Heat Load in Feedlot Cattle

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Report prepared for MLA by:

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EXECUTIVE SUMMARY

Objectives

The Meat and Livestock Australia Ltd has funded this study to review the relevant literature and industry experience, and provide factual information on the impact and interrelationship of:

- elements of the physical environment,
- animal related factors, and
- nutrition related factors
- on heat load in feedlot cattle.

Brief Methodology

The study reviews the available literature and industry experience, and provides an understanding of: the relative importance of the factors associated with heat load in cattle, their predicability, and the techniques available to possibly modify their impact. Proactive counter-measures for minimising heat load effects in the Australian Feedlot Industry are discussed in the context of strategic and tactical management programs and practices.

Main Results and Conclusions

Basis of Heat Load

Heat load in cattle may be largely explained in terms of the practical application of the principles of thermodynamics. Cattle are homeotherms and try to maintain their body core temperature within reasonably narrow temperature ranges so that their body cells and tissue can function optimally.

Excessive heat load (EHL) occurs where a combination of local environmental conditions and animal factors lead to an increase in body heat content beyond the animal's normal physiological range and the animal's ability to cope.

EHL in cattle is the result of a number of complex interacting factors: physical (conduction, convection, radiation, evaporation), animal (breed, adaptation and acclimatization, behaviour, coat colour/type, body condition, health status), and nutrition (metabolic heat of nutrients, ingredients, diet, DMI, time of feeding, water availability) and management practices (resource use and maintenance, livestock care, personnel).

Cattle are normally able to maintain their preferred level of body heat and thus body temperature by behavioural and physiological thermoregulatory mechanisms. This may however be difficult during very hot adverse weather. The principal overall source of heat gain for a typical feedlot steer during hot, humid and low wind conditions, is metabolic heat, and the principal route of heat loss is via evaporative cooling. Other components (conduction, convection, radiation), while not large, are additives which at times may be sufficient to contribute critically to the accumulation or dissipation of body heat. If the normal thermodynamic processes are compromised, body heat content can build up and hyperthermia can develop.

EHL occurs in the Australian feedlot industry, as it does in the USA industry and elsewhere. Australia experiences ongoing periodic instances when EHL is associated with mortality and production loss. There have been occasions when these losses have been most significant. It is reasonable to assume additional unnoticed and/or unreported losses have occurred, and will continue to occur.

Overall, the economic costs associated with morbidity and mortality during EHL events are high. Commonly, it is the most finished, longest fed, and hence most valuable stock that suffer the highest mortality. Furthermore, it has been demonstrated that there are long term financial losses associated with hot weather induced reduced feed intake (DMI) and subsequent reduced production, which can exceed the financial loss from cattle mortality.

Strategies

There are strategies recommended to reduce the incidence and/or minimise the effect of EHL in feedlot cattle. Whilst there is no single definitive action or structure able to fully eliminate its occurrence in the current feedlot industry, there are aspects of the feedlot operation which if properly managed can combine to reduce or eliminate EHL significance. These address site selection, infrastructure and management practice.

The important elements in managing EHL are **planning**, **recognition**, and **action**.

Planning embraces both pre-development site assessments as to suitability and the provision of suitably designed infrastructure including effective shades for vulnerable cattle, an efficient sprinkler system, robust watering with multiple troughs per pen, and an automated pen micro-environment monitoring system (THI-hours). A supply of portable waterers for vulnerable cattle should be maintained on site. Existing establishments need to review the adequacy of their infrastructure and upgrade or modify as necessary and practical, pre-summer.

Influencing management practices includes ensuring the adequacy of infrastructure. Pre-summer, operational programs and practices are reviewed with attention to identifying vulnerable cattle on the basis of degree of finish/weight, breed, coat colour, health, adaptation since received, and pen exposure to wind, convection and solar radiation. Water troughs are maintained clean and fresh. The pen micro-environment is maintained by frequent cleaning to minimise pad depth by constructing well formed compacted mounds within pens, and by the judicious use of sprinklers.

Nutritional programs are reviewed pre-summer for optimum summer production, and an EHL event diet and feeding program established for implementation should an event occur. Summer diets are reviewed with respect to their adequacy to achieve production objectives, but with particular attention to: nutrient and ingredient heat increments, protein levels, micro-element levels, and provision for potential hot weather storage influence on quality. EHL event diets will provide for increased roughage to reduce dietary energy and hence metabolic heat, and possibly deferred feeding.

Staff are made aware of the animal behavioural patterns preceding and during an EHL event, and of the accompanying management programs. An action plan is prepared should an EHL event occur.

Recognition of a potential EHL event or its occurrence is achieved through staff awareness, careful observing of cattle, in particular the more vulnerable animals e.g. those with respiratory problems, and pen micro-environment monitoring (THI-hours).

Action is taken once animals are recognised in distress or there is pre-warning of an EHL event, to implement the prepared action plan. Action embraces: the judicious use of sprinklers if advantages to in regard advantageous to humidity, cessation of animal handling and movement, altering the time of feeding (if not already practiced) and/or altering diet to reduce dietary energy intake. Additional portable waterers are provided for vulnerable cattle.

It is more effective to implement a program (that has been carefully prepared in advance of the event), to minimise the risk of EHL and/or reduce its effect, than to respond to the event after it strikes.

Feedlot management can benefit from advance notice of weather conditions likely to be associated with an EHL event. It appears probable a tailor made EHL weather alert forecasting service can be developed in Australia. Such a service, meaningfully forecasting a possible EHL event 3-6 days in advance, would enable pro-active environmental management counter-measures, planned prior to the onset of hot weather, to be implemented most efficiently.

Recommendations

Specific recommendations are that the existing knowledge on infrastructure design and optimum management practice be developed, and extended to industry. Particular recommendations address the need to determine the optimum effective shade structure for the industry, the development of effective weather alert forecasting services and an EHL Environment Index (THI-hours), the validation of developing nutritional concepts under commercial feedlot conditions, and the further development of heat load management programs.

The research recommendations in the area of systems development, knowledge extension, and ongoing research and development are as follows.

- Systems Development
  - conduct EHL Weather Risk Assessment.
  - develop Heat Load Management Programs.
  - develop EHL Weather Alert Forecast Service.
  - develop EHL Incident Reporting Mechanism.
- Knowledge Extension
  - develop program of extending existing knowledge.
  - foster international research and extension linkage.
- Research and Development
  - determine the cost of summer heat load.

- conduct an applied scientific evaluation of shades.
- examine the practical contribution convection can make to reducing EHL.
- develop model of heat load in feedlot cattle.
- develop EHL Environment Index (THI-hours).
- validate nutritional concepts commercially.
- examine relevance of ammonia in feedlot production.
- review water intake under EHL conditions.
- support gene technology.

CONTENTS

1. INTRODUCTION

1.1 Background

The periodic occurrence of persistent hot weather can reduce livestock production efficiency in much of the world's temperate, sub tropical and tropical cattle producing areas. It is most noticeable in the intensive cattle feedlot industry, where excessive animal heat load (EHL) may result in deaths when animals are unable to cope. However, less obvious residual production penalties may occur as a result of ongoing reduced feed dry matter intake (DMI) and impaired immune function in the survivors.

In February 2000 extreme adverse environmental conditions caused significant cattle losses in a Southern NSW feedlot. The occurrence was examined and reported on by two independent and separate Review Committees, who prepared individual reports for the Director General, NSW Agriculture, and for the Feedlot Industry Accreditation Committee (FLIAC). The reports were considered by an Australian Lot Feeders Association (ALFA) working party.

The ALFA working party identified areas requiring further review and/or research prior to addressing the major recommendations of the separate Review Committees, in particular, factors associated with the impact of:

- Elements of the physical environment
- Animal related factors, and
- Nutrition related factors on heat load in feedlot cattle.

Meat and Livestock Australia Limited (MLA) has, as a result, commissioned two independent studies, namely:

FLOT. 307-309 - Recommendations for Reducing Impact of Heat Load in Feedlot Cattle, which is this study, and

FLOT. 310 - Measuring Micro-environment Variations in Two Australian Feedlots
to provide a solid knowledge basis to assist enterprise and industry management, and future policy development.

1.2 Study Definition and Objectives

The Terms of Reference of this study, namely FLOT. 307-9, defining the project study, are contained in Appendix 1.
The objective of the study is to provide factual information on the impact and inter relationships of:

- Elements of the physical environment,

- Animal related factors, and

- Nutrition related factors, on heat load in feedlot cattle, as a basis for:

- the development of pre-emptive and day to day management strategies that can be employed to minimise the adverse effects of EHL in feedlot cattle,
- identifying any knowledge gaps that require additional research and development to further support and achieve the above, and
- developing recommendations.

The study reviews the available relevant literature and industry experience, providing where possible an understanding of the relevant relative importance of the factors associated with EHL in cattle, their predicability, and techniques available to possibly modify their impact. Proactive counter-measures are discussed in the context of strategic and tactical management programs and practices for consideration to minimise heat load effects on the Australian Feedlot Industry.

2. THE EXTENT 0F HEAT LOAD IN FEEDLOT INDUSTRIES

2.1 Excessive Heat Load in Cattle

Excessive Heat Load (EHL)[1] occurs where a combination of local environmental conditions and animal factors leads to an increase in body heat content beyond the animals normal physiological range, and its ability to cope. High body temperatures may cause changes in body metabolism and tissue damage, which if extreme, will cause death (Young and Hall, 1993).

2.2 Incidences of EHL in Feedlot Industries

Cattle are feedlot finished worldwide with production systems varying considerably in regard to scale, intensity, technical sophistication and efficiency.

The industry is in its largest and most developed form in North America, Australia and South Africa.

Feedlot cattle deaths have occurred when persistent adverse weather conditions have occasionally reached severe levels. Examples in North America include some 725 dairy cows lost in Southern California during a severe heat wave with accompanying high humidity in August 1977 (Oliver *et al*., 1979); several hundred feedlot cattle lost in central and eastern Nebraska in an August 1992 heat wave following a relatively mild and cool summer (Hahn & Nienaber, 1993); more then 4,000 feedlot cattle lost in Nebraska and Iowa in July 1995 (Hahn and Mader, 1997); modest feedlot cattle losses also reported in Nebraska in July 1997 (Hahn *et al*., 1999); and, more then 5,000 feedlot cattle lost in eastern Nebraska in July 1999 when a heat wave followed a period of relatively cool weather (Hahn *et al*., 2000).

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[1] ***EHL*** is a thermodynamic description allowing affected animals to be assessed quantitatively, and to identify and describe differences between animals and situations. In contrast, the often-used generic term “heat stress” lacks clear quantitative definition, and is difficult to assess objectively (Young, 1993). Furthermore, the term “stress” carries negative emotional implications and is frequently used even when there is no evidence of any disruption in physiological function. The term “stress” tends to be a catch-all and used when we don’t fully understand what is going on.

Overall economic losses from deaths and reduced performance during such events are high, with estimates of US$28 million and US$40 million for the two major events in Nebraska and Iowa respectively (Smiley, 1996; Mader, 1999b). Additionally, whilst death losses were drastic for some feedlots, Balling (1982) showed the long term financial losses from reduced DMI and decreased production gain associated with adverse (summer and/or winter) weather conditions normally would be much greater than the direct financial loss resulting from cattle mortality.

Similarly in Queensland, Australia, in a February 1991 heat wave, in excess of 2,681 feedlot cattle were reported lost near Texas, 77 feedlot cattle lost near Condamine, another 130 feedlot cattle lost nearby, together with 32 cattle held for slaughter at a nearby meat works (Douglas *et al*, 1991). During the same period 30 and 91 feedlot cattle were lost in two northern NSW feedlots (Vanselow, 1996). In southern NSW some 1255 feedlot cattle were lost in February 2000 (Entwistle *et al*., 2000) with concurrent unconfirmed reports of 105 losses at three nearby sites (McKiernan, personal communication). In both these periods there were sudden changes in climatic conditions.

In both the above incidents the economic losses associated with reduced DMI and subsequent lowered production performance of the surviving cattle, are unknown.

Infrequent low-level losses often go unreported. It is reasonable to assume that over time there has been quite significant unnoticed and/or unreported periodic losses within the international feedlot industry due to EHL.

EHL deaths are claimed to have only rarely occurred in the South African feedlot industry despite the occurrence of severe heat wave conditions. There were 20 feedlot cattle lost in a rare occurrence in 1988 in the North West Province (Van Reenan, personal communication).

The South African industry is characterised by feeding cattle of (wholly or partly) *Bos indicus* origin for a relatively shorter period (maximum 120 to 140 days) and to a lesser degree of fatness (Ford, personal communication) than the long-term grain fed cattle in the North American and Australian industries.

2.3 Common Themes

There are common broad environmental characteristics reported present in the recorded instances where EHL has caused mortality in cattle. Predominant are a combination of two or more of the following:

- a high ongoing minimum and maximum ambient temperature,
- a recent rain event,
- a high ongoing relative humidity,
- an absence of cloud cover with a high solar radiation level,
- low, or the absence of, air movement over an extended period (4-5 days),
- a sudden change to adverse climatic conditions.

Feedlot deaths have been greatest after several days of high temperature, high humidity with low air movement where there has been only limited night time cooling relief.

Feedlot mortality is highest amongst the *Bos taurus* highly finished (usually long days on feed), best preforming cattle, then in order the newly arrived cattle, the sick cattle, and finally the recently transported or handled animals. There is much within pen incidence variation. Animal dehydration is evident after death.
Surviving cattle frequently experience an ongoing reduced DMI as a result of the EHL event, which affects growth and production efficiency after the event, and overall industry profitability.

3. PRINCIPLES OF THERMODYNAMICS IN LIVESTOCK

3.1 Introduction

Cattle are **homeotherms** and try to maintain their body core temperature within reasonably narrow temperature ranges so that their body cells and tissues can function optimally. When environmental conditions are thermally severe homeotherms expend considerable physiological and behavioural effort to maintain their normal body temperatures. If body temperatures fall below the normal acceptable range, the animal is said to be **hypothermic** i.e. hypothermia occurs, and, if body temperatures are above acceptable levels **hyperthermia** occurs. With severe or prolonged hyperthermia damage occurs to tissues and organs and the animal may fail to cope and may die.

This section **provides an overview** of dietary energy partitioning and the thermodynamics of animals, focusing on the theories and mechanism associated with potential hyperthermia in large mammals such as beef cattle. The review provides a foundation and scientific framework for the subsequent sections, which consider the practical application of thermodynamics to cattle in Australian feedlots.

3.2 Homeothermy

Homeothermy or homeokinesis is the condition of maintaining a relative constant temperature in the core of the animal's body despite wide fluctuations in environmental temperatures. The body core temperature of cattle is normally about 39°C, which is ideal for the cellular and biochemical activities to operate most effectively. However, not all the various parts of the body are at this core temperature. Tissues and organs deep in the body core, like the brain, the liver and some other visceral organs, operate at high metabolic rates when body temperature is optimal. Tissues of the extremities (legs, ears, tail, etc) and the skin, being away from the main metabolic heat sources and in near contact with the outside, usually are at temperatures lower than the deep core tissue temperature. The temperatures of the tissues on the extremities and skin vary considerably and are dependent upon heat produced from cellular metabolism, the temperature of the animal's surroundings, and the thermal (heat or cold) loads placed on the animal.

Under hot condition the tissues in the extremities warm up considerably, and are usually abundantly supplied with blood to assist in the transfer of body heat to the surface where it can be lost to the environment. Under such circumstance body surface temperatures approach those of the core.

However, rarely do body surface temperature increase much above these of the body core. In situations where the effective temperature of the animal's surroundings is higher than the core temperature of the body, (eg. where there are very high air temperatures and/or there is high radiation impact on the animal) then heat may flow from the environment into the animal's body as a result of the temperature gradient between the surface and the deeper tissues of the body.

The physiological and biochemical activities in animals are dependent partially on temperature. In principal, there is a direct relationship between temperature and the rate of a chemical reaction although some enzymes modify the temperature dependence of specific biochemical reactions. The overall temperature dependence is called the van't Hoff effect, which indicates that for each 10ºC rise in the temperature of a tissue the metabolic rate of the tissue will double. By maintaining reasonably stable temperatures animals can function in a steady fashion. If tissues get too cold, metabolism and efficiency tend to drop off, while with warming of tissues metabolism speeds up, but not always with greater efficiency.

If body cells and tissues become too hot, physiological processes begin to fail. With the speeding of metabolism there is greater metabolic heat production and thus the tissues get even hotter causing metabolism to accelerate even more. The consequence is uncontrolled metabolism and a situation called "run-a-way" hyperthermia, which if not quickly brought under control will lead to death of the animal (Young and Hall, 1993). With body temperatures above about 42ºC there is a high risk of "run-a-way" hyperthermia.

In addition to the accelerating metabolism, the high tissue temperatures lead to the denaturing of proteins, the disruption of cell membrane integrity and possible permanent tissue damage (Guyton, 1981). Thus if the animal does not die from hyperthermia there is the risk of long-term morbidity and subsequent poor production performance.

Changes in the temperature of the tissues at the extremities and skin are largely responsible for the variation in the amount of heat an animal stores in its body. Such temperatures and heat storage change from time to time, tending to be higher in the afternoon because of feeding and daily activities, and low in early morning after inactivity during the night. Furthermore, high producing animals have higher rates of metabolic heat production (see below) and tend to have higher levels of stored body heat (Hall, 2000).

The thermal environment and diurnal variations in the thermal load also impact on the amount of heat in the body. In hot conditions animals tend to store substantial amounts of body heat while in cooler conditions lesser amounts are stored. Consequently in cyclic thermal conditions, such as in a desert with high heat loads during the day and cold night conditions, animals tend to absorb or retain body heat during the day and then "dump it" during the night (Hardy, 1979). Some desert-adapted animals, such as camels, are very efficient at survival in the desert because they not only allow the temperature of their extremities to fluctuate between day and night but also they allow their core temperature to vary diurnally by up to 6°C (Schmidt-Nielsen, 1983). Cattle exhibit this capacity to allow their extremities and core to vary diurnally but not to the same extent as the desert-adapted animals (McLean *et al.,* 1983; Slee, 1972). The concept of variations in body heat content is developed further later in this review where the Body Heat Content (Heat Bank) Model is reviewed (refer 3.7).

3.3 Partitioning of Dietary Energy

Animals consume dietary energy for the basic life processes and to meet production needs. The amount of energy in a feed is measured by various means. In Australia, we currently use a feeding system that relies on the **metabolisable energy** (ME)[2] content of feedstuffs (SCA, 1990). The energy in a feed is expressed in terms of mega-joule per kg of DM (MJ/kg DM), while the daily amount of energy fed to animals is expressed in terms of mega-joule per day (MJ/day).

The biochemical reactions supplying biological energy to an animal from feedstuffs are exothermic releasing heat into the animal's body. The sum of these heat sources become what is called the **metabolic heat production** (MHp) of the animal. Digestion starts the process of breakdown of feed to ready it for absorption then metabolic processes partition and direct energy into the various body functions. Some energy, which cannot be utilised by the body, is disposed of as material waste (faeces, methane and urine) while the remainder is termed metabolisable energy (ME) and used for physiological functions accumulated in body stores (Figure 3.1).

Much of the ME is oxidized for maintenance and productivity processes to be released as heat, i.e. MHp. Under cold conditions, MHp can be of value in maintaining body temperature and reducing the need for the body to generate extra heat by shivering or other thermogenic processes. Under hot conditions, MHp needs to be dissipated to the environment by passive or active means. Any retention of heat increases tissue temperature and may contribute to the animal's body heat load. Maintenance metabolic heat is largely dependent upon body weight but is modulated by genetic factors, age, adaptation and activity of the animal. In addition, heat generated through the inefficiencies of production processes of pregnancy, lactation and growth will add to the level of heat production by an animal. The energetic efficiency of milk production is about 60% while efficiency of growth is less than 30%; thus the inefficiency components of 40% and 70%, respectively, are major sources of metabolic heat in high producing animals. The higher producing animal must dissipate a greater heat load than the lower producing animal, and thus, high producers will have reduced tolerance to high environmental heat (Young *et al.*, 1997).

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[2] *Metabolisable Energy (ME)* A measure of the dietary energy that an animal can extract from its diet and utilise for functions in its body, ie, metabolism. Several different units are used to express the amounts and rate of conversion or fluxes of energy. While some of these still appear in the literature, for example the British Thermal Unit (BTU) and the Calorie (cal) the recent trend has been to adopt the International Standard units of the Joule (J) as the unit for the amount of energy and the watt (W) and the unit for the flow or flux on energy.

Energy exists in several forms (chemical, electrical, mechanical, potential and heat) which can be transformed from one form to another and likewise some forms of energy (electrical and heat) can flow from one material or site to another.

Typical values:

Steer eating 10 kg of high grain ration per day consumes about 140 MJ of ME.
An average man weighing 85 kg produces 100 W of heat, the same as a 100 W light bulb.
An average feedlot steer weighing 600 kg produce 1200 W of heat, the same as a room heater.

Conversion values:

1.0 J = 0.239 cal = 0.000949 BTU Thus 4.183kcal = 1.0 kJ.
1.0 W = 1.0 J/sec = 14.3 cal/min = 0.858 kcal/h =20.56 kcal/day
1.0 kW = 1.0 kJ/sec = 14.3 kcal/min = 0.858 Mcal/h =20.56 Mcal/day

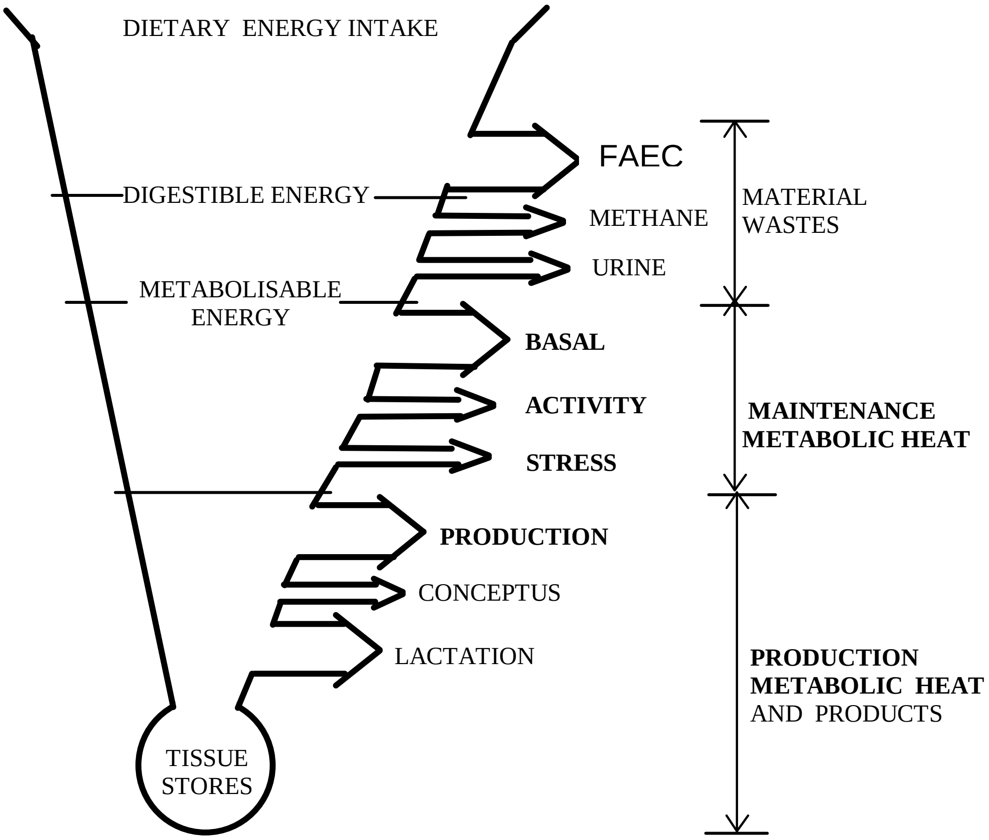


Figure 3.1: Funnel Energy Model - Schematic representation of the flow of energy through an animal with sources of metabolic heat emphasised in bold (Young, 1975).

3.4 Thermal Balance in Animals

A wide array of animal and environmental factors affect an animal's heat balance. Metabolic heat, rates of physical heat exchange, thermal insulation and behaviour of the animal also play significant roles. A combination of these factors that tilts the balance to hypo or hyper thermia can be very disruptive to animal function. Animals are usually able to maintain their preferred level of body heat and thus body temperatures by behavioural and physiological thermoregulatory mechanisms, balancing the rates of heat gain and heat loss processes (Figure 3.2).

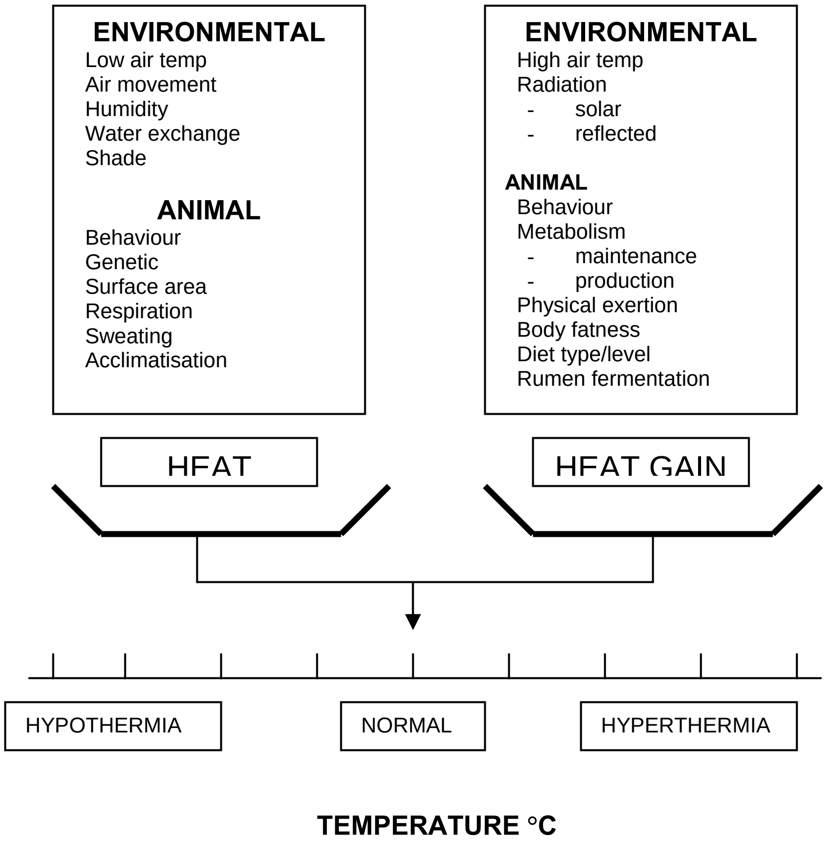


Figure 3.2: Factors contributing to thermal balance of cattle (Young & Hall, 1993).

When there is net heat gain, the body heat load increases and body temperatures will increase. If the increase in body temperature is severe there is disruption of normal physiological functions.

For simplicity the five principal thermal factors and their potential directional influence on the rates of heat gain or loss by feedlot cattle are illustrated in Figure 3.3. In the practical field situation there is a complex set of interacting factors many of which are still to be fully understood. It is by focusing on these principal factors contributing to rapid changes in the rate of heat gain and loss by feedlot cattle, that resources can be more readily focused to where effective remedial outcomes are most likely.

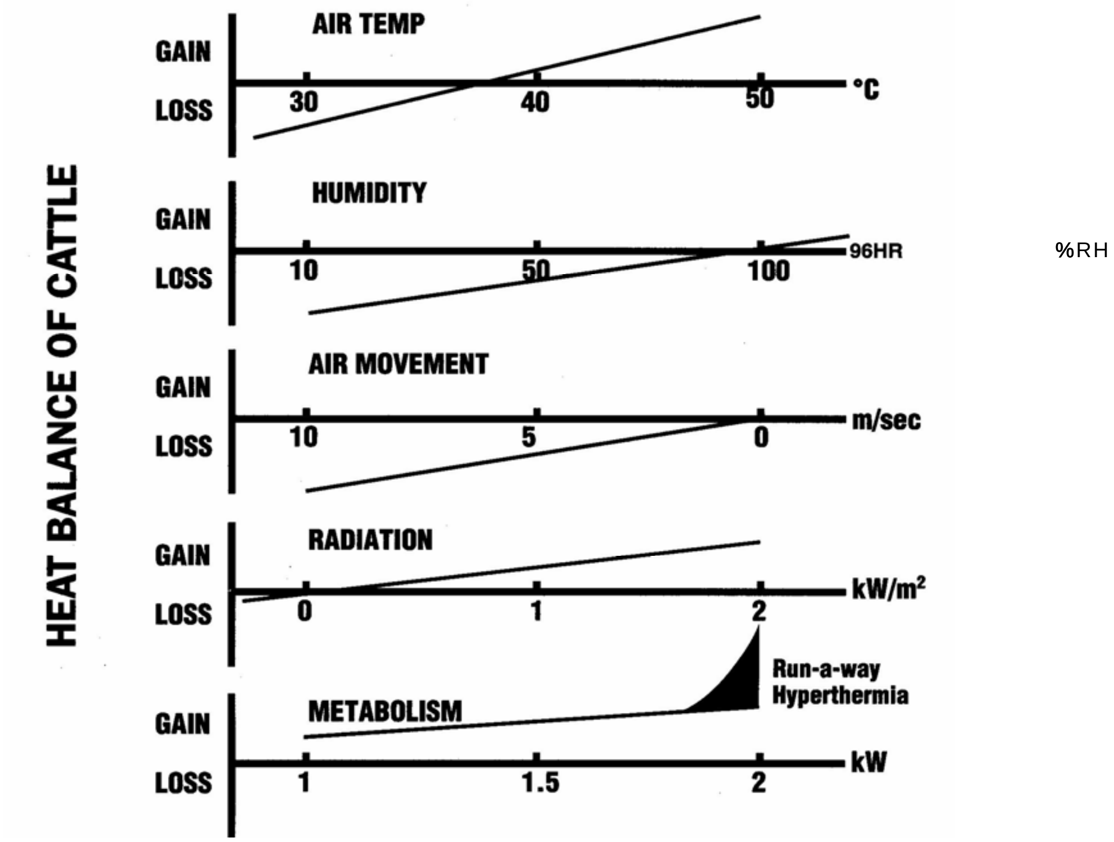


Figure 3.3: Directional influences of the main factors affecting heat balance in feedlot cattle (Young and Hall, 1993.)

The presently identified principal factors contributing to thermal exchange in feedlot cattle are: air temperature, relative humidity, air movement, net radiation, and rate of metabolic heat production. The net gain or net loss of heat from the animal body depends upon interactions of environmental and animal factors, and, the summation effects. Animal thermal load problems usually rarely arise when only one or even two of the principal factors are impinging on the animal, as there is usually a compensation achieved via the other factors. However, when several of the principal factors compound and continue to contribute to heat gain over an extended time period, without relief from compensating factors, there is an accumulation of heat in the animal's body and body temperatures can then rapidly rise.

3.5 Environmental Temperature-Metabolic Rate Model

One of the first models, the Environmental Temperature-Metabolic Rate Model, developed to describe the effects of the thermal environment on homeotherms, relies on the relationship between the environmental temperature and the rate of metabolism of the animal (Figure 3.4). Over a temperature zone, the thermo-neutral zone or zone of thermo neutrality, the animal is non-responsive to slight changes in the thermal environment. As temperatures fall a point is reached, the lower critical temperature (CT), below which the animal must increase its rate of MHp to compensate for the increased rate of loss of heat to the environment. The rate of increase in metabolism as temperatures fall is inversely related to the thermal insulation of the animal. If the environment temperature continues to fall then a point is reached (the lower critical threshold) when the animal can no longer produce sufficient heat to compensate for the high heat demands from the cold environment. At this point the animals' body will cool and metabolism slows and if the situation is not corrected the animal will succumb to hypothermia.

The relationship between metabolism and environmental temperature is not so well defined at the hot end of the thermal environmental range. In fact, there is still considerable scientific debate as to whether metabolic rate goes up or down as an animal is exposed to increasingly hotter conditions. The issue is complicated by a number of interacting factors, especially the effect of hot conditions on tissue temperatures, and appetite for food. Increasing tissue temperatures will increase metabolism (van't Hoff effect) while the reduced appetite and reduced DMI under hot conditions reduces metabolism. These issues of what happens to the rate of metabolism on an animal under hot conditions are further complicated by variations in animal behaviour and the ability of animals to adapt physiologically. Thus the Environmental Temperature-Metabolic Rate Model is finding questionable application in heat load situations.

Boundary zones within the Environmental Temperature-Metabolic Model define different physiological states of an animal in relation to changing environmental temperature. However, any thermodynamic model solely based on predicting a response using an increasing environmental temperature scale is *reductionist* in approach, failing to recognise the effects of age, stage of reproduction (cattle) or coat characteristics (Mount, 1979; Hahn *et al*., 1983; Blaxter, 1989) or to incorporate any 'accumulative effect over time' that daily cycles and seasonal shifts have in the short and long term. Temporal constraints will elicit a very different set of animal responses (both immediately and after some time due to a lag effect), than any response based on, for instance, the maximum or minimum temperature daily. A complete set of parameters that defines the environment meaningfully must include, for example, the moment-by-moment fluctuations in temperature, wind speed, radiation and at the same time include any modification to that environment by the animal eg. changing orientation to the sun, or management.

Conclusion:

The Environmental Temperature – Metabolic Rate Model is best used to describe the relationship(s) between responses in an animal and a single, or, several clearly defined and controlled environmental factors that can be expressed in terms of ambient temperature.

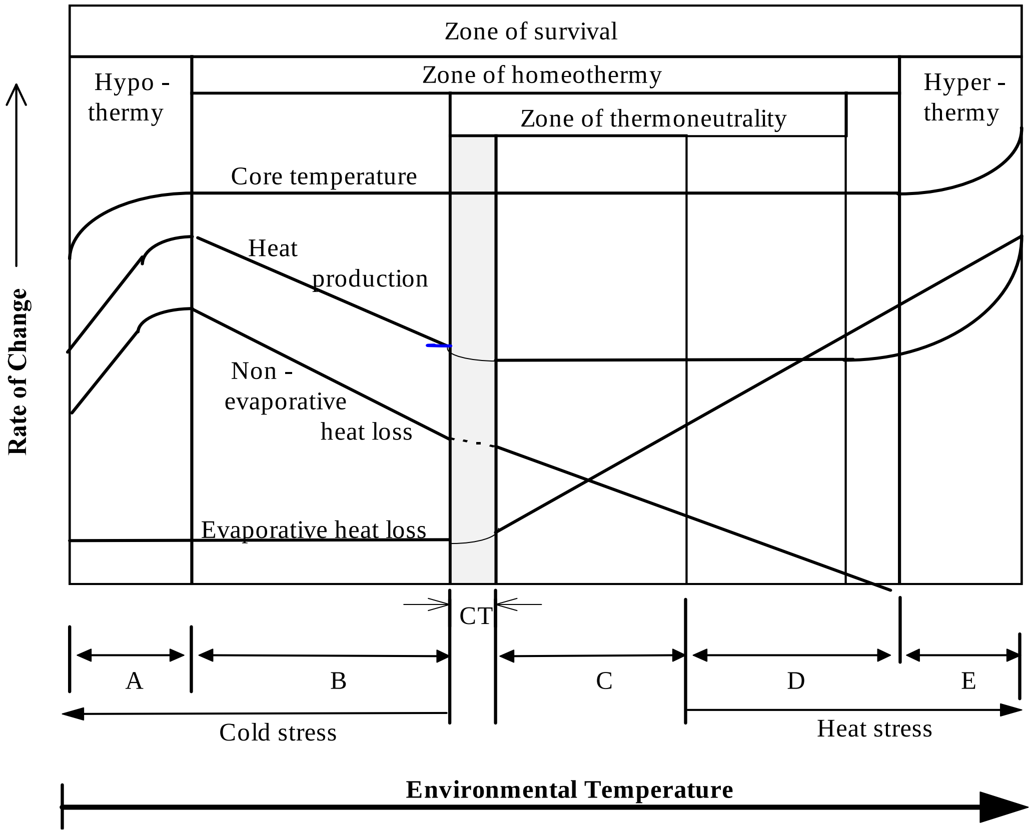


Figure 3.4: The Thermo neutral Model of thermal zones based on increasing environmental temperature. Adapted from Bianca (1976) and Mount (1979).

Zone A The animal cannot produce sufficient heat from metabolism to maintain its core temperature, inducing hypothermia.

Zone B The core is at its optimum temperature, but, as the environmental temperature continues to fall, the animal must increase heat production, and reduce non-evaporative heat loss, to maintain this core temperature. C T is the region of ‘critical temperature' where, to the left, a rise in heat production must occur if ambient temperature falls and to the right, a constant rate of heat production occurs with a concomitant constant body temperature.

Zone C Zone of thermal indifference – or thermal comfort – where metabolic heat production is balanced by evaporative and non-evaporative heat loss mechanisms. This allows the core temperature to remain at its optimum.

Zone D The animal must increasingly employ cooling strategies to maintain optimum body temperature. However, as the environmental temperature rises and non-evaporative heat loss strategies decline, the animal must increasingly rely on evaporation as its cooling strategy.

Zone E Temperature control mechanisms cannot provide sufficient cooling to maintain normal body temperature and hyperthermia occurs. On either side of the zone of survival the animal is unable to halt the processes of either hypothermia or hyperthermia and will die.

3.6 Dynamic Environmental Stress Model

A conceptual model of the dynamics of the responses of animals expected to live and perform satisfactorily in a wide range of environments to which they are adapted has been presented by Hahn & Nienaber (1993).

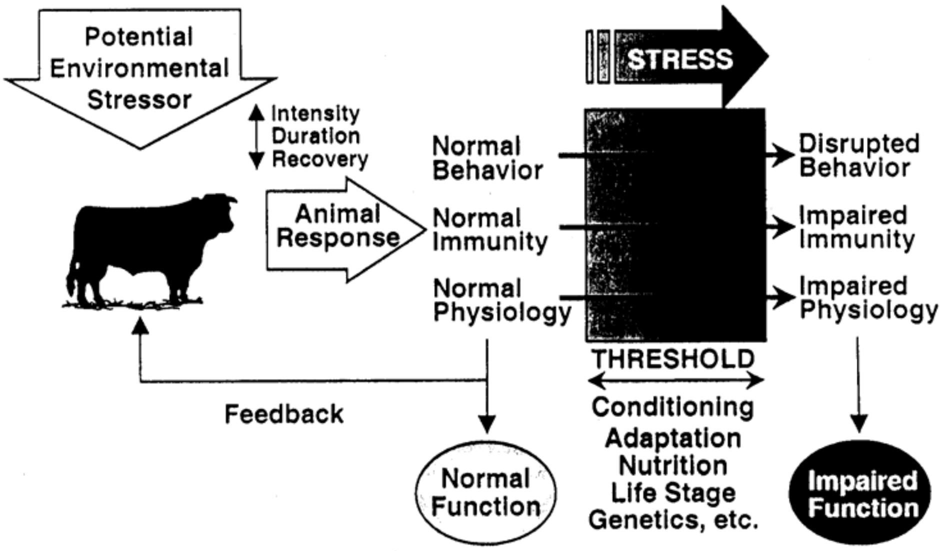


Figure 3.5: Responses of animals to potential environmental stressors, which can influence performance and health (Hahn & Nienaber, 1993).

An acute or chronic variation in the physical, chemical or biological environment may challenge animals and compromise their productivity or even life itself. For various environmental challenges there are specific biological response functions. These functions can however, be modified by an animal and reflect its phenotypic capacity to adapt and thus better cope with future challenges. The Dynamic Environmental Stress Model concepts of physiological adaptation of animals to harsh environments include temporal and other factors that influence physiological functions and adaptation.

Animals are able to maintain life and productivity in a relatively broad range of physical, chemical and biological environments. As environmental conditions change in an acute or chronic manner, adverse conditions may arise outside the optimal range with negative consequence to animal performance. The deviation may be relatively minor and remain within a commercially acceptable range, i.e. minor losses in performance may be acceptable or not justify a corrective response. In hot environmental situations the deviation may be substantial and have severe and unacceptable consequences to the animal. Some environmental parameters like ambient temperatures produce potential deviations both above and below the optimal threshold for normal body function.

Animals, when challenged by an environmental stressor, do not initially mobilize all their coping capabilities at once. The progressive recruitment of coping mechanisms may be represented by different functional relationships, depending on the specific mechanism. For example, the shift from first to second phase breathing is indicative of reduced efficiency of nasal cooling capacity. The extent and nature of phenotypic responses are dependent upon animal as well as environmental factors.

The physiological response of an animal to an environmental challenge is dependant upon the prior history and thus adaptation of the animal (Slee, 1972). The response and consequences can be so different that while an animal with developed physiological adaptation may be insignificantly affected, an un-adapted animal may suffer severely. For example, in the wet tropics ambient temperatures are usually high but with minimal variation diurnally and seasonally, while in desert or temperate regions there may not only be major diurnal difference in day-night temperature, but also significant seasonal variations. Animals and people adapted to tropical, relatively constant conditions, have difficulty coping with highly variable ambient temperatures. In contrast, animals and people adapted to highly variable temperate conditions often have difficulties in the hot conditions of the tropics. Furthermore, animal responses to environmental challenges can be drastically altered by biological factors such as age, physiological state, prior conditioning, form of diet and health status.

The process of coping in a harsh environment either through physiological response mechanisms or adaptation may be very different from an animal's viewpoint compared with man's commercial interest in achieving maximum productivity, efficiency and economic returns. When under environmental strain, an animal's priority is relief from the unfavourable conditions, prevention of risk to its homeostatic state, and survival. For example, in hot weather conditions an animal achieves relief from body heat load by reducing DMI. While the lowered metabolic heat from the reduced DMI is of direct benefit to animal comfort, the resultant reduced level of production is in conflict with man's desire for high levels of production.

In Summary:

The Dynamic Environmental Stress Model illustrates how animals can perform satisfactorily over a wide range of environments. There are biological response functions that describe the stress and potential losses in productivity as the environment deviates from optimal to harsh conditions. Furthermore, there is considerable biological capacity in most animals to withstand deviations in the environment and physiologically adapt. Frequently, however, the animal response to reduce stress and improve animal comfort, may as a consequence, result in reduced productivity.

3.7 Body Heat Content (or Heat Bank) Model

Body heat content is a function of body mass, specific heat of tissues and tissue temperatures, and varies in the short term mainly through changes in tissue temperatures. The feedlot animal will function most efficiently (eg. feed efficiency and weight gain) when body heat content remains within a functional Heat Content Range (HC_{FR}) range (NRC, 1981).

The body heat content model is based on the magnitude and dynamics of heat in the body rather than on the rate of heat production or loss by an animal relative to environmental variables. Body heat content is the accumulated balance between the rates of heat gained from metabolic processes and the environment, less the heat lost to the environment by sensible (conduction, convection and radiation) and insensible (evaporative) mechanisms.

Figure 3.6 identifies equilibrium "heat bank" or a "functional heat content range" wherein the body heat content is consistent with normal physiological function. Animals will function efficiently and produce normally as long as their thermal balance does not cause tissue temperatures to exceed their functional boundaries.

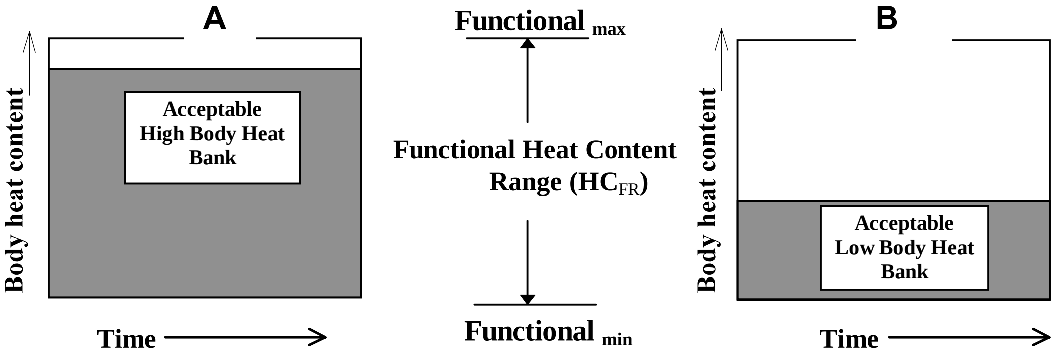


Figure 3.6: Functional Body Heat Content Model. Normally, the body heat content will fluctuate within a functional maximum (HCfx) and minimum (HCfn) level. Box A represents an animal with a relatively high body heat content which fluctuates within the functional heat content range – this may be seen under mild heat load conditions. Box B is an animal with a lower heat content, which is also within the functional range – this could be the same animal as A, but under cool thermal conditions (Young and Hall, 1996).

The consequences of a sudden increase in heat content (from an environmental metabolic source) wherein the functional maximum is exceeded is illustrated in Figure 3.7. Such a disruption demands the evoking of behavioural and/or physiological mechanisms for the animal to increase its net rate of heat loss. The area under the curve bounded by 'bcd' represents an EHL that is incompatible with sustained homeostasis, i.e. the animal may fail to cope.

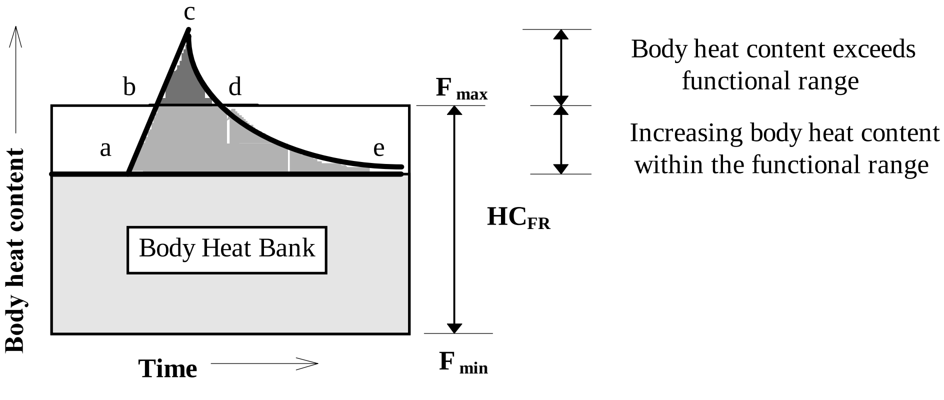


Figure 3.7: Functional Body Heat Content Model. Heat content bounded by 'abde' is within the functional range while the EHL is evident by 'bcd' (Young and Hall, 1996).

This model based on functional heat content encompasses the dynamic interactions between the animal and its thermal environment. The net thermal status, body heat content, is the overall measure. Potential failure zones are identified when body heat content, and hence tissue temperatures, exceed their functional limits.

In natural situations, there are constantly changing thermal conditions, and thermally induced physiological adaptation. Hahn *et al.* (1990) estimated 8 to 10 days of exposure to a new thermal environment were required for an animal to physiologically adapt and reach a new thermodynamic equilibrium. For example, the ingestion of food increases heat production (Adam *et al.*, 1984). Depending on the ration composition and rate of ingestion, the short-term elevation in rate of heat production can be 35% to 70% above the pre-feeding rate. The consumption of large meals can result in a substantial additional heat load on the animal body (see Figure 3.7). The natural coping mechanism is for animals to reduce their DMI in hot conditions and thus the amount of metabolic heat arising from the ingestion of food.

If the level of tissue heat in the heat content hovers near HC_{fx} then only a small increase in heat gain over heat loss will push the body heat content again above HC_{fx}. Animals will function more efficiently if there is 'room to play' with body heat content within HC_{FR}, i.e. the body heat content is away from HC_{fx} and HC_{fn}.

In extreme heat gain situations, the body heat content may rise and remain above the functional maximum HC_{fx}. With the excessive tissue temperatures, the rate of cellular metabolism will accelerate and this will contribute to an even faster accumulation of body heat gain and thus a further rise in tissue temperatures. Uncontrolled, "run-a-way" hypothermia concomitant with the rapid increase in cellular metabolism may occur and if progressed the animal may not be able to cope with the EHL resulting in heat prostration and even death (Young and Hall, 1996).

Rather than define the effect of each individual component causing a change in body heat balance the combined factors and their interactions over time can be grouped as the biophysical environment factors producing increased body heat load, whose net effect is reflected in the animal as a change in body heat content and body temperatures. Thus the philosophy upon which the Body Heat Content Model is based is to recognise the animal itself as the ultimate "instrument" to monitor the net effect of the complexity of environment and animal factors.

In an idealised steady state environment, changes in body heat content will approach zero, and heat gain will equal heat loss (i.e. there is little net variation in the amount of heat present in body tissues) resulting in homeothermy and maintenance of a near constant body temperature (McLean *et al.*, 1982). In reality however, the rate of heat flow through the animal is a dynamic process causing continual fluctuations in body heat content through periodic activity (eg. eating or exercise), diurnal and seasonal cycles (variations in the rate of heat input) and in the ability of the animal to shed heat (Berman and Morag, 1971; Watts *et al.*, 1977; Purwanto, 1991).

Recently, Hall (2000) adapted the Body Heat Content Model to dairy cows in a hot environment, (summarised, Figure 3.8). The adaptation includes various environmental, animal and management factors associated with modifying the rate of heat gain or loss in high producing lactating dairy cows and uses the concept of the Model to describe changes in body heat content. This diagram attempts to illustrate the complexities of physiological control and management decisions required to maintain a cow's body heat content within the optimal $HC_{\mathbf{FR}}$ and the resultant consequences if body heat content exceeds the functional maximum. Time is an essential component when predicting the net effect of any change in body heat content on physiological and productive functions, with age, gestation and thermal adaptability as well as immediate and lag responses by the animal, all having an influence (Hahn, 1989a). Possible factors and interactions causing a tissue heat gain or heat loss are collectively represented by input and output boxes respectively. The "heat gain" and "heat loss" boxes includes various environmental and animal factors (refer Figure 3.2), and the principal influences of heat flow factors, for cattle identified in Figure 3.3. While the work of Hall relates specifically to the high producing dairy cow, a similar sequence of factors is likely to be involved with feedlot beef cattle in hot conditions.

The possible factors inducing a heat load and the biophysical factors controlling heat loss are represented by heat gain and heat loss 'boxes', respectively. The regulation of the rates of heat gain and heat loss by the animal, as well as management, are represented by input and output 'regulators'. As body heat content rises, as depicted by the changes in the body 'heat banks – over time', the animal will increasingly employ behavioural and physiological means to reduce the level of heat in the bank. If the level of body heat exceeds the maximum functional level for an extended period of time, physiological failure will occur (Hall, 2000).

Body heat gain and loss can be actively regulated through environmental, animal and managerial factors. This regulation of body heat content is depicted as 'valves' in Figure 3.8 that can be 'opened or closed' depending on the rates of heat gain and heat loss. The 'regulators', primarily by the animal but also by management practices, attempt to maintain the level of heat content in the body within HC_{FR}.

Thermoregulation by the animal includes increasing physiological processes to shed heat (e.g. increased respiration rate, increased sweating, etc) along with concurrent behavioural modification of the environment (e.g. shade seeking, orientating to the sun or wind, standing or lying) to reduce heat input. Thermal load modification by management can occur through altered diet, change in feeding or activity times, or provision of shade (heat input regulator) or improvement in heat output using, for example, water sprays or fans when appropriate.

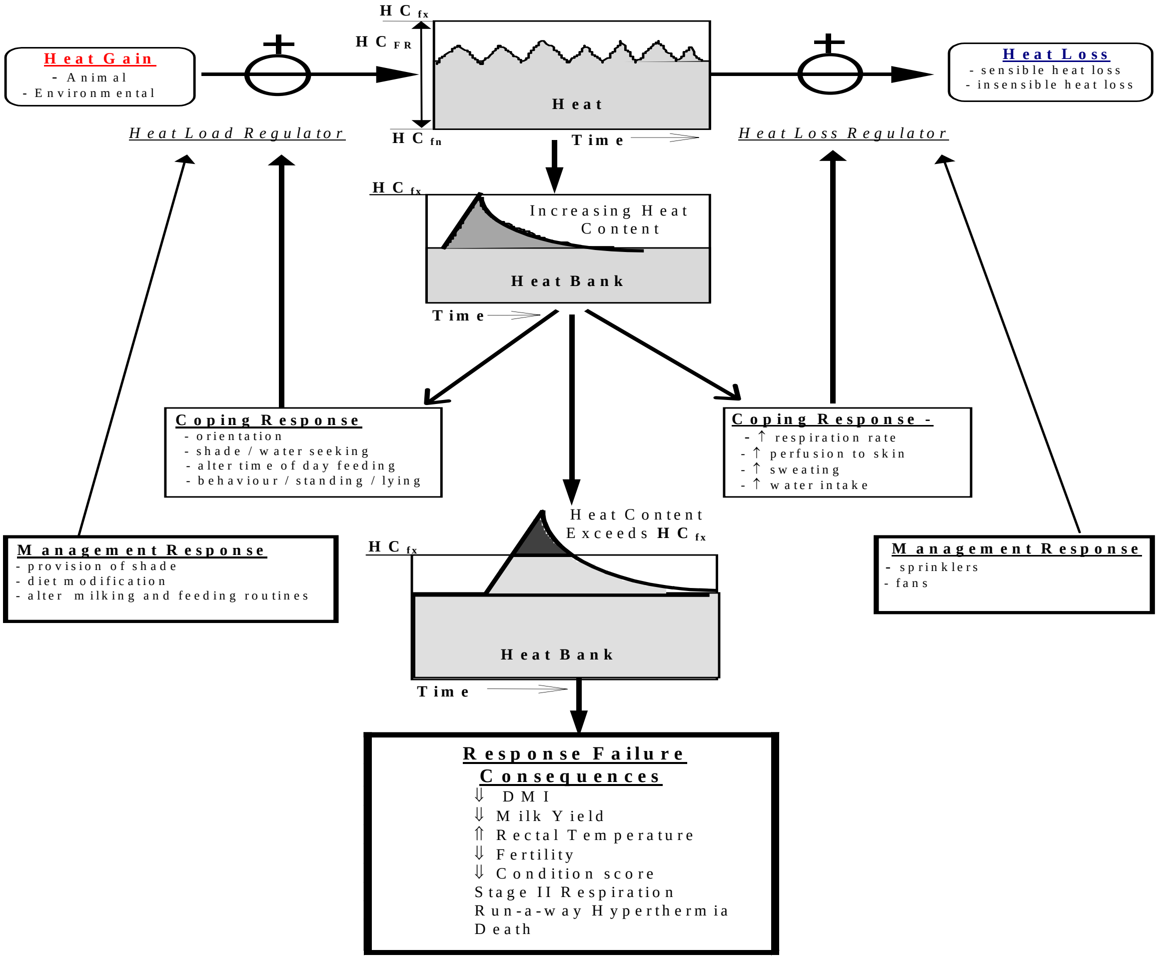


Figure 3.8: Schematic flow chart of increasing heat content in the dairy cow (Hall, 2000).

Environmental, animal and managerial modifications and the ability of animal to physiologically respond may be sufficient for the high producing feedlot animal to contain its body heat content within the HC_{FR} over prolonged periods. However, whenever the body heat content exceeds HC_{fx} there can be physiological failure within the animal. The consequences of this depend on the magnitude of the excursion and length of time HC_{fx} is exceeded. Hahn *et al.* (1999) have developed the concept of an accumulative heat load index, which attempts to take into account the magnitude and duration of thermal load excursions from the acceptable range, see below.

The classical work of Schmidt-Nielsen (1964) showed that camels could have significant diurnal variations in their core body temperature and in body heat content. In desert conditions the camels apparently vary their core body temperature by up to 6ºC between the heat of the day and the cool of the desert night. Similarly, sheep (Slee, 1972) and cattle (McLean *et al*., 1983) have a 2ºC to 3ºC diurnal variation in body temperature when exposed to diurnally varying thermal conditions. The diurnal variations in these animals are associated with mechanisms of physiologically coping. A 6ºC variation in body core temperature represents a diurnal variation of about 10 MJ in a 500 kg camel and sufficient to aid in a daily reduction of over 4 litres evaporative water loss. Furthermore the higher body temperatures aid in the physical transfer of heat out of the animal into the environment, when a positive temperature and radiant exists.

Recently Hahn and co-workers (Scott *et al.*, 1983; Hahn *et al.*, 1999) have built diurnal variation capacity into thermodynamic models and descriptors of the thermal environment, incorporating the influence of time into the Temperature Humidity Index (THI). These measures of the thermal environment are described in 4.1.8.

3.8 Conclusion

There is a more complete understanding of the effects of cold on animals than the effect of heat because of the substantial amount of thermal physiological research done in the cold countries of the northern hemisphere and the fact that cold exposure conditions can be more readily duplicated in a research laboratory than the complexity of interacting factors associated with hot weather and EHL in man and animals. Thus much of the information used to develop the concepts of thermodynamics in animals is based on laboratory experiments where the impact of various single factors of heat transfer were examined while other factors were held constant. While such research work has been essential in understanding the physical basis of body temperature regulation, the simplified reductionist approach has not incorporated the consideration of complex field situations, or much of the thermoregulatory effects of animal behaviour, and dynamic diurnal factors occurring under natural outdoor hot conditions.

Whilst the relationship between metabolic rate and the environmental temperature is a satisfactory model for animals in cold conditions, its application in hot environments is limited. The concepts and model based on body heat content and thermal buffering capacity are likely to be the more appropriate for application to feedlot cattle in hot climates such as in Australia.

4. FACTORS INFLUENCING HEAT LOAD IN CATTLE

The emphasis on interpreting how animals cope in hot environmental situations frequently differs between individuals as a result of a difference in perception. Animal physiologists may view the situation from the stand point of being primarily concerned with the internal bioenergetics of animal functions, engineers from their concern with heat fluxes between the outer surface of the animal and its environment, while feedlot managers from their concern with the welfare of their animals and animal performance.

For animals to cope in hot weather the overall aim is to reduce their rate of heat production or increase their rate of heat loss to achieve thermal balance. Specific feedlot industry case studies and an appreciation of the principles of thermodynamics in livestock highlight the array of possible factors associated with the development of EHL in feedlot cattle. Despite the current body of scientific and practical knowledge, considerable uncertainty still exists as to the inter relationships of thermodynamic factors, and their relative importance. The basic interpretation of physiologists and engineers sometimes differ especially in relation to how to manage heat load in animals. The penultimate interpretation is that of the on-site feedlot manager, with the ultimate reserved for the animals themselves.

4.1 Physical

4.1.1 Introduction

The physical environment is well recognised as being important to the thermal balance of animals (Esmay, 1969; NAS, 1971; McDowell, 1972; Monteith and Mount, 1974; Mount, 1979; Gates, 1980; NRC, 1981; Rosenberg *et al*., 1983; McLean and Tobin, 1987; Monteith and Unsworth, 1990), and the physical laws controlling each of the main routes of heat exchange extensively reviewed.

The Australian feedlot industry is located in areas nearby to significant sources of suitable feedstuffs, in particular in the principal grain growing regions. Individual establishments are also strategically located to achieve regulatory environment management requirements and reasonable access to abattoir facilities. Feedlots are generally open, the cattle exposed to the climatic elements. In the past, possibly insufficient attention has been given to locating and developing feedlots to minimise the possible detrimental impact of adverse and severe climatic conditions. Understandably, this has arisen because there has been insufficient understanding of the critical climatic risk factors to consider when locating and developing a feedlot.

A brief review follows of the major physical environmental factors involved in the transfer of heat (thermal energy) via the processes of conduction, convection, radiation and evaporation, and the measures and calculations that can be used to assess their possible impact on cattle in feedlots. Care is necessary in interpreting the laws governing physical heat exchange as biological systems are seldom ideal and are influenced by the physiology, behaviour and management of the animal. The dynamic nature of an animal's reactions to the environment (reactions such as changing position, redistributing blood, reducing DMI, etc, which the animal uses to aid in the heat coping process) complicate the theoretical heat flow relationships that, in any but controlled steady-state conditions, are very complex.

4.1.2 Physical Heat Transfer

Generally heat flows from warm objects to cooler objects. In an animal system metabolic processes within the animal generate the majority of the heat which is then transferred via the processes of conduction, convection, radiation and evaporation to the environment (Figures 5.1; 5.2; 5.3). A small amount of heat is also transferred in and out of the animal with the ingestion of feed and water, and the voiding of faeces and urine. Additionally, in a hot environment there can be some environmental heat transferred into an animal's body by the physical thermal exchange processes.

Most of the metabolic heat (Refer 3.3) arises in the core of the animal's body and flows with the aid of the blood circulation to the cooler shell and ever-cooler surfaces of the animal. Heat is then transferred to the animal's surroundings when the ambient environment is cooler, as it usually is, than the body's surface. The behavioural and physiological thermoregulatory functions of the animal work towards achieving regulated flows of heat and a near constant core temperature (homeothermy) for animals in fluctuating thermal environments (Bligh, 1973; Schmidt-Nielsen, 1983). In an extremely hot situation, the above thermal gradient and the behavioural and physiological thermoregulatory processes of the animal may be insufficient to dissipate the metabolic heat and thus heat will build up in the body of the animal to cause EHL and hyperthermia (Refer 3.2; 3.3).

The rate of the physical heat transfer from an animal to the surrounding environment is dependent upon the temperature (or vapour pressure) gradient. Conduction, convection and radiation are referred to as the **sensible** heat transfer processes because they involve differences in the temperatures of the materials involved. In contrast, evaporation is referred to as **insensible** heat exchange as it involves latent heat and a change in the kinetic energy of molecular arrangement without a change in material temperature. For example, with the transformation of liquid water to water vapour there is absorption of the latent of heat evaporation. In accord with the law of conservation of energy, "energy cannot be made or destroyed, but it can be changed from one form or location to another". With the transfer of heat, one object loses internal energy and another gains energy. The amount of energy in a system is measured in **joules (J)** while the rate of energy transformation is measured in **watts (W)**.

While the physical heat transfer processes are described separately, it must be recognised that they operate in concert with each other and the behavioural and physiological functions of the animal. The net physical heat gains and losses of an object (the animal) can be grouped into a single net 'heat transfer' equation, with the direction and rate of heat flow dependent on the direction and force of the thermal and vapour pressure gradients between the animal and the environment (Esmay, 1969; Curtis, 1983). The general equation of physical heat exchange can be expressed as:

Net Rate of Physical Heat Transfer (H_E) = $\pm K \pm C \pm R - E$ (Equation 4. 1)

Where, **H_E** is the net heat gained and/or lost by conduction **(K)**, convection **(C)** and radiation **(R)**, and the insensible heat lost to the environment by evaporation of water from the animal's skin and respiratory tract **(E)**.

This physical heat transfer equation excludes the rate of metabolic heat production by the animal, an important biological heat source which is considered elsewhere.

4.1.3 Conduction (K)

Conductive heat transfer is due to the physical contact of the animal with a surface, air or a liquid. The rate of heat flow is dependent upon the area of contact, the thermal conductivities of the materials involved, the distance the heat needs to flow, and the temperature gradient. Animals when standing are mainly in contact with air except for hooves on the ground (about 2% of the body surface area). A lying animal has substantial contact with the ground (25% to

30%) to which there can be substantial conductive heat transfer. Provision of bedding with good thermal insulative properties will reduce the rate of heat transfer.

The flow of heat through matter is down a temperature gradient from particle-to-particle (molecules) and is dependent on the temperature gradient and conductivity or insulative properties of the materials through which the heat flows. For animals the characteristics of surface tissues (subcutaneous fat, blood flow, skin and hair) and the physical characteristics of the microenvironment adjacent to the animal's surface (wetness of the coat and surrounding air, mud impacted in coat, etc) are of importance in determining conductive heat flows to the surface of the animal and to the environment (Esmay, 1969; Curtis, 1983).

The rate of conductive heat flow is expressed by the equation: **Conductive Heat Flow (K) = -k . Ak . (T1 – T2) / L (Equation 4. 2)**

Where, **(K)** is the net conductive heat flow, **–k** is the thermal conductivity of the material through which the heat flows, **Ak** is the effective thermal conductivity contact surface, **(T1 – T2)** is the temperature gradient along which heat flows and **L** is the heat flow path length.

In cattle the net conductive heat exchange depends upon several interacting conditions. Surrounding each animal is a thin boundary layer of air entrapped in the coat and at the surface of the skin (Gebremedhin, 1985). As air is a poor thermal conductor there is relatively minor amounts of conductive heat losses or gains from the boundary layer. However, local eddies of air movement in the hair, over the animal's surface, and/or wind, exchanges air from the boundary layer. Thus through a combination of conduction and convection, substantial heat can be lost from the body surface, (Refer 4.1.4). The disturbance to the boundary layer of air is less the deeper and more dense the hair coat. Of course, water, mud or other contaminants in the coat will destroy its insulative properties and result in increased conductive transfer of heat.

Direct conductive heat exchange occurs if the animal is in contact with a solid surface at a different temperature to the surface of the animal. As indicated above, the transfer of heat is usually minimal in a standing animal surrounded by dry air. The small contact surface via the hooves transfers relatively little heat. However for an animal lying on a surface or partially submerged in water, the conductive heat exchange can be substantial. Thus cattle tend to stand in hot weather to avoid contact with the hot surface of the ground. Similarly, in hot weather animals sometimes stand in water, because water is a better thermal conductor than air, and when the water is cooler than the skin there is a temperature gradient out of the animal, which assists in conductive heat loss. The legs of cattle are well supplied with surface blood vessels and having a relative high surface area are thus effective heat exchangers (Schmidt-Neilsen, 1983; Bligh, 1973).

In Summary:

Normally in the feedlot environment during hot conditions, heat exchange by conduction is probably the least important mode of the physical exchange processes (Esmay, 1969; Gates, 1980). However, in combination with convection, (4.1.4), and in situations where there is water, mud and/or contact with solid surfaces, conductive losses may be substantial.

4.1.4 Convection (C)

The convective transfer of heat is by the movement of heated molecules. This movement of heat occurs by both passive and forced means. In **passive** or natural convection, fluids (air, water, etc) near hot surfaces warm, become less dense and rise in small streams to be replaced laterally or from below by cooler and denser material. In **forced** convection, fluid (air or water) is drawn or pushed past the animal's surface carrying warmed molecules and the thermal energy. Air movement from wind or from a fan is forced convection. Similarly, the circulation of blood through vessels and capillaries by the pumping of the heart, carries warm blood from the core of the animal's body to the extremities and the skin surface. Blood circulation is the major thermal mixing process in an animal's body (Bligh, 1973).

Convection combines with conduction, radiation and evaporation to transfer heat passively across the boundary layer of air surrounding an animal. At the surface of the skin there is a thin layer of relatively still air entrapped on the surface and in the hair (Gebremedhin, 1985). Heat moves from the surface to the boundary layer by conduction, by radiation and evaporation of water. The heating of the boundary layer air is responsible for its reduced density and the development of local eddies (passive convection). The displacement of the air is slow when the air around an animal is calm. Despite the lack of wind the passive convection prevails and is responsible for a small but at times a very important transfer of heat from the animal. Of course, the presence of wind disrupts the boundary layer, reducing its thickness and more rapidly carries air away from the surface of the animal itself thus increasing the convective heat transfer. Similarly, any movement of the animal aids in disruption of the boundary layer and convective heat removal from the surface. In contrast, the depth and density of the hair coat plays a significant role in securing the boundary layer around the animal (Schmidt-Nielsen, 1983). Thus a substantial hair coat is important for conservation of body heat in cold weather but is not necessarily desirable in hot conditions (NRC, 1981; Monteith and Mount, 1974; McDowell's, 1972).

Overall, the rates of convective heat transfer depend upon the surface temperature and area of the animal, properties of the hair coat, air temperature and its heat holding capacity, and the movement of air over the animal's surface (Esmay, 1969). The movement of air is critical for convective heat transfer. It comes from natural wind or forced air movement from fans, and possibly from natural eddies arising near the surface of the animal or other warmed surfaces such as the feedlot pad.

The literature demonstrates an absence of studies into the measurement of passive and/or forced convective air movement in cattle feedlots, as would be predicted from the basic physics of air movement around warmed surfaces.

The heat transfer power of passive convection is relatively small compared with the cooling power of forced convection. However, in calm still-air conditions the cooling achieved via passive convection may be vital to the animal as in calm air conditions an animal has few processes available to rid itself of body heat.

Passive convection and forced convection are considered separately due to their differences. The formulae presented below are somewhat theoretical, but provide a basis for understanding convective heat transfer. As these formulae are not readily applicable to the practical feedlot situation, an alternate approach is presented in subsequent discussion.

The rate of passive convective heat transfer from the surface of an animal has been expressed by the following formulae (Gressman, 1973; Curtis, 1983).

Passive Convective Heat Transfer (C) = Ac. kcs. (Ta – Ts) (Equation 4.3)

Where, **C** is the net rate of passive convective heat exchange, **Ac** is the animal surface effected by passive convection, **kcs** is the convective coefficient, **Ta** is air temperature and **Ts** is the mean temperature of the animal's surface.

The value of the convective coefficient (kcs) in near still air situations is difficult to estimate depending on the properties of the body surface covering, the animal's size, shape and orientation, and the force of any air movement. Theoretical calculations of the effects of free convection on animals are complex, and scientists have used cylinders and spheres to represent the animal's shape to achieve estimates of free convective heat fluxes (Mitchell, 1974; Mitchell, 1976).

The effect of forced air on the rate of transfer of heat via convection has been developed from physical analyses on steady-state inanimate objects, as directly proportional to the square root of air speed and dependent upon the difference between the temperature of the air and the temperature of the animal's surface (Schmidt-Nielsen, 1983; Esmay, 1969; Curtis, 1983). However, there is currently insufficient understanding to give a clear description for cattle in hot conditions, largely because these animals are in a dynamic state, and concurrently utilise a number of different heat transfer processes.

In laboratory analyses Thompson *et al*. (1954) found that the effect of wind velocity (0.4 to 10 mph, or, 0.18 to 4.47 m/sec) on the rate of total body heat loss of cattle, was directly dependent upon the wind velocity and the (gradient) difference between air temperatures and the surface temperature of the animal. At air temperatures near the body surface temperature of their animals, wind velocity had virtually no effect on convective heat transfer. The equation developed by Thompson *et al*. (1954) was:

$$\textbf{Forced Convection Heat Transfer (C)} = 4197 - 1.413\,Ta + 19.35\,v\,.\,(Ts - Ta)$$

(Equation 4.4)

Where, **C** is the forced convective rate of heat exchange (BTU/hr), **Ta** is the air temperature (^{o}F), **Ts** is the surface temperature of the cattle (^{o}F), and **v** is the wind velocity (mph). This equation illustrates that the direction of the convective heat between animals and their environment can be out of or into the animal depending upon whether the air temperature is below or above the surface temperature of the animal (Esmay, 1969).

In the complex and dynamic situation of cattle in a feedlot, convective heat exchange occurs in several forms concurrently with, and interacting with other processes of heat exchange. The precise calculation of the magnitude of each of the components for cattle in practical situations is not currently possible. However, the consequences of convective heat transfer are recognised to be important for the cattle in feedlots. The following illustrate the practical involvement of convective processes.

Calm Air Situations: Passive or natural convection arises from the small movement of air eddies under calm conditions induced by differences in air density associated with its warming. There are two important aspects, namely eddies developed from the warm surface of the animal, and eddies from the heated surface of the feedlot pad.

Eddies that develop at the surface of the animal carry heated and moist air away from the skin of the animal. The hair coat tends to decrease free convection by interfering with free movement of eddies close to the animal. Fortunately, cattle in summer tend to have a short sleek coat that minimises the entrapment of air in the coat (Robertshaw, 1985). Rosenberg *et al*., (1983) have estimated that free convection may account for 30 to 40 W/m^2 of body surface. Thus heat losses of 170 to 230 W occur for a 500 kg animal when there is a temperature difference of 10°C between the animal's surface and the surrounding air. Under calm conditions this relatively small heat flux could be vitally important to the animal.

Eddies also develop from the feedlot pad, and may aid in corrective cooling of cattle. The darkened surface of the feedlot pad can reach high temperatures during summer from direct solar radiation. This heated surface has the potential to generate natural convective air movement and local streaming of air. The warmed air tends to rise to be replaced laterally by cooler air in situations where there is no natural wind. The natural eddies and updrafts from the pad and potential channelling of airflow may provide thermal relief to cattle. Observations of cattle preferring specific within-pen locations may be explained by the small difference in air movement. Feedlot aspect, pad moisture, mounds, fences and other structures in and about the lot, can influence the streaming of the convective air movement. Little is currently understood of the importance of this passive convective air movement within feedlots.

Wind: Forced convection is air movement induced by natural wind, powered fans, and mechanical blowers, etc. During forced convection, the insulative properties of the hair and entrapped air are disrupted, causing an increase in convective heat transfer (Monteith and Unsworth, 1990). As air velocity increases, its theoretical cooling power increases in proportion to the square root of the velocity (Esmay, 1969; Curtis, 1983). Rapid air movement can thus play an important role in the removal of heat from animals. In hot situations, wind has an important cooling effect if the air temperature is at a lower temperature than the surface of the animal and is not fully ladened with water vapour. The movement of cool and low humidity air can achieve important cooling for cattle, while air movement comprising hot and high humidity air provides little thermal relief to cattle in hot situations.

Respiratory Effectiveness: Respiratory convection is particularly important in animals that pant. Through the enhanced ventilation of the upper respiratory tract, the large surface area of the turbinate bones and increased blood supply allow the temperature of inspired air to rapidly adjust to that of the body (Robertshaw, 1985). For panting animals in hot situations the majority of the metabolic heat production is lost via the respiratory tract (Brody, 1945; Esmay, 1969; Schmidt-Neilsen, 1983). This is in contrast to animals that do not normally pant, such as man, where respiratory convection accounts for less than 10% of metabolic heat loss (Mitchell, 1974). (Respiration is considered in detail in 4.2.3).

In Summary:

The potential to move heat into the body, or to remove heat from the body surface by forced convection is appreciable, while, the amount transferred by passive convection can be relatively small. However, passive convection occurs importantly when there is no appreciable wind, and during times when any relief from thermal load, be it small, is important to the animal.

4.1.5 Radiation (R)

Radiant heat transfer arises from the fact that a warm surface will emit heat, via electromagnetic waves, when its temperature is higher than absolute zero (-273ºC). Bodies radiate heat to and from each other, but in practice, we are more interested in the net rate of heat transfer that is dependent upon temperature difference and characteristics of the radiating surfaces. The net transfer of heat is usually from the warmer to the cooler surface.

For animals, the radiant heat transfer is dependent upon the exposed surface area of the animal, and the emissivity and temperature of the surfaces and structures surrounding the animal. Emissivity is the inherent ability of a surface to emit radiant energy waves. The length of the electromagnetic waves is dependent upon surface temperature. Visible light, short waves or **solar** radiation (0.3 to 3 um) originate mainly from the sun that is very hot (>6,000ºC), while the longer waves or **infra-red** radiation (3 to 100 um) originate from bodies at temperatures more usually uncounted on earth (Esmay, 1969; Schmidt-Nielson, 1983).

An animal radiates energy to all surfaces in its surroundings. Likewise, the surrounding surfaces radiate to the animal. Thus the animal is continually emitting and receiving radiant energy. The net radiation transfer is negative for animals in cool environments, but may be positive in situations of direct sun exposure or when the animal is surrounded by hot surfaces, such as, may occur in a feedlot (Schmidt-Nielsen, 1964).

The behaviour and positioning of animals greatly influences the type and amount of net radiation emitted and received by them. Solar radiation intensity is high in areas where there are clear cloudless skies. The incoming solar radiation occurs from sunrise to sunset reaching a peak of about 860 W/m^2 of perpendicular surface to the sun (Esmay, 1969; Finch, 1983). In contrast, infra-red and reflected radiation from hot surfaces and outgoing radiation to the sky, continue both day and night. At night a clear sky has no incoming radiation and is an important radiant heat sink for animals. Night cooling occurs largely from exposure to the clear night sky (Schmidt-Nielsen, 1964).

The theories and equations describing the rates of thermal radiant energy exchange between animals and their environment are too complex to include herein. However, approximations can be achieved using the Stefan-Boltzmann law plus some practical simplifications. Thus for estimating the net radiant heat exchange the following formula can be applied:

Radiant Heat Transfer (R) = Ar. S-B . (a.Te-4 - e.Ts-4) (Equation 4.5)

Where, **R** is the net radiant flux, **Ar** is the effective radiant surface area of the animal, **S-B** is the Stefan-Boltzmann constant, **a** is the absorptivity of the animal's surface (Table 4.1.1), **Te** is the average absolute temperature of the radiant environment, **e** is the average emissivity of the environment exposed to the animal (Table 4.1.1), and **Ts** is the average absolute temperature of the radiant surface of the animal.

Table 4.1.1: Relative absorptivity and emissivity of cattle coats and dark soil feedlot pad surfaces relative to ideal black-body surface values

Surface	Solar Wavelengths	Infra-red Wavelengths
Polished Aluminium	0.26	0.05
New Galvanised Iron	0.80	0.28
Black Cattle Coat	0.90	0.95
Red Cattle Coat	0.80	0.95
White Cattle Coat	0.50	0.95
Dark Soil Dry (feedlot pad)	0.95	0.95
Dark Soil Wet (feedlot pad)	0.95	0.95
Green Grass	0.70	0.95

Colour and reflectivity determine radiation absorptivity and emissivity of short wave or solar radiation. In contrast, all non-polished surfaces mostly behave like “black bodies” and effectively all animal and environmental surfaces have similar values for long-wave infra-red radiation (Table 4.1.1). The sun is effectively a single point source of radiation and the angle of which sunlight hits a surface influences its intensity. The aspect of a feedlot and the time of day affect the amount of incoming solar radiation. At night there is effectively no natural short wave radiation. Visible light from artificial lighting is within the short wave spectrum but its intensity is so low that it can be ignored as a source of radiant heat transfer for cattle.

Dark-coloured cattle have radiation absorptivity values for solar radiation between 0.8 and 0.95 at perpendicular incidence. Radiation intensity drops slowly as the angle of incidence increases to about 75 degrees and then rapidly thereafter. The solar absorptivity of light-coloured cattle is about 0.6 at perpendicular incidence to the sun and at angles of incidence up to 30 degrees before dropping rapidly (Riemerschmid and Elder, 1945; Gates, 1980). Clouds and dust reduce atmospheric transmission of solar radiation. High light cloud (cirrus) reduces insolation by 20%, medium density cloud (cumulus) by 50% while dense cloud (nimbostratus) and fog by 80%. Dust and the distance the irradiation travels through the atmosphere because of the angle of the sun (low latitudes, winter sun and early morning and late afternoon) further reduce solar intensity.

For practical purposes we can consider radiation in the short-wave range to arise only from the sun and thus the effects on cattle in the feedlot can be reasonably estimated from knowledge of the intensity of the sun’s radiation and the orientation of the sun relative to the exposed surfaces of the animals.

The solar radiant exposed surface of cattle is effectively the area of the animal’s shadow when assessed perpendicular to the sun. While this can vary depending upon the orientation of the animal, cattle tend to behave to orientate themselves during times of maximum solar radiation such that they have minimal direct exposure to the sun and therefore their shadow has minimal area. For an average feedlot animal this area is approximately one square meter. This assumption of one square meter is within the error of other assumptions used to estimate the solar radiation inflow to cattle fully exposed to solar radiation.

The effective surface for infra-red radiation exposure is considerably greater than for solar exposure because the infra-red radiation is not coming from a single source (the sun) but from the complete surroundings of the animal. The situation is however made more complex because out going radiation from the animal is transmitted in all directions while the incoming infra-red radiation for an animal in an open feedlot is mainly from the ground and surrounding solid structures. There is some from dust particles and clouds in the atmosphere but little from a clear sky.

The outgoing infra-red radiation surface from an animal can be assumed to be near equivalent to the total surface area of the animal, while that for the incoming radiation is effectively equivalent to the lower two-thirds of the animal’s surface when the animal is standing in an open pen. A roof, or structure over an animal, blocks exposure to the sky and its temperature becomes a part of the infra-red radiant surroundings for the animal. Likewise, when animals crowd around each other, some of the radiant surface adjoins that of adjacent animals. As adjacent animals would likely have similar surface temperatures, the net exchange of radiant heat between animal surfaces would tend to be neutral. If the animals were in a situation of net loss of radiant heat, heat from close-by animals could cancel effective out flow to cool surroundings. However, in a situation of very hot surroundings where there is a net inflow of radiant energy, adjacent animals could protect each other from high infra-red radiant loads. It is probable animals respond to a degree to high infra-red radiant loads from the environment by crowding together.

The calculation of the net infra-red radiant flux in feedlot cattle is very complex and justifies simplification for practical interpretation. For cattle standing in an open feedlot, infra-red radiant flux can be considered to be in two parts, namely the lower two-thirds of the animal being exposed to the ground, surface structures and nearby animals and, the upper one third of the animal exposed to the sky. A clear sky has, for practical purposes, no direct long-wave incoming radiation but there is a small amount of scattered and reflected radiation from clouds and dust particles in the atmosphere.

During daytime when there is substantial solar radiation the feedlot pad and structures absorb solar irradiation, become hot, and are a major source of infra-red radiation. The surface of the pad and structures in feedlot can reach 60ºC to 80ºC in situations of direct high solar radiation but these surfaces cool rapidly once the sun sets (Gaughan, unpublished). The surface of the pad and other surfaces in the lot can also be effectively cooled by spraying with water and the evaporation of moisture when atmospheric conditions are suitable. Despite the clear importance of irradiation temperatures to which feedlot cattle are exposed there is very little research information available to provide reasonable practical estimates of the effects in feedlots.

In Summary:

Solar radiation is a significant source of incoming radiation heat for exposed animals in particular during the middle of the day. The relative temperature of surfaces especially the relationship between the animal surface and that of the feedlot pad are likely to be important for cattle trying to balance their heat content during periods of hot weather. Additionally, infra-red radiation can be responsible for either a net influx or outflow of radiant heat. A clear night sky (i.e. excluding the sun) is not a source of radiation but an important heat sink, and critical to the cooling of the animal following days of high heat load.

4.1.6 Evaporation (E)

Feedlot cattle depend greatly on their ability to vaporise moisture and generate heat loss. Evaporation of water occurs from the animal’s wet respiratory tract and skin surfaces and, on occasions, from the feedlot pad. The surfaces of the upper respiratory tract of cattle are well equipped with mechanisms for secreting moisture and have large surface areas well supplied with blood vessels to allow for efficient evaporative cooling of air as it passes through the upper respiratory tract during breathing and rapid panting (Brody, 1945; Blaxter and Wainman, 1961). Moisture on the animal’s skin surface can be from sweat glands, sprinklers or rain, etc.

Evaporation of water from the body of cattle is about 40 to 60 ml/h/m^2 during periods of cool weather but increases rapidly as conditions get warmer owing to increases in respiratory rate and sweating (Brody, 1945). In hot situations, cattle with high respiratory frequencies have been measured to evaporate over 200 ml/h/m^2 which when converted to an equivalent rate of heat transfer from the animal’s body, is more than the animal’s immediate rate of metabolic heat production (Brody, 1945; Esmay, 1969).

Rates of evaporative heat loss from surfaces are dependent, so far as environmental factors are concerned, on air temperature and humidity (thus capacity of the ambient air to take on water vapour), and the movement of the air which exchanges the air laden with moisture with adjacent air containing less moisture. Rapid breathing (high respiratory rate) is the mechanism whereby cattle ensure the movement of a large volume of air over the moistened surfaces of the upper respiratory tract (Brody, 1945; Blaxter and Waiman, 1961).

The latent (or insensible) heat is exchanged when a material changes its state of molecular aggregation without a change in temperature (Esmay, 1969). The evaporation of water, whether by respiration, sweating, or from the feedlot pad, requires heat energy (the latent heat of vaporisation) and a diffusion gradient (Stanier *et al*., 1984). If there is a steep vapour pressure gradient across the air boundary layer from the respiratory tract or moist skin to the atmosphere, evaporative cooling can be very effective. Climate laboratory studies have shown that cattle and sheep when panting can lose most of their total body heat outflow via evaporative mechanism (Kibler and Brody, 1952; Blaxter *et al.,* 1959; Blaxter and Wainman, 1961). If, however, there is a high relative humidity, there is little or no evaporative capacity even if heat energy is available. Evaporation decreases with increasing relative humidity of air at constant temperature but increases with increasing air temperature at a constant relative humidity (Esmay, 1969).

In warm very humid conditions, as the air approaches temperatures near to that of the skin, skin evaporative cooling tends to be limited (Schmidt-Nielsen, 1983; Blaxter *et al*., 1958; Blaxter and Wainman, 1961). However, respiratory cooling may still be effective because the temperature of the inhaled respiratory air is warmed further to body core temperature and can still take on more water vapour. Of course, the temperature of the inspired air can only be raised to body core temperature and saturated with water vapour at that temperature. If the air being inhaled is already near to core temperature and near saturation the scope for respiratory cooling is limited (Esmay, 1969).

Estimates of the amount of heat an animal can lose as a consequence of moisture evaporation can be best made from the heat needed to raise the temperature of water to 100ºC plus the latent heat of evaporation of water (2260 J/g water). It should be noted that part of the heat used in vaporising moisture at the animal surfaces comes from the environment, and the above calculation may slightly over estimate the actual amount of heat drawn from the animal during the evaporation process. To adjust for this overestimation consideration is often given only to the amount of water evaporated and its latent heat of vaporisation. Thus the simplified evaporation heat transfer formula becomes:

Evaporative Heat Transfer (E) = Mw . L (Equation 4.6)

Where, **E** is the heat lost from the animal via evaporation, **Mw** is the mass of water evaporated and **L** is the latent heat of evaporation of water.

Applying this equation it can be estimated that cattle of 500kg in a hot environment, evaporating moisture at a rate of 200 g/h/m2, lose body heat at a rate of over 700 watts from evaporation alone (Esmay, 1969; Blaxter and Wainman, 1964).

4.1.7 The Practical Physical Environmental Factors

Most information on the effects of the physical environment on animals has been obtained from research studies on single or small groups of animals in controlled climate research facilities. These studies provide a basic framework for our understanding of rates of heat exchange between animals and their environment. Laboratory facilities however, have been unable to replicate the entire range of variables and the dynamic changes that occur in natural commercial feedlot situations. It is difficult, and even at times somewhat misleading, to extrapolate directly from controlled biophysical studies made on animals in constrained laboratory situations to the practical field situations such as in a commercial feedlot. The situation is made even more complex by the behaviour and physiological responses of the animals themselves, and the constraints and changes made in housing and management of the cattle.

Under practical situations there is considerable difficulty in applying the laws of physical heat transfer as each of the modes of heat transfer operate concurrently and modify the effectiveness of each other. For example, one of the main driving forces for physical heat exchange processes is the temperature gradient between the animal's surface and the environment. As a consequence of evaporation of moisture from sweat glands, the temperature at surface of the skin is reduced with a direct consequence on radiant heat transfer. Animal physiological and behavioural responses are dynamic and result in changes in the position and orientation of the animal, surface blood flow, respiration rate, food intake, etc., and thus further complicate any attempt to apply the laws of thermodynamics as they affect cattle in a feedlot. Furthermore, cattle have a large mass and therefore have substantial thermal buffering capacity. A change in the thermodynamics of heat flow of say an imbalance of 100 watts into an animal for one hour, would result in a shift of 360 kJ in the stored heat in an animal of 500 kg and a rise in mean body temperature of only 0.2ºC. This reflects the substantial thermal buffering capacity of cattle and provides practical protection to the animals against short-term fluctuations in rates of heat gain or loss. Despite these complications and difficulties, understanding the physical heat exchange principles is important to the care and management of Australian feedlot cattle during the summer.

The following are some examples from the literature of interactions of physical heat exchange process influencing the thermodynamic responses of animals.

Air Movement: Free and forced convection generally occur together in natural environments with their influence changing with variations in wind velocity and direction, as well as with animal movement. Turbulence, created by surface irregularities in animal shape and temperature, and the characteristics of the land form and structures around the animal, will further add to the variability of convective heat transfer. The animal may behave to orientate itself to maximise wind over body in order to enhance the rate of heat loss. Wind affects the boundary layer resistance according to the inverse square root of the wind velocity striking the exposed surface of the animal (Gates, 1980). As long as the air temperature is lower than the surface temperature of an animal, increasing air velocity should increase convective heat loss, but the natural environment is complicated because any lowering of surface temperature by increased convection will concurrently decrease radiant and perhaps evaporative heat loss (Morrison, 1972).

Solar Radiation: Diurnally sunshine is not constant. Cloud cover and the dust content of the atmosphere vary; animals may seek shade, and there are differences due to breed and coat characteristics. All influence the solar radiant heat load reaching an animal. Surface solar reflectivity is strongly dependent on coat colour with darker coats having a reflectivity of 10% and lighter coats up to 60%. In assessing the impact of radiant heat on an animal's incoming heat load, Stewart and Brody, (1954), used increasing levels of artificial radiation from radiant heaters to mimic solar radiant loads and found they were not able to even reach typical levels of short wave radiation seen outdoors in the summer. This was because the short wave radiation from the sun comes from a body at 6,000°C while no man made radiator can be maintained at this temperature. Finch *et al*. (1980) investigated the interaction between solar radiation and coat colour in goats with their long axis to the sun, and later

Finch (1983) argued that, to mimic an outdoor air temperature of 30°C with solar radiation, a climate chamber would need to be set up to about 50°C to account for potential heat load from solar radiation. Practical difficulties clearly arise when trying to expose test animals to 50°C.

Dynamic Physiology of Animals: In cattle under defined controlled climatic room conditions, sensible heat loss mechanisms decline with increasing ambient temperature and reach a zero net effect at air temperatures of about 40°C (Esmay, 1969; Kibler and Brody, 1950; McLean and Calvert, 1972; Webster, 1983). The situation is further complicated when there is variation in the level of relative humidity as would be seen in normal outside diurnal variations. In steers held at 15°C where the level of relative humidity is increased from 62% to 92%, the heat loss from the animal is predominantly through sensible transfer, approximately 350 W compared to 85 W via by respiratory evaporation. These values are also relatively constant over the range of relative humidities. However, at an air temperature of 35°C as relative humidity increases from 32% to 72%, the rate of heat loss by respiratory evaporation by way of increased respiratory frequency, increases to be three times more than the sensible heat. The evaporative loss declines as RH % increases, from approximately 400 W to 320 W (McLean and Calvert, 1972).

In Summary:

The section has set out to document the basic physical principles determining the rates of heat transfer into and out of feedlot animals during summer. This exercise illustrates that the physical heat exchange laws are subject to many complications during application to feedlot cattle in situations of high heat load. The over riding importance of the rate of metabolic heat production as the primary source of body heat, and evaporation of moisture as the primary route of heat loss during hot conditions, will become further evident in a later section. Despite the pre-dominance of these two factors, an understanding of the physical processes of heat exchange is important to the management of EHL.

4.1.8 Measurements and Indices of the Physical Environment

There are standard meteorological procedures to measure the physical environment (air temperature, humidity, radiant energy and wind speed) normally applied by meteorological services at selected locations, and by private operations recording at on-site locations. Whilst these are reasonable assessments of conditions in a region or at a site, they are not always directly equivalent to the micro-environment to which feedlot animals are exposed in the pen.

The actual feedlot pen micro-environment, as the animal experiences it, can vary significantly from measurements made outside the pen, at the nearest meteorological station or feedlot weather station.

The feedlot pen micro-environment conditions are not well documented, and require further clarification. Whilst air temperature measurements from outside the pen may be reasonably reliable measures of those within the pen, the relative humidity, air movement (especially in situations of low natural wind conditions) and long-wave (infra-red) radiation components of the pen micro-environment may differ greatly, not only with that outside the pen, but between pens and within pens.

(a) Standard Meteorological Measurements

Standard meteorological measurements include the following:

Air Temperature, Dry Bulb Temperature, Ambient Temperature (°C). Air temperature expresses the hotness of the thermal environment. It is however, not the only factor determining the heat load on animals and in fact to rely solely on measures of air temperature could be misleading (Mount, 1979; Yamamoto and Mundia, 1996).

Air temperature is a measure of the temperature of the air-vapour mixture registered on a thermometer, while dry bulb temperature is independent of the air's moisture content (Curtis, 1983; NAS, 1971).

The term ambient temperature (Ta), is the temperature immediately surrounding and impinging on the animal, and for practical interpretation is synonymous with air temperature.

Wet Bulb Temperature (°C). The temperature of moist air is measured by a thermometer evaporatively cooled by contact with a water wetted wick. The difference between wet and dry bulb temperatures provides for the estimation of relative humidity. Likewise dew-point temperature, the temperature of the air below which moisture precipitates from the air, is also used to estimate air relative humidity.

Relative Humidity (%). Relative humidity (RH) is the ratio of the pressure of water vapour present in air to the pressure of water vapour in saturated air at the same temperature, in percentage units. A value of 100% relative humidity means that the air at that temperature cannot absorb any more water vapour, i.e. it is saturated. If the temperature of the air rises, then its relative humidity will fall, and it can then take up additional moisture. If however, the temperature of moisture saturated air falls then moisture will condense out of the air and form water droplets.

The amount of water vapour that can be taken up by air is critical for evaporative cooling by animals.

Wind Velocity (m/sec, km/h). Air movement, wind velocity, or wind speed are all simply the rate of movement of air at a particular point.

Air movement influences convective heat loss from animals.

Solar Radiation (W/m^2). For practical purposes solar (short-wave) radiation can be considered as that radiation arising entirely from the sun. Solar radiation is highly dependent on the time of day, and the angle of incidence of the sun (Curtis, 1983; Esmay, 1969).

(b) Integrated Measures of the Thermal Environment

There have been several approaches to estimate the combined thermal effects of components of the physical environment on man and animals, namely:

(i) The summation of the various heat transfer components to obtain estimates of the net effect of the thermal environment on the heat balance of the animal (refer 5.0).

(ii) The development of **instrumentation** that combines the effects of two or more meteorological measures to give an estimate of a potential thermal effect on an animal.

(iii) Combining the meteorological measures into equations and weighting them (in a **Heat Load Index**) to provide estimates of likely animal response.

To date none of the presently available instruments or derived equations take into account all of the possible biometerological factors. Difficulties also arise because of differences between animal species and their thermal tolerance. Present systems are sufficient to, at best, characterize environments with respect to the major effects on heat transfer.

Some examples of (ii) **Instrumentation**, above, follow:

Black Globe Temperature (BGT). This is a simple instrument that integrates the influences of air temperature, radiation, and air movement. The instrument consists of a temperature sensor in the centre of a black globe of about 250 mm in diameter. The globe of 1 mm thick copper or aluminium is hollow and air filled (Bedford and Warner, 1934).

Thermal Load Monitor (TLM). This is a development from the BGT but involves maintaining a solid aluminium globe at a constant temperature and measuring the needed heat flux into or out of the globe to maintain the globe at the constant temperature (Gaughan *et al*., 1997b).

The TLM was designed to integrate meteorological parameters to simulate as closely as possible the thermal reactions of an animal with a near-constant internal temperature. The primary sensory unit of the TLM, a blackened solid aluminium sphere (250 mm diameter), is maintained at a constant 40°C by controlled additions and subtractions of heat via a heat flow tube. The instrument continually monitors the heat flux (W) entering or leaving the primary sensor and records these data along with standard meteorological information. The heat flow from the primary sensor needed to maintain the sensor at a constant temperature is a reflection of heat load. This load is a consequence of the interaction of air temperature, short and long wave radiation, and air movement. In its present form the instrument is however insensitive to humidity. Further development work is needed to incorporate a humidity component into the TLM to make it more ‘animal-like’ in its sensitivity to hot weather situations.

The TLM has potential for incorporation in feedlot pens and could provide an indication of the actual heat load to which cattle were being subjected at any particular time.

Kata Thermometer. This measures the rate of heat loss from a polished surface at near animal body temperature (McConnell and Yagloglou, 1924). The instrument is a silvered bulb “alcohol in glass” thermometer with a scale calibrated to measure the rate of cooling of the bulb. The thermometer is heated above body temperature by immersion in warm water and, after drying, is allowed to cool in the environment to be tested.

The rate of cooling from 37.5°C to 25°C is then timed to obtain an estimate of the cooling power of the environment (NAS, 1971).

With respect (iii) above, a calculated **Heat Load Index** combining the meteorological measures, there has been considerable scientific effort to develop indices mathematically representing the physical environment (air temperature, humidity, radiation, wind speed) in terms of one or more measurable physiological or animal production response.

A number of derived indices exist but not one alone is suitable for all species or types of animal. Some are here mentioned:

Wet-Bulb Globe Thermometer Index (WBGT). The WBGT index was developed to express the relative environmental heat load of exercising humans (Yoghou and Minard, 1957).

$$\mathbf{WBGT = 0.7wb + 0.2GT + db \text{ (Equation 4.7)}}$$

Where **wb** is wet bulb temperature (°C), **GT** is the Black Globe temperature, and, **db** is the dry bulb temperature.

Temperature-Humidity Index (THI). THI is an empirically determined index weighting dry bulb and wet bulb or dew point temperatures for comparison with animal performance. This index arose from an earlier “Discomfort Index” for humans (Thom, 1959). Kibler (1964) adapted Thom’s measurements to develop the Temperature-Humidity Index (THI) for evaluating the combined effects of air temperature and humidity on the DMI and milk yield of dairy cows.

While the THI index is widely used in livestock industries, its origin is from research on dairy cows to estimate the effect of hot and humid environments on milk production, and, as yet, has not been fully evaluated for use with feedlot cattle with regard to beef production or animal survival. Various weightings for the temperature and humidly values are reported in the literature (Finlay, 1958; NAS, 1971; Baeta, 1985; Hahn, 1994; Hahn & Mader, 1997).

The relative weighting of wet and dry bulb temperatures in assessing thermal loads on different species, illustrating the relative importance of wet and dry bulb in creating thermal strain are summarised in Table 4.1.2.

The concept of the THI is to have a mechanism able to express the combined effect of air temperature and humidity in a single figure, enabling the construction of chart lines of equal effect on psychometric charts.

Table 4.1.2 Relative weighting of wet and dry bulb temperature used to derive THI equations (after NAS, 1971).

Species	**Weighting Factor %**		**Wet/Dry**
	Wet Bulb	**Dry Bulb**	**Ratio**
Man	85	15	5.7
Dairy Cattle	65	35	1.9
Young Pig	35	65	0.5

Source: After NAS, (1971)

Kiblers (1964) THI equation, developed for dairy cattle, is:

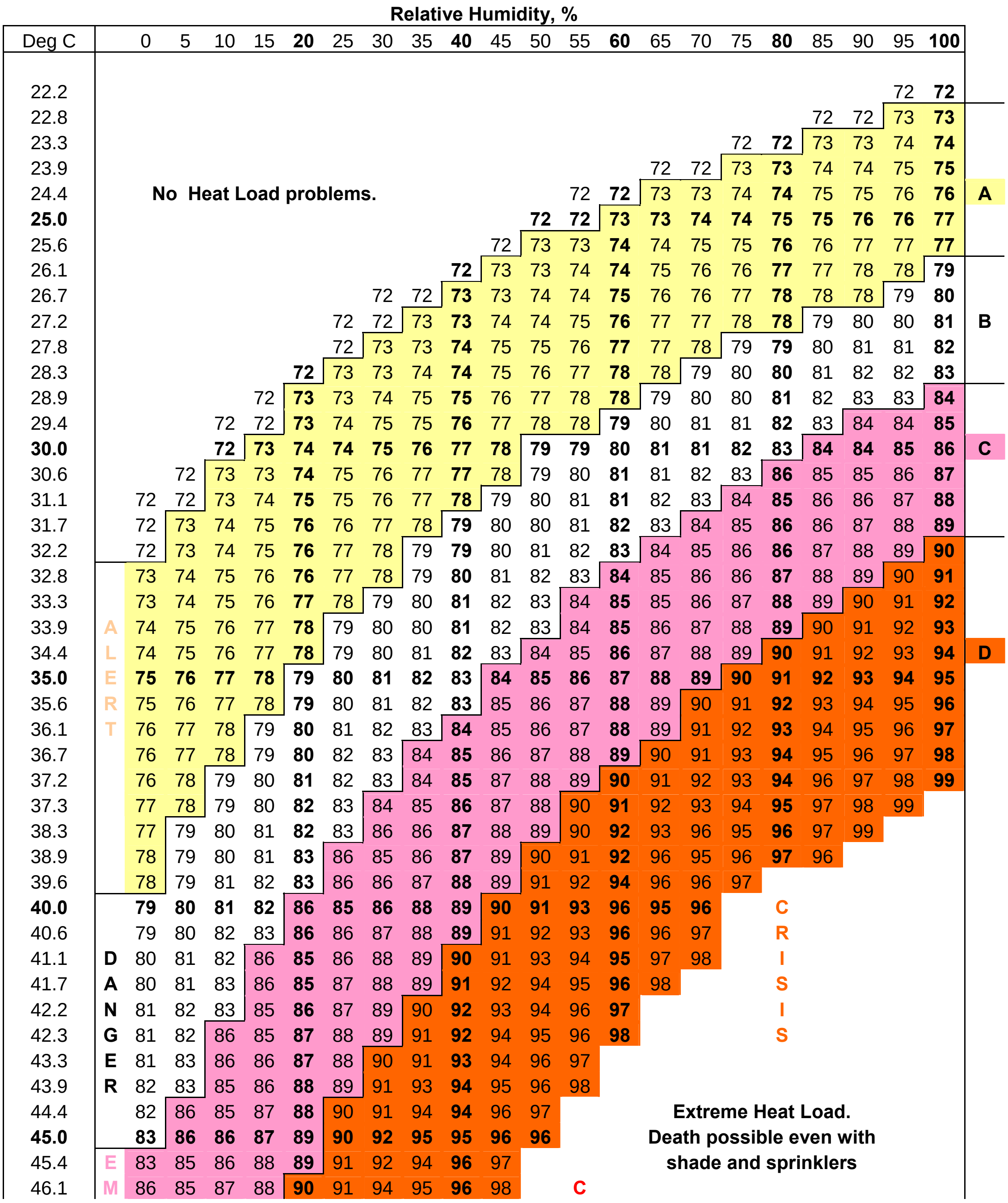
$$\mathbf{THI = db + 0.36\ dp\ 41.2 \text{ (Equation 4.8)}}$$

Where db is dry bulb temperature, and dp is dew point.

Research from the University of Missouri (Johnson *et al*., 1963; Kibler, 1964; Hahn & McQuigg, 1976) showed that there were reductions in the milk yield of dairy cattle related to increasing THI. Lactating cows had little discomfort at THI <70, but feed intake and milk yield were depressed at THI >75. Cattle of most types showed measurable discomfort at THI > 78 and discomfort became more severe as THI values further increased.

Whilst it is still uncertain which single set of weighting factors is suitable to construct a meaningful THI for beef cattle of various ages, weights, and levels of production Hahn (1994) has further adapted the THI to represent the environment as a basis to provide warning or alert signals for safe or hazardous conditions for confined livestock (Table 4.1.3).

Table 4.1.3: Temperature-Humidity Index Values



		Relative Humidity, %																					
Deg C		0	5	10	15	**20**	25	30	35	**40**	45	50	55	**60**	65	70	75	**80**	85	90	95	**100**	
22.2																					72	72	
22.8																			72	72	73	73	
23.3																	72	72	73	73	74	74	
23.9															72	72	73	73	74	74	75	75	
24.4			**No Heat Load problems.**										72	72	73	73	74	74	75	75	76	76	**A**
25.0												72	72	73	73	74	74	75	75	76	76	77	
25.6											72	73	73	74	74	75	75	76	76	77	77	77	
26.1										72	73	73	74	74	75	76	76	77	77	78	78	79	
26.7								72	72	73	73	74	74	75	76	76	77	78	78	78	79	80	
27.2							72	72	73	73	74	74	75	76	77	77	78	78	79	80	80	81	**B**
27.8							72	73	73	74	75	75	76	77	77	78	79	79	80	81	81	82	
28.3						72	73	73	74	74	75	76	77	78	78	79	80	80	81	82	82	83	
28.9					72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	83	83	84	
29.4				72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85	
30.0				72	73	74	74	75	76	77	78	79	79	80	81	81	82	83	84	84	85	86	**C**
30.6			72	73	73	74	75	76	77	77	78	79	80	81	81	82	83	86	85	85	86	87	
31.1		72	72	73	74	75	75	76	77	78	79	80	81	81	82	83	84	85	86	86	87	88	
31.7		72	73	74	75	76	76	77	78	79	80	80	81	82	83	84	85	86	86	87	88	89	
32.2		72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90	
32.8		73	74	75	76	76	77	78	79	80	81	82	83	84	85	86	86	87	88	89	90	91	
33.3		73	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90	91	92	
33.9	A	74	75	76	77	78	79	80	80	81	82	83	84	85	86	87	88	89	90	91	92	93	
34.4	L	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	**D**
35.0	E	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	
35.6	R	75	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94	95	96	
36.1	T	76	77	78	79	80	81	82	83	84	85	86	87	88	89	91	92	93	94	95	96	97	
36.7		76	77	78	79	80	82	83	84	85	86	87	88	89	90	91	93	94	95	96	97	98	
37.2		76	78	79	80	81	82	83	84	85	87	88	89	90	91	92	93	94	96	97	98	99	
37.3		77	78	79	80	82	83	84	85	86	87	88	90	91	92	93	94	95	97	98	99		
38.3		77	79	80	81	82	83	86	86	87	88	89	90	92	93	96	95	96	97	99			
38.9		78	79	80	81	83	86	85	86	87	89	90	91	92	96	95	96	97	96				
39.6		78	79	81	82	83	86	86	87	88	89	91	92	94	96	96	97						
40.0		79	80	81	82	86	85	86	88	89	90	91	93	96	95	96		C					
40.6		79	80	82	83	86	86	87	88	89	91	92	93	96	96	97		R					
41.1	D	80	81	82	86	85	86	88	89	90	91	93	94	95	97	98		I					
41.7	A	80	81	83	86	85	87	88	89	91	92	94	95	96	98			S					
42.2	N	81	82	83	85	86	87	89	90	92	93	94	96	97				I					
42.3	G	81	82	86	85	87	88	89	91	92	94	95	96	98				S					
43.3	E	81	83	86	86	87	88	90	91	93	94	96	97										
43.9	R	82	83	85	86	88	89	91	93	94	95	96	98										
44.4		82	86	85	87	88	90	91	94	94	96	97						**Extreme Heat Load.**					
45.0		83	86	86	87	89	90	92	95	95	96	96						**Death possible even with**					
45.4	E	83	85	86	88	89	91	92	94	96	97							**shade and sprinklers**					
46.1	M	86	85	87	88	90	91	94	95	96	98		C										

Table 4.1.3: Temperature-Humidity Index Values

Relative Humidity, %

Deg C		0	5	10	15	**20**	25	30	35	**40**	45	50	55	**60**	65	70	75	**80**	85	90	95	**100**
46.7	E	86	86	87	89	**90**	92	94	95	**97**			**R**									
47.2	R	85	86	88	89	**91**	93	94	96	**98**			**I**									
47.3	G	85	87	88	90	**92**	93	95	97				**S**									
48.3	E	85	87	89	90	**92**	94	96	97				**I**									
48.9	N	86	88	89	91	**93**	94	96	98				**S**									
49.4	C	86	88	90	92	**93**	95	97														
	Y																					

A Alert phase – mild heat load effects especially on vulnerable cattle. Time to think about and implement heat load reduction strategies. Death not likely.

B Danger phase – strong to severe heat load effects on cattle. Death unlikely but possible. Sprinklers should be used judiciously at this time.

C Emergency phase – severe to extreme heat load effects on cattle. Death possible in vulnerable cattle without access to shade or sprinklers.

D Crisis phase – extreme heat load (EHL). Death possible even with shade and sprinklers.

NOTE: Use THI in conjunction with observing the cattle. The THI must be used in conjunction with observing the animal and other factors (eg. wind speed). For example, use the animal to gauge the severity of the heat load. If the RR is high (above 80 bpm) even under mild ambient conditions, there could be a heat load problem. Conversely there may be times when the THI is high, but because of high wind speed or low solar radiation, heat load effects will be reduced.

THI-hour. THI-hour is an adaptation of THI incorporating a time dimension. This is achieved by assessing the amount of time (h) the THI exceeds a threshold index (Hahn *et al*., 1999). The selected threshold value is selected on the basis of animal vulnerability to EHL. Usually three threshold indices are used, these are a THI of 73, 79 and 84. These values are the lower THI values for the alert, danger and emergency categories of the THI chart. THI hours is calculated by the following equation:

$$\textbf{Daily THI hours} = \Sigma\ (\textbf{THI} - \textbf{base})\ \textbf{(Equation 4.9)}$$

The accumulated THI hours without relief from heat load, indicates the severity of the thermal strain on the animal. An accumulated 15-20 THI hours or more per day above a threshold of 84 for two or three days is likely to cause death in vulnerable cattle.

The recovery time is also important, and so THI hours below a recovery threshold should also be calculated. The best recovery is obtained when THI is below 70 for at least 6 hours. Recovery time is calculated by the following equation:

$$\textbf{Daily THI hours} = \Sigma\ (70 - \textbf{THI})\ \textbf{(Equation 4.10)}$$

An example illustrates the application of THI-hour in a feedlot context (Table 4.1.4).

Table 4.1.4: Example, illustrating the application of THI-hour principles for 24 hours.

Time	Recorded THI	**Accumulative THI Hours** (THI hours above threshold) 73	79	84	**Accumulative Recovery Hours** (THI hours below THI threshold) 74	72	70
800	74	1			4	8	
900	78	6					
1000	80	13	1				
1100	84	24	6				
1200	88	30	15	4			
1300	87	44	23	7			
1400	89	60	33	12			
1500	90	77	44	18			
1600	85	89	50	19			
1700	83	99	54				
1800	80	106	55				
1900	79	112					
2000	79	118					
2100	78	123					
2200	76	126					
2300	72				6	8	
2400	70				10	10	
100	68				16	14	2
200	68				22	18	4
300	70				26	20	
400	74				26	20	
500	72				28	20	
600	73				29	20	
700	75						
Total THI Hours		**126**	**55**	**19**	**29**	**20**	**4**

In this example, steers are spending 126 THI hours above a THI threshold of 73, and 19 THI hours above a THI threshold of 84. Recovery hours below 70 THI, are limited (4 hours). Therefore we would assume that these animals are at risk, especially if the next day comes in hot.

The THI-hour concept with further development locally has potential for evaluating heat load situations in Australian feedlots. The threshold values, the accumulated index values, and the effect of relief times when index values are below the threshold value, need local determination.

THI-hours are calculated by subtracting the base THI from the hourly THI, and then adding the previous THI-hour. For example, from table 4.1.4 the THI at 800h is 74, therefore THI-hour = 1 (74-73). At 0900h THI is 78, so THI-hour = the THI hour at 0800h (i.e. 1) plus the THI hour at 0900h which is 78 – 73 = 5. The 1 and the 5 are added giving an answer of 6. At 1000h, THI = 80 therefore THI-hours = 6 + (80 – 73) = 13, and so on.

Effective Environment or Temperature. The effective environment measurements attempt to represent the physiological consequences of an environment by a single number, although calculated from two or more meteorological parameters measured separately. Several of these composites have been derived (NAS, 1971), but as yet have not found application in the beef industry.

Wet Globe Temperature Index (WGTI). The WGTI (Lee, 1980; ASHRAE, 1993) combines Wet Bulb with Black Globe Temperatures to effectively account for long wave infra-red radiant heat transfer and dry bulb temperature:

$$\mathrm{WGTI} = 0.7\ \mathrm{wb} + 0.2\ \mathrm{BGT} + 0.1\ \mathrm{db} \quad \text{(Equation 4.11)}$$

Black Globe Humidity Index (BGHI). The BGHI was developed (Buffington *et al*., 1981) substituting the Black Globe Temperature for Dry Bulb Temperature in the THI formula, in an attempt to integrate dry bulb temperature, relative humidity, net radiation and wind movement into a single value:

$$\mathrm{BGHI} = \mathrm{GT}+(0.36\ \mathrm{wb}) + 41.5 \quad \text{(Equation 4.12)}$$

In Conclusion:

While a number of bioclimatic instruments and calculation procedures have been developed to record and to estimate the effective thermal load on animals, few as yet have been specifically developed for beef cattle.

The principle of determining THI and THI-hours may however, even at its current state of development, be used to commercial advantage at the feedlot to indicate the ongoing severity of heat load on cattle, and as a guide to management response. Further development will improve its efficiency.

4.2 Animal

4.2.1 Introduction

Environmental factors are constraints on efficient intensive livestock production. Adverse environmental conditions directly affect animal performance, health, and well-being, to the extent that in the extreme animals may not be able to cope or compensate (Hahn *et al*., 1998).

When evaluating an animal's response to heat load all of the contributing factors need to be considered. Some are external to the animal (e.g. ambient temperature, relative humidity) and are the primary measures of heat load. Others are internal factors, such as the quality and quantity of feed consumed, and its digestion which also contribute to the heat load on the animal, by producing metabolic heat.

Predicting an animal's response to heat load, or for that matter what makes up heat load is difficult. The factors which contribute to a heat load are complex. The understanding of their interactions is important. For example a situation where there is high temperature coupled with high humidity but no wind, will induce a different response in cattle exposed to the same conditions with wind.

DMI and feeding patterns, genotype, method of housing, previous history of exposure to hot conditions, health status and coat colour, all contribute in varying degrees to an animal's heat load. The animal is the best indicator of the severity of heat load. Its physiological and behavioural responses are best used to determine the severity of its effect.

Cattle are remarkable in their ability to mobilize coping mechanisms when challenged by environmental stressors. Within limits, they are able to adjust physiologically, behaviourally, and immunologically to maintain homeostasis, so that adverse consequences are minimized (Refer 3.0).

When cattle are challenged, not all coping capabilities are mobilized at the same time. Growing *ad libitum* fed *Bos taurus* cattle will have markedly increased respiration rate (RR) as increasing air temperature (Ta) exceeds 21° C (Hahn *et al*., 1997). Above 25° C, body temperature (BT) begins to increase, with a concomitant decrease in DMI, which ultimately results in reduced growth if the adverse environmental conditions continue (Hahn *et al*., 1992). These and other observations such as behaviour lead to RR, BT and DMI as generalized functions of air temperature.

4.2.2 Animal Factors Influencing Response to EHL

(a) Breed Effects

It is well known that certain breeds of cattle, namely *Bos indicus* genotypes such as the Brahman have greater heat tolerance than *Bos taurus* genotypes such as the Angus. There are however exceptions. The Tuli, for example which is closely related to *Bos Taurus,* appears to have a high degree of heat tolerance (Gaughan *et al*., 1997; Hammond *et al*., 1998). Bennett *et al*. (1985) reported that when given access to shade during periods of hot weather, Brahmans sought shade the least and Shorthorn's the most. The Shorthorn steers spent 1 hour longer in the shade each day than did the Brahman steers. The Brahman also had lower rectal temperatures (RT) and RR compared to the Shorthorn cattle. However, Hammond *et al*. (1998) reported that the RT of Brahman cattle were similar to Angus cattle (40.0°C and 40.9°C respectively). Under the same conditions the RT of Senapol cattle was 39.6°C. Gaughan *et al*. (1999) found that the RT of Hereford steers was on average 1.3° C higher than for Brahman steers (40.3 °C vs 39.0°C) when exposed to a THI > 90.

Breed differences for evaporative cooling from the respiratory tract have been reported. *Bos taurus* cattle reach maximal vaporization rates at approximately 27°C, while *Bos indicus* cattle reaches peak evaporation rates at 35°C (Yousef *et al*., 1968). The peak RR is considerably lower for *Bos indicus* cattle compared to *Bos taurus* cattle. Work by Rhoad (1936) showed that the RR of Zebu cattle was approximately 30 breaths per minute (bpm) at 35°C, while the RR of Holsteins at the same temperature was over 100 bpm. The RR of Holstein x Zebu crosses was approximately 80 bpm at 35°C. Olbrich *et al*. (1973) reported a respiration rate of 122 bpm for *Bos taurus* heifers and 25 bpm for *Bos indicus* heifers at 31°C. Hammond *et al*. (1998) found that the RR of Brahman and Angus heifers was 39 bpm and 74 bpm respectively at a THI of 84 units. During the same study the RR of Senapol and Tuli x Angus heifers was 50 and 60 bpm respectively. Mean respiration rates of 104 bpm for Brahman, and 168 bpm for Hereford steers were reported by Gaughan *et al*. (1999). These cattle were exposed to a THI >90. Recent Australian work has reported that the mean RR of crossbred steers (3/4 Murray Grey ¼ Hereford) and Shorthorn heifers exposed to ambient temperatures above 35° C were approximately 90 bpm and 110 bpm respectively (Gaughan *et al*., 2001).

Genetic diversity within a breed will also influence the level of response and degree of adaptability to adverse conditions. Studies undertaken at Gatton, Queensland, have seen individual *Bos taurus* cattle (Hereford and Shorthorn) withstand temperatures in excess of 38^o C with little increase in RR or BT, and no decrease in DMI. In the same study a Brahman steer had elevated BT (41^o C for rectal temperature) and decreased DMI.

Selection of individuals with high tolerance to heat as breeding animals has the potential, albeit long term, to improve the heat tolerance of *Bos taurus* cattle.

Further differences between breeds will be highlighted throughout the remainder of this section.

(b) Adaptation and Acclimatization[3]

The terms adaptation and acclimatization have different meanings, although they are often considered to be the same. The basic difference is that adaptation is a response to the total environment, whereas acclimatization is a response to climate. Brahmans are adapted to the harsh conditions of Northern Australia, which includes, climate, nutrition and parasites. Angus cattle from Queensland may be acclimatized to the climate, but not adapted to poor nutrition and ticks. Most cattle will adapt to prevailing environmental conditions provided the temperature range is not too wide. However, adaptation to the total environment often comes at a price, usually seen in the form of decreased performance. Acclimatization to unfamiliar climatic conditions may also lead to lower productivity, while the climatic conditions exist.

Production performance of feedlot cattle can be expressed in terms of DMI, live weight gain (LWG) feed conversion efficiency (FCR), meat quality and health status. Cattle that adapt to hot conditions usually do so by decreasing heat production or increasing heat dissipation. Increasing heat dissipation works up to a point. Cattle exposed to hot humid conditions will sweat, drink more water and have a greater RR than under thermo neutral conditions (Mader *et al*., 2001; Gaughan *et al*., 1999). These measures work up to a point, usually where the heat load is of short duration (1 or 2 days).

If high heat load conditions continue, cattle will need to reduce heat production. In most cases, this is by a reduction in feed intake (acclimatization not adaptation). Cattle on high energy grain diets may reduce DMI by more than 25%, and after the high heat load conditions abate, will not return to previous levels of DMI (Hahn, 1996; Gaughan, 2001). That is they adapt by reducing feed intake. Cattle on low quality roughage (low energy) diets experience variable intake reductions, often around 10%, and are more likely to return to full feed when conditions return to thermo neutral.

Observations by Hahn *et al*. (1990) and Hahn and Neinaber (1993) have confirmed the close association between tympanic temperature and feeding activity. The feeding pattern seen under thermo neutral conditions (TNC) is disrupted by hot conditions. During TNC eating activity was associated with a decrease in tympanic temperature of 0.3^oC to 0.5^oC. During hot conditions, and especially the first couple of days, tympanic temperature variation was reduced. Concurrently, eating bouts became more frequent with less feed being consumed. At $10^o \pm 7^oC$, 48% of meals lasted 6 minutes or less; at $30^oC \pm 7^oC$, 49% of the meals lasted

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[3] ***Adaptation*** – A change, which reduces the physiological strain produced by a stressful component of the total environment. This change may occur within the lifetime of an organism (phenotypic) or by the result of genetic selection in a species or subspecies (genotypic).
Acclimatization – A physiological change occurring within the lifetime of an organism, which reduces the strain caused by stressful changes in the natural climate (e.g. seasonal or geographical). (Source: Yousef 1987)

4 minutes or less, although meal duration tended to increase after the first 5 days of exposure (Table 4.2.1).

Table 4.2.1: Feeding activity analysis for steer 3472 during a sequential exposure to moderate and hot environments (Hahn *et al*., 1990).

	% of total feeding events		
Eating duration, min	**10 °C ± 7°C**	**20 °C ± 7°C**	**30 °C ± 7°C**
1 to 2	17.4	24.6	18.9
3 to 4	12.0	24.6	24.2
5 to 6	18.7	20.2	15.8
7 to 8	13.3	10.8	14.7
9 to 10	12.0	7.9	11.6
11 to 12	2.7	4.4	5.3
13 to 14	5.3	1.0	2.1
15 to 16	4.0	3.5	3.2
17 to 18	4.0	1.0	1.9
19 to 20	1.3	0	0
>20	9.3	2.0	2.1

Providing they do not overheat, cattle will normally adapt substantially to hot conditions after about 4 days of exposure (Hahn, 1995b). Figure 4.2.1 shows the tympanic temperature of a growing Bos taurus steer before and after the transition from cool (10° ± 7° C) to hot (30° ± 7° C) cyclic conditions (Hahn, 1996). These measurements further define the acute (days 1 to 3 of heat exposure) and acclimatization (after day 4) responses to the heat stressor, illustrating that:

- cattle typically require about 3 to 4 days to balance heat production from feed intake with their heat dissipation capabilities;

- acclimatization occurs over several days (with peak BT typically declining as a rate of 0.1° to 0.4° C/day) before the circadian rhythms of BT stabilize around a new, higher mean temperature resulting from the hot conditions;

- the maximum BT of acclimatized *Bos taurus* cattle will be 2° C lower than for non acclimatized cattle (Finch 1986).

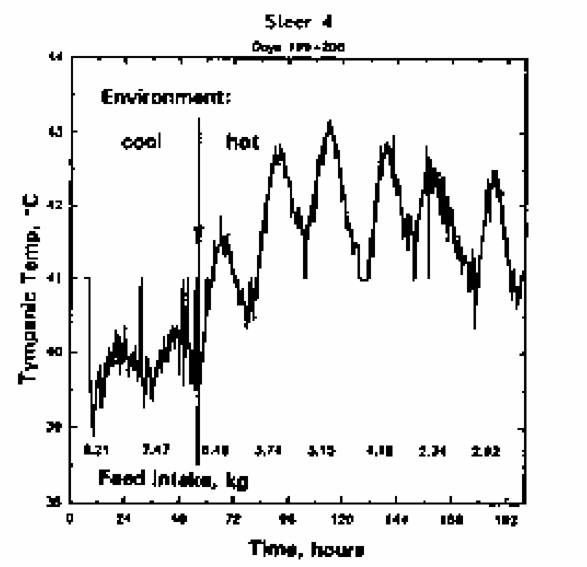

Figure 4.2.1: Tympanic temperature recorded at 320 sec intervals from a steer during a sequential exposure to moderate ($10^oC \pm 7^oC$) and hot ($30^oC \pm 7^oC$) sinusoidal diurnal controlled environments (Hahn, 1995b).

There are also shifts in the lag time between peak ambient conditions and the peak BT, as well as changes in the means and amplitudes of the daily BT (Hahn, 1996).

The importance of a lack of prior conditioning (acclimatization) to weather events is illustrated by the recorded incidences of EHL losses (Refer 2.2).

(c) Coat Colour/Coat Type

The effects of **coat colour** on heat tolerance are contradictory. Schleger (1962), Finch and Western (1977), and Peters *et al*. (1982) have reported that cattle with darker coat colour had lower body temperatures and better growth performance under hot conditions, which is opposite to what would be expected (Gebremedhin *et al*., 1997). Other studies have shown that animals (cattle) with dark coat colour acquire greater solar heat loads (Bonsma, 1949; Hamilton and Heppner, 1967; Finch *et al*., 1984; Gaughan *et al*., 1998), have lower performance, and are more likely to seek shade under hot conditions (Gaughan *et al*., 1998). However, Walsberg (1983) stated that “there is no simple relation, even in a qualitative sense, between coat colour and radiative heat gain”. Recent cattle death losses in the USA (1995, 1999) and in Australia (1991, 2000), however, have occurred in pens which held both dark coated and light coated cattle. Busby and Loy (1996), and Mader (personal communication, 1999), reporting on deaths in the USA observed that in pens with 20% black cattle, 80% of the death loss was from the black-coated animals. Studies involving dairy cows show that cows with high percentage black in their coat have lower production levels during summer (Goodwin *et al*., 1997). Furthermore, Gaughan *et al*. (1998) reported that cows with a predominately white coat did not actively seek shade during periods of hot weather. Observations by Mader and Gaughan (unpublished) suggest that RR and RT of black-coated cattle were higher than white-coated cattle with red-coated animals being intermediate. Holt (2001) reported higher RR in black-coated cattle under both TNC and hot conditions. Holt (2001) also found that the effect of coat colour was more pronounced as cattle became fatter. Early work undertaken in South Africa by Riemerschmid and Elder

(1945) showing the importance of coat colour on absorption of solar radiation are presented in Table 4.2.2.

Table 4.2.2: The mean absorptivity to solar radiation of hides of different colours.

	White[1]	Cream	Red[1]	Dark Red	Black
Mean Absorptivity (%)	49	50	78	83	89

[1] *Bos indicus* breeds (Adapted from Findlay, 1950)

In the USA, some feedlot managers will actively seek light coated cattle for summer feeding Gaughan (personal communication, 2001). The general suggestion is that light coated cattle are better able to cope with EHL than are dark coated cattle.

Coat type (hair density and length) is also an important consideration. Cattle with dull woolly coats tend to have higher BT than similar animals with slick glossy coats. Findlay (1950) reported that BT of woolly coated and glossy coated cattle exposed to an air temperature of 37° C was 39.6° C and 38.9° C respectively. Part of the explanation for this is that glossy coats reflect more sunlight than woolly coats. Fur length impacts on heat transfer from the skin, and may therefore impact on the efficiency of sweating. In the commercial feedlot this may impact on the effectiveness of sprinkler systems, especially if droplet size is insufficient to wet the animals' skin. This means that a white coated animal with a woolly coat may be 'hotter' than a black coated animal with a slick coat, when they are exposed to the same climatic conditions.

Other factors, such as breed (Srikandakumar *et al*., 1993; Gaughan *et al*., 1999), environmental conditions (Walsberg, 1983; Gaughan *et al*., 1998), non-uniformity in colour (Gebremedhin *et al*., 1997), the thermo physical and optical properties of the fur layer (Yeates, 1977; Gebremedhin *et al*., 1997), and the correlation between coat type and other adaptive features including sweating rate and skin blood flow (Turner, 1962) may explain the lack of consistency between the various authors.

In Conclusion:

- Generally light coloured cattle are less susceptible to EHL.
- *Bos taurus* cattle with a woolly winter coat are more susceptible to EHL, than the same animals with a summer coat.

(d) Body Condition/Days on Feed

Generally heavier fatter cattle are more susceptible to the effects of high heat load. A survey of feedlots reporting deaths in the July 1995 heat wave in Iowa, USA are reported in Table 4.3. Busby and Loy (1996) found that while non-shaded feedlots with cattle weighing from 487 to 535 kg had a higher death loss than feedlots with cattle weighing 544 to 567 kg, (5.9% vs. 5.0%), the feedlots with lighter weight cattle (362 to 476 kg) had a death loss of only 3.4% (Table 4.2.3). Similar results were seen in the July 1999 Nebraska heatwave, namely, heavier cattle, i.e. those close to market weight were more susceptible to the effects of EHL than lighter weight cattle carrying less finish and fat (Mader, personal communication, 1999). Similar results were reported by Entwistle *et al*. (2000) for cattle, which died in NSW during February 2000.

Table 4.2.3: A comparison of heat wave mortalities in relation to liveweight in 46 non-shaded feedlots in Iowa, USA, based on the average cattle liveweights 11th, 12th July 1995.

Item	362 to 476 kg	487 to 535 kg	544 to 567 kg
No. of feedlots	16	18	12
No. of cattle	1625	2851	1413
Est. live weight (kg)	445	508	554
Death loss (%)	3.4	5.9	5.0
Feedlots with no deaths (%)	25	22	17

Gaughan *et al*. (2000) reported that the response of cattle to chronic heat stress changed over time. Under the same environmental conditions, RR and BT increased as body condition (fatness) increased. The fatter heavier animals consumed more feed, probably because they are more productive, and have a higher maintenance requirement, which further contributes to heat load.

The study of US feedlot deaths suggest a majority of the cattle that died were either close to market weight and finish (i.e. within 7 – 10 days of slaughter), or should have already been marketed.

(e) Health Status

It is likely that animals with impaired health status have a reduced ability to cope with high ambient temperatures. Post mortem findings from cattle which died during the heat wave in Nebraska USA during July 1999, indicated an underlying health problem (mostly respiratory) in many of the dead cattle (Mader, personal communication, 1999). Any disease or syndrome which raises body temperature or reduces lung capacity will increase the susceptibility of an animal to a heat load related death.

The health status of an animal is affected by stressors. Stress can be defined as any disturbance of homeostasis, which causes immunological changes (Kelley, 1985). Cattle recently exposed to transport or handling, over-crowded pens, disruption of social order, and/or inadequate access to water trough space and feed bunk space are exposed to stressors, which can have a negative impact on health status. The cumulative impacts of stressors on animal health are difficult to quantify. However, we do know that stressed animals are more likely to succumb to disease. Morrow-Tesch and Hahn (1994) found, in a study to determine the dynamic immunological response of steers to heat stress, that following a period of chronic heat stress, reaclimatisation to thermo neutral conditions was physiologically costly to the animal. They concluded that this could be a factor in increased disease incidence in transitional environmental conditions. Importantly the immunological changes, in this case white blood cell counts, remained elevated for at least 12 days after the heat event.

This may explain why heat wave death rates are often higher when a second high heat episode follows the first by 3 to 6 days.

4.2.3 Animal Responses to Heat Load

(a) *Physiological Responses*

An animal's ability to cope with changes in the climatic environment depends on specific compensating or adjusting mechanisms activated by the body's regulatory systems (Bligh, 1973,1979; Jansky *et al*., 1986; Werner and Graener, 1986). It is essential an animal has the ability to detect and interpret a disruption in its internal equilibrium, and has the ability to initiate appropriate behaviour and/or metabolic responses to restore homeostasis (Young *et al*., 1989).

Biological systems are dynamic (Haken and Koepchen, 1991), with body functions interacting in a complex manner (Aschoff, 1981). Thermoregulation is a dynamic process in homoeothermic animals, as observed from short-term changes in body temperature, which reflect temporary imbalances in heat production and heat dissipation (Hahn *et al*., 1993). An understanding of the dynamic responses of animals in a thermally challenging environment is necessary for both environmental and animal management. These dynamic responses can help us to evaluate acclimatisation of animals (genotypes), to refine performance models of animals and threshold limits in the development of energetic and thermoregulatory models of animals, and to evaluate linkages among physiological, immunological and behavioural responses (Hahn, 1994). Under TNC an animal's core body temperature remains relatively constant. However, when exposed to climatic conditions where its heat loss or heat gain exceeds thermo neutral heat production energy will be diverted from live weight gain (or some other production parameter) to heat production or heat loss. Thus to maintain homeothermy a loss of performance is incurred.

Exposure of cattle to thermal stress leads to a number of physiological responses, such as: increased *sweating rate* (SW), elevated *rectal temperature* (RT), increased *respiration rate* (RR) and/or increased *pulse rate* (PR). Associated with these are declines in feed intake and DMI (a direct attempt to reduce heat production), milk production, growth, health and well being (Hafez, 1968; McDowell, 1972; Kabunga, 1992; Hahn and Nienaber, 1993; Gaughan *et al*., 1996). McDowell (1972) compiled the following factors for an animal, which is compensating following exposure to increasing ambient temperature (above TNC):

- Change in vascular blood flow
- Increased sweating rate
- Increased respiration rate
- Changes in hormone secretion or endocrine activity
- Changes in behavioural patterns
- Increased water intake
- Increased body temperature
- Changes in the used of body water
- Change in the state of hydration

The order in which these functions take place has not been reliably determined. It has been argued that behavioural changes take place before there is any physiological response. Robertshaw (1985) stated that the first response to increasing thermal load is behavioural. Animals firstly change posture, seek shade, wallow, and/or decrease DMI. If these are not options, then the animal will use physiological functions (e.g. blood flow, sweating, panting) to alter body temperature. Young and Hall (1993) listed behaviours which could identify cattle experiencing EHL, with the onset of open-mouthed panting, laboured panting and excessive salivation/drooling suggested as indicators of an animal failing to cope and needing immediate attention to avoid collapse and possible death (Refer 4.4).

Autonomic control mechanisms (Figure 4.2.2) in an animal attempt to maintain a balance between thermolysis (heat loss) and thermogenesis (heat production) (Shafie, 1991). The simplest model of thermoregulation implies that:

- External sensors in the skin and mucous membrane of the buccal cavity assess the ambient temperature, and internal sensors in the spinal cord and hypothalamus assess the internal tissue and blood temperature (Bligh, 1985).
- The hypothalamus has a regulatory function, dictating set point reference temperature.
- The correctors are both neural and endocrine, and
- The effectors are the physiological functions for input and output of heat (Shafie, 1991).

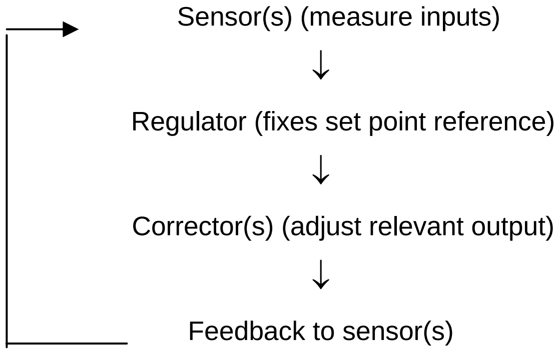

Figure 4.2.2: Animal assessment of heat balance (Shafie, 1991)

A failure to return to a thermal equilibrium at a previous or higher level will be evident by progressive failure of the heat regulation mechanisms (McDowell, 1972). Excess heat is dissipated by evaporation of sweat as a protective mechanism by the body to prevent overheating. At the same time, RR and /or panting increases and becomes much more shallow to permit an efficient ventilation of the upper respiratory tract, without undue over ventilation of the lungs (Shafie and Abdelghany, 1978).

In the case of an animal being unable to maintain homeothermy, heat production is reduced by the animal by internal physiological means in an attempt to re-establish thermal balance. If the physiological mechanisms fail to reduce EHL, body temperature rises and the animal begins to suffer excessive thermal load (Alnaimy *et al*., 1992). If these systems fail to inhibit the rise in body temperature, the animal may eventually suffer heat stroke and die.

(b) *The Respiratory System*

As ambient temperature (T_a) (or heat load) increases, the animal ‘initiates’ vasomotor mechanisms, followed by sweating in order to maintain BT as we have already seen. If T_a continues to increase and vasomotor and sweating rate are not sufficient to regulate BT, then RR will increase. The respiratory response is therefore not an instantaneous reaction; there is typically a lag period. Recent work suggests that the RR response lags T_a by approximately two to three hours (Hahn *et al.*, 1997; Gaughan, 2001).

The respiratory system has two major functions, namely (i) gaseous exchange, and (ii) evaporative heat loss from the upper respiratory tract. Generally these two functions are not in conflict. However if the animal is exposed to EHL a conflict may arise. As panting changes from deep breathing to shallow breathing, the animal's need to alleviate BT may be compromised by its need to balance blood CO_2 (Figure 4.2.3).

An increase in RR is an attempt by the animal to remove excessive body heat. However, as RR increases there is an increase in cellular activity (Bligh, 1973). The increase in cellular activity results in an increase in heat production and an increased CO_2 release into the blood. The animal continues to increase RR as BT rises, until a point is reached where the CO_2 level in the blood becomes critical. At this point, RR changes and breathing shifts from rapid shallow to a deeper slower breathing, i.e. RR decreases.

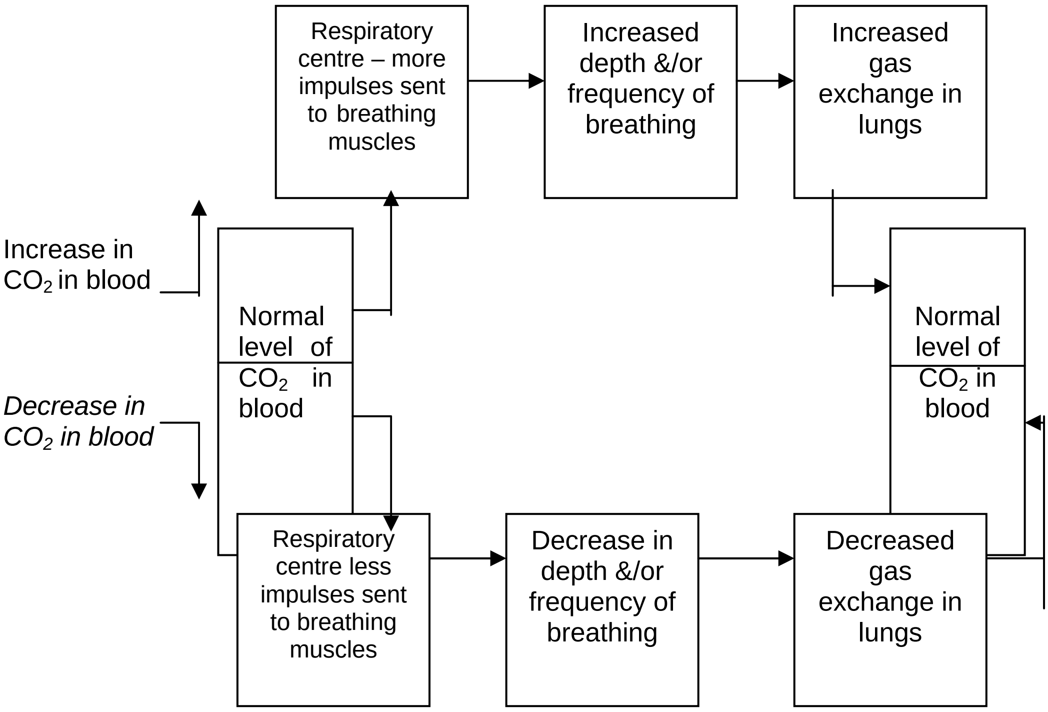

Figure 4.2.3: Homeostatic control mechanisms involved in regulating gas exchange in mammals. (Adapted from Baker and Allen, 1971).

The CO_2 concentration in the blood has a powerful influence on ventilation (Keenan, 1990). The respiratory centre, which is located in the medulla part of the brain stem responds to the amount of CO_2 in the blood. As blood passes through the respiratory centre sensors stimulated by the level of CO_2 send impulses to rib cage muscles to increase the rate of respiration (Baker and Allen, 1971).

Acidity, or H ion concentration of the blood is directly related to CO_2 concentration. An increase in blood acidity will stimulate respiration in conjunction with a rise in CO_2. At this stage O_2 concentration has a minor influence. The rate of O_2 release in body tissues is increased by an increase in blood CO_2, blood acidity, a rise in BT, reduced partial pressure of O_2 (PO_2) in surrounding tissue and a rise in 2,3-diphosphoglycerate which is formed when cells are actively metabolising (Keenan, 1990). A rise in BT or a fall in blood pH affects the haemoglobin binding properties. As a result a higher PO_2 is required for haemoglobin to bind a given amount of O_2 (Ganong, 1975). Panting is started by a fall in the partial pressure of CO_2 (PCO_2), and its primary function is not to increase evaporative heat loss, but to raise tissue PCO_2 and thus lower the rate of metabolism (Baker and Allen, 1971; Bligh, 1973). If there is a fall in PCO_2, CO_2 and energy (heat) will be released via panting.

When blood passes through the lung capillaries both CO_2 and heat are removed. If an animal is coping with a given heat load, the rate of tissue metabolism is modulated by the opposing local influences of temperature and PCO_2 (Bligh, 1973).

Gaseous ammonia is a severe respiratory tract irritant capable of inhibiting the efficiency of the respiratory system at high levels. It is periodically released from the feedlot pad, particularly when damp warm conditions prevail. There appears little information however, on ammonia levels in open pens or the factors influencing these levels (pad depth, diet, shade).

The animal health effects from breathing ammonia are illustrated in Table 4.2.4, and the human effects in Table 4.2.5.

Table 4.4: Animal Health Effects from Breathing Ammonia

Short-term Exposure (less than or equal to 14 days)		
Levels in Air (ppm)	**Length of Exposure**	**Description of Effects***
50	3 hours	Slowed breathing rate in rabbits; coughing, eye, mouth, and nose irritation, poor weight gain and food intake in pigs.
100	6 hours	Increased irritability in rats.
500	7 days	Decreased weight gain and food intake in rats. Decreased resistance to disease in mice.
1000	16 hours	Death in rats and mice.
Long-term Exposure (greater than 14 days)		
Levels in Air (ppm)	**Length of Exposure**	**Description of Effects***
653	90 days	Death in rats.

* These effects are listed at the lowest level at which they were first observed. They may also be seen at higher levels.

Source: Agency for Toxic Substances and Disease Registry, Division of Toxicology, 1600 Clifton Road, E-29, Alanta, Georgia 30333.

Table 4.2.5: Human Health Effects from Breathing Ammonia

Short-term Exposure (less than or equal to 14 days)		
Levels in Air (ppm)	**Length of Exposure**	**Description of Effects***
0.5		Minimal risk level.
50	Less than 1 day	Slight, temporary eye and throat irritation and urge to cough.
500	30 minutes	Increased air intake into lungs; sore nose and throat.
5000	Less than 30 minutes	Kills quickly.
Long-term Exposure (greater than 14 days)		
Levels in Air (ppm)	**Length of Exposure**	**Description of Effects***
0.3		Minimal risk level
100	6 weeks	Eyes, nose and throat irritation.

* These effects are listed at the lowest level at which they were first observed. They may also be seen at the higher levels.
Source: Agency for Toxic Substances and Disease Registry, Division of Toxicology, 1600 Clifton Road, E-29, Alanta, Georgia 30333.

Ammonia can be smelled by humans when the concentration exceeds 0.6ppm. People repeatedly exposed to ammonia may develop a tolerance (or acclimatisation) to irritating effects after a few weeks (Canadian Centre for Occupational Health and Safety, personal communication).

(c) *Animal Performance*

In this review, animal performance is expressed in terms of LWG, DMI, FCE, meat quality and health status. LWG and FCE are functions of ME intake and maintenance energy (Ames, 1986). The thermal environment affects both ME intake and the maintenance requirement, which in turn alters LWG and FCE. Numerous trials with pigs (Heitman *et al*., 1958; Mangold *et al*., 1967), sheep (Ames and Brink, 1977), beef cattle (Gaughan *et al*., 1996; Mader *et al*., 1999a), and dairy cattle (McDowell *et al*., 1976), have shown that animal performance is adversely affected when of animals are exposed to environmental conditions outside TNC. The major factor appears to be an increase in maintenance energy requirement with less energy being available for production. When exposed to hot conditions, the requirement for maintenance energy increases, due to factors such as an increase in RR, sweating, etc, and DMI is reduced. The relationship between energy output (performance) and energy input (feed intake) results in reduced energetic efficiency when animals are exposed to heat stress (NRC, 1981).

Substantial declines in animal performance have been observed in response to specific environmental conditions. However, long-term responses may tend to ameliorate acute effects. Hahn *et al*. (1974) found that after five weeks of "moderate" heat load followed by a return to TNC, grain fed *Bos taurus* steers exhibited compensatory growth and within one or two weeks were back at the weight of a control group. However, cattle exposed to severe heat load, may demonstrate limited recovery of growth when hot conditions abate (Mader, personal communication, 1999).

4.2.4 Assessing the Impact of EHL on Feedlot Cattle

A useful approach when assessing the impact of heat load on cattle is to use indicators of thermal strain (i.e. animal markers), which serve as sensitive alarms of distress.

(a) *Sweating Rate*

Sweating rate (SW) of cattle is not easy to measure under most conditions (Schleger and Turner, 1965). Finch *et al*. (1982) reported that the relationship of the sweating response to mean rectal temperature was negative. Thus, the SW response seemed to be a good indicator of the thermoregulatory ability of the animal. Finch *et al*. (1982) also reported that, between animals within breeds, the sweating response was negatively correlated with metabolic rate. This suggests that cattle with high sweating rate (good heat adaptation) may have lower metabolic potential. Gaughan (2001) found a positive response between SW and rectal temperature when steers were exposed to hot conditions, but no relationship under TNC.

There is however considerable variation in the literature in regard to breed and SW (Allen *et al*., 1970; Pan *et al*., 1969; Amakiri and Onwuku, 1980; Finch *et al*., 1982). Generally the SW of *Bos indicus* cattle is greater than for *Bos taurus* cattle when exposed to EHL (Schleger and Turner, 1965). However, Gaughan *et al*. (1999) reported little difference in SW, 171 and 175 g/m^2/h for Brahman and Hereford steers respectively, that were exposed to THI > 90. The SW of Brahman x Hereford steers exposed to the same conditions was greater at 221 g/m^2/h (Gaughan *et al*., 1999) suggesting a heterosis effect (Schleger and Turner, 1965). A similar SW for different breeds, does not necessarily indicate a similar cooling effect. Nay and Hayman (1958) reported differences in the location of sweat glands and density of sweat glands between *Bos indicus* and *Bos taurus* cattle. They found that *Bos indicus* cattle had larger and more numerous sweat glands than *Bos taurus* cattle. The sweat glands of *Bos indicus* cattle were more numerous on the midside than on the dewlap, and closer to the surface than for *Bos taurus* cattle. They suggest that these differences mean that the peripheral blood vessels on the dewlap are cooled by evaporation of sweat running down the dewlap.

The effectiveness of sweating is also dependant on coat type. If moisture is captured in the hair then the efficiency of sweating is reduced. However, there does not appear to be a breed effect on SW (Allen *et al*., 1970), even though hair samples showed differences between breeds.

Variation in SW is due to a combination of factors such as: the site of measurement on the animal, breed, whether the animals are acclimatised to hot conditions, climatic conditions prior to and during measurement, time of measurement, whether cattle are inside or outside, closeness to other cattle and availability of drinking water.

In Conclusion:

- Sweating rate (SW) is an important indicator of an animal’s heat tolerance.
- Under field conditions SW cannot be easily used as an indicator of thermal load in cattle.

(b) *Skin Temperature*

Skin temperature, although dependent upon skin colour, may be as good an indicator of heat strain as RR (Ingram and Whittow, 1962). An increase in skin temperature alone is sufficient to increase sweating (Shearer and Beede, 1990b) and panting rates in cattle (Curtis, 1983). During EHL blood flow is directed away from internal organs, for example uterus and gastrointestinal tract, to the periphery for enhanced heat transfer (Shearer and Beede, 1990b). The result of this transfer is an increase in skin temperature. An indirect index of steady state blood flow to the skin can be determined using the thermal circulation index $((T_{skin} - T_{air})/(T_{RT} - T_{skin}))$ (Burton and Edholm, 1955). Direct skin thermal conductance has also been measured, with Brahman cattle exhibiting the highest rate increase in trunk skin thermal conductance with T_a increase from 25^o to 41^o C (Finch, 1985). An increase in T_a from 20^oC to 30^o C results in a 2.5 fold increase in water loss through sweating and panting resulting in additional stress to homeostatic processes (McDowell and Weldy, 1967). At extreme T_a (i.e. 40^o C), skin vaporization accounts for 66% to 84% of evaporative heat loss (Kibler and Brody, 1950a), while panting is only 16% of the evaporative heat loss (McLean, 1963).

(c) *Internal Body Temperature*[1]

Internal body temperature is usually measured as rectal temperature or tympanic temperature. Internal body temperature may be useful as a predictive indicator of cattle comfort and performance (Shearer and Beede, 1990a), but like sweating rate is difficult to measure under field conditions.

Knowledge of the relationship between the circadian change in BT and environmental thermal conditions is needed to increase our understanding of maintenance requirements and limitations to productive performance (Araki *et al*., 1984). Likewise, such information is essential for the evaluation of the benefits of any environmental modification (Igono and Johnson, 1990). In earlier studies, BT of cattle was measured at only selected times of the day (Bond *et al*., 1957; Mendel *et al*., 1971; Bond and McDowell, 1972; Thompson, 1973; Morrison and Lofgreen, 1979). Even then it was known that cattle exhibit a diurnal variation in BT, that is a combination of the thermal and physiological status of the animal (Wren *et al*., 1961; Simmons *et al*., 1965; Bianca, 1968; Berman and Morag, 1971; Scott *et al*., 1983). Feeding time may also be a factor that alters BT (Simmons *et al*., 1965; Bianca, 1968).

The diurnal rhythm for internal BT is often a reflection of the pattern of change in T_a. However there are breed differences. Gaughan *et al*. (1997) demonstrated the effect of hot conditions on RT of Hereford, Brahman and crossbred steers (Figure 4.2.4). In this study peak RT for all steers (except Brahman) occurred approximately 1 hour after peak T_a. The RT of the Brahman steers peaked around midnight, which was 8 hours after peak T_a.

BT rhythms during short-term EHL usually lag T_a rhythms by 3 to 5 hours, instead of the 8 to 10 hour lag found under TNC (Hahn, 1995; Holt *et al*., 1998). A similar shift backwards in time of peak core BT was noted in beef cattle exposed to constant heat stress under

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[1] ***Measurement BT:*** BT is usually measured using tympanic temperature probes (Hahn et al., 1990: Hahn 1995), and/or rectal temperature probes (Gaughan et al., 1996; Holt et al., 1998). Tympanic probes are normally removed after 7 days, whereas rectal probes can remain in place for up to 24 days. Both types of probes are attached to data loggers to allow continuous collection of data. Implanted temperature sensors may also be used. These devices transmit data via telemetry (radio waves) to a receiver.

controlled conditions (Zhang *et al*., 1994). In addition, daily mean and amplitude values (i.e. the differences between maximum and minimum) for internal BT are increased during periods of EHL (Hahn, 1995). For Brahman, BT increased during the night, to effect an increase in the gradient for heat transfer to the environment (i.e. enhanced cooling). Lefcourt and Adams (1996) reported that daily maximum core temperature exhibited a linear increase when cattle were exposed to increasing T_a (above 25.6 ^{o}C). The increase in body temperature with maximum T_a was 0.085 ^{o} C core temperature per 1 ^{o}C T_a increase, above the T_a threshold of 25.6^{o} C. In addition, sharp peaks in core temperature were seen late evening (~2200 h), long after the daily decrease in T_a.

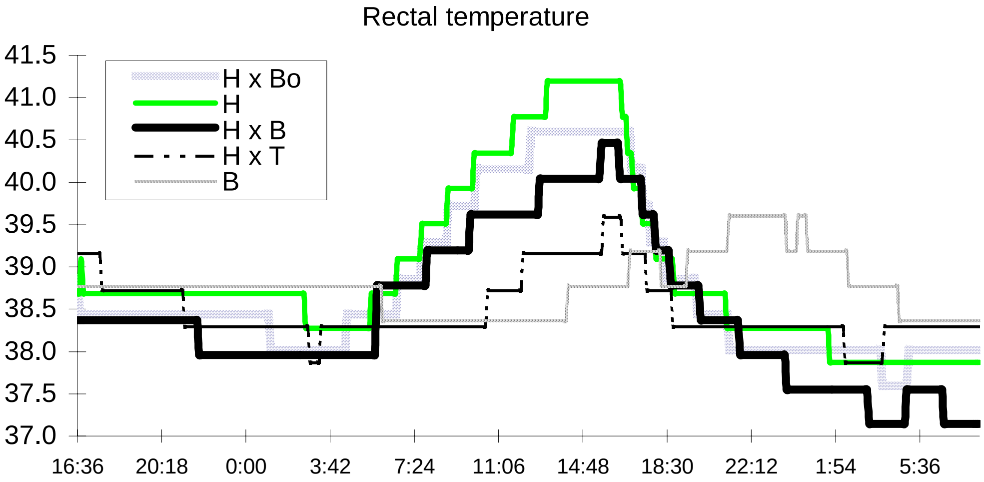


Figure 4.2.4: Rectal temperature of Hereford x Boran (H x Bo), Hereford (H), Hereford x Brahman (H x B), Hereford x Tuli (H x T) and Brahman (B) steers exposed to a THI of 95 between 6 am and 4 pm.

In Conclusion:

Changes in BT over time are a useful indicator of an animal's ability to cope with hot conditions, and under experimental conditions this is a useful tool. However, it is difficult to use under field conditions and is therefore of limited value in assessing heal load in feedlot cattle.

(d) *Effect of EHL on DMI and BT*

Altered daily rhythms in core BT during periods of EHL (refer to previous section) are usually accompanied by a reduction in DMI, which is different for acute, chronic and adaptive phases of response (Hahn *et al*., 1992). DMI coupled with environmental conditions, influences an animal's ability to cope with heat load (Brosh *et al*., 1994: Reinhardt and Brandt, 1994). Purwanto *et al*. (1990) concluded that total heat production (within the animal) is dependent, in part, on DMI.

Reducing ME intake through feed restriction improves feed efficiency in ruminants (Hicks *et al*., 1990: Murphy *et al*., 1994) possibly by lowering maintenance energy expenditure and increasing diet digestibility (Murphy and Loerch, 1994; Sainz *et al*., 1995). However, there appears to be considerable variation among commercial feedlots which have implemented restricted feeding programs (Mader, personal communication, 2001; Gaughan, personal communication, 2001). Restricting ME intake by diluting high concentrate diets with fibre may have the same effect as restricting feeding of a high-energy diet. Feeding fibre to reduce the impact of heat load may be offset by its higher heat increment (NRC, 1981; Webster, 1983). This appears to be true to a point. Much of the data in this area has been collected from dairy cows, and may not be relevant to feedlot beef production. While increased concentrate feeding is common practice in the US dairy industry during time of EHL, caution is needed. The concentrate levels used in US dairy production do not approach the levels used in Australian feedlots. Mader *et al*. (1999a), and Gaughan (2001) have shown that beef cattle fed diets high in fibre (28%) had a significantly lower RT compared to those fed diets low in fibre (6%) (Figure 4.2.5).

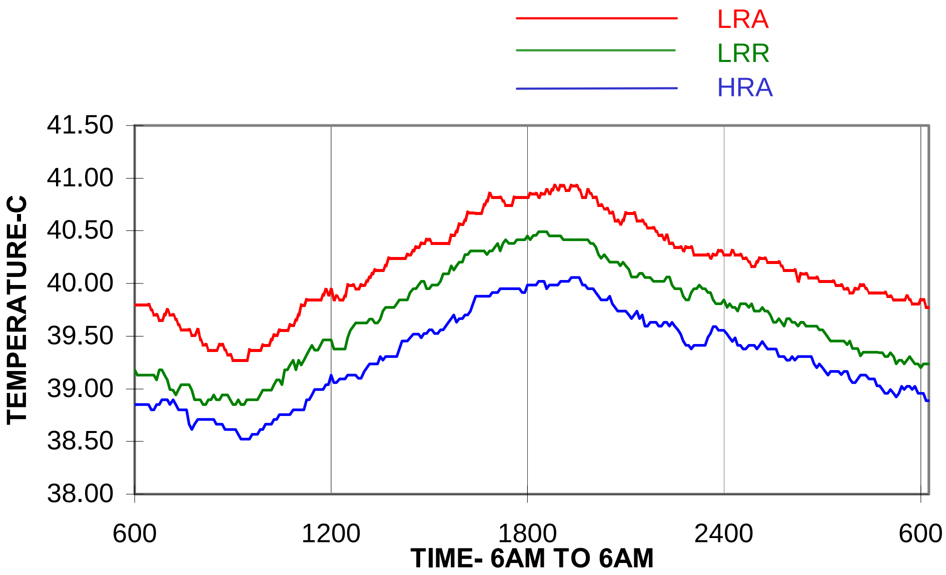


Figure 4.2.5: The effect of feeding a low fibre diet (6%) *ad libitum* (LRA), a low fibre diet restricted (LRR) or a high roughage diet (28%) *ad libitum* (HRA) on rectal temperature of Hereford steers exposed to EHL over a 24-hour period, all fed at 0800 hours.

A reduction in energy intake in cattle is followed by a reduction in metabolic rate (Turner and Taylor, 1983). The lowered intensity of heat production is due to decreased maintenance heat production, due to increased metabolic efficiency, and a reduction in heat from product (LWG) formation (Coppock, 1985). A further effect of limited food intake is a change in the diurnal range in internal BT via a reduction in a lower BT lower limit (Finch and King, 1982). This means that the swings in BT are greater when cattle are exposed to EHL, and there is a trend to reach a lower minimum than under TNC (Hahn, 1996). Such diurnal change in internal BT, in response to feeding, is an appropriate strategy to conserve energy particularly during drought conditions (Finch, 1986). Reduction of the heat increment of feed by dietary manipulation may partially protect cattle from EHL (Blackshaw and Blackshaw, 1994). During summer, cattle limit-fed in the evening had a better FCR than those fed in the morning (Reinhardt and Brandt, 1994). The assumption from this was that metabolic heat production would be lower, and metabolic efficiency would be better in the evening fed cattle. However, Gaughan *et al*. (1996) reported that there was little benefit to afternoon feeding when limited night time cooling occurred.

Gaughan *et al*. (1996), Holt (2001) and Gaughan (2001) have shown that manipulation of the diet, either via changes to the time of feeding or by restricting access to feed, may have a positive effect on BT.

In Conclusion:

The manipulation of feed quality and/or DMI can have a positive effect on reducing body temperature. There are however, aspects still requiring a better understanding.

(e) *Respiration Rate*

RR is a useful indicator of heat load. A RR of 20 to 60 bpm is typical of cattle under TNC, while 80 to 120 bpm are indicative of cattle under moderate thermal stress. When RR is greater than 120 bpm cattle are considered to be under EHL (Mount, 1979; Hahn *et al*., 1997; Gaughan *et al*., 1999). At this point close monitoring by feedlot personnel is required. Cattle with a RR greater than 140 bpm are under considerable stress, and cooling is required.

RR is primarily influenced by T_a, solar radiation, RH, and wind velocity. Of these variables, T_a has been identified as the most important (Hahn *et al*., 1997). A threshold air temperature for increases in RR in *Bos taurus* beef cattle was found to be 21.3^o C, with the slope of the linear relationship between RR and T_a above this point being 4.1 bpm per 1 ^{o}C T_a. This is lower than the 24^o to 25^o C threshold for the increase in internal body temperature and associated decrease in feed intake (Scott *et al*., 1983; Hahn *et al*., 1990, 1992). Likewise, the T_a threshold for increases in RR is below that found to increase water intake (NRC, 1981). In general, RR of steers can increase from non-stress levels of 30 to 60 bpm to a maximum rate within approximately one hour during both acute (two to three days) and chronic (seven to eight days) exposure to peak T_a. However, peak RR (~170 vs ~140 bpm) is greater for acute compared to chronic exposures, respectively. Although an adaptive RR response to T_a does exist (Hahn *et al*., 1992). Black Angus cattle exposed to 32.2^o C for seven days followed by a 20 days recovery period, exhibited a lower RR to the same range of T_a when tested a second time (Spiers *et al*., 1994).

There are sometimes alternating periods of rapid shallow and slower deeper breathing (possibly a result of conflicting thermoregulatory and respiratory requirements). Hahn and Gaughan (unpublished) have observed cattle exposed to hot conditions change RR from 150 bpm to 30 bpm for short periods of time (5 minutes in a 2 hour period). Hales (1969) suggests that the onset of the slower deeper phase of panting is associated with a brain temperature of 40.5^o to 40.8^o C.

A **RR ceiling** has been documented that is associated with a shift from rapid shallow breathing to slower open mouth panting. Gaughan *et al*. (1999) reported that the RR of Brahman steers peaked at 125 bpm, of Hereford steers peaked at 189 bpm, over the first 6 – 8 hours of exposure to hot conditions ($T_a = 36^o$ C), and then fell. Similar results have been reported by a number of authors (Kibler *et al.,* 1949; Spiers *et al.,* 1994). Therefore a fall in RR does not necessarily indicate that an animal is coping with the hot conditions, it may in fact indicate a worsening situation. Hence, the need to observe RR and panting at the same time. A simple panting score has been used by Holt (2001) to assist in the assessment of heat load in cattle (Plate 4.2.1). The scoring system used is outlined in Table 4.2.7.

Table 4.2.7: A panting score used in the assessment of heat load in feedlot cattle.

Panting Score	**Breathing Condition**	**RR** (a)
0	No panting	Less than 40
1	Slight panting	40 – 70
2	Fast panting, occasional open mouth	70 – 120
3	Open mouth + some drooling	120 – 160
4	Open mouth, tongue out + drooling	<160+ (b)

[a] Count respirations for at least 2 minutes.
[b] At this stage, RR may decrease due to change to deep phase breathing.

Cattle that have had prior exposure to hot conditions (previous day or so) tend to increase RR at lower ambient temperatures and at a faster rate than those without prior exposure (Gaughan, unpublished). This is part of the adaptation/acclimatization process.

The relationship between RR and T_a is complex. Curvilinear (Gonyou *et al*., 1979; Gaughan, 2001), quadratic (Gaalaas, 1945; Robinson *et al*., 1986; Spain and Spiers, 1996; Hahn *et al*., 1997), and sigmoid relationships (Kibler and Brody, 1950b; Worstell and Brody, 1953) have been reported. The differences in the relationship may be due to many of the factors outlined above, such as breed, degree of adaptation and body condition, to name a few.

While incorporating RR into a heat load model would improve the usefulness of short term prediction equations there is need for caution. Recent studies by Gaughan *et al*. (2000) suggests that RR of cattle at a given ambient temperature depends on:

- whether ambient temperature is increasing or decreasing,
- body condition, and
- time of day.

Gaughan (2001) has shown that the relationship between RR and T_a is strong (R^2 = 72% to 89%), with 72% to 89% of the respiratory response due to T_a.

RR lags T_a but the response is not clear-cut. Significant correlation coefficients for lags ranging from zero to four hours have been found (Hahn *et al*., 1997). During chronic hot conditions (4+ days of exposure), the highest correlations were generally for RR lagging T_a by two hours. The two-hour lag also is apparent visually in Figure 4.2.6. For acute hot conditions (first couple of days of exposure), observed overall lags tended to be slightly longer (typically two to three hours) than for chronic hot, primarily a result of the delayed RR recovery at night. Responses were less closely linked to T_a during TNC.

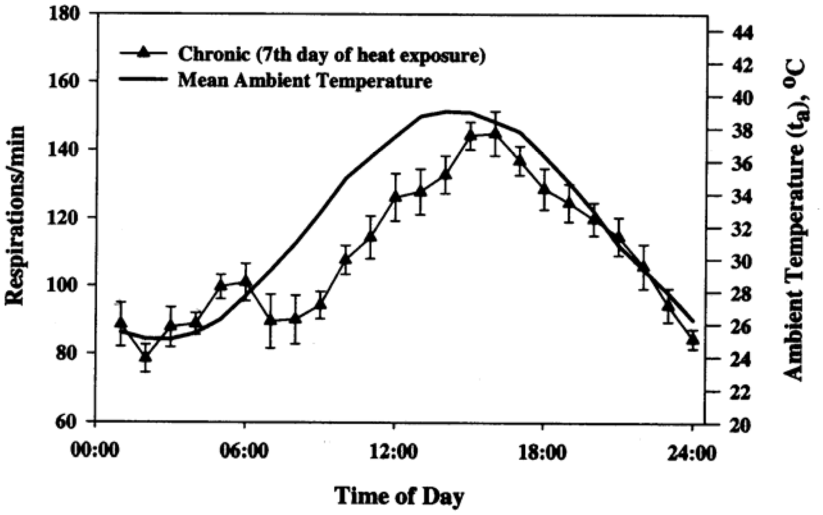


Figure 4.2.6: Average hourly RR of steers during chronic exposure to hot cyclic conditions (ie. hot days and cool nights).

In Conclusion:

- RR is a useful indicator of thermal load.
- RR principally increases with increasing T_a until it reaches a ceiling.
- RR responses to a given T_a depend on whether T_a is increasing or decreasing, prior exposure, breed, body condition etc.
- Changes in RR and BT lag behind T_a by 2 – 4 hours. Therefore it is desirable to record RR observations 2 – 4 hours prior to the hottest part of the day.

Plate 4.2.1: A steer with a panting score of 4

4.3 Nutrition

4.3.1 Introduction

Animals' diets directly influence their thermal balance. The diet of feedlot cattle is determined by the selection of ration ingredients, their quality and processing, diet formulation, feeding regime, and the management practices applied.

Nutritional factors determine the metabolic heat produced and hence contribute to the animal's ability to withstand EHL. The extent to which the diet meets the animal's nutrient requirements, can also influence its well being and contribute to its ability to cope with and handle adverse environmental conditions.

4.3.2 Nutrition - Heat Load Interactions

(a) *Metabolic Heat*

Metabolic heat is influenced by a range of factors, including the amount, type and quality of food ingested.

Metabolisable energy (ME) is applied to maintenance creating metabolic heat of maintenance, and to production, creating metabolic heat of production. This is illustrated in Figure 3.1, and explained by NRC (1981) as follows:

Dietary intake energy (IE) is the combustible energy ingested daily and is determined from the combustible energy density of the feed, its opportunity for ingestion, and the appetite of the animal. Feed is not completely digested or absorbed. The non-absorbed fraction is voided as faeces and its combustible energy is referred to as faecal energy (FE). Digestible energy (DE) may be calculated as IE – FE. However, as faeces also contain endogenous material, not all of the combustible energy of faeces arises directly from the non-absorbed fraction of the feed. Because of the endogenous component the calculated value (IE - FE) is more correctly termed the apparent DE. Similarly, metabolisable energy (ME) intake may be calculated by subtracting from the intake energy the energy losses occurring in faeces, urine (UE) and the gaseous products of digestion (GE), namely ME = IE – FE – UE – GE. Therefore, by definition, the ME intake is that which is available to an animal for maintenance and productive functions.

Maintenance functions involve the utilisation and oxidation of ME for:

- basal metabolism, that is represented by the heat energy created in sustaining body integrity by the vital life processes,
- voluntary activity and obtaining nutrients including the muscular activity of seeking and obtaining food, the processes of digestion, absorption, conversion of food into metabolisable forms, and the formation and excretion of waste products, and
- combating of external stressors related to an immediate and direct imposition of stress or stresses on the animal.

With respect to the last, animals are consistently faced with various types and magnitudes of stress to which they must continually adjust both behaviourally and physiologically. The ME oxidised for the various maintenance processes is released in the animal as heat (maintenance heat) and is ultimately disposed to the environment through physical avenues of heat exchange.

ME for production is available after the maintenance needs of the animal are met. The inefficiencies of product synthesis (heat of production), mean that energy available for production is not entirely incorporated into animal products, be it retained in tissue growth or fattening, or expelled in a product, such as milk, pelage, eggs, or offspring. The latter includes inefficiencies of product synthesis as well as the costs of retaining or expelling the product.

Typically, animals retain energy as glycogen, lipids, and/or protein when ME intake exceeds immediate needs. Retained energy is mobilised when the animal's demand is greater than the energy available from feed. For example, dairymen allow their cows to accumulate body fat (energy) when not lactating, expecting it to be mobilised and utilised during peak lactation when maximum intake may be insufficient to meet the cow's immediate needs for both maintenance and maximum levels of lactation.

In Summary:

The metabolic heat of maintenance is the heat generated from chemical processes for basal metabolism sustaining basic life processes, for voluntary activity and for combating of external stresses. The metabolic heat of production is the heat generated from productivity (synthesis) processes, for example the production of wool, and milk, and also for growth. Figure 3.1 represents the dietary intake of feed energy and its partition through the major routes of energy disposed of as wastes, as expelled products, and as heat or retained as tissue. Heat is dissipated via several pathways under the control of thermoregulatory mechanisms to prevent a rise or decline in body temperature.

During cold stress, heat from maintenance and productive processes may be of immediate value to the animal in maintaining body temperature, reducing the need of the animal to produce extra body heat by shivering or other cold-induced thermogenic processes. On the other hand, during heat load thermoregulatory mechanisms are activated to dissipate heat from the body in an effort to maintain homeothermy. Thus heat that may be beneficial during cold exposure may be a burden to the animal during periods of high heat load. For example, heat evolved during productive functions effectively lowers the thermo neutral zone resulting in a greater magnitude of heat load at a given temperature for productive animals compared with non-productive animals. The higher producing animals, which are consuming more feed and thereby creating greater metabolic heat, would appear to be the more susceptible to EHL.

Behavioural and physiological adjustments by the animal to external stressors of, affect feed intake, and hence energy intake and its partition within the animal, the amount of energy available for production, the level of productivity, and the efficiency of utilization of feed.

Severe heat load reduces appetite, which decreases DMI, hence productivity and metabolic heat production (NRC, 1981) (Refer 4.3.3.1).

(b) *Nutrients and Metabolic Heat*

The *Nutrient Requirements of Beef Cattle* (NRC 1996) expresses **nutrient energy** requirements in terms of net energy for maintenance (Ne_m), net energy for gain (Ne_g), ME and total digestible nutrients (TDN) for a range of growing and finishing animal types, providing for body weight, rate of gain, sex, pregnancy and lactation. There is provision to make allowance for differing environmental conditions, which has been discovered by industry to be of limited relevance when applied to commercial conditions, (Sparke, unpublished data).

The severity of heat load in beef cattle depends on a number of factors including quantity and quality of diet ingested, level of productivity, acclimatisation, breed of animal, and the environmental conditions affecting the animal's ability to rid itself of excess body heat (refer 4.1; 4.2).

Under very hot conditions, the ruminant in an attempt to maintain homeostasis, will reduce DMI and consequently heat generated from ruminal fermentation and metabolism. The less digestible the diet, the greater the rate and extent of reduction in intake during hot conditions (Beede and Collier, 1986). However, the energy requirement for maintenance increases by 10% to 30% at 30ºC to 40°C, over requirements at 18°C to 20°C (McDowell *et al*., 1969; Robertshaw and Finch, 1976; Purwanto *et al*., 1993). This higher maintenance need results from the elevated body metabolism and physiological activity needed to shed excess body tissue heat.

During severe heat load, maintenance requirements increase through the increased cost of panting and alterations in tissue metabolism because of increased tissue temperatures. The type and intensity of panting can provide an index for an appropriate adjustment in maintenance requirements. Oxygen consumption, and thus maintenance energy requirement, increases about 7% while the animal is in first-phase panting, i.e. rapid shallow panting, but 11% to 25% during second-phase open-mouth panting (Hales, 1973; Hales and Finlay, 1968; Kibler and Brody, 1951). The greater the expenditure of nutrient energy on maintenance and production, the greater the production of body heat.

Lower DMI during hot weather (Refer 4.3.3.1) reduces the nutrients available for absorption, with the available nutrients being absorbed less efficiently (West, 1999).

Nutrient fats have the lowest heat increment, followed by carbohydrates, then protein. However carbohydrates such as cellulose have higher heat increments then the more soluble carbohydrates, for example sugar and starch (Conrad, 1985). Diets with a lower roughage and higher fat content will reduce the thermic effect of feed (Table 4.3.1).

Table 4.3.1: Average efficiencies of utilisation of feed components, and their resultant heat increments (MJ/kg) of metabolisable energy in ruminants.

	Efficiency		**Heat Increment**	
Nutrient	**below maintenance**	**above maintenance**	**below maintenance**	**above maintenance**
Fat	-	0.79	-	0.21
Carbohydrate	0.8	0.54	0.2	0.46
Protein	0.7	0.45	0.3	0.55

Source: Adapted from Blaxter (1989)

Whilst inadequate nutrient intake may be of particular importance during hot weather, excesses of nutrients such as crude protein can also contribute to reduced efficiency of energy utilisation, potentially adding to livestock body heat load (West, 1999).

An excess of degradable **dietary protein** is undesirable. Nitrogen in excess of requirements must be metabolised and excreted as urea, requiring energy, so contributing to body heat (West, 1999), with the heat increment for protein metabolism being greater than for nutrient fats and/or carbohydrates (Conrad, 1985).

West (1999) reviewing nutritional strategies for managing the heat stressed dairy cow, concludes some mineral nutrients are required at higher levels during hot weather. **Mineral** losses via drooling and sweating (primarily K) and changes in blood acid-base chemistry resulting from hyperventilation reduce blood bicarbonate and blood buffering capacity and increase urinary excretion of electrolytes.

The source of additional supplementary electrolytes is relevant, with K and Na carbonates or bicarbonates suggested as the preferred sources rather than KCl or NaCl for cows subjected to hot conditions.

Examples are cited where lactating dairy cows subjected to hot climatic conditions supplemented with K well above minimum NRC recommendations (NRC, 1989) responded with greater milk yield. Similarly cows supplemented with 0.55% Na during hot climatic conditions demonstrated greater DMI and milk yield compared to those receiving 0.18% Na.

Beede and Collier (1986) recorded similar observations in lactating dairy cows. The authors also referred to one trial in Florida where LWG and FCE of feedlot steers were not improved by providing dietary K and Na above NRC (1984) recommendations during a subtropical Florida summer. It was suggested that this might be due to a lower metabolic requirement for K in non lactating compared with lactating heat-stressed animals.

Page *et al*. (1959) noted that a short term thermal stress caused a 30% decline in the hepatic **Vitamin A** store of steers. The reduction of liver Vitamin A content occurred whether animals were in sufficient Vitamin A status before being subjected to thermal stress, or if they were first depleted by feeding a Vitamin A deficient diet for 105 days before thermal stress was imposed. The effect of this decline on production or nutrient utilisation has not been recorded, and there appears an absence of follow on work.

Studies involving supplementing lactating dairy cattle during summer months with **niacin** are cited by West (1999). The results appear inconclusive, and offer little guidance to the cattle feedlot industries.

The South African (underground) mining industry has made significant reductions in the incidence of heat related disease in miners over the last several decades. This has been achieved as a result of investment and new practices, including a process of extensive acclimatisation of new miners prior to going underground, (takes 10-14 days) altering a range of physiological responses including the sweating response (MLA, 2000). **Vitamin C** consumption accelerates acclimatisation, particularly in the early stages (Stewart, 1989). No Vitamin C issues have been detected in ruminants, but there may be a relationship to rate of acclimatisation worth investigating.

An apparent **Vitamin E** deficiency, and a lower leg swelling in feedlot cattle during periods of prolonged hot weather has been identified under Australian conditions (Vanselow, 1996; Vanselow, personal communication, 2001).

Vitamin E is quickly depleted in stored feed with the deterioration accelerated during hot weather (Lynch, 1991; Coelho, 1991a, 1991b). Its shelf life is largely associated with an adequate antioxidant accompaniment.

In a Vitamin E response trial conducted at a NSW commercial feedlot when the (swelling) condition arose, additional Vitamin E supplementation of the diet fed affected animals alleviated the swelling condition and apparently prevented it reappearing (Vanselow, 1996). It is proposed Vitamin E deficiency damages microcirculation in the lower leg and in turn this damage impairs the animals' body temperature regularity ability. Additionally it has been proposed that animals with mud covering the lower legs may have their body temperature regulatory ability (physically) impaired (Vanselow, personal communication, 2001). The direct effect of a vitamin E deficiency, with probable associate impaired microcirculation in the lower leg, is unknown.

It has been suggested that **ergot** contamination of grains may exacerbate EHL in cattle (Entwistle *et al*., 2000). In practice, an ingredient quality control program monitoring ergot alkaloid content should eliminate this prospect.

(c) *Feed Ingredients and Metabolic Heat*

Feed ingredients influence metabolic heat by way of their individual characteristic heat increment and their influence on DMI.

Nutrient fats have the lowest heat increment, then carbohydrates (soluble forms less then cellulose), then protein (Refer 4.3.2.1). The ingredients with the lowest heat increments are the fats and oils, generally followed by the oilseeds, the grains and concentrates, then the roughages and forages with increasing heat increments associated with decreasing digestibility. High quality roughages such as corn silage have a lower heat increment then for example, the relatively high fibre stubble hays.

It is often stated that roughage feeding will increase heat production due to the heat of digestion. While this is partly true it should be pointed out that the digestion of roughage (digestion rate decreases with decreasing quality) is not as fast as grain based diets, and cattle cannot consume the same weight of roughage as they can grains. Therefore any heat production in cattle fed roughage is probably spread over a longer time period compared to those fed a grain diet.

The rate of fermentation will determine the rate of release of metabolic heat. This may vary between grains and is confused by variety, method and efficiency of processing, and rate of breakdown. Molasses with its rapid rate of fermentation releases its heat of metabolism early and if in the diet at high levels will bring forward the peak metabolic heat, after consumption. However, this is probably of little concern at the current industry diet inclusion rates.

During periods of hot weather where cattle are able to satisfactorily thermo regulate their body temperature by dissipating excess body heat, theoretical heat production assessments favour the use of feed ingredients with a lower heat increment. The lower fibre, high grain diets may indeed reduce metabolic heat production and contribute to lower heat load in the animal. Further, the low fibre, high grain diets provide more efficiently used end products, which contribute to lower dietary heat increment. This principle is supported for lactating dairy cows by both Beede and Collier (1986) and West (1999).

Mader (1986) demonstrated that feedlot cattle fed high energy finishing, were affected most by hot weather challenges. Gaughan *et al*. (1997a) showed that increasing heat load compromises the ability of feedlot cattle to adapt to high energy (10% roughage) diets and that BT increases with increasing ME intake and heat load.

The effects of diet ingredient composition on DMI and ME intake have been demonstrated in cattle under simulated feedlot conditions, by Mader *et al*. (1999a). Steers exposed to hot and thermo neutral (TN) environmental conditions, were assigned to three diet treatments, namely a 6% roughage (lucerne hay) diet fed *ad libitum* (LRA), the same diet limit fed by restricting intake to 90% of *ad libitum* (LRR) and a 28% roughage (lucerne hay 19%, barley straw 9%) (HRA) diet fed *ad libitum* such that ME intake approximated that of the LRR group (Table 4.3.2).

Table 4.3.2: The mean daily dry matter intake (DMI), metabolisable energy intake (MEI), and water intake (WTI)[a]

Variable	**TN**			**HOT**			
	LRA	**LRR**	**HRA**	**LRA**	**LRR**	**HRA**	**SE**
DMI (kg/d)[b,c,d]	7.13	6.52	7.17	6.06	6.22	5.88	0.18
MEI (MJl/d)[b,c,d,e,f]	89.11	81.46	81.84	75.77	77.74	67.07	2.17
DMI (% BW)[b,c,d]	2.00	1.80	1.99	1.67	1.75	1.67	0.03
MEI (% BW)[b,c,d,e,f]	5.98	5.38	5.42	4.99	5.23	4.55	0.10
WTI,							
L/d[e,f,g]	21.31	25.56	25.75	19.63	27.19	24.81	1.27
L/kg DMI[b,e,f,g]	3.04	3.78	3.46	3.02	4.36	4.27	0.22
L/MJl MEI[b,e,f,g]	0.239	0.314	0.315	0.259	0.349	0.369	0.08

[a] Cattle were fed a 6% roughage diet *ad libitum* (LRA), or approximately 90% of the *ad libitum* (LRR), or fed *ad libitum* a 28% roughage diet (HRA) while being exposed to thermo neutral (TN) or hot (HOT) conditions.
[b] ENV effect *(P<0.05).*
[c] ENV x RE diet interaction *(P<0.05).*
[d] ENV x LRA and LRR diet interaction *(P<0.05).*
[e] Diet effect *(P<0.05).*
[f] LRA vs LRR *(P<0.05).*

DMI declined significantly for all diets under hot conditions, and significantly more so for the 28% roughage (HRA) diet, with corresponding ME intake decline.

Under hot environmental conditions steers fed the high fibre 28% roughage (HRA) diet had significantly lower BT then those fed the low fibre 6% roughage (LRA) and the restricted (LRR) diet, and steers fed the LRR diet had significantly lower BT than those fed the LRA diet. Steers fed the HRA diet tended to have lower RR then those the LRA diet (Figure 4.2.5; Gaughan, personal communication).

The lower BT of the HRA and LRR fed steers would indicate that the ME intake prior to exposure to excessive heat, influences the ability of cattle to cope with the challenge of hot environments. In contrast, when cattle were exposed to cold conditions at or below TN environmental levels, higher energy diets were beneficial compared to higher roughage (lower energy) diets (Mader and Dahlquist, 1992).

The data suggests that under hot environmental conditions cattle with reduced DMI fed a higher roughage diet maintain lower body temperature. In essence, reduced ME intake under hot conditions incurs less metabolic heat, and hence lower body temperature (Mader *et al*., 1999a).

This has applied implications in that increasing the roughage level prior to exposure to EHL conditions has the capability to influence the ability of the cattle to cope with subsequent exposure to EHL.

Additionally, Mader *et al.* (1999a), Gaughan *et al.* (1997b), observed that the ability of feedlot cattle to adapt to high energy low roughage diet (40% roughage, then 25%, then 10%) was compromised when exposed to hot conditions. As dietary energy levels increased, ME intake generally increased, and BT increased. Only when the cattle were fed the most energy dense diet (10% roughage) did heat exposure appear to result in a significant reduction in DMI and ME intake. Intakes of individually fed cattle were maintained when 40% and 25% roughage diets were fed regardless of environmental conditions. However, BT and PR increased as diet energy increased, under both TNC and hot conditions. Results suggest that stepping up to and feeding high-energy diets to feedlot cattle increased BT, tended to increase metabolic rate and contributed to heat related stress during periods of high temperature and humidities. This implies that adapting cattle to high energy diets when exposed to high temperature and humidities, partially contributes to EHL.

Restricting high concentrate diets intake as a means of alleviating the severe stress of feedlot cattle under hot climatic conditions by way of lowering heat production, has been examined by Holt (2000). Cattle on two diets had their DMI restricted to 70%-80% of *ad libitum* intake for either 21 or 42 days. Cattle fed restricted diets maintained lower body temperatures during periods of heat stress, and it was concluded that under hot environmental conditions heat levels may be reduced by restricted feeding and may be beneficial in protecting cattle from forecasted hot conditions. This work was researched under conditions providing 1.2 metre bunk space per beast, or sufficient for all cattle to front the bunk at once. This differs significantly from the commercial feedlot industry standards, where restricted feeding is commonly associated with marked DMI variances between dominant and submissive cattle, and subsequent increased risk of acidosis incidence.

Under controlled environment conditions, Nienaber *et al*. (2001) demonstrated cattle subjected to “severe” environmental conditions, adapt to conditions by regulating feed intake, with a high correlation between meal size, number of meals, and daily DMI, with Ta. Restricting feed intake also had an effect, but the results were not conclusive. The short term restriction of intake prior to an EHL event may be counterproductive if unrestricted *ad libitum* feeding occurs with the onset of the heat challenge. The intake rebound can cause increased heat load, and increased mortalities.

Mader *et al*. (2000b) state that overall, programmed feeding systems generally have not provided long term improvements in feed efficiencies in feedlot cattle, and would only be recommended for use during periods of hot weather. Greater long term reductions in BT appear to occur if the cattle are on the programs for 1-2 weeks prior to the heat wave occurring. Also, since the benefits of reduced intakes appear to carry over for a period of 1-2 weeks, depending on length and severity of restriction, short term reductions in BT will exist once cattle go back to being fed *ad libitum*. The reduced BT is likely due to a reduction in metabolic heat load and a concurrent reduction in metabolic rate. The reduction in metabolic rate is likely the contributing factor keeping BT down during the initial period *ad libitum* feeding takes place. Utilising programmed feeding systems from December to early March would appear to be sufficient to cover most heat wave periods in Australia.

4.3.3 Feed Intake

(a) *Environment Interactions*

Environmental conditions affect the level of DMI and the utilization of ME ingested.

In general, cattle will decrease DMI (Bianca, 1965), or reduce grazing time when exposed to hot conditions (Bennett *et al*., 1985). The effects of EHL on DMI of cattle have been measured mostly under controlled conditions (Dahlquist, 1993). Results from field studies do not always agree with data collected under controlled experimental conditions. For example, Rittenhouse and Senft (1982) found that the optimum T_a for grazing activity changed from month to month. The shift was probably due to thermal acclimation by the cattle (Senft and Rittenhouse, 1985).

Heat wave events have frequently demonstrated the reduction in voluntary DMI in commercial cattle feedlots (eg. Hahn, 1996; Hahn and Mader, 1997).

Estimates of change in DMI with Ta ranges, derived from feedlot feeding experiments are illustrated in Figure 4.3.1 (NRC, 1981).

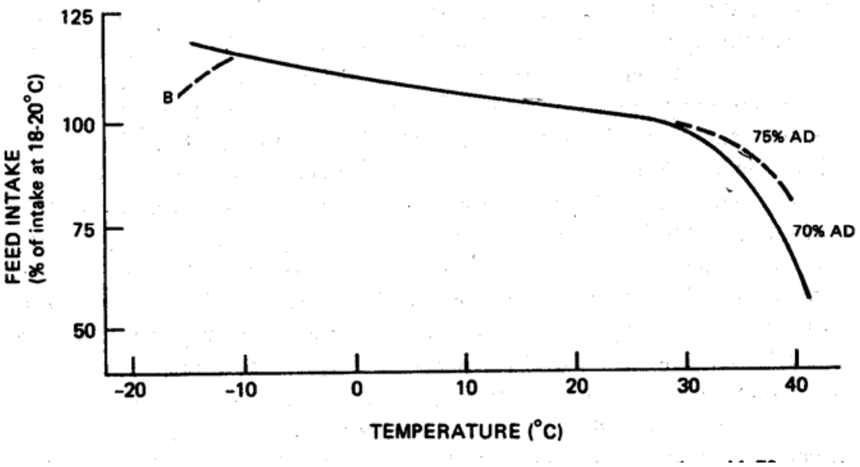


Figure 4.3.1: Estimated changes in DMI of feedlot cattle on a ration with 70% apparent digestibility or at temperatures above 27°C, 75% apparent digestibility. "B" indicates behavioural changes (adapted from Leu *et al*., 1977; Milligan and Christison, 1974).

From 10°C to 25°C there was little change in feed consumption; however on a 70% digestibility diet daily DMI declined rapidly when the cattle were exposed to more then 6 hours per day of temperature above 30°C. Increasing the energy value of the ration to 75% apparent digestibility appeared to help animals maintain DMI.

It was concluded that above 25°C and below -10°C the type of ration and level of temperature markedly affected intake, but from near 0°C to 25°C the digestibility of the ration is more important than Ta. Even though Ta is the environmental variable most frequently associated with DMI, lot surface and space per animal, the animals' thermal susceptibility, acclimation and diet, and their interaction effects, are also important to DMI (NRC, 1981; Young, 1987).

In principal, there is an inverse relationship between Ta and DMI, voluntary food intakes tending to increase as Ta decreases and decrease as Ta increases (Table 4.3.3).

Table 4.3.3: mary of Voluntary Food Intake of Beef Cattle in Different Thermal Environments.

Thermal Environment	**DM Intakes Relative to Values Tabulated in *NRC Nutrient Requirements of Beef Cattle***
> 35°C	Marked depression in intake, especially with high humidity and/or solar radiation and where there is little night cooling. Cattle on full feed – 10% to 35 % depression. Cattle near maintenance – 5% to 20 % depression. Intakes depressed less when shade or cooling available and with low fibre diets.
25°C to 35°C	Intakes depressed – 3% to 5 %.
15°C to 25°C	Preferred values as tabulated in *NRC Nutrient Requirements of Beef Cattle.*
5°C to 15°C	Intakes stimulated – 2% to 5 %.
-5°C to 5°C	Intakes stimulated – 3% to 8 %. Sudden cold snap or storm may result in digestive disturbances in young stock.
-15°C to -5°C	Intakes stimulated – 5% to 10 %.
< -15°C	Intakes stimulated – 8% to 25 %. Intakes during extreme cold (< -25°C) or during blizzards and storms may be temporarily depressed. Intake of high roughage feeds may be limited by bulk.

Source: NRC (1981); Conrad (1985)

The effect of Ta on relative DMI is illustrated in Table 4.3.4.

Table 4.3.4: Effect of ambient temperature on relative DMI[a]

	Relative Intake[b]						
Ambient temp. °C:	**6-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**
B. taurus, 5 - 7 mo[c]			1.00		0.86		
B. indicus, 5 - 7 mo[c]			1.00		0.89		
Lact. cows, wind <0.2 m/s[d]			1.00		0.88		0.56
Lact. cows, wind 3.5 – 4 m/s[d]			0.97		0.93		0.76

	Relative Intake[b]						
Ambient temp. °C:	**6-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**
Dry cows, wind <0.2 m/s[d]			1.00		0.92		0.79
Dry cows, wind 3.5 – 4 m/s[d]			0.97		0.96		0.83
Lact. cows, RH < 50%[e]			1.00		0.88	0.87	0.74
Lact. cows, RH > 50%[e]			1.00	0.97	0.87	0.79	
B. taurus, conc. diet[f]	1.30		1.00			0.83	
B. taurus, roughage diet[f]	1.10			1.00			0.60
B. indicus, conc. diet[f]	1.38		1.00			0.88	
B. indicus, roughage diet[f]	1.07		1.00			0.87	

[a] Adapted from Young (1987).
[b] Ratio of DMI to intake at thermo neutrality.
[c] Colditz and Kellaway (1972).
[d] Brody et al. (1954).
[e] Johnson et al. (1963).
[f] Olbrich et al. (1973).

The immediate response of cattle exposed to hot conditions is to reduce DMI, especially when they have access to high energy diets. The reduction in DMI is an attempt to bring metabolic heat production in line with heat dissipation capabilities (NRC 1981,1987).

The level of DMI under hot conditions can be maintained close to TNC intakes by the provision of shade structures, and when there is adequate night time cooling (Muller and Botha, 1997; Holt *et al*., 1998).

Cattle with access to shade structures (Mader *et al*., 1999b), cooling (Holt *et al*., 1998), will under some conditions have higher DMI intake compared to those without access to such facilities. There appears to be a stage of adaptation to facilities, and greater DMI may not occur straight away.

In the commercial feedyard environment, an overall feedyard DMI reduction in summer may indicate the onset of a severe heat load event in the cattle.

(b) *Ration Composition*

DMI generally increases as the proportion of roughage increases under TNC. Roughages tend to be more highly digested during warm conditions than when the same diet is fed to cattle exposed to cold temperature. The NRC suggest a basis for adjustment for thermal effect on digestibility of ingredients and diet component values, an example of which is provided in Table 4.3.5.

Table 4.3.5: Example of Adjustment to the Feeding Value of Alfalfa Hay for Feeding to Beef Cattle Exposed to Warm (30°C), Thermo neutral (20°C), and Cold (-5ºC) Environmental Conditions.

	Environmental Temperature (°C)		
	30	**20**	**-5**
ME (MJ/kg)	8.12	8.03	7.82
NE_m (MJ/kg)	4.77	4.73	4.64
NE_g (MJ/kg)	1.67	1.67	1.63
TDN (%)	53.5	53.0	51.7
Digestible protein (%)	11.5	11.4	11.4

Source: NRC (1981)

Warren *et al*. (1977) in a study using Holstein steers which were fed chopped forages found reduced rates of passage of ingesta during a period of thermal stress led to increased gut-fill, and concluded that the increased gut-fill probably depressed the animal's appetite. There is also the possibility of a direct negative effect of elevated BT on the appetite centre of the hypothalamus (Baile and Forbes, 1974). While research data remain limited on the physiological mechanisms of this influence of the environment the effect appears associated with rate of passage of digesta, metabolic acclimatisation, and thyroid hormone activity (NRC,1981).

(c) *Frequency and Timing of Feeding*

The act of actually providing feed to the feed bunk stimulates eating behaviour in feedlot cattle. Supplying feed to the cattle is commonly practiced in both the morning and afternoon.

The feeding activity of animals is closely linked to photoperiod, with feeding activity stimulated by sunrise and sunset (Gonyou and Stricklin, 1984). Southern Queensland field studies demonstrated cattle feeding activity closely followed natural feeding peaks at sunrise and sunset, with most feeding activity occurring at sunset (Lawrence, 1998). Earlier work demonstrated most of the eating activity of feedlot steers occurred at sunrise and during early afternoon (winter) or early evening (summer) with most animals normally preferring rest and rumination in between these times with minimal feeding activity occurring (Ray and Roubicek, 1971).

The heat production of feedlot cattle in a hot environment were shown to be closely affected by time of feeding (Brosh *et al.,* 1998), increasing during and after feeding. Feed quality has a major effect on heat production. With a pending high heat load situation, reducing feed quality and/or changing the time of feeding to the late afternoon generally relieves the situation. Feeding in the cooler hours of the day may improve passive dissipation of heat from the body to the environment.

Gaughan *et al.* (1996) not surprisingly found there to be no benefit from afternoon feeding when limited night time cooling occurs. Nienaber and Hahn (1991) observed cattle fed *ad libitum* increased the number of meals each day under hot conditions, while the size of the meals decreased in comparison to cattle under moderate conditions.

4.3.4 Water Intake

(a) *Water Sources*

Water is a nutrient essential for animal life. The needs of livestock are sourced from:

- free drinking water
- water contained in foods, and
- metabolic water produced by oxidation of organic nutrients.

The first two sources are of major concern in the management of livestock, although in periods of negative energy balance (when depot fat and/or tissue protein are being utilised) metabolic water may be important. Water in feeds is highly variable. Water losses by animals are principally by way of:

- urine
- faeces, and
- evaporation from the body surface and respiratory tract.

In cattle with their relatively high fibre diets requiring proportionately more fluid to carry the ingesta through the gastro-intestinal tract compared with non ruminants, the loss of water through faeces is substantial and approximates urinary losses.

Water loss from the respiratory tract is extremely variable, depending on RH and RR. Expired air is over 90% saturated; hence under conditions of low RH, respiratory losses are high. Conversely losses are low when inspired air is near saturation. When the RR increases in response to high Ta or other behavioural stimuli, the rate of respiratory water loss is increased, for example, for cattle doubling from when at 27ºC till when under severe heat load (NRC, 1981).

Under severe heat load cattle may lose significant water through drooling (McDowell and Weldy, 1967).

(b) *Water Needs*

The total water needs of feedlot cattle vary with their live weight, diet and ration composition, DMI, physiological state, environmental factors and water quality. Feedlot cattle satisfy their major water requirements as free drinking water with consumption increasing markedly as the ambient temperature rises above 25ºC.

The relationships between ambient temperature and water requirements of beef cattle has been summarised by NRC (1981).

Table 4.3.6: Water Requirements of Beef Cattle in Different Thermal Environments.

Thermal Environment	Water Requirements
> 35°C	8 to 15kg water per kg DMI.
25°C to 35°C	4 to 10kg water per kg DMI.

Thermal Environment	**Water Requirements**
15°C to 25°C	3 to 5kg water per kg DMI. Young and lactating animals require 10%-50% more water.
-5°C to 15°C	2 to 4kg water per kg DMI.
< -5°C	2 to 3kg water per kg DMI. Increases of 50% – 100% occur with a rise in ambient temperature following a period of very cold temperature, e.g. a rise from –20°C to 0°C.

Source: NRC (1981)

In comparison with this data, the water intake estimates for Dalby, Queensland (Table 4.3.7) appear minimal.

Table 4.3.7: Estimated water intake (Dalby) for cattle of different liveweights (applying Winchester and Morris, 1956)

Cattle Liveweight (kg)	**300 kg**	**450 kg**	**600 kg**	**750 kg**
Dry Matter Intake (% of liveweight)	2.7%	2.7%	2.4%	2.1%
(kg per day)	9.0	12.15	14.4	15.75

Month	**Max. Temp.**	**Min. Temp.**	**Mean Temp.**	**Daily Water Intake (L/hd/day)**			
Jan	31.6	18.5	25.1	42.5	57.3	68.0	74.3
Feb	31.3	18.2	24.8	41.9	56.5	67.0	73.3
Mar	29.5	16.3	22.9	38.8	52.3	62.0	67.9
Apr	27.1	12.6	19.9	35.4	47.8	56.7	62.0
May	22.6	7.8	15.2	32.8	44.3	52.5	57.4
Jun	19.8	5.6	12.7	32.1	43.3	51.3	56.1
Jul	18.8	3.9	11.4	31.8	42.9	50.8	55.6
Aug	20.6	5.4	13.0	32.1	43.4	51.4	56.2
Sep	24.1	8.3	16.2	33.2	44.8	53.1	58.1
Oct	27.5	12.7	20.1	35.6	48.1	57.0	62.4
Nov	30.1	15.4	22.8	38.6	52.1	61.7	67.5
Dec	31.3	17.4	24.4	41.1	55.5	65.8	72.0
Mean			**18.5**	**33.9**	**48.4**	**57.4**	**62.8**

Source: Watts *et al*. (1993)

Shade in a pen can affect summer water consumption, as demonstrated during the 1993-1994 summer in two South East Queensland commercial feedlots (MRC, 1994). In feedlot A, the peak flow rate was 2.09 L/100kg LW/hour compared to 1.78L/100kg LW/hour and average daily water consumption 8.2 L/100kg LW/day compared to 7.5 L/100kg LW/day, for unshaded and shaded pens respectively. In feedlot B where average daily temperatures were generally less, average daily water consumption was 6.6 L/100kg LW/day compared to 6.1 L/100kg LW/day for unshaded and shaded pens respectively.

In contrast, Brosh *et al*., (1994) in a South East Queensland study concluded shades did not significantly affect water consumption.

(c) *Factors Affecting Water Intake*

As **air temperature** rises the water intake of feedlot cattle generally increases. The estimated water intake of non-lactating cattle expressed as kg water/kg DMI is portrayed in Figure 4.3.2.

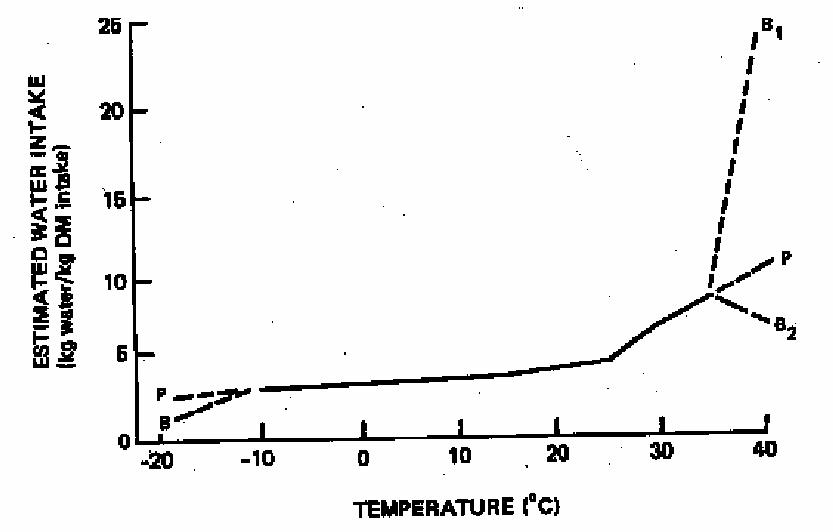


Figure 4.3.2: Estimated *ad libitum* water intake for non lactating cattle over the temperature range –10°C to 35°C; solid line with extensions "P" at high and low denoting physiological needs; "B_1" and "B_2" indicate behaviour patterns at extreme temperature. Source: NRC (1981).

It is estimated from -10°C to 20°C there is a slight progressive rise in water consumption. Above 25°C consumption rises more sharply due to the initiation of sweating and an increased RR. The estimated physiological needs are 10 kg water/kg DMI at 40°C, but usually the cattle are so distressed that behaviour becomes variable, in which case water intake may rise markedly (B_1) or even decline (B_2) as illustrated in Figure 4.3.2. This decline in water intake might be as a result of a DMI decline (Yousef *et al*., 1968).

In hot environments, a major physiological reaction is an increase in water intake resulting in an increase in body water content. As water is lost during a heat challenge a temporary deficit occurs, and the resultant increased body fluid mineral concentration stimulates the hypothalamic thirst centre to increase water consumption (Alnaimy *et al*., 1992).

Yousef *et al*. (1968) found increased water consumption is also associated with increasing evaporative cooling and that above 30°C, cattle tended to drink more often, at least every two hours. *Bos Taurus* heifers increased the average number of drinks from 60 drinks/day at 20°C to 90 drinks/day at 30°C. There is also a change in time of drinking, with night water consumption increasing (Yousef *et al*., 1968). McDowell (1972) reported that water consumption of lactating cows was 29% higher at 30°C compared to 18°C.

The effects of **water temperature** on water intake appear variable. Lofgreen (1975) found British cattle in a hot environment consumed more feed, and gained more weight with improved energy utilisation when given access to water cooled to 18.3°C compared to 32.2°C. The level of roughage in the ration did not affect the response to cold water. Cattle provided with cold water drank significantly less than those given warm water. Brahman X

British crossbred cattle under the same conditions performed similarly on cold or warm water. Feed intake and efficiency of energy utilisation declined with British cattle on warm water, in contrast to the crossbred cattle, which appeared unaffected.

Table 4.3.8: Effect of Drinking Water Temperature – Comparison of British and Brahman X British Cattle.

Item	Water Temperature	
	32.0°C	**18.3°C**
<u>British Cattle</u>:		
Daily feed intake (kg)	8.12^{a}	8.33^{b}
Daily weight gain (kg)	0.99^{a}	1.15^{b}
Feed per unit gain (kg/kg)	8.17^{a}	7.23^{b}
<u>Brahman x British crosses</u>:		
Daily feed intake (kg)		
Daily weight gain (kg)	8.40^{b}	8.11^{a}
Feed per unit gain (kg/kg)	1.14^{b}	1.10^{b}
	7.35^{b}	7.36^{b}

^{a,b} Means in appropriate comparisons having different superscripts are significantly different (P<.01).

It has been demonstrated that **drinking water flow rates** can influence water intake, animal behaviour and performance in dairy cows (Andersson *et al.*, 1984). Higher flow rates into drinking bowls led to a significant increase in water intakes, with daily drinking frequency highest at the lowest flow rate. There were no observed signs of water shortage, nor signs of dehydration on the lowest flow rate and overall feed consumption was not significantly affected. Also, dominant cows consumed significantly more water and hay then the submissive cows; milk yield was also significantly higher for the dominant cows.

The influence of **breed** on water intake is small. Whilst it was originally postulated *Bos indicus* cattle had lower intake of water then *Bos taurus*, it has been concluded after making adjustments for a constant body size and DMI the differences are negligible (NRC, 1981).

The animal's **physiological state** influences water intake. Young cattle generally have higher intakes of water per kilogram of DMI than do older cattle (Pettyjohn *et al*., 1963). In the 15°C to 25°C comfort zone young and lactating cattle require 10% to 50% more water (Table 4.3.6).

Water consumption is also influenced by the **physical form** of the diet, and by its protein and salt levels. The need for water increases with increasing intakes of protein and salt (NRC, 1981). Animals consuming a high salt, high protein and/or a high roughage diet consume significantly more water then those on low salt, low protein and/or low roughage diets (Hafez, 1968; Yousef *et al*., 1968).

(d) *Quality and Availability*

Water quality is important to cattle, especially with respect to the content of salts and toxic compounds (NRC, 1974). Poor quality water can reduce water intake; newly introduced cattle may be reluctant to drink water associated with unusual odour or taste. In extreme cases low quality bore water may influence water intake and be an important consideration limiting maximum intake under high temperature conditions.

Additionally, water sourced from streams may deteriorate in quality (mud, taste, smell, appeal) after increased flows following storms, which may inhibit water intake, and be a major concern should high temperatures concurrently prevail.

Feedlot cattle require access to adequate good quality water at all times (Refer 6.1.7), and in particular during hot weather conditions.

4.3.5 Growth

(a) *Compensatory*

An inherent aspect of back grounding programs that restrict growth by limiting feed quality or quantity or adverse pastoral or feedlot conditions that restrict growth, is a period of accelerated growth once cattle are reinstated on a high energy diet, a phenomena commonly referred to as compensatory growth (Carstens, 2001).

The degree of compensation following periods of growth restriction is highly variable and affected by a number of factors including the stage of maturity at the start of the growth restriction, the severity of growth restriction, the duration of growth restriction, and the pattern of growth during realimentation. Complete compensation, that is the same weight at the same age as non restricted contemporaries, is rarely observed in cattle (Ryan *et al*., 1993). Carcase characteristics and overall production efficiency may be affected.

Growth during the compensatory period is faster and more efficient than growth during continuous *ad libitum* feeding of high grain diets.

Hot weather alters feeding times and reduces feed intake as the animal attempts to maintain homeothermy by balancing heat production and heat dissipation capabilities (Hahn, 1996). This has a consequent adverse effect on growth. The extent to which recovery from suppressed growth is achieved can relate to the severity of the heat stress and its longevity. A moderate heat load has been noted to have minimal effect on eventual market weight and carcase quality, while a severe heat load may eliminate the possibility of full recovery from suppressed growth (Hahn *et al*., 1974).

The immediate effect of a heat load episode is a reduction in DMI of up to 30%. However, the carry over effect can be for considerably longer and permanently ongoing, as cattle rarely return to the previous DMI (Gaughan, personal communication).

(b) *Meat Quality*

Brosh *et al*. (1994) reported the belief among some Queensland cattle feedlot operators that shade reduces marbling fat and hence potentially the carcase value for Japanese orientated markets. This belief is probably based on the observations of Clarke (1993) who found that Brahman cross steers given access to shade, had more rump and rib fat and less intramuscular fat, suggesting shade may increase subcutaneous fat and reduce intramuscular fat.

The observations of Fell *et al*. (1993) were inconclusive as to the full effect of shade on meat quality but did suggest some adverse effects on marbling scores in those situations where growth rate had been enhanced by shade. No differences in subcutaneous fat thickness or dressing percentages were observed and only minor differences in fat colour and meat colour were identified.

In three summertime trials over three consecutive years, Mader *et al*. (1999a) noted carcass characteristics (dressing %, fat thickness, marbling score) were not significantly different between shaded and not shaded cattle.

There appears a lack of objective evidence as to the effect of EHL syndrome on the meat qualities of feedlot steers, other then the natural effect of reduced productivity and possibly reduced growth rate, necessitating a greater time to achieve the intended finish. The effect of the associated stress may logically influence meat quality during the immediate following period by increasing the incidences of dark cutters.

(c) *Conclusion*

Animals' diets directly influence their thermal balance with metabolic heat a major influence on the animals' susceptibility to, and ability to withstand, EHL events.

The metabolic heat produced basically reflects the dietary energy intake and is influenced by nutrient and ingredient heat increments, diet adequacy, DMI, ME intake, and environmental interactions. Additionally, the time and frequency of feeding, and water intake affect the animals' ability to cope with metabolic heat under hot weather conditions.

Research indicates the application of sound nutritional principles and judicious dietary manipulation to reduce metabolic heat, and, attention to feeding practice, may contribute to reducing the adverse effects of seasonal hot weather conditions on feedlot cattle productivity and so reduce the incidence and effects of EHL.

Management program recommendations applying these nutritional principles follow (Refer 6.3).

4.4 Behaviour of Cattle Exposed to EHL

Exposure of cattle to EHL will initiate behavioural change. Behavioural change is primarily an attempt to maintain acceptable comfort levels. Behavioural responses to climatic conditions are highly variable and appear to be poorly correlated with performance (Hahn and Bond, 1977). In addition, Ingram (1978) reported that animals free to choose among various environments that could alter their heat balance did not always select the least stressful situations (Holt, 2001). This adds to variability in behavioural responses to changing climatic conditions. Some of these behavioural responses, such as changes in RR, DMI and water consumption are discussed in Section 4.2. The following list adapted from Young and Hall (1993) shows the behavioural symptoms of cattle when they are progressively exposed to EHL conditions.

1. Body alignment with solar radiation. (4.4.1)
2. Shade seeking. (4.4.2)
3. Increased time spent standing. (4.4.3)
4. Reduced DMI. (4.2.3.3)
5. Crowding over water trough. (4.4.4)

6. Body splashing. (4.4.5)
7. Agitation and restlessness (4.4.6)
8. Reduced or stopped rumination
9. Bunching to seek shade from other cattle. (4.4.7)

10. Open-mouth and laboured breathing. (4.2.4.5)
11. Excess salivation.
12. Ataxia/inability to move.
13. Collapse, convulsions, coma.
14. Physiological failure and death.

Failing to cope

According to Young (1993) cattle will usually cope up to symptom 9. The onset of behavioural symptom 10 is a sign that cattle are failing to cope with the hot conditions. Behavioural symptoms should not be used on their own as an indicator of thermal stress. Factors such as those outlined in Section 4.2 also need to be considered.

4.4.1 Body alignment with solar radiation

When exposed to hot climatic conditions, and in the absence of shade, animals will align their bodies to minimise exposure to solar radiation.

4.4.2 Shade seeking

Will cattle seek shade? Unfortunately there is not a lot of behaviour data available. Providing shade is one of the primary methods used to protect cattle from EHL (Curtis, 1993). Fraser (1985) reported that European breeds of cattle will seek shade when ambient temperature exceeds a threshold somewhere between 22^{o} – 27^{o} C. Bennett *et al*. (1985) found that the time spent in shade increases by 23 minutes per 1^{o} C increase in ambient temperature between 15^{o} and 36^{o} C. Vandenheede *et al*. (1995) reported that Belgian Blue bulls increased their use of shelter from 10% of the day to 49% of the day when maximum ambient temperature exceeded 20^{o} C. Hoffman and Self (1973) studied the behaviour of feedlot steers during summer and winter in the USA. They found that the steers spent 46% of the time under shade during summer and 21% of the time during winter. During the summer the cattle used the shade to the greatest extent between 0900 hours and 1800 hours. Ray and Roubicek (1971) reported that feedlot steers commenced movement to shade when ambient temperature was approximately 28^{o} C. In their study all cattle were under shade by the time ambient temperature was 30^{o} C, and remained under shade for approximately 11 hours. Gaughan *et al*. (1998) working with dairy cows reported 43% of cows were under shade when ambient temperature was between 26^{o} and 29^{o} C, and that 90% were under shade when ambient temperature was between 30^{o} and 34^{o} C. Clarke (1993) reported that 73% of Brahman cross steers were using shade at 1500 hours when air temperature was 35^{o} C. When air temperature was 30^{o} C, 54% of the steers were under shade at 1500 hours. It appears as if natural shade (trees) is the first preference for cattle (Beede *et al*., 1987). When given the opportunity with artificial shade structures cattle will choose the structure that provides the highest protection from sunlight (Bennett *et al*., 1985; Gaughan *et al*., 1998).

Conclusions:

- *Bos taurus* cattle will commence shade seeking as ambient temperature exceeds 20° C.
- Adapted *Bos taurus* cattle will commence shade seeking activity when ambient temperature is approximately 28° C.
- Solid shade structures are preferred by cattle.

4.4.3 Time spent standing

Shultz (1984), Igono *et al*. (1987) and Frazzi *et al*. (2000) observed that dairy cows exposed to EHL spent more time standing, in an attempt to dissipate body heat, than those that were cooled. However, Gaughan (2001) using beef steers did not find any difference in the amount of time spent standing or lying between steers exposed to EHL or those that were cooled by sprinklers. However, in the study by Gaughan (2001) the housing system (steers were restrained in stalls) used may have had an impact on animal behaviour. The cattle did not have the ability to choose where they could stand or lie, and could not avoid the sprinklers. In the studies by Shultz (1984), Igono *et al*. (1987) and Frazzi *et al*. (2000) the cattle had the ability to move freely and were able to move outside or choose resting areas away from sprinklers. Muller *et al*. (1994) reported that cows without access to shade spent more time standing than those with access to shade (510 vs 450 min/day). Bennett *et al*. (1985) did not find any difference between breeds (Brahman, Shorthorn and Brahman cross steers) for time spent lying, standing or ruminating during the summer. Hoffman and Self (1973) reported that the time feedlot steers spent lying was approximately 12 hours per day and was not affected by season.

4.4.4 Crowding over water trough

It has often been observed that feedlot cattle will crowd around water troughs when they are exposed to EHL. Crowding around a water trough is not necessarily an indicator of increased water intake. Cattle will often place their heads above the water trough in an effort to cool their heads. Water evaporating from the trough will lower the air temperature immediately above the trough, and thus provides a cooler micro-environment. During the 1999 heat wave in Nebraska, USA, cattle were observed to be dunking their muzzles into water troughs but not actually drinking (Holt, personal communication 2001). Similar observations have been made with feedlot steers and dairy cows in Australia.

Plate 4.4.1: Cattle crowding around a water trough in a Nebraska feedlot during the 1999 heat wave. (Source Holt, unpublished data).

This type of behaviour can cause problems because it will restrict access to the trough.

4.4.5 Body splashing

If available cattle will stand in dams, creeks and even water troughs in an attempt to cool their body. Some dairy feedlots in Florida have installed wading ponds so that cows can cool themselves. Where this is not an option cattle will try other means to cool them selves. This may include dunking their heads in water troughs.

4.4.6 Agitation/Restlessness

In the 1999 Nebraska USA heatwave one feedlot operator reported that at approximately 12 noon cattle became restless and agitated in a number of pens. The animals moved as a herd from one end of the pen to the other, in what appeared to be aimless wandering. By approximately 6 pm cattle had begun to die in these pens.

4.4.7 Bunching

Bunching is a phenomenon seen in cattle and sheep. During periods of hot weather, especially if there is a lack of shade, and if cattle are under duress they will bunch together. Bunching is thought to occur for a number of reasons. One is that cattle are seeking shade, so will stand close to another animal to obtain shade from that animal. Secondly, when animals are distressed they “herd” together. If flies are a problem cattle may also bunch in an attempt to escape from the flies. Holt (2001) found that cattle tended to bunch together during periods of hot weather, and that there was a relationship between coat colour and bunching under hot conditions (Figure 4.4.1).

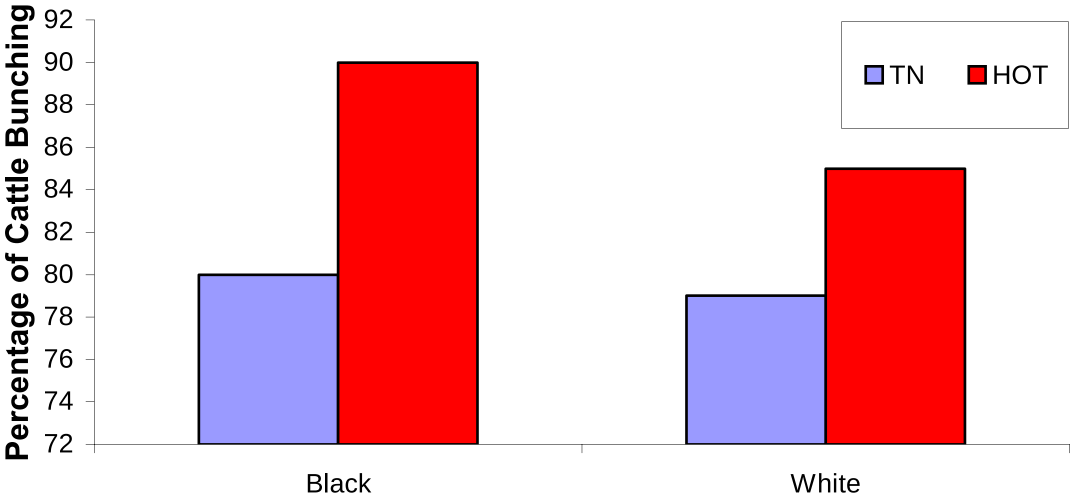


Figure 4.4.1: The effect of climatic conditions and coat colour on bunching by feedlot cattle. (Adapted from Holt, 2001).

Plate 4.4.2: Feedlot cattle bunching, seeking shade from each other, during exposure to EHL.

Bunching reduces the ability of cattle to dissipate heat, and therefore management needs to have strategies to reduce this phenomenon.

4.5 Management

Feedlot management has at its disposal the means to influence the severity of heat load placed on cattle during hot environmental conditions. These include: use of the available resources (eg. pen design, waters, pen mounds, shade producing shelters, sprinkler systems) the husbandry of livestock (eg. processing, movement and handling, feeding programs), and the involvement of personnel. These management areas are considered under:

- resource management,
- livestock management, and
- personnel management.

4.5.1 Resource Management

Resource management involves the continuous use of natural and man-made physical resources. These comprise the natural topography, climate, weather, soil type and water, and, the man made feedlot infrastructure of pens, waters, mounds, shades, and sprinklers. The management of these resources is in design (eg. type, location), and use (eg. stocking density, waste management).

To date little consideration has probably been given to the potential incidence of EHL in cattle and its management when selecting feedlot sites or when adding additional pens to an existing feedlot. Generally the principal factors considered are proximity to feed and water resources, suitable livestock resources, and markets, along with environmental issues and the cost of establishment and operation. However, climatic conditions (temperature, solar radiation, air movement, rainfall and humidity) and natural soil type, topography, prevailing winds and aspect, can exacerbate or ameliorate EHL in cattle.

The pen micro-environment may be influenced by the topographical relief of the feedlot influencing rainfall, humidity and prevailing winds. Also site aspect has a direct effect on pen exposure and absorption of solar radiation. In the Southern Hemisphere a northwest aspect generally presents maximum exposure to solar radiation for longer periods so influencing reflected/reabsorbed radiation by the animals.

Dark colour pen floors absorb more solar radiation than lighter ones. Wet pads are dark in colour, dry pads are a light brown to grey. Regular pen cleaning maintaining a minimum pad reduces the pads ability to hold moisture (rainfall, effluent), enabling it to dry more quickly and return to the lighter colour, as well as minimising the humidity component dilemma of the micro-environment following rain.

Plate 4.5.1: Example illustrating pad build up and resultant dark colour after rain, and increased micro-temperature and humidity.

The amount of rainfall received in the feedlot area may add to the heat load dilemma. The most serious recorded EHL events (refer 2.2) have occurred following periods of rain and resultant increased humidity. Effective natural and by design drainage (eg. pen, slope, management eliminating depressions, water collecting areas, trough overflows, and drainage to pen) and pad management (minimising pad thickness) all contribute to reducing micro-environment humidity.

Air movement aids evaporative cooling. Feedlot pens with restricted air movement offer less relief to EHL in cattle. Air movement may be hindered by adjacent crops (eg. maize), shades, sheds, grain storages, feed mills, livestock handling and processing facilities, or by other pens when located in their midst.

The nature of a feedlot pen is such that cattle are unable to apply their normal behavioural instincts to maintain heat balance, for example seeking shade (trees), air movements (hills), or relief wading in dams or creeks. In response, feedlots have frequently attempted to better accommodate cattle by providing **mounds**, **shades** and installation of **sprinkler** systems.

The pen manure pad accumulates deepest in areas where animals congregate or spend a large proportion of their time (eg. adjacent feed bunks, shades, and waters). Accumulated manure absorbs and retains moisture following rainfall so increasing pen humidity, and may disrupt drainage. Pad fermentation of undigested feed may add to the heat of the pen micro-environment. Additionally air quality may deteriorate with accelerated ammonia release levels. Entwistle *et al*., (2000), suggested ammonia levels under the shaded areas were twice that of the unshaded areas during the February 2000 Southern NSW EHL incident.

Mounds constructed from the pad manure assist the manure dilemma and also create a further avenue for dispersal of cattle and access to air movement. Recent data (Mader *et al*., unpublished, 2001) suggest that there is an increase of air movement within a pen with mounds. The increased air movement can assist the animal's evaporative cooling capabilities so reducing the EHL risk. Mounds need to be compacted to minimise any heat of composting developing (Refer 6.1.3).

The common usage of term “shade” in a feedlot pen context embraces a great array of ill-defined structures, which have vast differences in dimensions (area, height), construction (materials), pen position and orientation, form, shape and style, with a range of associated construction and maintenance costs.

Whilst research findings are inconclusive, field observations strongly support the inference that ample well designed and constructed shades will assist the vulnerable animals (eg. heavily finished, black, *Bos taurus*, and/or the sick, in particular with respiratory problems) when EHL conditions exist, and potentially reduce mortality (Refer 6.1.5).

These shades would provide an adequate area per beast where the animals can experience an improved micro-environment protected from solar radiation. These optimum dimensions require further research.

Sprinklers may alleviate or further exacerbate an EHL situation depending on the soundness of their design, and the effectiveness of the management of their operation (Refer 6.1.6).

Sprinklers in common with rain add to local humidity. Under hot conditions when humidity is already high, sprinklers can exacerbate an acute EHL situation, by adding to an already high humidity situation. Sprinkler systems are most effective when periodic wetting by large droplet sprays thoroughly wets the animal through to the skin surface, aiding effective evaporative cooling to take place. Misting or fogging provides little benefit to cattle, as only the hair coat is wetted, whilst also adding to humidity problems (6.1.6).

Air movement aids sprinkler contribution. Pens need to provide adequate drainage. Sprinklers can successfully suppress dust, reducing dry weather respiratory problems, which is also a hindrance in hot weather.

Cattle require adequate clean fresh water (Hahn and Mader, 1997), as elsewhere reviewed (refer 4.3.4, 6.1.7). Hahn and Mader (1997) suggest that during an EHL event, water trough space needs to be 75 mm/hd standard cattle units (SCU). The water supply of pens may be supported with additional supplementary troughs (portable) when the weather is excessively hot. Adding supplementary water troughs during an EHL event reduces the influence of dominant cattle and the bunching effect about waters.

4.5.2 Livestock Management

Livestock management factors influencing EHL include, identification of and appropriate treatment for susceptible and/or vulnerable cattle, timing of livestock movements and handling (eg. dispatch, induction, sick animal removal and treatment), and nutrition and feeding programs.

The most vulnerable feedlot cattle are:

- heavily finished cattle (i.e. long DOF, approaching market specifications)
- newly received, or newly arrived cattle
- hospitalised cattle (especially those exhibiting respiratory illnesses)

Additionally, *Bos taurus* are more susceptible than *Bos indicus*, and black cattle more so than light coloured cattle.

Cattle most vulnerable to episodal EHL are likely to be those with greatest finish, (eg. fat score 4.5 – 5.0). Entwistle *et al.*, (2000) reported a strong correlation between DOF (indicating finish) and mortality. The relationship was essentially linear up to 200 days, thereafter increasing dramatically, demonstrating the greater susceptibility of heavily finished long fed cattle to EHL.

Vulnerable animals may be assisted by allocating them to pens providing the maximum cooling effects, during summer periods (eg. pens with shade, sprinklers, at least two waters, and those which enjoy the maximum air movement). Pens with less scope for heat relief will contribute more to the EHL situation.

Newly received cattle are pre-disposed to EHL. They are acclimatising and adapting to new and unfamiliar social influences (pen size, group dynamics) and new diets. If experiencing respiratory problems they are more susceptible. The immune system is impaired during EHL events (Kelley, 1985). It is therefore necessary to ensure respiratory and other disorders are maintained in check during summer when hot conditions or EHL events may be prevalent.

It is desirable that cattle movements be minimised during hot conditions. Preliminary USA trials (Mader, personal communication, 2001) noted cattle BT was raised an average of 1ºC simply by their moving through working facilities during a normal summer day. This was when the cattle were not exposed to any other stressors such as ear tagging, vaccination and implanting which would further increase body temperatures.

Flies can agitate cattle. Fly numbers need to be controlled to minimise disquiet and unrest amongst cattle, in particular during hot conditions.

During transportation cattle are bunched together. During hot periods, this can markedly contribute to EHL. It is advisable to avoid shipping cattle during hot parts of the day.

The animal's nutrition and feeding practice influences EHL (refer 4.3). Greater emphasis on feeding in the late afternoon or evening can shift peak body temperature from the hottest part of the day (with traditional heavy morning feeding) to the evening where there is greater opportunity for dissipation of heat during the cooler night hours.

Lawrence, (1998) in a commercial feedlot study suggested that feeding times should coincide with the natural feeding behaviour of cattle, where summer feeding activity is greatest at sunset followed by sunrise and limited during the midday hours.

4.5.3 Personnel Management

Proactive management is to be preferred to reactive management.

It is important **all** employees, staff members and management are informed on the strategies in place to reduce the occurrence of, recognise the signs of, and appreciate the steps to take to minimise the effect of EHL in feedlot cattle. Staff involved in the day-to-day feedlot operations can exacerbate an EHL situation by either ignorance and/or lack of motivation. Staff unable to identify the signs of, or the effects of, EHL in feedlot cattle, or who lack motivation to inform those in a position to act on information, will only impede or delay action, which may be costly.

In particular, pen riders and feed truck drivers require the ability to detect animals **approaching** or **experiencing** an EHL situation, by monitoring their behavioural and physiological symptoms (eg. bunching activity, panting). Concerns should then be reported as appropriate to staff in a position to improve the situation. Feedback from the pens to management is an essential link.

5. RELATIVE EFFECTS OF HEAT LOAD FACTORS FOR FEEDLOT CATTLE

There are continuous fluxes of heat in and out of an animal's body and the net effect determines body temperatures and changes to body heat content over time. If a sustained imbalance occurs in the rate of heat gained or lost from the animal body, there will be an accumulative change in body heat content that will ultimately result in hypo- or hyper-thermia (Figure 5.1).

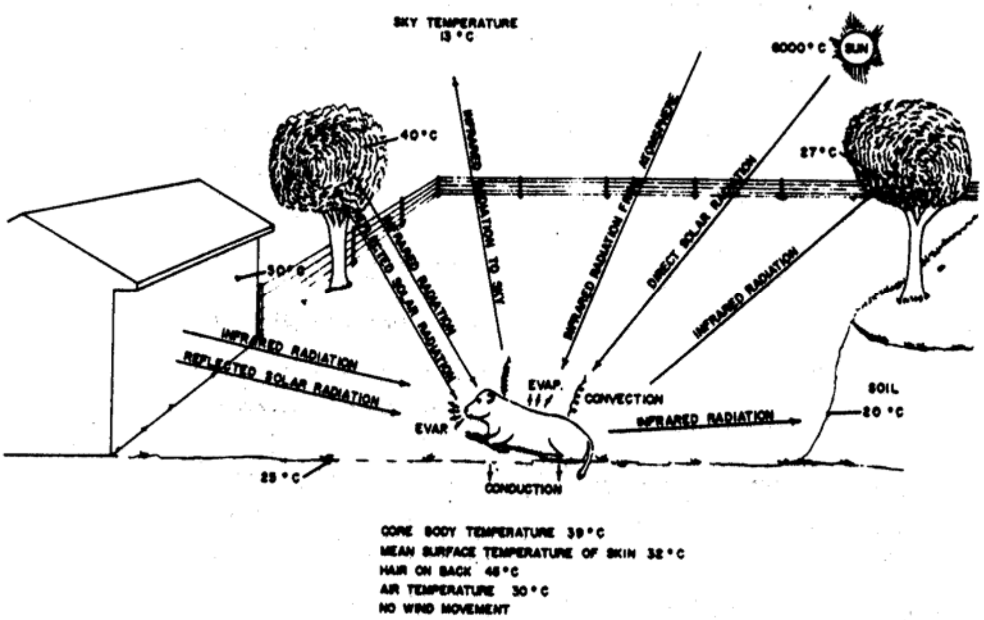


Figure 5.1: Schematic illustration of heat fluxes into and out of an animal exposed to a hot environment (Hahn, 1994).

In a feedlot, the animal's immediate environment (the feedlot pen) is subjected to the additions and losses of heat. If the pen absorbs a large amount of heat from radiation or the air relative to that lost to the air and atmosphere, the cattle are exposed to increasingly hot conditions, which in the extreme can be detrimental.

A computer simulation model (Feedlot Heat Load Model) has been developed to assess and illustrate the relative contributions to daily heat fluxes and the daily thermal balance of a typical 200 DOF feedlot (Young, unpublished data, 2001). The basic assumptions were that the steer was one of 200 in a typical pen environment fed a balanced 12MJ/kg DM diet, exposed to full sun on a hot humid day in mid summer.

The model steer with several months of acclimation to summer conditions, was assumed to have an initial core temperature of 39ºC, an initial surface temperature of 32ºC, and therefore not thermally challenged.

The simulation model estimates hour-by-hour variations in the routes of heat flux in and out of the steer's body along with the net heat balance. During the 24 hour period, illustrated in Figure 5.1, the steer gained approximately 31 MJ of heat energy in its body, which raised the body core temperature by 2.1ºC. The major proportion (72%) of the daily heat gain arose from the metabolic heat produced (MHp) within the animal's body plus some contributions during the heat of the day from infra-red radiation from the feedlot pad and direct solar radiation. These heat inputs were largely balanced by the evaporative heat loss.

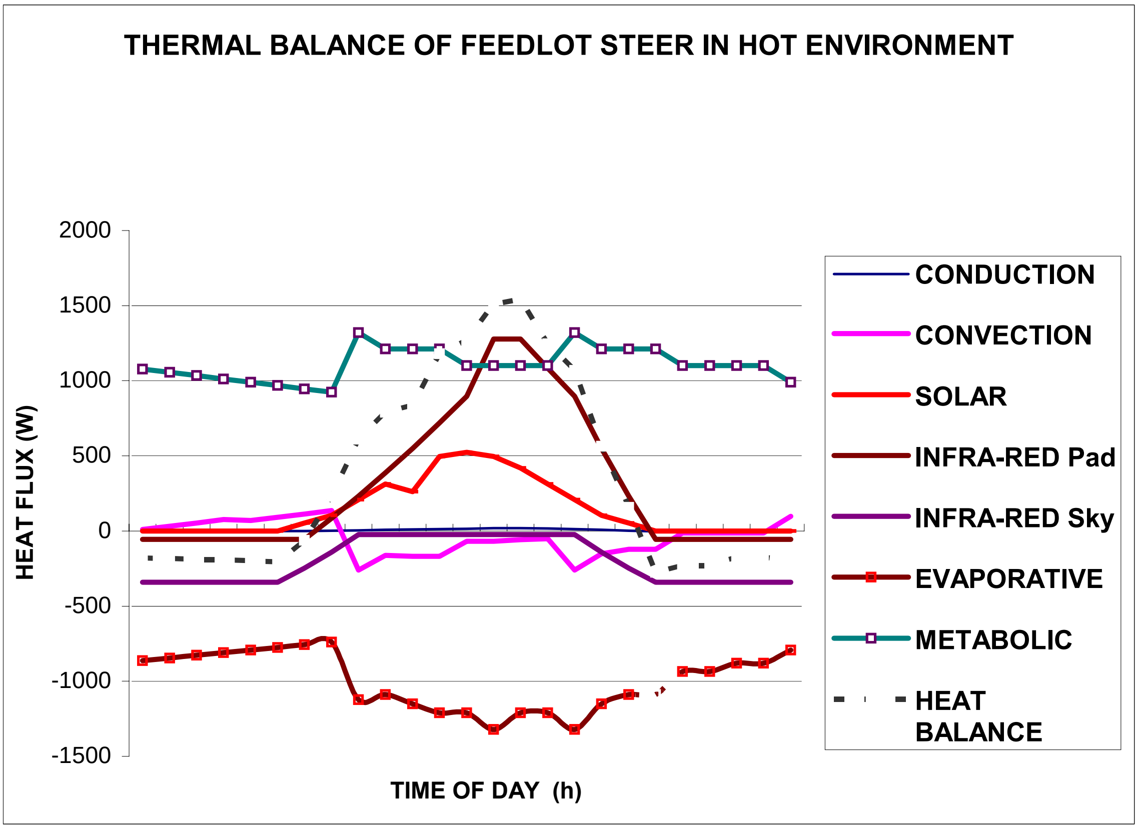
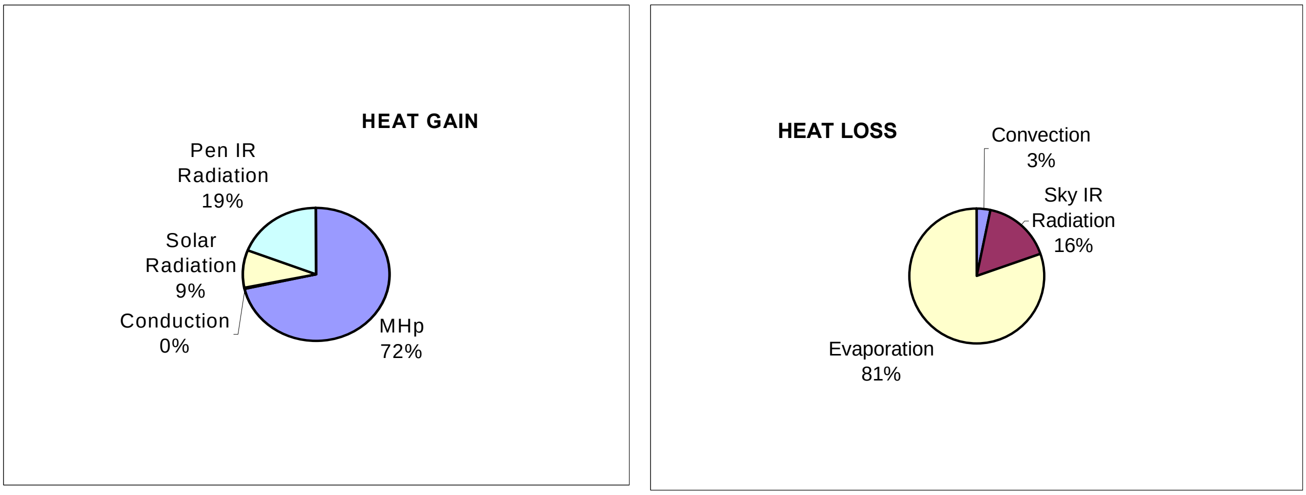


Figure 5.1: Computer simulation estimates of routes of heat fluxes in a feedlot steer during exposure to hot humid summer conditions where there is minimal wind.

Figure 5.2 summarises the total daily fluxes of (a) heat gain, and (b) heat loss, by the typical feedlot steer during hot humid and low wind conditions. It is clear from these estimates that

- the main overall source of heat gain in the feedlot steer was metabolic heat, while
- the main route of heat loss was via evaporative cooling.

Other components, while not large, are additive and at times could be sufficient to make critical contributions to the accumulation of body heat.



(a) (b)

Figure 5.2: Model estimates of the relative contributions to daily heat fluxes into (heat gain) and out of (heat loss) a typical feedlot steer during the heat of summer when there is hot humid conditions and minimal wind.

The model provides the opportunity to readily simulate the rate of heat gain in the feedlot steer utilising several different options. For example, the amount or composition of the diet offered to the animal can be modified or shade can be provided, and an evaluation made on the effect on the heat balance of the test steer. The rate of metabolic heat production relies largely upon the amount of metabolisable energy consumed (DMI times energy density of the diet). Metabolisable energy intake can be varied by reducing or increasing the energy density of the ration, or alternatively, the daily DMI further. Normally the natural response of an animal in hot conditions is to reduce its DMI. The feedlot manager also has the option of reducing the energy concentration of the diet to reduce metabolisable energy intake.

In Figure 5.3 the model has simulated the heat fluxes in the same steer and situation as shown in Figure 5.2 (a) but with the effect of solar radiation eliminated by provision of shade. All other components of the model have been kept the same. The model indicates that the “provision of full effective shade” reduces the estimated daily heat gain from 30.7 MJ to 17.8 MJ, with resultant estimated daily rise in body core temperature of 3.1ºC vs 1.2ºC, respectively. On this basis complete shade is predicted to reduce the daily gain in body core temperature by about 0.9ºC.

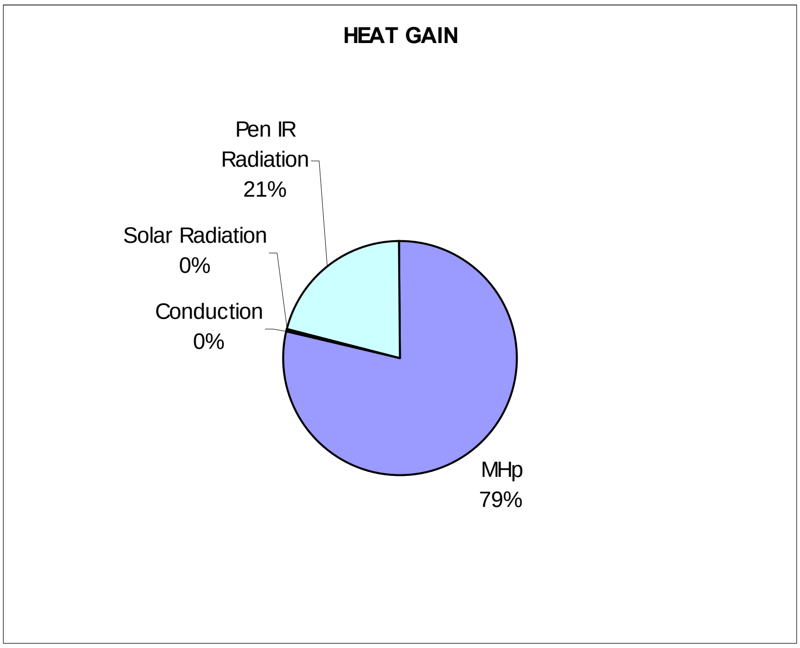


Figure 5.3: Partition of routes of heat gain in a feedlot steer fully protected from solar radiation (shaded). The same animal under similar circumstances but exposed to full solar radiation is illustrated in Figure 5.2 (a).

In a practical situation there are complex interactions between the many components of heat flux and animal response. The simulation model provides predictions and possible indications of likely outcomes, and as such can highlight areas of further consideration, but eventually model estimates must be supported by field observations to confirm their validity and practical value to the industry.

The model predictions need to be evaluated and ratified against actual and independent data. Unfortunately, currently there are no sets of data for the thermal balance of steers in feedlots available to evaluate parts of the model.

The partitioning of heat loss by cattle in climate chambers as related to environmental temperature is illustrated in Figure 5.4. Depending upon the thermal environment, heat is lost by non-evaporative or sensible (i.e. radiation, convection and conduction) or evaporative processes (sweating and panting). It is clear from this that the major source of heat loss is from the body surface and not from respiration. The relative importance of evaporative heat loss increases in a hot environment and diminishes in a cold environment.

Yousef (1987), in describing the defence of mammals against hyperthermia highlighted that in a hot environment heat is lost from the animal mainly by skin and/or respiratory evaporative water loss. When the surrounding air is dry, evaporative heat loss is most effective but its importance is reduced as the ambient air becomes saturated with moisture. This accounts for the simple fact that prevention of over heating by animals in hot dry areas is easier than in hot humid areas.

The further development of simulation modelling, offers a tool to evaluate feedlot practice and procedures and their possible individual and accumulative effects on heat load, and, to identify possible areas for further research.

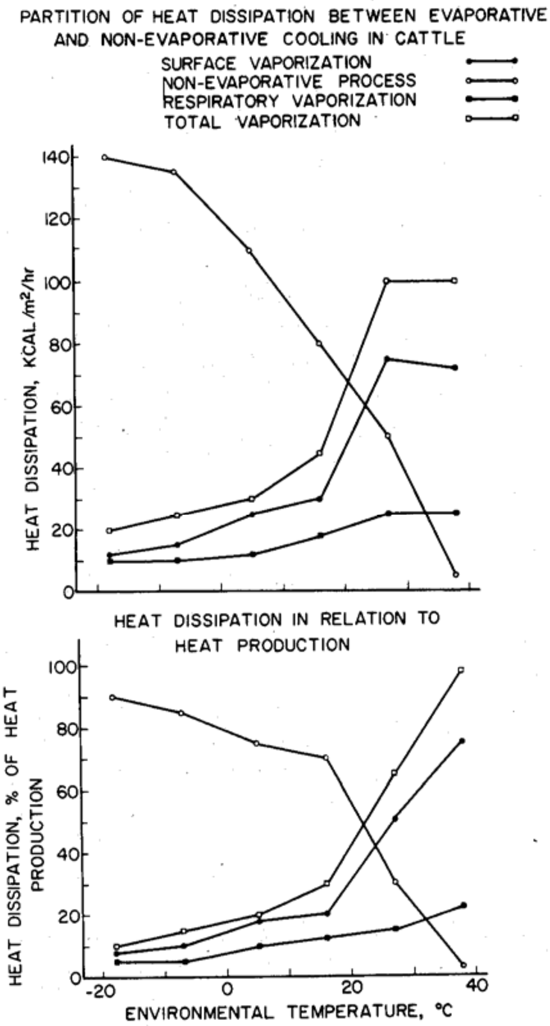


Figure 5.4: Partition of heat loss in cattle as related to environmental temperature (from Kibler and Brody, 1952).

6. TECHNIQUES TO MODIFY HEAT LOAD FACTORS FOR FEEDLOT CATTLE

This section lists and evaluates various techniques and opportunities available for feedlots to modify heat load factors or practices. Not all the listed techniques are suitable in all situations.

This list is undoubtedly incomplete. There will be possible solutions for over coming EHL in feedlots within the feedlot industry and with those that work closely with the feedlot industry. The present listing of techniques and opportunities available for overcoming EHL and reducing the impact of summer heat load on productivity will be able to be expanded and improved by further tapping into the knowledge and understanding existing within the industry, and the further comprehensive analysis of EHL events when they do occur.

6.1 Physical

A range of physical factors appear significant in contributing to or ameliorating the effect of EHL. These include: geographic location, the use of water ponds in pens, convective air movement, solar shades, sprinklers and foggers and water supply.

6.1.1 Geographic Location

It is important that the initial selection of the feedlot location take into consideration the climatic factors, the potential risk of extreme weather situations and their effect on animal production and welfare, as well as aspects optimising financial and operational conditions (eg. access to feed resources, sourcing of animals, markets, environment and waste management issues, etc).

A weather assessment for a potential feedlot location within Australia would evaluate the site for the possible impact of climate and weather patterns on production and animal welfare, considering for example:

- Regional annual weather patterns, summer heat and winter cold, rainfall, relative humidity and radiation.
- Probability (risk assessment) of excessive cold and/or heat load situations.
- Wind patterns, speeds and directions including probability of cooling summer, and/or chilling winter, winds.
- Probability of relief (cool nights) from EHL situations.
- Site-specific local weather and micro-environmental influences (aspect, convection, humidity, etc).

Pros:

- Reducing the effects of adverse annual and seasonal weather patterns on production efficiencies and enterprise profitability.
- Reducing risk of heat load situations impacting on morbidity and mortality.
- Forewarning the need for possible design modifications and/or inclusions to minimise weather effects.

Cons:

- Of limited value to existing feedlots unless expansion or redevelopment under consideration.
- Introduces weather risk factors as additional impacting variables for review in optimum feedlot location and site selection.

Conclusion:

Weather and micro-environmental factors impact on animal welfare, feedlot productivity and profitability. Their complete assessment when initially selecting a feedlot location and site will assist in optimising production efficiency, minimising potential risks, and maximising investment worth and return.

6.1.2 Water Ponds In Pens

The installation of shallow ponds in dairy feedlot pens has been used in North America to allow cattle to use conductive cooling from their legs, thus dumping heat during hot conditions (McDowell, 1972; Bray and Shearer, 1988).

Pros:

- Apparently effective in reducing body heat load in animals.
- Readily used by cattle during periods of hot weather.

Cons:

- Needs larger size of pens than pens without ponds.
- Needs reliable water source.
- Increases construction costs.
- Increases operational costs, associated with pond cleaning and dry waste removal.
- Increases pen relative humidity.
- Complicates cleaning of dry waste from pens.
- May muddy animal's coat and lower leg.
- Possibly increased risk of spreading infections.

Conclusion:

This animal cooling option is used for animals in hot climates particularly for dairy cows, but introduces possible costly and complex management issues for feedlot cattle.

6.1.3 Passive Convective Air Movement

In situations of very low wind, passive convective air movement and local eddies may provide some relief for animals when hot conditions prevail.

Air moves naturally from areas of high air density to areas of lower density, and heated air is of lower density than cooler air. Air close to the warm skin of an animal or the hot feedlot pen surface gains heat, becomes less dense and tends to rise, and is replaced with cooler air. While its effectiveness is not yet scientifically established, passive convective currents may aid the cooling of hot cattle. Heat from the animal's body warms the surrounding air, which tends to rise from passive convection and is replaced by cooler air from under or next to the animal.

Mounds in feedlot pens and **sloping** sites tend to cause small updrafts of air when there is little natural air movement. This local convective air movement is conspicuously sought out by animals apparently to take advantage of the additional cooling, be it small, from such a situation. Mounds also may be preferred for other reasons. They elevate animals to where there is less likelihood of obstruction to air movement from other animals and structures. Alternatively, mounds may be used simply as a means for animals to express dominant behaviour.

The total feedlot pen area can be viewed as a large convection unit. During hot weather, with substantial solar radiation, the feedlot pad surface and some surrounding structures become rather hot. Air near these hot surfaces warms and rises through natural convective processes, to be replaced by cooler air from surrounding areas. When an expanded hot surface such as a feedlot is adjacent to a relatively cool area such as an irrigated green field, warm light air rises above the pens drawing in heavier cool air from the adjacent green field. Thus with appropriate placement of the feedlot and irrigated green fields there could be a natural, passive circulation of air from areas surrounding the feedlot.

Pros:

- Small passive air movement can be generated in situation where there is little or no natural wind air movement. These can be just the animal's surface and/or over the expanse of a feedlot by judicious site selection incorporating slopes, mound construction, or where practical, in conjunction with adjacent green fields.

- Passive convective air movement occurs most when the conditions are hot, with high solar radiation and when there is little or no wind i.e. when there is high risk of devastating heat load situations.

- Mound construction is low cost, and can be constructively incorporated in a sound pad maintenance program.

- If adjacent green field option is developed, and incorporated in initial design, the field may concurrently provide evaporative cooling to the air carried into the feedlot, as well as be a source of feed.

Cons:

- The magnitude of naturally occurring convective air movement and its cooling effects are small. They can however, be additive and effectively assist in situations where there is little or no relief from other mechanisms.

- Unless the site is naturally sloped, the construction and incorporation of effective slopes will be expensive.

- Mounds need solid compaction and correct orientation to facilitate drainage.

- If sprinklers are applied when humidity is low, water spraying of the feedlot pad may quickly reduce the surface temperature of the pad and so slow down the rate of natural convective air movement.

- Areas adjacent to a feedlot may not be suitable for green field use and/or there may not be adequate irrigation water available to maintain a cooling green field.

- The green field option may add significantly to the pen micro-environment relative humidity.

- There is presently no scientific evaluation of the possible contribution mounds, a natural slope, or the green field option might make to animal cooling.

Conclusion:

Passive convective air movement may provide cooling relief to cattle in critical heat load situations. While any relief may be small, mounds appear able to contribute positively to the pen environment, and their construction in conjunction with a sound pad maintenance program is a relatively cheap source of cooling able to be incorporated into existing establishments. The irrigated green field option may also be a practical consideration particularly for small operations if provisions are made during the design and construction stages.

6.1.4 Forced Convection - Mechanical Fans

Mechanical fan systems are frequently used in intensive animal housing production systems to assist with air movement and convective cooling of dairy cattle (McDowell, 1972). Such fans are normally mounted to blow air onto the animal backs where there is near zero natural air movement.

Animal housing with wind-tunnel evaporative cooling is being currently developed in Asia which has potential application to small scale confined cattle feedlot operations (Hsia *et al*., 1999).

The use of mechanical fans in open beef feedlots raises levels of scale not encountered in confinement feedlots. There may however, be possibilities for the principles of forced convection to apply with temporary, rather then permanent, installations. For example, there are locations where large mechanical fans are used in fruit orchard frost relief programs. These may have an off-season application to blow air over cattle in nearby feedlots in a critical or approaching critical situation.

Similarly, it has been claimed a light aircraft operated in a stationary ground position to blow air through the feedlot or part of the feedlot has provided heat relief. Suggestions also include the use of helicopters over feedlot cattle to blow air down onto the cattle. No reference has been found in the literature or press as to the success or contribution of any of these temporary methods under commercial conditions. Similarly, no one with first-hand knowledge has been discovered.

Pros:

- The effective generation of air movement in situations where there is little or no natural wind will by convective cooling reduce animal heat load.

- There is proven effective technology generating air movement for housed cattle, especially in the dairy industry.

- Wind generating fan systems (where available) need be brought in only when necessary, thus avoiding large capital and maintenance costs.

Cons:

- Unknown effectiveness due to lack of objective scientific evidence or practical experience.
- Costs of hire and operation.
- Large frost fans are not available in many feedlots locations. Light aircraft and helicopters are more widely available, but may be difficult to position effectively. The effectiveness of using these means is unknown.
- Unknown impact of noise and/or the dust created from a light aircraft, or helicopter on animals.
- A helicopter could cause major disruption in animal behaviour, increasing physical activity and hence increasing body heat production.

Conclusion:

Frost fans seem a reasonable option in some districts, and warrant investigation as to availability and effectiveness. Light aircraft to blow air over cattle in specific situations of low wind, appears worth further investigation. Engine overheating may be a concern. The helicopter option could bring with it animal disturbances which could be more devastating than the lack of convective cooling.

6.1.5 Solar Shades

There are parties which widely advocate the use of shade structure in both the dairy and cattle feedlot industries as a means of alleviating heat load. Rarely, however are the shades specified (area, height, shape) and research has discovered a vast array of responses to their use (eg. Hahn, 1985; Hahn and Mader, 1997; Fell *et al*., 1993; Brosh *et al*., 1994; Clarke, 1993). Most commonly, shades have been evaluated on the benefit they might offer to summer livestock production (LWG, FCR) rather than their contribution to reducing mortality under very hot EHL situations when they occur. There are also inconclusive observations with respect to the impact of shade on meat quality (Refer 4.3.5.2). In practice, their contribution to the well being and productivity of feedlot cattle is inconclusive.

There are however reported instances where shade has significantly reduced mortality in vulnerable stock during an EHL event. Clarke (1993) observed mortality in Charolais cross steers as a result of EHL in an unshaded group (4 out of unspecified number), compared to none in the shaded group in a southern Queensland feedlot study, in February 1993.

Importantly, Entwistle *et al*. (2000) noted shade played a highly important role in influencing cattle deaths with significantly more deaths in unshaded than in shaded pens (5.8% vs 0.2%) in the February 2000 southern NSW EHL incident. There was a significant correlation between DOF (indicating body size and condition) and mortality in unshaded pens, cattle longest on feed having the highest mortality rate. For those cattle without shade, mortalities were high even at shorter days on feed (51 – 100 days), and increased incrementally with increasing time on feed.

Without question animals seek out and use shade during periods of high solar radiation. Solid shade structures will block 100% of direct short wave radiation while 80% shade cloth allows 20% of short waves to reach the animal. While shade blocks out direct short wave radiation there remains some reflected short wave and long wave irradiation heat transfer into the animals. The extent of these secondary irradiations is dependant upon the height and form of the shade structure, and the shade area per animal.

Logically, the relative value of shades varies with location, orientation, size, design and type of structure, and management practices. There appears scope for developing shade designs encouraging passive convection air movements. Additionally, it may be practical for shade to incorporate low volume forced convection (fans) appendages, thus potentially enhancing their value and contribution to animal well being.

There is need for a meaningful study to sort out the current controversy, with particular reference to the comparative efficiency of different design features, and areas, and the likely contribution to a range of cattle types with varying degrees of vulnerability to EHL.

The following is a summary of the relevant aspects of shade design based on the publications of Armstrong (1994, 1995), Bucklin *et al*. (1991, 1992), Hahn (1982, 1985), Hahn *et al*. (1982, 1999), Mader *et al*. (1999b, 1999c), and QDPI (1996), recognising the impact of shade is on solar radiation, rather than directly on temperature and/or humidity (Hahn *et al*., 1970).

Materials: Aluminium, or white or galvanised metal roofing materials preferred, whose efficiency is enhanced with 25mm of insulation directly below the metal. The insulation can be a problem if inhabited by birds or other pests. Shade cloth is initially less expensive, but provides less protection, incurs greater maintenance costs, and is generally less effective. Slatted shades are less effective than solid shades.

Area: Minimum shaded 1.5m^2 to 2.5 m^2/SCU, with 3.5 m^2/SCU better. In excess of 4.5 m^2/SCU probably offers little extra benefit as animals tend to group, even under shade.

Orientation: Represents a compromise between most effective animal shading and the maintenance of dry ground surface conditions under the shade. In Australia, where rainfall exceeds 125mm annually the north-south longitudinal axis orientation exposes the maximum area under the shade to morning and afternoon sun assisting keeping it dry.

Height: Minimum height 3.7m, and desirably 4.5m high to allow better sunlight penetration, greater ventilation and air movement, minimisation of radiation from the shade roof to animal, and ease of pad maintenance.

Location: Towards centre of pen, avoiding feed bunks, water troughs, and their adjacent areas, and beyond sprinkler range.

Pros:

(a) Shades are generally readily used by animals.

(b) The provision of shades reduces crowding about water troughs allowing less dominant animals better access.

(c) There is some evidence though inconclusive of shades reducing the effect of hot summer weather on production efficiency and mortality, in particular in the vulnerable cattle.

(d) There is more conclusive evidence of the positive value of shades during an EHL event, reducing mortality amongst the more vulnerable cattle. For this group well designed and constructed shades may be considered sound insurance against EHL mortalities.

(e) Erection of shade provides perception that appropriate animal welfare procedure has been implemented.

Cons:

- Uncertainty about what constitutes the design optimum effective shade.
- Inconsistent evidence of effectiveness – may be dependent upon regional weather, design, area, height, structure, etc.
- Apparent reluctance of some animals to leave shades for feed and water, reducing productivity.
- High establishment costs and extra maintenance costs.
- Interference with pen cleaning and pen micro-environment.
- Crowding of animals under shade may cause local moisture build up and increased gaseous ammonia levels.

Conclusion:

In practice, shade structures are ill defined. The determination of their value as an aid to summer productivity in the feedlot industry is inconclusive and there is still much to be understood about the factors determining their effectiveness, and commercial value in feedlots.

At the same time, there is strong field evidence of shades alleviating the effects of EHL, with reduced EHL mortalities amongst vulnerable cattle, suggesting shades should be considered as a part solution to the reduction of EHL in feedlot cattle.

Suggestions however that solar shades alone are the solution to EHL in feedlots is simplistic and misleading.

6.1.6 Sprinklers and Foggers

Sprinklers and foggers are used in feedlots during hot weather to assist in reducing heat load in animals. Their effectiveness is dependent on various interacting factors.

Foggers applying fine sprays may cool the air, but add considerably to the humidity of the air. In contrast, sprinklers can apply large droplets able to quickly settle onto the animal's coat or the feedlot pad. These larger droplets can have a direct cooling effect, and also an evaporative cooling effect on the pad surface. While large droplets cause a less immediate increase in water vapour, they do contribute to increased air humidity to the same degree as foggers.

The potential cooling effect of sprinklers and foggers is rather complex. Cooling is achieved by evaporation, and in the case when applying a lot of large droplets, the washing of heat from the animal's body. Furthermore, there are secondary effects reducing surface temperatures, thus reducing net long wave radiation (eg. moisture precipitation on the feedlot pad rapidly cools the pad, reducing the infra-red irradiation from the pad to the animals).

Sprinklers can increase the moisture content of the feedlot pad, encouraging microbial fermentation and the release of ammonia. This effect is minimised with sound pad management, minimising its thickness.

There are several mechanisms to apply water. Fixed sprinklers are used for their potential cooling effect and also ability to control dust. They are used periodically during the day for short periods, covering only a portion of the pen.

Foggers or other fine misting sprays are used for their capacity to increase evaporative cooling, in dairy feedlots and other intensive animal housing. They are often associated with fans and the cooling of air blown around the animals (Hsia *et al*., 1999).

Alternatively, water can be sprayed (in large droplet form) from mobile water trucks with high pressure hoses travelling along the feed bunk roads, or cattle alley at rear. Regional and local fire fighting services have water tankers, pumps and high pressure sprays that may be able to be recruited to resolve emergency situations.

If used incorrectly, sprinklers may have little long term effect in reducing heat load. Sprinklers should be of large droplet size (~150 micron). There should be a minimum of two, desirably three sprinklers per pen. It is necessary for the sprinklers to be able to be turned on and off independently from each other, providing a control to reduce muddy areas developing in pens. Sprinkler range should avoid areas adjacent to water troughs, shades and feed bunks, and cover at least 2.5m^2 to 3.0m^2 per SCU when selectively used (Mader, personal communication, 2001).

The design of a feedlot sprinkler watering system needs to ensure it is at no time competing with the water trough water requirements. It needs be a stand alone system with adequate water supplies on its own right.

Sprinklers are best applied (periodically, thoroughly wetting the animal by large droplets) for 5 – 10 minutes on and 15 – 20 minutes off, rather then continuously (Hahn, 1968), and need be guided by observing the animal response and the pen environment.

Holt *et al*. (1998) studying the effectiveness of night cooling *vs* day cooling of *Bos taurus* beef cattle reported that RR, RT and HR were significantly reduced when cattle were sprinkled during the cooler night hours than during the day. Night sprinkling was a most effective time to assist the animal reduce body temperature (i.e. when humidity conditions are suitably low). Cattle can better withstand daytime hot conditions where there is sufficient night-time relief for the body to dissipate accumulated daytime heat.

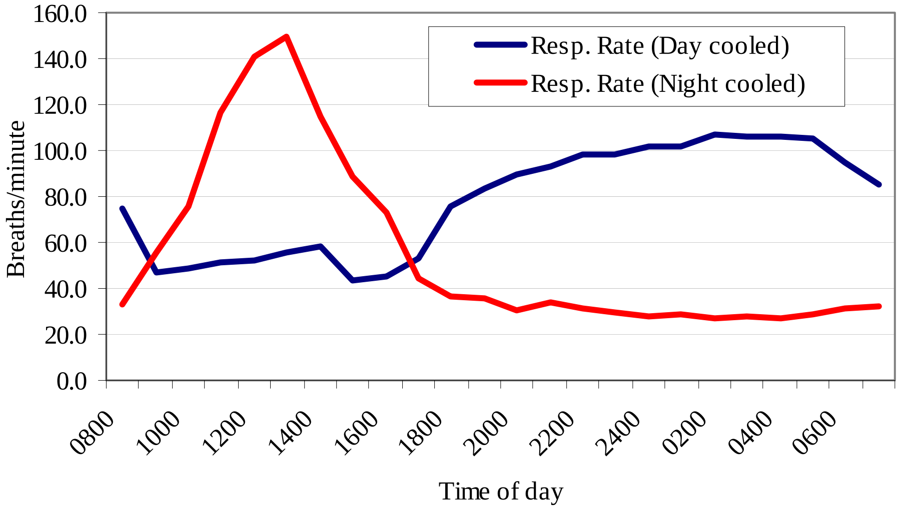


Figure 6.1.1: Mean hourly RR of steers exposed to either day or night cooling during hot conditions (Holt *et al.,* 1998).

It is frequent industry practice to turn sprinklers off late in the afternoon or early evening as air temperature falls. However, cattle that have been cooled during the day may then face a heat challenge even though ambient conditions have improved.

Cattle cooled while exposed to THI>84 will have lower RT and RR than those not cooled, and these cooled cattle typically demonstrate a rapid rise in RR and RT following the cessation of cooling especially when there is inadequate night time cooling. This is illustrated in Figures 6.1.2, 6.1.3 (Gaughan *et al*., 2001) where RR followed in similar pattern to RT. This indicates that the removal of a sprinkler spraying when THI is falling may in fact increase the stress level on cattle. Sprinkling should continue as long as THI remains above 79, or if RR remains elevated i.e. above about 80bpm. It is necessary to always assess RR within one hour of turning sprinklers off, if RR goes up turn sprinklers back on.

Figure 6.1.2

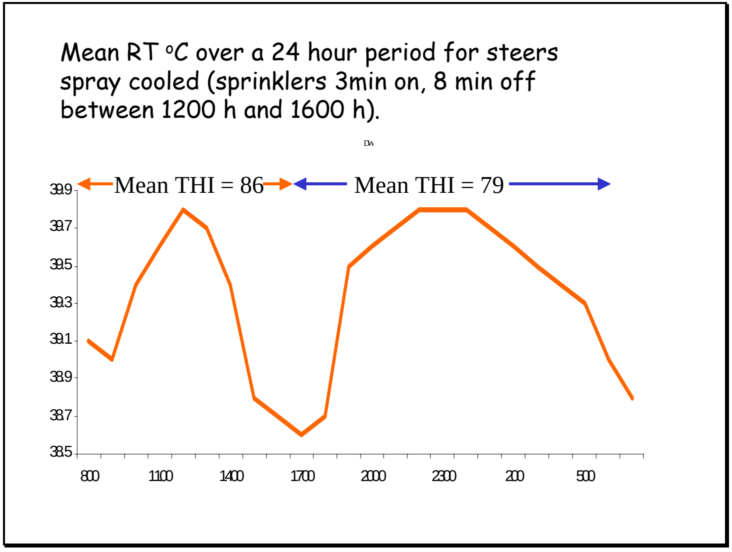

Mean RT °C over a 24 hour period for steers spray cooled (sprinklers 3min on, 8 min off between 1200 h and 1600 h).

Figure 6.1.3

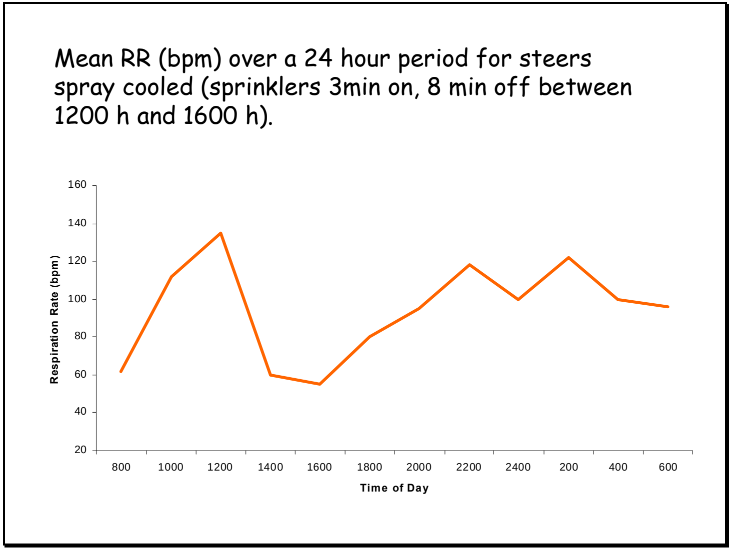


Plate 6.1.1: An example of a poor sprinkler installation located above water trough. This has created undesirable bunching of cattle about watering trough.

Pros:

- Evaporative cooling from the body surface is an important mode of overall heat loss by cattle.
- Direct washing of animals with water will carry heat from the animal's body.
- Cooling of the feedlot pad and surrounding surfaces will considerably reduce the amount of infra-red irradiation from these surfaces.
- Sprinklers can disperse cattle, disrupting bunching and grouping.
- Dust suppression by sprinkling aids in reducing respiratory problems.

Cons:

- Evaporative cooling is less effective when air humidity is high.
- Sprinklers and foggers increase the humidity in a feedlot pen.
- Water applications increase the pad moisture content potentially increasing micro-environment humidity and ammonia release. (This may be minimised with sound pad management).

Conclusion:

Sprinklers, of adequate design and judiciously used, assist in the amelioration of EHL in feedlot cattle, and should be considered a desirable permanent installation in feedlots in much of Australia.

6.1.7 Waters

Water is an essential nutrient for feedlot cattle, where intake increases dramatically during hot periods. Water helps offset the negative effects of metabolic heat during periods of hot weather. It is required to prevent dehydration, but many animals will drink and use extra water just to cool the body by placing the tongue and nose in the water to relieve it of body heat.

In summary Hahn *et al*., (1999a) conclude that there needs to be at least two water troughs per pen with provision for a minimum of linear 25mm/head of waterer space for normal conditions and 75mm/head for very hot episodes. Increasing linear waterer space and providing multiple waterers can reduce the influence of dominant animals during hot weather, permitting increased access for the more submissive pen members. Providing additional (portable) waterers during hot weather periods can further reduce the influence of dominant animals and be important for vulnerable animals.

All waters should be tested to supply at least 15 litres/100kg body weight daily of penned animals, during feedlot peak demand periods, and able to meet the daily peak consumption needs in a four hour demand period (Hahn *et al*., 1999a; Mader *et al*., 1999b).

For coolness, the delivery system of water to water troughs needs to be entirely underground, avoiding exposed pipes. Basically, troughs need to be lengthy and relatively shallow, with robust high volume delivery. Removable drainage stand pipes draining to an integrated entire feedyard waste water collection and disposal system clear of the pens and alleys, eliminating trough overflows and pen wetting when trough cleaning, so reducing pad wetting and micro-environment humidity and areas where cattle group. The overall water supply needs to be absolutely secure, supported by reliable backup and secondary delivery systems.

The source of water as it affects quality is important. If the supply is from surface streams the water quality following storms may be an important consideration. Increased stream flows following storms may cause water quality to deteriorate (eg. due to mud, smell, taste, appeal) which may inhibit animal intake. This quality deterioration would be a major concern if hot weather conditions, when animal water requirements are greatly increased, followed the storms and subsequent increased stream flows. This threat should be recognised in designing water supply systems, and its elimination provided for.

Additionally, in extreme cases, poor quality bore water may influence water intake and be an important consideration limiting maximum intake under hot weather conditions, especially amongst the vulnerable recently received and less adapted cattle.

Pros:

- Water is an essential nutrient, whose quality, quantity and reliability of supply to livestock at all times, need to be beyond doubt and reproach.

Conclusions:

An assured supply of adequate water of suitable high quality at all times, importantly when hot weather conditions prevail, is an essential to minimise EHL in feedlot cattle. This necessitates careful consideration to the siting design and construction of the installation.

6.2 Animal

Breed, phenotype and coat colour in cattle are relevant to the management of EHL.

6.2.1 Breed

(a) *Use of Bos indicus*

The most obvious method is to change the breed of cattle entering feedlots in spring from *Bos taurus* breeds to *Bos taurus* x *Bos indicus* breeds, or pure bred *Bos indicus*.

Pros:

- Almost no problems with high heat load.

Cons:

- May not meet specific market specifications.
- Lower growth and feed: gain performance compared to *Bos taurus* if EHL not encountered.
- Sourcing suitable cattle may be difficult especially in Victoria and southern NSW.

Conclusion:

The greater use of the *Bos indicus* breeds offers advantages in regard to high heat load in cattle, but there are commercial and practical considerations also determining the extent to which they might be used.

(b) *Heat Tolerance*

Development of specific heat tolerant *Bos taurus* genotypes. This could be done using existing breeds, importation of heat tolerant breeds (e.g. Tuli and Senapol) or development of new breeds. There is also the possibility of using gene marker technology to identify cattle with the “heat tolerance” genes. This is currently under investigation in the USA.

Pros:

- Heat tolerant *Bos taurus* breeds have better prospect of meeting market specifications than *Bos indicus* cattle.
- Heat tolerant *Bos taurus* breeds are less likely to suffer from EHL.

Cons:

- High cost involved in importation of semen, embryos etc and development of breed.
- High cost in identification of heat tolerance gene.
- This is a long-term solution.

Conclusion:

The advances in developing gene marker technology should be monitored by the industry with respect to the identification of heat tolerance genes.

6.2.2 Phenotype

(a) *Adaptation and Acclimatisation*

Use *Bos taurus* cattle that have adapted/acclimatised to hot and humid conditions. Cattle moving from north Queensland to southern Queensland are less likely to suffer from EHL than cattle moving from Victoria to southern Queensland.

Be aware that recently received cattle have increased vulnerability to EHL till adapted to the feedlot conditions and environment.

Pros:

- Adapted *Bos taurus* breeds are less likely to suffer from EHL.

Cons:

- Sourcing adequate numbers of cattle could be a problem.

Conclusion:

Feedlot operators need to be aware of the processes of adaptation and acclimatisation, particularly when sourcing cattle for the summer feeding period. Additionally the vulnerability of recently received cattle, till adapted to feedlot conditions, should be recognised.

6.2.3 Coat Colour

(a) *Light Coloured Cattle*

Use light coloured cattle during the summer months. White is better than red, and red is better than black. However, acclimatization is still important.

Pros:

- Light coloured cattle are less likely to suffer from EHL.

Cons:

- Sourcing adequate numbers of cattle could be a problem.
- Market specifications may not be met.

Conclusions:

Black cattle tend to be more vulnerable to EHL, especially when fed for a long period and heavily finished.

6.3 Nutrition

6.3.1 Introduction

The proactive management of cattle nutrition and diet can contribute to ameliorating the adverse effect of seasonal hot weather conditions on feedlot cattle productivity, and in the extreme, can contribute to reducing the incidence of EHL, and the effect on production and mortality. There are basically two components to planning and implementation.

- **Pre-summer diet preparation**, involves the routine seasonal review of diets and practice to achieve optimum summer productivity and to establish a nutrition management program for EHL events should they occur.
- **EHL diet program**, involves the implementation of diet and feeding practice changes to minimise the effect of EHL just prior to and during the event, according to a predetermined program (above).

It is envisaged these components will be part of an all-embracing program to combat production losses suffered by the industry during seasonal hot weather periods.

6.3.2 Pre-summer Diet Preparation

An annual hot weather (predominately summer) nutritional review will define general practices for the forthcoming summer to minimise animal heat load while achieving productivity objectives. It will pay particular attention to the impact of metabolic heat on the animal heat load, addressing:

- Heat increments, nutrients, ingredients and diets

- Diet adequacy
- Ingredient and nutrient care
- Feeding practice
- Preparation of EHL diet program

For efficiency, summer diets need to maximise the use of the **low heat increment** ingredients from those locally available and commercially acceptable.

Nutrient heat increments are lowest in the order of the nutrient fats, then carbohydrates (soluble less then cellulose), then protein when in excess and metabolised.

Ingredients heat increments are lowest in the ingredient fats and oils, followed in general by the oilseeds, grains, high quality roughages (eg. corn silage, cotton seed hulls) then the high fibre roughages (eg. stubble hays).

Whilst ever the animal is able to adequately regulate body temperature by dissipating excess body heat, the highly digestible high-energy diets produce less metabolic heat per unit of production and are the most efficient forms of summer production.

Diet adequacy reviews will ensure summer diets are adequate in all nutrients, avoiding an excess of nutrient protein (excess metabolised, and an unnecessary source of metabolic heat) and a sufficiency in particular of K, and Vitamins A and E.

Additionally, a water (water is an essential nutrient) review will address its quality, its adequacy of supply, reticulation, and delivery (Refer 4.3.4.4).

Ingredient care reviews are desirable. Both Vitamin A and E are quickly depleted in stored ingredients and feeds, with the deterioration rate accelerated in hot weather. Their supply program and storage arrangements need care to ensure maximum freshness in delivery, minimum practical inventory in store, and minimum deterioration whilst stored. Diet inclusion rates may need adjustment for expected summer deterioration and losses.

Feeding practice can assist the animal dissipate excess body heat. Body temperature rises after feeding. Cattle are generally better able to dissipate body heat during the cooler night hours. Increasing the emphasis on afternoon (and early evening) feeding encourages the animal to better match the period of increasing body temperature with the cooler parts of the day when ridding excess body heat is easiest.

The pre-summer review will specify in advance an **EHL diet program** (For example refer 6.3.3) for implementation should adverse environmental conditions incur EHL in cattle during the subsequent summer.

Pros:

- Enables minimal metabolic heat production from available ingredient resources whilst maintaining optimum summer diet efficiency, and reducing EHL possibility.

- Ensures maximum preparedness in advance with a specified nutritional program to implement during an EHL event should one occur, so ensuring efficient application.
- Reduces undesirable metabolic heat production from unnecessary excessive dietary protein.
- Provides correction opportunity for potentially depleted Vitamin A, E in stored ingredients during summer, and for diet adequacy in micronutrients.
- Provides for better matching of animals peak daily period of metabolic heat production with cooler parts (night) of day for most efficient heat dissipation.

Cons:

- Increasing the emphasis on afternoon (and early evening) feeding may increase operating costs.

Conclusion:

The proactive pre-summer diet review can ameliorate the adverse effect of hot weather conditions on feedlot cattle. It will enable optimum overall summer production efficiency by minimising diet metabolic heat while concurrently ensuring diet adequacy.

Importantly, it also ensures the feedlot has a specified effective diet program prepared in advance to minimise the effect of an EHL event, should one occur.

6.3.3 Example of EHL Diet Program

The earlier review (refer 4.2.4.4; 4.3.2; 4.3.3) suggests the fundamental principles upon which to develop a feedlot diet program to minimise the effect of an EHL event on cattle. The research to date, while sound, is in some areas inconclusive, frequently minimal, and in some instances based on small numbers of animals and/or laboratory findings only. The research needs further ongoing validation under applied commercial industry conditions.

Nevertheless, recognising these limitations, an example of an EHL diet program is presented, based on the best assessment of the information available, and as a basis for further applied investigation.

Animals experiencing EHL stress decrease DMI so reducing metabolic heat. Increasing dietary roughage decreases dietary energy. Increasing dietary roughage under EHL conditions further decreases DMI as the digestion rate declines, and metabolic heat is further reduced as a consequence of both reduced DMI and reduced dietary energy intake.

This may be used to advantage in a diet program of two parts, relating to (i) there being an effective EHL pre-warning system in place and (ii) there being no EHL pre-warning system, namely:

(i) There is **pre-warning** (ideally, 3-6 days in advance) of impending adverse environmental conditions likely to initiate EHL in cattle, *or*

(ii) Without warning **cattle are suffering an EHL event** as a result of adverse climatic conditions existing.

In the first instance:

When **pre-warned** of an impending adverse environmental situation, diet adjustments gradually decrease the grain and increase the roughage proportions. This reduces dietary energy, and the animal heat load is then reduced with an associated decrease in metabolic heat as a consequence of:

- Reduced DMI associated with the hot conditions,
- Reduced heat increment of diet.

The program increases roughage to some 25% proportionally over the pre-warned period up to 3-5 days. If the pre-warning is 5 days, the change is 5% daily till reached, or if 2 days, 7+% daily. When the event is passed the adjustments are reversed in 5% increments, decreasing roughage 5% daily till the original diet is reached. This minimises adverse post EHL effects associated with increased DMI, and accompanying increased metabolic heat production, and potential acidosis.

In some instances, increasing roughage to the order of 25% may in effect be reverting to an established intermediate diet.

In summary, an example of the program when there is 3-5 days pre warning, comprises:

- Gradually increase diet roughage 5% daily (or 7+% when 2 days warning), in lieu of grain till increased to 25%, or the event has passed (ensuring always nutrient balance is maintained),
- When passed, reverse adjustments in 5% steps, decreasing roughage daily till original finishing diet is reached; and
- Concurrently, hold feedlot cattle on starter or intermediate diets, deferring their progression to higher density lower roughage diets till the EHL event has passed.

The advantage of an early warning of a likely EHL event is that it enables diet modification in advance, with time for the maximum response to the modifications to reduce metabolic heat. There is an animal response lag to diet change opined by various authors as from 1-2 days to 3-4 days.

In the event the early warning over-estimates the situation and the pre-warned adverse situation fails to eventuate (as will occur on occasions) reverting to the high production diet will be with minimal disturbance to animal production efficiency.

In the second instance:

When **without pre-warning** cattle suffer EHL (observed second stage panting, reduced DMI, showing distressed behaviour, on site weather monitoring and THI-hours), diet adjustments immediately, increase the roughage proportions. This reduces dietary energy, with an associated decrease in metabolic heat and animal heat load as a consequence of:

- Reduced DMI associated with the hot conditions.
- Reduced heat increment of diet. There is however, an animal response lag time with 3-4 days required for the full benefit of the dietary adjustments.

The program immediately increases roughage to some 25%. When the event is passed, the adjustment is reversed in 5% increments, decreasing roughage 5% daily, till the original diet is reached. This, as previously, minimises adverse post EHL effects associated with increased DMI, and accompanying increased metabolic heat production, and potential acidosis.

Increasing roughage to the order of 25% may, as previously, in effect be reverting to an established intermediate diet.

In summary, an example of the program for cattle suffering EHL stress without warning, comprises the following steps.

- Immediately increase diet roughage to some 25% in lieu of grain
- When an event has passed, reverse adjustments in 5% steps, decreasing roughage daily till original finishing diet is reached.
- Concurrently, hold feedlot cattle on starter or intermediate diets, deferring their progression to higher density lower roughage diets till the EHL event has passed.

An alternative to this second instance example of increasing the diet roughage content, is occasionally proposed by researchers largely as a result of studies conducted under a-typical feedlot conditions with luxurious available feed bunk space. This is to reduce DMI by restricting feed supply to possibly 80% of current consumption, so forcibly reducing intake of dietary energy, and reducing animal metabolic heat.

This is considered difficult to implement satisfactorily and impractical under commercial conditions where the influence of dominant feeders is greater when there is less bunk space. There is a greater risk of acidosis and its effects during the return to full feeding, with impaired production efficiency. This alternative is mentioned here but not recommended.

Pros:

- A dietary program prepared in advance for EHL events ensures the most efficient and effective application of principles and experience when required with minimal disruption to production efficiency.
- The example program (of two parts) reduces dietary energy reducing animal metabolic heat during an EHL event. Metabolic heat is reduced as a result of both diet adjustment, and a DMI decline accompanying hot conditions.
- A pre-warning (3-6 days) of an EHL event enables the most efficient application of dietary modifications to minimise EHL stress, by gradually increasing dietary roughage, with time for the animal to adjust to the changes.

- When the EHL event occurs without pre-warning, the immediate increase of dietary roughage aids the reduction of EHL stress, *albeit* less effectively than a gradual roughage increase when time permits.
- The programmed gradual return to pre-event roughage levels minimises adverse post EHL effects associated with a probable rebound increase in DMI, and accompanying metabolic heat production and potential acidosis.

Cons:

- The example program requires effective diet quality controls, and systems implementation.
- Ideally, the EHL diet program requires an effective pre-warning system to be in place so allowing for the animal response lag to the diet change, for greatest efficiency.
- In the absence of a pre-warning of the EHL event, the alternative immediate dietary change can be effective and beneficial, but is diminished in the absence of time for cattle to adjust.

Conclusions:

The example EHL diet program is based upon the research findings and observations available, but requiring validation under applied commercial industry conditions.

The effect of an EHL event can be reduced by dietary modifications, principally increasing roughage levels and so reducing dietary energy. Animal metabolic heat is then reduced as a result of a DMI decrease associated with the hot environment, and reduced dietary energy following diet modifications.

Principle dietary modifications involve increasing roughage levels to the order of 25% gradually over the available days when forewarned, or should the event occur without warning, immediately.

The establishment of an effective pre-warning system enhances the efficiency of dietary modification programs.

When the EHL event or its possibility has passed, the gradual reduction in roughage levels in (say) 5% increments minimises the impact of a probable rebound increase in DMI, with associated secondary EHL impacts and potential acidosis.

6.4 Behaviour

Most of the behaviour associated with cattle exposed to EHL is a response to the hot conditions. However, cattle behaviour primarily herding may, in a minor way, contribute to the heat load. Staff awareness of cattle behaviour and the use of strategies to modify that behaviour, can assist in managing the impact of EHL.

6.4.1 Identification EHL – Staff Awareness

The animal's behaviour is the ultimate indicator of how the animal is coping with EHL. In the previous list of symptoms (refer 4.4) the animal is seen to cope during stages 1-9, but fails at 10 and above.

The implementation of a program to handle EHL is dependant upon the recognition of these stages. All staff therefore, need training to be able to identify EHL at the various stages.

Pros:

- Facilitates earliest implementation of EHL remedial programs.
- Enables action to reduce EHL effect on cattle and feedlot.

Cons:

- Cost of training (very low)

Conclusion:

Staff awareness of the animal behaviour symptoms associated with the various degrees of EHL will enable the operation to implement counter-measures at the earliest opportunity, maximising their effectiveness.

6.4.2 Behaviour Modification - Infrastructure

There are livestock behaviour characteristics which make minimising EHL difficult. These include bunching (eg. about waters), crowding (eg. under shades) and the further development of the dominant animal syndrome.

Animal behaviour can be modified by the following infrastructure improvements.

- The placement of additional watering points in a pen.
- The placement of shades in a pen, their position and size.
- The modification to shade design to ensure its effectiveness in minimising EHL incidence (eg. area, height, effect on convection and micro-environment).
- Strategic use of sprinklers.
- The establishment of mounds in pens.

Pros:

- Reduce effect of dominant cattle.
- May permit greater air movement amongst cattle.
- Reduce behavioural stresses.

Cons:

- May incur additional costs.

Conclusions:

These are infrastructure improvements, which can favourably improve the feedlot pen animal behavioural environment and should be considered at the initial planning stages for most effective incorporation. However, they can still enhance the environment of established facilities.

6.5 Management

Proactive preventative management strategies or programs provide the most effective means to alleviate or minimise the impact of EHL on feedlot cattle. Pre-summer planning can in effect minimise the effects of an EHL situation.

A proactive pre-summer preparation program (the P3 Program) reviews the preparedness and adequacy of management for the summer in advance. This forms part of an overall pre-summer review (outlined in 7.2.4.1).

The P3 Program involves the preparation of:

- resources
- livestock
- personnel

in accordance with the principles outlined in 4.5.

6.5.1 Resources

Resources are evaluated for their inclusion, adequacy and effectiveness, in particular:

- Water
- Shade
- Sprinklers
- Mounds (in association with pad management)

Pros:

- The preparation of resources will assist to minimise the occurrence of EHL.

- Advance preparation provides time to overcome possible inadequacies or deficiencies.

- Preventative maintenance will enhance efficiencies decreasing maintenance costs.

- Planning ensures resources required are available, adequate and effective.

Cons:

- Possible costs involved.

6.5.2 Livestock

Livestock should be appraised in regard to their relative vulnerability or susceptibility to EHL conditions (eg. cattle approaching market finish, newly received cattle, hospitalised cattle). Pens are evaluated with respect to their comparative EHL risk factors (eg. pens with maximum cooling opportunities) and cattle movement (shipment, processing) practices are examined.

Pros:

- Preferential treatment can be given to the most vulnerable cattle in advance of summer.
- Animal welfare issues are addressed.

Cons:

- Nil

6.5.3 Personnel

All staff need to be kept informed of all reviews, assessments and programs formulated for the alleviation of EHL. Staff should be aware of their personal contribution and/or role, and provided with the necessary knowledge to make meaningful assessments and decisions.

Pros:

- Staff remain motivated and keep management better informed.
- Staff enjoy increased job satisfaction.
- Feedback from staff to management is enhanced.

Cons:

- Nil

Conclusions:

Management's principal function in reducing EHL is the preparation of programs in advance and their timely implementation, such as the P3 Program.

The main benefit derived from the P3 Program is the maintenance of optimum productivity in a typically low productive (summer) period, whilst addressing welfare issues.

7. MANAGEMENT PROGRAM RECOMMENDATIONS FOR THE AUSTRALIAN FEEDLOT INDUSTRY

Management programs are discussed for the feedlot industry overall, and for the individual operating feedlot.

7.1 Feedlot Industry

The industry is best equipped to address:

(a) the further assessment and possible development of an EHL weather forecasting service,

(b) the extension of knowledge on summer heat load and EHL to industry participants, and,

(c) matters of regulatory concern.

7.1.1 EHL Weather Alert Forecasting

It is more effective to implement a pre-planned program to minimise EHL in advance of the event than to respond to the event when it occurs. A 3 – 6 day meaningful weather forecast of hot conditions likely to cause an EHL event, will allow management to implement to greatest effect the pro-active environment management counter-measures prepared prior to the onset of the hot weather.

(a) *BoM Special Services*

Preliminary discussions with Bureau of Meteorology Special Services Division (BoM) Sydney (Whitaker, personal communication), and Brisbane (Davies, personal communication), suggest that it should be possible for industry to develop with BoM a meaningful tailored weather alert forecasting service, to forewarn of likely EHL conditions. This probability is enhanced by recent advances in BoM resources and analytical practices, and communication opportunities.

There is currently no similar effective forecast service for the feedlot industry elsewhere in the world, although it has been frequently discussed as desirable and possible in the literature. It is understood however, such a service is currently being investigated in the USA and is to be reported upon in May 2001 (Gaughan, personal communication). There are similar services provided for a diverse range of other industries in Australia. The service would incur a development cost and annual fee (Appendix 3).

An Australia wide EHL weather alert service could summarise the appropriate forecast meteorological conditions (ambient temperature, dewpoint, wind, cloud cover) into an index such as the THI (Index), together with provision for time (Time) the conditions might prevail. This information, for each of the 3-6 days forecast could be distributed to industry participants by way of a website, e-mail, or fax, in a summarised format as illustrated in Table 7.1. The information would be continuously updated and be sub regional specific, or possibly site specific.

Table 7.1: Example[a], EHL weather alert forecast, for day +1 (or +2, ….,+6).

BoM Environment Forecast		EHL Risk Alert	
No Wind	**Wind**	**Code**	**Name**
(Index, Time)<70	(Index, Time)<70	Green - 0	Low Risk
70<(Index, Time)<75	70<(Index, Time)<80	Amber - 1	Level 1- Amber Alert
75<(Index, Time)<80	80<(Index, Time)<85	Pink - 2	Level 2- Pink Alert
80<(Index, Time)	85<(Index, Time)	Red - 3	Level 3- Red Emergency

[a] Illustrative example only, the appropriate index to be determined.

The forecast would have the relevant line high lighted for the next 6 days. Feedlot management would interpret the EHL weather alert forecast in terms of their own on site pen micro-environment experienced by the cattle. There may be need for site-specific adjustments to the forecast conditions, based on local knowledge.

Feedlot management would be able to assess the forecast and then apply as necessary their pre-planned counter-measures to maximum effect and benefit.

(b) *Implementation*

The stages for industry to develop and implement an EHL weather alert forecast service include:

- Establishing likely costs, and means of cost recovery.
- Establishing a timetable for implementation pre-summer.
- Learning further of the USA proposals for release May 2001.
- Defining the optimum EHL event Index for Australian weather conditions.
- Consulting with BoM confirming their ability to meaningfully forecast the index nationally for 3-6 days.
- Proceeding with development.
- Trial running.

7.1.2 Advisory

(a) *General*

Information is available which can assist industry participants enhance their understanding of the dynamics and importance of summer conditions on feedlot productivity, in particular during very hot periods when cattle may experience EHL effects. This knowledge may be extended by manual, workshop, and industry based training programs within University, TAFE and Agricultural Colleges so that future graduates are informed.

(b) *Support Centre*

In the short term an accessible liaison support centre where industry operators can refer their enquiries about heat load and EHL minimising strategies may be constructive, particularly when:

- conducting an EHL risk assessment of their situation,
- initially establishing EHL risk minimising programs, and/or
- upon receiving a weather forecast of a likely impending EHL event, or, upon experiencing an EHL event.

7.1.3 Regulatory

The positive public perception of the feedlot industry as a proactive member of the commercial livestock community may be enhanced by addressing the animal welfare issues associated with the EHL syndrome in cattle.

This commitment may be conveyed by:

- The industry being informed of the factors influencing the incidence of EHL in cattle, at the macro- and micro-environment level.
- The industry being informed of the practices able to lessen the impact of heat load and EHL in cattle, in particular with respect to feedlot infrastructure design and construction, and management programs and practices.
- Adapting the *"National Guidelines for Beef Cattle Feedlots in Australia"* in the Australian Code of Practise for Welfare of Cattle in Beef Feedlots, to make them more explicit in regard to EHL factors.

7.2 Operational Feedlot

Management programs are discussed for a new feedlot development at inception, and for an existing established feedlot operation.

7.2.1 New Development

When a new feedlot is being considered, a site and design review should be completed prior to establishment.

The initial site assessment for a feedlot development needs to take into consideration factors influencing EHL in cattle. Additionally, in designing the feedlot, there are features which impact (favourably, unfavourably) on the incidence of, and severity of heat load and EHL in feedlot cattle. The design features highlighted are suggested for general incorporation in new Australian feedlot developments.

(a) *Site Review*

The initial site assessment reviewing EHL risk factors would comprise:

- A Regional Seasonal Climate and Weather Audit. This audit assesses the probability, likely incidences and severity of EHL events in the region, on the basis of meteorological records.
- A Local Climate and Weather Audit. This reviews slope, aspect, natural air movements, natural barriers and their possible effects on the micro-environment, on a site basis.

(b) *Design*

The features and infrastructure to consider during the siting, and design stages include air movement, water supply, shades, sprinklers and weather monitoring.

Air Movement – Natural summer air movement (eg. due to slope, prevailing winds) is advantageous. Sheltered, protected, or naturally calm areas may be disadvantageous.

Waters – In supplying water to feedlot cattle, the principal design considerations with regard to reducing the impact of very hot weather conditions (Refer 6.1.7) can be summarised as follows:

- Quality, quantity of water and reliability of supply to livestock at all times to be beyond doubt and reproach.
- Minimum two water troughs per standard pen.
- Minimum 25mm, and ideally 75mm linear trough access per SCU, under hot weather conditions.
- Water trough supply to be tested for capacity to supply daily minimum of 15 litres/100kg bodyweight of penned animals under peak demand conditions, and to meet daily peak consumption needs in a four hour demand period, on an entire feedyard demand basis.
- Supply to water troughs to be entirely underground.

- Troughs be equipped with overflow/waste water collection and integrated entire feedyard disposal system clear of pens.

- Portable waterers be retained on site for use by most vulnerable cattle during an EHL event.

Shades – On existing knowledge (Refer 6.4.5) adequately designed solar shades appear able to provide relief to cattle experiencing an EHL event, and can be an aid for the most vulnerable (eg. those most heavily finished and long DOF, *Bos Taurus*, black, recently received, and hospitalised). Whilst specifications of the optimum shade design require further elucidation, general aspects are summarised as:

- Minimum shaded area 1.5m^2/SCU, with probable improvements to 3.5m^2/SCU.

- North-south orientation.

- Solid shade, in preference to slates or shade cloth.

- Shade to be aluminium, or white, or galvanised metal roofing material.

- Height, minimum 3.7m and improving to 4.5m, (and possibly higher).

- Location, towards pen centre, avoiding feed bunks, water troughs, and sprinkler areas.

Sprinklers – Sprinklers, judiciously used, assist in relieving heat load in cattle, minimising EHL (Refer 6.1.6), and suppressing dust. Design considerations can be summarised as follows:

- The spray should be of large droplets, sized approximately 150 micron.

- Minimum of two, ideally three sprinklers should be provided per standard pen, each able to be turned off/on independently, ideally each with remote controls.

- Sprinkler area 2.5m^2 to 3.0m^2/SCU.

- Sprinkler range should avoid feed bunks, water troughs, and shades.

- Water supply should be stand alone not competing with supply of water to water troughs.

Weather monitoring – New feedlot developments of 5,000 head capacity or larger will benefit from their own on site weather station equipped with a computer link to enable automatic pen environment THI recording hourly, and processing along the principles outlined in 4.1.8.2.

7.2.2 Established Feedlot

A site and design review is completed for the existing development.

A review assessment of the feedlots' natural site and infrastructure design features, will provide an appreciation of the developments characteristics influencing localised EHL, and possibly suggest measures to alleviate it. Where appropriate and practical existing feedlot infrastructure should be upgraded.

(a) *Site Review*

As for a new development a site review of EHL risk factors involves:

- A Regional Seasonal Climate and Weather Audit. This audit assesses the probability, likely incidence and severity of EHL events in the region, if any, from meteorological records.
- A Local Climate and Weather Audit. This examines the natural qualities of the site (eg. slope, aspect, natural air movements, obstructions, wind barriers) and their effects on the micro-environment, on a site basis.
- Determination of high/low EHL risk pens. Individual pens across a feedlot frequently differ in their propensity to an EHL incidence, because of individual air movement patterns (pens up-slope vs down-slope; pens at edge vs centre; pens unobstructed vs adjacent obstructions), the ability to dry out (aspect north vs south; unshaded vs shaded) or the quality of the development (eg. number, size, and effectiveness of shades, sprinklers, waters).

Identifying the high/low risk pens enables management to care for the more vulnerable animals to best effect.

(b) *Design Review*

As for a new development, a review of the infrastructure features will identify those capable of adversely influencing EHL in cattle during hot conditions, and suggest improvements (refer 7.2.1.2). Locally, it may be difficult to upgrade an existing feedlot establishment to incorporate all the desirable design features available to a new development, but the same guiding principles will apply.

Air Movement - Identify obstacles to air movement, (eg. buildings, structures, crops).

Shades - Determine if installed, and if so probable effectiveness in assisting vulnerable animals tolerate EHL conditions. Determine upgrade desirability.

Sprinklers - Determine if installed, and if so effectiveness. Determine upgrade desirability.

Water - Assess quality and adequacy (eg. trough numbers, length, supply capability, location, backup supply and distribution, waste water controls) and efficiency. Determine upgrade desirability.

Pen micro-environment - Evaluate, and determine influencing factors in particular design features. Determine upgrade desirability.

The pen micro-environment, the animals' immediate environment, is principally the product of the macro-climate and weather (ambient temperature, rainfall, radiation, air movement), local influences (aspect, shade, mounds, drainage, sprinklers, obstacles, pad fermentation), the animal factor (stocking density, animal size, diet), and management (pen cleaning, trough overflows/discharges).

7.2.3 Weather Monitoring, THI-Hourly

Ideally, individual feedlots would have access to an effective EHL weather alert service. This remains to be developed.

The **THI-hour** concept can however be used to commercial advantage at the feedlot level in its current state of development, to indicate the ongoing severity of heat load on cattle and to provide a valuable guide to assist management response. Further development of the concept will improve its efficiency.

It is desirable that substantial feedlots, say of 5,000 head capacity or larger, have an on site weather station equipped with a computer link to enable the THI to be recorded automatically each hour, and processed along the principles outlined in 4.1.8.2, for regular ongoing monitoring.

7.2.4 Management E H L

Appropriate feedlot management for EHL conditions comprises three stages.

First – Apply a proactive **Pre-Summer Review** of the feedlots preparedness, so as to minimise the possible occurrence of an EHL event, and, should one occur, to minimise its effect (Refer 7.2.4.1).

Second - Maintain a **Summer Diligence Program** implementing practices to minimise the possible occurrence of an EHL event, whilst been alert to the earliest signs of a probable occurrence.

Third - Apply prepared **EHL Event Strategies** when an event is forecast or occurs.

(a) *Pre-Summer Review*

- The review embraces:
- An annual examination of the infrastructure condition and design with upgrade as necessary (Refer 7.2.1.1; 7.2.2.2).
- An examination of management of resource, livestock, and personnel practices, and implementing the P3 program (refer 6.5).
- Preparation of a summer nutrition program (Refer 6.3).
- Preparation of EHL event strategies, pre-planned in advance (Refer 7.2.4.3).

(b) *Summer Diligence Program*

The program is designed to minimise the occurrence of EHL in cattle, whilst maintaining vigilance for an event throughout the summer, and having a prepared strategy in place should an event occur. The program embraces:

- Ongoing infrastructure upgrade and maintenance (Refer 7.2.1.2; 7.2.2.2).
- Summer diet and EHL diet program (Refer 6.3).
- Ongoing management of resources, livestock and personnel (Refer 4.5).
- Ongoing monitoring THI-hours on site, animal behaviour, and EHL weather Alert Service forecast, if accessible.

(c) *EHL Event Strategies*

The principle component strategies when an event is forecast, or occurs are:

- **Plan** a response, of necessity completed in advance during the Pre-Summer Review (above).
- **Recognise** the event as likely imminent, or as occurring, by observing animal behaviour, monitoring on site THI-hours, or monitoring if accessible, EHL Weather Alert Service.
- Take **Action**, implementing the prepared response plan embracing:
    - preplanned diet programs (including time of feeding)
    - cessation of animal movements and handling and any animal stress causation practice
    - judicious use of sprinklers, if low humidity
    - use of portable water troughs for vulnerable cattle
    - use of forced air ventilation, if available and practical

8. RESEARCH RECOMMENDATIONS FOR AUSTRALIAN FEEDLOT INDUSTRY

The recommendations are that the Australian Feedlot industry be better informed of the direct and indirect impact of hot summer conditions on seasonal productivity and production efficiency, and have forewarning of likely EHL incidences. These recommendations are grouped under Systems Development, Knowledge Extension and Research and Development, without reference to any intended order or priority.

Systems Development

(a) Conduct EHL Weather Risk Assessment

The probability of weather influencing the incidence of EHL in Australia is unknown. An assessment of the relative risk of the occurrence of EHL in the Australian Feedlot Industry would be valuable background information to future policy and investment. This would be at the national and site level.

- National: Risk assessment categorising (nil, slight, moderate, or high risk) regions according to weather patterns, as background to developing new sites and appraising existing operations.
- Site: Develop guidelines for individual site appraisals.

It is recommended an EHL weather risk assessment be conducted for the Australian Feedlot Industry.

(b) Develop Heat Load Management Programs

There are important operational feedlot practices to counter the occurrence and effect of EHL in cattle. *It is proposed* that program guidelines be prepared embracing:

- Pre-Summer Review,
- (Ongoing) Summer Diligence Program, and
- EHL Event Strategies,

as preparation for managing hot summer weather conditions, in particular EHL event, in industry guideline format (refer 7.2.3).

This is recommended.

(c) Develop EHL Weather Alert Forecast Service

It is much more effective to implement a plan to minimise EHL in advance of the event. A 3-6 day alert forecast allows the implementation of pro-active environment management counter – measures to greatest effect.

A proposed program of development and implementation has been outlined in section 7.1.1.

It is recommended that the development of an EHL Weather Alert Forecast Service be further explored and if confirmed practical, implemented.

(d) Develop EHL Incident Reporting Mechanism

Each EHL incident offers the opportunity for the industry to expand its accumulated knowledge significantly. There is currently little reliable objective data on the circumstances of EHL incidents in commercial feedlots.

It is proposed that a confidential reporting system be developed on the following basis for EHL losses in Australia, similar to those for infectious diseases:

- Its object is to add to the understanding of EHL in cattle to reduce further losses.
- Absolute confidentiality is assured.
- It would not be the basis for incrimination.

This is recommended.

Knowledge Extension

(e) Develop Program of Extending Existing Knowledge to industry, by way of:

- Developing an applied industry extension manual.
- Ensuring the EHL concepts form part of the Course Curriculum at Universities offering veterinary and animal science training, TAFE, and Agricultural Colleges.
- Conducting industry workshops in heat load and EHL, conveying in particular the product of recommendation 2, and seeking industry feedback.

This is recommended.

(f) Foster International Research and Extension Links, in particular in regard to heat load in feedlot cattle. EHL in cattle is of international concern, and it is important to maintain an exchange of knowledge and ideas between like-minded people in research and extension, particularly in the USA where weather and pen micro-environments are often similar to those in Australia.

This is recommended as a means of keeping the Australian industry well informed of developments elsewhere.

Research and Development

(g) Determine the Cost of Summer Heat Load, on summer feedlot productivity (reduced DMI, LWG, FCE). Compensatory growth appears less then complete, and there appear “hidden costs” associated with heat load in cattle. Estimates from a large (70,000 head) US feedlot suggest a US$4/head of capacity cost due to summer heat load. (Commercial in confidence).

Studies are recommended to assess in economic terms the summer productivity losses in Australia feedlots.

(h) Conduct an Applied Scientific Evaluation of Shades. Shades are rarely defined, but of many varieties, areas, sizes, heights, shapes, pen position, and not surprisingly are found to offer varying degrees of protection to cattle. There are however, practical examples where “shade” has significantly reduced EHL mortalities in vulnerable feedlot cattle exposed to very hot weather conditions, and efficient shade appears good insurance for vulnerable cattle.

It is recommended the entire shade design issue be examined with regard to basic physical and engineering principles and applied experience, with the objective developing of the optimum practical cost effective shade model able to be incorporated in both existing and new developments, when warranted.

(i) Examine the Practical Contribution Convection can make to Reducing EHL in the feedlot environment. This would examine:

- Passive Convection – Air movement associated with mounds, natural site attributes and properties, aspect, so on.
- Forced Convection – For example fans, which may be: large or small, adjacent to shades or appendages to shade; or in combination with mists of water, and so on.

It is recommended convection be fully investigated, in particular the potential of forced ventilation to reduce EHL in feedlot cattle.

(j) Modelling Heat Load in Feedlot Cattle

Computer simulation modelling is a tool available for integrating information in complex situations. By modelling the feedlot and animal thermodynamics, of the completeness and reliability of existing information can be assessed, and predictions made of the relative effectiveness of various management strategies.

Such a model, if user friendly, also has much to offer as an extension and/or education tool.

It is recommended that research develop and ratify (under practical feedlot conditions) an user friendly computer simulation model on the thermodynamics of heat load in feedlot cattle.

(k) Development of EHL Environment Index (THI-hours)

On the basis of current knowledge and development, the THI-hour index offers a valuable support to feedlot operators in pre-warning the possible occurrence of an EHL event, and managing the event should one occur (eg. nutrition, sprinklers).

The index will benefit from further development embracing:

- The development of a THI-hour index (or score) to assist feedlot management better assess the thermal load on their cattle.
- The development of weighting factors for the range of THI values accumulated over time to better incorporate the benefit of night time cooling, enabling the accumulated THI-hours to be presented as an ongoing single indicative index.
- The development of a photo guide scoring the behaviour of cattle to hot and EHL conditions, in particular respiration and panting rates, to assist feedlot personnel rapidly assess cattle (and implement response strategies).

It is recommended that an EHL environment index be further developed.

(l) Commercial Validation of Nutritional Concepts

Research has shown that feedlot dietary manipulation reducing nutrient energy intake during hot weather conditions can influence the severity of an EHL event. However, the concepts generally lack validation under commercial feedlot conditions.

It is recommended that the nutritional concepts of adjusting dietary energy intake in particular by varying the roughage proportions, be further investigated under applied commercial feedlot conditions.

(m) Relevance of Ammonia in Feedlot Production

The production of feedlot ammonia as a result of the decomposition of the feedlot pad, and its effect on animal health and performance during hot weather conditions, is little understood.

It is recommended that studies be implemented to better quantify ammonia production and its possible influence on feedlot animal production.

(n) Water Intake Under EHL Conditions

A noted characteristic of cattle that have died as a result of EHL is their dehydration, even when water is readily available to them. This has similar aspects to observations on high performing athletes.

It is recommended that the biochemical and physiological factors which inhibit the desire to drink in cattle suffering from EHL be reviewed, to gain a better understanding of factors influencing water intake.

(o) Support, Gene Technology

Marker assisted selection (MAS) offers the opportunity to identify *Bos taurus* cattle with high heat tolerance. This would be a long-term project, which must first identify the genes which contribute to heat tolerance in cattle, and interactions with other genes which influence traits, such as marbling and growth potential.

It is recommended that research into gene technology be monitored.

9. CONCLUSIONS

EHL occurs where a combination of local environmental conditions and animal factors lead to an increase in body heat content beyond the animals' normal physiological range and its ability to cope.

EHL occurs in the Australian feedlot industry as it does in the USA industry and in the industry in other similarly placed parts of the world. Australia experiences ongoing periodic instances when EHL is associated with mortality and production loss. There have been occasions when these losses were most significant. It is reasonable to assume additional unnoticed and/or unreported losses have also occurred, and will continue to occur.

Overall, the economic costs associated with morbidity and mortality during EHL events are high. Furthermore it has been demonstrated there are long term financial losses associated with hot weather induced reduced DMI and subsequent reduced production, which can exceed the financial loss from EHL cattle mortality.

Additionally, the industry may suffer from the (unfavourable) publicity an EHL event might attract in terms of public perceptions, animal welfare issues, with ongoing repercussions.

There is considerable knowledge of the principles of thermo-dynamics in livestock and of the factors influencing EHL in cattle. Whilst incomplete in some areas, the further application of these known principles to developing infrastructure and sound management practice can greatly ameliorate or even eliminate the effect of EHL in commercial feedlot cattle.

There are many separate aspects of the feedlot operation which if implemented individually may have limited effect, but when applied in combination can reduce EHL significance. There is however no single structure or definitive action able to fully eliminate EHL in the current feedlot industry.

The infrastructure considerations include the initial feedlot site selection and its local characteristics, and, in feedlots where EHL might occur, the establishment of effective shades for vulnerable animals; a co-ordinated sprinkler installation; a robust quality livestock watering supply with multiple waterers per pen and portable waterers on hand; and a pen micro-environment monitoring station. There is need for further research into shade design, and the potential for further exploiting convection cooling in the pen.

Appropriate management practices include ensuring the adequacy of infrastructure; constant pen pad maintenance to minimise pad depth in conjunction with establishing compacted mounds; fly control; identification of vulnerable animals and pens; implementation of summer and strategic EHL event nutrition and feeding programs; judicious use of sprinklers, and ongoing pen environment and animal behaviour monitoring. EHL event strategies involve a plan of response prepared in advance; recognising the event as imminent, or present and taking action in relation to nutrition, cessation of animal movements, portable waters for vulnerable animals, and sprinklers. There is need for further research to validate nutritional concepts under commercial conditions, and the further refining of the THI-hours monitoring concept.

It is more effective to implement a pre-planned program for EHL in advance of an event, than to respond to the event when it occurs. It appears an EHL weather alert forecasting service is possible, a development for industry in conjunction with the Bureau of Meteorology, to predict an event 3-6 days in advance. There are similar services to a range of Australian industries. The concept warrants further examination.

The development of meaningful systems along the lines of early warning services and management programs, together with the extension of existing knowledge to the industry, and ongoing research, will significantly reduce the cost of EHL to the Australian feedlot industry.

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APPENDICES

APPENDIX 1 - TERMS OF REFERENCE

APPENDIX 2 - TERMINOLOGY

Abbreviations Used:

DESCRIPTION	SYMBOL	UNITS
Ambient Temperature	T_a	°C
Average Daily Gain	ADG	
Body Temperature	BT	°C
Body Weight (not after feed deprivation unless designated otherwise)	BW	
Breaths Per Minute	Bpm	
Calorie	cal	
Crude Protein (N x 6.25)	CP	
Day	d	
Degree Celsius	^{0}C	
Digestible Energy	DE	
Dry Matter	DM	
Dry Matter Intake	DMI	
Excessive Heat Load	EHL	
Feed Conversion Ratio	FCR	
Gram	G	
Gross Energy	GE	
Heat Load	HL	
Hectare	Ha	
Hot Conditions	HOT	
Hour	h	
International Unit	IU	
Joule	J	
Litre	L	
Mega Joule	MJ	
Metabolisable Energy	ME	
Metre	m	
Minute	min	
Month	mo	
Net Energy	NE	
Net Energy for Gain	NE_g	
Net Energy for Lactation	NE_1	
Net Energy for Maintenance	NE_m	
Pulse Rate	PR	Beats/min
Rectal Temperature	RT	°C
Relative Humidity	RH	%
Respiration Rate	RR	Breaths/min
Second	s	
Sweating Rate	SW	G/(m^2.h)
Temperature-Humidity Index	THI	

DESCRIPTION	SYMBOL	UNITS
The University of Queensland - Gatton	UQG	
Thermo neutral Conditions	TNC	
Thermo neutral Zone	TNZ	
Total Digestible Nutrients	TDN	
US Meat Animal Research Center	MARC	
Volt	V	
Watt	W	
Week	wk	
Year	yr	

APPENDIX 3 - CORRESPONDENCE – BUREAU OF METEOROLOGY

APPENDIX 4 - ADDITIONAL CONTACTS

During the course of the study, reference has been made to the literature and research establishments.

The attached lists additional contacts interviewed during the course of the project.

APPENDICES

APPENDIX 1 TERMS OF REFERENCE

MEAT & LIVESTOCK
AUSTRALIA
FEEDLOT PROGRAM

26 October 2000

Dear Sir/Madam

INVITATION TO OFFER

Meat and Livestock Australia hereby invites offers for the provision of consultancy services and conduct of project work in accordance with the attached Terms of Reference.

The closing date and time for lodgement of your offer is **Friday 24th November 2000 at 5.00 pm** (Queensland time).

Your offer, submitted in the format specified, may be posted to or lodged electronically with Des Rinehart, whose contact details appear at the bottom of this page, and must be received prior to the specified closing time.

Offers may be submitted against individual Terms of Reference. However, preference will be given to submissions that address Terms of Reference for FLOT.307, 308 and 309 within the one proposal, as it is envisaged that there are substantial benefits in integrating these studies. Separate submissions are required for FLOT.310 regardless of the option taken with respect to the other studies.

Depending on which template best suits your organisation; offers should be submitted in the format outlined in either the 'Consultancy' or 'Research Organisation' Full Application and Proposal Guidelines. Additional information can be included as attachments to the 'Schedule'.

INVITATION DOCUMENTS ATTACHED

1. **Terms of Reference**
   a) **FLOT.307** – Recommendations for reducing the impact of elements of the physical environment on heat load in feedlot cattle.
   b) **FLOT.308** – Recommendations for reducing the impact of animal related factors on heat load in feedlot cattle.
   c) **FLOT.309** – Recommendations for reducing the impact of nutrition related factors on heat load in feedlot cattle.
   d) **FLOT.310** – Measuring microclimate variations in two Australian feedlots.
2. **Consultancy Full Application and Proposal Guidelines.**
3. **Research Organisation Full Application and Proposal Guidelines.**

Des Rinehart
Program Coordinator

Program Coordinator
Des Rinehart
Phone: 07 5464 2277 **Fax:** 07 5464 2898 **Mobile:** 0417 728785
Email: rinehart@gil.com.au

RECOMMENDATIONS FOR REDUCING THE IMPACT OF ELEMENTS OF THE PHYSICAL ENVIRONMENT ON HEAT LOAD IN FEEDLOT CATTLE

TERMS OF REFERENCE

THE CONSULTANCY SERVICES

BACKGROUND

Following the reported loss of a significant number of feedlot cattle from extreme weather conditions in February 2000, two reviews were commissioned to review the incident and examine the appropriateness of industry guidelines, standards and codes of practice.

ALFA appointed a Working Party to consider the findings and recommendations contained in the reports from the Independent Committee, commissioned by NSW Agriculture Minister, Richard Amery, and the Industry Committee, commissioned by the Feedlot Industry Accreditation Committee (FLIAC).

The Working Party considered the reports and recommendations from both Committees and identified a number of areas that require further review and/or research before the major recommendations of the reviews can be addressed.

These Terms of Reference address one of the identified areas for further review.

OBJECTIVES

The objective of this project is to provide factual information on the impact of the elements of the physical environment on heat load in feedlot cattle, as a basis for:

a) The development of pre-emptive and day-to-day management strategies that can be employed to minimise the effects of excessive heat load; and,
b) Identifying any knowledge gaps that require additional R&D activities to further support/achieve (a).

Within this framework, the outcome of the project will be a report that:

a) Reviews the relevant scientific literature and industry experience, in the areas specified, to provide a solid knowledge base for:
    i. An improved understanding of the relative importance of the factors associated with excessive heat load events; and,

   ii. The development of risk assessment criteria to assist industry in the prediction of possible excessive heat load events.

b) Outlines the major relevant 'real' issues identified during the review process;
c) Based on the information gained during the project, recommends practical, cost-effective management options for addressing the identified issues; and,
d) Defines possible R&D needs to support the recommended management options.

Specific areas that are to be covered in the review include, but are not limited to, the following:

a) Available technologies and methodologies for predicting and objectively identifying periods of excessive heat load and their ability to address the essential climatic elements of the heat load equation within the feedlot environment - temperature, rainfall, relative humidity, airflow and radiant heat.
b) Relative importance of the identified elements, especially solar radiation and airflow, in the heat load equation.
c) Available computer-based systems for predicting microclimate variations within the feedlot environment.
d) Influence of feedlot topography and siting and design aspects on microclimate variations within the feedlot environment.
e) Elements of shade design and their impact on radiation, airflow, pad moisture, pen maintenance, construction and maintenance costs.
f) Relationship between airflow and the THI.
g) Interaction between water sprays and mists and the THI.
h) Methods of creating airflow – mechanical, mounds, etc.

REQUIREMENTS UNDER THE CONSULTANCY

Scope and Methodology

It is envisaged that a multi-disciplinary team, including engineers, animal physiologists and Industry practitioners, would be best suited to carry out this project. The project would necessarily involve a review of the scientific literature and industry experience in the specified areas, and may also require research and collation of information on commercially available products.

Consultants need to define their proposed methodology and work plan for addressing the project objectives.

Project Management

This project is a component of the MLA Feedlot Program, which has an Advisory Committee of Industry operators that will oversight the project and provide an ongoing guidance.

The outcome of this project will be referred to the Advisory Committee for endorsement prior to acceptance of the Final Report.

Output

The output of the project will be a Report that will be presented, in the first instance, as a Draft Final Report for the consideration and comments of MLA and the Advisory Committee.

The Report will be revised to address comments made on the Draft Final Report and be re-presented to MLA as a Final Report.

The Final Report will contain:

- An Executive Summary (2-8 pages), which will, as far as possible, read as a stand-alone document that effectively summarises the full document in a form suitable for Industry.
- A section detailing the implications to Industry of the findings of the report and conclusions drawn.
- An appendix detailing a list of contacts interviewed during the course of the project.
- An appendix containing the Terms of Reference for the project.

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Two (2) bound copies, and one (1) unbound copy, of the Draft Final and Final Reports will be provided to MLA, as well as an electronic copy of the Final Report using agreed software. MLA has guidelines for presentation of Final Reports, which will be provided to the successful Consultant at the commencement of the project.

Consultants should be aware that the Final Report may be reproduced in MLA format with due acknowledgment to their involvement in its preparation.

Access to Information

Where information is available which may assist the Consultant in meeting the requirements of this project, such information will be provided to the Consultant on a confidential, or other basis as indicated, by MLA.

Confidential information would not be reproduced in the Report, consistent with the caveats mentioned under 'Output'.

Timing

MLA is anticipating that a contract to proceed with the project will be finalised with the Consultant by 15 December 2000. An elapse time of 3 months to complete the project is envisaged with the Final Report being delivered to MLA by 31 March 2001.

Within the first fortnight of the project, the Consultant will deliver a brief Inception Report detailing suggestions (if any) on fine-tuning of the project scope and potential outcomes for consideration by MLA and the Advisory Committee.

Experience/Qualifications of Researcher(s)

The successful applicant(s) will have significant experience in this area of work, and a demonstrated record of high quality review achievements. Documentation supporting the credentials and experience of the review team should accompany the project proposal.

Costing

MLA seeks a quotation for the full review project to be conducted under these Terms of Reference. The quotation will provide details of the proposed methodology for conduct of the project and costing of each project component.

The details of costing provided to MLA will include professional fees, calculated on a daily rate for each person, or party involved, and will cover professional services of the Consultant, provision of office facilities, electricity, local telephone and facsimile calls, postage, clerical/secretarial services and indirect costs (overheads).

Out-of-pocket expenses will be reimbursed at cost for travel and accommodation, long distance telephone and facsimile calls and external costs of report preparation. Air travel costs will be reimbursed at a maximum of full economy rates. Estimates of expenses will be provided in the project proposal.

The details of the project content, methodology and costing may be adjusted with the agreement of MLA, following initial assessment of the project proposal. The project proposal should be submitted in the format outlined in the Research Proposal Preparation Guidelines attached as Annex A.

Consultative Group Meetings

Consultants need to make provision for two (2) half-day meetings, if required, with the Advisory Committee. The initial meeting will be held at the commencement of the project and the second at Draft Final Report delivery stage. These will be separately identified and costed within the project proposal. Costings should be based on attendance at meetings in Brisbane.

Industry Presentations

Consultants also need to make provision for presentation of the project findings to an appropriate forum, if so requested by MLA. The costing of such presentation will be separately identified and costed within the project proposal. Allowance of one (1) day and travel to Sydney should be provided for.

Payment

MLA will make progress payments against completion of the components of the project identified, with milestones agreed to by MLA.
Final payment for the project will be subject to written acceptance of the Report by MLA. All payments will be subject to receipt of invoices and appropriate supporting documentation from the Consultant.

Subcontracting

The Consultant may wish to subcontract certain activities and analyses to other parties. In this case full details of the party or parties to be subcontracted, their capabilities and background and the activities or analysis that they would perform in the context of this project will also be provided to MLA. Notwithstanding this, the responsibility for the performance of the subcontractor will rest completely with the Consultant, with whom MLA would be contracted.

Reporting and Liaison

The Consultant will report to MLA through Mr. Des Rinehart. In addition to the Inception Report at the end of the first fortnight, the Consultant will provide a brief statement of progress with the project (by letter or facsimile) at the end of each month.

Confidentiality

The Consultant may divulge that the project is being undertaken at the request of MLA. Otherwise, the specification of the project, contents and conclusions of the project and the Report produced are strictly confidential.

The Consultant may not disclose any details or information in respect of the project to any party without the prior consent of MLA.

Des Rinehart
Feedlot Program Coordinator
25 October 2000

RECOMMENDATIONS FOR REDUCING THE IMPACT OF ANIMAL RELATED FACTORS ON HEAT LOAD IN FEEDLOT CATTLE

TERMS OF REFERENCE

THE CONSULTANCY SERVICES

BACKGROUND

Following the reported loss of a significant number of feedlot cattle from extreme weather conditions in February 2000, two reviews were commissioned to review the incident and examine the appropriateness of industry guidelines, standards and codes of practice.

ALFA appointed a Working Party to consider the findings and recommendations contained in the reports from the Independent Committee, commissioned by NSW Agriculture Minister, Richard Amery, and the Industry Committee, commissioned by the Feedlot Industry Accreditation Committee (FLIAC).

The Working Party considered the reports and recommendations from both Committees and identified a number of areas that require further review and/or research before the major recommendations of the reviews can be addressed.

These Terms of Reference address one of the identified areas for further review.

OBJECTIVES

The objective of this review is to provide factual information on the impact of animal related factors on heat load in feedlot cattle, as a basis for:

a) The development of pre-emptive and day-to-day management strategies that can be employed to minimise the effects of excessive heat load; and,
b) Identifying any knowledge gaps that require additional R&D activities to further support/achieve (a).

Within this framework, the outcome of the project will be a report that:

a) Reviews the relevant scientific literature and industry experience, in the areas specified, to provide a solid knowledge base for:
    i. An improved understanding of the relative importance of the factors associated with excessive heat load events; and,

  - ii. The development of risk assessment criteria to assist industry in the prediction of possible excessive heat load events.

- b) Outlines the major relevant 'real' issues identified during the review process;
- c) Based on the information gained during the project, recommends practical, cost-effective management options for addressing the identified issues; and,
- d) Defines possible R&D needs to support the recommended management options.

Specific areas that are to be covered in the review include, but are not limited to, the following:

- a) Physiological responses to heat load.
- b) Threshold levels of airflow required for an evaporative cooling effect.
- c) Impact of temperature, humidity and radiation, and combinations of these factors, on heat load of the animal.
- d) Importance of ammonia levels.
- e) Effect of level of body condition/composition of animal and days on feed.
- f) Breed effects.
- g) Adaptation and acclimatisation.
- h) Duration of exposure.
- i) Health status.
- j) Stocking density.
- k) Coat colour/coat type.
- l) Water availability (quantity, trough space, placement), water temperature and practical options for keeping water cool.

REQUIREMENTS UNDER THE CONSULTANCY

Scope and Methodology

It is envisaged that a multi-disciplinary team, including animal physiologists and Industry practitioners, would be best suited to carry out this project. The project would necessarily involve a review of the scientific literature and industry experience in the specified areas, and may also require research and collation of information on commercially available products.

Consultants need to define their proposed methodology and work plan for addressing the project objectives.

Project Management

This project is a component of the MLA Feedlot Program, which has an Advisory Committee of Industry operators that will oversight the project and provide an ongoing guidance.

The outcome of this project will be referred to the Advisory Committee for endorsement prior to acceptance of the Final Report.

Output

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Experience/Qualifications of Researcher(s)

The successful applicant(s) will have significant experience in this area of work, and a demonstrated record of high quality review achievements. Documentation supporting the credentials and experience of the review team should accompany the project proposal.

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The details of the project content, methodology and costing may be adjusted with the agreement of MLA, following initial assessment of the project proposal. The project proposal should be submitted in the format outlined in the Research Proposal Preparation Guidelines attached as Annex A.

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Reporting and Liaison

The Consultant will report to MLA through Mr. Des Rinehart. In addition to the Inception Report at the end of the first fortnight, the Consultant will provide a brief statement of progress with the project (by letter or facsimile) at the end of each month.

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Des Rinehart
Feedlot Program Coordinator
25 October 2000

RECOMMENDATIONS FOR REDUCING THE IMPACT OF NUTRITION RELATED FACTORS ON HEAT LOAD IN FEEDLOT CATTLE

TERMS OF REFERENCE

THE CONSULTANCY SERVICES

BACKGROUND

Following the reported loss of a significant number of feedlot cattle from extreme weather conditions in February 2000, two reviews were commissioned to review the incident and examine the appropriateness of industry guidelines, standards and codes of practice.

ALFA appointed a Working Party to consider the findings and recommendations contained in the reports from the Independent Committee, commissioned by NSW Agriculture Minister, Richard Amery, and the Industry Committee, commissioned by the Feedlot Industry Accreditation Committee (FLIAC).

The Working Party considered the reports and recommendations from both Committees and identified a number of areas that require further review and/or research before the major recommendations of the reviews can be addressed.

These Terms of Reference address one of the identified areas for further review.

OBJECTIVES

The objective of this review is to provide factual information on the impact of nutrition related factors on heat load in feedlot cattle, as a basis for:

a) The development of pre-emptive and day-to-day management strategies that can be employed to minimise the effects of excessive heat load; and,
b) Identifying any knowledge gaps that require additional R&D activities to further support/achieve (a).

Within this framework, the outcome of the project will be a report that:

a) Reviews the relevant scientific literature and industry experience, in the areas specified, to provide a solid knowledge base for:
    i. An improved understanding of the relative importance of the factors associated with excessive heat load events; and,

   ii. The development of risk assessment criteria to assist industry in the prediction of possible excessive heat load events.

b) Outlines the major relevant 'real' issues identified during the review process;
c) Based on the information gained during the project, recommends practical, cost-effective management options for addressing the identified issues; and,
d) Defines possible R&D needs to support the recommended management options.

Specific areas that are to be covered in the review include, but are not limited to, the impact of the following on the animals heat load, tolerance of and adaptation to periods of excessive heat load:

a) Feed intake level and variations thereof.
b) Time of feeding/feed delivery.
c) Energy density of the ration.
d) Grain type and percentage in the ration.
e) Roughage levels and types.
f) Use of tallow and molasses and inclusion levels.
g) Vitamin and mineral additives, especially vitamin E.
h) Ration design for pre, during and post excessive heat load periods.

REQUIREMENTS UNDER THE CONSULTANCY

Scope and Methodology

It is envisaged that a multi-disciplinary team, including nutritionists, animal physiologists and Industry practitioners, would be best suited to carry out this project. The project would necessarily involve a review of the scientific literature and industry experience in the specified areas, and may also require research and collation of information on commercially available products.

Consultants need to define their proposed methodology and work plan for addressing the project objectives.

Project Management

This project is a component of the MLA Feedlot Program, which has an Advisory Committee of Industry operators that will oversight the project and provide an ongoing guidance.

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Des Rinehart
Feedlot Program Coordinator
25 October 2000

APPENDIX 2 TERMINOLOGY

Abbreviations Used:

DESCRIPTION	SYMBOL	UNITS
Ambient Temperature	T_a	°C
Average Daily Gain	ADG	
Body Temperature	BT	°C
Body Weight (not after feed deprivation unless designated otherwise)	BW	
Breaths Per Minute	Bpm	
Calorie	cal	
Crude Protein (N x 6.25)	CP	
Day	d	
Degree Celsius	^{0}C	
Digestible Energy	DE	
Dry Matter	DM	
Dry Matter Intake	DMI	
Excessive Heat Load	EHL	
Feed Conversion Ratio	FCR	
Gram	G	
Gross Energy	GE	
Heat Load	HL	
Hectare	Ha	
Hot Conditions	HOT	
Hour	h	
International Unit	IU	

Joule	J	
Litre	L	
Mega Joule	MJ	
Metabolisable Energy	ME	
Metre	m	
Minute	min	
Month	mo	
Net Energy	NE	
Net Energy for Gain	NE_g	
Net Energy for Lactation	NE_l	
Net Energy for Maintenance	NE_m	
Pulse Rate	PR	Beats/min
Rectal Temperature	RT	°C
Relative Humidity	RH	%
Respiration Rate	RR	Breaths/min
Second	s	
Sweating Rate	SW	G/(m^2.h)
Temperature-Humidity Index	THI	
The University of Queensland- Gatton	UQG	
Thermoneutral Conditions	TNC	
Thermoneutral Zone	TNZ	
Total Digestible Nutrients	TDN	
US Meat Animal Research Center	MARC	
Volt	V	
Watt	W	
Week	wk	
Year	yr	

APPENDIX 3 CORRESPONDENCE – BUREAU OF METEOROLOGY

SPECIAL
SERVICES
UNIT

BUREAU OF
METEOROLOGY

Mr Jim Sparke
Aquila Agribusiness Pty Limited
"Baromee Point"
North Arm Cove, NSW .2324

Customised Weather Services for the Australian Feedlot Industry

Dear Jim,

Thank you for visiting Mr Richard Whitaker, Bureau of Meteorology, Sydney and the opportunity to meet Professor Bruce Young and yourself at Gatton, on Wednesday 10th January 2001, to discuss our ability to forecast the relative contributions of extreme weather situations on the Excessive Heat Load Syndrome (EHLS) occasionally experienced by lot-fed cattle.

The Special Services Unit (SSU) is uniquely qualified to provide the Extreme Weather Threat Alerting Service that you are requesting for the Industry collectively and for individual feedlots.

We would propose to deliver our service via a customised webpage which may be linked, for example, to the ALFA or MLA Website. We will be able to provide an animated display of evolving temperature, dew point, wind, cloud cover and rainfall forecasts, on a regional and local basis for up to eight days in advance. Feedlot management can then combine this information with known site specific factors, such as the pen microclimate, to determine the threat of thermal discomfort and effect upon the feedlot.

Naturally we will be happy to follow and develop the application of any preferred weighted regression relationships the industry may develop, as might be possible.

It is suggested, for example, that the forecast comprise :

- The Forecaster's Overview, providing a brief look at evolving weather patterns over the next four to eight days with emphasis upon the likelihood of weather extremes known to impact upon the thermal discomfort of confined livestock.
- Weather Maps providing animated displays of the changing temperature, dew point, wind, cloud and rainfall patterns during the forecast period.
- A similar set Thermal Comfort Maps providing animated displays of the changing (to be specified) index patterns, regionally and locally.
- A map of Australia displaying states. The client can click on his chosen state to activate a drop-down menu which will reveal a list of sites. The client can click on a site to activate a forecast time-series of pertinent weather elements, index readings and short-period accumulations of these values at the site.
- Specific daily emailed summaries of these tabulated values, for specified sites.

15th Floor
295 Ann Street
Brisbane 4001
Australia

GPO Box 413
Brisbane 4001
Australia

Phone: (07) 3239 8610
Fax: (07) [illegible]

- Specific fax summaries for those clients without email access. A fax will incur an additional fee.

Whilst difficult to estimate costs at this stage of development, our indicative setup fee would be of the order $7,500-00, with an indicative on-going service fee of $25,000-00 for the first year, depending on job specifications. It would be prudent to evaluate the impact and relevance of our service during the later parts of the first year of service, and regularly thereafter.

The SSU looks forward to delivering an effective service to assist the Feedlot Industry minimise the incidence of EHLS in confined livestock.

Yours sincerely

Bryan Davies

Bryan Davies
Regional Manager, Queensland
Monday 29th January 2001

APPENDIX 4 ADDITIONAL CONTACTS

During the course of the study, reference has been made to the literature and research establishments.

The attached lists additional contacts interviewed during the course of the project.

Ames, D., Colorado State University, Colorado, USA.

Backus, R., Goonoo Feedlot, Comet, NSW, Australia.

Butterworth, K., RSPCA, Canberra, ACT, Australia.

Davies, B., Special Services Unit, Bureau of Meteorology, Brisbane, Qld, Australia.

Donovan, R., Myola Feedlot, Moree, NSW, Australia.

Fields, C., US Sugar Corporation, Clewiston, Florida, USA.

Ford, D., South African Feedlotters' Association, South Africa.

Gaden, R., NSW Agriculture, Armidale, NSW, Australia.

Hahn, L., US MARC, Clay Centre, NE, USA.

Hall, A., Curtin University, Perth, WA, Australia.

Hunter, R., CSIRO, Rockhampton, Qld, Australia.

Lelleyett, S., Special Services Unit, Bureau of Meteorology, Sydney, NSW, Australia.

Mader, T., University of Nebraska, Concord, NE, USA.

Mather, S., Caroona Feedlot, Caroona, NSW, Australia.

McKienan, W., NSW Agriculture, Orange, NSW, Australia.

McPhee, M., NSW Agriculture, Armidale, NSW, Australia.

McRae, D., Queensland Centre for Climate Application, Toowoomba, Qld, Australia.

Rinehart, D., MLA, Thagoona, Qld, Australia.

Van Raenen, Beefmaster Feedlot, Christiana, South Africa.

Vanselow, B., NSW Agriculture, Armidale, NSW, Australia.

Whitaker, R., Special Services Unit, Bureau of Meteorology, Sydney, NSW, Australia.

Wilkinson, I., Environdata Pty Limited, Warwick, Qld, Australia.