient temperature) in different THI zone is depicted in Fig.14. The highest wet-bulb temperature both exterior and interior was recorded in zone H3 followed by H2, H1 and L1 respectively. Both dry bulb and wet bulb temperatures followed similar distribution pattern in all zones in exterior and interior. While considering all zones together, the mean wet-bulb temperature both exterior and interior was noticed as 27.93± 0.25 °C and 26.74± 0.24°C respectively.

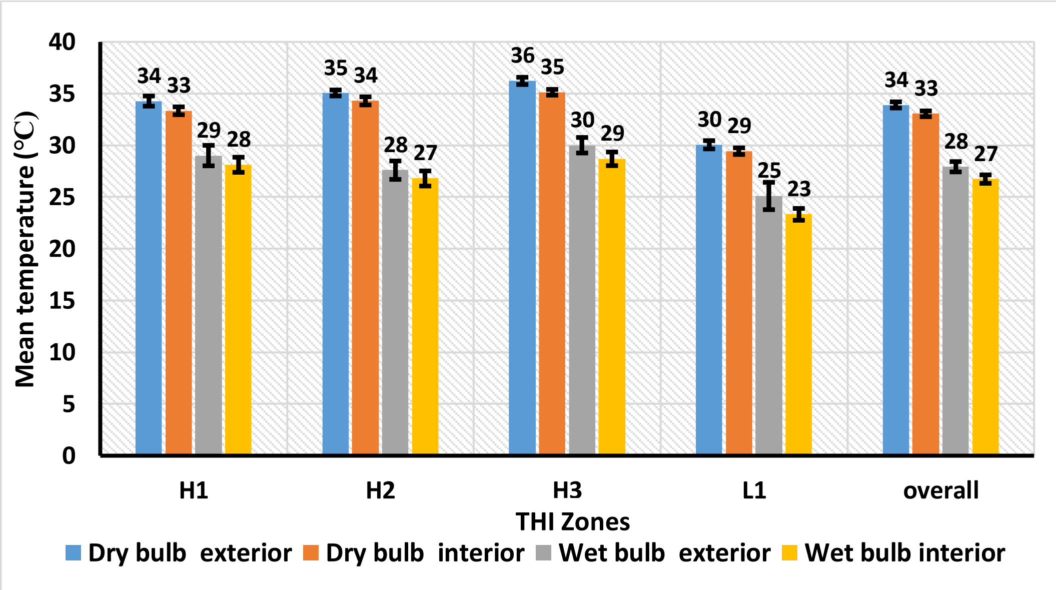

Figure 14. Distribution of dry bulb and wet bulb temperature exterior and interior of shelters in different THI zones

4.15.4 Relative humidity (%)

Relative humidity measured both exterior and interior of the shelters in different THI zone is shown in Fig.15. Relative humidity interior of the shelter was higher than exterior in all THI zones. The highest value of relative humidity both exterior and interior and was recorded in zone H1 (52.30 and 53.90 per cent respectively) and lowest in zone H2.

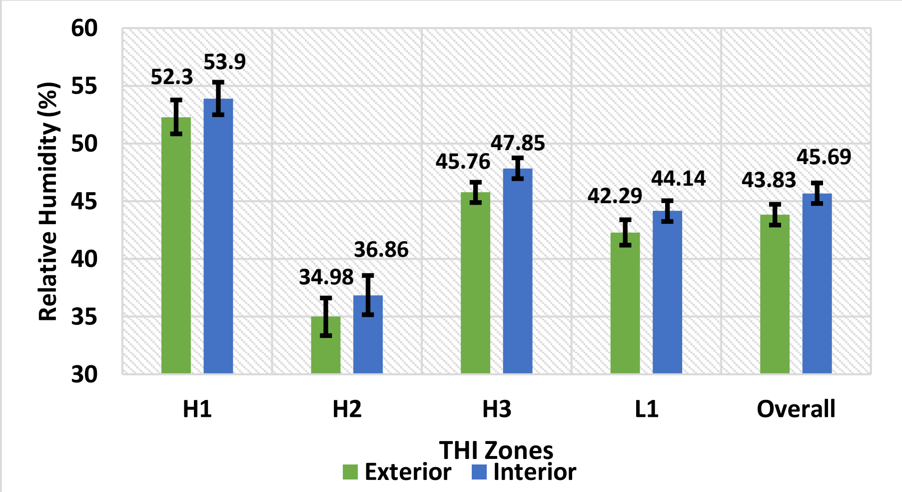

Figure 15. Relative humidity measured both exterior and interior to shelter in different THI zone

4.15.5. Wind Speed (m/s)

Mean wind speed interior of the shelter was lower than exterior in all THI zones. Highest value of exterior wind speed was in zone L1 (1.77 ± 0.52m/s) whereas the highest interior wind speed was recorded in zone H2 (1.39 ± 0.37m/s). At the same time, lowest value of both exterior and interior wind speed was noticed in the zone H1. Zone wise distribution of wind speed exterior and interior to the shelter is depicted in Fig.16.

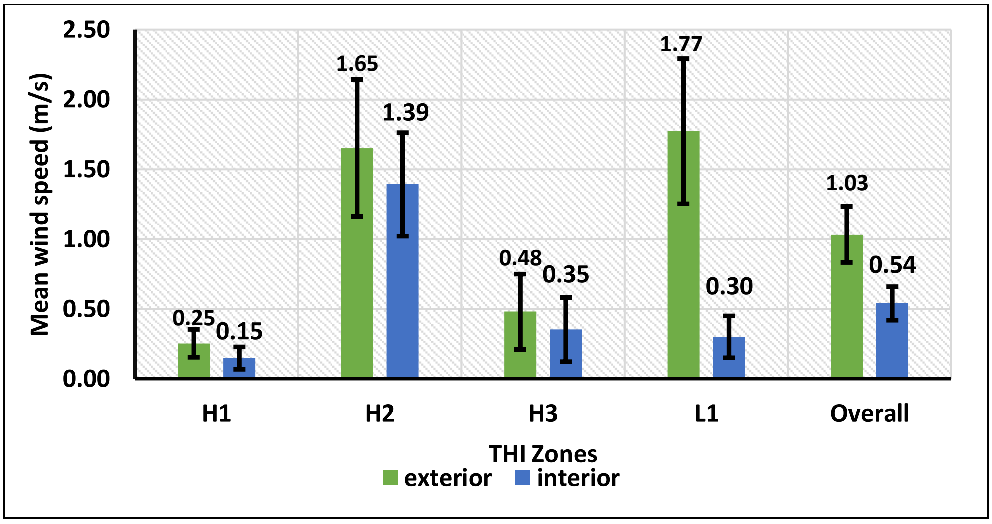

Figure 16. Zone wise distribution of wind speed exterior and interior to the cattle shelter

4.15.6 Relationship between ambient temperature and black globe temperature

Considering the pooled data from all zones, ambient temperature, both exterior and interior found to have a significant positive relation ($r = 0.751$, $p<0.01$) with black globe temperature Table 10. But when individual zones are considered, no significant relationship was observed in zone H3.

4.15.7 Relationship between relative humidity and wind speed

Relative humidity interior to the shelter had a significant negative correlation with wind speed when pooled data from all THI zones were accounted ($r= -0.244$, $p <0.05$) Table 10. A negative, but not significant relationship was observed between the relative humidity and wind speed in exterior condition.

4.16. Heat load Index interior and exterior of cattle shelters in different THI zones

The heat load index (HLI) both exterior and interior of the shelter was calculated by incorporating black globe temperature, relative humidity and wind speed from different THI zones (Table 10). In all THI zones, HLI exterior to shelter was found to have significant positive correlation with HLI interior ($r= 0.549$, $p < 0.01$). The HLI interior of the shelter in the zone L1 was lower and significantly different from the rest of the zones ($p<0.05$). Zone H1 and H3 recorded no significant difference ($p< 0.05$) in HLI interior. But zone H2 was lower and significantly different from H1 and H3 and higher and significantly different from than zone L1 ($p< 0.05$).

The highest value of HLI exterior was recorded at H3 zone followed by H1, however no significant difference in HLI between the two was noticed. The lowest HLI exterior was in zone H2 followed by zone L1, but no significant difference was noted between these two zones. At the same time, there existed a significant difference in HLI exterior between the zones H2, L1 and H1, H3.

Table 10. Heat load index (HLI) calculated exterior and interior in all THI zones

THI zones	Interior(Mean ± SE)	Exterior(Mean ± SE)
H1	$94.04^{a} \pm 1.20$	$96.876^{a} \pm 1.46$
H2	$83.944^{b} \pm 1.62$	$87.412^{b} \pm 1.49$
H3	$94.048^{a} \pm 1.20$	$96.992^{a} \pm 1.29$
L1	$79.284^{c} \pm 1.45$	$88.764^{b} \pm 1.81$
Overall	**87.829 ± 0.92**	**92.511 ± 0.87**

Means with different superscripts **a-c** differ significantly column wise

4.16.1. Distribution of farms in different HLI category

The Percentage distribution of farms in different HLI categories is represented in Fig.17. Thermoneutral (HLI below 70), warm (70-77), hot (77-86), and very hot (above 86) are the 4 distinct HLI categories used. It has been apparent from the graph that the majority of farms (60 per cent) fall in the very hot HLI category. The thermoneutral condition was observed only in five per cent of the total farms.

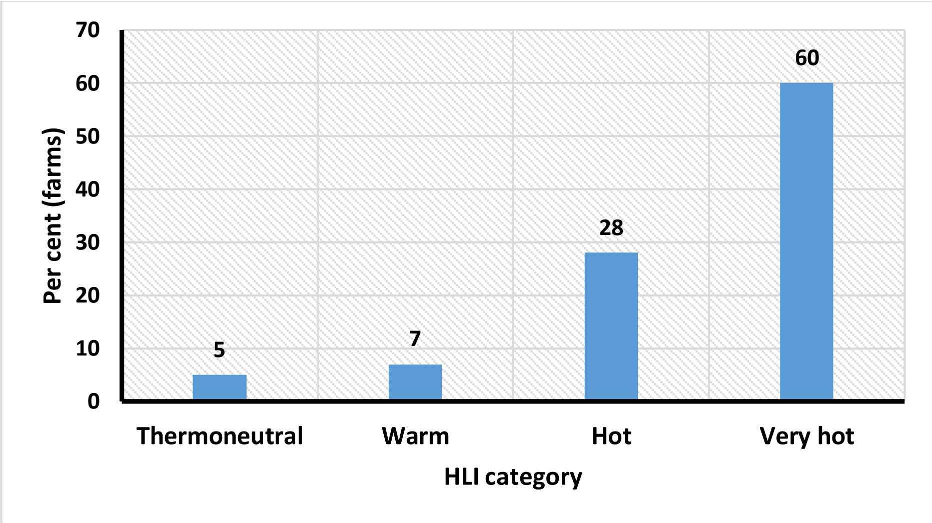

Figure 17. Distribution of farms in different HLI category

4.16.2. Relationship between HLI and altitude

Relationship between HLI and altitude in overall zones is depicted in Fig.18. Altitude was found to have significant negative relationship with HLI (r= - 0.541, p<0.01). As the altitude increased HLI decreased significantly. The relationship is represented by the linear equation as HLI = -0.0116 X Altitude in meters + 91.096 (R^2 = 0.299) as given in the figure.

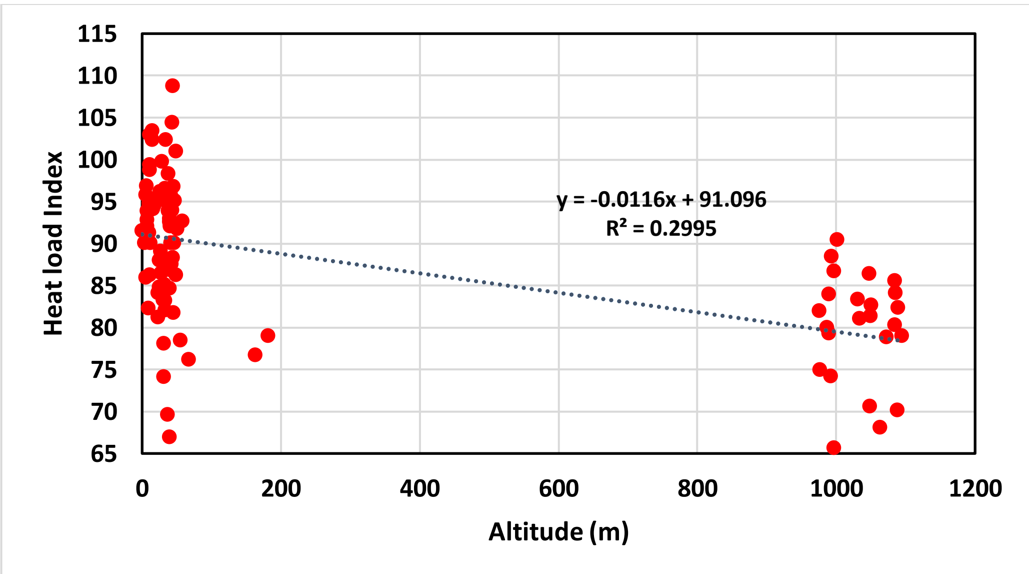

Figure 18. Relationship between HLI interior and altitude

4.16.3. Relationship between HLI (interior) and ambient temperature (interior) of different zones

The ambient temperature was found to have a significant effect on HLI ($p<0.01$) as shown in Fig.19. Highest value of HLI and ambient temperature was observed in zone H3 (94.05 ± 1.2 and 35.13 ± 0.28°C respectively) and the lowest was recorded in zone L1 (88.76 ± 1.45 and 29.44 ± 0.32°C). The relationship is represented by the linear equation as HLI = 1.7944 X Temperature in °C + 28.524 ($R^2 = 0.289$) as given in the figure.

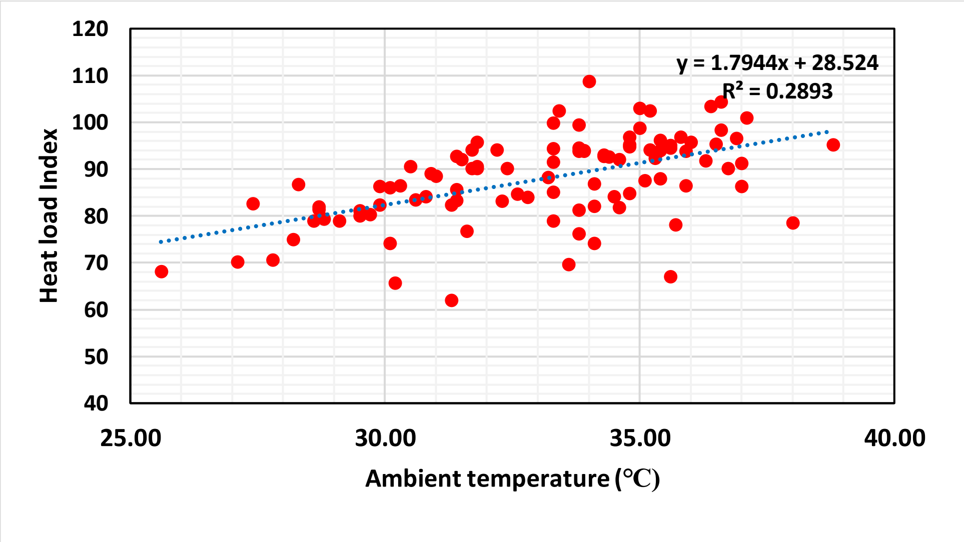

Figure 19. Relation of HLI interior with ambient temperature interior

4.17. Physiological responses of cattle in different THI Zones

4.17.1. Body temperature

Skin temperature of cattle was taken from forehead, left flank and udder of the animals. Taking average of all zones together, there exist a significant correlation between head, flank and udder temperature ($p<0.01$). Highest value of head and flank temperature was measured at zone H3 (34.94 ± 0.34 and 35.20 ± 0.29°C), while highest udder temperature was recorded at zone H1 (33.69 ± 0.31°C). Lowest temperature of all three categories was recorded at zone LI. The mean body temperature recorded from head, flank and udder region in all THI zones are depicted in the Fig.20.

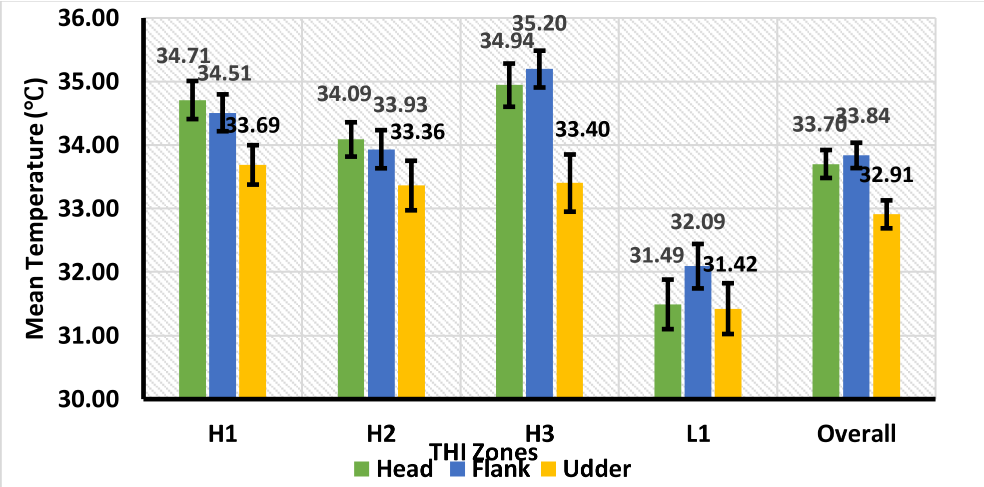

Figure 20. Mean body temperature of cattle in all the zones

4.17.2. Respiration rate

Table 11 showed the mean respiration of cattle in each THI zones. Cows in the zone H3 had the highest mean respiration rate, not significantly different from zone H1 and lowest in the zone H2, which was not significantly different from zone L1. Highest respiration rate of 110.50 bpm was reported from zone H1 with a mean respiration rate of 58.31 ± 3.87 bpm.

Table 11. Respiration rate of cattle in different THI zones

THI Zone	Highest	Lowest	Respiration rate (bpm) (Mean ± SE)
H1	110.50	38	58.31^{a} ± 3.87
H2	74.67	40.02	48.57^{b} ± 1.76
H3	100	42	59.47^{a} ± 4.01
L1	62.33	38	50.00^{b} ± 1.28

4.17.3. Relationship between body temperature and respiration rate

Considering all zones together, the mean respiration rate was calculated as 53.60 ± 1.46 bpm and noticed a significant positive relation with body temperature (head (r= 0.472), flank (r= 0.454), and udder (r= 0.376) temperature ($p<0.01$). A similar trend was also observed across the four zones also head.

4.17.4. Panting response.

Based on the respiration rates panting scores were assigned and showed in Fig 21. Farms in each THI zone were grouped on the basis of the panting score. Panting score 1 was noticed in 82 per cent of total farms studied while panting scores 0 and 2 were reported only 8 per cent and 10 per cent farms respectively. Fig.21 showed the distribution of panting scores in terms of the number of farms surveyed in each THI zone. Mean HLI calculated for each panting score observed was shown in Table 12. There exist a significant relation between HLI and panting score ($r = 0.465$, $p < 0.01$). Highest mean HLI of 98.3 ± 2.43 was recorded for panting score 2**.**

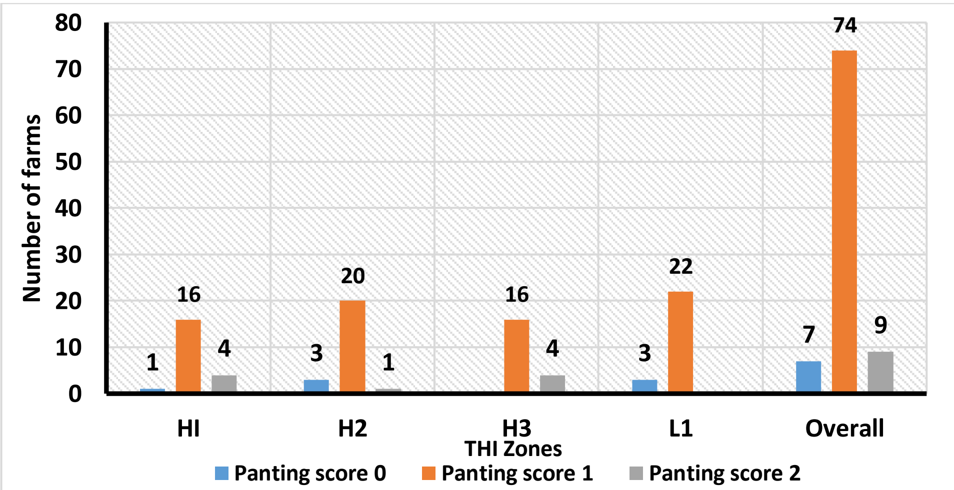

Figure 21. Panting scores of cattle in different zones

Table 12. Mean HLI calculated for each panting scores

Panting score	**HLI (Mean ± SE)**
0	**76.1 ± 3.34**
1	**87.1 ± 0.97**
2	**98.3 ± 2.43**

4.18. Correlation between HLI interior and physiological responses of cattle in different THI Zones

Table 14 is showing the correlation between HLI and physiological responses of cattle such as head temperature, flank temperature, udder temperature and respiration rate in different THI zones. It was evident that when pooled data from all zones were considered, all the physiological responses had a significant positive correlation with HLI ($p < 0.01$). Individually, all physiological parameters of zone H1, the head temperature of zone H2, the respiration rate of zone H3, udder temperature and respiration rate of zone L1 exhibited a significant positive correlation with HLI interior.

Table 13. Correlation between HLI and physiological responses of cattle in different THI zones

THI Zones	Physiological Parameters	Correlation coefficient	Mean ± SE
H1	Head temperature (°C)	0.68**	34.71 ± 0.30
	Flank temperature (°C)	0.77**	34.51 ± 0.29
	Udder temperature (°C)	0.56**	33.69 ± 0.31
	Respiration rate (bpm)	0.65**	58.32 ± 3.88
H2	Head temperature (°C)	0.55**	34.09 ± 0.27
	Flank temperature (°C)	0.15	33.93 ± 0.30
	Udder temperature (°C)	-0.04	33.36 ± 0.39
	Respiration rate (bpm)	0.15	48.57 ± 1.75
H3	Head temperature (°C)	0.29	34.94 ± 0.34
	Flank temperature (°C)	0.21	35.20 ± 0.29
	Udder temperature (°C)	0.11	33.40 ± 0.45
	Respiration rate (bpm)	0.53*	59.48 ± 4.02
L1	Head temperature (°C)	0.37	31.49 ± 0.39
	Flank temperature (°C)	0.14	32.09 ± 0.35
	Udder temperature (°C)	0.49*	31.42 ± 0.40
	Respiration rate (bpm)	0.54**	49.78 ±1.29
Overall	Head temperature (°C)	0.65**	33.70 ± 0.22
	Flank temperature (°C)	0.54**	33.84 ± 0.20
	Udder temperature (°C)	0.40**	32.91 ± 0.22
	Respiration rate (bpm)	0.50**	59.48 ± 1.47

** Correlation is significant ($p < 0.01$)

* Correlation is significant ($p<0.05$)

4.19. Relationship of roof and floor temperature with different parameters

The relationship of roof and floor temperature of shelters with different climatic variables such as ambient temperature, black globe temperature, wet bulb temperature, shade and height of the shelter were examined (Table 14). A significantly positive relation was observed between floor temperature and roof temperature ($r = 0.462$, $p < 0.01$). A mean roof temperature of 40.8 ± 0.90°C was obtained when all zones were combined and it showed a significantly positive relationship with ambient temperature, black globe temperature and wet bulb temperature ($p<0.01$) as well as significantly negative relation with the percentage of shade ($p<0.01$) and altitude ($p<0.05$). Apart from this, there was a significant positive correlation with the roof temperature and height of the shelter ($p<0.01$).

Table 14. Correlation of roof and floor temperature with different parameters

Parameters		**Correlation coefficient**	
		Roof	**Floor**
Ambient temperature (°C)	**Interior**	0.360**	0.656**
	Exterior	0.389**	0.640**
Black globe temperature (°C)	**Interior**	0.473**	0.535**
	Exterior	0.284**	0.149
Wet bulb temperature (°C)	**Interior**	0.419**	0.747**
	Exterior	0.414**	0.664**
Head temperature (°C)		0.521**	0.706**
Flank temperature (°C)		0.439**	0.661**
Udder temperature (°C)		0.287**	0.551**
Respiration (bpm)		0.420**	0.461**
Roof height (m)		0.310**	0.152
Altitude (m)		-0.233*	-0.584**
Percentage of shade (%)		-0.481**	-0.305**

** Correlation significant ($p < 0.01$)

* Correlation significant ($p<0.05$)

4.20. Relationship between roof and floor temperature and HLI

Roof and floor temperature found to have a significant positive relation with HLI ($p<0.01$) when combined zones were considered. The Fig.22 depicted the variation in HLI with roof and floor temperature in all THI zones. The mean roof and floor temperature in each THI zones along with the correlation coefficient were given in Table 16.

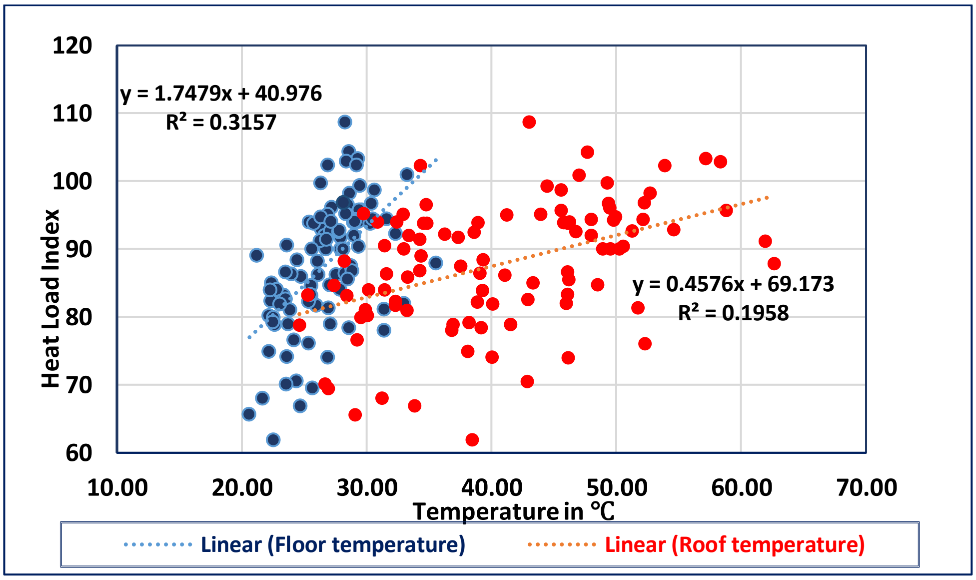

Figure 22. Variation in HLI with roof and floor temperature

Table 15. Correlation between HLI and roof and floor temperature

THI Zones	Structural Parameters (°C)	Correlation coefficient	Mean ± SE
H1	Roof Temperature	0.56**	43.63 ± 1.93
	Floor Temperature	0.60**	27.99 ± 0.40
H2	Roof Temperature	0.49*	39.62 ± 1.80
	Floor Temperature	0.09	26.48 ± 0.49
H3	Roof Temperature	0.10	42.51 ± 1.81
	Floor Temperature	-0.08	28.92 ± 0.50
L1	Roof Temperature	0.37	37.41 ± 1.48
	Floor Temperature	0.49*	23.83 ± 0.43
Overall	Roof Temperature	0.44**	40.80 ± 0.90
	Floor Temperature	0.56**	26.81 ± 0.30

**Correlation is significant ($p < 0.01$)

* Correlation is significant ($p<0.05$)

4.21. Relation between HLI and other structural parameters of the shelter

Correlation between HLI and other structural parameters of the shelter such as length, width, roof height from the centre, eaves height and total air volume of the shelter is given in Table 16. No significant relation could be established between HLI and structural parameters except for zone H1 where significant negative relationships have been established between HLI and roof height from the centre. However, a negative correlation was evident in all zones with these parameters and HLI.

Table.16. Correlation between HLI and other structural parameters of the shelter

THI Zones	Structural parameters	Correlation coefficient	Mean ± SE	Structural parameters	Correlation coefficient	Mean ± SE
HI	**Length (m)**	-0.072	5.85 ± 0.45	**Eves height (m)**	-0.247	2.34 ± 0.13
	Width (m)	-0.215	3.06 ± 0.22	**Air volume (m^3)**	-0.348	53.98 ± 8.64
	Height from centre (m)	-0.56**	2.79 ± 0.14	**Light Intensity (lux)**	0.321	1973.60 ± 372.23
H2	**Length (m)**	0.207	8.14 ± 0.87	**Eves height (m)**	-0.014	2.26 ± 0.09
	Width (m)	-0.024	3.84 ± 0.51	**Air volume (m^3)**	0.011	118.42 ± 29.76
	Height from centre (m)	0.019	2.84 ± 0.21	**Light Intensity(lux)**	0.133	869.80 ± 160.19
H3	**Length**	-0.390	7.49 ± 1.27	**Eves height (m)**	-0.271	2.19 ± 0.08
	Width	-0.210	3.78 ± 0.50	**Air volume (m^3)**	-0.273	162.92 ± 59.13
	Height from centre	-0.198	2.90 ± 0.21	**Light Intensity (lux)**	-0.238	794.52 ± 156.36
L1	**Length**	-0.002	6.06 ± 0.66	**Eves height (m)**	0.102	2.32 ± 0.11
	Width (m)	-0.141	3.44 ± 0.35	**Air volume (m^3)**	-0.168	67.11 ± 18.17
	Height from centre (m)	-0.055	2.67 ± 0.12	**Light Intensity (lux)**	0.111	866.17 ± 143.56
Overall	**Length (m)**	-0.054	6.88 ± 0.44	**Eves height (m)**	-0.081	2.28 ± 0.05
	Width (m)	-0.109	3.53 ± 0.20	**Air volume (m^3)**	-0.050	100.43 ± 17.63
	Height from centre (m)	-0.055	2.80 ± 0.08	**Light Intensity (lux)**	0.214*	1128.65 ± 123.74

4.22. Relationship between HLI and shade over the shelter

The influence of shade in terms of percentage shade had significantly negative correlation with HLI ($r= -0.199$, $p<0.05$) while considering all zones together. But when individual zones are considered, a significant negative correlation was noticed only in zone H2 while in other zones not significant but negative relation was observed. Negative relation with HLI and percentage shade is established in Fig. 23. Farms with complete shade (100%) recorded a mean HLI of 84.07 **and** it increased to 89.93 when shade was completely absent (0 %).

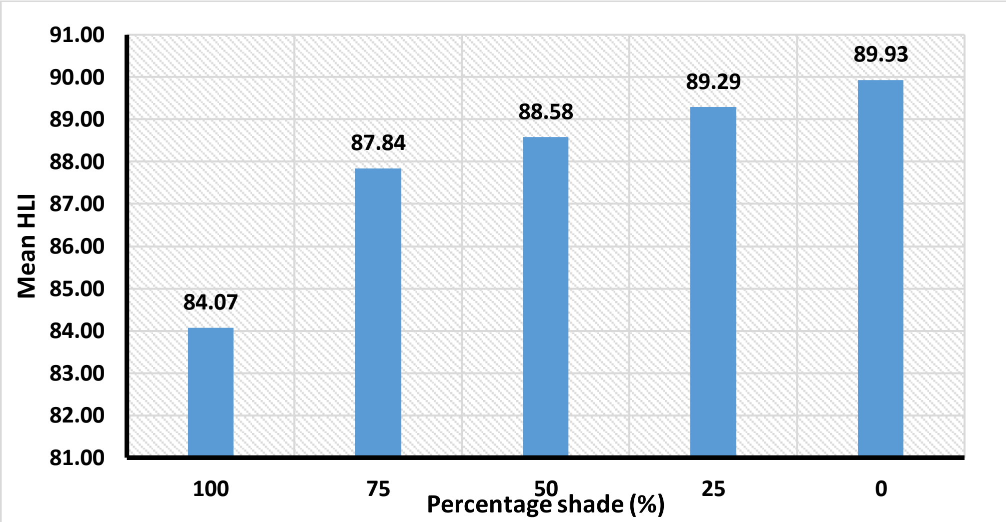

Figure 23. Relation between HLI and shade over the shelter

4.23. Mean light intensity in farms of different THI zones

Table 17 showed mean light intensity recorded interior of the shelter in each THI zones**.** Highest value of light intensity was observed in H1 zone and the lowest at zone L1.

Table 17. Mean light intensity of farms in different THI zones

THI zones	Mean ± SE (Lux)
H1	1973.60 ± 372.24
H2	866.17 ± 143.56
H3	794.52 ± 156.36
L1	869.80 ± 160.19

4.24. Relation between light intensity and influence of shade

The influence of shade in terms of percentage shade had significantly negative correlation (r= -0.256) with light intensity ($p<0.05$) while considering all zones together. But when individual zones are considered, a significant negative correlation was noticed only in zone H1 while in other zones not significant but negative relation was observed. Negative relation with light intensity and percentage shade was shown in Fig.24.

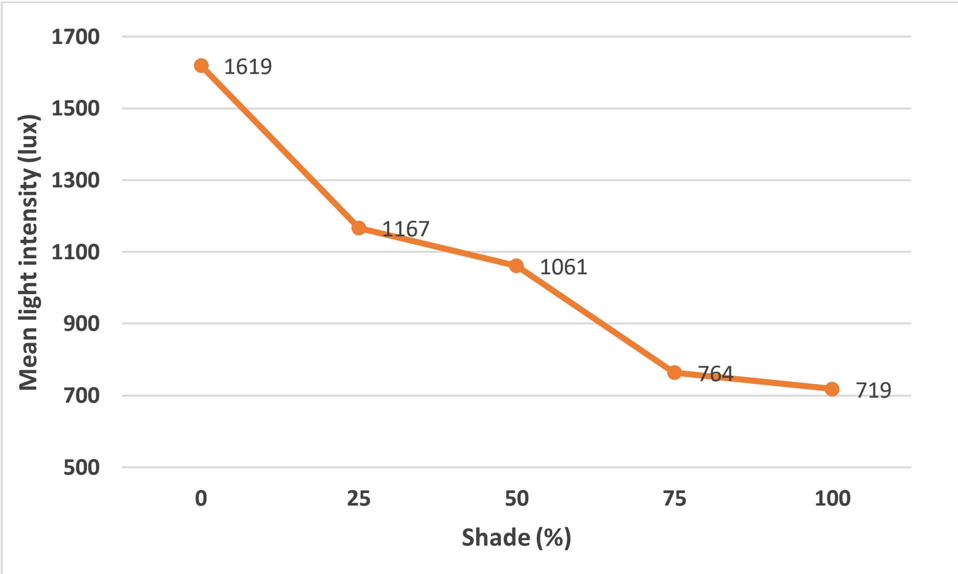

Figure 24. Relation between light intensity and influence of shade

4.26. Milk production details in each THI zones

Average milk produced per day in each THI zone has been collected. Taking the average of all zones, 9.22 Kg milk is being produced. Maximum milk yield was reported in zone L1 and minimum in H1. Zone wise milk yield per day as reported by the farmers is shown in Fig.18. Nearly 60 per cent of the farms produced 5-10 Kg milk per day (Fig.26).

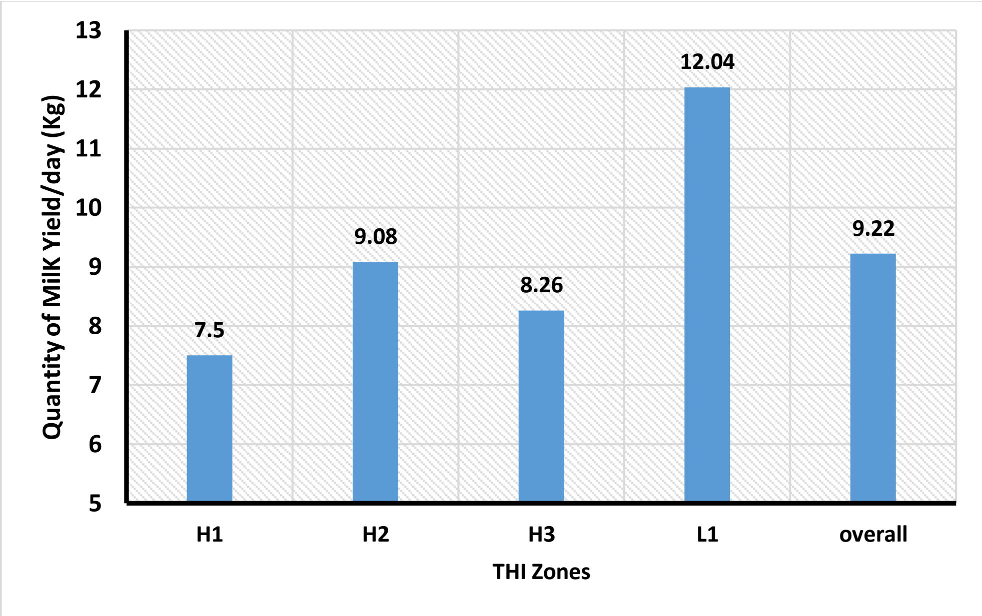

Figure 25. Milk production details in each THI zones

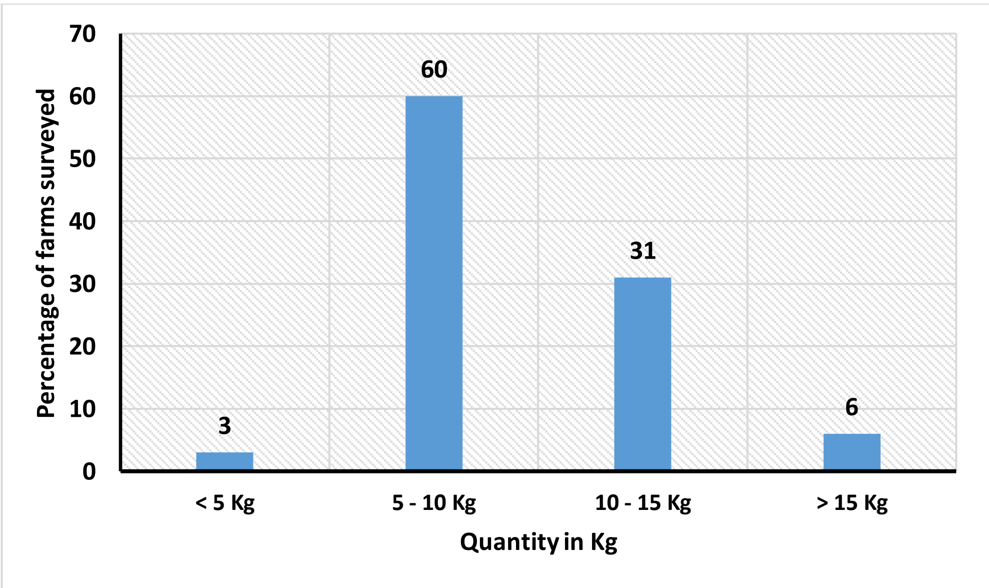

Figure 26. Milk yield (all zones combined)

4.27. Use of ameliorative interventions to compact thermal stress

In 77 per cent of farms, extra showering of animals two to three times a day was practising as an ameliorative method to reduce stress during the high THI period. Fans are installed in 21 per cent of the farms, however working properly only in 9 per cent of farms (Table 18)

Table 18. Ameliorative interventions in different zones

Zone	Fan installed	Fan functioning	Extra showering
HI	11	4	19
H2	6	3	21
H3	2	2	24
L1	2	0	13
Overall	21	9	77

4.28. HLI and shelter orientation

The orientation of cattle shelter had no significant ($P < 0.05$) effect on mean HLI interior to the shelter. However, it was evident from Fig.19 that high HLI was recorded inside North-south oriented shelter (88.75 ± 1.09) compared to East – West (86.20 ± 1.68).

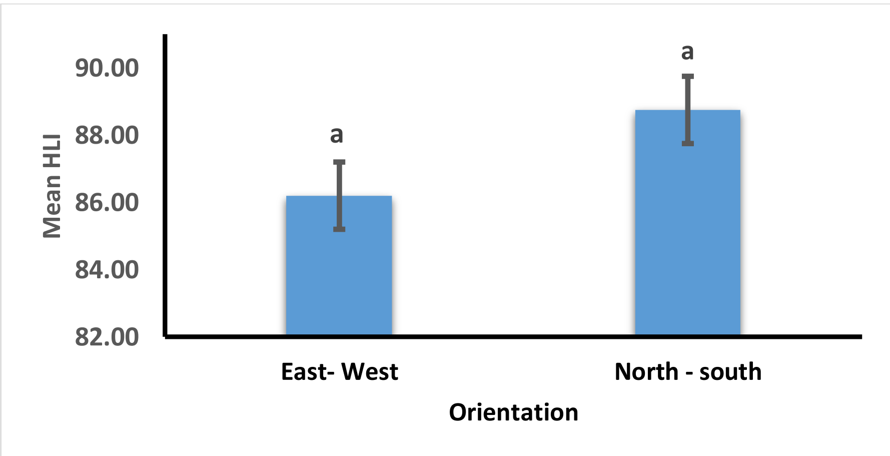

Figure 27. HLI and orientation of shelter

4.29. Meteorological model for predicting micro environment inside cattle shelter

Climatological, physiological and structural details collected from all THI zones are pooled together for developing meteorological models for predicting heat load inside the cattle shelter. All parameters showing significant linear relationship with HLI interior of the shelter were considered for developing the model are shown in Table 20.

Table 19. Parameters showing significant linear relationship with HLI interior

Significant parameters			
Biotic parameters	**Correlation coefficient**	**Abiotic parameters**	**Correlation coefficient**
Head temperature	0.648**	Altitude	-0.547**
Flank temperature	0.539**	Ambient temperature interior	0.538**
Udder temperature	0.404**	Roof temperature	0.443**
Respiration	0.501**	Floor temperature	0.562**
		Light intensity	0.214*
		Percentage of shade	-0.199*

**Correlation is significant ($p < 0.01$)
 * Correlation is significant ($p<0.05$)

4.28.1. Model predicting heat load index considering biotic factors alone

Multiple linear regression analysis for all significant biotic factors such as head, flank, udder temperatures and respiration rate with HLI was done. It showed that head temperature and respiration rate accounted for 47 per cent of variation in HLI and the overall regression model was significant, $p < 0.001$ (Table. 20). The relationship is represented by the linear equation

$$\text{HLI} = -3.37 + 2.42 \times \text{Head temperature} - 0.17 \times \text{Respiration rate} \quad (r^2 = 0.469).$$

Where, Head temperature (°C), Respiration rate (beats/ mint)

Table 20. Regression analysis considering significant biotic factors alone

R	R^2	Adjusted R^2
0.685	0.469	0.457

ANOVA table					
Source of variation	**Sum of squares**	**Degrees of freedom**	**Mean Sum of square**	**F-value**	**p-value**
Regression	3770.358	2	1885.179	38.391	<0.001
Residual	4272.131	87	49.105		
Total	8042.489	89			

Model	Coefficients		T	p-value
	B	Std. Error		
(Constant)	-3.374	12.476	-0.270	0.787
Head temperature	2.419	0.405	5.971	<0.001
Respiration	0.171	0.060	2.834	0.006

4.28.2. Model predicting heat load index considering abiotic factors alone

Multiple linear regression analysis for all significantly correlated abiotic factors such as altitude, ambient temperature, percentage of shade, roof and floor temperature and light intensity with HLI was done. It indicated that 44 per cent variance in HLI was explained by altitude, roof temperature and floor temperature and the overall regression model was significant $p < 0.001$ (Table 20). The relationship is represented by the linear equation:

HLI= 58.47+ 0.77× Floor temperature + 0.263 × Roof temperature - 0.007× Altitude (r^2= 0.438)

Where, Floor temperature (°C), Roof temperature (°C), Altitude (m)

Table 21. Regression analysis considering significant abiotic factors alone

R	R^2	Adjusted R^2
0.662	0.438	0.420

ANOVA table					
Source of variation	**Sum of squares**	**Degrees of freedom**	**Mean Sum of square**	**F-value**	**p-value**
Regression	3684.724	3	1228.241	24.401	<0.001
Residual	4731.645	94	50.337		
Total	8416.370	97			

	Coefficients			
Model	**B**	**Std. Error**	**T**	**p-value**
(Constant)	58.468	8.381	6.976	<0.001
Floor temperature	0.772	0.325	2.373	0.020
Altitude	-0.007	0.002	-3.459	0.001
Roof temperature	0.263	0.091	2.901	0.005

4.28.3. Model predicting heat load index considering all significant parameters

When multiple linear regression analysis of all significantly correlated parameters (both biotic and abiotic parameters as given in Table 19) with HLI was done, it has been observed that 51 per cent variance in HLI was explained by head temperature, respiration rate and altitude and the overall regression model was significant, $p < 0.001$. The relationship is represented by the linear equation:

HLI = 25.79+1.56×Head temperature+ 0.20×Respiration rate - 0.006× Altitude ($r^2 = 0.514$)

Where, Head temperature (°C), Respiration rate (beats/mint), Altitude (m)

Table 22. Regression analysis considering all significant parameters

R	R^2	Adjusted R^2
0.717	0.514	0.496

ANOVA table					
Source of variation	**Sum of squares**	**Degrees of freedom**	**Mean Sum of square**	**F-value**	**p-value**
Regression	4111.401	3	1370.467	29.562	< 0.001
Residual	3894.216	84	46.360		
Total	8005.618	87			

	Coefficients			
Model	**B**	**Std. Error**	**T**	**p-value**
(Constant)	25.786	17.090	1.509	0.135
Head temperature	1.559	0.532	2.929	0.004
Respiration	0.202	0.060	3.360	0.001
Altitude	-0.006	0.002	-2.575	0.012

CHAPTER 5
DISCUSSION

5.1. Geographical details of the study area

The study was conducted in four zones in Kerala, classified based on the THI viz H1 (Moncombu), H2 (Vellanikkara) and H3 (Pattambi) with high THI in the coastal and midland and L1 (Pampadumpara) at high ranges with low THI. The L1 zone recorded a highest altitude of 1031.52 ± 8.55m above sea level which was approximately 1000m higher than other zones. THIs recorded in these zones were lower than the observations of Prasad (2014) for H1, H2 and H3 zones, but slightly higher for zone L1. Harikumar (2017) recorded THI of 79.24 ± 1.06 and 78.7 ± 0.65 respectively for exterior and interior of the shelter for zone H2 and these findings were slightly lower than that of the present study.

5.2. Classifications of dairy farms

In the present study dairy farms were categorised based on the number of milch cows (farm size). The results indicated that medium-sized farms with 3-10 milch cows were predominant with a share of nearly 50 per cent in all zones combined. On contrary to this, Sabin (2016) reported that small-sized farms were predominant in five agro-climatic zones of Kerala with a share of nearly 80 per cent whereas in the present study, it was 36 per cent only. This variation in the farm size with respect to the previous study was due to the difference in the study area and number of samples studied. However, this study confirmed the predominance of small and medium farms that are the typical features of dairy farming in Kerala.

5.3. Breed wise classification of cattle

In the present study more than 95 per cent of cattle were crossbreds with 68 per cent crossbred HF and 27.2 per cent crossbred Jersey. It was evident from the study that the preference for indigenous breeds was negligible. This distribution of cattle breeds reflected the general picture of cattle population of Kerala where almost 90 per cent are crossbred of either HF or Jersey. This observation was similar to the findings of Sabin (2016) where he reported a higher population of crossbred HF, followed by crossbred Jersey and indigenous breeds. This was due to its lower milking potential compared to crossbred cattle whereas greater milk production potential was the reason for the huge demand for crossbred cattle in Kerala.

5.4. Classification of cattle based on skin colour

Nearly fifty per cent of cattle studied had black skin colour. White, black and white, fawn, white and fawn colours formed the remaining fifty per cent of cattle population. The predominance of black skin colour was evident because 68 per cent of cattle studied belonged to crossbred HF. Studies conducted by Brown-Brandl *et al*. (2006) indicated that cattle with dark hides had higher respiration rates, panting scores and surface temperatures than the breeds of cattle with light-coloured skins. Cattle with darker hides were more thermally stressed during summer seasons compared to light hided breeds.

5.5. Distribution of different roofing materials for cattle shelter

It was observed during the study that the majority of cattle shelters were made of Galvanised Iron (GI) sheet (44.4 %) followed by asbestos (21.2 %), tin sheets (9.1%) and clay tiles (9.1%). However, this observation was contrary to the findings of Prasad (2014) where tiled roofing formed the major material followed by the tin sheet and asbestos. Sabin (2016) found a share of 37.1, 56 and 86.70 per cent distribution of metal roofing respectively in small, medium and large farms. Either GI or asbestos sheets were used in well-organized large farms since it was easy to install and durable. This was in agreement with the findings of Sastry and Thomas, (2012). Sahu *et al*., (2018) suggested thatch roof as a good insulator and cheap material when compared to other roofing, which was observed only in three per cent of total farms. Locally available thermal insulating materials such as palm leaves, wooden planks, hay, cardboard and thermocol were observed in eight per cent of the farms as a false ceiling under GI, Asbestos, tin sheet and clay tiles. A microclimatic study conducted by Das *et al*. (2015) in the northern and southern districts of Goa found that cattle shelters with false ceiling roof favoured higher milk production and better animal comfort. Similar study conducted by Ayub (2009) in small, medium, large farms of central and northern Kerala found a greater percentage distribution of thatched roof (44.3 per cent), followed by tiled, asbestos/ tin sheet (28.9 per cent each).

5.6. Flooring materials used in cattle shelter

It was observed during the study that the concrete floor was a common feature in 99 per cent of the large, medium and small farms. In large and medium farms rubber mats were laid on concrete floor which was less common in small farms. Thermal conductivity, strength, durability and cushioning effect of rubber mat on hooves were beneficial for cows but the high cost was a limiting factor especially in small farms. Vanegas *et al*. (2006) indicated that cows on concrete floor had a greater risk of developing as well as exacerbating existing heel erosion than cows on rubber flooring. Sabin (2016) found a share of 37.1, 56 and 86.70 per cent distribution of concrete floor respectively in small, medium and large farms. However usage of rubber mat along with concrete flooring was not mentioned in that study. Overall concrete floor with rubber mat was preferred over 63 per cent of farms, were as concrete floor alone was seen in 36 per cent of farms (Fig.7). Similar study conducted by Ayub (2009) in small, medium, large farms of central and northern Kerala found that concrete flooring with rubber mat was preferred by 85.3% farms whereas concrete floor alone was seen only in 14.7 per cent.

5.7. Orientation of cattle shelters

Alignment of long axis of building in an east- west direction reduced the encroachment of direct solar radiation on the side walls or entering inside the shelter and achieves maximum amount of shade under the structure for confined animals in hot climate (Schultz *et al*. (2010), Das *et al*., (2015). However findings from the current study revealed that east- west orientation was preferred only in 36 per cent, whereas north south orientation was found in 64 per cent farms. Studies conducted by Hatem *et al.* (2006) in Egypt also suggested that east-west orientation was preferred for hot climate but in the current study majority of the shelters were oriented in north- south direction.

5.8. Orientation of animals inside the cattle shelters

Unlike the orientation of shelter, no particular trend was observed in the orientation of animals inside the shelter**.** Animals were oriented in different direction depending on the structural designing of the building as shown in the

Fig.12. Earlier studies relating to animal orientation inside the shelter were not found.

5.9. Presence of shade over the farms

It was observed during the study that 75 per cent of farms were under the shadow of vegetation with shade varying from 25 per cent to 100 per cent and the rest of the farms were directly exposed to the sun. It could be observed that a major fraction of the no shaded cattle (0 per cent shade) shelters were mostly located near paddy fields where shade trees were at the bare minimum. In accordance with the findings of Abdel-Aziz *et al.* (2015), shade trees were effective to reduce the incidence of solar radiation directly on the building facades and significantly reduced the dependence on mechanical cooling.

5.10. Roof and floor temperature of cattle shelters

Results from the present study showed that roof and floor temperature of cattle shelters varied between different THI zones of Kerala. The highest values for roof and floor temperature were recorded from zones H1 and H3. Likewise, the lowest values of both roof and floor temperature were noticed from the zone L1. Roof and floor temperature had significant effects on the thermal stress on dairy cows by altering the microclimate underneath the covered area (Sahu *et al.*, 2018). Results of the present study also showed that mean roof temperature recorded during the summer period was slightly higher than the findings conducted in cattle shelters of North East Zone of Tamil Nadu (Sivakumar *et al.*, 2017). Prasad *et al.* (2013) compared the temperature of concrete floor and rubber mat and found that temperature of materials varied from 26.96°C to 30.65 °C during different times of a day and this was in accordance with the present study.

5.11. Roof temperature for different roofing materials

While analysing the mean temperature recorded for different roofing materials, it was understood that surface temperature of thatched roof was lower and significantly different ($p < 0.05$) from the surface temperature of other roofing materials such as Galvanised Iron (GI), tarpaulin, tin sheet, clay tile, and asbestoses. Kamal *et al.* (2014) observed that surface temperature of asbestos roof was significantly higher than the temperature of thatched roof. Another study conducted by Sahu *et al.* (2018) found that shelters with false ceiling with thatch beneath asbestos sheet recorded a significantly lower temperature compared to shelters having asbestos sheet only. In contrary to this, temperature recorded for asbestos roof in the present study (38.90± 1.37ºC) was slightly higher than that recorded by them (37.49 ± 1.51ºC). This might be due to the change in location and time. In the present study, no significant difference in temperature was observed for thatch and false ceiling roof. According to Das *et al*. (2015), false ceiling roof would render more comfort to the animals, resulting in higher milk production. Similar study conducted by Sivakumar *et al*. (2017) found that highest temperature was recorded for concrete roof, followed by metal, tiled and thatched roof. Similar results were obtained from the present study also, where GI sheet recorded the highest temperature while thatched roof recorded the minimum. Bhattacharyya and Bordoloi (2015) compared the effect of roof material thatch, GI and asbestos on the milk production in Jersey cattle in Guwahati, and advocated that thatched roofs were suitable for dairy cows and yielded apparently more milk compared to others. But durability of thatched roof was not so longer (Sahu *et al.* (2018), hence not preferred for large scale production systems as observed in the study. Without compromising the durability, we can recommend GI or metal roofing with false ceiling for all types of farm.

5.12. Mean temperature for different flooring materials

No significant difference in temperature was observed for concrete slatted floor alone and concrete slatted floor covered with perforated rubber sheet. However, a small drop in temperature was (approximately 1°C) observed on the floor covered with a rubber mat. In contrary to the present study Prasad *et al.* (2013) observed a significantly higher temperature for rubber mat flooring than concrete flooring. Sahu *et al.* (2018) compared the temperature of concrete cement floor and sand bed floor and recorded a significantly higher temperature on cement concrete floor. This was found to be lower than the value obtained in the present study. It was observed that rubber mats were used in more than 60 per cent of the farms because of its firm grip, dryness, soft and elastic nature that offered a relatively less challenging environment that enabled animals to express normal behaviour (Platz *et al*., 2008 and Prasad *et al*., 2013).

5.13. Body weight and metabolic body weight of cows

The mean body weight of all the cattle studied was 438.22 ± 6.33 Kg and the mean metabolic body weight was 95.61 ± 1.03 kg. No specific trend in the distribution of body weight was observed, however, cows in the L1 zone recorded the highest body weight and metabolic body weight compared to other zones. Prasad (2014) also reported highest body weight from zone L1 followed by H1, H2 and H3.

5.14. Behaviour response of cattle in different THI zones

Standing and lying times could be considered as an important indicator for cow welfare (Kooij *et al*., 2012). According to pooled data collected from all THI zones in the present study, major fraction of the animals were exhibiting standing behavior which confirmed the thermally stressed physiological state of animals. Similar trend was reported from individual THI zones also. This finding was in confirmation with Brown-Brandl *et al*. (2006), Tucker *et al*. (2009) and Harikumar (2017) where standing behavior was observed in thermally challenged dairy cows in confined management system. During thermal stress animals remained in standing position by exposing greater body surface area to surrounding air as an attempt to increase evaporative cooling.

Feeding and ruminating behavior exhibited by animals were comparatively lower in all THI zones. According to Soriani *et al*. (2013) ruminating time was negatively correlated with heat stress, as it was in agreement with the present study. Moallem *et al*. (2010) reported that rise in THI reduced feed intake, which would subsequently led to a decline in rumination. However, in present volume of feed intake remains unknown hence data was not sufficient to establish a relation between heat load, feed intake and rumination time.

5.15. Climatic variables recorded exterior and interior of cattle shelter

There are several reports suggesting the significance of immediate climatic environment surrounding the animals in assessing the heat stress by comparing with measurements from nearby meteorological stations and confirmed that heat stress was underestimated both in magnitude and duration (Davis and Mader, 2003; Brouček *et al*., 2006; Kučević *et al*., 2013, Da Silva *et al*., 2010 and Shock *et al*., 2016). So in this study climatic variables were measured in on farm condition. It was observed that climatic variables recorded exterior to the shelter had a strong significant positive correlation with the same variable recorded interior in all zones. All climatic variables except relative humidity exterior to the shelter were found to be higher than interior. This was in agreement with the earlier findings of Prasad, 2014 and Harikumar, 2017.

5.15.1. Ambient temperature (°C)

The ambient temperature was a noble predictor of body temperature of heat-stressed cows in subtropical environment and effectively approximated the magnitude of hyperthermia as suggested by Dikmen and Hansen (2009). In the present study the mean exterior and interior temperature showed an increasing trend from zone H1 to H3. Lowest ambient temperature, both exterior and interior, was recorded from the zone L1. These observations were in agreement with the findings of Prasad (2014) from these respective zones. But, interior temperature obtained in zone H3 in the present study was slightly higher than the findings of Prasad (2014). Mean ambient temperature recorded exterior to the shelter exhibited a strong positive correlation with ambient temperature interior. Interior temperature was lower than exterior although the difference was less. Similar findings were reported by Harikumar (2017) when pooled data from all THI zones were considered. The mean ambient temperature exterior and interior of the shelter was 33.91 ± 0.30°C and 33.05 ± 0.28°C respectively which was higher than the upper critical temperature of 28.4°C as reported by Dikmen and Hansen (2009). In this case ambient temperature exceeded the upper critical temperature and the overall welfare and productivity of animals was under stress.

5.15.2. Black globe temperature (°C)

According to Harikumar (2017) solar radiation should also be monitored continuously along with dry bulb temperature and relative humidity, to understand the macroclimatic impact on microclimate and thermal stress in animals. As expected, black globe temperature showed an increasing trend from zone H1 to H3.

Similar to the trend in ambient temperature, the black globe temperature interior to the shelter also increased significantly with changes in exterior globe temperature. The majority of farms in these zones were located in open areas where the shade effect of large trees was comparatively lower. As suggested by Buffington *et al.* (1981), the influence of shade trees was visible in the present study. Compared to other zones a large difference between exterior and interior black globe temperature was recorded in zone L1 as it was at a higher altitude with a difference of approximately 1000m.

5.15.3. Wet bulb temperature (°C)

Wet-bulb temperature exhibited a similar trend as observed for ambient temperature except for zone H1, where it recorded a temperature higher than zone H2. It was due to the higher relative humidity prevailing in that zone (Table 7).

5.15.4. Relative humidity (%)

Mean relative humidity recorded exterior to the shelter exhibited a strong positive correlation with interior relative humidity. On contrary to other climatological variables, relative humidity measured inside the shelter was found to be approximately two per cent higher than outside in all THI zones. This might be due to management practices such as regular cleaning of floor with water. This was in accordance with the observations recorded by Harikumar (2017). Relatively higher relative humidity was reported from zone H1, which belonged to Kuttanad region in Kerala having high humidity throughout the year in general (Sreejith, 2013). Relative humidity for zone H1 recorded in this study was similar to the observation of Prasad (2014), however, remaining zones recorded lower values.

5.15.5. Wind Speed (m/s)

Wind speed significantly influenced thermal balance of cattle by altering the convective cooling mechanisms as suggested by Davis and Mader (2003). In all THI zones, mean wind speed inside the shelter was lower than outside. This was due to the presence of obstacles to air movement such as buildings and nearby structures and trees. Highest exterior wind speed was reported from zone L1 and the lowest from H1, which were the highest and lowest elevated areas in the study. Difference in the altitude was the reason for this variation of wind speed. At the same time, highest value of interior wind speed was recorded in zone H2 located in Thrissur, where a characteristic high speed wind blowing through Palakkad gap from the neighbouring state Tamil Nadu.

5.15.6. Relationship between Ambient temperature and Black globe temperature

Black globe temperature found to have strong significant positive correlation with ambient temperature in all THI zones except zone H3, where highest ambient temperature (>35°C) was recorded and was similar to the findings of Hajizadeh *et al.* (2017). They observed that the correlation between black globe temperature and dry-bulb temperature was statistically insignificant in the range higher than 35°C but, significant at temperature less than 25 °C and between 25 and 35 °C. This is because, at higher temperature the fluctuations in black globe temperature is considerably higher than the dry-bulb temperature (Hajizadeh *et al.*, 2017).

5.15.7. Relationship between relative humidity and wind speed

While considering pooled data from all THI zones, relative humidity interior to the shelter showed a significant negative linear relationship with wind speed. This was in agreement with the findings of Bolton (2018). He referred that as wind blows, it sweeps away airborne water particles in the air and reduces humidity.

5.16. Heat load Index interior and exterior of cattle shelters in different THI zones

Harikumar (2017) analysed fittingness of various bioclimatic indices for tropical humid climate and found that HLI was one of the major bioclimatic indices to be accounted with due attention. In the present study HLI was calculated both interior and exterior of the shelter. Mean HLI recorded interior and exterior to shelter showed a strong significant positive correlation with each other in all THI zones. In this study, zone L1 recorded significantly lower HLI compared to other THI zones. Highest value of HLI interior was recorded from the zone H3, having no significant difference with HLI of zone H1. At the same time zone H2 reported HLI significantly lower than H1 and H3 and significantly higher than zone L1. According to Gaughan *et al*. (2008), threshold HLI for *B. taurus* steers was 86 and relating to the present study, it could be inferred that the zone H1 and H3 had higher HLI, and for zone L1 it was much lower.

HLI exterior to the shelter in the present study varied quite differently from HLI interior. Since the lowest HLI exterior was reported from zone H2 however not significantly different from zone L1. These variations were in accordance with the changes in black globe temperature. Harikumar (2017) recorded HLI of 91.18 ± 2.80 in midlands of Thrissur district which was almost similar to the overall HLI observed in the present study.

5.16.1. Distribution of farms in different HLI category

Categorical distribution of farms based on heat load index revealed that more than 90 per cent of the total farms from different THI zones of Kerala was experiencing thermal stress of varying degrees of severity. Zones H1 and H3 were categorised as very hot condition (HLI>86) and zone H2 and L1 as hot condition (HLI 77.1 to 86) as classified by Gaughan *et al*. (2008). Entire data for the present study were collected during mid-February to mid-March, prior to the incidence of peak summer in Kerala. This observation underlined the need for adopting ameliorative measures to compact the adversities of thermal stress on dairy cattle across the state.

5.16.2. Relationship between HLI and altitude

Altitude was found to have significant negative effect ($p< 0.05$) with HLI. The relationship is represented by the linear equation as HLI = -0.0116 x Altitude in meters + 91.096 ($r^2 = 0.299$). This was in conformation with the result obtained by Prasad (2014). In the present study, lowest value of HLI was obtained from the high altitude zone L1, whereas higher HLI was obtained from the lower altitudes H1 (Moncombu) and H3 (Pattambi).

5.16.3. Relationship between HLI (interior) and ambient temperature (interior) of different zones

Ambient temperature showed a strong significant positive correlation with HLI. The relationship could be represented as HLI = 1.7944 x Temperature in °C + 28.524 (r^2 = 0.289). As expected, highest value of both HLI and ambient temperature was observed from zone H3 and the lowest from L1. Berman *et al.* (2016) claimed that for developing a sensible heat-based THI, strong interaction between temperature and humidity should be considered in order to establish potential effect of these variables on bovine thermoregulation. Otherwise the effect of air temperature would be overestimated and the effect of relative humidity would be underestimated.

5.17. Physiological responses of cattle in different THI Zones

5.17.1. Body temperature

While considering pooled data from all THI zones, head, flank and udder temperatures showed a strong significant positive correlation with each other. Pooled data were considered, since no particular relationship could be established between them in each THI zones. There were several reports (Collier and Zimbelman, 2007), Ganaie *et al.* (2013), Patel *et al.* (2016), Rejeb *et al.* (2016) and Nascimento *et al.* (2019) suggested that rectal temperature was a sensitive indicator of thermal stress as it was corresponding to the changes in core body temperature whereas Harikumar (2017) recorded vaginal temperature as core body temperature in dairy cattle to assess thermal stress. But the present study dealt with a large and varied cattle population from the different zones within a specified time period, monitoring rectal temperature was a cumbersome task. Therefore the skin temperature was accounted as the body temperature and measured by infrared thermography from different anatomical locations of cattle. In the present study, skin temperature was measured from head (Yadav *et al.*, 2017), flank (Bland *et al.*, 2013), and udder (Chaudhari and Singh, 2015). Mean head and flank temperature from all zones in the present study was higher than the findings of Yadav *et al.* (2017) in cross breed cattle of Izatnagar, Uttar Pradesh and Bland *et al.* (2013) respectively, but similar udder temperature was recorded by Chaudhari and Singh (2015) in lactating Murrah buffaloes during hot humid climate of Karnal, Haryana. Highest values all three parameters were reported from zone H3, which recorded the highest HLI and ambient temperature. The lowest value was from zone L1 having the minimum reported HLI and ambient temperature.

5.17.2. Respiration rate

In the present study, it was understood that respiratory rate was higher in zone H3 and the lower in zone L1. This was in agreement with the findings of Prasad (2014), where he found the higher incidence of panting in higher THI zones. Respiration rate was reliable indicator of heat load in cattle because it was the first visual response (Gaughan *et al*., 2002). Similar observations had been made by Brown-Brandl *et al*. (2005) and Eigenberg *et al*. (2005). Highest mean respiration rate was reported from zone H3, where the highest ambient temperature, black globe temperature and second highest relative humidity were observed. The lowest respiration rate was found in zone L1, which reported the lowest ambient temperature, relative humidity and black globe temperature. These findings should be considered in the lights of earlier works, where increased respiration rate had been associated with increased dry bulb temperature (Gaughan *et al*., 2002), relative humidity, solar radiation and decreased wind speed (Mader and Davis, 2002, (Eigenberg *et al*., 2005). Yadav *et al*. 2017 demonstrated that cattle increased their respiration rate as an effort to lower their body temperature when environmental temperature elevated above 35°C. This was followed in the present study also.

5.17.3. Relationship between body temperature and respiration rate

Body temperature found to have strong significant positive correlation with respiration rate. This was in agreement with the findings of Gaughan *et al*. (2000) and Brown-Brandl *et al*. (2005). Similar findings were also reported by Chaudhari and Singh (2015), Yadav *et al*. (2017) and Nascimento *et al.* (2019). This indicated that the body temperature and respiration rate acted as a reliable indicator of heat load. Studies conducted on cross breed cattle in Brazil, Nascimento *et al.* (2019) reported higher respiration rate and body surface temperature even at a lower ambient temperature compared to the present study. This change could be attributed to the difference in the location of study. Yadav *et al*. (2017) reported a similar head temperature but lower respiration at an exposure temperature of 35°C in climate chamber compared to present study. The positive correlation between skin temperature and respiration rate observed in the present study could be explained by prevailing higher heat load condition. When ambient temperature increased, lower temperature gradient between skin temperature and environment impeded the efficiency of sensible heat dissipation. Therefore animal relied on evaporation, respiratory or cutaneous heat loss at a higher ambient temperature to maintain thermoregulatory mechanisms as reported by Nascimento *et al.* (2019).

5.17.4. Panting response

It was evident that more than 80 per cent of the total farms were experiencing a slight panting (panting score of 1 i.e. respiration rate between 40 and 70). Similar trend was observed in all THI zones also. But, Prasad (2014), had reported a significantly different higher incidence panting (panting score of 2 i.e. respiration rate between 70 and 120) in higher THI zones. On contrary to his findings, panting score of 2 was very less (10 per cent of total farms). This decrease could be due to the increased adaptability of crossbred population to thermal stress in the study area or due to the change in time period of study. In the present study, entire data was collected between mid-Februarys to mid-March, before peak surge in ambient temperature recorded in Kerala. According to Gaughan *et al*. (2000); Brown-Brandl *et al*. (2005) and Eigenberg *et al*. (2005) panting scores have been used to evaluate the heat load in cattle. Gaughan *et al.* (2008) demonstrated that panting score increased when HLI exceeded 86 and claimed that HLI model could explain 93 per cent variation in panting score. This was followed in the current study as it pointed out that HLI increased with panting score ($p<0.01$). Similar findings were also reported by Lees (2018).

5.18. Correlation between HLI interior and physiological responses of cattle in different THI Zones

It was evident from the current observations that when pooled data from all THI zones were considered, physiological responses such as body temperature (head, flank and udder) and respiration rate exhibited a significant positive correlation with HLI. This was in agreement with the findings that body temperature and respiration rate were reliable indicators of heat load in cattle Gaughan *et al*. (2000). Studies conducted by Nascimento *et al*. (2019) found a significant positive correlation between various THIs and physiological variables such as rectal temperature, body surface temperature respiration rate and heart rate for crossbred dairy calves reared in tropical environment. Similarly Dalcin *et al.* (2016) also established that the response of physiological parameters increased with another THI viz Black Globe Humidity Index (BGHI).

5.19. Relationship of roof and floor temperature with different parameters

Climatic parameters such as ambient temperature, black globe temperature and wet bulb temperature recorded interior and exterior to the shelter showed a significant positive linear relationship with both roof and floor temperature. This could be explained in the light of mean temperature reported for different roofing and flooring materials. As observed in the study the major roofing materials used in cattle shelters were GI sheet, tin sheet and asbestos. Physiological responses such as the morning and evening rectal temperature, respiration rate and pulse rate were significantly higher in asbestos shelters as compared to modified shelters with thatch ceiling (Sahu *et al.*, 2008). Similar results were obtained in present study also where significantly lower roof temperature of 29.20 ± 2.14ºC was recorded in thatched roof. Sivakumar *et al.* (2017) also reported similar observations with significantly higher temperature and THI with cement sheets followed by lowest with thatched, tiled and metal roofing.

Concrete floor was observed in 99 per cent farms under the study and 63 per cent of them are laid with rubber floor mat also. Rubber mat recorded lower temperature when compared to concrete floor by 1ºC, therefore rubber mat was found to be a better option. Similarly Sahu *et al.* (2018) noticed a significantly higher temperature for cement concrete floor compared to sand bed during peak hours of the day.

Roof temperature found to have significant positive relation with roof height. Hatem *et al.* (2004) and Schütz *et al.* (2009) studied the microclimatic influence of increasing roof height and found that, it enhances aeration and decreases dry bulb temperature which consequently reduces THI.

Influence of shade by trees were found to be very effective in intercepting direct solar radiation and decreasing heating up of roof surface of cattle shelters (Bloomberg and Bywater (2007); Herbut and Angrecka (2013) and Abdel-Aziz*et al.* (2015)). In accordance with these findings, it was evident that influence of shade in terms of percentage shade significantly reduced the roof under surface temperature in the farms studied. Since it significantly reduced ambient temperature also (Bloomberg and Bywater, 2007), similar decreasing trend could be expected for floor temperature also as observed in the current study.

Likewise, roof and floor temperature also showed a decreasing trend with altitude of the location. Negative relation between temperature and altitude was reported by Becerra *et al*. (2016) and Prasad (2014). Similar findings were observed in present study also with respect to roof and floor temperature where both showed significant positive relation with each other as well as with climatic parameters.

5.20. Relationship between roof and floor temperature and HLI

While analysing roof and floor temperature obtained from all THI zones, it has been observed that both of them established a significant positive correlation with HLI. The relationship between HLI and roof temperature could be represented by the equation: HLI = 0.4576 x Roof temperature + 69.173 (r^2 = 0.1958). This was in agreement with the findings of Kamal *et al*. (2013), where they found that mean THI increases with roof temperature, and differ significantly with roofing materials with different thermal conductivity. Sivakumar *et al*. (2017) found that the morning and evening THI values exceeded critical value in all seasons except cold seasons and suggested that thatched roof, followed by tile and metal roof housing system were found to be suitable for the North East Zone of Tamil Nadu, India. Similarly, floor temperature also found to have a significant positive correlation with HLI. This could be illustrated as HLI = 1.7479 x floor temperature + 40.976 (r^2 = 0.3157).

5.21. Relation between HLI and other structural parameters of the shelter

While analysing structural parameters, no significant relation could be established between HLI and structural parameters of the shelter. But a negative correlation was evident in all zones with most of these parameters and HLI. Hatem *et al*. (2006) demonstrated that increasing height of the shade structure improved the microclimate by enhancing aeration under the shelter. In the present study the mean roof height was 2.8 m which showed an insignificant negative correlation with HLI. This height was found lower than the roof height of 3.0 - 5.0 m recommended for cattle shelter in hot humid climate by Belsare and Pandey (2008) and Sharma *et al.* (2019) mainly for commercial farms. It could be assumed that the present height of cattle shelter in the study area was sufficient with respect to the prevailing ambient temperature and HLI.

The mean width of the shelters found in the study was more or less similar to the recommended mean width of 5-6m (Belsare and Pandey, 2008). Wide width of the shelter help to lower ground temperature underneath the animal and reduces heat load to animal from ground surface. In the present study, width of shelter doesn't account for the manger space and front extensions, and also mean was calculated for all types of farms together even though it varies considerably depending on its size. Length of shelter depends on requirements of the farms and are highly variable (Belsare and Pandey, 2008). Angrecka *et al.* (2017) demonstrated that extension of barn eaves to 1 m will reduce the insolation and solar heat gain by sidewall stall surface over 90 per cent of the area. Not significant, but negative relationship between eaves height from ground and HLI was evident from the Table 16.

5.22. Relationship between HLI and shade over the shelter

Several studies showed that solar radiation, in combination with other environmental parameters had very significant impact on thermoregulatory mechanisms of dairy cows when compared to protected ones (Davis and Mader, (2003) and Tucker *et al.* (2008)). Present study also provided some crucial evidence for the radiation intercepting property of shade trees. When pooled data from all THI zones were considered, influence of shade trees in terms of percentage shade showed a statistically significant negative correlation with HLI ($p<0.05$). HLI value of 84.07 recorded under fully shaded shelters increased to HLI 90 when tree shades were completely absent (0%). Tree shades were very effective to reduce thermal stress in dairy cattle by intercepting direct solar radiation. This study was also in agreement with Bloomberg and Bywater (2007) who estimated the effect of shade on heat stress in New Zealand dairy cows using HLI and found that tree shades completely eliminated the occurrence of severe heat stress. Herbut and Angrecka

(2013) opined that planting trees surrounding the shelter would reduce the influence of solar radiation on the value of THI.

5.23. Mean light intensity in farms of different THI zones

While analysing the data of light intensity inside the shelter, it could be concluded that large variation in light intensity was obtained from all zones and no particular relationship could be established. Highest mean light intensity was recorded from zone H1 (Moncombu), where majority of the farms surveyed were located near paddy fields and direct solar radiation enters into the shelter since shading effect of trees with thick canopy were at the minimum. It was also observed that large sized farms had more light intensity than smaller ones due to the effect of roof height which allowed more sunlight to enter into the shelter.

5.24. Relation between light intensity and influence of shade

Mean light intensity showed a significant negative correlation with influence of trees in terms of percentage of shade. From the observations it was evident that shelters with less proximity to vegetation recorded highest light intensity and vice versa. While considering individual zones, significant relation was found only in zone H1. Because in zone H1 majority of the farms surveyed were located near paddy fields which are having the least shade effect of trees and recorded the highest light intensity. Hence, the relationship between them is more pronounced compared to other zones. This observation proved the effectiveness of trees in intercepting direct solar radiation subsequently reduced the intensity of light inside the shelter. This finding was in accordance with the reports of Bloomberg and Bywater (2007); Herbut and Angrecka (2013) and Abdel-Aziz*et al*. (2015).

5.26. Milk production details in each THI zones

The pooled data from all zones of Kerala together showed the milk production potential of crossbred cattle. Most of the cows (60 per cent) were yielding 5-10 L per day. According to Prasad (2014) majority of cows (71 per cent) of Kerala produced 5-10 L per day which was in accordance with the present study. While considering individual zones, highest milk yield was reported from the lower zone L1, having the lowest HLI. The lowest milk yield was reported from the zone H1, followed by H3. This trend in milk production was in accordance with the distribution of HLI. There were several reports suggesting the impact of thermal stress on milk production (Broucek *et al*. (2009), Bernabucci *et al*. (2010); Zimbelman and Collier (2011), Hammami et al. (2013). Prasad (2014) and Harikumar (2017)).

5.27. Use of ameliorative interventions to compact thermal stress

Results indicated that 77 per cent of the farms used wetting the body by bathing two to three times per day as an ameliorative method to reduce stress during the high THI period. But there was no uniformity in timing, frequency or quantity of water used among farmers. This was in agreement with earlier works of Prasad (2014) in THI zones of Kerala. Results also indicated that fan was installed in nearly 21 per cent of the farms, but only 9 per cent of them were in working condition. Majority of farmers had found that extra power used for working fans and other techniques were not profitable for smallholder farmers.

5.28. Relation between HLI and shelter orientation

There was no significant difference in the mean HLI in the north- south (88.75 ± 1.09) and east-west (86.20 ± 1.68) oriented cattle shelters. But significantly lower THI was observed in east-west oriented shelters by Das *et al*. (2015). This could be attributed to the fact that east- west orientation considerably reduced the incidence of direct solar radiation into the cattle shelter. Insignificant relation in the present study may be because of the smaller sample size. Much more promising results can be expected if detailed continuous studies were conducted in each zones.

5.29. Meteorological model for predicting micro environment inside cattle shelter

Local climatic conditions along with various animal factors significantly influenced the heat load content in dairy cattle. The new meteorological model was developed based on Heat Load Index (HLI) introduced by Gaughan *et al*., 2008. In light of results obtained by Harikumar (2017) that HLI was one of the major bioclimatic indices to be accounted for elucidating thermal stress responses in dairy cattle in tropical humid climate specifically in Kerala. Various biotic and abiotic parameters showing significant linear relationship with HLI interior to the shelter were considered for developing the model. Pooled data from all THI zones were considered for developing meteorological models predicting heat load inside the cattle shelter. Three multiple regression models were developed (1) considering only the significant biotic factors (2) considering only the significant abiotic factors and (3) considering all the significant biotic and abiotic factors. A similar kind of study conducted by Lees (2018) developed a Dairy Heat Load Index (DHLI) based on panting score, black globe temperature and relative humidity to predict the impact of heat load on sub-tropical and tropical dairy regions of Australia.

5.28.1. Model predicting heat load index considering biotic factors alone

Respiration rate, head, flank and udder temperature were the biotic factors that had shown a significant linear relationship with HLI. A linear regression analysis was performed on the basis of this with HLI as response variable and respiration rate, head, flank and udder temperature as independent variable, with results shown as

HLI= -3.37+2.42×Head temperature - 0.17× Respiration rate (r^2 =0.469)

The equation have a value for the coefficient of determination r^2 of 0.469, which means that 46.9 per cent variation in HLI could be predicted by head temperature and respiration rate and $p<0.001$, which proved that the group of variables, head temperature and respiration rate reliably predicted HLI. Whenever every unit increase in head temperature occurs, 2.42 unit increase in HLI would be predicted holding the other variables as constants. Likewise for every unit increase in respiration rate, there was a 0.17 unit drop in predicted HLI holding all other variables constant. All parameters in the model were significant with head temperature having $p < 0.001$ and respiration rate having $p < 0.05$.

5.28.2. Model predicting heat load index considering abiotic factors alone

Altitude, ambient temperature interior, roof temperature, floor temperature, Light intensity and Percentage of shade are the abiotic factors that had shown a significant linear relationship with HLI. A linear regression analysis was performed on the basis of this with HLI as response variable and these significant abiotic factors as independent variable, with results shown as

HLI= 58.47+ 0.77× Floor temperature + 0.263 × Roof temperature - 0.007× Altitude

The equation had a value for the coefficient of determination r^2 of 0.438 which means that 43.8 per cent variation in HLI could be predicted by floor temperature, roof temperature and altitude ($p < 0.001$), which proved that the these variables reliably predicted HLI. And also, for every unit increase in floor temperature and roof temperature, 0.77 and 0.263 unit increase in HLI would be predicted respectively holding the other variables as constants as well. For every unit increase in altitude, there was a 0.007 unit drop in predicted HLI holding all other variables constant. All parameters in the model were significant ($p < 0.05$). Studies conducted by Mader *et al* (2006) in order to determine the environmental factors that influence heat stress in cattle and found that wind speed and solar radiation significantly influence the heat load and adjustments were made to the THI equations. Adjusted THI equations have showed a higher correlation with panting score and proved its appropriateness in predicting THI during hot hours of the day.

5.28.2. Model predicting heat load index considering all significant parameters

A linear regression analysis was performed on the basis of this with HLI as response variable and all significant factors (both biotic and abiotic) as independent variable, with results shown as

$$HLI = 25.79 + 1.56 \times \text{Head temperature} + 0.20 \times \text{Respiration rate} - 0.006 \times \text{Altitude}$$

The equation has a value for the coefficient of determination R^2 of 0.514 which indicated that 51.4 per cent variation in HLI could be predicted by head temperature, respiration rate and altitude ($p<0.001$), which proved that the group of variables, head temperature, respiration rate and altitude reliably predicted HLI. From this we could infer that model using all significant parameters better predicted variation in HLI compared to separate model using biotic and abiotic factors. And also, for every unit increase in head temperature and respiration rate, 1.56 and 0.20 unit increase in HLI respectively would be predicted holding the other variables as constants. Also for every unit increase in altitude, there was a 0.006 unit drop in predicted HLI holding all other variables constant. All parameters in the model were significant ($p < 0.05$).

CHAPTER 6

SUMMARY

Thermal stress is an increasingly formidable challenge to the production and development of livestock sector especially for dairy cattle in the hot and humid tropical climate of Kerala. The present study envisaged to assess the relationship between various meteorological variables, structural parameters of cattle sheds and physiological responses of the cattle. A location-specific meteorological model considering the onsite measurement of climate data and biotic and abiotic factors was also developed to predict the HLI value inside the cattle shelter.

A detailed field study was conducted in four THI zones of Kerala including three higher zones such as H1 (Moncombu), H2 (Vellanikkara), H3 (Pattambi) and one lower zone L1 (Pambadumpara) during the summer months in February and March of 2020. Twenty-five farms were selected from each zone which was further grouped into small, medium, and large farms based on the number of milch animals. Macroclimatic and microclimatic data of the cattle shed were collected using electronic loggers. In addition to this, topographical, structural, and physiological responses of the animals were also collected and analysed.

All climatological variables, ambient temperature (°C), black globe temperature (°C), relative humidity (%), wet bulb temperature (°C), and wind speed (m/s) and HLI recorded strong significant positive correlation between exterior and interior values.

The HLI interior was lower in the zone L1 (79.284 ±1.45) and significantly different from the rest of the zones. Zone H1 (94.04 ±1.20) and H3 (94.048 ± 1.20) recorded no significant difference in HLI interior whereas in zone H2 (83.944 ±1.62) it was lower and significantly different from zone H1 and H3 and higher than zone L1. But, the HLI exterior to the shed varied quite differently from the HLI interior.

Biotic factors such as respiration rate, head and flank and udder temperature had shown a significant linear relationship with HLI. A linear regression analysis was done on the basis of this with HLI as a response variable and a meteorological model predicting HLI considering biotic factors alone was developed. The model obtained was follows: HLI= -3.37+2.42×Head temperature - 0.17× Respiration rate (r^2 = 0.469).

Abiotic factors such as altitude, ambient temperature interior, roof temperature, floor temperature, light intensity and percentage of shade had shown a significant correlation with HLI. Meteorological model developed on the basis of this with HLI as response variable was given by HLI= 58.47+ 0.77× Floor temperature + 0.263 × Roof temperature - 0.007× Altitude (r^2 = 0.438).

When regression analysis was performed with all significant biotic and abiotic factors, the model equation obtained was given by HLI = 25.79+1.56×Head temperature+ 0.20×Respiration rate - 0.006× Altitude (r^2 = 0.514).

Not significant, but a negative relationship between HLI and structural parameters such as length, width, roof height and eves height was evident from all THI zones.

Roof temperature found to have a significant linear relationship with HLI. It was also noticed that roof temperature varied significantly with different materials. Even though the most durable and highly preferred roofing material GI sheet recorded the highest roof temperature (44.08 ± 1.46ºC) it could be rectified effectively by providing a false ceiling beneath the metal roofing. Not significant but a small drop in temperature was recorded for concrete flooring with rubber mat (26.43 ±0.37 ºC) compared to the concrete floor alone (27.28 ± 0.46 ºC) and found to have a significant linear relation with HLI. In addition to this influence of shade trees showed a significant negative relationship with HLI.

The following strategies and recommendations can be drawn from the study.

- Head temperature and respiration rate of dairy cattle and altitude of the location are effective in predicting heat load in cattle shed
- Thatched roofing can be recommended for small farms depending on its availability.
- Without compromising the durability, metal roofing with false ceiling can be recommended for all types of farms.
- Percentage shade above 50 per cent can be recommended.
- The model was developed specifically for the hot-humid tropical climate which better predicts heat load index in cattle shed the, helps farmers to initiate suitable ameliorative interventions for crossbreed cattle population in Kerala

CHAPTER 7
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PREDICTING HEAT LOAD INSIDE CATTLE SHELTER BY ANALYSING BIOTIC AND ABIOTIC FACTORS IN TROPICAL HUMID ZONE

by

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(2015 – 20 - 015)

ABSTRACT

Submitted in partial fulfilment of the

requirements for the degree of

B.Sc. – M.Sc. (Integrated) Climate Change Adaptation

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2020

ABSTRACT

The study was conducted to predict the influence of various biotic and abiotic factors on the microclimate of the cattle shelter and develop a meteorological model specifically for the Kerala climate. Data collected from three higher THI zones and one lower THI zone of Kerala during the summer months in February and March of 2020. Macroclimatic and microclimatic data of the cattle sheds were collected using electronic loggers. Details of farms, topographical information of locations, structural characters of cattle sheds and physiological responses of animals were collected and analysed. Heat Load Index (HLI) was calculated to quantify the thermal stress factors for analysing stress responses of animals and for developing meteorological model. Biotic factors such as respiration rate, head, flank and udder temperature and abiotic factors such as altitude, ambient temperature interior, roof temperature, floor temperature, light intensity and percentage of shade had shown a significant correlation with HLI. Multiple regression analysis was performed on the basis of this and developed following three mathematical models that reliably predicted heat load. HLI= -3.37+2.42×Head temperature (°C) - 0.17× Respiration rate (beats/ min), HLI= 58.47+ 0.77× Floor temperature (°C) + 0.263 × Roof temperature (°C) - 0.007× Altitude (m) and HLI = 25.79+1.56×Head temperature (°C) + 0.20×Respiration rate (beats/ min) -0.006× Altitude (m). These models will be useful for adopting thermal stress alleviating measures and designing dairy farm in the climate change scenario.