On farm

Measuring Microclimate Variations In Two Australian Feedlots

Project number FLOT.310
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ABSTRACT

Heat stress has caused catastrophic stock losses infrequently in Australia and does cause production losses over summers. While a considerable body of research has been undertaken on defining heat stress with respect to cattle comfort, health and production, few data are available on the micrometeorological characteristics of feedlots, shaded pens in feedlots and differences between feedlots and their surrounds.

A study was undertaken to define these microclimates and therefore to identify the probable causes of heat stress. The study found that feedlot climates are different to their surrounds. Generally they are hotter and more humid and have lower wind speeds under shade. The study found that shade benefit cattle by reducing radiation heat loads but have the deleterious effects of increasing manure moisture contents, relative humidity and ammonia levels. Ammonia is identified as a possible stressor but its importance must be further defined.

The study has shown that gross heat load is influenced most by the generation of heat within the body through metabolic processes and the loss of heat by convective means. In the latter case, continuously high temperatures (daytime and night-time) limit the ability of the animal to shed heat and therefore act as the key stressor of stock. Potential stress events can be forecast and mitigation measures can be utilised.

EXECUTIVE SUMMARY

The occurrence of heat stress causes catastrophic stock losses infrequently in Australia. Heat stress can also contribute to production losses over summers. While a considerable body of research has been undertaken on defining heat stress with respect to cattle comfort, health and production, few data are available on the micrometeorological characteristics of feedlots, shaded pens in feedlots and differences between feedlots and their surrounds. The project FLOT.310 aimed to install micrometeorological instrumentation in two feedlots for the 2000/2001 summer to measure microclimate variations within the feedlots and to identify the probable causes of heat stress.

The need for this research was identified by an ALFA appointed Working Party following the review of two reports relating to the incident in February 2000 where a significant number of feedlot cattle were lost due to extreme weather conditions. 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.

The fundamental aims of project FLOT.310 were to:

1. Quantify temperature, humidity and gas profiles in the air mass over a feedlot;

2. Examine the variance in these profiles as a result of changes in surface characteristics (landscape features such as slope etc) or variations in the physical environment (eg. shade);

3. Investigate the effects of these variations on cattle within the feedlot.

To achieve these aims the project endeavoured to measure the following parameters:

- The climatic conditions surrounding a feedlot;
- The microclimate conditions within feedlot pens;
- The levels of ammonia gas (NH_3) within feedlot pens;
- Pen surface conditions (in particular manure depth and moisture content);
- Cattle behaviour in response to varying climatic conditions.

Two feedlots were selected for the study, one located in southern Queensland (Feedlot A), the other located in southern New South Wales (Feedlot B). The feedlot site selection aimed at ensuring that the sites selected were representative of operations in both southern and northern Australia.

At each site six weather stations were installed in order to measure the climatic conditions of the feedlot environments. Four weather stations were positioned outside the feedlot area and two weather stations were situated within two separate feedlot pens (one shaded and one unshaded). The installation of equipment at Feedlot A commenced in mid December and climatic measurements commenced on the 1 January 2001. Following this, equipment installation at Feedlot B was completed and climatic measurements commenced on the 9 January 2001.

The purpose of locating stations outside of the feedlot was to define potential topographical effects on the climate at the feedlot (including landscape features, slope, aspect etc) and differences in the external and internal climates. The two internal stations were used to

define microclimatic differences between shaded and unshaded pens. The study aimed to define the climate of the feedlot through the determination of the following factors:

- the temperature and humidity profile in and around the feedlot;
- the mixing of air in and outside the feedlot;
- the evaporative potential in and outside the feedlot;
- the gross radiation load from convective heating of air masses, incoming radiation, and outgoing radiation;
- the 'albedo' of the surfaces in and outside of the feedlot and therefore the amount of re-radiated energy.

The elements measured at the weather stations included:

- Air Temperature;
- Relative Humidity;
- Black Globe Temperature;
- Wind Speed;
- Wind Direction;
- Soil Temperature;
- Rainfall;
- Incoming Solar Radiation;
- Outgoing Solar Radiation.

All sensors installed at the stations had undergone standard calibration by the manufacturer prior to delivery. In order to ensure that the collected data was of quality and remained accurate throughout the study period mobile communications were established at selected stations and regular site visits were undertaken by E.A. Systems staff. The majority of the recorded climatic data were collected at the time of the fortnightly visits undertaken by E.A. Systems staff. During these visits all stations were serviced to ensure that all sensors were clean and fully operable. The visits were also used to verify station measurements and to identify and remedy any faults.

In addition to the climatic data, pen surface and cattle measurements were undertaken at both feedlot sites.

Sampling of the manure pad in the study pens was undertaken to enable data on pen surface condition and manure moisture content to be collected. These data were collected by means of direct sampling to ensure accuracy and reliability of the data. Sampling involved the use of a 50 mm core sampling tube to collect a series of samples from each pen. Common samples were bulked on the basis of the location with which they were collected ie. one single composite sample was collected from each of the unshaded pens, and two composite samples were collected from each shaded pen (one from samples collected under the shade area, and one collected from outside the shade area.

Manure moisture content data collected show that as expected the moisture content of pen surfaces steadily increases over time and dramatic increases occur in conjunction with significant rainfall events. These data show that the moisture content of the shaded pen areas increased at a more rapid rate than those of the unshaded areas. This is primarily due to congregation of cattle within the shaded areas, which sees a greater amount of faeces and urine applied to the areas under shade. The presence of shade also reduces the drying of these areas.

Daily cattle measurements were recorded in order to monitor cattle behaviour. The monitoring involved the observation of cattle behaviour in the both the unshaded and shaded study pens where climatic monitoring and pen measurements were undertaken. A number of variables were monitored relating to both cattle behaviour and comfort. These observations were designed to provide an indication of when cattle become stressed and to provide data on their behaviour corresponding to these stress periods.

Data on ammonia levels in pens were collected with the use of a hand held gas monitor. This equipment was utilised during the fortnightly site visits to undertake ammonia measurements in both the shaded and unshaded pens at each feedlot site.

The ammonia data collected highlight a general trend in the ammonia concentrations where levels rapidly increase at the start of the day as the pen surface is warmed, and then stay relatively constant during the middle of the day, and finally decrease as the temperatures drop. This demonstrates the strong relationship between ammonia generation rates and temperature.

The study has highlighted the following variations in the micrometeorology of the feedlot, its surrounds, and between shaded and unshaded pens. These can be summarised as follows:

- Lower minimum temperatures occur outside the feedlot. Differences of around 1°C on average were noted in over night temperatures between the feedlot and its surrounds;

- Humidity in the shaded pens was typically 4 to 9% higher than that of the unshaded pens;

- Soil temperature was 5 to 14°C lower under shade than compared to the unshaded pen and the feedlot surrounds;

- Shade significantly reduces incoming solar radiation and hence black globe temperatures;

- The ‘albedo’ of the feedlot pens was found to be lower than that of the external environment.

The higher night time temperatures with the feedlot compared to those outside the feedlot is due to the manure composition of the pen surface which is generally dark and moist and has a greater ability to store heat compared to soil. Reducing the depth of the manure pack over summer months can mitigate the increased temperature effects. The increased relative humidity levels observed in the feedlot environment can also be reduced by limiting the wetting of the feedlot pen areas. An increase in humidity levels causes a reduction in the cattle’s ability to shed heat through convective losses.

The comparison of cattle measurements and climatic data allowed the effects of climatic variations on cattle within the feedlot to be investigated. Based on the field measurements the occurrence of ‘stress events’ is related to cumulative effects of a number of variables. These variables are not limited to, but primarily include:

- Constant high ambient temperatures (ie. over both the days and nights) that result in an accumulated heat loading of stock;

- Significant radiant heat loads (ie. high global incoming, outgoing solar radiation reflected off ground surfaces and longer wave radiation re-radiated from ground surfaces);

- Low wind speeds;

- Elevated ammonia (NH_3) levels.

In the case of the recorded stress events a number of relationships were defined that were common. Prior rainfall with an associated increase in atmospheric humidity, and increase in ammonia levels from wet manure can have an additive effect in stress situations. Rainfall prior to a period of significant temperatures provides cooler antecedent conditions. Once the rainfall event is completed, the onset of increasing temperatures and solar radiation, combined with the increased ammonia levels generated from the moist manure surfaces, creates uncomfortable conditions for cattle. If the temperatures increase over a period of several days, the cattle are exposed to these conditions continually. This sees the heat load on cattle slowly increase over this period, and if wind speeds remain low there is no respite for the animal from this load through convective losses (losses are increased by both cooler temperatures and increased wind speed). As such there is potential for a ‘stress event’ because there is no opportunity for animals to shed the accumulated load nor offset the effects of ammonia intake.

If night time temperatures are high, the heat load that the animal has accumulated through the day may not be lost and is carried into the next day. It is an accumulation of heat/energy load and an inability to shed this energy that causes stress events. While radiant heat load increases gross heat and is therefore significant in initiating “stress” events by adding to heat loads, it is not as significant as continuous conditions of high daytime and night time temperatures that limit shedding of excess energy.

The key differences in micrometeorology are that temperatures steadily increase to the point where animals were not able to lose accumulated heat. Solar radiation increases the heat load and therefore shading will reduce radiation loads on any given day. Its primary effect is to reduce the rate of heat/energy accumulation. Consequently, it will reduce the probability of “stress” events and the magnitude of “stress” events BUT not prevent “stress” events.

Few data exist on the relationship between ammonia concentrations and cattle health effects. As such this is an area that requires further investigation. It is known that high ammonia concentrations can have detrimental effects on cattle. This is verified by existing research and data relating to humans and other livestock industries. It was noted that the ammonia levels recorded during this study exceeded the recommended short-term exposure limit level for humans (35 ppm) on a number of occasions. As such it should be recognised by feedlots that there may be OH&S issues arising from high ammonia levels during the warmer periods of the day.

Although specific values for critical ammonia levels and detrimental effects on cattle health are not fully defined, it is certain that the high ammonia levels that can be generated from moist manure surfaces under warm conditions do cause cattle discomfort and may contribute to cattle stress events. Further study is required in this area.

Shade provides several benefits that may reduce the probability of a ‘stress event’ and the magnitude of a ‘stress event’. However, shade structures also have the potential to detrimentally increase the effects of certain cattle stressors. The primary effects of shade on the physical environment are:

- Reduced solar radiation and therefore a reduction in the radiant heat load on cattle;
- Increased moisture content of pen surfaces;
- Reduced wind speeds and air movement;
- Increased humidity levels;
- Increased ammonia levels.

The study found that there were no significant differences in the ambient temperatures of shaded and unshaded pens.

The study and further assessment have shown that key sources of heat and energy are the ration and the radiant load, and that key loss mechanisms occur through convective systems. A less significant loss is through ingestion of water and evaporative cooling (ie. panting). While shade will reduce radiation loads, clearly reducing the metabolic production heat load is a primary means of managing heat load accumulation.

Shade will also reduce the probability of ‘stress events’ and thus cattle deaths (since direct radiant heat load is a significant variable) and it will also change the circumstances under which such catastrophes will occur. Shade design can be altered to reduce pen manure wetting and increase air speeds under shades. Changes need to be made to shade design to better the physical environment of stock. Designs must consider increasing wind movement (and vertical ventilation) beneath shade structures, maximising drying of pen manure and limiting re-radiation of energy beneath shade structures.

Potential stress events can be forecast which would allow mitigation measures to be utilised. Management practices that will assist in reducing the potential for cattle stress include providing an abundant supply of cool water for drinking and also minimising the wetting of pens for evaporative cooling. The wetter the pen surface the higher the relative humidity and ammonia levels will be, both of these variables contribute to cattle stress. This study has highlighted that ammonia is likely to be a significant factor in contributing to cattle stress, however the exact extent of this still remains uncertain.

CONTENTS

1. INTRODUCTION

1.1 Project Background

The project FLOT.310 "Measuring Microclimate Variation in Two Australian Feedlots" was funded by Meat and Livestock Australia, with support from E.A. Systems Pty Limited and the University of Southern Queensland. The project was formally contracted in late December 2000. It aimed to install micrometeorological instrumentation in two feedlots for the 2000/2001 summer to measure microclimate variations within the feedlots.

The anticipated variations were expected to result from the effects of feedlot topography and other siting and design factors. The two feedlots were selected on the basis that they were representative of operations in southern and northern Australia.

At both of the selected feedlot sites measurements were made outside the feedlot area and within the feedlot pens (shaded and unshaded). Data on cattle behaviour were also recorded by the feedlot staff. These data were collected for the purpose of relating cattle behaviour to microclimate variations. Feedlot staff also collected manure samples from the feedlot pens throughout the duration of the project. These samples were obtained in order to define pen surface conditions. During regular site visits by E.A. Systems staff, hand held gas sensors were used to collect data on ammonia levels within the feedlot pen areas.

The need for this research was identified by an ALFA appointed Working Party following the review of two reports relating to the incident in February 2000 where a significant number of feedlot cattle were lost due to extreme weather conditions. These reports were:

(a) 'A Report to the Director General, NSW Agriculture - *Mortalities in Feedlot Cattle at Prime City Feedlot, Tabbita, NSW, February 2000*'- K. Entwistle, M. Rose, and B. McKiernan;

(b) 'Report to the Feedlot Industry Accreditation Committee on the Review of the Prime City Incident' - K. Roberts, K. Sullivan, R. Burton, and D. Rhinehart.

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. Following from this Meat and Livestock Australia Limited (MLA) commissioned the following studies:

(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.

Projects FLOT.307-309 were combined into a single study that produced a review of relevant scientific literature and industry experience that examined in detail the factors associated with heat load in cattle, their predicability, and techniques to minimise the risk of these factors.

The project FLOT.310 involved the undertaking of field measurements of microclimate over the summer of 2000/2001. This report presents the findings of Project FLOT.310.

1.2 Project Objectives

The objectives of the study were to:

(c) Establish a series of weather stations at two feedlot sites (southern NSW and Queensland) by 30 December, 2000

(d) Measure and quantify the magnitude of microclimate variations that occur within the feedlot pen area as a result of the effects of:

- Topography;
- Aspect;
- Relative position within the feedlot pen area;
- Provision of shade;
- Adjacent structures.

(e) Verify, collate, and interpret the collected data to establish the relationship between ambient weather conditions and conditions experienced by animals within the feedlot pen area.

(f) Document and present the findings to industry and producers.

(See Terms of Reference for Project FLOT.310 presented in Appendix A.)

This study aimed to provide feedlot managers with a better understanding of the connection between cattle behaviour, the physical environment, and micrometeorology. It is hoped that the information presented will enable the design, layout, and management of feedlots to be better adapted to reduce the potential for cattle losses caused by extreme weather conditions.

2. INTRODUCTORY THEORY

2.1 Climate

Australia has a generally arid climate over much of the continent. This is attributed to a number of factors. As described by the Bureau of Meteorology (BOM, 1999) it is primarily due to Australia’s position relative to the region of large scale descent at the poleward edge of the southern hemisphere Hadley Cell, and the associated belt of eastward migrating high pressure systems.

Naturally the large size of the continent sees that there is much variation in climate across Australia. Figure 1 below shows the climate classification of Australia using the Köppen classification scheme. In the Köppen classification scheme, the climate of each region is based on annual and monthly means of temperature and precipitation and also takes into account the vegetation limits (as vegetation types are an indicator of the both temperature and rainfall).

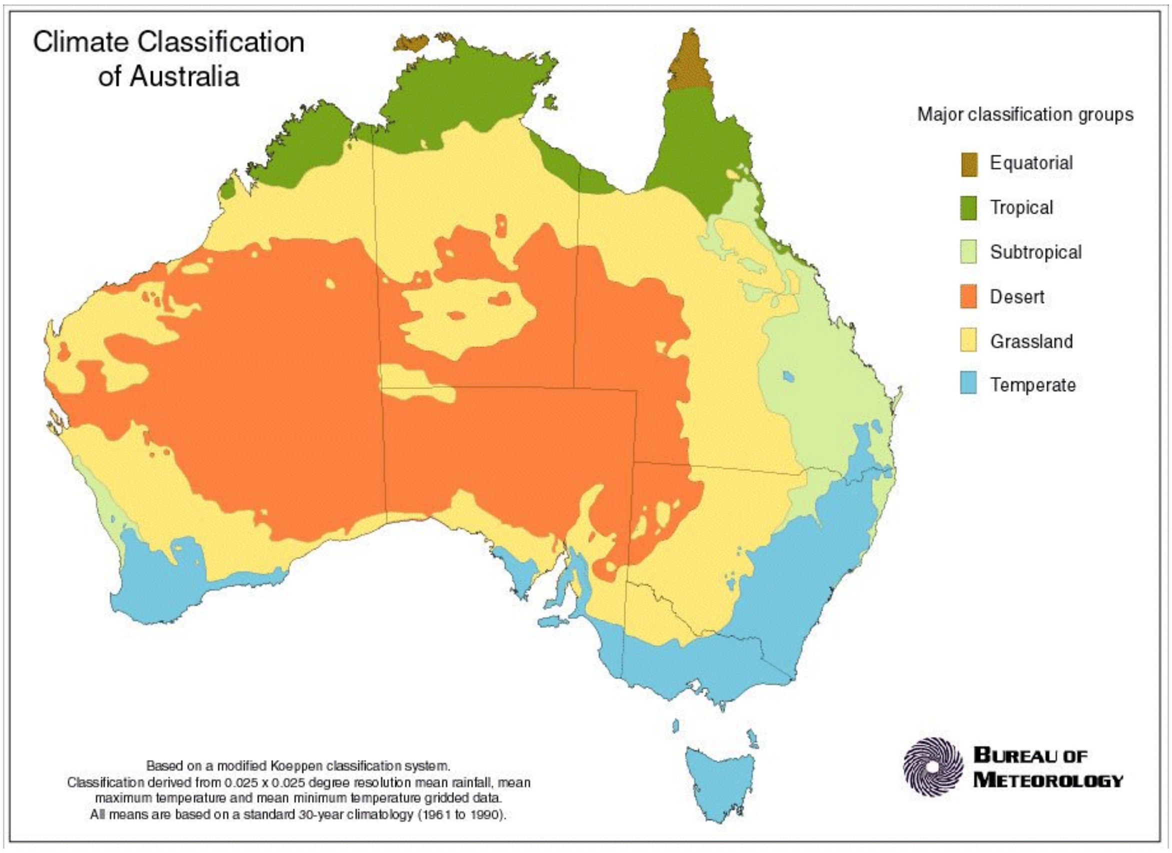

Figure 1. Climate classification of Australia (based on the Köppen classification system).

The above figure shows that around one third the continent is classified as desert. This group represents areas that receive less than 250 mm/year of rainfall and experience hot summers with significant changes in daily temperature. Bordering the desert region are areas classed as grassland. These areas experience a semi-arid climate of hot summers, mild winters and light precipitation. The northern extremities of Australia are consistently hot and experience only two seasons, a dry season and a wet season. The wet season sees heavy rains occurring, predominantly in the summer months. These northern areas are classified in the equatorial and tropical groups. The southern regions of the continent are grouped into the temperate group which experience moderately warm to hot summers, cool winters and moderate precipitation. The eastern most regions are grouped as either temperate or subtropical. The north eastern regions through Queensland fit into the subtropical classification that experiences warm to hot summers, warm or mild winters, and moderate precipitation. The eastern areas of New South Wales and Victoria are in the temperate group. These areas are excluded from the zonally aligned belt of grassland/desert areas due to the orographic influence of the Great Dividing Range that contributes to higher rainfall in these regions.

Linacre and Hobbs (1977) state that there are four main factors responsible for climate. These are:

- Atmosphere;

- Solar radiation;
- Water in the air - that creates humidity and precipitation;
- Earth's rotation and topography - which control the pattern of winds.

Theses four factors are closely linked and influence one another. The most significant influence is between the first two. Linacre and Hobbs (1977) describe that the atmosphere is 'set into motion' by solar radiation, as solar radiation is the power source for all atmospheric processes.

2.2 Radiation Balance

The rate at which thermal energy is radiated from a body is dependent on the temperature of the body. The total energy emitted by a body is given by the Stefan-Boltzmann Law. This is as follows:

$$\text{Energy emitted} = \sigma T^4$$

where σ = Stefan-Boltzmann constant (5.67×10^{-8} W/m^2·K^{-4})
T = surface temperature of the body

The above equation relates to bodies that emit the maximum possible amount of radiation per unit of surface area. These bodies are known as a 'black body' or 'full radiator' and have a surface emissivity (ε) equal to 1. Emissivity is a number between 0 and 1 that represents the ratio of the rate of radiation from a particular surface to that of a full radiator. For bodies with an emissivity of less than 1, this needs to be included in the Stefan-Boltzmann equation (ie. Energy emitted = $\varepsilon\sigma T^4$).

The temperature of an emitting body also determines the wavelength of the energy radiated. As outlined by Linacre and Hobbs (1977), Wein's Law states that the dominant wavelength of an emission is inversely proportional to the absolute temperature of the body (ie. the hotter the body the shorter the emission wavelength). As such, the radiation emitted from the sun (solar radiation) is classed as 'short wave radiation' with a wavelengths between 0.1 and 3.0 μm.

The amount of solar radiation that reaches the earths surface varies and is primarily dependent on the distance between the earth and the sun, and the amount of radiation that is absorbed by the atmosphere or clouds. Based on the average distance between the sun and the earth, the fixed amount of radiation energy received by a surface above the Earth's atmosphere is 1367 W/m^2 (Oke, 1987). This value is known as the 'solar constant'. Averaged over a period of a year the mean input of solar radiation is exactly ¼ of the solar constant or 342 W/m^2.

Once it enters the atmosphere, solar radiation is either reflected or absorbed. The amount of radiation that is reflected is dependent of the reflectivity of the surface. This is defined by the 'albedo' (α) of a surface. The albedo is defined as the ratio of upwards to downwards radiation fluxes (Linacre and Hobbs, 1977) and is a number between 0 and 1. Surface with higher albedo values reject less radiation and as such become hotter. Albedo values for various surfaces are presented in the table below.

		Albedo, α
Soils	Dark, wet Light, dry	0.05 - 0.40
Desert		0.20 - 0.45
Grass	Long (1 m) Short (0.02 m)	0.16 - 0.26
Eucalypt Forest		0.15

(Sources: Oke, 1987; Linacre & Hobbs, 1977)

Oke (1987) describes the energy balance of the incoming solar radiation within the earth-atmosphere system. A summary of this is presented in the table below. This table shows the amount of solar radiation that is absorbed and reflected by both the atmosphere and the earth.

	Percentage
Incoming Solar Radiation	**100% (342 W/m^2)**
Reflected by clouds	19
Reflected by atmospheric constituents	6
Absorbed by clouds	5
Absorbed by atmospheric constituents	20
Reflected by Earth	3
Absorbed by Earth	47

The above table highlights some interesting points. Of the total incoming solar radiation, 25% is reflected back to space, 25% is absorbed by the atmosphere, and a considerable amount is absorbed by the earth (47%). The atmosphere is semi-transparent to short wave radiation so it absorbs less and as such is not greatly heated. The solar radiation that is absorbed by the earth is converted to thermal energy that warms the earth's surface (Oke, 1987). In this report we will define this radiation as 'global (short wave) radiation' which includes both that radiation energy reaching the ground directly from the sun, and that received indirectly from the sky, scattered downwards by clouds, dust particles etc.

Oke (1987) describes that the net incoming solar energy must be balanced by energy lost from the earth-atmosphere system to space, otherwise there would be a net energy gain or loss in the system. This would result in a rise or fall of the average earth-atmosphere system temperature (ie. a climatic shift). As shown in the table above of the total incoming solar radiation, only 28% is reflected by the atmosphere (25%) and the earth (3%). As such the system appears to be unbalanced with a shortfall of 72% between the incoming and outgoing energy. This balance is achieved by 'long wave radiation'.

As mentioned previously, Wein's law sates that emitted wavelength is dependent on temperature, with bodies of higher temperature emitting shorter wavelengths. The earth is significantly cooler than the sun and as a result the radiation generated by the earth is long wave radiation. Long wave radiation varies from short wave in that long wave radiation is not visible (its in the infra-red spectral range) and the reflectivity of long wave radiation for most materials is almost zero (Linacre and Hobbs, 1977).

Using the Stefan-Boltzmann equation, Oke (1987) calculates that based on a mean annual temperature of the earth of 288K (15°C), the amount of long wave radiation emitted from the earth (terrestrial long-wave radiation) is 390 W/m^2. This is 114% of the incoming solar radiation (342 W/m^2). Of this 5% is lost to space and 109% is absorbed by the atmosphere. The atmosphere also emits long wave radiation both upwards and downwards. Oke (1987) calculates that this total output is 163% (557 W/m^2), with 67% being emitted to space and 96% being emitted to the earth's surface. So Oke (1987) concludes that with the inclusion of both long and short wave radiation the whole earth-atmosphere system is in radiative equilibrium. The total incoming solar radiation (100%) is matched by the short wave reflection from the atmosphere and earth (25% and 3%), and the long wave emissions from the earth and atmosphere (5% and 67%).

Although the whole earth-atmosphere system is in equilibrium, the sub-systems are not. Figure 2 shows the radiation inputs and outputs at the earth's surface. As shown in the figure these interactions vary from day to night, and as a result the net radiation balance differs diurnally.

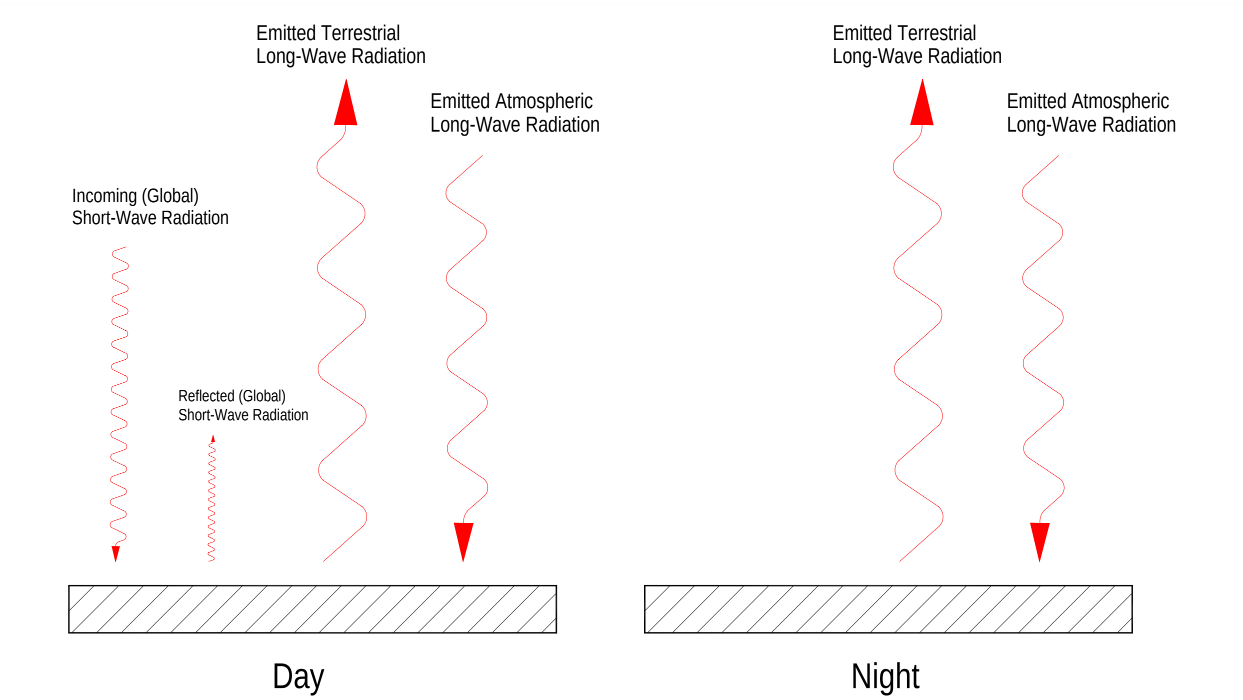

Figure 2. Radiation inputs and outputs at earths surface during the day and night.

The diurnal radiation balances depend on the factors that influence the individual radiation fluxes. These include (Linacre and Hobbs, 1977):

- Elevation of the sun;
- Amount of cloud;
- Turbidity (ie. reduction in transparency to solar radiation);
- Albedo;
- Temperature and dryness of the atmosphere;
- Altitude.

During the day the incoming solar radiation is dominant which results in a net downward radiation flux. At night the radiation balance is comprised solely of long-wave radiation as there is no incoming solar radiation. There is also a reduction in the terrestrial long-wave radiation due to the cooler ground temperatures however it still remains higher than the atmospheric radiation, so there is a net upward radiation flux. This results in further cooling of the ground. The rate of cooling is dependent on the amount of cloud cover at the time, with less clouds providing faster cooling rates (Linacre and Hobbs, 1977).

2.3 Microclimate

Microclimate can be defined basically as the climate on a small scale. Oke (1987) defines microclimate as atmospheric features whose horizontal extent falls within the scale 10^{-2} to 10^{3} metres (10 cm to 10 km) ie. interaction between the atmosphere and earth's surface. Oke (1987) further describes the microclimate as being limited to the lowest 10 km of the atmosphere (troposphere layer), but over a period of a day the influence is restricted to a much shallower zone, referred to as the planetary or atmospheric boundary layer ('boundary layer').

Geiger *et. al.* (1995) state that microclimate is characterised by rapid vertical and horizontal changes due to the effects of surface frictional drag, soil type, surface slope and orientation, vegetation cover, and surface moisture content. Geiger *et. al.* (1995) explains that as the ground surface is approached many atmospheric elements change rapidly. For example the closer to the ground the more wind speed is reduced by friction, and the less the mixing of air. The ground surface absorbs solar radiation and emits its own radiation, influencing the air in contact with it. The ground surface is also a source of water vapour (which escapes into the atmosphere by evaporation) and particulates and gases that diffuse from the soil.

A phenomenon that occurs on the microclimate level is referred to as the 'oasis' effect. It is believed the variations in ground surface conditions created by the feedlot environment can lead to an 'oasis' effect. The 'oasis' effect occurs in a situation where a 'normal' surface has a high albedo (ie. much of the radiation that is intercepted by the earth is re-radiated - that is, the surface is reflective). As a consequence the re-radiated energy heats the air over the surface. If in the middle of this surface is another surface where a greater amount of the radiation is adsorbed (such as a dark wet feedlot pen) its surface will heat to a greater temperature than the surrounding landscape. A temperature differential can exist between the air mass over each surface. If a gentle wind blows the heated air from the surrounding landscape over the 'oasis' - the net heat load in that environment will actually increase. This is because as a hotter air mass passes over, the surface is heated to a higher temperature through greater energy absorbance.

2.4 Cattle Heat Stress

Oke (1987) describes the interaction between the atmosphere and animals as one of the highest levels of complexity in the boundary layer. He suggests that the energy balance of an animal can be written as follows (note: nomenclature varies to that used by Oke):

$$R_{total} + MH_p = C + E + K + \Delta S$$

where R_{total} = total radiation input (sum of both long and short wave radiation fluxes)
MH_p = metabolic heat production
C = convection
E = evaporative cooling

K = conduction
ΔS = net change in heat body storage

In the above energy balance, the most constant energy input is metabolic heat production (this is always a heat source). Radiation is a heat source during periods of strong radiant heat loading, and convection and conduction can be heat sources if the immediate environment surrounding the animal (eg. air and ground) is warmer than the animals body temperature. The animal can dissipate energy through cooling (conduction, convection, evaporative losses) although the rate of loss is variable depending on climatic conditions. The factor ΔS represents the 'net heat gain or storage' and the value of this is dependent on the rate of heat inputs and losses. As stated by Oke (1987), in most animals this must remain close to zero because the range of tolerable body temperatures is small. Significant changes in ΔS can be deleterious to the health of an animal.

Cattle suffer 'heat stress' when their ability to dissipate heat or lose it by other means is limited. In most cases heat stress is precipitated when the gross 'heat load' exceeds the physiological abilities of the animal to metabolically or behaviourally loose heat. The core body temperature of most mammals ranges from 35 to 40°C. Oke (1987) explains that these values lie towards the upper end of the range of atmospheric temperatures and as such mammals are relatively well adapted to heat conservation, but their ability to dissipate heat to prevent over-heating is less well developed. The various heat sources and loss mechanisms relating to cattle are described in further detail in section 5.3 'Thermodynamics of Livestock'.

Based on anecdotal evidence and recent studies the phenomena of "heat stress" can not be simply based on excessively high temperatures and humidity. It appears to be a culmination of factors that most likely include:

- the rate of change in both day and night time temperatures;
- changes in humidity linked to precipitation;
- consistently low wind speeds;

and may possibly include microclimate factors in feedlot pens such as:

- increased heat loads over pens caused by the 'oasis' effect (described above);

- increased evaporation rates from dark wet pen

- surfaces that adsorb significant quantities of radiation (this may cause a dramatic increase in humidity and ammonia levels in near proximity to the pen surface and thus the climate in which stock live).

3. METHODOLOGY

The fundamental aims of the project were to:

1. Quantify temperature, humidity and gas profiles in the air mass over a feedlot;

2. Examine the variance in these profiles as a result of changes in surface characteristics (landscape features such as slope etc) or variations in the physical environment (eg. shade);

3. Investigate the effects of these variations on cattle within the feedlot.

To achieve these aims the project endeavoured to measure the following parameters:

- The climatic conditions surrounding a feedlot;
- The microclimate conditions within feedlot pens;
- The levels of ammonia gas (NH_3) within feedlot pens;
- Pen surface conditions (in particular manure depth and moisture content);
- Cattle behaviour in response to varying climatic conditions.

The methods of undertaking these measurements are outlined in the following sections.

3.1 Site Descriptions

The requirements of the project were to select two feedlots, one located in southern New South Wales; the other located in southern Queensland. The feedlot site selection was aimed at ensuring that the sites selected were representative of operations in both southern and northern Australia. Two large feedlots were selected for the study as described below.

Feedlot A is located in southern Queensland on the Darling Downs some 16 km north east of Dalby (151°15’ E, 27°10’ S). The nearest Bureau of Meteorology (BOM) stations that record climatic data additional to rainfall are Dalby Post Office (station no. 041023), Dalby Airport (station no. 041522), and Oakey AMO (station no. 041359).

Feedlot A has a capacity of 18,000 head. Four individual pens were used for the cattle and pen surface measurements. Each of these pens had an area of approximately 3200 m^2 and were stocked at an average density of 14.2 m^2/head over the study. Two of the selected pens contain permanent 15 metre wide shade structures composed of galvanised iron sheets (see Plate 1). Typically the pens at Feedlot A have manure mounds constructed in the centre of the pens. For the purpose of this project the feedlot staff removed the mounds in the study pens to ensure similar pen conditions to Feedlot B. Aside from the mounds, the pens are on a slope of about 2.5% with a westerly aspect.

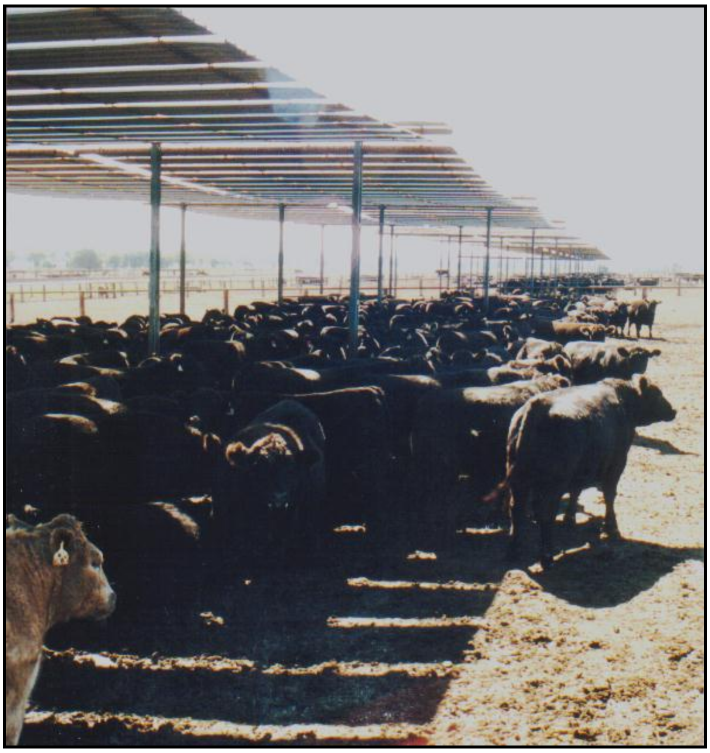

Plate 1. Galvanised Shade Structure at Feedlot A.

Feedlot B is located in the Murrumbidgee Irrigation Area (MIA) of southern NSW. The feedlot is situated 10 km south east of Yanco (146°24' E, 34°36' S). The closest BOM stations to this site are Narrandera Airport (station no. 074148), Narrandera Council Depot (station no. 074221), and Narrandera Post Office (station no. 074082).

Feedlot B has a capacity of 53,333 head. The pens at this site are larger than those at Feedlot A and as such only two of the 6400 m^2 pens were used for the cattle and pen surface measurements. Over the project duration the stocking density of these pens averaged 15 m^2/head which was only slightly higher than those of Feedlot A. Both pens contained fixed pole structures that enabled a 15 metre wide strip of shade cloth to be fastened across the length of the pen. Management of the feedlot operation sees that the pens are shaded over the warmer months of December to March. For the purpose of the project the shade cloth was removed from one of these pens for the duration of the study. The pens at Feedlot B are on a slope of about 2 to 3% with a westerly aspect.

3.2 Project Duration

The Terms of Reference for Project FLOT.310 stated that data collection was to be undertaken during the 2000-2001 summer period and suggested the period from mid December to end March.

Due to the large amount of instrumentation that was required for the field measurements there were some initial delays in the manufacturing and supply of weather station components. Notwithstanding this, installation of equipment at Feedlot A commenced in mid December and climatic measurements commenced on the 1 January 2001. Following this, equipment installation at Feedlot B was completed and climatic measurements commenced on the 9 January 2001.

Commencement of cattle and pen surface measurements at both sites also occurred around this time. The cattle observations and pen surface measurements were completed on the 28 March at Feedlot B as it was necessary to remove stock from the pens for slaughter. Feedlot A completed their measurements on 31 March 2001. The climatic measurements were completed and all field equipment was decommissioned in late April and early May for Feedlot A and Feedlot B respectively. Specific activity dates for both feedlot sites are detailed in Table 1 below.

Table 1. Outline of Progress for Field Measurements.

Activity	Feedlot A	Feedlot B
Commencement of Weather Station Installation	19th December 2001	2nd January 2001
Commencement of Climatic Data Recording	1st January 2001	9th January 2001
Commencement of Cattle Comfort Measurements	9th January 2001	8th January 2001
Commencement of Pen Surface Measurements	8th January 2001	8th January 2001
Completion of Cattle Comfort Measurements	31st March 2001	28th March 2001
Completion of Pen Surface Measurements	30th March 2001	28th March 2001
Completion of Climatic Data Recording	22nd April 2001	7th May2001
Dismantling of Weather Stations	23rd April 2001	8th May 2001

It should be noted that the period over which data analysis was concentrated was from January to March 2001. Cattle comfort measurements and pen surface measurements coincided with the collection of climatic data over this time.

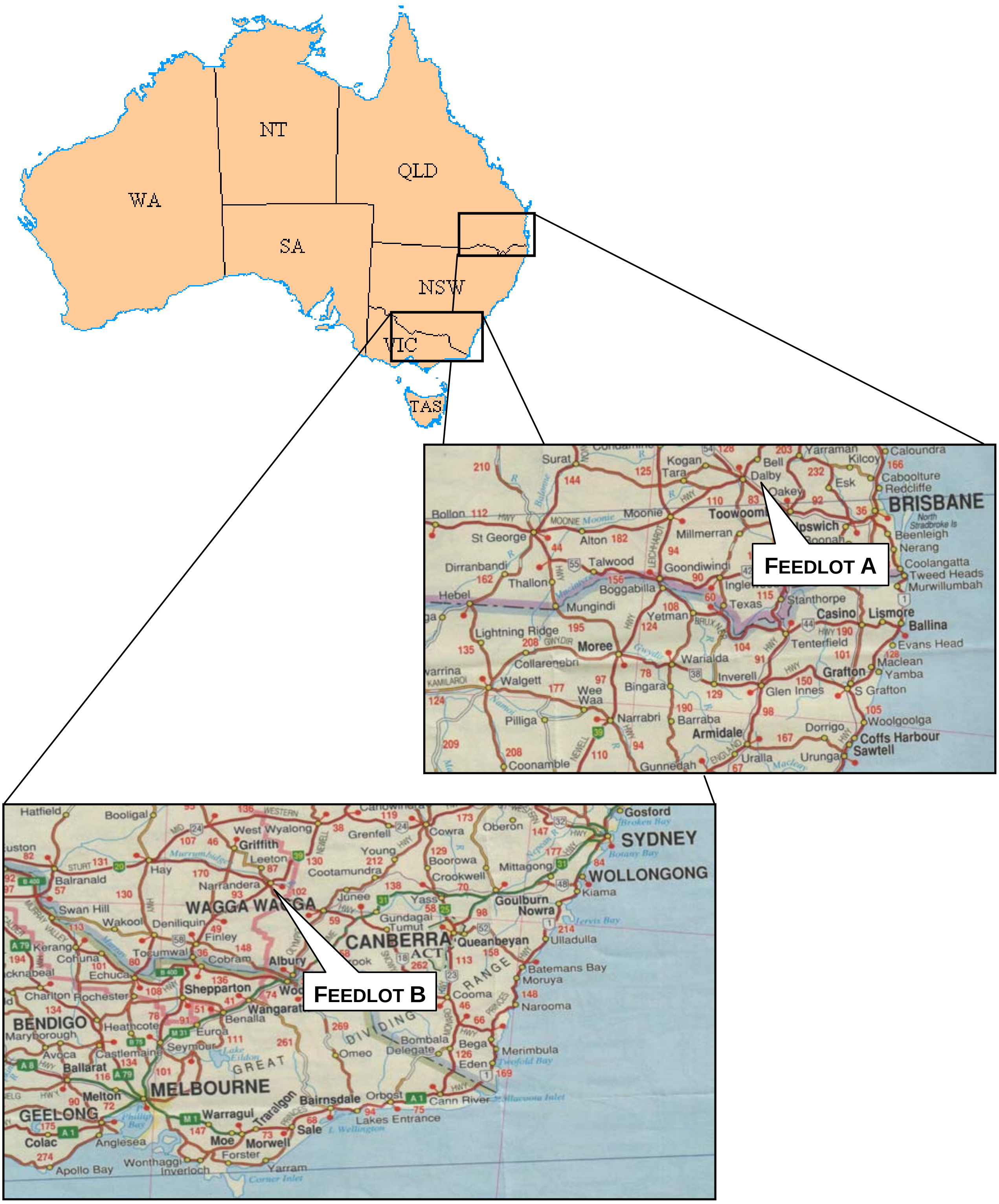

Figure 3. Location of Feedlot A and Feedlot B within Australia.

3.3 General Microclimatic Measurements

In order to measure the climatic conditions of each of the feedlot environments, four weather stations were positioned outside the feedlot area (referred to as the external stations in this report). In addition to these, two weather stations were situated within two separate feedlot pens (referred to as internal stations and described in section 3.4 below). As outlined in Table 1 the four external stations were used to record climatic data for a 16 week period from 1 January to 22 April 2001 for Feedlot A, and a 17 week period from 9 January to 7 May 2001 for Feedlot B.

All of the four stations located around the feedlot extents were 10 metres in height. The positioning of these stations around the outside of the facility was based on a north-south and east-west axis. These axis were used to position the four stations, with a station located to the North, South, East and West of the feedlot. Weather stations were moved off an axis where interference was expected from the feedlot or farm structures, vegetation, or other topographical features. Plate 2 below shows two of the stations used for the project.

Plate 2. Station 4 (North) at Feedlot A [left] and Station 1 (East) at Feedlot B [right].

In general terms each of these weather stations was not located within 100 metres of the feedlot, and not within a distance proportional to 10 times the height of any surrounding features or obstacles likely to have an affect on weather monitoring measurements. Where this was not possible, the criteria was reduced to 50 metres from the feedlot, whilst still ensuring maximum separation distances from surrounding features and obstacles.

The position of each of the stations located at both Feedlot A and Feedlot B is shown in Figure 4 and Figure 5 below. These diagrams show the arrangement of the four external stations and two internal stations at each site in relation to the general feedlot perimeters and the study pens used in the project.

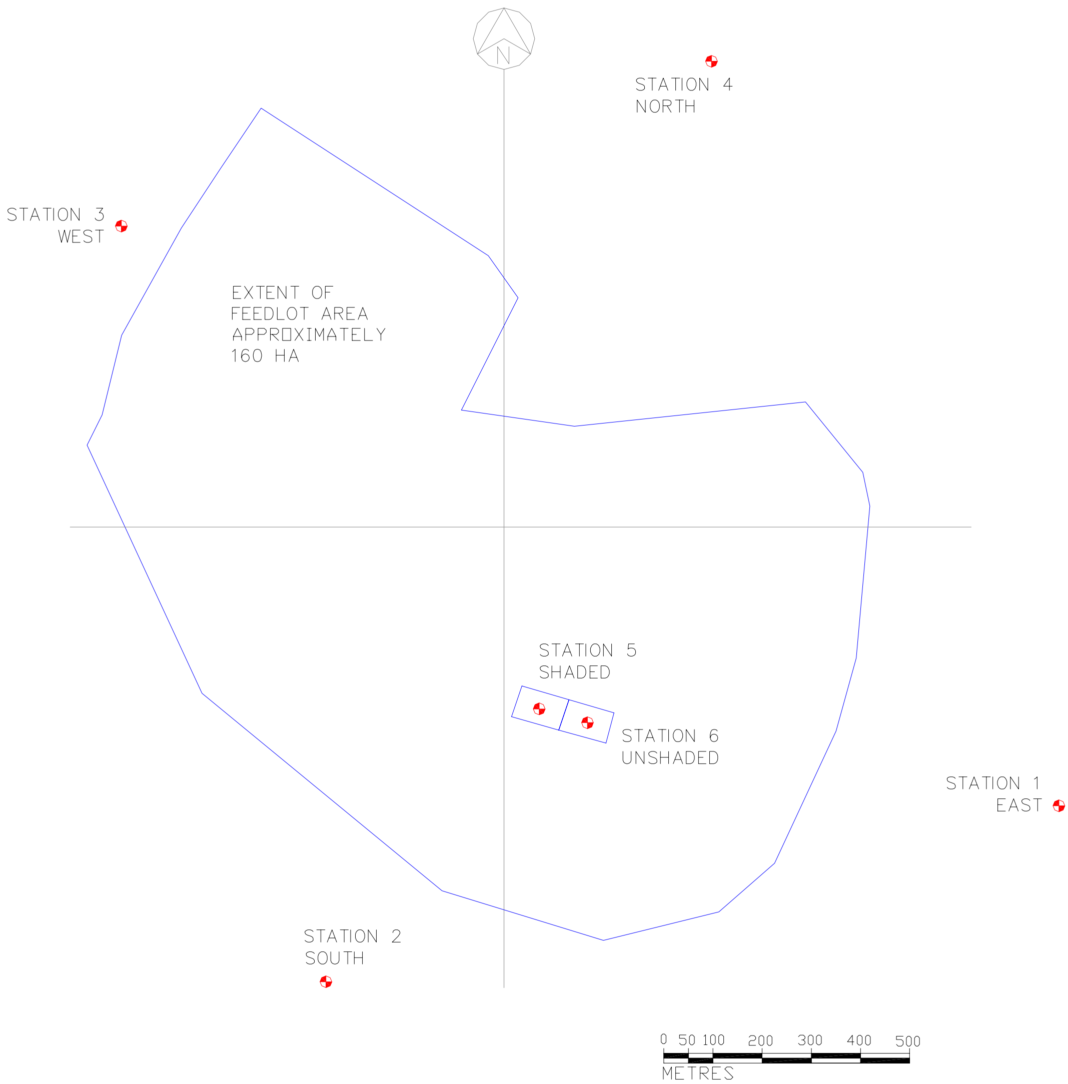

Figure 4. Layout of Weather Stations at Feedlot A.

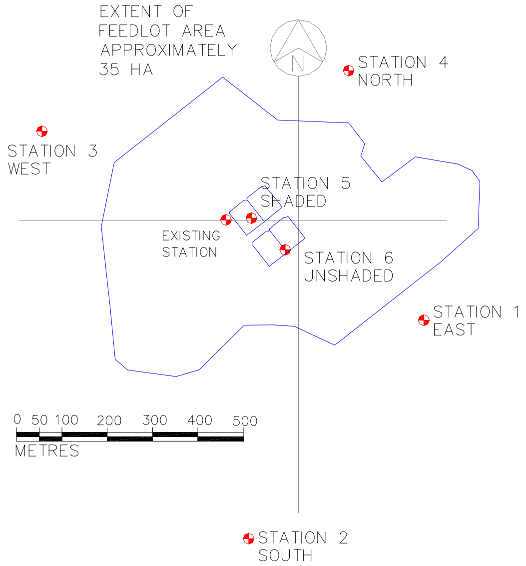

Figure 5. Layout of Weather Stations at Feedlot B.

The purpose of locating stations outside of the feedlot was to define potential topographical effects on the climate at the feedlot (including landscape features, slope, aspect etc) and differences in the external and internal climates. The two internal stations were used to define microclimatic differences between shaded and unshaded pens. The study aimed to define the climate of the feedlot through the determination of the following factors:

- the temperature and humidity profile in and around the feedlot;
- the mixing of air in and outside the feedlot;
- the evaporative potential in and outside the feedlot;
- the gross radiation load from convective heating of air masses, incoming radiation, and outgoing radiation;
- the ‘albedo’ of the surfaces in and outside of the feedlot and therefore the amount of re-radiated energy.
- The climatic variables recorded at each of the four stations positioned outside the feedlot are outlined below in Table 2. The weather station configuration was kept consistent between both feedlot sites.

Table 2. Sensor Configuration for the 'External' Weather Stations - Located around Feedlots A & B.

Sensor Type	- Sensor Location -			
	Station 1 - East	Station 2 - South	Station 3 - West	Station 4 - North
Air Temperature	1.2 metres	1.2 metres	1.2 metres	1.2 metres
Humidity	1.2 metres	1.2 metres	1.2 metres	1.2 metres
Black Globe	2 metres	2 metres	2 metres	2 metres
Wind Speed	2 & 10 metres	2 & 10 metres	2 & 10 metres	2 & 10 metres
Wind Direction	10 metres	10 metres	10 metres	10 metres
Soil Temperature	Ground	Ground	Ground	Ground
Rain Gauge	Ground	Ground	Ground	Ground
Incoming Solar Radiation	10 metres	-	-	10 metres
Outgoing Solar Radiation	10 metres	-	-	10 metres

In addition to the climatic variables listed above, it was intended to include sensors at selected stations that would measure vertical wind speed. The purpose of these sensors was to define the extent of uplift and vertical mixing. However it was not possible to have these particular sensors manufactured by the required project commencement date, or at a time early enough during the field measurements to obtain an adequate data set.

Outgoing radiation was measured by using a standard radiation sensor (identical to the incoming radiation sensor) orientated towards the ground surface. This sensor was located at a height of 10 metres on the weather stations to minimise the potential increase in readings that could be caused from reflection off the surface of the stations structures (concentrated at the lower sections).

Time zone differences occurred between the feedlot sites due to the occurrence of daylight saving in NSW. To standardise the climatic measurements, the timed recording at all weather stations was set to Eastern Standard Time (EST). As such all "times" noted in this report refer to EST unless otherwise stated.

All sensors used had undergone standard calibration by the manufacturer prior to delivery. In order to ensure that the collected data was of quality and remained accurate throughout the study period mobile communications were established at selected stations and regular site visits were undertaken by E.A. Systems staff.

The establishment of mobile communications involved the installation of a modem/telephone (GSM) and antenna in selected stations. Communication systems were installed in both of the stations located within the feedlot pens and also at the eastern station located outside the feedlot.

It was decided to establish mobile communications with both the stations located in the feedlot pens to ensure that any problems in data collection were quickly identified and remedied. It was important to collected reliable and uninterrupted data from these internal stations, as these stations were not replicated. In short the four external stations were replicates, while the two stations within the pens (shaded and unshaded) were both collecting unique data.

The eastern station was selected from the external stations for the establishment of mobile communications because this station was recording the most climatic variables and also it is known that easterly patterns typically prevailed and these measurements were least likely to be affected by the feedlot. The quality of mobile phone reception was also considered at both sites and was found to be adequate at both eastern weather station sites. The mobile communication systems were used to check the stations on a regular basis (weekly) for both changes in weather conditions and sensor integrity. It also allowed more frequent down loading of recorded data as required.

The majority of the recorded climatic data were collected at the time of the fortnightly visits undertaken by E.A. Systems staff. During these visits all stations were serviced to ensure that all sensors were clean and fully operable. The visits were also used to verify station measurements and to identify and remedy any faults.

Verification of the sensor readings involved both the checking of spot measurements and the downloaded data for any anomalies. Wind direction readings were also checked through spot readings (using a compass) and visual verification of the vane direction. Battery voltages and solar panel outputs were also tested using an ammeter. Any noted faults were repaired on site. These repairs typically involved replacement of individual sensors or realignment of wind direction sensors. Simple calibration checks were also undertaken by E.A. Systems staff at the time of the regular site visits. These included the verification of temperature and humidity sensors using a hand held sling psychrometer.

3.4 Feedlot Microclimate Measurements

As described in section 0 the purpose of stations outside of the feedlot was to define the climate at the feedlot and any variations due to topographical effects/landscape that may occur. These measurements were then to be compared with the microclimate and its associated variations within the feedlot itself. The measurements of the microclimate within the feedlot pens aimed to define the following factors:

- the temperature and humidity profile in both an unshaded and shaded pen;
- the mixing of air within the feedlot;
- the evaporative potential within the feedlot (this dictates moisture and gas loss from the pen surfaces - especially when wet);
- the gross radiation load from convective heating of air masses, incoming radiation, and outgoing radiation;
- the ‘albedo’ of the pen surfaces and therefore the amount of re-radiated energy.

In order to measure the microclimatic conditions within the feedlot pens, two weather stations were installed in separate pens at each feedlot site. The feedlot pens selected at each site included one pen with shade structures, and a separate pen that either contained no shade (Feedlot A) or had the shade removed for the purpose of the study (Feedlot B). Pen selection was aimed at ensuring that the study pens were representative of the general feedlot conditions at each site and that they were comparable across the sites. It was also important to ensure that the location of the pens were not in close proximity to the edge of the feedlot area (in order to prevent variations caused by boundary effects).

At Feedlot A, a 10 metre station was positioned close to the boundary fence adjoining the two unshaded pens that were selected for the study. This was done to enable the collection of data that would be representative of both pens. It also enabled the fence to be utilised for additional protection for the station from cattle. In order to ensure that adequate fastening points were available to secure the guy wires of this station, it was necessary to locate the station in close proximity to the pen feed bunk where three pen fences intersected. This allowed the guy wires to be fixed to support posts that were welded to the fences by feedlot staff (at a height clear of cattle and stockman movements). Plate 3 below shows this 10 metre station located in the unshaded pen at Feedlot A.

The station located in the unshaded pen at Feedlot A was 2 metres in height to enable it to be placed under the shade structure. This station was situated as close to the centre of the shade structure as possible whilst still allowing the existing shade support posts to be utilised as braces for the fence panels that were erected to prevent cattle from damaging the station. This required the station to be moved slightly off centre, and as such the station was located closer to the adjoining shaded pen that was also used for the study.

The layout of the four study pens at Feedlot A and location of these stations within the pens are shown in Figure 6 below.

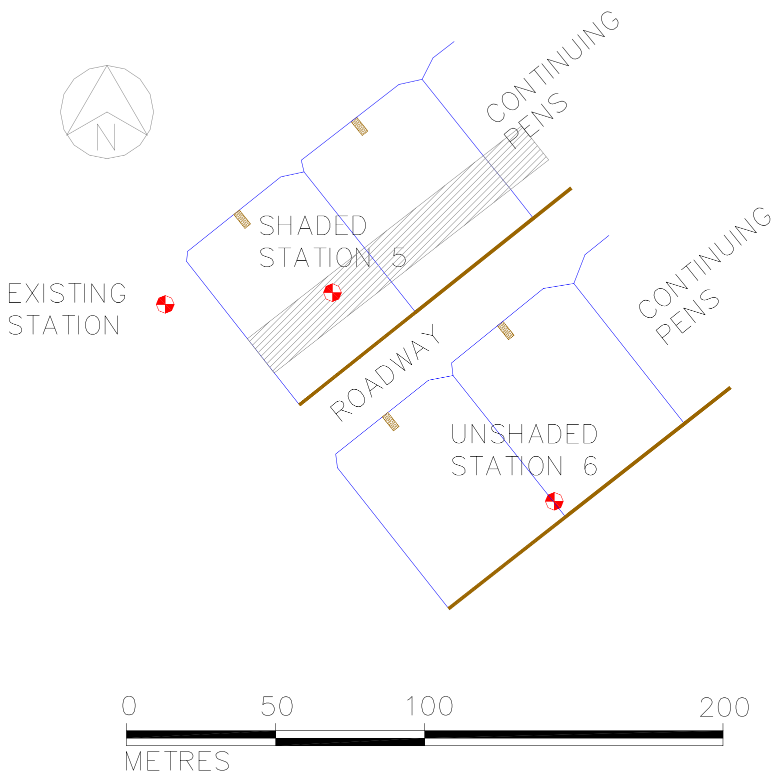

Figure 6. Layout of Study Pens and Internal Stations at Feedlot A.

The 10 metre station located in the unshaded pen at Feedlot B was positioned in the centre of the pen. This ensured that the measurements recorded were representative of the single unshaded study pen used at this feedlot. (Only one unshaded and shaded pen were utilised in the study at Feedlot B due to the larger pen size compared to Feedlot A). Poles located within this pen for the purpose of securing shade cloth were utilised for the fastening of guy wires. This station was protected from cattle using portable fence panels fixed to star posts.

The shaded pen selected for the study at Feedlot B was the neighbouring pen west of the unshaded pen. The 2 metre station located in this shaded pen was situated in the centre of the pen directly under the shade cloth. This station was also protected from cattle using portable fence panels fixed to star posts.

Figure 7 below outlines the layout of the two study pens at Feedlot B and location of these stations within the pens. The 10 metre station located in the unshaded pen at Feedlot B is shown in Plate 3.

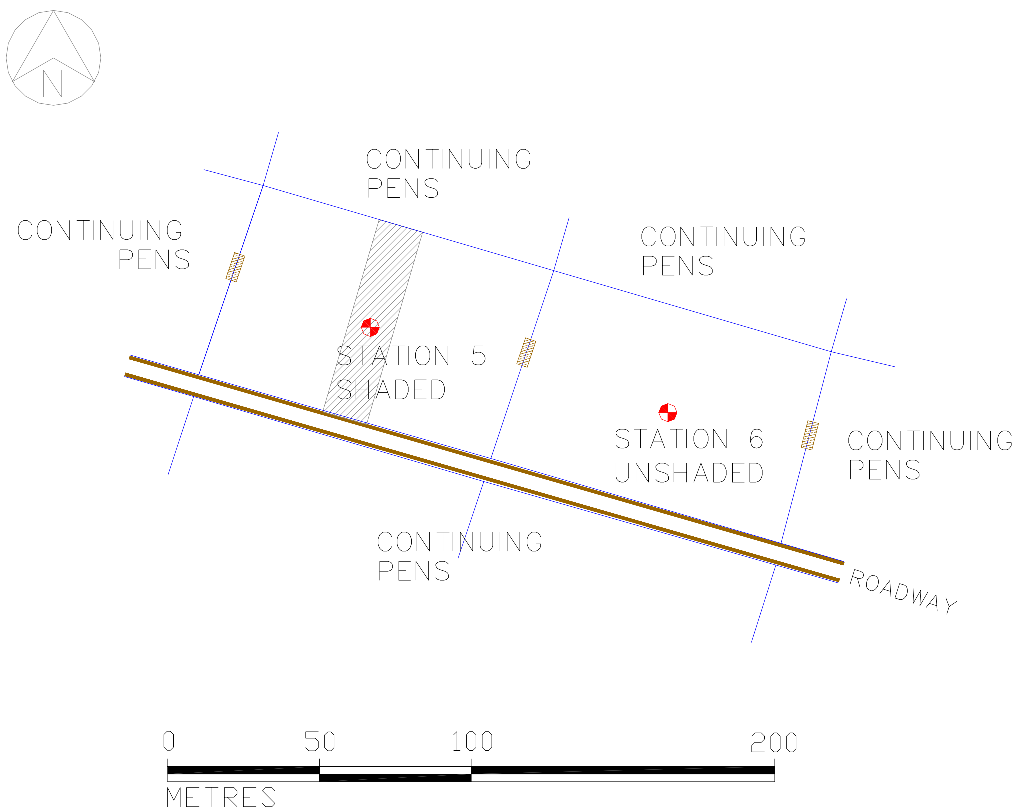

Figure 7. Layout of Study Pens and Internal Stations at Feedlot B.

The climatic variables recorded at the stations positioned within the feedlot pens are outlined in Table 3 below. The weather station configuration was kept consistent between both feedlot sites and the external stations. There was one minor exception to this in that the wind direction sensor of the station in the unshaded pen at Feedlot B was located at 2 metres rather than 10 metres. This was required due to a manufacturing fault in the 10 metre cross-arm of this station which prevented the sensor from being adequately secured. The internal stations were used to record climatic data for the same period as the external stations, that is a 16 week period for Feedlot A, and a 17 week period for Feedlot B (as outlined in Table 1 of section 3.2).

Table 3. Sensor Configuration for the 'Internal' Weather Stations - Located within the Feedlot Pens.

Sensor Type	***- Sensor Location -***	
	Station 5 - Shaded Pens	***Station 6 - Unshaded Pens***
Air Temperature	1.2 metres	1.2 metres
Humidity	1.2 metres	1.2 metres
Black Globe	2 metres	2 metres
Wind Speed	2 metres	2 metres & 10 metres
Wind Direction	2 metres	10 metres - Feedlot A 2 metres - Feedlot B
Soil Temperature	Ground	Ground
Incoming Solar Radiation	2 metres	2 metres
Outgoing Solar Radiation	2 metres	2 metres

The purpose of the incoming and outgoing radiation sensors was not only to measure the direct solar radiation, but also to define the albedo of the surfaces and therefore determine the amount of re-radiated energy that may affect the air in the feedlot pens. This directly relates to the heat load experienced by the cattle.

In addition to the climatic variables listed in Table 3 above, it was also intended to include vertical wind speed sensors at the internal stations. The purpose of these sensors was to define the extent of uplift and vertical mixing of the air within the feedlot pens. As outlined in section 0 above these sensors could not be manufactured in time. Static NH_3 gas analyser sensors fitted to each station were also trialled at these locations during the study. These were found to be unreliable, and as such no useable data were collected from these sensors. This is outlined in more detail in section 3.5 below.

The mobile communications established in the internal stations (outlined in section 0 above) allowed regular checking of the quality of collected data, and also enabled any problems in data collection to be quickly identified and resolved. The site visits by E.A. Systems were used to undertake identical servicing, calibration, data verification and downloading procedures with the internal stations as was employed with the external stations. These procedures are detailed in section 0 above. It should be noted that due to the location of the internal stations within the feedlot pens, significantly more cleaning was required during the fortnightly site visits to ensure sensor and data integrity.

Plate 3. Station 6 (Unshaded Pen) at Feedlot A [left] and Feedlot B [right].

3.5 Ammonia Measurements

It was proposed to install static electronic gas analyser sensors in selected stations (including both the external and internal stations) for the duration of the trial. The purpose of these sensors was to record ammonia gas (NH_3) levels over time. This would provide an understanding of the variations and daily fluctuations in ammonia levels within feedlot pens. Data would also be collected from the external stations to determine background levels of NH_3 or drift of NH_3 downwind of each feedlot.

Due to the specialised nature of these sensors it was necessary to source them from an overseas supplier. Unfortunately the supply of these sensors was delayed and as such the equipment was not received until mid March 2001. Once received the sensors were installed into selected stations at each feedlot site during a fortnightly site visit. Analysis of the data as it was collected highlighted some significant anomalies in the sensor readings and the data were found to be unreliable. These data could not be used with any confidence and it was not possible to have the sensors calibrated before the program of field measurements was completed.

However, other recording of ammonia levels in feedlot pens was undertaken during the study to offset this problem. These data were collected with the use of a hand held gas monitor. The hand held monitor used was a ‘VRAE PGM-7800 Multi Gas Monitor’ fitted with an ammonia sensor. This equipment was utilised during the fortnightly site visits to undertake ammonia measurements in both the shaded and unshaded pens at each feedlot site. These measurements were typically taken by positioning the hand held monitor on a weather station located in a study pen. The monitor was then set to automatically log the ammonia levels at a set interval (generally once every 10 to 30 seconds) until it was either removed, or ran out of battery power. The battery life of the monitor was found to be in the order of 10 to 12 hours.

The use of the monitor was varied with measurements being undertaken in both the shaded and unshaded pens at both feedlot sites. The time that data recording commenced was also varied in an attempt to record ammonia measurements across a full 24 hour period. It was hoped that this would provide an understanding of trends in ammonia generation (and thus concentrations) in feed yard pens over a typical day and also highlight variations in ammonia concentrations caused by differing pen surface conditions and shade structures.

During the final stages of the project a second hand held gas monitor was obtained. This hand held monitor was a 'MultiRAE Plus PGM50-4 Multi Gas Monitor'. The two gas monitors which take similar measurements (they had been calibrated prior to E.A. Systems taking receipt of them) were used to undertake simultaneous measurements of ammonia levels (see Plate 4). During the decommissioning of equipment at Feedlot A, simultaneous measurements were recorded with one monitor located in the shaded pen and the other in the unshaded pen. At Feedlot B this was not possible, as feedlot staff in preparation for the cooler months had already removed the shade cloth. Both sensors were used to measure ammonia concentrations at varying heights in the now unshaded pen. A summary of the ammonia measurements recorded is presented in section 4.3.

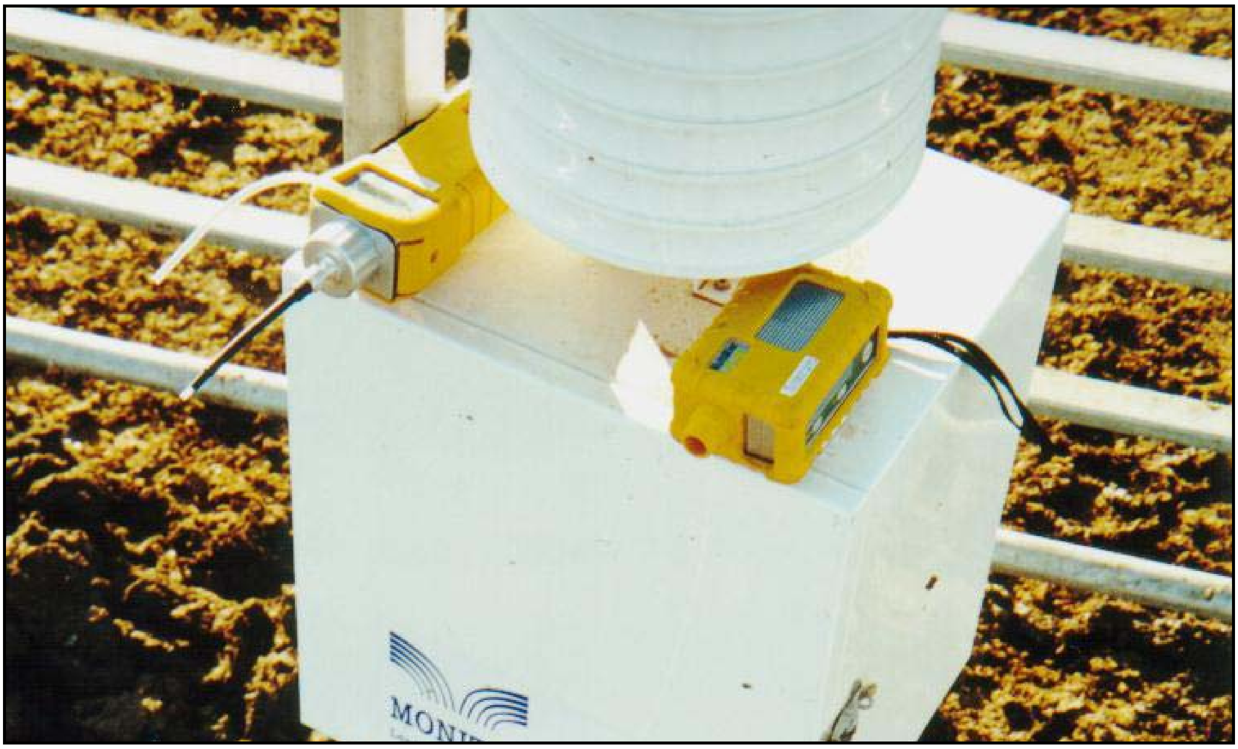

Plate 4. Hand held gas monitors used in the study - VRAE [left] and the MultiRAE [right].

3.6 Pen Surface Measurements

Sampling of the manure pad in the study pens was undertaken from early January through to the end of March. The sampling was undertaken by a member of the feedlot manure management or pen maintenance team. The purpose of this sampling was to enable data on pen surface condition and manure moisture content to be collected. These data were collected by means of direct sampling to ensure accuracy and reliability of the data.

While the weather stations in the study pens collected all climatic and pen surface temperature data, they were not able to accurately measure manure moisture content levels. Other methods to obtain this data such as the use of gypsum or calcium silica blocks etc. have been trialled in the past with minimal success (S. Lott, pers. comm. 2000/1). Past attempts have also been made to develop several sensor prototypes (such as conductance sensors) to undertake moisture measurements, but these have also been unsuccessful. It was decided that the best means to accurately determine the moisture content is through direct sampling.

The sampling for pen manure moisture content was typically undertaken each Monday, Wednesday and Friday for the 12 week period from early January through to the end of March. This sampling was undertaken by feedlot staff. Sampling involved the use of a 50 mm core sampling tube that was hammered into the pen surface until the underlying clay layer was struck. The core was removed from the tube and the depth of sample recorded. A series of samples were collected from each pen and common samples were bulked on the basis of the location with which they were collected ie. one single composite sample was collected from each of the unshaded pens, and two composite samples were collected from each shaded pen (one from samples collected under the shade area, and one collected from outside the shade area. The bulking of composite samples are outlined in Table 4 below.

Table 4. Number of Manure Samples at Each Sampling Period.

Pen Type	**Number of Individual Samples Bulked for Composite Sample**	
	Unshaded Area	**Shaded Area**
Shaded	6	3
Unshaded	9	-

The collected composite samples were bagged and labelled and then stored on site at below 0°C. Samples were collected from the feedlots at the time of the fortnightly site visits where they were transferred to a laboratory for analysis. All samples were analysed at Lanfax Laboratories, Armidale where the wet and dry weights, and hence moisture content, was determined. Because the depth of the sample was measured, the width of the core known, and the dry weight of the collected manure was ascertained, bulk densities could be determined. In general terms this allowed the ‘condition’ of the pen manure to be tracked through time.

To enable comparisons to be made between the two feedlot sites, each study pen was cleaned prior to commencement of the study. In the case of the pens at Feedlot A mounds had been used for accumulation of harvested manure. These mounds were removed from the pens prior to the start of the trial to ensure similar pen conditions to those of Feedlot B. In essence each pen started with the same pen manure condition. At the commencement of the study the manure depth was about 30 mm in both feedlots. The results of the pen surface measurements are presented in section 4.4.

3.7 Cattle Measurements

For the same 12 week period that pen surface measurements were undertaken, daily measurements were recorded in order to monitor cattle behaviour. It was aimed to undertake these measurements in a similar manner to previous studies conducted by Dr Lloyd Fell (1994) and Dr Ross Clarke (1996). The monitoring involved the observation of cattle behaviour in both the unshaded and shaded study pens where climatic monitoring and pen measurements were undertaken.

A number of variables were monitored relating to both cattle behaviour and comfort. These observations were designed to provide an indication of when cattle become stressed and to provide data on their behaviour corresponding to these stress periods. As with the manure moisture sampling, this monitoring was undertaken by feedlot staff under instruction from E.A. Systems Pty Limited. Unlike the pen surface measurements that were undertaken three days per week, feedlot staff collected this information at two separate periods throughout the day, five days per week.

To assist the recording of cattle measurements, E.A. Systems supplied a simple check sheet that the staff then used to record animal behaviour in the monitored pens. At Feedlot B these measurements occurred between 7 and 8 am and 2 to 3 pm Eastern Daylight Saving Time, which was 6 to 7 am and 1 to 2 pm EST at Feedlot A.

The observations that were recorded on the check sheets are shown in Table 5 below for each feedlot.

Table 5. Observations that were recorded with the Cattle Measurements.

	Shaded Pens		***Unshaded Pens***
	Area outside shade	**Area under shade**	
Number around water trough	✓	-	✓
Number at feed trough	✓	-	✓
Number of cattle lying	✓	✓	✓
Number of cattle standing	✓	✓	✓
Number of cattle panting	✓	✓	✓
Number of cattle with increased slobbering	✓	✓	✓

Additional space was also included on all observation sheets for any comments that observers wished to record. In addition to the above cattle comfort observations, records were taken on daily pen data including:

- Number of head in pen;
- Time of recording;
- Average cattle weight;
- Feed intake; and
- Daily pulls and mortalities.

Feedlot A also recorded information relating to the ration type that was being fed to the cattle and the actual feed times. To assist the staff undertaking these observations, the following terms were defined as shown in Table 6.

Table 6. Definition of Terms for the Cattle Observations.

Term	Definition
Pulls	The number of individuals removed from a pen.
Number around water trough	The number of cattle standing as close as they can to the water trough, even if not actually drinking.
Number of cattle at feed	The number of cattle in the process of ingesting feed at the feed trough.
Number of Cattle panting	The number of cattle showing an increase in respiration rate. This was broken further into fast or slow, and deep or shallow breathing
Number of Cattle with increased slobbering	The number of cattle showing an increase in slobbering

The collection of all data was benchmarked to ensure that data collected at one feedlot could be compared to another. The results of the cattle observations and measurements are presented in section 4.5. The trial aimed to keep consistency between the cattle used in the trial. This was achieved by ensuring that both identical cattle breeds (Angus) and similar sized cattle were used in the trial pens at both sites. A summary of the cattle details from both feedlot sites is presented in Table 7.

Table 7. Cattle Types and Average Weights for the Study Period.

	Feedlot A			**Feedlot B**		
	Cattle Type	**Average Weight (kg) 09 January**	**Average Weight (kg) 31 March**	**Cattle Type**	**Average Weight (kg) 08 January**	**Average Weight (kg) 28 March**
Shaded Pens	Angus	Pen 1 - 585 Pen 2 - 653	Pen 1 - 676 Pen 2 - 726	Angus	679	774
Unshaded Pens	Angus	Pen 1 - 609 Pen 2 - 703	Pen 1 - 695 Pen 2 - 769	Angus	668	775
Average Weight	-	637.5 kg	716.5 kg	-	673.5 kg	774.5 kg

4. RESULTS

4.1 Summary of Climatic Measurements

For the purpose of this study the climatic measurements presented will primarily consist of data collected in the period January to March 2001. Although climatic data were recorded at both feedlot sites after this period, it was important to concentrate on this three month period as it coincides with the collection of the cattle and pen surface measurements.

A summary of the climatic data recorded over these months is presented in Table 8 and Table 9 below. These tables show average monthly values recorded at the external stations of each feedlot site compared to the long term average monthly data obtained from nearby Bureau of Meteorology (BOM) stations. The long term BOM data presented in Table 8 is an average of the values recorded at Dalby Airport and the Dalby Post Office. The BOM data presented in Table 9 is the average long term values from Narrandera Airport, Narrandera Council Depot and Narrandera Post Office.

Table 8. Recorded Monthly Average Climate Data for the study period compared with Average Long Term Monthly Averages for nearby Climate Stations – Feedlot A.

	January		*February*		*March*	
	Recorded	**BOM Long Term Average**	**Recorded**	**BOM Long Term Average**	**Recorded**	**BOM Long Term Average**
Air Temperature (°C)	24.4	25.4	23.0	24.7	22.7	22.9
Relative Humidity (%)	62.9	58.0	69.0	59.0	67.7	55.0
Total Rainfall (mm)	100.9	86.6	44.3	84.2	85.1	52.4
Soil Temperature (°C)	29.0	-	25.7	-	26.0	-
Incoming Solar Radiation (W/m^2)	320.2	-	315.6	-	245.2	-
Outgoing Solar Radiation (W/m^2)	49.5	-	63.0	-	48.0	-
Black Globe (°C)	28.4	-	26.1	-	25.6	-
2m Wind Speed (km/hr)	9.2	-	9.9	-	8.7	-
10m Wind Speed (km/hr)	17.0	-	12.3	-	9.9	-
Wind Direction (°)	153.3	-	125.4	-	153.1	-

In general, the conditions at Feedlot A over the period 1 January to 31 March 2001 were "average". The only significant difference in the recorded values and the BOM long term average values was in the observed humidity readings. In comparison, the data presented in Table 9 shows that over the study period Feedlot B experienced a warmer more humid summer compared to the conditions normally experienced. However, rainfall was slightly below average.

Table 9. Recorded Monthly Average Climate Data for the study period compared with Average Long Term Monthly Averages for nearby Climate Stations – Feedlot B.

	January		*February*		*March*	
	Recorded	**BOM Long Term Average**	**Recorded**	**BOM Long Term Average**	**Recorded**	**BOM Long Term Average**
Air Temperature (°C)	27.8	24.9	25.9	24.7	20.1	21.5
Relative Humidity (%)	42.5	47.7	52.9	49.0	56.7	51.3

	January		*February*		*March*	
	Recorded	**BOM Long Term Average**	**Recorded**	**BOM Long Term Average**	**Recorded**	**BOM Long Term Average**
Total Rainfall (mm)	20.6	38.4	39.6	30.9	31.9	32.9
Soil Temperature (°C)	32.8	-	28.3	-	24.5	-
Incoming Solar Radiation (W/m^2)	372.1	-	281.3	-	243.7	-
Outgoing Solar Radiation (W/m^2)	94.4	-	67.3	-	58.2	-
Black Globe (°C)	30.4	-	28.5	-	23.4	-
2m Wind Speed (km/hr)	6.6	-	6.7	-	7.2	-
10m Wind Speed (km/hr)	12.3	-	11.6	-	11.9	-
Wind Direction (°)	172.9	-	170.9	-	175.8	-

Additional climatic data were sourced from the Bureau of Meteorology in order to compare the measurements recorded at each feedlot site with climatic data recorded in surrounding areas. The closest climate stations to Feedlot A with available data for the period January to March 2001 were found to be Oakey Aero (station number: 41359) and Dalby Airport (station number: 41522). The average monthly data for these stations are presented in Table 10 along with the average monthly data recorded at Feedlot A. The average monthly data for the Feedlot was obtained by averaging the recorded climatic data recorded at each of the four external stations.

These data show that the recorded climatic data external to Feedlot A were very similar to the BOM recorded climate of the surrounding areas for the period January to March 2001. A variance occurs in recorded monthly rainfall values. This is expected due to the spatial variability of rainfall. The total rainfall recorded at Feedlot A over these three months is about the mean recorded at Dalby and Oakey.

Table 10. Comparison of Recorded Data at Feedlot A with BOM Stations Oakey Aero and Dalby Airport for January to March 2001.

	***Air Temperature* (°C)**			***Relative Humidity* (%)**			***Total Rainfall* (mm)**		
	Recorded Averages	**BOM Averages**		**Recorded Averages**	**BOM Averages**		**Recorded Totals**	**BOM Totals**	
		Oakey Aero	**Dalby Airport**		**Oakey Aero**	**Dalby Airport**		**Oakey Aero**	**Dalby Airport**
January	24.4	24.2	25.8	62.8	62.8	63.5	100.4	50.0	83.6
February	23.0	22.6	23.8	69.0	73.6	70.1	39.1	114.8	90.4
March	22.7	22.7	23.6	67.7	66.1	67.7	82.6	10.8	68.8
Ave./Total	*23.4*	*23.2*	*24.4*	*66.5*	*67.5*	*67.1*	*222.1*	*175.6*	*242.8*

The closest BOM stations to Feedlot B with available data were Yanco Agricultural Institute (station number: 74037) and Narrandera Golf Club (station number: 74221). Table 11 below presents a summary of the average monthly data for these stations and the data recorded at Feedlot B. The climatic data for Feedlot B presented in this table was obtained by averaging the data recorded by the four external stations surrounding the feedlot. It should be noted that the climatic measurements commenced at Feedlot B on 9 January 2001 and as such the average monthly data presented for January excludes days prior to this date.

Table 11. Comparison of Recorded Data at Feedlot B with BOM Stations Narrandera Golf Club and Yanco Agricultural Institute for January to March 2001.

	***Air Temperature* (°C)**			***Relative Humidity* (%)**			***Total Rainfall* (mm)**		
	Recorded Averages	**BOM Averages**		**Recorded Averages**	**BOM Averages**		**Recorded Totals**	**BOM Totals**	
		Yanco Ag	**Narran. Golf**		**Yanco Ag**	**Narran. Golf**		**Yanco Ag**	**Narran. Golf**
January	27.8	28.3	30.4	42.5	34.2	37.4	16.9	21.8	19.3
February	25.9	26.2	27.9	52.9	46.6	44.0	33.9	32.4	27.2
March	21.1	20.8	22.6	56.7	52.2	47.6	25.0	34.2	26.5
Ave./Total	*24.9*	*25.1*	*27.0*	*50.7*	*44.3*	*43.0*	*75.8*	*88.4*	*73.0*

The data presented above shows that the recorded climate data external to the feedlot only varied slightly from that of surrounding areas as recorded by the BOM. Variance in the recorded humidity levels at the feedlot site is noted. These levels were about 4 to 8 % higher than the levels measured at the surrounding BOM stations. The reasons for this can be attributed to the generally 'wetter' conditions of the feedlot environment caused by dust minimisation activities such as road and pen surface watering, and irrigation of grassed areas. At Feedlot B the pens were watered at night to minimise dust generation.

Table 12 below presents a comparison of the monthly and minimum temperatures recorded at each feedlot site. This table shows the maximum and minimum temperatures recorded by the air, black globe, and soil temperature sensors. Comparison of the two feedlot sites shows that Feedlot B generally experienced a greater range of climatic variation than that of Feedlot A.

Table 12. Comparison of Average Monthly Temperatures recorded at each Feedlot Site.

		Feedlot A		***Feedlot B***	
		Monthly Maximum	***Monthly Minimum***	***Monthly Maximum***	***Monthly Minimum***
Air Temp (°C)	*January*	39.2	11.0	44.2	12.4
	February	36.5	11.7	38.4	13.1
	March	33.2	11.1	34.1	5.9
Black Globe (°C)	*January*	49.5	14.5	55.2	12.0
	February	46.9	10.6	49.9	9.9
	March	46.9	9.6	50.1	4.6
Temp	*January*	42.0	20.0	43.4	17.2

	Feedlot A		Feedlot B	
	Monthly Maximum	Monthly Minimum	Monthly Maximum	Monthly Minimum
February	37.9	20.3	41.5	15.3
March	37.3	18.7	37.5	10.9

4.2 Microclimate Measurements

The climatic data collected within the feedlot pens was compared to the climate measured in the area surrounding each feedlot. This enabled the variations in climate created by the feedlot (by changed surface conditions, presence of structures etc) to be ascertained.

A summary of the climatic variables recorded at both the internal and external stations is presented in Table 13 and Table 14 for Feedlot A and Feedlot B respectively. This table shows the average monthly values for all recorded climatic parameters for both the unshaded and shaded pens and also the average data sourced by averaging all four external stations at each site.

Table 13. Average Monthly Climate Data Recorded Outside the Feedlot, and within both an Unshaded and Shaded Pen – Feedlot A.

	January			February			March		
	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen
Air Temperature (°C)	24.4	24.5	25.0	22.8	23.2	23.4	22.7	23.0	23.3
Relative Humidity (%)	62.9	71.6[ab]	63.5	69.1	77.5[ab]	69.5	67.7	76.2[ab]	68.7
Soil Temperature (°C)	29.0	24.9[ab]	31.1	25.7	22.9[ab]	29.4	26.0	23.0[ab]	29.9
Incoming Solar Radiation (W/m^2)	320.2	71.0[ab]	300.0	315.6	76.0[ab]	288.7	245.2	51.7[ab]	235.6
Outgoing Solar Radiation (W/m^2)	49.5	9.3[ab]	44.0[b]	63.0	10.8[ab]	37.7	48.0	9.4[ab]	31.4
Black Globe (°C)	28.4	26.9	28.7	26.1	24.3	26.2	25.6	23.9	25.5
2m Wind Speed (km/hr)	9.2	7.8[a]	8.7[b]	9.9	7.7[a]	8.8[ab]	8.7	6.3	7.0
10m Wind Speed (km/hr)	17.0	-	16.9	12.3	-	13.9	9.9	-	11.9
Wind Direction (°)	153.3	108.1	118.3	125.4	90.4	107.2	153.1	139.9	149.9

[a] – Significant difference between feedlot and external.
[b] – Significant difference between shaded and unshaded.

Table 14. Average Monthly Climate Data Recorded Outside the Feedlot, and within both an Unshaded and Shaded Pen – Feedlot B.

	January			*February*			*March*		
	External	**Shaded Pen**	**Unshaded Pen**	**External**	**Shaded Pen**	**Unshaded Pen**	**External**	**Shaded Pen**	**Unshaded Pen**
Air Temperature (°C)	27.8	27.7	27.5	25.9	25.8	25.4	20.1	20.6	20.1
Relative Humidity (%)	42.5	45.9 [ab]	43.2	52.9	56.9 [ab]	52.2	56.7	61.8 [ab]	56.3
Soil Temperature (°C)	32.8	19.5 [ab]	39.1 [ab]	28.3	16.6 [ab]	30.6	24.5	12.4 [ab]	25.1
Incoming Solar Radiation (W/m^2)	372.1	101.7 [ab]	329.3	281.3	85.6 [ab]	299.4	243.7	76.1 [ab]	267.5
Outgoing Solar Radiation (W/m^2)	94.1	23.5	55.8	67.3	18.5	46.6	58.2	20.6	44.8
Black Globe (°C)	30.4	28.9 [ab]	30.4	28.5	27.0 [ab]	28.3	23.4	22.1 [ab]	23.3
2m Wind Speed (km/hr)	6.6	8.1	8.3	6.7	7.6	7.9	7.2	7.8	7.7
10m Wind Speed (km/hr)	12.3	-	12.7	11.6	-	9.1	11.9	-	10.0
Wind Direction (°)	172.9	157.8	184.3	170.9	142.5	137.5	175.8	167.8	158.0

[a] – Significant difference between feedlot and external.
[b] – Significant difference between shaded and unshaded.

From the tables presented above it can be seen that some variations are noted when comparing the climatic data collected from the area outside the feedlot to the data collected from within the unshaded pens. The most significant differences are in the soil temperatures and also in the outgoing solar radiation.

The differences observed in both of these parameters are related to, and are caused by, the nature of the ground surface. It was observed that soil temperatures outside the feedlot area were lower than those recorded within the unshaded pen. Also the outgoing solar radiation levels were lower within the unshaded pen compared to those measured at the external stations. This can be attributed to the darker manure surface of the pen which is less reflective than the surfaces outside the feedlot. They, therefore absorb a greater amount of radiation (which becomes heat energy) than that of the natural surface outside the feedlot. This is shown diagrammatically in Figure 8 below. Other factors that cause the pen surface to absorb more radiation include the rougher surface of the manure pad and the typically higher moisture content of the manure compared to the outside soils. The vegetative cover of the soils assists in deflecting direct radiation which lessens potential increases in soil temperatures.

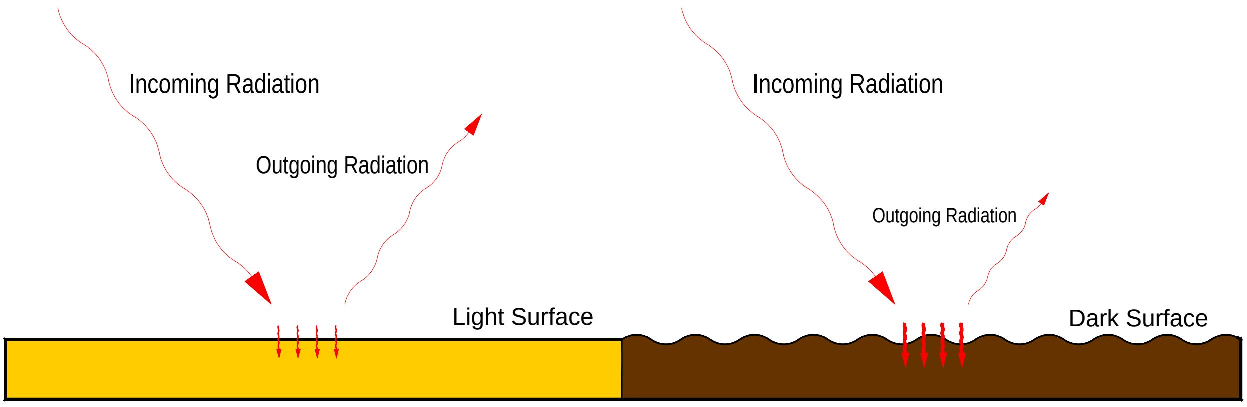

Figure 8. Schematic showing the effects of different ground surfaces on radiation.

Some minor anomalies are noted when comparing the general trends in climatic variations between the external and unshaded pen environment of the two feedlot sites. These include data showing that at Feedlot A the 2 metre wind speeds were typically higher outside the feedlot when compared to the measurements recorded in the unshaded pen. However the data from Feedlot B show an apposing trend of lower wind speeds (at 2 metres) outside the feedlot area. In this instance the variations could be attributed to the differences in topography at the two sites and also station positioning in relation to surrounding structures and features.

The data recorded in the shaded pen show lower wind speeds than those in the unshaded pens and outside locations. Clearly the presence of shade structures has a significant effect on the micrometeorology of feedlot pens through a reduction in wind speeds. The implications on energy/heat loads that occur due to the inclusion of shade within a feedlot pen are discussed in detail in section 0.

Slight differences in incoming solar radiation between external stations and unshaded pens are most probably related to a reduction in sensor effectiveness due to dust accumulation. Clearly, even with fortnightly cleaning dust effects the data in the feedlot.

4.3 Ammonia Levels

The failure of the gas analysers that were installed in the weather stations at each feedlot site meant that significantly fewer data on ammonia levels were obtained than was hoped. To ensure that some understanding of the trends and variations in ammonia concentrations within the feedlot pens was obtained the hand held gas monitor was used extensively during the fortnightly site visits. The data recorded by this equipment did enable typical diurnal variations of ammonia generation (and hence concentration) to be determined.

From the limited ammonia data collected it is not possible to make definitive conclusions regarding the effects that shade, manure moisture content, manure depth and other factors have on ammonia generation rates. It was expected (based on odour research) that shade structures would increase pen surface moisture levels that in turn would contribute to increased ammonia generation. However, this statement could not be verified by the limited ammonia readings that were recorded during this study.

Spot measurements undertaken at Feedlot B during a site visit on the 8 February provide an indication of the difference between ammonia levels in an unshaded pen and a shaded pen. The gas monitor was carried around the noticeably wetter areas under the shade at a height of less than 50 cm. The readings obtained during this period were typically in the range of 20 to 30 ppm. Undertaking the same measurements in the neighbouring unshaded where the pen surface was noted as being considerably drier the measurements varied between 10 and 20 ppm. It should also be noted that readings recorded in wet areas of the unshaded pens (ie. around water troughs) showed notably higher reading similar to those recorded under the shade. In both pens, peak readings of 60 to 70 ppm were periodically obtained by placing the sensor at a height of less than 10 cm over noticeably wet manure surfaces. These measurements provide some indication of the effect that moisture content has on ammonia generation rates, but the brevity of the data does not allow any strong relations to be determined.

Further data on ammonia levels are shown in Figure 9 and Figure 10. These data show the ammonia levels recorded in the unshaded pen at Feedlot A during two separate site visits. Figure 10 shows ammonia data that was collected in the shaded pen at Feedlot B on two separate occasions. It is not possible to compare these measurements purely on the basis of shaded and unshaded pens due to the different feedlot locations and also the significant time periods between measurements.

What is clearly shown by these measurements is a similar trend in the ammonia concentrations where levels rapidly increase at the start of the day as the pen surface is warmed, and then stay relatively constant during the middle of the day, and finally decrease as the temperatures drop. This demonstrates the strong relationship between ammonia generation rates and temperature.

The VRAE gas monitor was located on top of the station logger housing at a height of approximately 1.2 metres for all these ammonia measurements presented in these figures.

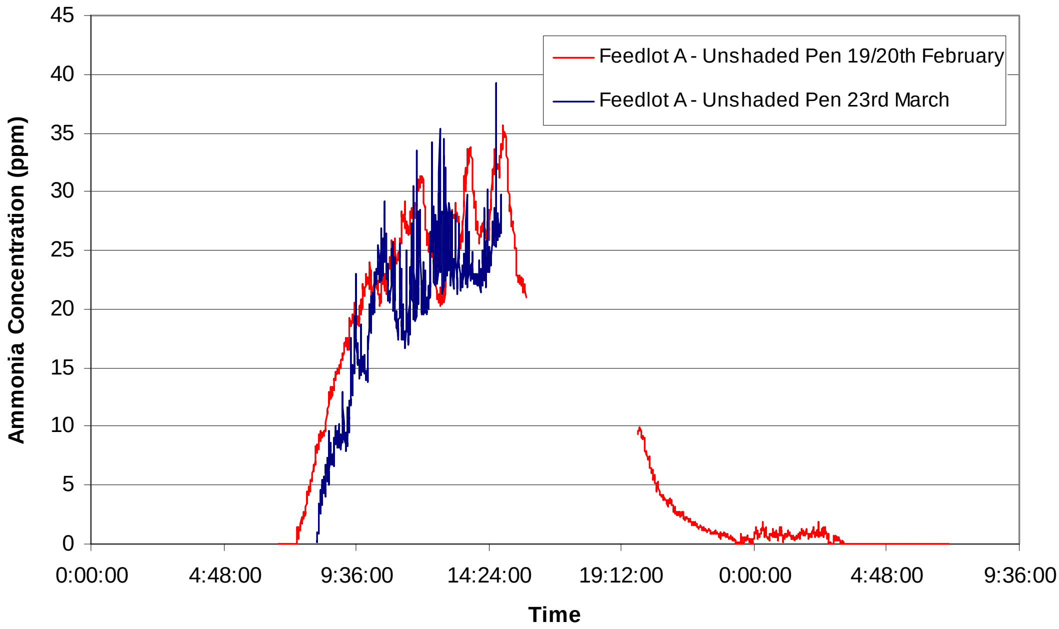

Figure 9. The variation of ammonia concentrations over time in the unshaded pen at Feedlot A.

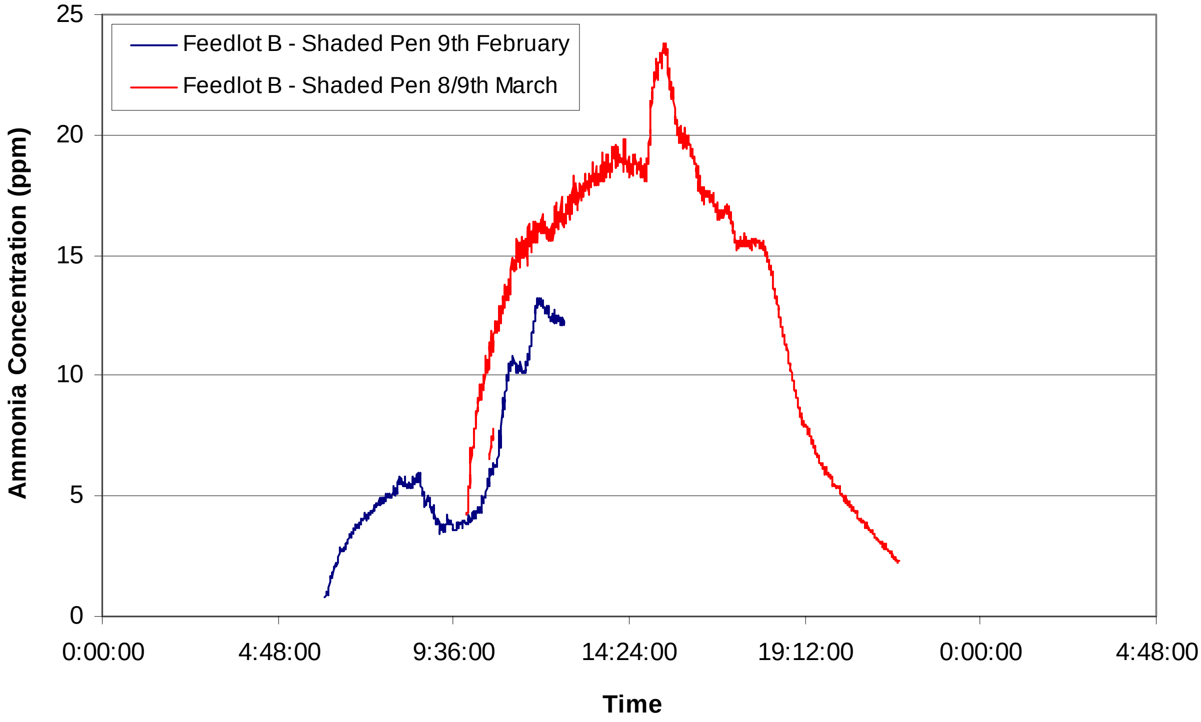

Figure 10. The variation of ammonia concentrations over time in the shaded pen at Feedlot B.

During the decommissioning of field equipment at Feedlot B in early May 2001 both hand held gas monitors were positioned in the shaded pen at two separate heights. The VRAE monitor was positioned at a height of approximately 1.5 metres and the MultiRAE monitor was set at a height of 0.3 metres. Both monitors were left to collect data for approximately an 8 hour period from around 0940 to 1720 hours. During this period each monitor automatically logged ammonia readings every 10 seconds. The recorded ammonia concentrations are presented graphically in Figure 11 below.

It is important to note that during the decommissioning of equipment at Feedlot B the shade in the feedlot pens had been removed, and as such at the time of these measurements the shaded pen did not actually contain any shade cloth. Notwithstanding this, it was noted that the pen still retained the wetted area beneath the shade. Therefore these data can be considered to be a comparison of ammonia emissions from two different levels in a moist unshaded pen at a time of cooler temperatures.

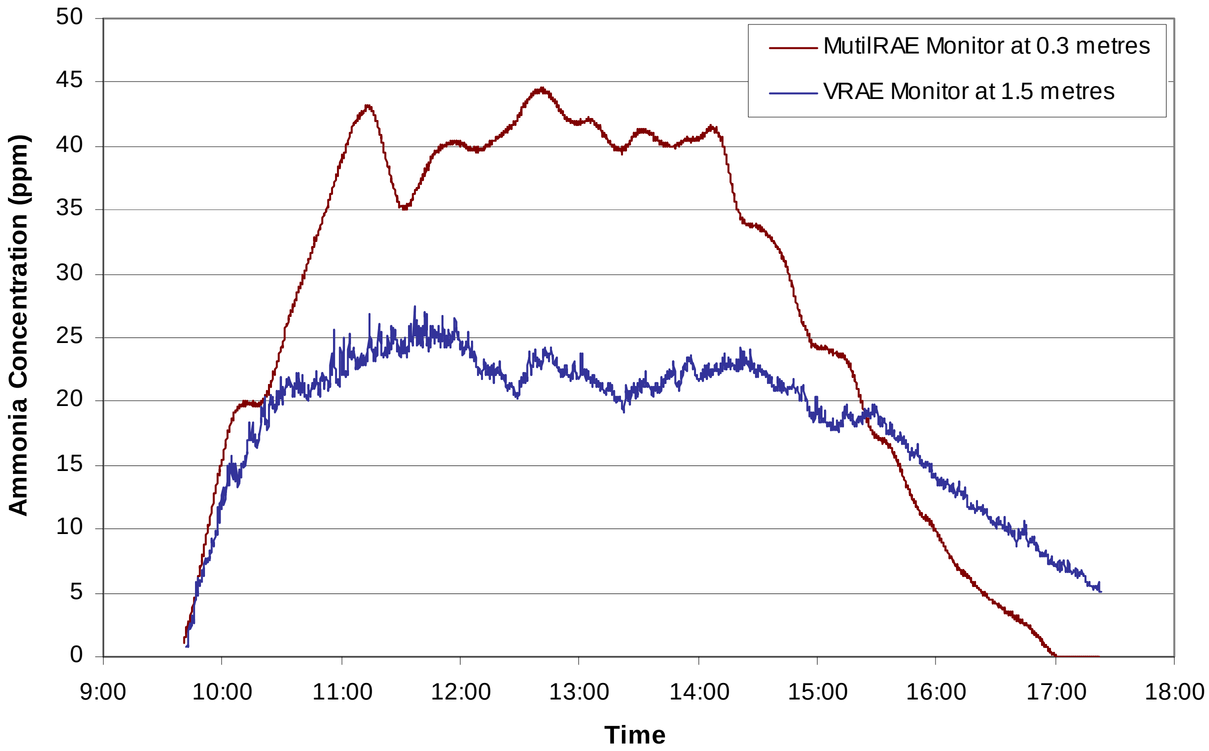

Figure 11. Ammonia concentrations recorded in the shaded pen (with shade removed) at Feedlot B.

The above figure highlights the significant variation in ammonia concentrations related to height above the manure surface. The data show that at a height of 1.5 metres the concentration of ammonia is significantly less than the levels recorded at 0.3 metres above the pen surface. The peak reading at the lower height was 44.6 ppm, whilst at 1.5 metres the peak ammonia concentration was 27.4 ppm. The ammonia concentrations measured at both heights followed the same diurnal trend previously recorded.

The data show that the short term readings of the VRAE monitor tend to fluctuate more than those of the MultiRAE. This is due to the fact the VRAE has an internal sampling pump (operating at 400 cc/min) that actively pulls air into the monitor. The MultiRAE has no internal pump and obtains readings through diffusion of air across the sensors. As such the VRAE is more sensitive to rapid variations in gas concentrations. Both monitors were calibrated and despite differences in sensitivity they have provided data useful for these assessments.

4.4 Pen Surface Measurements

Lott (1998) defines various pen manure states. The manure in the feedlot pens can generally be described as being 'dry loose' in exposed areas and 'moist compact' or partially pugged in nature in the vicinity around and underneath pen shade structures. However, following significant amounts of rain the manure profile was wet and it consequently softened, expanded and became pugged.

The analysis of the manure samples collected during the study periods allowed the condition of individual pen surfaces to be tracked over time. These samples were analysed by Lanfax

Laboratories, Armidale in order to accurately determine their moisture content. From this data and also the sample depths recorded by the feedlot staff the bulk densities of the samples were calculated. On examination of the bulk density values many anomalies were noted and as such it was decided not to use the manure depth data. The most probable reason for the anomalies in the bulk density data would be related to inaccurate values of sample depth being recorded. It may be possible that the bulking of manure samples also introduced some variations from the true bulk density values.

Figure 12 and Figure 13 present data on the changes in manure moisture content through time for each feedlot. Also shown in these figures are daily rainfall values for the study period. Sudden changes in moisture content can be noted in conjunction with significant rainfall events. These data show that the moisture content of the shaded pen areas increased at a more rapid rate than those of the unshaded areas. This is primarily due to congregation of cattle within the shaded areas, which sees a greater amount of faeces and urine applied to the areas under shade. The presence of shade has also reduced the drying of these areas.

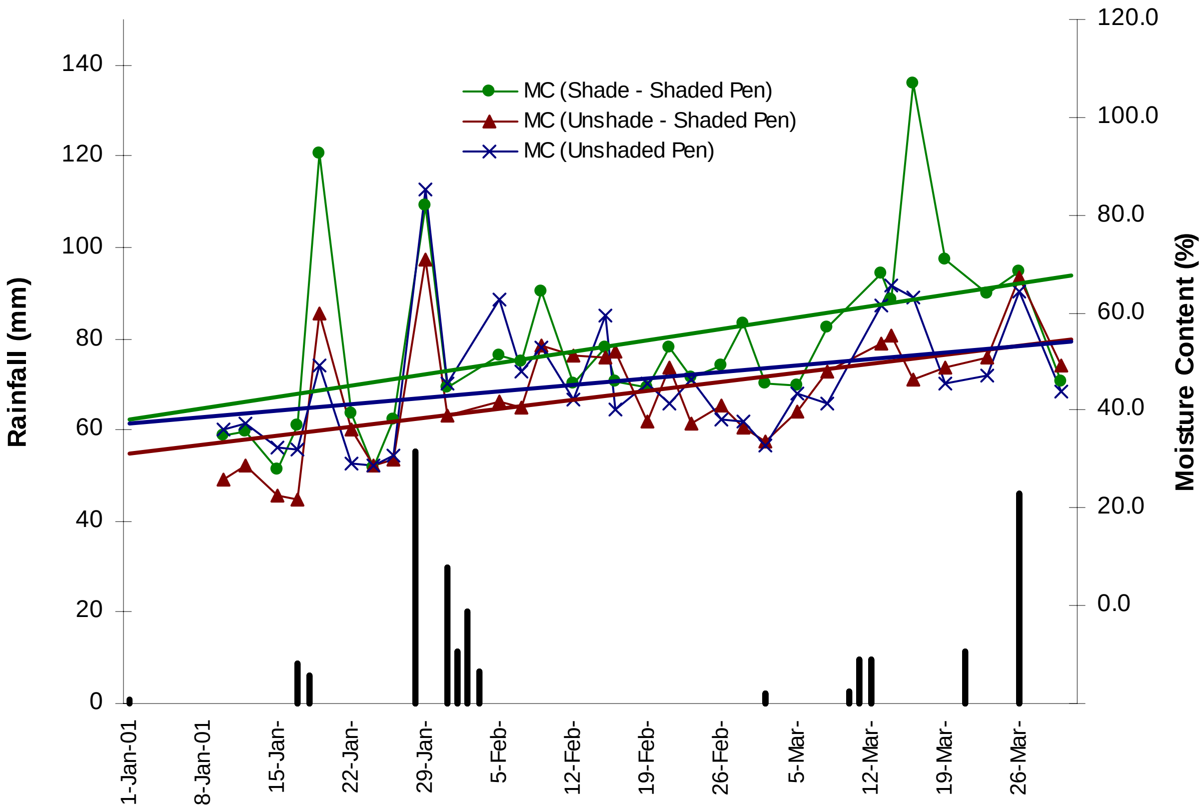

Figure 12. Comparison of Pen Moisture Content and Rainfall at Feedlot A.

Manure moisture content increased with manure accumulation. As manure accumulation increased so did the depth of the manure pack. These data indicate that the gross amount of water stored in the pens increased significantly with time. This manure pack is able to adsorb and store a lot of energy which is emitted as long wave radiation.

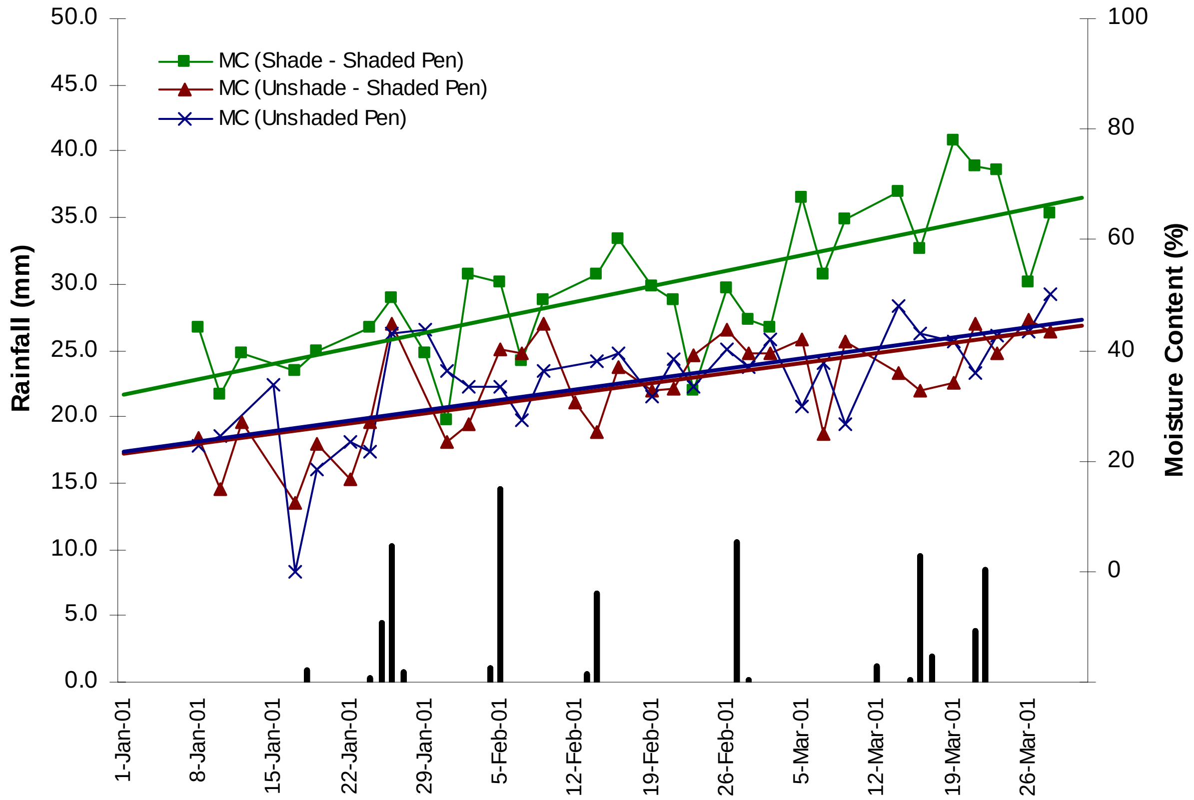

Figure 13. Comparison of Pen Moisture Content and Rainfall at Feedlot B.

4.5 Cattle Measurements

Section 3.7 describes the types of cattle measurements collected. Analysis of the data recorded by feedlot staff enabled periods of cattle stress at each feedlot site to be identified. Table 15 and Table 16 detail the key dates that were identified as cattle stress periods and also outlines the antecedent conditions of these periods.

Although the recording of cattle comfort measurements relating to their behaviour was largely successful, the type of observations recorded made it difficult to place an exact numerical value on the quantity of stressed cattle. This was because of difficulties in determining whether the same individual stressed animal was recorded as having both fast and shallow breathing, or if in fact these were two separate individual animals, both of which were stressed. It was however possible to estimate a qualitative value for each stress period that was identified. This was done by classifying the periods when cattle appeared stressed as either slight, moderate, or severe. The classification was based on the following criteria:

- Slight: 5 to 30% of total cattle within pen stressed;
- Moderate: 30 to 60% stressed;
- Severe: greater than 60% stressed.

At both feedlots these values were based largely upon the data obtained from the unshaded pens during the afternoon measurement period, as it was these times when the majority of stressed cattle were identified. Consideration was also placed upon the shaded pens and the morning observation values.

Although not shown by the cattle observations made by feedlot staff, a severe stress event that was observed by Dr Lott and Mr Petrov on 8 February was included in these results. During this event cattle were noted as being in a ‘comatosed’ state, and were observed to be breathing at a rapid rate with open mouths and increased slobbering. The data collected throughout the study indicate that in several cases the mid-afternoon observations were undertaken too early to detect stress events that became clearly evident between the hours of 4 to 6 pm. “Stress” escalated during these times, as it was common to experience the maximum temperatures between these hours. As such it is recommended that future cattle measurements for the purpose of heat stress studies be targeted over the critical afternoon period.

The summary of stress events presented in the tables below include values for the maximum and minimum temperatures, maximum humidity, maximum incoming solar radiation and wind speed as these elements were considered the most significant contributors to cattle stress. The values included in the table were obtained from the data recorded in the unshaded pen at each feedlot. Any rainfall events within the preceding 5 days are also presented in these tables, as it appears that this is a common factor in many of the stress events.

Selected ‘stress events’ noted in the tables presented below have been examined in detail. This involved study of the recorded climatic data in the period leading up to and during the event. The purpose of these investigations was to identify key climatic elements that appear to have the most influence on cattle discomfort. The analysis and interpretation of several key events recorded at each feedlot site is presented in section 5.2.

Examination of the feed data provided by the feedlots has shown that during stress events there appears to be a generally lower and more erratic feed intake. However without further and more detailed analysis of the feed data, no conclusive relationships were noted that would greatly assist in the prediction of stress events.

Table 15. Summary of Stress Events for Feedlot A (January to February).

Date	Severity of Cattle Stress	Rainfall (mm) in Preceding 5 Days					Accumulative Radiation Prior to Event (W/m^2)					Max. Temp. (°C)	Min. Temp. (°C)	Max. Humidity (%)	Max. Incoming Solar Radiation (W/m^2)	Mean 2m Wind Speed (km/hr)
		5 days prior	4 days prior	3 days prior	2 days prior	1 day prior	5 days prior	4 days prior	3 days prior	2 days prior	Event Day					
26-Jan-01	Slight	0.1					8273	16481	25202	34291	39980	35.4	20.2	83.3	1103.9	5.4
27-Jan-01	Moderate						8208	16930	26019	31707	39661	38.5	23.4	72.2	1228.5	9.7
28-Jan-01	Slight						8722	17811	23499	31453	38453	34.4	20.7	94.4	1195.7	7.8
30-Jan-01	Moderate				55.2		5688	13642	20643	26366	31697	30.8	21.0	89.2	865.1	7.9
5-Feb-01	Slight	29.8	11.6	20.3	7		3260	6258	11449	19018	27754	28.7	17.7	93.0	1403.3	7.8
6-Feb-01	Slight	11.6	20.3	7			2997	8188	15757	24493	32565	28.1	17.1	93.8	1233.6	10.2
11-Feb-01	Slight						6655	12435	19233	27868	35629	30.4	17.2	88.8	1111.4	6.8
12-Feb-01	Severe						2613	9462	16567	20798	25733	30.6	17.8	86.9	1148.9	9.9
14-Feb-01	Slight						8635	16397	23309	31254	39813	30.6	17.6	89.9	1113.4	9.1
15-Feb-01	Moderate						7761	14674	22619	31178	39587	31.8	17.8	90.5	1101.6	7.8
25-Feb-01	Slight						5590	14080	22184	30317	38334	34.1	18.0	87.4	1080.6	6.1
27-Feb-01	Moderate						8104	16237	24254	32003	39715	36.6	18.2	70.8	1037	6.5

Table 16. Summary of Stress Events for Feedlot A (March).

Date	Severity of Cattle Stress	Rainfall (mm) in Preceding 5 Days					Accumulative Radiation Prior to Event (W/m^2)					Max. Temp. (°C)	Min. Temp. (°C)	Max. Humidity (%)	Max. Incoming Solar Radiation (W/m^2)	Mean 2m Wind Speed (km/hr)
		5 days prior	4 days prior	3 days prior	2 days prior	1 day prior	5 days prior	4 days prior	3 days prior	2 days prior	Event Day					
12-Mar-01	Severe				2.7	9.8	4587	7639	12749	17935	22986	31.4	20.5	89.8	1144.3	7.1
13-Mar-01	Slight			2.7	9.8	9.9	3052	8162	13348	18399	25468	31.8	18.9	96.5	998.3	5.5
15-Mar-01	Slight	2.7	9.8	9.9	0.1		5186	10237	17306	22790	29275	27.5	16.0	89.0	996.3	8.0
16-Mar-01	Moderate	9.8	9.9	0.1			5051	12120	17603	24088	31158	28.3	14.7	92.0	1159.2	7.9
17-Mar-01	Moderate	9.9	0.1				7069	12552	19038	26108	32740	31.2	17.9	88.8	1117.9	6.2
18-Mar-01	Moderate	0.1					5483	11969	19039	25671	30658	31.0	19.1	88.3	967.9	8.5
19-Mar-01	Severe						6485	13555	20187	25174	31660	31.9	14.5	77.8	1113.5	4.3
20-Mar-01	Severe					0.2	7070	13702	18689	25175	30365	30.6	18.6	87.5	958.1	7.6
23-Mar-01	Moderate		0.2		11.6		6486	11676	14289	21138	28239	30.0	13.0	85.3	991.3	3.6
25-Mar-01	Severe		11.6				2613	9462	16562	20798	25733	32.9	20.7	87.8	1134.5	5.9
27-Mar-01	Moderate					46.2	7101	11336	16271	19838	26117	29.0	18.9	87.9	916.9	4.7
28-Mar-01	Moderate				46.2	0.1	4236	9171	12737	19017	24274	29.8	19.0	92.2	1037.3	6.1

Table 17. Summary of Stress Events for Feedlot B.

Date	Severity of Cattle Stress	Rainfall (mm) in Preceding 5 Days					Accumulative Radiation Prior to Event (W/m^2)					Max. Temp. (°C)	Min. Temp. (°C)	Max. Humidity (%)	Max. Incoming Solar Radiation (W/m^2)	Mean 2m Wind Speed (km/hr)
		5 days prior	4 days prior	3 days prior	2 days prior	1 day prior	5 days prior	4 days prior	3 days prior	2 days prior	Event Day					
20-Jan-01	Moderate				0.9		7656	16899	23831	32864	41866	32.9	20.2	54.6	1167.6	7.9
3-Feb-01	Slight						8230	15719	24773	33656	40743	35.8	21.4	62.4	1233.8	10.0
4-Feb-01	Severe						7489	16543	25426	32513	37222	34.1	24.9	79.9	1000.5	7.0
7-Feb-01	Slight			1.1	14.6	0.1	7087	11795	14884	21593	29771	21.8	19.4	76.5	1163.0	17.6
9-Feb-01	Severe	1.1	14.6	0.1			3089	9798	17976	25908	30493	36.5	25.2	71.2	1220.6	7.5
18-Feb-01	Moderate	0.6	6.8	0.1	0.1		1879	10641	19360	27995	36815	30.3	17.2	65.9	1166.8	7.3
20-Feb-01	Moderate	0.1	0.1				8719	17354	26174	34826	43460	30.8	17.7	64.2	1161.1	8.6
21-Feb-01	Moderate	0.1					8635	17455	26107	34742	43103	31.2	17.8	67.4	1193.8	8.1
3-Mar-01	Severe		10.6	0.2			5995	14069	22064	30217	37603	31.7	18.2	71.5	1203.3	7.6

5. DISCUSSION

5.1 Microclimate Variation

In the following sections the climatic variations that occur due to the inclusion of shade within a feedlot pen are discussed. The significant differences in the micrometeorology of feedlot pens and the surrounding environment are also outlined.

5.1.1 Air Temperature

Comparison of the air temperature data recorded in the shaded pen with that of both the unshaded and outside stations show that there were only minor variations in the average daily air temperatures. However closer investigation of the collected daily data highlighted a significant variation in the climatic conditions outside the feedlot area and that recorded in the feedlot pens. It was found that there was a significant difference between the minimum overnight temperatures recorded within the feedlot pens compared to the values obtained from the external feedlot stations. A comparison of minimum temperatures recorded in the shaded and unshaded pen, and the average values from outside the feedlot show that within the feedlot, temperatures remain higher over night. These data are presented in Figure 14 for Feedlot A and Figure 15 for Feedlot B.

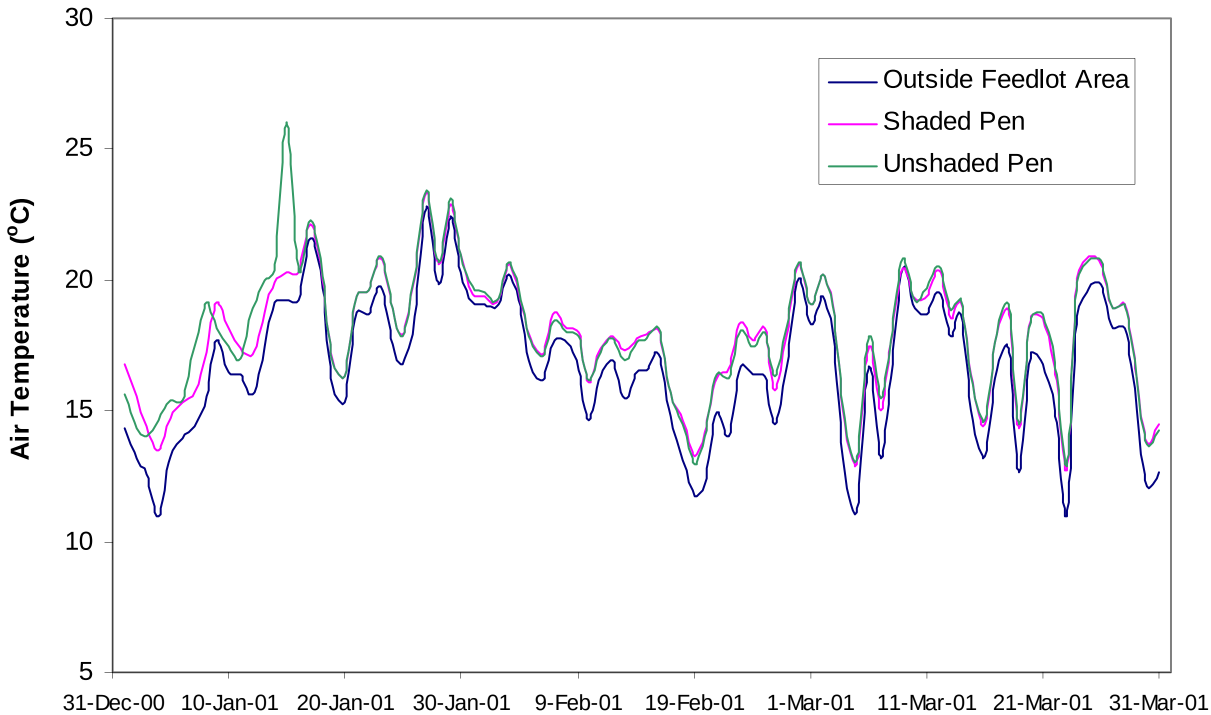

Figure 14. Daily Minimum Air Temperatures Recorded at Feedlot A.

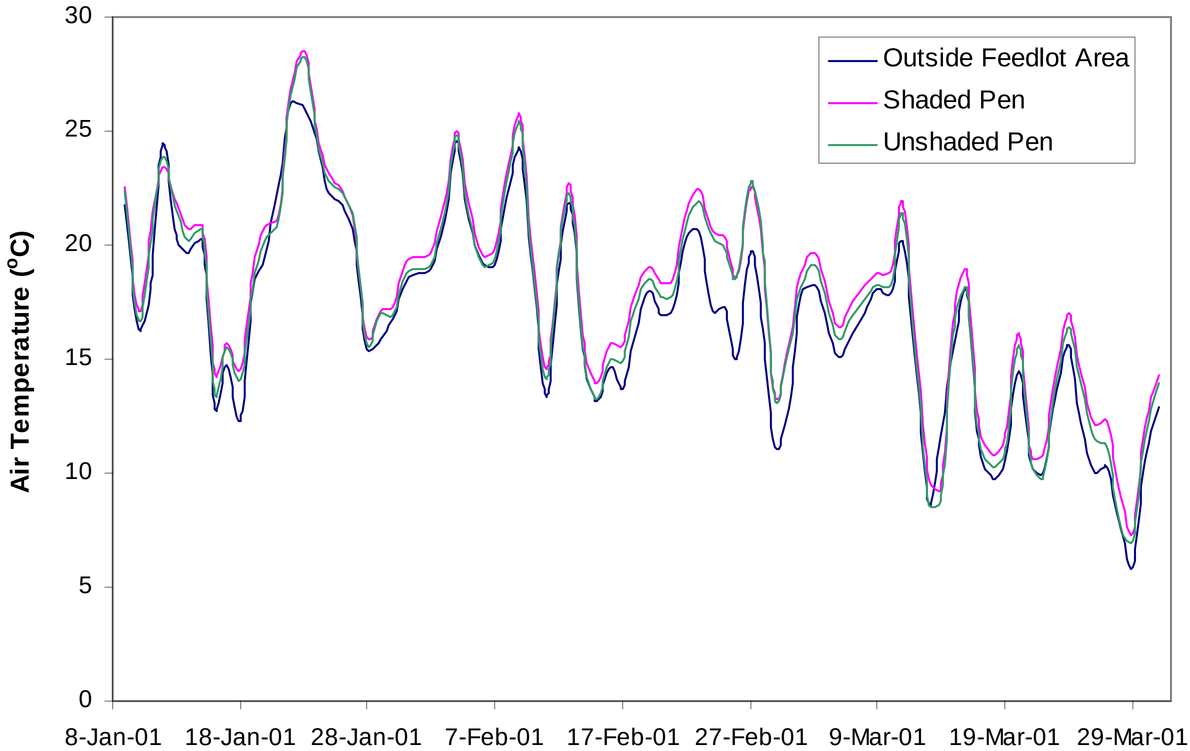

Figure 15. Daily Minimum Air Temperatures Recorded at Feedlot B.

The above figures show a clear difference in the minimum temperatures recorded outside the feedlot compared to those recorded within the pens. Averaging this daily data to compare monthly averages shows that over the three month study period the difference in minimum temperatures between the external an internal feedlot environment averaged around 1.2°C and 0.9°C for Feedlot A and Feedlot B respectively. These monthly average data are presented in Table 18 and 0 below.

Table 18. Comparison of Minimum Temperatures Recorded in the Feedlot Pens and outside the Feedlot - Feedlot A.

	Average Monthly Minimum Temperature (°C)			
	External Feedlot Area	Within Shaded Pen	Within Unshaded Pen	Mean Difference between Internal and External Feedlot Environment
January	17.3	18.5	18.9	1.4
February	16.3	17.5	17.4	1.1
March	16.4	17.6	17.7	1.2

Table 19. Comparison of Minimum Temperatures Recorded in the Feedlot Pens and outside the Feedlot - Feedlot B.

	Average Monthly Minimum Temperature (°C)			
	External Feedlot Area	**Within Shaded Pen**	**Within Unshaded Pen**	**Mean Difference between Internal and External Feedlot Environment**
January	19.5	20.4	20.1	0.7
February	18.3	19.7	19.3	1.2
March	13.4	14.6	14.0	0.9

The higher overnight temperatures recorded within the feedlot pens can be attributed to the nature of the pen surfaces and the higher humidity levels found in pen areas. The pen surface is primarily composed of manure which is generally dark and moist and has a greater ability to store heat compared to soil. As such the feedlot surface can store a greater amount of heat energy during the day (provided by solar radiation and ambient temperatures) compared to that of the ground surface outside the feedlot area. During the cooler night time periods this 'heat bank' releases its heat energy and as a result it assists in reheating air over the surface and thus maintenance of generally higher air temperatures. This phenomenon can contribute to heat stress in cattle as the higher overnight temperatures can reduce an animal's capacity to shed accumulated heat load. This is discussed in more detail in section 5.3.

5.1.2 Humidity

A significant difference was noted in humidity levels in the shaded pens at both feedlot sites compared to the levels recorded in the unshaded pen and the external stations. Comparing the average monthly data for these stations shows the humidity levels under the shade in the shaded pens were typically 8 to 9% higher at Feedlot A and 4 to 6% higher at Feedlot B. The different types of shade structures used at each feedlot site could account for the variation between feedlots. The shade cloth used at Feedlot B permits some radiation through (and thus drying of manure) and allows increased air movement through the actual shade material compared to the galvanised iron installed at Feedlot A.

5.1.3 Soil Temperature

Soil temperatures recorded in the shaded pens were lower than those of the unshaded pen and outside areas. This is due to a reduction in the amount of direct sunlight (ie. solar radiation and heat energy) that reaches the pen surface with the presence of shade structures. Of particular interest is the dramatic difference between these variations when feedlot sites are compared. The average soil temperature in the shaded pen at Feedlot A was on average 5 °C lower than the soil temperatures recorded at the five other feedlot stations. At Feedlot B this difference was found to be closer to 14 °C. Several factors could contribute to this 9 °C difference between feedlot sites. The generally lower pen surface temperatures at Feedlot B could be caused by a number of reasons. These may include the fact that the geographical location of Feedlot B is further south, or the soil temperature sensor may have been located closer to the pad surface, or the cloth shade structures may be more effective in ensuring cooler pen surface conditions than the galvanised iron structures at Feedlot A (which may re-radiate more heat downwards). Without undertaking further investigations it is not possible to isolate the primary reason for the anomaly at this stage however it is likely to be a combination of the reasons mentioned above.

5.1.4 Solar Radiation (Incoming and Outgoing)

As is expected, the presence of shade structures significantly reduces the amount of incoming solar radiation. This in turn reduces the amount of solar radiation that is reflected from the pen surface (referred to as outgoing radiation). Another significant factor that effects the level of outgoing radiation is the condition and type of ground surface. Figure 16 and Figure 17 show the values of incoming and outgoing solar radiation recorded in the shaded and unshaded pens and from the external feedlot area. These figures present the data recorded during the daylight hours of a randomly selected day for each feedlot site. It should be noted that the data for the randomly selected days were visually inspected to ensure that there were no atypical variations.

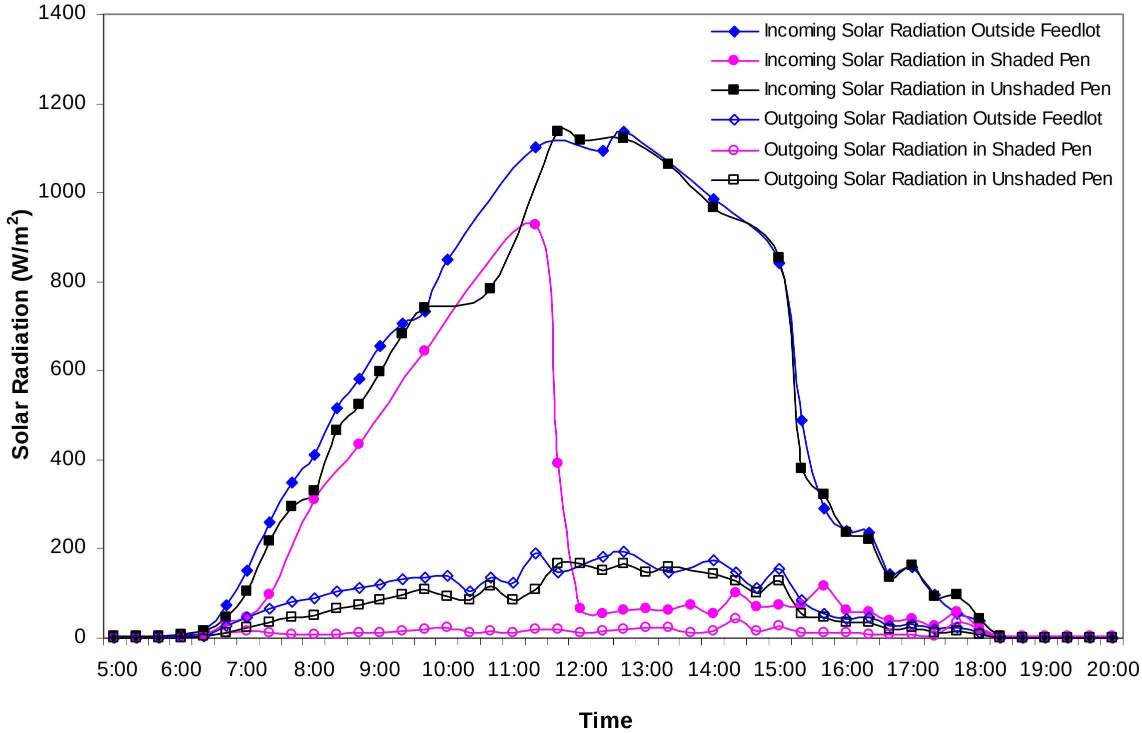

Figure 16. Variations of Incoming and Outgoing Radiation Recorded on the 17/3/01 in the Shaded Pen, Unshaded Pen, and External Stations at Feedlot A.

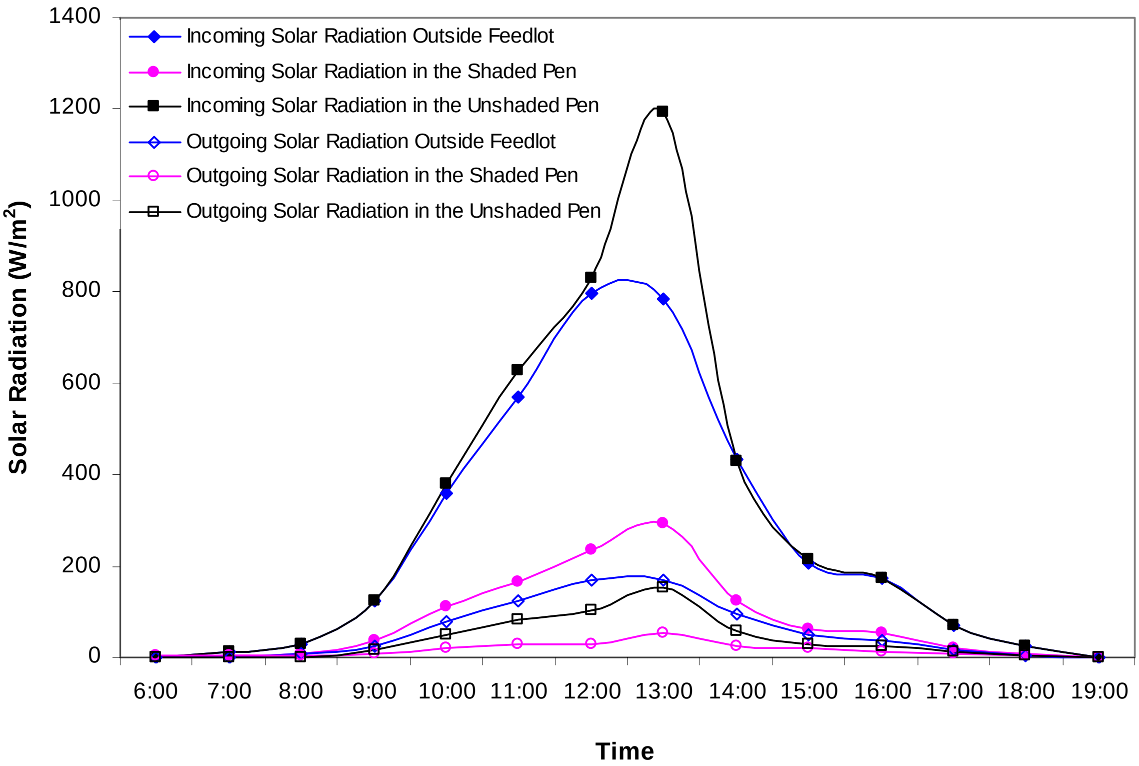

Figure 17. Variations of Incoming and Outgoing Radiation Recorded on the 24/3/01 in the Shaded Pen, Unshaded Pen, and External Stations at Feedlot B.

The data provided in the above figures highlight several important points in relation to variation in solar radiation levels. Firstly, comparing the incoming solar radiation levels measured in the shaded pens at each feedlot illustrates the individual characteristics of the different shade structures. The data in Figure 16 show that at the weather station located under the galvanised iron structures, effective shade is only provide from around 1100 hours. Prior to this time the solar radiation levels closely follow the increasing trends of the unshaded and external stations. This occurs because direct sunlight is either passing under the edge of the shade or through a gap in the shade structure. Once the sunlight is blocked out by the galvanised iron, the solar radiation levels are dramatically reduced.

By comparison, the shade cloth at Feedlot B consistently reduces the incoming solar radiation by approximately the same factor throughout the entire day. This can be seen in Figure 17 where the incoming solar radiation recorded at all three locations are observed to be following the same trends throughout the day. The total reduction in solar radiation is not as significant as that provided by the galvanised iron due to the translucent nature of shade cloth.

Using the average monthly data presented in Table 13 and Table 14 of section 4.2 the approximate effectiveness of each shade structure can be determined. This is calculated by comparing the incoming solar radiation levels of the external and unshaded station to the incoming solar radiation of the shaded station. The difference in recorded values can be assumed to be the amount of solar radiation that is adsorbed or reflected by the shade structures. Expressing these values as a solar radiation reduction percentage enables a simple comparison of the effects of the different shade structures. These data are presented in Table 20 below.

Table 20. Comparison of Monthly Average Incoming Solar Radiation Levels (in W/m^2) and Approximate Shade Reduction Percentages.

Incoming Solar Radiation (W/m^2)	**Feedlot A - Unshaded Pen**			**Feedlot B - Unshaded Pen**		
	January	**February**	**March**	**January**	**February**	**March**
	300.0	288.7	235.6	329.3	299.4	267.5
Shaded Pen	71.0	76.0	51.7	101.7	85.6	76.1
% Reduction	76%	74%	78%	70%	71%	72%

The data presented above show that over the trial period both shade structures provided similar reduction in solar radiation values. The calculated average reduction in solar radiation caused by the galvanised iron shade structures at Feedlot A was slightly higher at around 76% compared to the calculated values of around 71% for the shade cloth at Feedlot B. It should be noted that these calculated values are only crude indications of shade structure effectiveness. They have only been used to provide a general comparison between the effects of the two different shade structures at each feedlot site.

The outgoing radiation measurements recorded by the weather stations can be used to determine the 'albedo' of the feedlot pen and external ground surfaces. Albedo is a number between 0 to 1 that indicates the proportion of energy reflected off a surface. For example an albedo value of 0.25 indicates that 25% of incoming solar radiation is reflected and 75% would be absorbed by the surface. Using the average monthly solar radiation values the albedo of the feedlot pen surfaces and the external feedlot surface can be calculated. These data are presented in Table 21 and Table 22 below.

Table 21. Average Monthly Solar Radiation Data and Calculated Albedo Values – Feedlot A.

	January			***February***			***March***		
	External	**Shaded Pen**	**Unshaded Pen**	**External**	**Shaded Pen**	**Unshaded Pen**	**External**	**Shaded Pen**	**Unshaded Pen**
Incoming Solar Radiation (W/m^2)	320.2	71.0	300.0	315.6	76.0	288.7	245.2	51.7	235.6
Outgoing Solar Radiation (W/m^2)	49.5	9.3	44.0	63.0	10.8	37.7	48.0	9.4	31.4
Albedo	0.15	0.13	0.15	0.20	0.14	0.13	0.20	0.18	0.13

Table 22. Average Monthly Solar Radiation Data and Calculated Albedo Values – Feedlot B.

	January			*February*			*March*		
	External	**Shaded Pen**	**Unshaded Pen**	**External**	**Shaded Pen**	**Unshaded Pen**	**External**	**Shaded Pen**	**Unshaded Pen**
Incoming Solar Radiation (W/m^2)	372.1	101.7	329.3	281.3	85.6	299.4	243.7	76.1	267.5
Outgoing Solar Radiation (W/m^2)	94.1	23.5	55.8	67.3	18.5	46.6	58.2	20.6	44.8
Albedo	0.25	0.23	0.17	0.24	0.22	0.16	0.24	0.27	0.17

The data presented are consistent with those recorded by Lott (1998) for albedo's of wet and dry manure surfaces. It should be noted that the albedo values for the shaded pens are based on a proportion of the incoming radiation that has already passed through the shade, which is generally only 20 to 30% of the global incoming values used to calculate the albedo of the unshaded pens. This difference may incur some deviation for the true albedo values of the open surface. Also the re-radiation of energy from beneath the shade structures could influence the calculated albedo values.

5.1.5 Black Globe Temperature

Black globe temperature is an integrated measure of radiant heating. It is best described as a combined measure of temperature and the heat effects of solar radiation (or radiant heat load). Black globe temperature readings are strongly influenced by solar radiation and as expected the measurements undertaken during the study show that the black globe temperatures were lower in the shaded pens compared to the unshaded pens and external feedlot environment. The average monthly data presented in Table 13 and Table 14 do not fully depict the variation in black globe temperatures that were experienced in the shaded pens compared to the unshaded and external stations. The reason for this is that the monthly data presented in these tables are averaged over full 24 hour periods. The radiant heat contributed by solar radiation significantly increases black globe readings to temperatures well over those recorded by air temperature sensors. However during the night when solar radiation levels are zero, there is little to no difference between the ambient air temperature and the black globe temperature.

5.1.6 Wind Speed and Direction

Only minor trends were observed between the recorded wind measurements at each weather station. The most noticeable difference was that the shade structures at Feedlot A reduced the 2 metre wind speeds in comparison to the measurements for the unshaded pen. This reduction may be attributed to higher stocking densities that occur with the congregation of cattle under the shade structure. No significant variations were noted in the wind speed measurements in the shaded pen at Feedlot B. It is noted that the 2 metre wind speeds were generally lower outside the feedlot area compared to those recorded in the pens at Feedlot B. This could be due to the stubble and grass cover outside of the feedlot and also the relatively closer proximity of the external stations to trees. Wind direction readings recorded at the external and internal weather stations showed no obvious variations as a result of the feedlot area or shade structures.

5.2 Analysis of Cattle Stress Events

The following A3 pages present figures that show the time series data for two severe 'stress' events. One of the events presented was observed at Feedlot A and the other was observed at Feedlot B. Each graph spans a period of several days to allow the climatic variations to be investigated over the days proceeding and following the event. The graphs present data for:

- Ambient air temperature;
- Relative humidity;
- Black globe temperature;
- Wind speed (2 and 10 m);
- Solar radiation in/out;
- Numbers of stressed cattle at 2 pm; and,
- Rainfall.

The details of each event are described in the following sections.

5.2.1 Stress Events at Feedlot A (23/25 March, 2001)

Key features of these data are:

- Rainfall on 21 March (11.6 mm);
- Increased humidity levels as a result of the rainfall;
- Some suppression of ambient air temperature at the time of rainfall;
- A dramatic increase from cool overnight temperatures to maximum day temperatures on the 23 March;
- An increase of radiation, daytime maximum and night time air temperatures from the rainfall event until the time of the event. Rainfall on the 26 March decreased these factors following the event;
- Low wind speeds prior to the event on the 23 March;
- High black globe temperatures on the day of both events.

5.2.2 Stress Events at Feedlot B (7/8 February, 2001)

Key features of the plot of the data are:

- Rainfall on the 5 February (14.6 mm);
- Increased humidity levels as a result of the rainfall;

- Some suppression of ambient air temperature at the time of rainfall;
- A step-wise increase in radiation, daytime maximum and night time air temperatures upward until the time of the event (4 to 8pm EST 8 February) and until a further weather change late on the 9 February;
- Extremely low wind speeds (recorded at both 2 and 10 metres) just prior to and at the time of the event;
- A few deaths occurred between 6 to 8 pm and at a time when the sun was setting (low radiation) but ambient air temperatures (ie. night time temperatures) remained above 25°C.

Mr. Ryan Petrov and Dr Simon Lott were present at Feedlot B over the period 6 to 9 February. A further 'stress' event (or continuation of the 8 February event) would have occurred on 9 February had a southerly change not lifted wind speeds and reduced temperatures at around 1700 hours on the 9th. At this time a significant number of cattle were stressed in the shaded and unshaded pens (approximately 25 and 60 respectively - determined by counts of heaving and slobbering stock by Dr Lott on foot). It is noted that while the counts for stressed cattle at 2 pm provided an indication of their condition over time (ie. on a daily basis) the number of stock stressed at Feedlot B increased between 2 pm and 5 pm. This is consistent with continued heat loading of animals. Time of cattle counts should be made later in the afternoon (or over the afternoon) should further heat stress studies be undertaken.

5.2.3 Common Features of Cattle Stress Events

Common features observed from the two severe 'stress' events that are presented include:

- Over 10 mm of rainfall two days prior to the stress events;
- Increased humidity levels as a result of the rainfall;
- Some suppression of ambient air temperature at the time of rainfall;
- A step-wise increase of radiation, daytime maximum and night time air temperatures from the rainfall event until the time of the event;
- Low wind speeds prior to and during the event;
- High black globe temperatures on the day of both events.

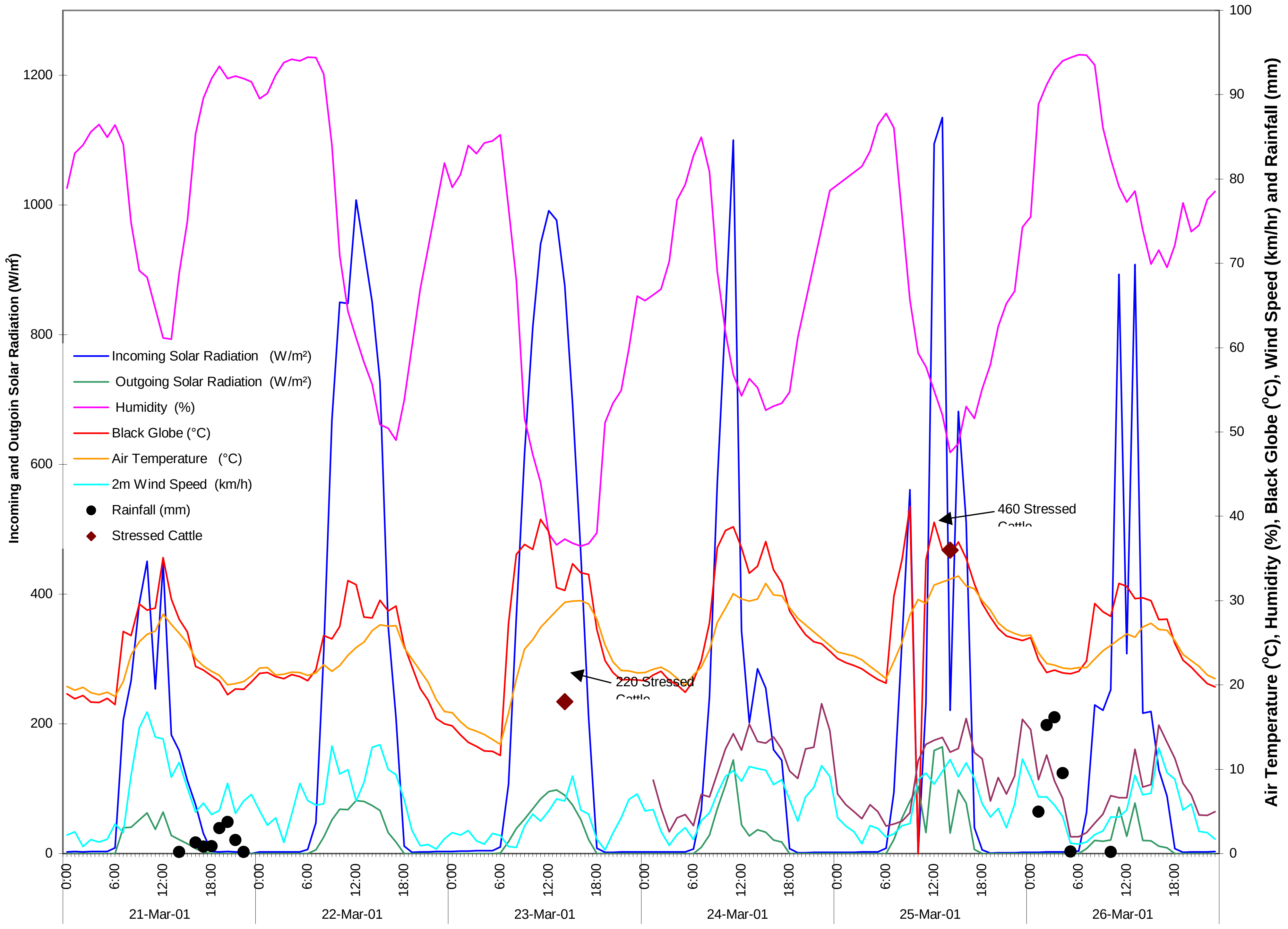

Figure 18. Event Data for Unshaded Pen 21/3/01 to 26/3/01 at Feedlot A.

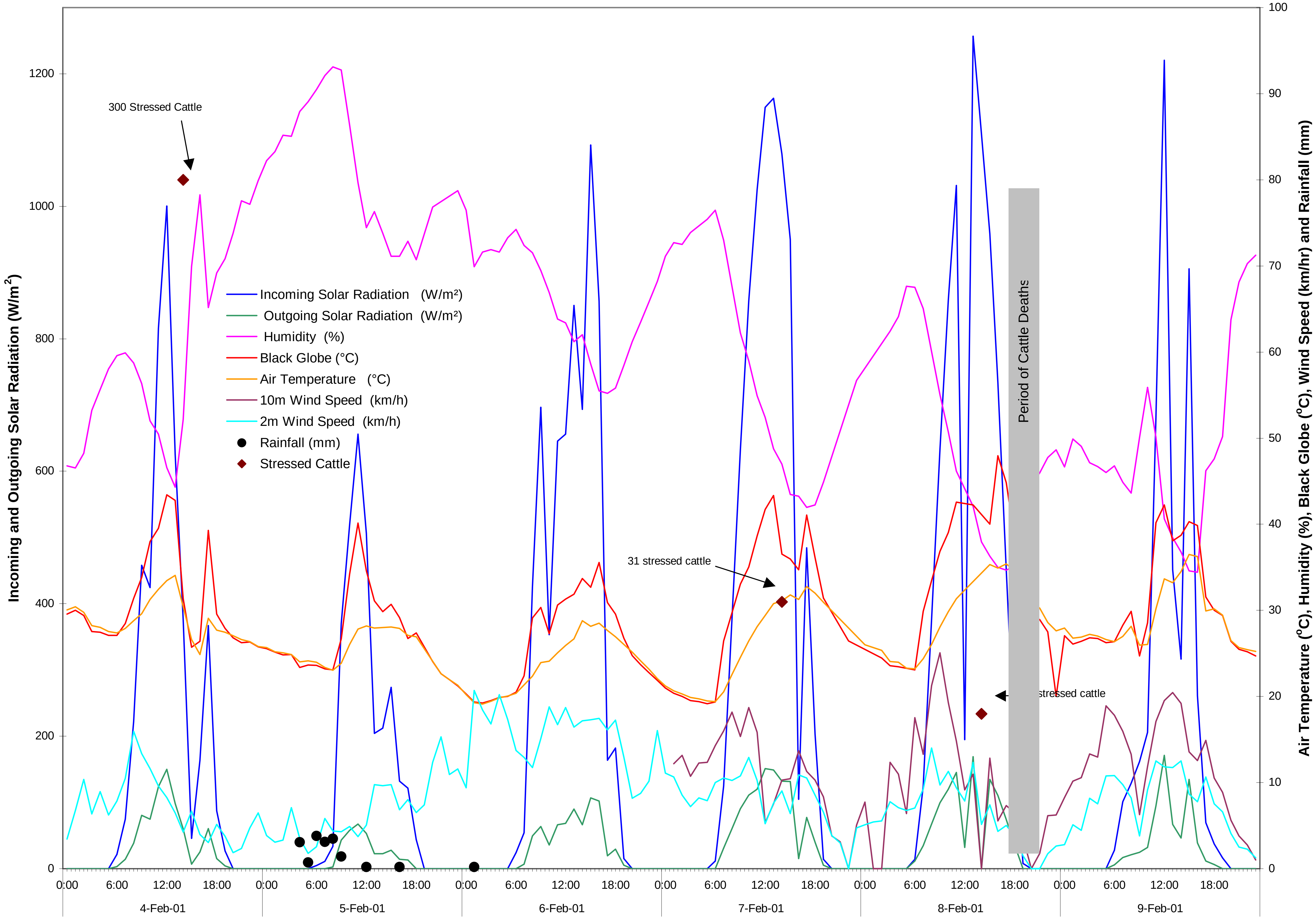

Figure 19. Event Data for Unshaded Pen 4/2/01 to 9/2/01 at Feedlot B.

5.3 Thermodynamics of Livestock

The laws of thermodynamics dictate that energy is passed from a heated mass to a cooler mass. This law governs many of the processes of energy transfer in an animal and between the animal and its environment. In the case of a heated solid, energy will be passed to the cooler air around it by conduction and convection.

Figure 20 presents a schematic drawing of the energy balance of a lot fed steer and some of the transfer systems described above. Key components of these energy transfer systems follow:

1. **Digestion and Metabolic Heat Production:** A mass of food is decomposed by microbes in the rumen resulting in exothermic reactions (ie. heat is released) and some heat is passed from the rumen fluid into the body. A 600 kg steer will consume between 10 to 15 kg of feed per day. On the assumption that 10 kg of feed is consumed this equates to a consumption of food with a gross energy content of 140 MJ (see p.8 Sparke, *et al.*, 2001). Based on these "typical" values of metabolic heat production (MH_p), Sparke *et al.* (2001) state that 1,200 W of heat is generated per day (104 MJ). This heat would be transferred from the animal body to the environment – so long as the air around the body and surfaces in which it is in contact with are cooler than its body temperature.

2. **Water Consumption:** A full grown bullock (~600 kg) will consume about 60 to 70 litres of water on a hot day (water consumption varies as a function of a range of variables including temperature, humidity, cattle size and type, water availability and presentation, and water temperature). If the water consumed is at 15°C then heat will be transferred from the body of the animal to the water. It takes 4.19 kJ to increase the temperature of 1 kg of water 1°C. Therefore to increase 60 L of water from 15°C to body temperature (39°C) it requires 6.03 MJ over a day. If the drinking water is 'hot' and has a temperature of 25°C, the amount of energy absorbed by the water as it is brought up to the animals body temperature is 3.5 MJ. While this heat sink is relatively small, the potential "cooling" effects of cold water at times of heat stress are likely to be profound. Therefore, it is important that feedlot water trough design and reticulation systems be designed to present cool water to livestock even under extremely hot conditions. An available supply of cool water is also required to assist in evaporative cooling (described below).

3. **Radiant Heating:** A body will become heated by radiation. In the case of solar radiation, the amount of energy incident on a surface (based on the days preceding the major stress event at Feedlot B on 8 February, 2001) is around 8,000 W/m^2. On the basis that the average planer area of a 600 kg bullock (ie. area perpendicular to the aspect of the sun) is 1.5 m^2 then the gross potential for heating is 12,000 W over each day of the two days preceding the stress event. Not all of this energy is transferred to the animal – a large amount is reflected. The proportion of energy reflected is determined by the albedo of the surface. A matt black surface may have an albedo of less than 0.1. That is, less than 10% of incoming solar radiation is reflected and 90% would be absorbed by the hair covering the hide. However, this hair acts as an insulative barrier over the animal that ensures that not all of the 1200 W of energy (based on an albedo of 0.1) is passed to the animal. This transfer of energy occurs by conduction.

4. **Evaporative Losses:** In the situation where the air of the surrounding environment is warmer then the core body temperature of an animal, then the animal must undergo one of two possibilities. Either it must allow heat storage in the body (ie. an increase in core body temperature); or it must utilise water to sustain evaporative cooling (Oke, 1987). The process of evaporative cooling becomes more important as temperatures increase. This is due to the fact that as the environmental temperatures rise closer to the core body temperature of an animal, non-evaporative heat losses are reduced due to the smaller temperature gradient between the animal and the environment. In fact, as detailed by Oke (1987), at very high temperatures (ie. in excess of an animals body temperature) evaporative cooling is the only means of heat loss. Notwithstanding this the loss of energy by natural mechanisms of evaporative cooling are relatively small compared to the overall energy balance.

As cattle have a limited ability to sweat, the main process of evaporative cooling is through their respiratory system (ie. by panting). The main sites of cooling in cattle is in the nasal sinuses, mouth and lungs. The evaporative cooling process involves an increase in the respiratory rate, which is easily identifiable in cattle through rapid, shallow breathing.

Having an inadequate water supply, or a water supply of high temperatures that will increase the heat load on cattle, will break down the evaporative cooling process. Likewise, if the humidity levels of the surrounding environment are high, then there is insufficient humidity gradient between the animal and the air to enable effective evaporative cooling. The use of sprinklers under hot conditions would increase humidity levels and as a result may limit the cattle's ability to dissipate energy by means of evaporative cooling (see section 6.4).

Conduction Heat/Energy Transfer: The transfer of the energy in heated hair/hide to the animal body occurs by conduction (or heat from the body to the hair at times when the body is hotter than the hair). The rate of conduction between the air and the body (the theorem for heat conduction) has been described by Sparke, *et al.* (2001). It is provided below:

$$K = -kA_k(T_1 - T_2)/L$$

where:
K = Non conductive heat flow
$-k$ = Thermal conductivity
A_k = Effective conductivity contact surface
T_1 = Temperature of body 1
T_2 = Temperature of body 2
L = Heat flow path length

(The presentation of this equation has not included units)

It is affected by:

(a) The 'conductivity' of the hair (k); and,

(b) The effective thermal conductivity contact surface (A_k) which is equivalent to the total surface area of the hide (4 to 5 m^2) plus the additive surface area of the hair. This is assumed to increase the effective surface area to 50 m^2.

Conductivity of the hair is likely to be low and while radiant load on the hair/hide is high (~12,000 W/day or 1040 MJ) it is most likely that only a small proportion of this energy transferred to the animal. Few data are available for conductivity values (k). However, tabulated data are provided by Joel (1971) and Young (1992) for various materials. These are summarised below in Table 23.

Cattle have hair in order to trap air in a layer around its body. The primary purpose of this is to create an air blanket in cold, windy conditions. In this case the animal is using the air blanket as an insulative protection mechanism and it underpins why hair has low heat conductive properties (ie. to minimise heat loss into this layer). However, by default the air mass increases the contact surface area of the animal with the greater air mass. Once the hair becomes matted, the effective area is reduced and conduction between the animal and air mass may in fact be reduced (contrary to that stated by Sparke, *et al.* 2001). These phenomena are geared to allowing animals to survive in environments where the ambient air temperatures are significantly lower than its body temperature. In these conditions the animal must conserve heat/energy. In warm climates these basic insulative/thermal characteristics limit the ability of an animal to dissipate heat by conduction and convection.

Table 23. Conductivity values (k) for various materials.

Material	**k** (W/m·K)
Steel	45
Glass	1.04
Brick (red)	0.6
Wood	0.12-0.4
Wallboard/Paper	0.04
Felt	0.04
Ground	0.04
Air	0.024
Hydrogen	0.14
Oxygen	0.023

If the k value for felt is used with an estimated effective area of 50 m^2 (combined hide and hair surface area) and a heat flow path of 12 mm is assumed then the conductive heat flow K can be calculated using the equation $K = -kA_k(T_1 - T_2)/L$.

Substituting the above values gives $K = 0.04$ W/m·K $\times$ 10 $m^2 \times (T_1 - T_2)/0.012$ m, so for a 1 K (or 1°C) temperature rise, the transfer of heat is only about 33.3 W. If the hide is heated to an average of 50°C for 6 hours per day then the energy transfer would be in the order of 80 MJ over the day. This is less than the amount of heat actually generated by the animal (1,200 W) over the day which equates to 104 MJ. Clearly the use of shade will reduce this radiant and thus additional heat load on the animal. The data in section 5.1.4 shows that direct radiation loading is reduced by at least 70%, but is not completely eliminated.

1. **Radiant Heat Loss:** As described by Hillman and Gebremedhin (1997) radiant heat transfer (ie. re-emitted radiation, R_L) is determined by knowing the surface temperature of the hair coat and the ambient temperature. The formula to calculate radiant heat transfer is given as follows:

$$R_L = \sigma \times \varepsilon_{coat} \times \varepsilon_{ambient} \times A_{coat} \times (T_{coat}^4 - T_{ambient}^4)$$

where:
σ = Stefan-Boltzman constant (5.70×10^{-12} W/m^2·K^4)
ε_{coat} = emissivity of the hair coat (assumed to be 0.97)
$\varepsilon_{ambient}$ = emissivity of the environment or ambient air (assumed to be 0.97)
A_{coat} = sample area
T_{coat} = surface temperature of the hair coat
$T_{ambient}$ = radiant temperature of the surrounding environment (ambient air temperature)

Using this formula values of radiant heat transfer from an animal to the environment under various conditions can be can be calculated. The value for coat temperature used in the calculations is very conservative and is based on the assumption that the coat temperature is the same as the animals core body temperature. Realistically this is not the case and there would be a significant gradient of decreasing temperatures as you move away from the centre of the animal. It is likely that coat temperatures could vary as much as 10 to 15 °C from the animals core body temperature on cooler days, and may be in fact warmer than 39°C on hot days with high solar radiation.

Table 24. Potential Radiant Heat Energy Loss from an Animal (at 39°C).

Air Temperature		*Coat Temperature*		*Energy Loss*	
(°C)	**(K)**	**(°C)**	**(K)**	**(W)**	**(MJ/day)**
10	283	39	312	1633.5	141
20	293	39	312	1123.5	97
30	303	39	312	558.6	48
35	308	39	312	254.3	22
40	313	39	312	-65.1	-6

The above table shows that radiant heat loss depends on the temperature gradient between the animal and the surrounding environment. Whilst the animals temperature remains higher than that of the environment it is able to radiate heat. As the temperature of the environment rises closer to that of the animals (ie. the temperature gradient is reduced) the amount of radiant energy able to be emitted by the animal is decreased.

2. **Convective Heat Transfer:** The effects of convective energy transfer are understated in the “Heat Load in Feedlot” report (Sparke, *et al.*, 2001). 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 as is its heat holding capacity. The heat holding capacity of air is directly influenced by its moisture (water) content. A clue to the potential adsorptive properties of water are found in Table 23 which presents data on conductivity of various material. It shows that

hydrogen (which forms part of the water molecule) is a much better conductor than oxygen.

Through laboratory analyses Thompson *et al.* (1954) found that the effect of wind velocity (0.18 to 4.47 ms^{-1}) 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:

$$\text{Forced Convection Heat Transfer (C)} = 4197 - 1.413T_a + 19.35v \times (T_s - T_a)$$

where:

C = The forced convective rate of heat exchange (BTU/hr)
T_a = Air temperature (°F)
T_s = Surface temperature of the cattle (°F)
v = wind velocity (mph)

This equation shows that the direction of the convective heat between animals and their environment can be out of or into the animal depending upon if the air temperature is below or above the surface temperature of the animal (Esmay, 1969). Table 25 shows the potential loss of energy from an animal for a range of conditions. The calculation used assumed the body temperature of the animal is 39°C (102°F).

Table 25. Potential Heat Energy Loss (through Convection) from an Animal (at 39°C).

Air Temperature		***Wind Velocity***		***Energy Loss***	
(°C)	**(°F)**	**(km/h)**	**(mph)**	**(BTU/hr)**	**(MJ/day)**
10	50	0	0.00	4126	104
10	50	5	3.11	9177	232
10	50	10	6.22	14227	360
20	68	0	0.00	4101	104
20	68	5	3.11	7410	188
20	68	10	6.22	10719	271
30	86	0	0.00	4075	103
30	86	5	3.11	5643	143
30	86	10	6.22	7210	183
35	95	0	0.00	4063	103
35	95	5	3.11	4759	121
35	95	10	6.22	5456	138

The above data highlight that forced convective heat transfer is highly dependent on wind speed (as stated by Thompson *et al.* 1954). As can be seen from the above table there is basically no difference between the potential heat energy losses at 10 °C and 35 °C when there is no wind. By comparison, with a wind speed of 10 km/h, the potential heat energy loss at 10 °C is over 2 ½ times greater than that at 35 °C.

Convective heat loss is also limited by higher humidity levels. Although the relationship between convective loss and humidity is not well defined, it is known that a more viscous air or liquid medium slows convection. As such, air that contains higher moisture levels has a higher viscosity, and results in a reduction of heat loss by convection.

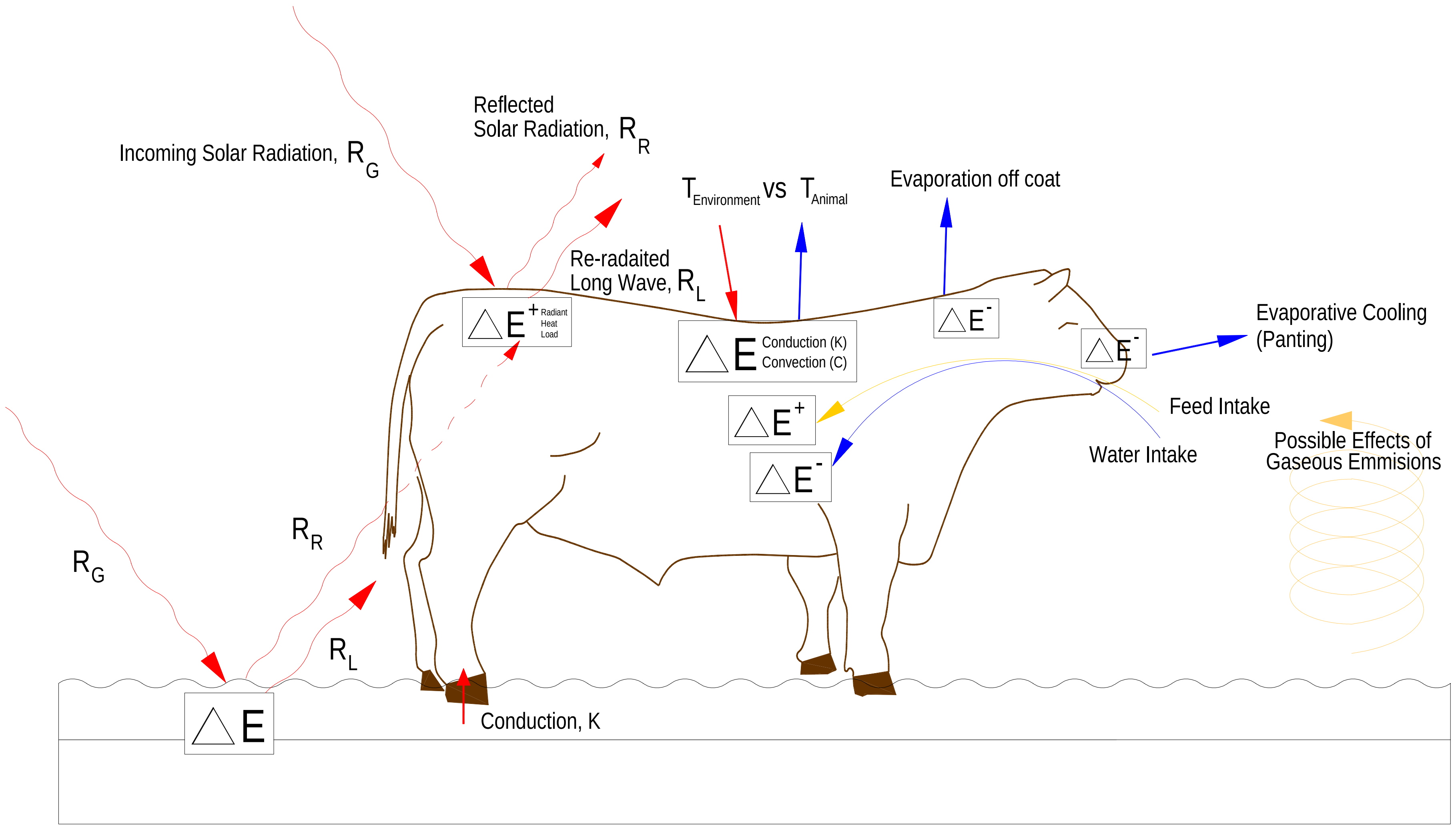

Figure 20. Energy balance of a steer in the feedlot environment.

5.2.4 Energy Balance Scenarios

Using the energy transfer systems described in section 5.3, estimates on energy balances can be made for varying climatic scenarios. Although the energy transfer systems are quite complex, an understanding of differences in heat loading can be obtained by making the following calculations.

For simplicity, the calculations are based on four separate climatic scenarios applied to a shaded pen and an unshaded pen. The climatic scenarios are based on temperature and wind speed only. Temperature is defined as either cold (10°C) or hot (35°C), whilst wind speed is defined as still (0 km/hr) or windy (10 km/hr). As such the eight scenarios presented below are:

- Cold and still (shaded and unshaded pen);
- Cold and windy (shaded and unshaded pen);
- Hot and still (shaded and unshaded pen);
- Hot and windy (shaded and unshaded pen).

Using these scenarios the energy transfer by convection, conduction, and radiant heat loss can be calculated. For simplicity, incoming radiation load will be assumed to be constant for all four scenarios. These constants are quite conservative and are based on the average monthly incoming solar radiation values measured over the study. The daily values used are 300 W/m^2 for an unshaded pen and 80 W/m^2 for a shaded pen. Assuming a planer area of 1.5 m^2 for a steer, then the total energy input over a day equates to 39 MJ for cattle in the unshaded pen and 10 MJ for cattle under shade. A constant value of 104 MJ/day (as calculated in section 5.3) will be used for metabolic heat production. Values for energy loss through water consumption are taken from the calculations in section 5.3. These are 6.0 MJ/day for water consumed at 15°C (ie. on a cold day), and 3.5 MJ/day for water consumed at 25°C (ie. on a hot day). A summary of the energy transfers for the different scenarios are presented in Table 26 below.

Table 26. Calculated Energy Transfer under Difference Climatic Scenarios.

	Cold and windy		Cold and still		Hot and windy		Hot and still	
	Shaded	**Unshaded**	**Shaded**	**Unshaded**	**Shaded**	**Unshaded**	**Shaded**	**Unshaded**
Metabolic Heat Production	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ
Incoming Radiation	+ 10 MJ	+ 39 MJ	+ 10 MJ	+ 39 MJ	+ 10 MJ	+ 39 MJ	+ 10 MJ	+ 39 MJ
Radiant Heat Loss	- 141 MJ	- 141 MJ	- 141 MJ	- 141 MJ	-22 MJ	-22 MJ	-22 MJ	-22 MJ
Water Consumption	- 6.0 MJ	- 6.0 MJ	- 6.0 MJ	- 6.0 MJ	- 3.5 MJ	- 3.5 MJ	- 3.5 MJ	- 3.5 MJ
Convective Loss	- 360 MJ	- 360 MJ	- 104 MJ	- 104 MJ	- 138 MJ	- 138 MJ	- 103 MJ	- 103 MJ
Net Energy Change	**-393 MJ**	**-364 MJ**	**-137 MJ**	**-108 MJ**	**-49.5 MJ**	**-20.5 MJ**	**-14.5 MJ**	**+14.5 MJ**

The data in the above table relate to daily values of energy change (ie. over a 24 hour period). The data presented above are calculated over a 24 hour period as they are presented primarily for comparison purposes.

It is important to note the trends in the above table, rather than the actual values. What is highlighted by the comparison of the scenarios is that the heat losses based on the 'hot' (35°C) conditions are significantly lower than those of the cold conditions. Of note, the major heat loss mechanism is through convection. The effect of wind in assisting heat loss by convection is a key factor. The reduction that shade provides in radiation heat load is important. Heat loss through evaporative cooling is highly variable and as such difficult to define. As it is also a small contributor to total heat loss it has not been included in the above table. From the data in the above table it can be presumed that cattle experiencing the final three scenarios (hot, windy and unshaded, through to hot and still) would potentially be prone to some heat stress.

From these data and brief appraisal of the thermodynamics of the animal/environment system, it would appear that basic energy sources and sinks add to a surplus of energy in the animal. This energy can then only be lost through conductive (K) and convective (C) losses from the animal to its surrounding air mass (given that it is standing) and evaporative losses through panting. This transfer of excess heat occurs through the hide and hair, both of which have insulative properties. The rate of heat transfer is a function of the 'conductivity' of the material and this is influenced by various factors in the boundary layer surrounding the animal (Sparke, *et al.* 2001).

5.2.5 Summary of Energy Balance

One of Newton's laws of thermodynamics states that the "rate of cooling of a body is proportional to the excess temperature of the body above its surrounds". In simple terms this means that the rate of heat transfer from the animal to its surrounds (by convective loss) proportionally diminishes as the ambient air temperature around the animal increases towards its body temperature. Therefore, at times when the daytime temperature (ie. the temperature of the air mass around the animal) is close to the animals body temperature, excess body heat (metabolic heat + radiant/conducted heat transfer – cooling by water ingestion - evaporative cooling) is lost extremely slowly by convection. As such the animal becomes dependent on cooler night time temperatures to increase the rate of heat loss and to shed any accumulated heat load.

If night time temperatures are high, the heat load that the animal has accumulated through the day may not be lost and is carried into the next day. It is an accumulation of heat/energy load and an inability to shed this energy that causes stress events. While radiant heat load increases gross heat and is therefore significant in initiating "stress" events by adding to heat loads, it is not as significant as continuous conditions of high daytime and night time temperatures that limit shedding of excess energy.

This is demonstrated by the data of cumulative radiant heat loads presented in the summary stress event tables in section 4.5. These show that the observed "stress" event at Feedlot B when stock died had lower radiation loads than other "stress" episodes when losses did not occur. The key differences in micrometeorology were that temperatures steadily increased to the point where animals were not able to lose accumulated heat. While solar radiation increases the heat load, and therefore shading will reduce radiation loads on any given day, its primary effect is to reduce the rate of heat/energy accumulation. Consequently, it will reduce the probability of "stress" events and the magnitude of "stress" events BUT not prevent "stress" events. This is supported by the fact that stock have been lost in shaded pens at Prime City (see Entwistle *et. al.* 2000 and Roberts *et. al.* 2000). At the time of this incident stock were lost at Feedlot B and the numbers lost in shaded pens were similar to those in unshaded pens. In this latter case relative humidity levels were high.

This study has shown the feedlot environment has higher night time temperatures compared to those outside the feedlot. This is due to the manure composition of the pen surface which is generally dark and moist and has a greater ability to store heat compared to soil. Reducing the depth of the manure pack over summer months can mitigate the increased temperature effects. The increased relative humidity levels observed in the feedlot environment can also be reduced by limiting the wetting of the feedlot pen areas. An increase in humidity levels causes a reduction in the cattle's ability to shed heat through convective losses and evaporative cooling.

5.4 Ammonia Levels

Few data exist on the relationship between ammonia concentrations and cattle health effects. As such this is an area that requires further investigation. It is known that high ammonia concentrations can have detrimental effects on cattle. This is verified by existing research and data relating to humans and other livestock industries.

The 'Livestock Waste Facilities Handbook' (MWPS, 1985) states that low concentrations of ammonia causes irritation of the eyes and respiratory tract in humans. At levels of 25 to 30 ppm ammonia begins to burn eyes. It is also stated in this literature that animal responses to ammonia (up to levels of 200 ppm) include sneezing, salivation, and appetite loss, but no loss of feed efficiency. In chickens, it is found that eye inflammation develops at levels above 50 ppm and prolonged exposure may increase respiratory diseases and pneumonia (MWPS, 1985).

Taylor *et. al.* (1994) state that ammonia can be detected by smell at levels of around 5 ppm. They further explain that levels of 50 to 70 ppm have shown little effect on healthy older pigs, however these same levels can reduce the ability of younger pigs to clear bacteria from their lungs. As such Taylor *et. al.* (1994) recommend that ammonia levels are kept to below 20 ppm in pig housing.

For humans the recommended 'short-term exposure limit' is 35 ppm (specified by the American Conference of Governmental Industrial Hygienists). The ammonia levels recorded during this study exceeded this recommended exposure level on a number of occasions. As such it should be recognised by feedlots that there may be OH&S issues arising from high ammonia levels during the warmer periods of the day.

Although specific values for critical ammonia levels and detrimental effects on cattle health are not fully defined, it is certain that the high ammonia levels that can be generated from moist manure surfaces under warm conditions do cause cattle discomfort and may contribute to cattle stress events.

6. CONCLUSIONS

6.1 Micrometeorological Variations

The study has highlighted the following variations in the micrometeorology of the feedlot, its surrounds, and between shaded and unshaded pens. These can be summarised as follows:

- Lower minimum temperatures occur outside the feedlot. Differences of around 1°C on average were noted in over night temperatures between the feedlot and its surrounds;

- Humidity in the shaded pens was typically 4 to 9% higher than that of the unshaded pens;

- Soil temperature was 5 to 14°C lower under shade than compared to the unshaded pen and the feedlot surrounds;
- Shade significantly reduces incoming solar radiation and hence black globe temperatures;
- The 'albedo' of the feedlot pens was found to be lower than that of the external environment;
- The higher 'albedo' of the feedlot surface does cause an 'oasis' effect, with higher temperatures noted in the feedlot pens compared to the feedlot surrounds (this was more evident in over night temperatures).

6.2 Stress Events

Based on the field measurements the occurrence of 'stress events' is related to cumulative effects of a number of variables. These variables are not limited to, but primarily include:

- Constant high ambient temperatures (ie. over both the days and nights) that result in an accumulated heat loading of stock;
- Significant radiant heat loads (ie. high global incoming, outgoing solar radiation reflected off ground surfaces and longer wave radiation re-radiated from ground surfaces);
- Low wind speeds;
- Elevated ammonia (NH_3) levels.

It should be noted that although high relative humidity can contribute to the likelihood of 'stress events', these events can occur in situations with a low relative humidity. (This is based on experience of a 'stress event' during the study period which occurred at a time of relatively low humidity and a review of physical data from previous 'stress events'.) Higher humidity levels increase cattle stress by reducing the evaporative cooling capacity (and thus ability to reduce heat load) of the animal, both by panting and through the skin. Humidity also reduces the amount of energy that can be lost by convective mechanisms.

In the case of the recorded stress events a number of relationships were defined that were common. Prior rainfall with an associated increase in atmospheric humidity, and increase in ammonia levels from wet manure can have an additive effect in stress situations. Rainfall prior to a period of significant temperatures provides cooler antecedent conditions. Once the rainfall event is completed, the onset of increasing temperatures and solar radiation, combined with the increased ammonia levels generated from the moist manure surfaces, creates uncomfortable conditions for cattle. If the temperatures increase over a period of several days, the cattle are exposed to these conditions continually. This sees the heat load on cattle slowly increase over this period, and if wind speeds remain low there is no respite for the animal from this load through convective losses (losses are increased by both cooler temperatures and increased wind speed). As such there is potential for a 'stress event' because there is no opportunity for animals to shed the accumulated load nor offset the effects of ammonia intake.

6.3 Effects of Shade

Shade provides several benefits that may reduce the probability of a ‘stress event’ and the magnitude of a ‘stress event’. However, shade structures also have the potential to detrimentally increase the effects of certain cattle stressors. The primary effects of shade on the physical environment are:

- Reduced solar radiation and therefore a reduction in the radiant heat load on cattle;
- Increased moisture content of pen surfaces;
- Reduced wind speeds and air movement;
- Increased humidity levels;
- Increased ammonia levels.

The study found that there were no significant differences in the ambient temperatures of shaded and unshaded pens.

It was noted during the trial that stock housed in pens with shade did become stressed. From the main stress event recorded during the summer trial, the majority of cattle deaths did occur in unshaded pens. It is important to note that the stress event was related to a ‘dry heat’ of consistently high ambient temperatures, high solar radiation (and hence radiant heat loads), medium to low humidity, and very calm wind conditions.

The increase in manure moisture content that is created by the presence of shade structures contributes to a notable increase in ammonia levels beneath shade structures. The ammonia levels recorded under shade structures were found to be significantly higher than those measured in open pens. It should also be noted that high levels of ammonia were recorded in the water trough areas of open pens, where the pen surface is typically more moist.

While shade reduces the radiant heat load on stock, it reduces convective losses (ie. the ability for animals to pass heat to the environment) because humidity levels are greater. It also reduces wind speed and thus reduces heat losses to the atmosphere by both animal surface air interactions and also evaporative cooling

Given that ammonia levels and humidity levels are higher beneath shade structures, and that there is no significant difference in ambient air temperatures, it remains most probable that catastrophic cattle deaths will occur from time to time even if feedlots are fully shaded.

In previous stress events and in the case of the recorded stress event, the inclusion of shade reduced the number of cattle deaths. Shade will also reduce the probability of stress events and thus cattle deaths (since direct radiant heat load is a significant variable) and it will also change the circumstances under which such catastrophes will occur.

Shade design can be altered to reduce pen manure wetting and increase air speeds under shades. Changes need to be made to shade design to better the physical environment of stock. Designs must consider increasing wind movement (and vertical ventilation) beneath shade structures, maximising drying of pen manure and limiting re-radiation of energy beneath shade structures. A considerable body of information is available in relation to shade design. This information should be reviewed and designs undertaken using such a review and the conclusions of this report.

6.4 Effects of Sprinklers

It was observed that the feedlot environment had increased relative humidity levels. The use of sprinklers for the purpose of cattle cooling would further increase these levels. An increase in humidity levels causes a reduction in the cattle's ability to shed heat through convective losses and evaporative cooling.

It is likely that evaporative cooling could be increased by artificial means through the wetting of cattle. However, while this may have a useful instantaneous effect, it is also likely to exacerbate other stressors in the period after initial wetting and subsequent drying of stock. The detrimental effects that may arise due to the use of sprinklers include:

- Increased humidity levels;
- Reduction in natural evaporative cooling;
- Reduction in energy losses through convection;
- Increased moisture content of pen surfaces and potential increase in ammonia generation.

As such under hot still conditions where the primary means of heat energy loss are already limited (ie. convection, conduction, and radiant heat loss), the increase in humidity levels potentially created through the use of sprinklers can limit heat loss by evaporative cooling and further reduce convective losses.

6.5 Reducing Heat Stress

The study and further assessment have shown that key sources of heat and energy are the ration and radiant load, and that key loss mechanisms occur through convective systems. A less significant loss is through ingestion of water and evaporative cooling (ie. panting). Although it should be noted that when convective losses are limited by high air temperatures, the role of evaporative cooling becomes more important. While shade will reduce radiation loads, clearly reducing the metabolic production heat load is a primary means of managing heat load accumulation.

Management practices that will assist in reducing the potential for cattle stress include providing an abundant supply of cool water for drinking and also minimising the wetting of pens for evaporative cooling. The wetter the pen surface the higher the relative humidity and ammonia levels will be, both of these variables contribute to cattle stress. This study has highlighted that ammonia is likely to be a significant factor in contributing to cattle stress, however the exact extent of this still remains uncertain.

7. RECOMMENDATIONS

7.1 Further Research

1. Undertake further field studies by collecting another record of data over a summer period with intense measurements of micro-meteorological variables and other ambient conditions inside a feedlot pen. The aim of these studies would be to:

(a) Duplicate the studies undertaken so far but with more focused measurements to expand the available data sets and in particular determine vertical wind movement (ie. circulation) in feedlots. These studies should aim at examining the relationships between horizontal and vertical wind movement, and also determine the differences between shaded and unshaded areas.

(b) Increase the level of measurements of atmospheric ammonia to better define the extents of ammonia generation in feedlot pens and the profile concentration over the pen surface and consequent effects on stock.

2. Develop a stress index based on the existing data and trial it in the field over the coming summer. The information can be used as an early warning system for the feedlot industry on a 'trial' basis. The "stress index" must be cognitive of the key outcomes of the literature review projects (FLOT 307-309) and outcomes of FLOT.310 and subsequent industry review.

   Because there are differences in the micro-climate between areas surrounding feedlot and the feedlot, forecasting systems will need to collect data inside feedlots to provide a 'picture' of feedlot conditions rather than using a more general regional climatic prognosis. The data set collected by this study would provide a useful tool in undertaking preliminary (theoretical) trials of potential stress indexes.

3. Review shade design on the basis of the findings of the project report and provide key design principals as a prelude to obtaining advice on the structure design of a "new generation" of shade structures.

4. Undertake simple thermodynamic studies to investigate the relationship between trough design and water temperature. These studies should define those systems that limit heating of water.

5. Define the effects of ammonia (NH_3) on lot fed cattle.

7.2 Operational issues for Existing Research Project

1. Sell four (4) of the weather stations not fully utilised in the experimentation OR alternatively utilise them for spares or place them at a third site in central NSW over the coming summer.

2. Service the weather stations and prepared them for installation at each site for a period covering October 2001 to March 2002.

7.3 Practical

1. It is recommended that the feedlot industry moves toward programmed manure harvesting practices where manure packs are minimised over the summer period as a direct means of limiting the incidence of deep wet manure which can give rise to elevated humidity and ammonia levels in pens.

2. Ammonia levels in feedlot pens can be at levels that are toxic to humans and indeed well above those recognised as maxima in OH&S guidelines. It is

recommended that feedlots recognise this in their QA program and note critical criteria for managing this situation. For example summer pen cleaning should be undertaken in the early morning, prior to ammonia levels increasing with heating of the feedlot pad.

3. Only water pens at times of low relative humidity levels.

4. During stress event periods provide abundant cold water.

5. Shade pens in regions where heat stress may occur.

6. Construct shades that are at least 5 metres above the pen floor and in a configuration that:

   - Maximises through ventilation;
   - Maximises manure drying under the shade;
   - Maximises the amount of shade available per animal in the afternoon.

   The construction of shade structures should be based on the outcomes from a review of shade design (see point 3 above).

7. Investigate the formation of rations that will reduce the metabolic heat production (MH_p) and hence the heat generated through digestion of feed.

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