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THE MICROCLIMATE OF AUSTRALIAN CATTLE FEEDLOTS

A Dissertation submitted by

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CERTIFICATION OF DISSERTATION

I certify that the ideas, experimental work, results, analyses, software and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

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ABSTRACT

The incidence of cattle heat stress is a significant production and welfare issue for the feedlot industry. It is hypothesised that the presence and physical nature of feedlots causes significant microclimatic variations compared to the external environment.

In order to test this hypothesis, data was collected using a series of automatic weather stations located in the external environment surrounding two Australian feedlots. Comparison of this data with regional Bureau of Meteorology sites was undertaken to verify the quality of these 'control' sites. To determine the climate within the feedlot separate automatic weather stations were placed within the cattle pens at each site, with one station located in an unshaded pen and one directly under an artificial shade structure within an adjacent pen.

This dissertation reports the collection and analyses of detailed climatic data from the surrounds and within the cattle pens of these two Australian feedlots. The project also sought to determine microclimatic differences within the feedlot pen area that may be caused by the presence of the shade structures.

It was found that the presence of a feedlot does create significant microclimatic variations. Specifically, it was determined that the albedo values of the feedlot pen surface are significantly lower (ranging from 0.13 to 0.19) than those of the external feedlot environment (typically 0.15 to 0.25). This is a result of the surface changes arising from the establishment of clay based manure covered pens. Under wet conditions the differences in albedo values were further increased. It was found that the short wave radiation reflection from the external feedlot environment was 4% greater than that from the unshaded feedlot pen surfaces under dry conditions and 10% greater under wet conditions. The increased adsorption of solar radiation by the feedlot pen surface created ground temperatures that were on average 2 to 4°C warmer than those of the feedlot surrounds. The re-radiation of heat from the pen surface was found to create warmer air temperatures within the feedlot pens compared to the external environment, particularly overnight. Between the hours of 4am to 6am it was found that on average the air temperatures of the shaded and unshaded feedlot pens were 0.7°C and 0.5°C warmer than the external feedlot environment.

It was found that feedlot pen infrastructure and cattle significantly reduce wind speeds under a height of 10 metres. The average 2 metre wind speeds of the external feedlot environments were found to be 29% and 9% higher than those recorded in the unshaded pens at the northern and southern feedlots respectively.

Shade structures within feedlot pens were found to be effective in reducing incoming solar radiation with the galvanised sheeting reducing incoming solar radiation by 76% and the shade cloth providing a 72% reduction. These reductions provided both lower ground temperatures and a significant reduction in radiant heat loads under the shade. It was determined that the environment under shade structures was more humid compared to that of the unshaded pens with humidity levels recorded being 8 to 12% higher. Shade structures also restrict horizontal wind movement with the 2 metre wind speeds in the shaded pens being on average 11% and 0.5% lower than those recorded in the unshaded pens for the Queensland and NSW feedlots respectively.

Research has shown that microclimatic variations such as increased air temperatures, increased humidity and restricted air movement can have an adverse effect on cattle health. It is concluded from this project that in order to mitigate these effects a number of feedlot design concepts be implemented, and management practices should be adopted. Maintaining minimal quantities of manure on the pen surface will provide lower ground temperatures, dryer pen conditions and inhibit the re-radiation of heat and evapotranspiration from the pen surface. Adequate air flow should be maintained by siting feedlots in areas of suitable topography, and designing feedlot infrastructure and shade structures to maximise air movement. Shade structures need to aim at providing dryer pen surfaces to minimise humidity levels. Incorporation of these recommendations into feedlot design and management will assist in optimising the feedlot microclimate.

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TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

CHAPTER 2

CHAPTER 4

CHAPTER 5

TABLE OF FIGURES

CHAPTER 2

CHAPTER 3

CHAPTER 4

Chapter 5

TABLE OF PLATES

CHAPTER 2

CHAPTER 3

CHAPTER 5

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

The beef cattle lot feeding sector is a substantial and important industry in Australia. The industry body Meat and Livestock Australia (MLA) highlights the significant economic and market benefits derived from feedlots in the form of job creation, regional growth, increased market stability and new market opportunities. The most recent major economic survey of the feedlot industry showed that (ALFA, 2002):

- feedlots consumed 2.3 million tonnes of feed commodities, of which 1.5 million tonnes was grain valued at $260 million;
- feedlots purchased two million cattle valued at approximately $1.2 billion;
- feedlots turned off (sold or slaughtered) two million cattle valued at around $2 billion;
- the freight costs of the feedlot industry would have contributed $80 million to the transport industry;
- feedlots purchased preventative medicine and veterinary products worth approximately $15 million; and
- the feedlot industry used fuel, spare parts and other consumable items worth an estimated $40 million.

In 2000 there were 703 feedlots in Australia with the total capacity being approximately 840,000 cattle (ALFA, 2002). Over recent years the industry continues to grow, with a total feedlot capacity of just over 1 million head recorded in June 2005 (ALFA, 2005).

A significant production and welfare issue for the feedlot industry, not only in Australia but also in the United States and South Africa, is the incidence of cattle heat stress. Hyperthermia (heat stroke) occurs when the body temperature is elevated due to excessive heat production or absorption, or to deficient heat loss (Cronin, 2001). Sparke *et al.* (2001), explain cattle 'heat load' through the practical application of thermodynamic principles. That is, they state that cattle are homeotherms which try to maintain their body core temperature within a relatively narrow temperature range (based around 39°C) to ensure that their body cells and tissue can function optimally.

As detailed in Sparke *et al.* (2001), excessive heat load occurs where a combination of local environmental conditions and animal factors leads to an increase in body heat content that exceeds both the animal's normal physiological range and the animal's ability to cope. The physical and animal factors that can influence heat load are numerous and can include conduction, convection, radiation, evaporation, feed and water intake, metabolic heat production, animal breed, size of beast, and coat colour (Sparke *et al.*, 2001; Petrov *et al.*, 2001).

Excessive heat load occurs in the feedlot industries of Australia, the United States, and South Africa. These ongoing incidents can lead to cattle mortality, production loss and high economic costs (Sparke *et al.*, 2001). There are recorded incidents where the occurrence of excessive heat load or heat stress has caused catastrophic stock losses in Australia. Whilst these events are infrequent, the repercussions from heat stress incidents bring the feedlot industry under increasing scrutiny and the cattle deaths create significant economic losses.

A considerable body of research has been undertaken on defining heat stress with respect to cattle comfort, health and production (Hahn, 1985; Oke, 1987; Mader, 1996; Gaughan *et al.*, 1996); however by 2000 few data were still available on the micrometeorological characteristics of feedlots and the probable causes of heat stress in feedlots. The need for this research was identified by an ALFA appointed Working Party following the review of two reports relating to an 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 required further review and/or research before the major recommendations of the reviews could be addressed.

Meat and Livestock Australia (MLA) commissioned the research project FLOT.310 which involved the installation of 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 study aimed to provide feedlot managers with a better understanding of the connection between cattle behaviour, the physical environment, and micrometeorology. This research project was undertaken by E.A. Systems Pty Limited. The climatic data collected from the feedlot sites as part of project FLOT.310 were used as the basis for the analyses set out in this project[1].

1.2 OBJECTIVES

It was hypothesised that the presence and physical nature of feedlots causes variations in their microclimate compared to the external environment (ie. the undeveloped areas surrounding the immediate feedlot site). In addition to this, the presence of feedlot pen shade structures was thought to have an influence on the feedlot microclimate.

The fundamental aim of this project - comprising data collection and analyses - was to determine whether the feedlot microclimate varied from the climate of the surrounding external environment. The analyses also sought to determine microclimatic differences within the feedlot pen area caused by the presence of artificial shade structures. To achieve these aims the project endeavoured to measure both the climatic conditions surrounding a feedlot, and the microclimate conditions within feedlot pens, with sufficient accuracy to resolve these differences. In summary the specific objectives of the project were to:

- install and maintain a series of automatic weather stations at two separate feedlot sites representing 'typical' Australian feedlot operations;
- collate and analyse the microclimatic data collected from within and around these two Australian feedlots;
- examine the specific differences between the microclimate within a cattle feedlot and that of the surrounding 'external' environment;
- determine microclimatic variations caused by the presence of artificial shade structures within feedlot pens;
- describe the microclimatic differences caused by the presence of feedlots; and
- describe the microclimatic differences between shaded and unshaded feedlot pen environments.

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[1] The project FLOT.310 also investigated in detail the animal and atmosphere interactions in order to ascertain the probable causes of heat stress in feedlots, but this is outside the scope of this dissertation (as outlined in section 2.5).

1.3 POTENTIAL PROJECT BENEFITS

Typically, a significant number of larger beef cattle feedlots in Australia have an automatic weather station located on site. The level to which the data collected by these stations are used as a management tool is variable.

Whilst data recorded by the weather stations located on the feedlot premises may provide some site specific climatic information, these data are not typically representative of the conditions within the feedlot pen areas. This is due to the fact that automatic weather stations installed at feedlots are generally located in close proximity to the office area, away from the feedlot pens. It is impractical to install automatic weather stations within the feedlot area as the harsher environmental conditions (eg. caused by dust, cattle, pen cleaning machinery etc) can significantly reduce the useful working life of the sensitive electronic equipment within the station and the associated sensors.

As such, defining relationships that will enable pen climatic conditions to be synthesised from data collected outside the feedlot area would be of significant benefit to the feedlot industry.

1.4 DISSERTATION OVERVIEW

Chapter 2 of this dissertation provides background theory on the climate of Australia, climatic processes and interactions, and the characteristics of microclimates. In addition to this, an overview of the Australian feedlot industry is presented. Chapter 3 sets out the methodology and experimental design used for the project. It describes the two feedlot sites used over the data collection period, and details the instrumentation used to record the climatic data.

The climatic data recorded by the automatic weather stations located outside the feedlot pen area are analysed in Chapter 4. In particular this chapter details the collation of these data sets and compares the recorded data with similar data recorded by nearby Bureau of Meteorology (BoM) stations in order to determine the integrity of the project climatic data. Chapter 5 provides the results and detailed analyses of the climatic data recorded within the feedlot sites. The significance of the climatic differences observed through the data analyses are discussed in Chapter 6 along with potential methods of optimising the feedlot microclimate. Chapter 7 presents the conclusions of the project.

CHAPTER 2 BACKGROUND

2.1 INTRODUCTION

This chapter provides a general overview of firstly, the Australian climate, climatic processes and interactions, and the characteristics of microclimates applicable to the meteorological analysis of feedlots. An overview of the Australian feedlot industry is then presented, and in order to provide a general understanding of feedlot facilities, the standard components of a feedlot are described. The distribution of feedlots within Australia is outlined, as this has relevance to the general climates that these facilities experience. Finally, the common meteorological measurements that are undertaken at Australian feedlot sites are discussed to provide an indication of the site specific climate data currently available.

2.2 CLIMATE

The Australian Bureau of Meteorology (BoM) defines climate as “the atmospheric conditions for a long period of time, and generally referring to the normal or mean course of the weather” (BoM, 1991). The BoM further detail that climate includes the future expectation of long term weather, in the order of weeks, months or years ahead.

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, 1991) it is primarily due to Australia’s latitude and position relative to the region of large scale descent at the poleward edge of the southern hemisphere Hadley cell[2], and the associated belt of eastward migrating high pressure systems.

Naturally the large size of the continent results in much variation in climate across Australia. Figure 2.1 shows the climate classification of Australia using the Köppen classification scheme (BoM, undated). In the Köppen classification scheme, the

[2] The Hadley cell is created by convection currents and consists of rising air at the equator and descending air at 30° North and South.

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).

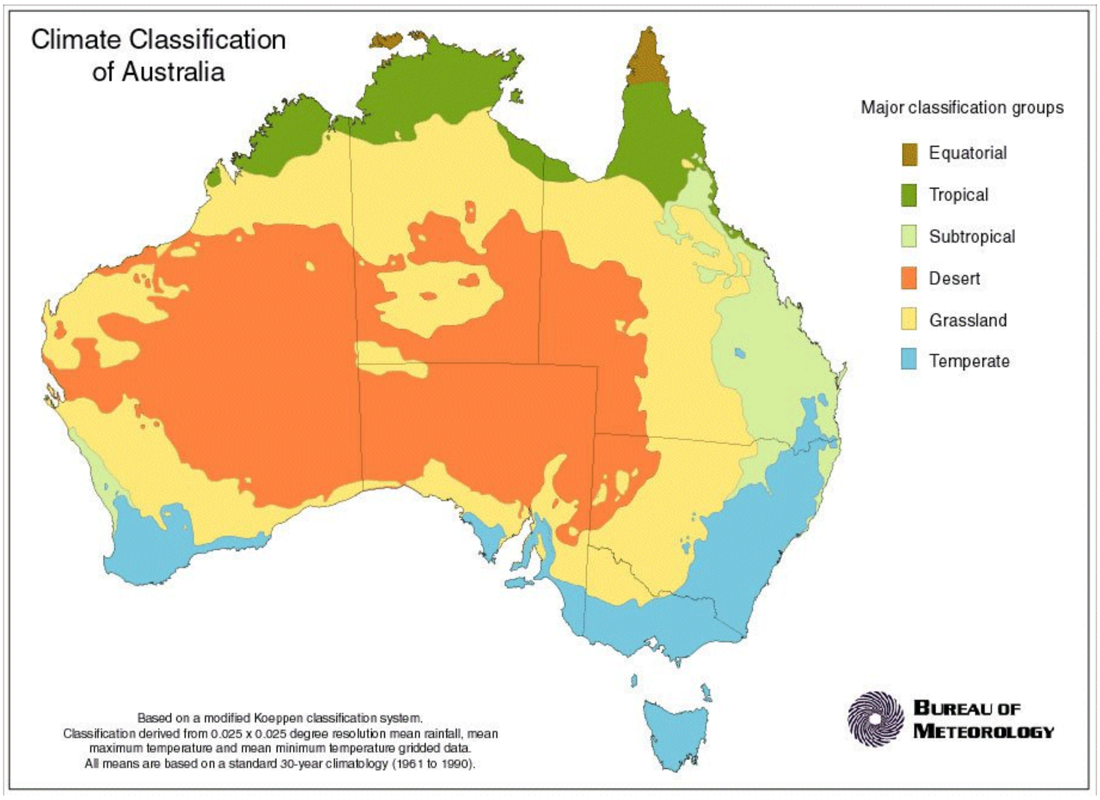

Figure 2.1. Climate classification of Australia. (Source: BoM, undated).

The above figure shows that around one third of 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 belt of grassland/desert areas due to the 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; and
- Earth's rotation and topography - which control the pattern of winds.

These four factors are closely linked and influence one another. The most significant influence is between the first two.

2.2.1 Radiation Balance

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.

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:

$$\text{energy emitted} = \sigma T^4 \qquad \textit{[Eq. 2.1]}$$

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 wavelengths between 0.1 and 3.0 μm.

The amount of solar radiation that reaches the earth’s 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. As described by Rosenburg (1974), the amount of solar radiation received on a surface also depends on the altitude and azimuth of the sun, which are functions of the latitude, time of day, and the solar declination (dependent on the day of year).

Based on the average distance between the sun and the earth, the fixed amount of radiation energy received by a plane surface placed normal to the solar beam and located 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 one quarter (¼) of the solar constant or approximately 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. Surfaces with lower albedo values reflect less radiation and as such become hotter. Albedo values for various surfaces are presented in Table 2.1 below.

Table 2.1. Typical albedo values for natural surfaces.

		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
Water	Small zenith angle	0.03 - 0.10

(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 Table 2.2 below which shows the amount of solar radiation that is absorbed and reflected by both the atmosphere and the earth.

Table 2.2. Energy balance of incoming solar radiation (Oke, 1987).

	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

† - Mean input of solar radiation energy (averaged over a yearly period) received by a plane surface located above the atmosphere and placed normal to the solar beam.

Table 2.2 highlights some significant 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). This radiation is referred to 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, 25% by the atmosphere and 3% by the earth. 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'.

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 in the infra-red spectral range and hence not visible, 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%), plus 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 2.2 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.

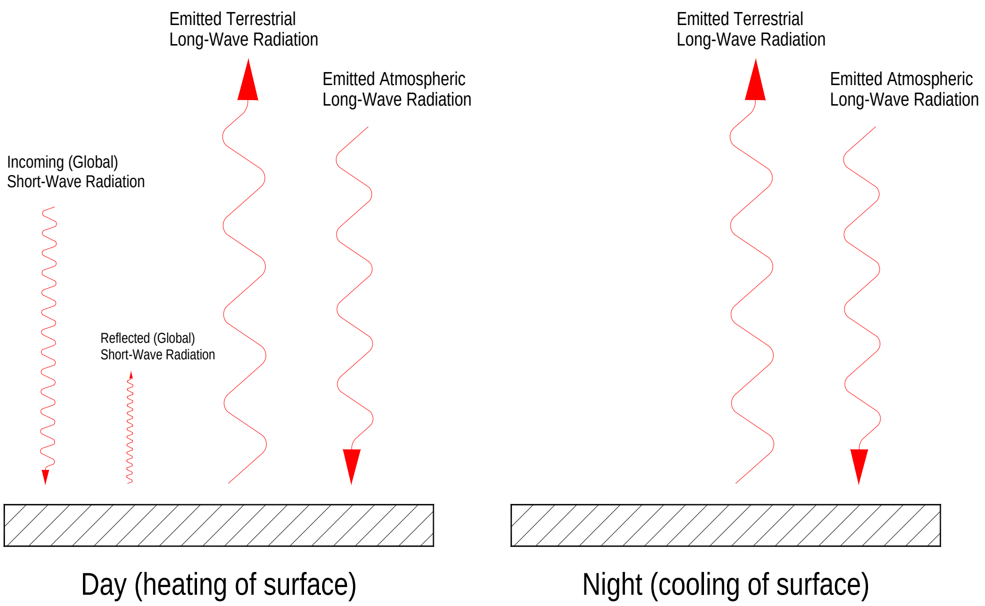

Figure 2.2. Radiation inputs and outputs at earths surface during the day and night.

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 moisture content of the atmosphere; and
- 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 fewer clouds providing faster cooling rates (Linacre and Hobbs, 1977).

2.2.2 *MICROCLIMATE AND 'OASIS EFFECTS'*

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 mm to 1 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) explain 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 at the microclimate scale is referred to as the 'oasis effect'. The oasis effect is described as being created when differences in moisture availability occur between two areas (Rosenburg, 1974; Oke, 1987). The area with the greater moisture source will be cooler than the more arid area. As a result there may be advection (horizontal air movement) of the hotter air from the arid area to the area above the moisture source.

In relation to the feedlot environment this phenomenon may be identified at two scales. Firstly, comparing the bare clay feedlot pen area to the typically vegetated external surroundings, it is observed that the moisture source of the feedlot pens is limited compared to the surrounding areas. This being the case, and applying the situation described by Oke (1987), the small amount of moisture in the pen surface would be evaporated. This process would only use a small proportion of the available radiant energy (due to the limited amount of moisture) and the surplus heat would then be dissipated (by convection) as sensible heat. This implies a warming of the air creating a hotter environment than the external surroundings adjacent to the feedlot.

On a smaller scale, a second application of the oasis effect can be identified. This is the potential difference between the air above the surface of a dry feedlot pen, compared to a moist pen surface (as created under shade where cattle congregate). Again, by the process described above, the dry pen surface would exhibit warm air above its surface due to the convection of surplus heat. Evaporation from the moist pen surface (which is assumed to have a free availability of water) would consume more radiant energy than that available in the immediate environment. This results in the warm air of the surrounding areas (ie. over dry pen surfaces) passing over the evaporating surface. This phenomenon will cause the moist pen surface to act as a heat sink until the moisture source is depleted (Rosenburg, 1974). It is noted that with the sensible heat being directed towards the pen surface, the heat input towards the lower atmosphere is primarily in the form of latent heat. As detailed by Oke (1987) latent heat does not directly contribute to the warming of this atmosphere, but does increase humidity.

2.3 FEEDLOTS

2.3.1 AUSTRALIAN FEEDLOT INDUSTRY

A beef feedlot is defined as "a confined yard area with watering and feeding facilities where cattle are completely hand or mechanically fed for the purpose of production" (SCARM, 1997). This definition is as agreed between both industry and Government.

Since its commencement in the 1960s, cattle lot feeding has become an increasing industry in Australia. The most rapid expansion in the Australian lot feeding industry occurred during the mid 1980s as a result of the growth of export markets combined with favourable climatic conditions (ALFA, 2002).

The two major representative bodies of the Australian feedlot industry, the Australian Lot Feeders Association (ALFA) and Meat and Livestock Australia (MLA), determined that in 2000 there were 703 feedlots accredited under the National Feedlot Accreditation Scheme[3] (NFAS). The total capacity of these feedlots was

[3] National Feedlot Accreditation Scheme (NFAS). A quality assurance program established in 1995 to ensure that agreed industry standards are adhered to.

approximately 840,000 cattle. A similar survey undertaken in September 2002 showed that the number of NFAS accredited feedlots had dropped to 598 however this represented a total capacity of 862,083 cattle. At the time of the survey, 88% of these feedlots were currently stocked and feeding (ALFA, 2002). In June 2005 the feedlot capacity in Australia reached 1,028,440 head, with 86% of this capacity being utilised at the time of the survey (ALFA, 2005).

Comparison of the 2000, 2002 and 2005 survey data reflects the current trend of existing feedlots to expand there capacity as the markets increase. It is noted that larger feedlots are predominant in Australia. In 2002, 80% of the total capacity was held in 12.4% of the feedlots (ALFA, 2002). The results of the 2002 ALFA/MLA survey also showed that 78 of the Australian feedlots had a capacity of over 1000 head and the largest feedlot had a capacity of more than 50,000 head. The 2005 data showed that 91% of feedlot cattle were held in facilities with a capacity of 1000 head or greater (ALFA, 2005).

A general description of Australian feedlots is presented in the following sections.

2.3.2 Typical Australian Feedlot Layout and Operation

The design and layout of Australian feedlots is generally incorporated of the following standard components (as identified by Watts & Tucker, 1994):

- feeding system;
- watering system;
- cattle management system;
- manure management system;
- effluent management system; and
- staff/business facilitates.

Whilst the extents of these individual components will vary between individual feedlot operations, Australian feedlots are comprised of an integration of the above components. The incorporation of these individual components is shown diagrammatically in Figure 2.3. To provide a general overview of Australian feedlot operations the following sections outline each component in more detail.

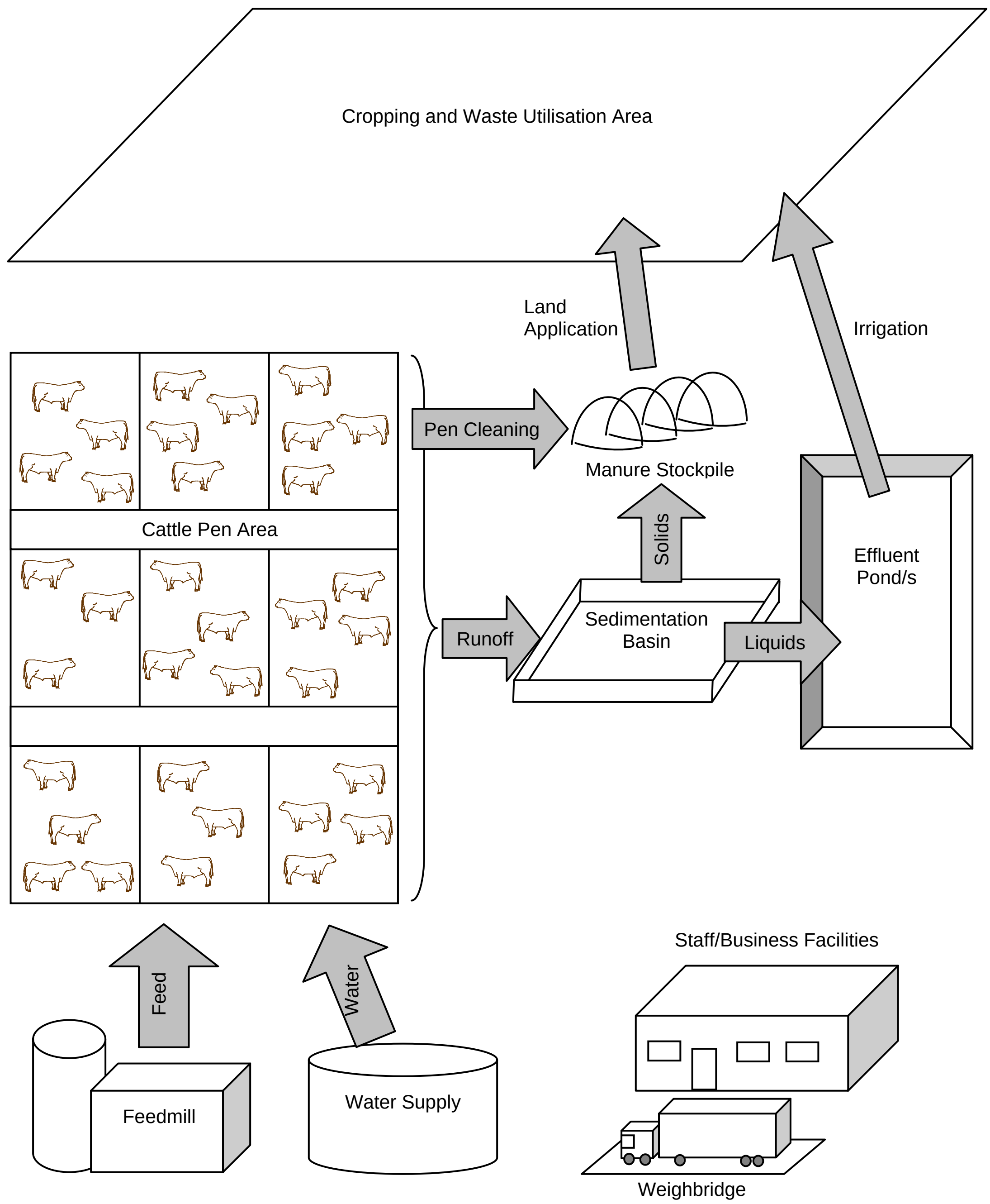

Figure 2.3. Typical components of an Australian Feedlot.

2.3.2.1 Feeding System

The feeding system incorporates the storage of the various commodities that are used as cattle feed; the processing of these commodities into the cattle rations; the feed mixing and delivery trucks; the feed alleys, troughs and self feeders.

Commodities used in feed rations vary between operations and are dependent on a variety of factors including feedlot location, cattle type, operation size, and commodity availability. Some common feed ingredients used in the Australian feedlot industry include grains (sorghum, barley, wheat), roughage (silage, hay, cotton seeds, pulps, pellets), and liquid supplements (molasses, fat). These feed ingredients listed are just a selection of the wide variety used in the Australian feedlot industry.

Feed products can be either imported to the feedlot or produced on site. In some circumstances smaller feedlots (generally less than 1,000 head) have their rations mixed and milled off-site. More commonly, the larger feedlots store their various commodities for processing in a feed mill located on-site. Feed rations are provided to the housed cattle through either self-feeders located within the cattle pens, or more commonly trucks deliver the feed into open troughs along one edge of the pens.

2.3.2.2 WATERING SYSTEM

Cattle consume in the order of 35 to 85 L of water per day (Watts *et al.*, 1994a). Individual stock water consumption is dependent on cattle size, cattle breed, feed type, and climate. Water consumed by cattle is used for digestion, metabolism, respiration, and cooling. In addition to stock water requirements, feedlots use water for dust control, fire protection, feed processing, cleaning purposes, veterinary use, and irrigation. Water losses in feedlots can also occur through animal wastage, leaks in reticulation systems, evaporative and seepage losses. It is estimated that the total annual water requirement for a 10,000 head feedlot in Australia is in the order of 115 to 250 ML depending on location and cattle type (Watts *et al.*, 1994a).

In order to meet these water requirements, feedlots are typically established with a watering system that incorporates a water source, a system of pumps, storages, mainlines, pen reticulation systems and water troughs. In Australia, feedlots source their water from on-site dams, nearby water courses, shallow ground water or deeper artesian bores. Individual operations may use more than one of these sources depending on location, cost, water quality, availability and reliability.

2.3.2.3 CATTLE MANAGEMENT SYSTEM

The cattle management system of a feedlot typically comprises the most land area of the facility, with exception to the land area used for farming and the utilisation of wastes. The cattle management system comprises the feedlot pens, as well as receival and induction facilities, cattle lanes, cattle hospital yards, and dispatch facilities (Watts & Tucker, 1994).

The feedlot pens with which cattle are kept for the purpose of production typically consist of a compacted gravel/clay base. Feedlot pen construction aims at establishing a smooth and uniform compacted base that will withstand the bearing pressures of cattle, assist in pen drainage, and minimise infiltration of surface waters.

Once cattle are stocked in the pens a manure layer is established over the prepared pen surface. As described by Lott *et al.* (1994), this deposited manure forms a distinct profile. The surface of this manure layer forms a hard crust under dry conditions. Beneath this, the manure generally remains moist and plastic, whilst just above the original pen surface is what is referred to as the 'interface' layer - a mixture of soil and manure.

Current feedlot guidelines suggest that this interface layer should be maintained as the dense and impermeable nature of this layer provides several benefits. The interface layer prevents contamination of ground waters that can occur through leaching of nutrients and salts. It also provides a firm and comfortable surface for cattle, assists pen drainage, and as it is in this layer that anaerobic decomposition of organic matter occurs, hence disturbance of the layer can result in the emission of offensive odours (ILSU, 2001a; Lott *et al.*, 1994).

Pen capacities in Australian commercial feedlots commonly range from 50 to 250 head. Current feedlot guidelines suggest that cattle stocking densities should be maintained within the range of 9 to 25 m^2 per head, and it is suggested that a 600 kg animal is provided with 15 m^2 of pen area (SCARM, 1997). The industry standard stocking density is generally above the minimum recommendation of 9 m^2/head. This was reflected in a national survey undertaken by Tucker *et al.* (1991), where it was found that the median stocking density in commercial Australian feedlots was 14 m^2/head. Generally, commercial feedlots in Australia will have stocking densities between 12 to 18 m^2/head (Watts & Tucker, 1994). Based on these values, the pen area of a 10,000 head feedlot is 12 to 18 ha, not including the area required for access lanes, roads, drainage systems etc. Based on this land area, it is probable that the establishment of a feedlot creates a significant change to landscape characteristics of the immediate environment.

2.3.2.4 MANURE MANAGEMENT

A feedlots manure management system involves manure cleaning from pens, transport of this manure to stockpiling or utilisation areas on site, or transport off site. As stated by Lott *et al.* (1994), "one of the most important factors in optimising the performance of cattle in feedlots is maintaining pen conditions that promote drainage and cattle performance, reduce moisture adsorption, minimise odour and reduce pen maintenance expenses". As such it is important that feedlots implement an effective pen manure cleaning program.

Frequency of pen cleaning varies between feedlot operations. The rate of manure accumulation in pens primarily depends on cattle size and stocking density (Lott *et al.*, 1994) but is also influenced by factors such as cattle breed, digestibility of the feed ration, moisture content, and climatic conditions (ILSU, 2001b). The 'National Guidelines for Beef Cattle Feedlots in Australia' suggest that the frequency of pen cleaning must be adequate enough to provide sufficient area free from wet manure to allow cattle to rest (SCARM, 1997). Wet and muddy feedlot pen conditions can limit cattle performance (growth and weight gain). Generally, cattle do not like to lie on wet surfaces as it drains body heat through the process of conduction. As such cattle prefer dry areas to rest. If cattle do not have access to suitable resting areas they will continually stand which reduces performance through fatigue (ILSU, 2001c). It is noted however, that in hot conditions cattle can lie on wet surfaces (if available) to assist in cooling (Mader, 2003).

As a general guide, pen cleaning operations in Australian feedlots are undertaken as often as every 10 weeks and the maximum interval is typically 26 weeks. Most feedlots adopt the recommended practice of maintaining the 'interface' layer by ensuring 25 to 50 mm of manure is left on the pen surface (as suggested in Lott *et al.*, 1994 and ILSU, 2001a). The Queensland Department of Primary Industries Feedlot Reference Manual (Skerman, 2001) recommends that the amount of accumulated manure on the pen surface does not exceed a depth of 200 mm.

It is highly significant that the characteristics of the pen manure surface change significantly depending on moisture content. As described by Lott (1998), manure has different physical characteristics from those of soil, and manure in a feedlot pad has varying characteristics compared to manure from grazed animals due to the increased compaction as a result of the higher stocking densities. A significant difference between the characteristics of manure and soil is the fact that manure is extremely high in organic matter and hence has a capacity to absorb substantially more water than soil (Lott, 1998).

Lott (1998) describes that pen manure becomes powdery when cattle scuff the surface that has a moisture content less than 25% (dry basis; db). When the moisture content is around 30 to 50% (db) the loose manure is compacted into a hard top layer. Lott (1998) notes that at moisture contents of 80 to 100% (db) impressions are made in the manure surface by cattle hooves. Manure in feedlot pens loses its structure and forms a slurry when its moisture content exceeds its liquid limit, roughly 250 to 400% (db). It is also observed that at higher moisture contents the manure surface becomes increasingly dark in colour. When it is dry, the pen surfaces at feedlots are typically a light brown colour. Under wet conditions the pen surface appears to be very dark, almost black, in colour. These differences are illustrated in Plate 2.1 below.

Plate 2.1. (Left) A typical feedlot pen manure surface under dry conditions; and (Right) the author collecting weather station data under very wet pen manure surface conditions.

2.3.2.5 Effluent Management

Feedlots generate effluent through surface water runoff from contaminated areas such as feedlot pens and drains. The amount of effluent generated by individual feedlots is dependent on the amount of rainfall received at the site and the characteristics of this rainfall. In order to manage this effluent so as not to create environmental harm, feedlots have a system of drains, sedimentation systems, ponds and utilisation areas associated with their facility. In short, the principle of a feedlots effluent management system is to ensure all contaminated surface runoff is captured, stored and suitably disposed or utilised.

This is typically achieved through an adequately designed drainage system that captures runoff and directs it to the holding pond system for treatment and storage. It is common for the effluent to be passed through a sedimentation system prior to storage so that entrained solids can be removed from the waste stream. As the effluent generated by feedlots is rich in nutrients (especially nitrogen and phosphorus) it is commonly utilised as both a nutrient and water source at the crop production areas associated with the feedlot. Some smaller feedlots in high evaporation and low rainfall areas utilise an evaporation basin to dispose of their effluent.

2.3.2.6 Staff/Business Facilities

The final component of a feedlot as described by Watts and Tucker (1994) is the staff facilities. This component can consist of offices, amenities, lunch rooms, car parks, a weigh bridge, and work place safety facilities. It is these facilities that are utilised by feedlot staff in the management, administration and undertaking of feedlot operations. If a feedlot facility has an automatic weather station located on-site, for convenience it is generally situated in close proximity to the staff facilities.

2.4 Climates of Australian Feedlots

2.4.1 Location of Feedlots within Australia

Whilst feedlots are located within each state of Australia, they are concentrated in Australia’s mixed farming country with the majority located in south-east Queensland, and the Northern Tablelands and Riverina regions of New South Wales (ALFA, 2002). As identified by Tucker *et al.* (1991), Australian feedlots are concentrated in the major sorghum and barley grain growing areas, most of which are within the Murray Darling basin. A typical feedlot steer consumes approximately 12 kg of feed per day (Watts *et al*., 1994b), which equates to over 4 tonnes per annum. It is therefore important that feedlots are located close to the source of feed commodities to ensure they are economically viable. Other considerations that influence feedlot locations are proximity to store cattle, labour, water resources, major highways, abattoirs and saleyards (Watts, 1994). Figure 2.4 shows the distribution of feedlots across Australia.

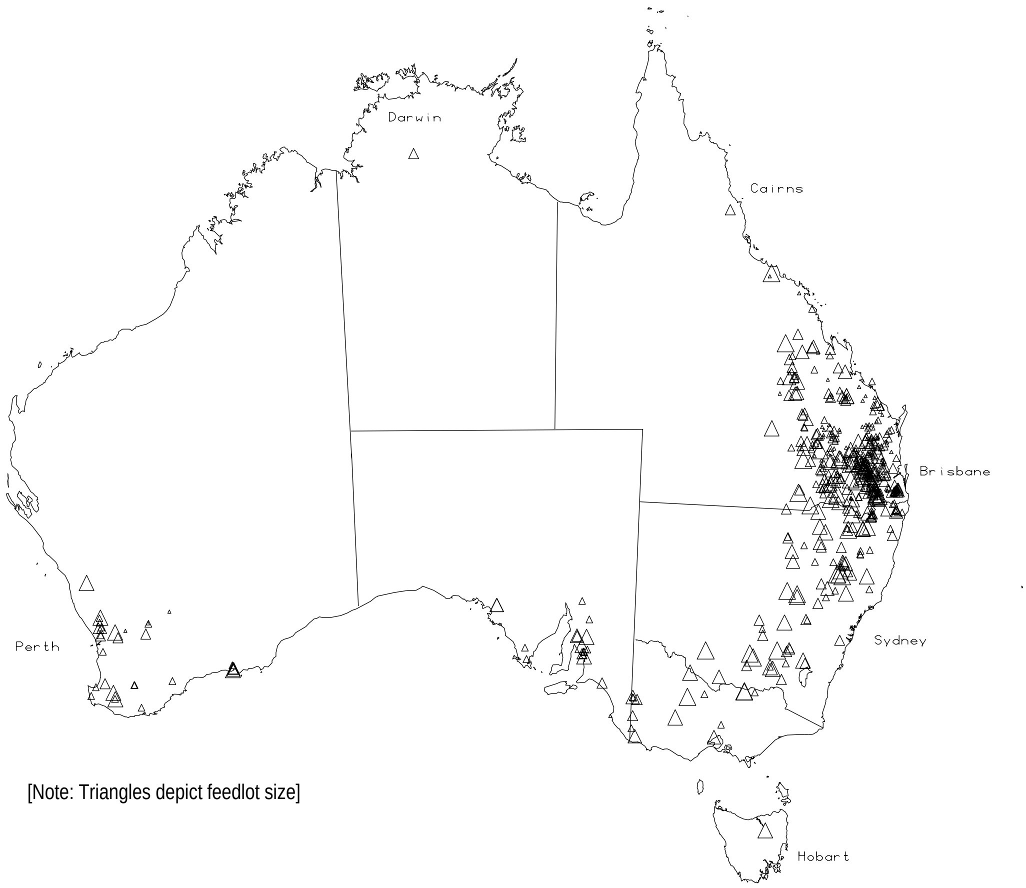

Figure 2.4. Location of Feedlots in Australia. (Source: Tucker *et al*., 1991)

2.4.2 *Regional Climates of Australian Feedlots*

Climatic conditions have an impact on both the environmental performance of a feedlot and the welfare of the cattle fed there (Watts, 1994). In relation to climate, wet conditions typically compromise the environmental performance of feedlots more significantly than other factors. Under these situations odour generation and excess run off can cause both nuisance to surrounding neighbours and environmental degradation. Watts (1994) details that locating feedlots at sites with a high annual moisture deficit and areas with a summer dominant rainfall pattern is desirable. In terms of animal welfare, it has been found that productivity decreases as the temperature increases above 35°C (Watts, 1994). Incidences of high environmental temperature and high relative humidity can also lead to hyperthermia (heat stroke) in cattle (Cronin, 2001).

Comparison of the location of Australian feedlots (Figure 2.4) with the climate classifications shown in Figure 2.1 (section 2.2), shows that the majority of feedlots fall within the 'temperate' areas of Australia. An exception to this is the large proportion of Queensland feedlots which are located within the 'subtropical' zones. The climates of the three main regions within which the majority of Australian feedlots are located are outlined in Table 2.3. The data presented in this table is derived from the Bureau of Meteorology climate maps presented in Appendix A.

Table 2.3. General climates of the three major feedlot regions in Australia.

	South-East Queensland	*Northern Tablelands New South Wales*	*Riverina New South Wales*
Mean Annual Temperature 50th Percentile	18 - 21 °C	12 - 15 °C	15 - 28 °C
Average Daily Relative Humidity - 9 am	60 - 80 %	70 - 80 %	60 - 70 %
Average Daily Relative Humidity - 3 pm	30 - 50 %	50 - 60 %	40 - 50 %
Average Annual Rainfall	400 - 800 mm	600 - 800 mm	400 - 600 mm
Average Annual Evaporation	1600 - 2000 mm	1400 - 1800 mm	1600 - 1800 mm

2.4.3 *EXISTING AND TYPICAL METEOROLOGICAL MEASUREMENTS AT AUSTRALIAN FEEDLOTS*

The ‘National Beef Cattle Feedlot Environmental Code of Practice’ (MLA, 2000) recommends that all feedlots monitor and record daily rainfall. Similarly, the ‘National Guidelines for Beef Cattle Feedlots in Australia’ (SCARM, 1997) state that “key climatic parameters may require monitoring, for example, rainfall and evaporation”. In addition to this, the guidelines maintain that “feedlot management and staff must be aware of the climatic conditions and the clinical signs in cattle that are associated with heat stress” (SCARM, 1997).

It is common for feedlots to record daily rainfall, as is the case for the majority of Australian rural properties. These data assist with the farming side of the feedlot operations (such as crop and pasture production). Rainfall records are usually derived through daily observations taken from an on-site manual rain gauge. The quality of this rainfall record is variable and can often include missing observations or misread data.

Recording of rainfall alone does not provide any great advantages in the management of animal welfare. As such, an increasing proportion of the larger beef cattle feedlots in Australia have an automatic weather station located on site. The level to which the data collected by these stations is used as a management tool is variable. Climatic parameters monitored typically include air temperature, relative humidity, rainfall, wind speed and wind direction. Additional sensors may also be installed that record barometric pressure, solar radiation, soil temperature, and soil moisture. However, experience has shown that if the data from this equipment is not readily accessible to the relevant staff, it tends not to be utilised in the day to day management of the feedlot operations.

Whilst the National Guidelines recommend that evaporation is monitored, this is not common in Australian feedlots. Recently, some commercial automatic weather station manufacturers have introduced the technology where evaporation can be calculated (by either the Priestly-Taylor formula or the Penman/Monteith formula). However this requires the station to be fitted with both a temperature and solar radiation sensor and it is desirable to also have a humidity and wind speed sensor fitted to improve accuracy. Some manufacturers do produce a Class A evaporation pan sensor that can be fitted to automatic weather stations, however this is not commonly used and is labour intensive as the pan requires manual refilling.

The quality of the collected data by automatic weather stations can be extremely variable depending on the age of the equipment and the on-going maintenance that is applied to the equipment. Automatic weather stations require regular checks and maintenance to ensure continuous operation and accuracy. Personal experience in the contract maintenance of these stations has shown that commonly, once they are installed on a feedlot site they are neglected and as such, continuous climatic data records are not often obtained.

The feedlot environment is not an ideal surrounds for sensitive electronic equipment. The harsh conditions of the feedlot environment (eg. dust, cattle, machinery) can significantly reduce the useful working life of automatic weather stations and the associated sensors. A typical example of an automatic weather station located at an Australian feedlot is shown in Plate 2.2. The sensors are situated at a nominal 2 metres above ground level and inspection revealed that they were in poor condition and some had failed due to lack of maintenance.

Plate 2.2. A 2 metre automatic weather station in poor condition located at a feedlot in south east Queensland.

In general, it can be concluded that site specific climatic data from Australian feedlot sites is not readily available. Of the feedlots that have been recording climatic data over the years, it is not uncommon for their data sets to contain significant gaps which limit the applications for which they can be used.

2.5 FEEDLOT CLIMATE STUDIES

A number of studies have been undertaken that involve the collection of climatic data around and within feedlot pens. The bulk of this work has aimed to investigate the animal and atmosphere interactions, and in particular their relation to animal heat stress and animal performance. As mentioned in Chapter 1, the MLA research project conducted over the 2000/2001 summer period also aimed to investigate the probable causes of heat stress within the feedlot climate. In allowing the climatic data to be used for this dissertation, it was agreed that this project would not investigate the interactions between the feedlot climate and animal, but rather focus purely on the climatic data in order to better quantify the microclimate variations created by, and within Australian feedlots. Notwithstanding this, it is worth examining previous studies that have been undertaken in the past, with particular consideration of the climatic data that they utilised.

The effect of climate on the performance and health of animals housed within intensive livestock systems has been the subject of a number of studies. In the US, research has been undertaken to examine the effect of both heat stress (Hahn, 1999; Mader, 2003; Mader *et al.*, 2006) and periods of severe cold (Mader, 2003) on animals. Such studies aimed to derive relationships between the recorded climatic parameters, and observed animal performance indicators (Mader *et al.*, 2006). The climatic parameters recorded were typically air temperature, relative humidity, wind speed, black globe temperature and radiation. As the key relationship for these studies was that between the climate and the animal, it was often the case that recording of climatic parameters was limited to a single site within the study area.

The effect of wind on cattle performance has also been examined (Mader *et al.*, 1997; Mader *et al.*, 1999). These studies undertaken in the US aimed to evaluate the effect that differing degrees of wind protection had on animal performance within a feedlot. The earlier study (Mader *et al.*, 1997) was conducted over a three year period, however site specific wind data was only collected from the immediate feedlot area for 3 months each year (2 months of winter and 1 month of summer) with the remainder of the climatic data obtained from a weather station 40 km from the site. The later study (Mader *et al.*, 1999) did involve the collection of climatic data (temperature, relative humidity, wind speed and direction and black globe temperatures) within the two study feedlots. As this study examined the effect of shade and wind, these climatic data were correlated against animal performance indicators and not used to compare climatic differences between sites.

A large body of research exists worldwide examining the effect of shade on animals and its relationship to heat stress (as summarised by Blackshaw and Blackshaw, 1994). For the majority of this work, climatic data is limited to that recorded by a single (or at best two) locations within the research sites. This is demonstrated by recent feedlot shade studies conducted in the US (Mitlöhner *et al.*, 2001; Mitlöhner *et al.*, 2002) and Australia (Gaughan *et al.*, 2004). Whilst these studies have collected climatic data from within the feedlot environment, their focus on the immediate effects on the animal, again only require that single sites be utilised for the recording of climatic parameters.

The limited number of climatic recording sites utilised during the research undertaken to date has restricted the level to which the climate within the feedlot can be characterised. In particular, this has prevented the direct microclimatic variations caused by the presence of feedlots, and within the feedlot environment to be determined.

CHAPTER 3 METHODOLOGY AND EXPERIMENTAL DESIGN

3.1 GENERAL METHODOLOGY

To achieve the aims of the project, the climatic parameters of several areas of the feedlot environment needed to be measured. Automatic weather stations were used to record climatic data of both the internal and external feedlot environments. The weather stations utilised allowed several climatic variables to be measured and logged at user defined intervals. These stations logged data automatically with manual input required for data retrieval and general station maintenance.

It was important to determine the climate of the area immediately surrounding the feedlot. That is, the climate of the local environment that is not affected by the presence of the feedlot and its associated facilities. It is this environment that would be used as the basis for comparisons with the internal feedlot climate in order to determine microclimatic variations that are caused through the presence of feedlots. The methodology of measuring the climate of the external feedlot environment is outlined in sections 3.2.2.1 and 3.3.2.

It was hypothesised that the presence and physical nature of feedlots causes variations in their microclimate compared to the external environment. To test the hypothesis, the internal feedlot microclimate had to be characterised. Automatic weather stations were located within the feedlot pen areas in order to measure the climatic parameters. An automatic weather station located within an open feedlot pen was used to measure climatic variables that could then be compared to those recorded within the external feedlot environment.

An increasing number of Australian feedlots provide some form of shade for cattle housed in pens. These shade structures cover a portion of the feedlot pen surface and aim to provide a cooler environment for the cattle by reducing radiant heat load. An aim of this project was to determine the influence that these shade structures have on the feedlot pen microclimate. To enable this, one of the automatic weather stations located in the internal feedlot pen environment was located under an existing shade structure within the pen. The methodology used to determine the microclimate of the internal feedlot environment, specifically within an unshaded and shaded pen, is outlined in sections 3.2.2.2 and 3.3.3 of this chapter.

The project also utilised climatic data recorded by the BoM. Available regional data was obtained for each feedlot area. This data was primarily used to validate the climatic recordings of the automatic weather stations located external to the feedlot. It was noted that some differences between the BoM regional data and the automatic weather station local data would occur due to locality, siting, and topographical differences. However, the available BoM data provided a data set that could be compared to the local measurements undertaken for this project as a relatively simple means of validation.

3.2 EXPERIMENTAL DESIGN - SITING

3.2.1 FEEDLOT SITE DESCRIPTIONS

Two feedlot sites were selected for the project. Both these feedlots were located within eastern Australia, with one site in southern Queensland, and the other situated in southern New South Wales. Feedlot selection aimed at ensuring that the sites were representative of operations in both southern and northern Australia. As detailed in section 2.4.1, these areas encompass the majority of feedlot operations in Australia. The sites were deemed as being representative of Australian feedlot operations. The geographic location of each feedlot is shown in Figure 3.1 below. The feedlots selected for the project are described in the following sections.

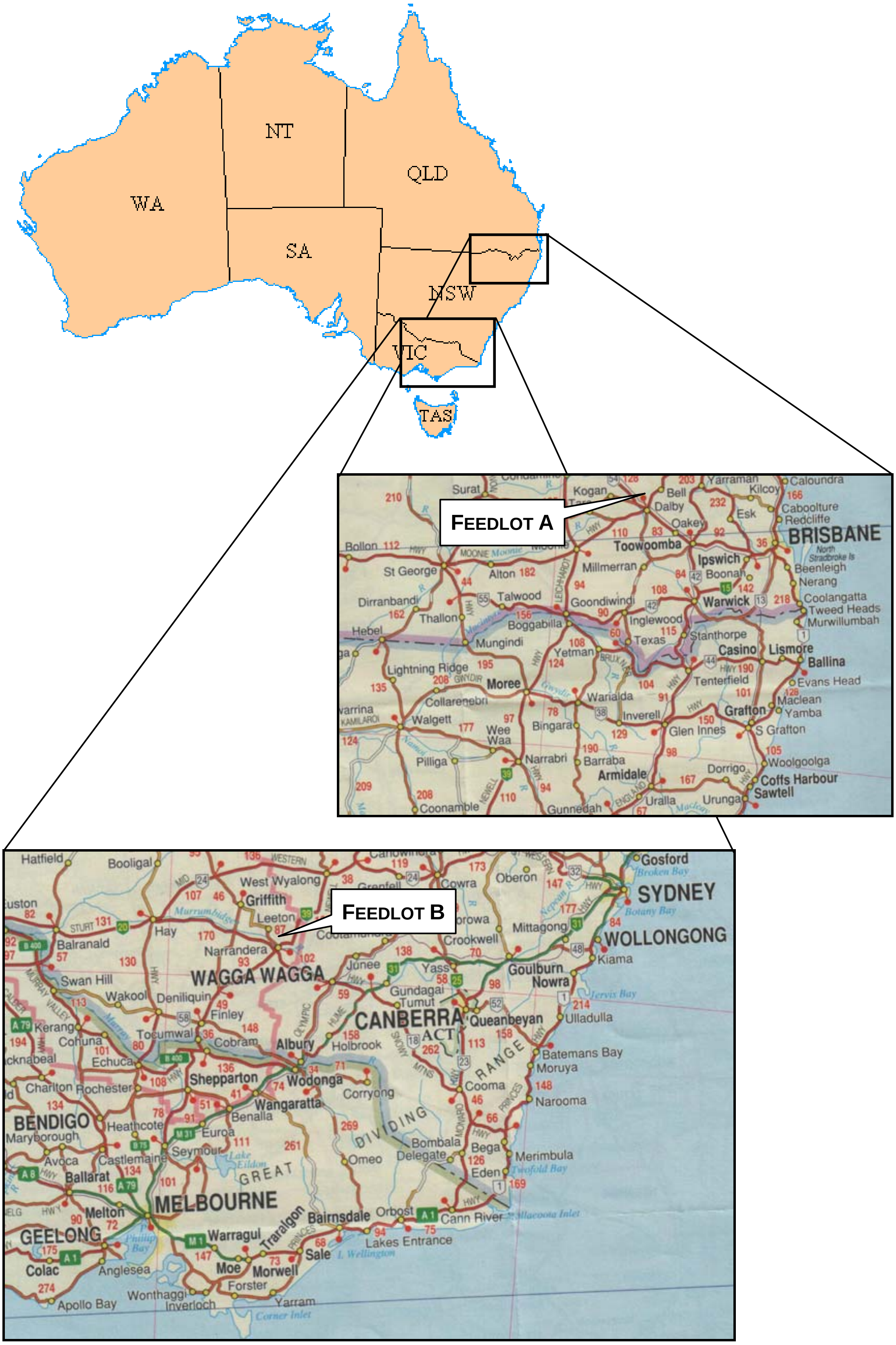

Figure 3.1. Location of Feedlot A and Feedlot B within Australia.

3.2.1.1 Feedlot A - Southern Queensland

The northern most feedlot used in the project, '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 immediate landscape of the feedlot facility can best be described as flat with the natural surface having slopes of 0 to 1%. The feedlot site is at an altitude of 370 metres AHD[4]. The surrounding area (within a 25 km radius) is also relatively flat with the only prominent features being a range 7 km to the north north east that rises to a peak of 450 metres, and beyond that a larger range with peaks of 550 metres located 16 km to the north and north east.

At the time of the project (January to March 2001) Feedlot A had an operational capacity of 18,000 head. The two feedlot pens that were selected for the siting of the automatic weather stations each had an internal area of 3200 m^2 (50 m wide by 65 m deep). Each pen was stocked with an average of 225 head of cattle over the data collection period which equates to an average stocking density of 14.2 m^2/head. These stocking densities are typical for the Australian feedlot industry.

The 2 metre weather station[5] was placed in a pen that contained a permanent 15 metre wide shade structure. This structure was composed of galvanised iron sheets, aligned north east -south west that allowed a high traverse of shade as shown in Plate 3.1. The height of the shade was approximately 4 metres above the pen surface. The galvanised sheets were 6 metres in length and two sheets were placed end to end to provide a total width of approximately 12 metres. The sheets were arranged with 300 mm spacing on all sides.

[4] AHD - Australian Height Datum

[5] Automatic weather station with a cross-arm located 2 metres above ground level on which wind and solar radiation sensors are placed. Air temperature and humidity sensors are located within a sensor shelter at a height of 1.2 metres.

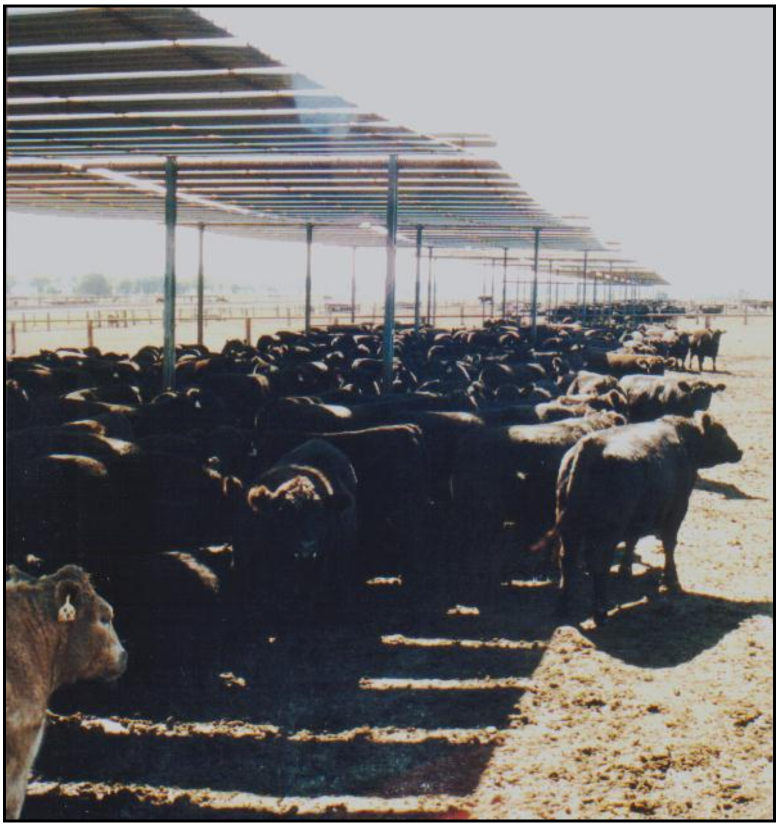

Plate 3.1. Galvanised Shade Structure at Feedlot A.

Typically the pens at Feedlot A have manure mounds formed in the centre of the pens. This is not an uncommon practice in Australian feedlots with the mounds being formed as part of the pen cleaning process. The mounds also assist in distributing stock within the pen as commonly a hierarchy is formed amongst the penned cattle with the dominant cattle positioning themselves atop the mounds and the lower orders located at the base and away for the mound. Typically the mounds are formed within the centre of the pens at heights of around 1 to 1.5 metres. For the purpose of this project, the feedlot staff removed the mounds and formed a uniform manure pad surface which had a slope of approximately 2.5% on a westerly aspect. The mounds were removed to ensure that the study pens at Feedlot A had similar pen conditions to Feedlot B where flat pen surfaces were maintained.

Several Bureau of Meteorology (BoM) stations are located within a 30 km radius of Feedlot A. At the time of the project, approximately 50 BoM stations were located in this area, and of these there were three stations that recorded meteorological parameters in addition to rainfall. These were Dalby Agricultural College (station no. 041497), Dalby Airport (station no. 041522), and Oakey Aero (station no. 041359).

The BoM station, Dalby Agricultural College is located closest to Feedlot A, being approximately 10 km to the west of the feedlot site (151°17’22”E, 27°08’57”S, 350 m AHD). This station has been recording daily precipitation and pan evaporation since January 1985.

The Dalby Airport station (151°16’02”E, 27°09’57”S, 345 m AHD), is located approximately 12 km to the west south west of the feedlot site and 3 km to the south west of the Dalby Agricultural College station. This station has been recording air temperature, relative humidity, dew point, mean sea level pressure, wind speed, wind direction, precipitation, and cloud observations since January 1992.

Oakey Aero is located approximately 45 km east south east of Feedlot A (151°44’29”E, 27°24’13”S, 406.4 m AHD). This station has been operating since January 1970 and over the study period recorded the same meteorological parameters as Dalby Airport.

3.2.1.2 FEEDLOT B - SOUTHERN NEW SOUTH WALES

The southern feedlot used in the project, ‘Feedlot B’ is located in the Murrumbidgee Irrigation Area of southern NSW. The feedlot is situated 10 km south east of Yanco (146°24’E, 34°36’S) and 12 km north west of Narrandera (146°33’E, 34°45’S).

The topography of the area surrounding the feedlot site is notably different to that of Feedlot A. The feedlot site is at an average altitude of 160 metres AHD. Several hills are located within a 5 km radius of the facility. From the centre of the feedlot pens, hills are located to the north west (205 m AHD), to the east (205 m AHD), and to the south east (228 m AHD). The ridgelines of these hills sees that the feedlot pens are arranged within what is best described as an ‘amphitheatre’ layout. The natural surface of the pen area has slopes of 2 to 4%.

Feedlot B has a licensed capacity of 53,333 head. The cattle holding pens at this site are larger than those of Feedlot A. The two pens used for the project were 100 m wide and 65 metres deep providing a total pen area of 6500 m^2. Over the project duration the stocking density of these pens averaged 15 m^2/head with over 400 head of cattle held in each pen. These stocking densities were only slightly higher than those of Feedlot A, and again are typical of Australian feedlot industry standards.

Both pens used for the project contained fixed pole structures that enabled a 15 metre wide strip of shade cloth to be fastened across the length of the pen. The shade cloth was located five metres above the pen surface and ran in a north south orientation (see Plate 3.2 below). Management of the feedlot operation sees that the pens are shaded over the warmer months of December to March, with the shade cloth pulled back the remainder of the year. For the purpose of the project the shade cloth was pulled back from one of these pens over the summer data collection period.

Plate 3.2. Shade cloth structures at Feedlot B.

The pens used for the project at Feedlot B were on a slope of 2 to 3% with a westerly aspect. The pen surfaces at this feedlot were maintained flat and relatively uniform with no manure mounds present in the pens.

The closest BoM stations to Feedlot B that record more than just rainfall data are Narrandera Airport (station no. 074148), Narrandera Golf Club (station no. 074221), and Yanco Agricultural Institute (station no. 074037).

The BoM station at Narrandera Airport is located approximately 7 km to the south east of the feedlot site (146°30’45”E, 34°42’26”S, 145 m AHD). This station has been in operation since January 1967 and at the time of the project recorded air temperature, relative humidity, dew point, wind speed, wind direction, precipitation, and cloud observations daily at 6am.

Narrandera Golf Club (146°33’33”E, 34°43’57”S, 173 m AHD), is located approximately 12 km to the south east of the feedlot site. Meteorological parameters have been recorded at Narrandera Golf Club since January 1969. Over the data collection period the station recorded air temperature, relative humidity, dew point, wind speed, wind direction, precipitation, and cloud observations daily at 9am and 3pm.

Yanco Agricultural Institute is located 6 km east north east of Feedlot B (146°25’58”E, 34°37’20”S, 164 m AHD). This station has been recording air temperature, relative humidity, dew point, mean sea level pressure, wind speed, wind direction, and precipitation at 3 hourly intervals since June 1999.

3.2.2 *Site Layout*

3.2.2.1 External Automatic Weather Stations

In order to measure the climatic conditions of the surrounding feedlot environment, four automatic weather stations were positioned outside each of the feedlot areas (referred to as the external stations). 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 general north-south and east-west axis with one station located on each side of the feedlot. This positioning was selected to measure the climatic parameters of the full feedlot surrounds. Situating one station on each side of the feedlot, allowed climatic variations that may be caused by changes in wind direction, general topography, vegetation differences, and location of structures associated with the feedlot and farming operation to be accommodated. This was particularly important due to the fact that it was not possible to undertake climatic measurements of each area prior to the establishment of the feedlot. For example, it was assumed that the station located down wind of the feedlot would be likely to experience climatic differences due to the modification of the airflow after traversing the feedlot pens. It was expected that differences in air temperature, humidity and wind speed may be observed.

Based on the above, a station was situated to the North, South, East and West of each feedlot. It was not possible to locate the stations on these exact compass points and stations were required to be moved off an axis where interference was expected from the feedlot or farm structures, vegetation, or other topographical features. The boundaries of the feedlot properties also created some constraints in station siting.

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 (in accordance with 10-times-the-height rule as outlined by AS 2923 - 1987). 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 final separation distances from the external automatic weather stations to the feedlot pen area boundary are detailed in Table 3.1 below. A brief description of the individual station locations are provided below.

Table 3.1. Separation distance from external weather stations to feedlot pen boundary.

Station Number (Location)	*Feedlot A*	*Feedlot B*
Station 1 (East)	78 metres	478 metres
Station 2 (South)	389 metres	298 metres
Station 3 (West)	174 metres	109 metres
Station 4 (North)	115 metres	602 metres
Station Average	189 metres	372 metres

Feedlot A

Figure 3.2 shows the arrangement of the four external stations and two internal stations at Feedlot A in relation to the general feedlot perimeters and the study pens used in the project.

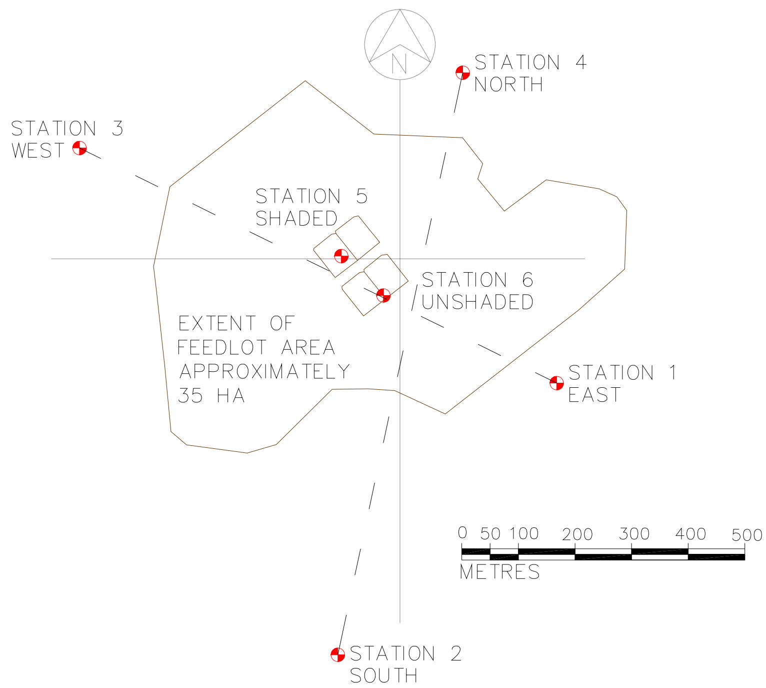

Figure 3.2. Layout of Automatic Weather Stations at Feedlot A.

The eastern station at Feedlot A (Station 1) was located within a grazed paddock between the feedlot pen area and the property boundary. The vegetation in this area consisted of grasses and weeds generally no higher than 0.4 metres. The area was stocked with horses which maintained the low vegetation cover. This station was the closest located to the feedlot pen area due to the constriction caused by the narrow area between the pens and the property boundary and also the required separation distance from a line of trees located along the property boundary.

Station 2 at Feedlot A was positioned south of the feedlot area. This station was located furthest from the pen area due to the proximity of the feedmill facility, storage sheds, and hay stockpiles immediately south of the feedlot. The station was situated beyond these structures to provide adequate separation distances. The station was located within a grazed paddock with low vegetation (less than 0.4 metres).

The western station (Station 3) was located within the middle of a paddock used for cropping. For the majority of the data collection period the paddock was in fallow and as such consisted of bare ploughed earth or minimal vegetation cover. There were no obstructions between this station and the feedlot pen area (see Plate 3.3 (a)).

Plate 3.3. The western [left] and northern [right] external automatic weather stations at Feedlot A.

Station 4 to the north of the feedlot was also located in a cropping paddock that was fallow for the data collection period. The closest obstruction to this station was a single tree however the horizontal separation distance to the station was greater than 10 times the height of the tree (see Plate 3.3 (b)).

Feedlot B

The position of the four external stations and two internal stations in relation to the feedlot pen area at Feedlot B is shown in Figure 3.3 below. It is noted that the same scale of mapping is used in Figure 3.2 and Figure 3.3 to permit direct comparison of size between the two feedlots.

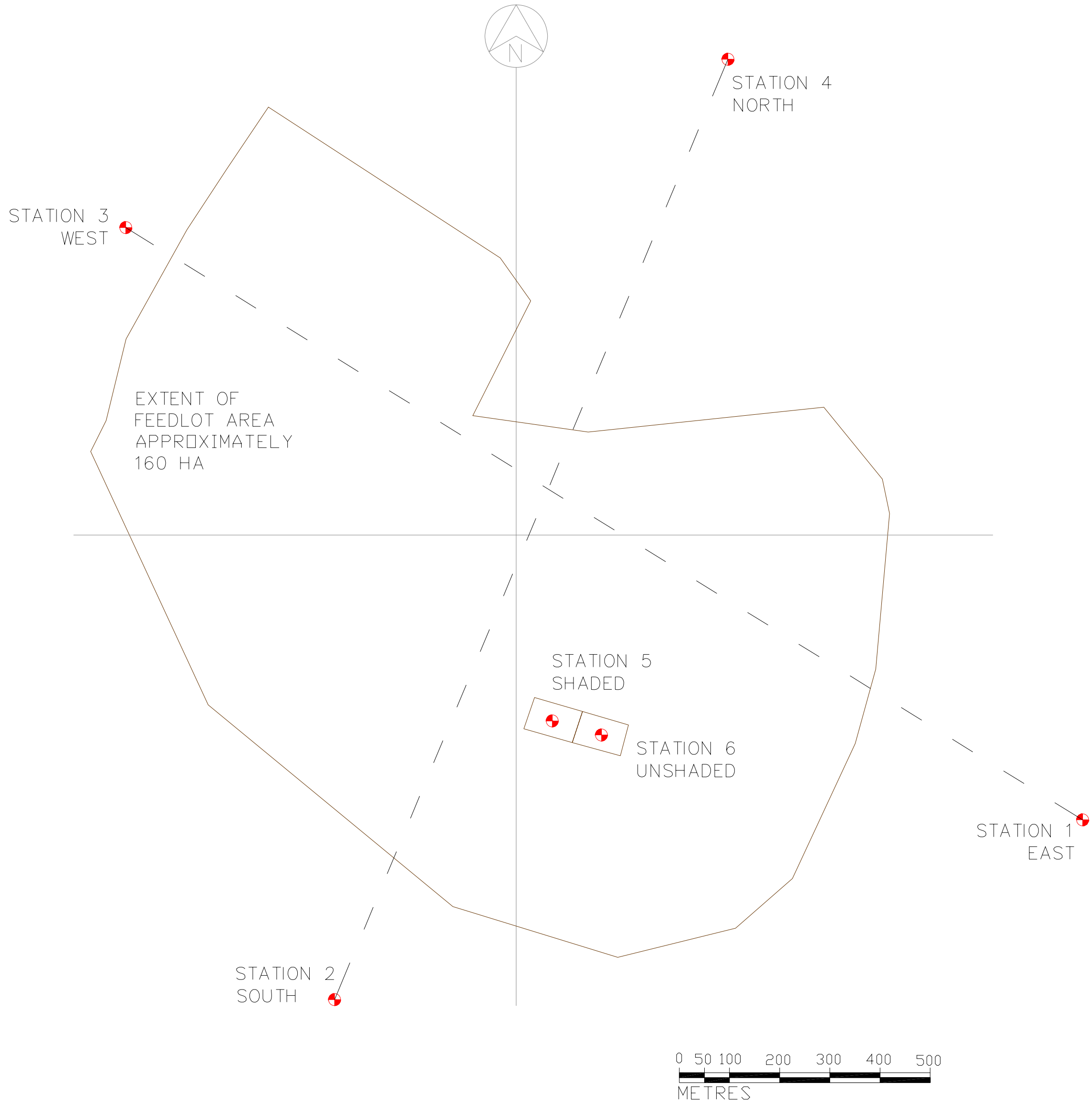

Figure 3.3. Layout of Automatic Weather Stations at Feedlot B.

At Feedlot B, there was restricted land area between the eastern edge of the feedlot pen area and the property boundary. Sufficient separation distance was required to eliminate any potential climate boundary layer effects that may be caused by the feedlot pens. It was important that the weather stations outside the feedlot pen area recorded climatic data representative of the external environment. To ensure adequate separation distance between the feedlot pens, the automatic weather station was situated on a neighbouring property.

The eastern station (Station 1) was located on an existing fence line on the neighbouring property. The paddock within which the station was located was vegetated with dry grasses up to approximately 0.8 metres in height. The grass within the weather station enclosure was cut to ensure minimal interference with the weather station operation and to allow easier access. The paddock directly to the south of the station had recently been ploughed and remained in fallow throughout the data collection period. The immediate land area around this station was relatively flat, however a small ridge with a large water tank was located between the station and the feedlot pens (illustrated in Plate 3.4).

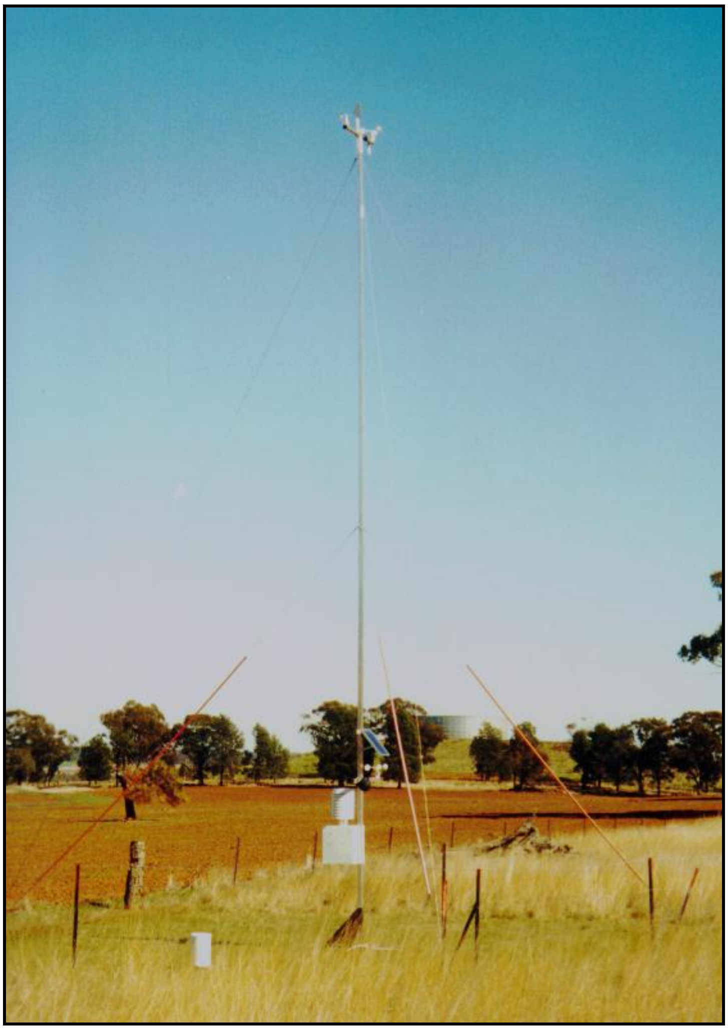

Plate 3.4. The eastern external automatic weather station at Feedlot B.

Station 2, located to the south of the feedlot pen area, was situated within a dry cropping paddock. Whilst the area surrounding this station was bare ploughed earth, some low level vegetation covered the ground immediately around the station mast and rain gauge. Some large ponds used for the storage of abattoir wastewaters were located approximately 500 metres to the west of the station. The station was located within a flat area of slopes less than 1%.

The western station (Station 3) was located on a slightly sloping area (2 to 3%). This station was the closest located to the cattle pen areas at Feedlot B. The land area around this station was relative uniform with the exception of a contour bank that was located between the station and the feedlot pens. The vegetation immediately around the weather station was generally grasses and weeds up to 0.4 metres in height. Approximately 50 metres to the north of the station the ground cover was markedly different consisting of well maintained lawns and a small golf course.

Station 4 to the north of the feedlot was situated higher than the other stations being located towards the top of a hill that incorporates the feedlot pen area. The altitude difference between this station and the lowest (Station 2) was approximately 35 metres. Although the station was situated on a hill, the immediate area surrounding the site was relatively flat. Groundcover consisted of weeds and grasses less than 0.4 metres in height. In close proximity to this station was an abandoned quarry (to the north) and current manure composting operations (located to the south east down the hill slope).

3.2.2.2 INTERNAL AUTOMATIC WEATHER STATIONS

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 aimed to ensure that the study pens were representative of the general feedlot conditions at each site and also that the selected pens were comparable across the two sites. It was also important to make certain 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).

The layout of the four study pens at Feedlot A and location of these stations within the pens are shown in Figure 3.4.

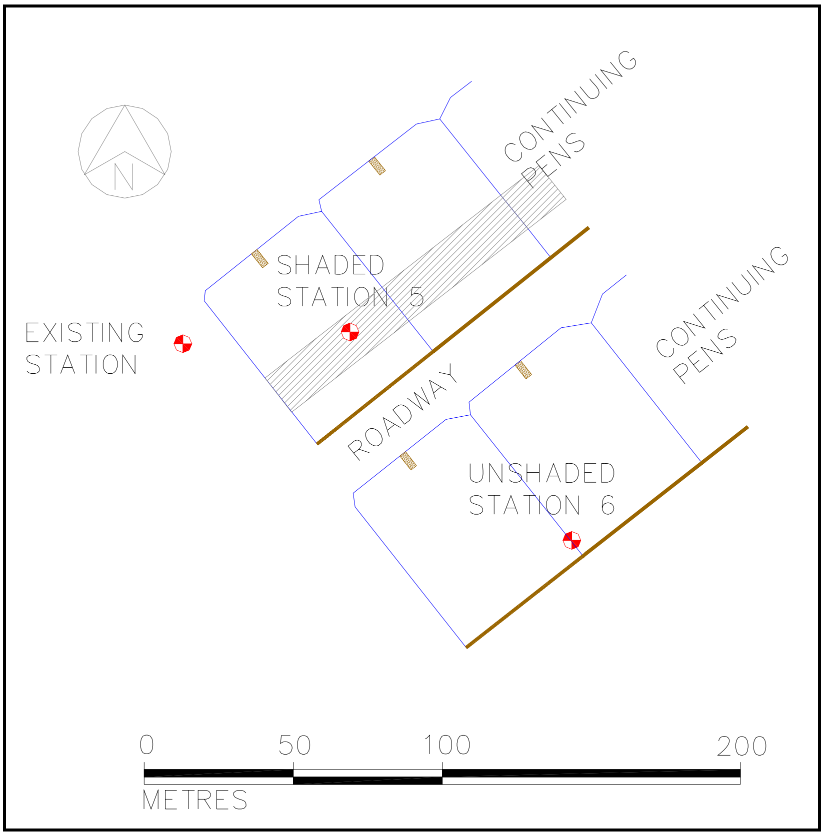

Figure 3.4. Layout of automatic weather stations within the feedlot pens at Feedlot A.

At Feedlot A, a 10 metre station was positioned close to the fence adjoining the unshaded pen that was 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).

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 equipment.

Figure 3.5 below outlines the layout of the two study pens at Feedlot B and location of these stations within the pens.

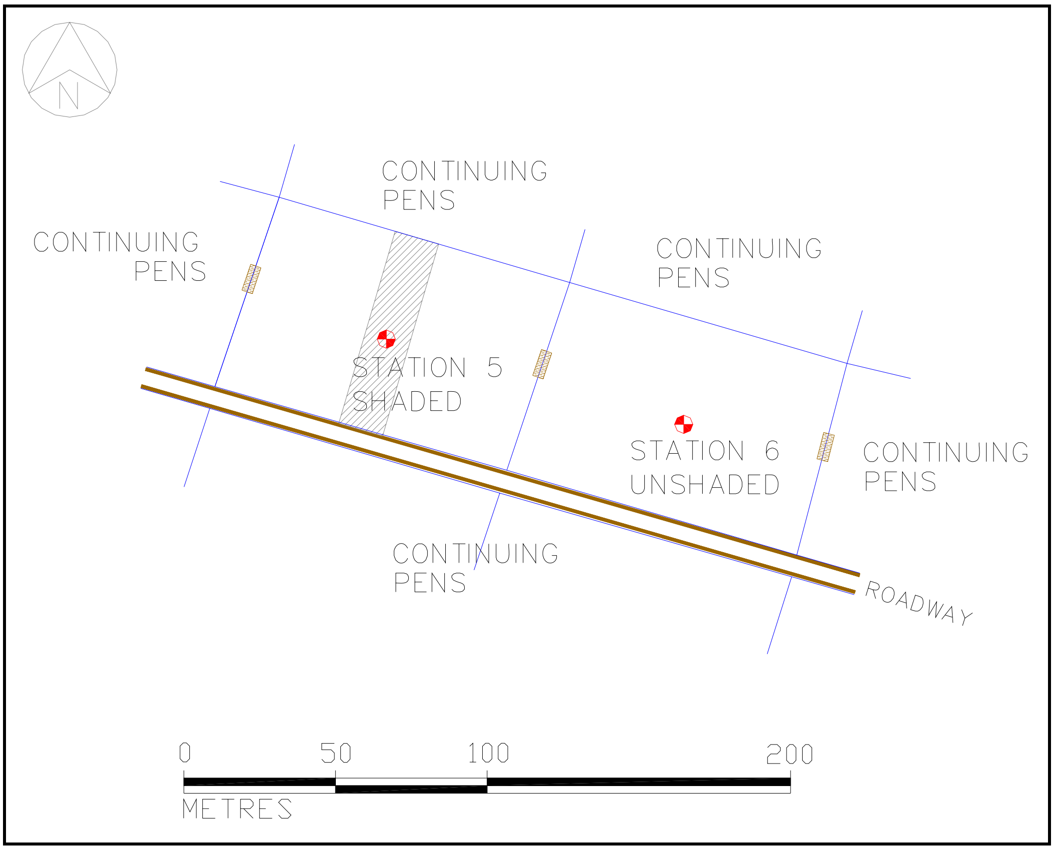

Figure 3.5. Layout of automatic weather stations within the feedlot pens at Feedlot B.

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. 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.

3.3 Experimental Design - Measurements

3.3.1 Climatic Parameters

The selection of climatic variables measured over the project period was primarily driven by the objectives of the industry funded MLA research project FLOT.310. That is, the terms of reference of the MLA project outlined some suggested climatic parameters that may be measured at each feedlot site. Whilst these suggested parameters were not mandatory, the strict time frames of the project and the quantity of monitoring sites required at each feedlot location restricted the project equipment to readily available "off the shelf" components.

The large amounts of automatic weather station components required for the project were supplied by one manufacturer. Sensors were obtained that would record air temperature, relative humidity, wind speed, wind direction, solar radiation, ground temperature and black globe temperature. The data logging equipment used in conjunction with these sensors allowed the frequency of data recordings to be set as required.

Black globe temperature was included in the measured variables primarily to assist in the animal heat stress observations undertaken for project FLOT.310. This measurement of 'radiant heat' is commonly used in studies of animal/environment energy relationships.

The solar radiation sensors used in the project measured the short-wave (global) spectrum only. Sensors that could measure long-wave (terrestrial) radiation were not available from the manufacturer and could not be sought in the required project time frames. The calculation of long-wave radiation through the measurement of soil surface temperature and estimation of emissivity was considered. However, the quantification of this parameter was not essential in meeting the objectives of the industry research project so it was decided not to acquire and install the soil surface sensors. As such, this project has not examined this aspect of the feedlot microclimates.

Relative humidity sensors were selected for the measurement and description of humidity. The primary reason for this is the general recognition that relative humidity provides a better indication of human (and therefore animal) comfort compared to other methods such as determination of absolute humidity or vapour pressure density. As previously outlined, an objective of the MLA project was to investigate animal comfort and in particular heat stress incidents.

3.3.2 *External Automatic Weather Stations*

The external stations positioned outside of the feedlot were installed for the purpose of enabling the potential topographical effects on the local climate at the feedlot to be defined. It was presumed that differences between the four stations would be recorded due to variations in landscape features, surface slope, aspect, and ground cover. Recording the climatic parameters at four separate locations around the perimeter of the feedlot would provide sufficient data sets that could be combined to provide a single set of meteorological parameters representative of the external feedlot environment. This would enable differences in the external and internal climates to be examined.

The climatic variables recorded at each of the four stations positioned outside the feedlot are outlined below in Table 3.2. The weather station configuration was kept consistent between both feedlot sites.

Table 3.2. Sensor Configuration for the External Weather Station.

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
Relative Humidity	1.2 metres	1.2 metres	1.2 metres	1.2 metres
Black Globe Temperature	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
Ground (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

3.3.3 *INTERNAL AUTOMATIC WEATHER STATIONS*

The two internal stations were used to define microclimatic differences between shaded and unshaded pens. The study aimed to define the microclimate of the feedlot through the determination of the following factors:

- the temperature and humidity profile in both an unshaded and shaded pen;
- the rate of air movement within the feedlot;
- 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.

The climatic variables recorded at the stations positioned within the feedlot pens are outlined in Table 3.3 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.

Table 3.3. Sensor Configuration for the Internal Weather Stations.

Sensor Type	*Sensor Location*	
	Station 5 - Shaded Pens	*Station 6 - Unshaded Pens*
Air Temperature	1.2 metres	1.2 metres
Relative Humidity	1.2 metres	1.2 metres
Black Globe Temperature	2 metres	2 metres
Wind Speed	2 metres	2 metres & 10 metres
Wind Direction	2 metres	10 metres - Feedlot A 2 metres - Feedlot B
Ground (manure pad) 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 pen surfaces which could then be compared to the albedo of the external feedlot environment.

3.3.4 PROJECT DURATION

The terms of reference of the commercial research project for which the data was collected required climatic parameters to be recorded during the 2000-2001 summer period. The suggested period was 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. These delays saw that 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 climatic measurements were completed and all field equipment was decommissioned in late April and early May for Feedlot A and Feedlot B respectively. Specific dates for both feedlot sites are detailed in Table 3.4 below.

Table 3.4. Outline of Progress for Field Measurements.

Activity	*Feedlot A*	*Feedlot B*
Commencement of Weather Station Installation	19 December 2001	2 January 2001
Commencement of Climatic Data Recording	1 January 2001	9 January 2001
Completion of Climatic Data Recording	22 April 2001	7 May 2001
Dismantling of Weather Stations	23 April 2001	8 May 2001

As outlined in the above table, the four external stations and two internal 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. For this project the detailed data analyses were focused on the period from January to March 2001. It is over this period that the most regular site visits and frequent weather station maintenance was undertaken to ensure data integrity (see section 3.4.3).

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).

3.4 EQUIPMENT

3.4.1 AUTOMATIC WEATHER STATION SENSORS

Specific details of the automatic weather station sensors used in the project are outlined in the following sections. The majority of this information was obtained from the weather station equipment manufacturer and supplier - Monitor Sensors. Appendix B contains the manufacturer specifications which provide more detailed information on each sensor type.

3.4.1.1 AIR TEMPERATURE SENSOR

Ambient air temperatures were measured using a 'Monitor Sensors μ-smart series model TA1 Air Temperature sensor'. The sensors were located within a sensor shelter on each automatic weather station. This sensor type uses a miniature diode connected transistor sensor mounted either at the end of a 4 mm diameter stainless steel tube projecting from the electronic sensor housing. The sensing element is connected to a microprocessor controlled electronics package and was set to a high resolution mode to provide an output in 0.002°C steps (refer Appendix B).

3.4.1.2 RELATIVE HUMIDITY SENSOR

For the project relative humidity was measured using a 'Monitor Sensors μ-smart series model HU1 Relative Humidity sensor'. This type of sensor utilises a polymer capacitor as a sensing element. The dielectric constant of the element surface changes with the absorption of atmospheric moisture which causes a change in capacitance that is detected and converted to a relative humidity reading. The sensing element is connected to a temperature compensated microprocessor controlled electronics package, providing an output resolution of 0.01% (refer Appendix B). The relative humidity sensors are encased in a stainless steel cylindrical body with a sintered bronze filter at one end that protects the sensor from insects and airborne debris. The relative humidity sensors were located along with the air temperature sensors inside a sensor shelter.

3.4.1.3 BLACK GLOBE TEMPERATURE SENSOR

Black globe temperature was recorded using a 'Monitor Sensors μ-smart series model TA1 Air Temperature sensor' located inside a 160 mm diameter copper globe coated with a matt black finish. This configuration enables the temperature sensor to monitor the effects of direct solar radiation on an exposed surface. The black globe temperature sensors had a resolution of 0.002°C.

3.4.1.4 WIND SPEED SENSOR

Wind speed data was measured using 'Monitor Sensors μ-smart series model WD2 Anemometer (wind speed sensor)'. These sensors are fitted with three conical aluminium anemometer cups that have been developed to provide an approximately linear relationship between rotational speed and actual wind speed. An internal electronic 'gear box' within the sensor provides a digital change of state output as a measure of wind run with one pulse representing 10 metres of wind run (refer Appendix B). The AN2 model anemometer has a starting threshold of 0.1 m/s, a range of 0.2 to 40 m/s (3.6 to 150 km/h) and provides a resolution of 0.001 m/s. The anemometers were mounted on both the 2 metre and 10 metre cross arms of the automatic weather stations.

3.4.1.5 WIND DIRECTION SENSOR

Monitor Sensors μ-smart series model WD4 Wind Direction sensors were used for the project. These sensors utilise a design that incorporates a continuous rotation type microprocessor controlled sensor to provide an accurate angular reading of the wind direction (refer Appendix B). The WD4 model wind direction sensor provides a single output of angle for wind direction and also computes the sigma theta directly in the sensor.

Sigma theta σ_θ is the standard deviation of the horizontal wind direction fluctuation and provides an indication of the variability of the wind direction that has been recorded over the averaging period. Sigma theta σ_θ is calculated as follows (US EPA, 2000):

$$\sigma_\theta = [1/N \sum (\theta_i - \theta_m)^2]^{½} \qquad [Eq. 3.1]$$

where N = number of valid wind observations

θ_i = azimuth angle of the wind vector (ie. the wind direction)

θ_m = mean azimuth angle of the wind vector (ie. the mean wind direction)

The calculation of sigma theta enables the standard deviation of the direction angle to be recorded in the data logger in association with the average wind direction based on the user defined period. For the project, the wind direction sensors were mounted on either the 2 metre or 10 metre cross arms of the automatic weather stations.

3.4.1.6 Ground Temperature Sensor

The Monitor Sensors ground (soil) temperature sensors are identical to the model TA1 air temperature sensors except that they are manufactured with extra cable to allow the sensor to be buried in the soil at the required depth. The stainless steel casing of the sensor is weather and corrosive resistant however the sensors were fitted inside a section of polyethylene pipe to provide extra protection for the project. The sensors were dug into the ground (soil for external stations, manure pad for internal stations) at depths of 50 to 100 mm.

3.4.1.7 Rain Gauge

In order to record precipitation selected automatic weather stations were fitted with a 'Monitor Sensors μ-smart series model RG2 Tipping Bucket Rain Gauge'. This equipment provides a reliable measurement of both rainfall quantity and rainfall intensity. Rainfall is captured in a 203 mm diameter collector funnel and is directed through a delivery pipe to fill a divided tipping bucket device. The bucket is pivoted through its centre and has a preset calibration to tip for 0.2 mm of rainfall. Once the bucket fills, it pivots and empties which magnetically closes and opens a switch, sending a pulse signal to the data logger or electronic counter. Once one side of the bucket tips, the other side is aligned to receive subsequent flow from the delivery pipe, hence the recording and tipping cycle continues with rainfall. The RG2 has a range of 0 to 508 mm rainfall per hour and an accuracy of ±2% for rainfall intensities greater than 127 mm/hr and ±3% when the intensity exceeds 254 mm/hr (refer Appendix B). The rain gauges used for the project were located on a levelled steel plate placed on the ground at least 4 metres from the base of the automatic weather stations.

3.4.1.8 INCOMING SOLAR RADIATION SENSOR

The project used 'Monitor Sensors μ-smart series model SR2 Solar Radiation sensors'. These are described as a solar radiation shortwave (global) spectrum sensor with a spectral response from 400 to 950 nanometres that can be used to record sunshine hours or total incident solar energy (refer Appendix B). The sensors use a shaped Teflon diffuser, in which is housed the photovoltaic sensor. This enables the sensors to correct for the changing angle of incidence as the sun moves across the sky. The manufacturer states that the "cosine correction" follows the theoretical spectral curve to within 2%. The model SR2 has a range of 0 to 2000 W/m^2 and an accuracy of ±5%. For the project the solar radiation sensors were installed at the highest cross arm of the automatic weather stations (10 metres for all stations except the 2 metre stations within the shaded pens).

3.4.1.9 OUTGOING SOLAR RADIATION SENSOR

Outgoing radiation was measured by using a model SR2 radiation sensor (identical to the incoming radiation sensor) orientated towards the ground surface. These sensors were 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 station structures, which are concentrated at the lower sections (eg. logger housing and sensor shelter).

3.4.2 AUTOMATIC WEATHER STATION INFRASTRUCTURE

The automatic weather station infrastructure used in the project was also obtained from Monitor Sensors. The AWS masts and cross-arms of the stations were constructed of square section aluminium. The aluminium masts and cross-arms of the 2 metre stations used in the project were protected by white PVC powder coating, whilst the majority of the 10 metre infrastructure was bare aluminium.

Both the humidity and air temperature sensors were housed within a sensor shelter on each station. The sensor shelters serve the same purpose as conventional 'Stevenson Screens' and are designed to use natural ventilation in order to minimise the inaccuracy of ambient air temperature and relative humidity measurements that may be caused through radiation effects. In addition to providing a barrier against solar radiation, the shelters provide some protection to the air temperature and humidity sensors.

As can be seen in Plate 3.5 the sensor shelters consist of eight spun aluminium louvres that are protected by a PVC powder coated finish. In order to minimise differentials between the screen and true ambient temperatures the shelter roof is insulated with Styrofoam and the louvres have a black matt coating on the underside.

The sensor shelters are situated on top of the logger housing of each station. The data logger, battery, and GSM systems are located within the logger housing. The data loggers used in the project allowed each sensor's sampling rate to be set individually from as frequently as 1 second to a maximum sampling period of 24 hours. Collected data could be retrieved from the loggers through a direct RS232 cable connection to a laptop computer or through the GSM communications.

The data logger and remote communication systems were powered by a battery system that was recharged by a solar panel permanently located on the automatic weather station. Plate 3.5 shows the components of a standard Monitor Sensors 2 metre automatic weather station similar to those used in this project.

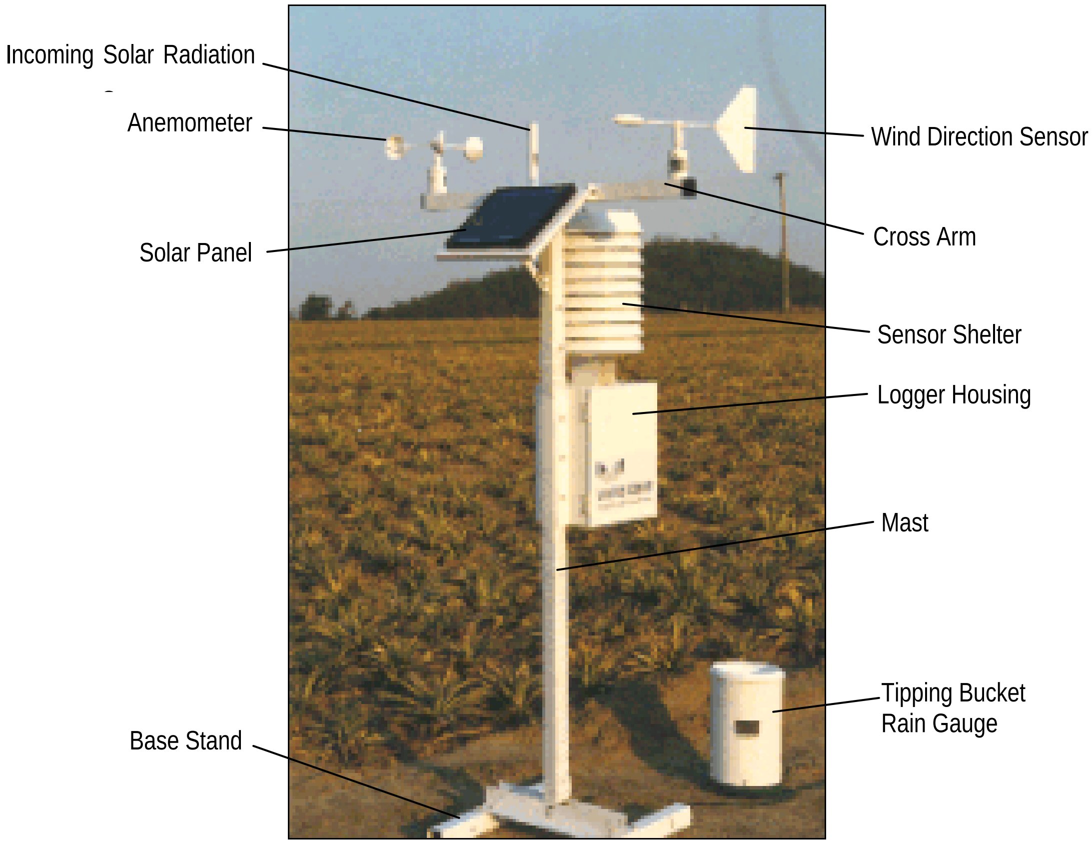

Plate 3.5. The components of a 2 metre automatic weather station. (Photo: Monitor Sensors).

3.4.3 DATA INTEGRITY

All sensors used had undergone standard calibration by the manufacturer prior to delivery. The majority of the sensor units were provided with a multi-point calibration curve.

In order to ensure that the collected data was of quality and remained accurate throughout the data collection period mobile communications were established at selected stations and regular site visits were undertaken by the author and E.A. Systems Pty Limited staff.

The establishment of mobile communications was undertaken through 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 collect 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. It was also presumed that easterly patterns typically prevailed at both sites hence these measurements were least likely to be affected by the feedlot. The quality of digital mobile phone reception was also considered at both sites and was found to be adequate at both eastern weather stations. The mobile communication systems were used to check the data and sensor integrity of the stations on a weekly basis. The mobile communications were also utilised for 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 to the feedlot sites. During these visits all stations were serviced to ensure that all sensors and solar panels 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 at the time of the regular site visits. These included the verification of temperature and humidity sensors using a hand held sling psychrometer.

It is 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. Dust and fly dung build up was more common within the feedlot pens. This had the potential to impair the performance of the solar panel, solar radiation, relative humidity and black globe sensors.

CHAPTER 4 COMPILATION AND ANALYSIS OF CLIMATE DATA EXTERNAL TO THE FEEDLOT

4.1 INTRODUCTION

This chapter outlines the data collection and collation processes that were undertaken for this project. In particular it details the procedure that was used to produce single representative external data records from the climatic data measured by the four individual external automatic weather stations located adjacent to each feedlot site. The purpose of this was to compile a single data set for each feedlot site that provided representative climatic data of the external feedlot environment. That is, the area immediately surrounding the feedlot facility whose climate was not significantly affected by the presence of the feedlot pens and associated infrastructure. Producing a single data set for each feedlot site provided efficiencies when comparing the external feedlot data to that of the climatic data collected within the feedlot pen area.

It was judged that the best means of ensuring integrity of the project data was to undertake a comparison of the external feedlot data with climatic data recorded by surrounding Bureau of Meteorology (BoM) stations. If the external feedlot data set was similar to climatic data recorded by nearby BoM stations, then a high level of confidence could be placed on the project data. This chapter details the analyses that were undertaken to compare the project and BoM data and provides the results of these analyses.

4.2 DATA COLLECTION

Data were collected directly from the automatic weather stations during the fortnightly servicing visits to each feedlot site. Communication with the data logger of each station was established using an RS232 data link cable connection to the serial port of a laptop. The Microsoft Windows® based program 'HyperTerminal' allowed the logger menu screen to be accessed on the laptop and the stored data could be viewed, captured and saved as a ‘comma-delimited text file’. This file type could easily be imported into Microsoft Excel® for compilation and analyses of the data.

Whilst mobile communications were established at three of the automatic weather stations at each feedlot site, this communication system was primarily used for weekly checking of the sensor and logger serviceability rather than obtaining data.

4.3 DATA COLLATION

4.3.1 COMPILATION OF RAW DATA

All downloaded data collected manually from the automatic weather stations were imported into Microsoft Excel® for compilation. The downloaded data were combined into a single spreadsheet for each individual weather station.

Initially these spreadsheets included recorded hourly data for all climatic parameters except wind speed and wind direction, which were logged every 10 minutes. In order to reduce the size of the data sets and to provide easier data management, the 10 minute wind data were reduced to hourly averages. The data were scrutinised for anomalies, and when found, these were rectified as described below.

Typical examples of data anomalies included instances when the logger recorded a false reading (eg. a text character) or where a transmission problem during the data download caused sections of retrieved logged data to be erroneous (eg. data columns scrambled or a series of nonsensical values). Generally, these errors were minor and occurred infrequently (affecting less than 0.1% of the total data set). Single readings that were obviously incorrect were deleted from the data set. In cases where these anomalies affected a large section of data, the logger would be accessed for a second time to retrieve the data for that affected period. It was uncommon for the same anomalies to occur over two separate downloads; hence the second set of collected data was used to replace the original errors.

This initial scrutinising and data compilation produced an hourly data set for each of the six stations from the two feedlot sites over the three month period from 1 January to 31 March 2001. It is noted that sporadic failure of some sensors and occasional logger errors did result in gaps within these data sets. Appendix C details these data gaps and the reasons for the missing data. This Appendix also highlights other errors in the readings that were found during the data collation and analyses.

4.3.2 *External Station Data Averaging*

The data from the four external stations at each feedlot site were combined to make a representative average of the climatic conditions outside the feedlot pen area. This was done to simplify the process of data comparison between the internal and external climatic data sets. It enabled comparisons to be made using one single data set from the external stations at each feedlot site, as opposed to separate data from the four individual stations.

In order to determine the integrity of the data, the differences in readings between the individual external stations were plotted against time. These plots were produced for the nine climatic parameters measured at the external stations. These were: wind direction; wind speed measured at 2 metres; wind speed at 10 metres; air temperature; black globe temperature; ground temperature; relative humidity; incoming solar radiation; and outgoing (or reflected) solar radiation.

For each parameter, six fortnightly plots were produced that covered the total period from 1 January to 31 March 2001. The plots were separated into two weekly periods so that the data was not clustered and could be better examined visually. An example plot is shown in Figure 4.1 below. This figure presents the differences in wind direction data recorded by the external stations at Feedlot A. The three data sets plotted are the data recorded at the southern external station (Station A2) less the data recorded at the other three external stations. This plot shows that data recorded at the western (A3) and northern (A4) stations were very similar, however the data plots lie around the 90° value. This indicates that these two stations were constantly recording readings that were in the order of 90° less than the wind direction recorded at station A2. This anomaly was found to be an error in the alignment of the sensor at station A2. The plot also shows the data from the eastern station (A1) was variable leading up to the 7 February and during this day the sensor ceased recording. It was found that on most occasions of individual sensor failure, this event was preceded by erratic and erroneous data.

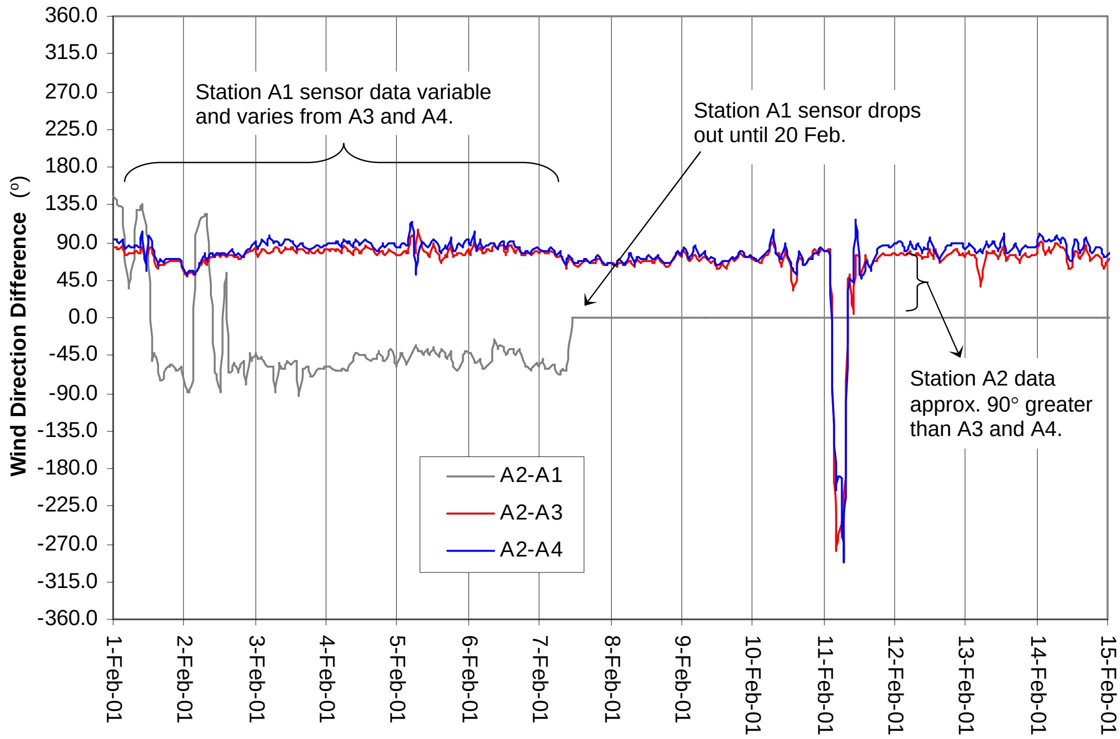

Figure 4.1. Wind direction differences measured by the external stations at Feedlot A for the period 1 to 14 February 2001.

For the period shown in Figure 4.1, the data used to provide a representative external 'average' was the wind direction data from stations A3 and A4. Whilst it appeared the data from A2 was approximately 90° different from A3 and A4, further analysis showed that this error was not constant and as such, the A2 data could not be simply corrected and incorporated into the data set. This process of plotting, examining, and then removing inconsistent data was undertaken for the nine climatic parameters recorded by the four external stations at each feedlot site. The end result was a single external data set for each feedlot site with which a high level of confidence was held in terms of its representativeness of the climatic conditions for the surrounding environment of each feedlot site.

It is noted that initially the compilation of the external station data was going to exclude data from the station located downwind of the feedlot pen area. This was based on the assumption that the downwind station would possibly be affected by the air moving from the feedlot pen area. This was not undertaken in the production of the final external data set for several reasons. The primary reasons were that several data gaps existed in individual station data which required that all available data be used, and secondly, a review of the wind direction data showed that for large periods the recorded wind direction varied significantly over short periods of time. This would have significantly complicated the compilation of a data record that consistently excluded the downwind station. Whilst the downwind station data was included in the final external average data set, it is envisaged that any anomalies in the data (caused by the presence of the feedlot or otherwise) would have been identified and removed in the initial data screening process detailed above. It was assumed that the averaging of all available climatic data of the external stations would minimise the effects of any anomalies from the downwind station.

Comparison of the entire two weekly data plots for all nine climatic parameters showed that generally there was minimal divergence between the data of the four external stations at each feedlot site. In particular air temperature, black globe temperature, relative humidity and incoming solar radiation data were closely aligned across all external stations, with the exceptions to this being during short periods of individual sensor faults (as summarised in Appendix C). Similarly, outgoing (reflected) radiation values showed minimal variations however some differences were noted in the daily maximum values as would be expected due to differences in ground surface conditions. As expected wind direction and wind speeds (particularly at 2 metres) showed greater deviation as would be expected due to siting variations such as landscape, topographical, and exposure differences. Differing soil conditions and sensor depths would have caused the minor variations observed in the plots of ground temperatures for each feedlot site.

4.4 COMPARISON OF PROJECT AND BUREAU OF METEOROLOGY DATA

Comparison was made with data from nearby Bureau of Meteorology (BoM) stations to ensure the integrity of the average external station data set produced for each feedlot site. Available climatic data was obtained from three BoM stations located in close proximity to each feedlot site. Details of the BoM stations are provided in section 3.2 of Chapter 3. A list of the data obtained from these BoM stations for the period 1 January to 31 March 2001 is provided in Table 4.1 and Table 4.2 below.

In addition to the data outlined in these tables, daily maximum and minimum values of air temperature were obtained for Oakey Aero, Dalby Airport, Yanco Agricultural Institute, and Narrandera Golf Club for the period 1 January to 31 March. Daily rainfall totals recorded at 9am for these stations were also obtained from the BoM for the same 3 month period.

Table 4.1. Data obtained from Bureau of Meteorology stations near Feedlot A.

BoM Station Name: *BoM Station No:*	Oakey Aero 41359	Dalby Ag College 41497	Dalby Airport 41522
Air Temperature (°C)	3 hourly	-	6am, 9am, 3pm & 9pm
Relative Humidity (%)	3 hourly	-	6am, 9am, 3pm & 9pm
Dew Point (°C)	3 hourly	-	6am, 9am, 3pm & 9pm
Mean Sea Level Pressure (hPa)	3 hourly	-	6am, 9am, 3pm & 9pm
Wind Speed (km/h)	3 hourly	-	6am, 9am, 3pm & 9pm
Wind Direction (compass point)	3 hourly	-	6am, 9am, 3pm & 9pm
Precipitation (mm)	3 hourly	Daily	6am, 9am, 3pm & 9pm
Cloud Observations	Daily at 9am	-	6am, 9am, & 3pm

Table 4.2. Data obtained from Bureau of Meteorology stations near Feedlot B.

BoM Station Name: *BoM Station No:*	Yanco Agricultural Institute 74037	Narrandera Airport 74148	Narrandera Golf Club 74221
Air Temperature (°C)	3 hourly	6 am	9am & 3pm
Relative Humidity (%)	3 hourly	6 am	9am & 3pm
Dew Point (°C)	3 hourly	6 am	9am & 3pm
Mean Sea Level Pressure (hPa)	3 hourly	6 am	9am & 3pm
Wind Speed (km/h)	3 hourly	6 am	9am & 3pm
Wind Direction (compass point)	3 hourly	6 am	9am & 3pm
Precipitation (mm)	3 hourly	6 am	9am & 3pm
Cloud Observations	-	6 am	9am & 3pm

4.4.1 *AIR TEMPERATURE*

4.4.1.1 SOUTHERN QUEENSLAND

The monthly average air temperature ranges obtained from the compiled external data set from Feedlot A are shown in Table 4.3 below. The monthly air temperature values recorded by the BoM stations, Oakey Aero and Dalby Agricultural College, are presented for comparison.

The data show that whilst temperatures recorded at the three sites were similar, it is noted the average temperatures obtained from the composite external data recorded at Feedlot A are slightly lower than the two BoM sites. Further analyses of the daily average air temperatures, showed that whilst there was no significant difference between average monthly temperature values of Feedlot A and Oakey Aero, a significant difference (based on two sample t-test, $P < 0.01$) exists between the Dalby Airport data and that of Feedlot A. This is more clearly seen in Figure 4.2 which graphically presents the average temperature ranges recorded at the three sites over the 90 day period, 1 January to 31 March 2001.

Table 4.3. Monthly average air temperatures recorded at Feedlot A and the BoM stations Oakey Aero and Dalby Airport for January to March 2001.

	Feedlot A External Average			Oakey Aero Station No. 41359			Dalby Airport Station No. 41522		
	Min (°C)	Max (°C)	Ave (°C)	Min (°C)	Max (°C)	Ave (°C)	Min (°C)	Max (°C)	Ave (°C)
January 2001	17.9	31.2	24.5	18.0	31.8	24.9	19.1	33.7	26.4
February 2001	16.8	28.8	22.8	16.7	29.0	22.8	18.0	30.9	24.5
March 2001	16.8	29.0	22.9	16.9	29.9	23.4	18.2	30.8	24.5
Average	*17.2*	*29.7*	*23.4*	*17.2*	*30.3*	*23.8*	*18.4*	*31.9*	*25.1*

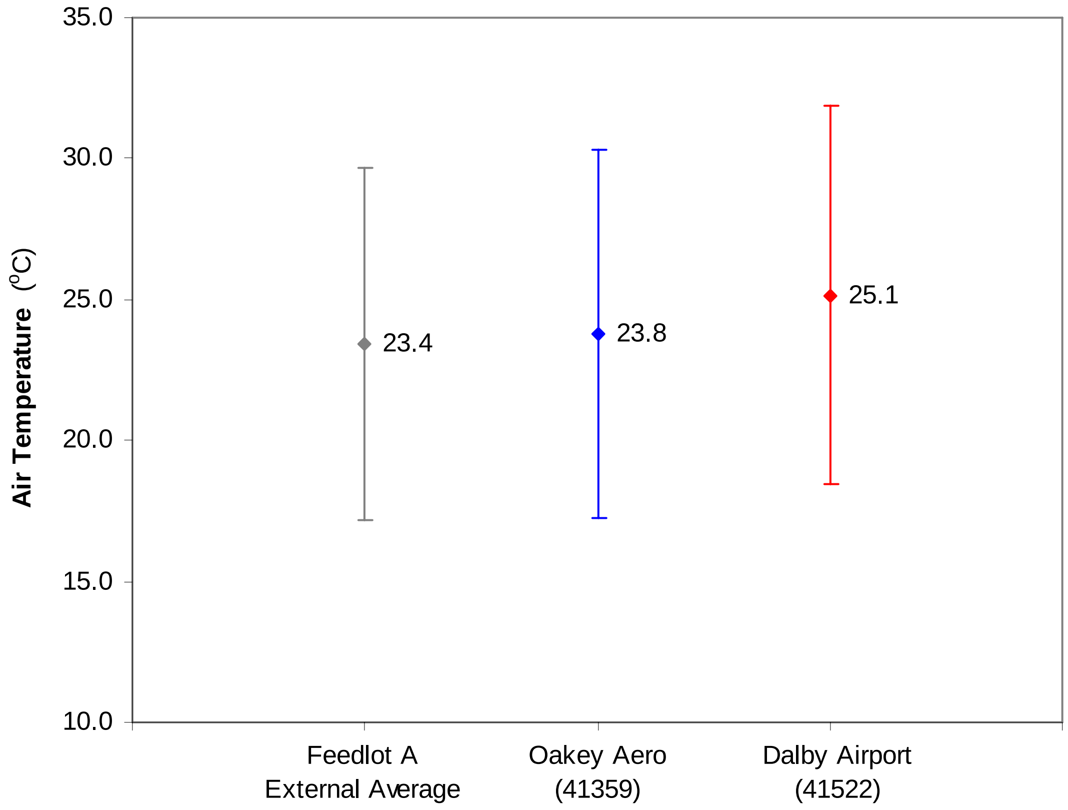

Figure 4.2. Average daily air temperature ranges recorded at Feedlot A and the BoM stations for the 90 day period 1 January to 31 March 2001.

The above figure confirms that averaged over the 3 month period, the data obtained from the external stations at Feedlot A is most similar to that recorded by the BoM station located at Oakey. The data indicate that the Dalby BoM station, which is located geographically closer to Feedlot A, recorded temperatures slightly higher than those at the feedlot.

Some of this temperature difference can be attributed to the fact that the Dalby BoM station is located at an altitude approximately 35 metres below that of the external stations at Feedlot A. As defined by Oke (1987), in dry (unsaturated) air the rate of temperature change in a discrete parcel of air with height is the constant value of 9.8×10^{-3} °C.m^{-1}. This value is called the 'dry adiabatic lapse rate' (Γ) and Oke (1987) describes that the process is caused by the fact that the rising parcel of air encounters lower atmospheric pressure which causes it to expand. The expansion of this parcel requires work in order to push away the surrounding air and the energy required for this work comes from the thermal energy of the air parcel itself. This loss of energy causes the air parcel to cool.

Based on the dry adiabatic lapse rate, an altitude difference of 35 metres between the Dalby BoM station and Feedlot A would result in air temperatures at Feedlot A being 0.34°C cooler than those recorded at Dalby Airport. The remainder of the observed difference in average daily air temperatures between Feedlot A and Dalby Airport may be attributed to instrumentation deviation, and siting variations such as landscape, topographical, and exposure differences.

Whilst the average temperature data indicates that the measurements recorded at Feedlot A appear to be representative of the region, further detailed analyses were used to confirm this. All available air temperature observations from the nearby BoM stations were plotted against the corresponding temperature data obtained from the external average data set produced for Feedlot A. The results of these analyses are shown in Figure 4.3 and Figure 4.4 below.

These plots show that there is a strong relationship between the external data set for Feedlot A and the air temperatures recorded by the BoM stations. As expected from a comparison of the average monthly values, it was found that the temperature data recorded at Dalby Airport was on average 5% greater than that recorded at Feedlot A. This can again be attributed to the reasons outlined above. It may also be due to the fact that the data from Feedlot A is an average of the four external stations. The averaging of these stations is likely to have resulted in the removal of some of the temperature data extremities. Comparison of the BoM sites and the external data set for Feedlot A, has provided a high level of confidence that the external data set of Feedlot A contains representative air temperature data.

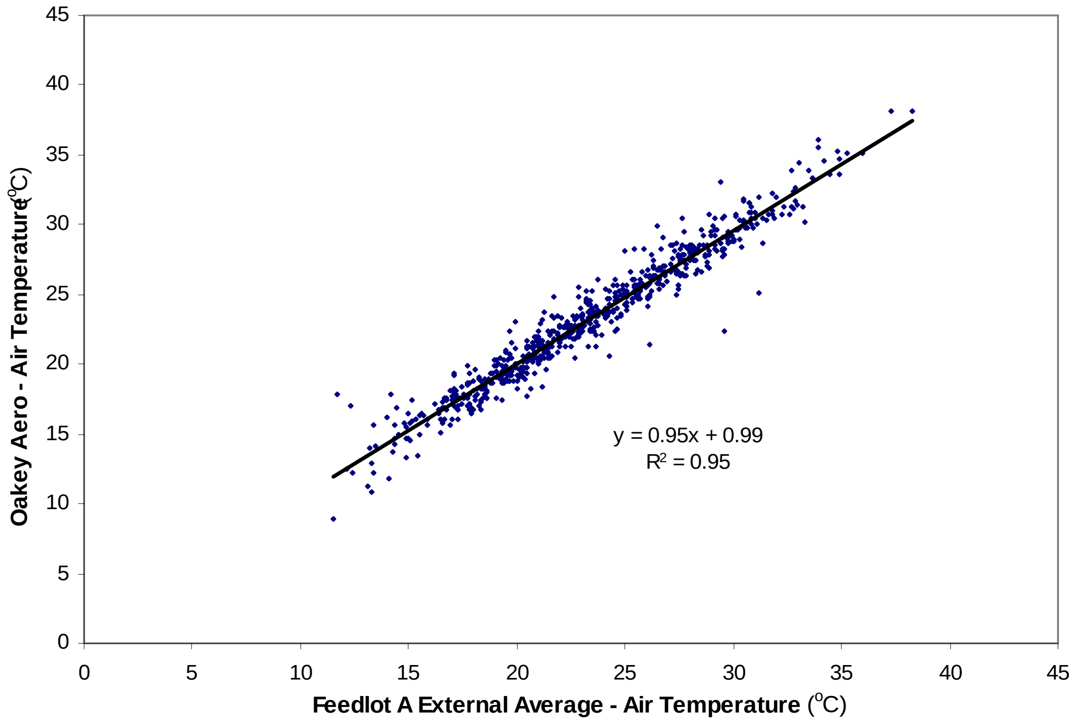

Figure 4.3. Air temperature values recorded 3 hourly at Oakey Aero plotted against corresponding values from the average external data at Feedlot A (n = 719).

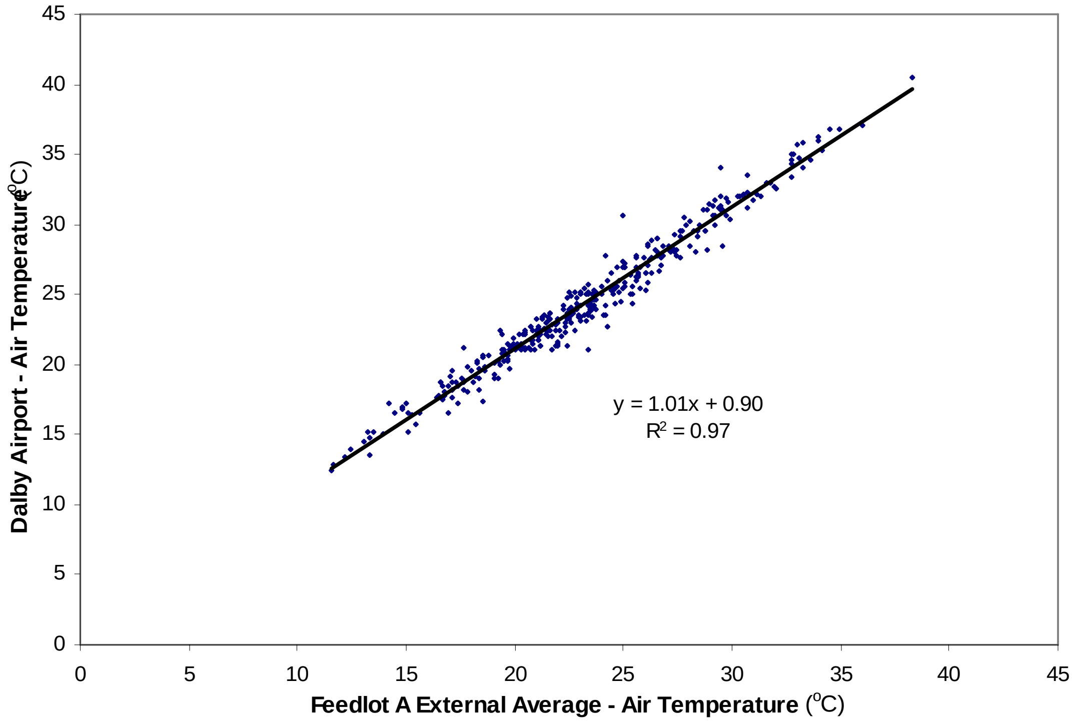

Figure 4.4. Air temperature values recorded at 6am, 9am, 3pm & 9pm at Dalby Airport plotted against corresponding values from the average external data at Feedlot A (n = 359).

4.4.1.2 SOUTHERN NEW SOUTH WALES

Similar data analyses were undertaken for Feedlot B in order to compare and verify the external feedlot data against the air temperature data recorded by surrounding BoM stations. As detailed previously in Table 4.2, measurements of air temperature were recorded at the three BoM stations located in close proximity to Feedlot B however, the frequency of recordings varied. In particular, Narrandera Airport only recorded climatic data at 6 am each day and as such, daily maximum and minimums are not available for this BoM station. Table 4.4 below provides the monthly average air temperature ranges obtained from Feedlot B, and the BoM stations located at Yanco and Narrandera. As was done for Feedlot A, data analyses were undertaken using the daily average temperatures from the external data set for Feedlot B and the nearby BoM sites. These analyses showed that no significant differences (based on two sample t-test, $P < 0.01$) were found between the Feedlot B data and those recorded at Yanco Agricultural Institute and Narrandera Golf Club.

Table 4.4. Monthly average air temperatures recorded at Feedlot B and the BoM stations Yanco Agricultural Institute and Narrandera Golf Club for the period January to March 2001.

	Feedlot B External Average			Yanco Agricultural Institute Station No. 74037			Narrandera Golf Club Station No. 74221		
	Min (°C)	Max (°C)	Ave (°C)	Min (°C)	Max (°C)	Ave (°C)	Min (°C)	Max (°C)	Ave (°C)
January 2001	20.0	34.2	27.1	20.7	36.6	28.6	19.1	36.4	27.6
February 2001	18.9	31.7	25.3	19.7	33.8	26.8	18.4	33.7	26.0
March 2001	13.9	26.2	20.1	14.1	28.0	21.0	13.1	27.8	20.5
Average	*17.3*	*30.3*	*23.8*	*18.1*	*32.7*	*25.4*	*16.8*	*32.6*	*24.6*

Figure 4.5 provides the average temperature range for Feedlot B and the two BoM Sites over the 3 month period of January to March 2001. The data show that the average temperature range for Feedlot B was slightly less than those experienced at the BoM sites. This is similar to the trend noted in relation to Feedlot A.

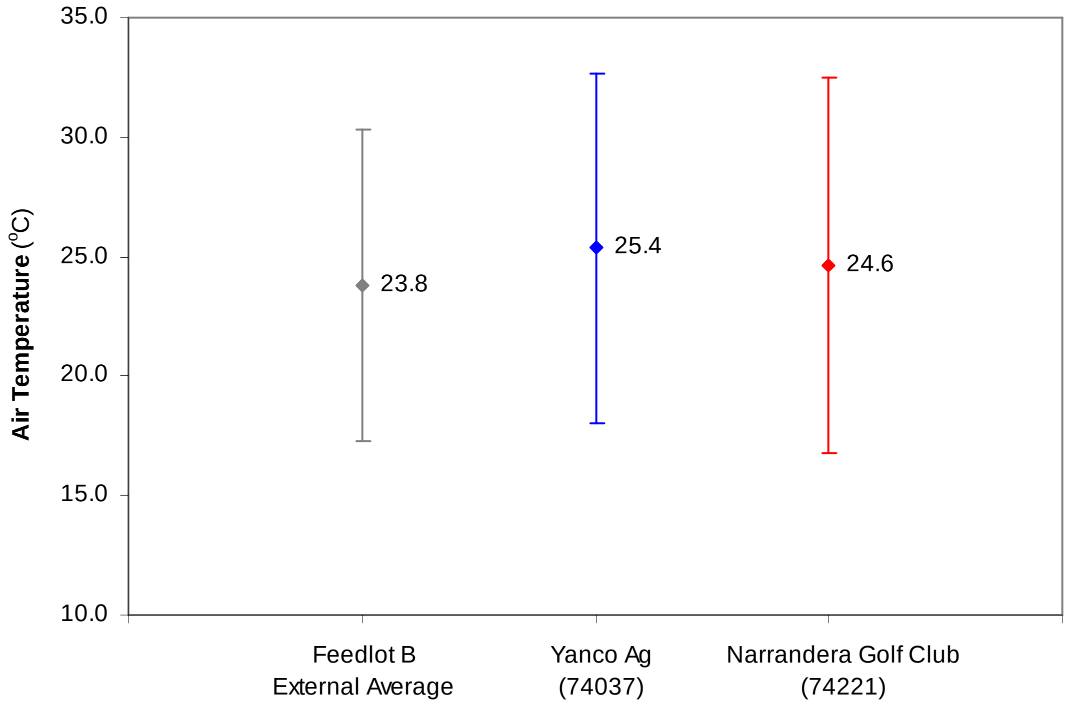

Figure 4.5. Average daily air temperature ranges recorded at Feedlot B and the BoM stations for the 90 day period 1 January to 31 March 2001.

Plots of air temperature data recorded at the BoM stations against the corresponding data obtained from the external data set for Feedlot B are shown in Figure 4.6 and Figure 4.7. These data show that there is a strong correlation between the external feedlot temperature data set and the temperatures recorded at the BoM stations, with both R^2 values being 0.95 or greater. Comparison of the raw data showed that the external data set for Feedlot B provided air temperatures very similar to those at the Narrandera Golf Club and only slightly below those recorded at Yanco Agricultural Institute stations (on average 3.4% lower). Similar to Feedlot A, this minor variation could be attributed to topographical and/or landscape features, or the fact that the feedlot external data set is an average of the air temperatures recorded by four separate automatic weather stations. It is noted that Feedlot B is located approximately 13 metres and 4 metres lower than the Narrandera Golf Club and Yanco Agricultural Institute stations respectively. As such the observed differences in air temperatures cannot be attributed to altitude for this feedlot site.

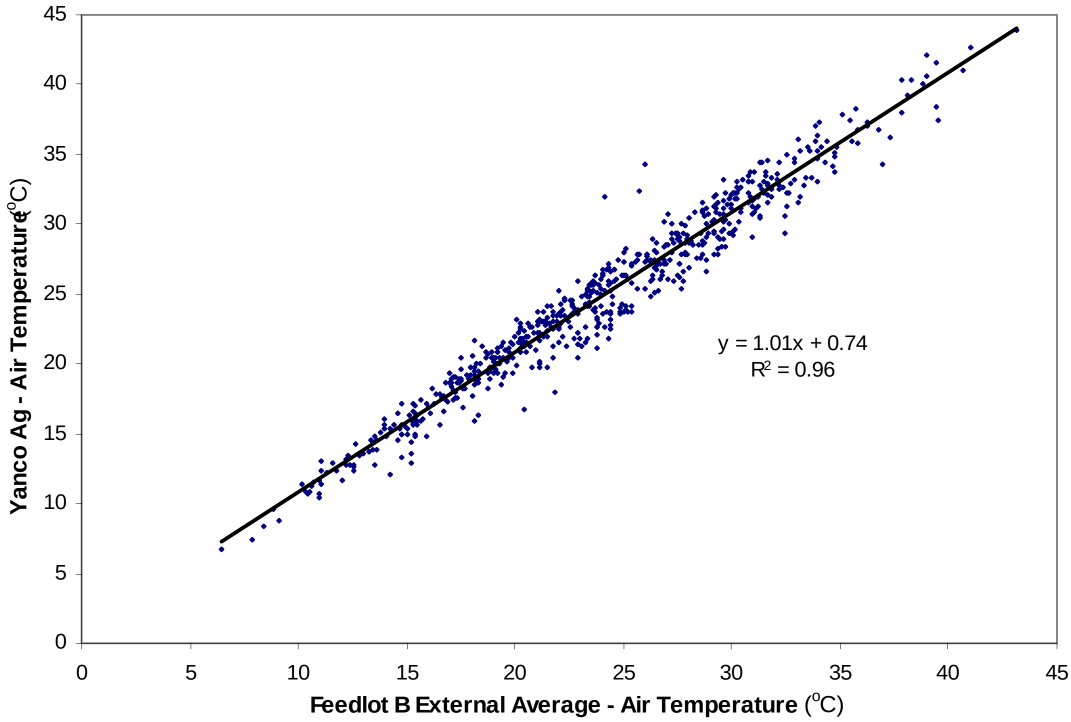

Figure 4.6. Air temperature values recorded 3 hourly at Yanco Agricultural Institute plotted against corresponding values from the average external data at Feedlot B (n = 641).

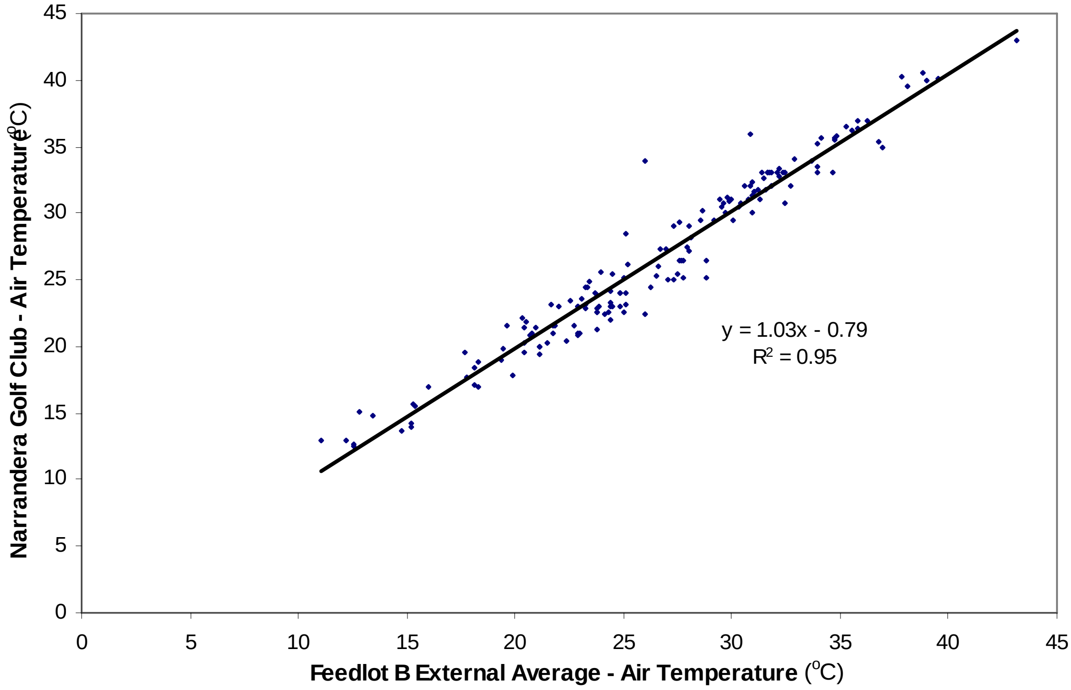

Figure 4.7. Air temperature values recorded at 9am & 3pm at Narrandera Golf Club plotted against corresponding values from the average external data at Feedlot B (n = 163).

4.4.2 RELATIVE HUMIDITY

4.4.2.1 SOUTHERN QUEENSLAND

Relative humidity was recorded every 3 hours at the BoM station located at Oakey Aero, and four times daily at Dalby Airport (refer Table 4.1). A summary of the average monthly relative humidity values derived from the BoM stations over the January to March 2001 period are presented in Table 4.5 below, along with the values obtained from the average external data set for Feedlot A.

Table 4.5. Monthly average relative humidity values recorded at Feedlot A and the BoM stations Oakey Aero and Dalby Airport for January to March 2001.

	Feedlot A External Average			Oakey Aero Station No. 41359			Dalby Airport Station No. 41522		
	Min (%)	Max (%)	Ave (%)	Min (%)	Max (%)	Ave (%)	Min (%)	Max (%)	Ave (%)
January 2001	41.1	85.3	63.2	36.1	87.4	61.7	39.9	86.1	63.0
February 2001	48.7	89.4	69.1	52.0	93.8	72.9	47.3	92.2	69.8
March 2001	45.6	88.2	66.9	40.5	89.0	64.8	43.7	89.5	66.6
Average	*45.0*	*87.6*	*66.3*	*42.6*	*89.9*	*66.3*	*43.5*	*89.2*	*66.3*

The above data show that the average relative humidity values recorded by the external automatic weather stations at Feedlot A were similar to those recorded by the regional BoM stations. This fact is reiterated by examining plots of all available relative humidity data from the BoM stations against those of the Feedlot A external data set. Plots for both Oakey Aero and Dalby Airport are shown below in Figure 4.8 and Figure 4.9 respectively. The plots demonstrate that there is a strong correlation between the relative humidity data recorded at Feedlot A and the two BoM stations located in a similar region of southern Queensland. It is noted that the R^2 values of 0.86 and 0.92 obtained from the line of best fit for these data plots indicate that the correlations are not as strong as those obtained from the similar comparison of the air temperature data for the same sites. This could be attributed to several reasons including the fact that the data collected from the feedlot sites used different methods for measuring relative humidity compared to the practices employed at the BoM sites. The different measurement methods are discussed in further detail in section 4.4.2.2.

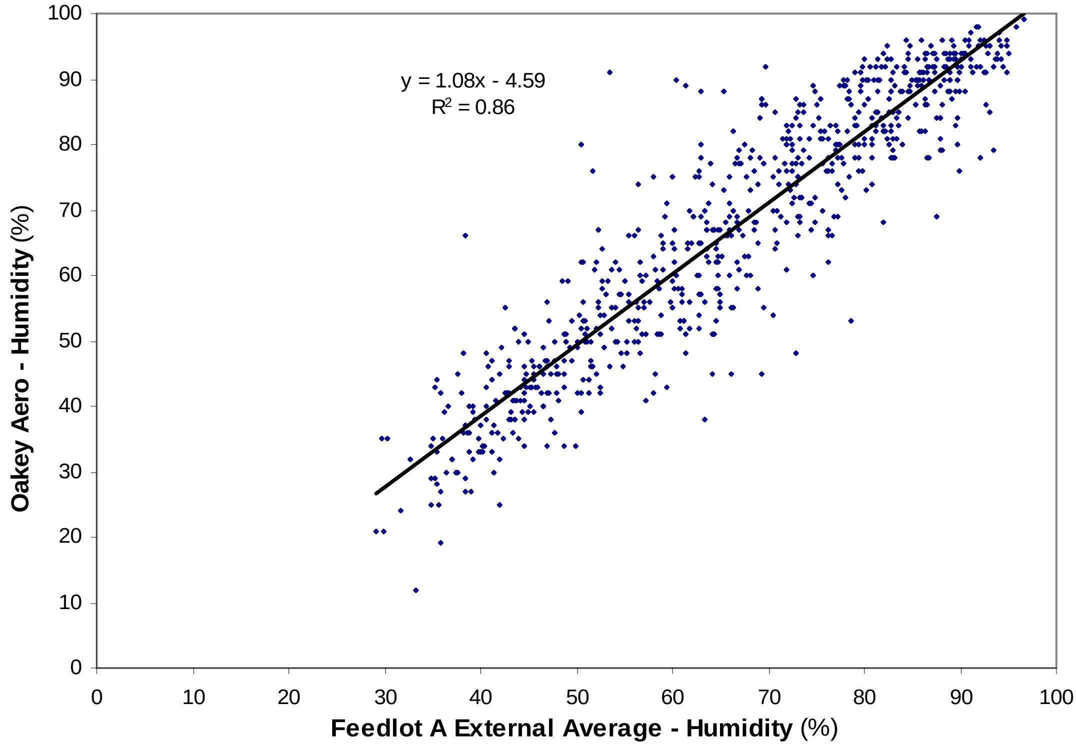

Figure 4.8. Relative humidity values recorded 3 hourly at Oakey Aero plotted against corresponding values from the average external data at Feedlot A (n = 719).

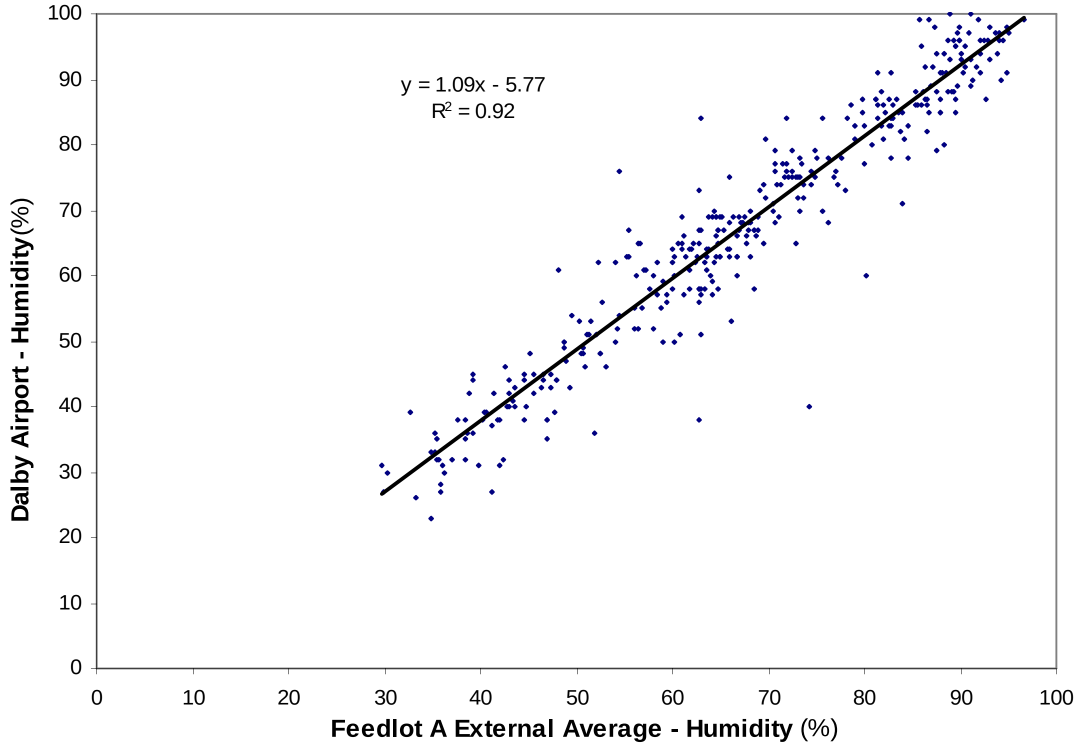

Figure 4.9. Relative humidity values recorded at 6am, 9am, 3pm & 9pm at Dalby Airport plotted against corresponding values from the average external data at Feedlot A (n = 359).

4.4.2.2 SOUTHERN NEW SOUTH WALES

There was some variation in the relative humidity values recorded at Feedlot B and the nearby BoM stations. This is shown in Table 4.6 below where the average monthly values indicate that the relative humidity was higher at Feedlot B compared to both the BoM sites. These data also show that the relative humidity values from the BoM station at Narrandera Golf Club are generally lower than those at Yanco Agricultural Institute. This difference is attributed to the fact that the values presented in Table 4.6 for Narrandera Golf Club were calculated from the limited relative humidity recordings available for this site, being 9am and 3pm observations only. By comparison, 3 hourly observations of relative humidity were made at the Yanco BoM station.

Table 4.6. Monthly average relative humidity values recorded at Feedlot B and the BoM stations Yanco Agricultural Institute and Narrandera Golf Club for January to March 2001.

	Feedlot B External Average			Yanco Agricultural Institute Station No. 74037			Narrandera Golf Club Station No. 74221		
	Min (%)	Max (%)	Ave (%)	Min (%)	Max (%)	Ave (%)	Min† (%)	Max† (%)	Ave† (%)
January 2001	27.5	62.7	45.1	19.2	49.8	34.5	26.8	48.4	37.6
February 2001	34.8	74.9	54.8	25.9	70.6	48.2	30.5	57.5	44.0
March 2001	37.9	79.0	58.5	28.9	77.9	53.4	32.3	62.9	47.6
Average	*33.9*	*73.0*	*53.5*	*24.6*	*65.9*	*45.3*	*29.9*	*56.2*	*43.0*

† - Maximum, minimum and average relative humidity values for Narrandera Golf Club determined from 9am and 3pm daily readings only.

Plots of the relative humidity observations at each BoM site against the Feedlot B external data set are presented in Figure 4.10 and Figure 4.11 for Yanco Agricultural Institute and Narrandera Golf Club respectively. Similar to the data relating to Feedlot A, these plots indicate that there is a good correlation between the relative humidity data recorded at Feedlot B and the two nearby BoM stations, with R^2 values of 0.91 and 0.86 for the Yanco and Narrandera plots respectively.

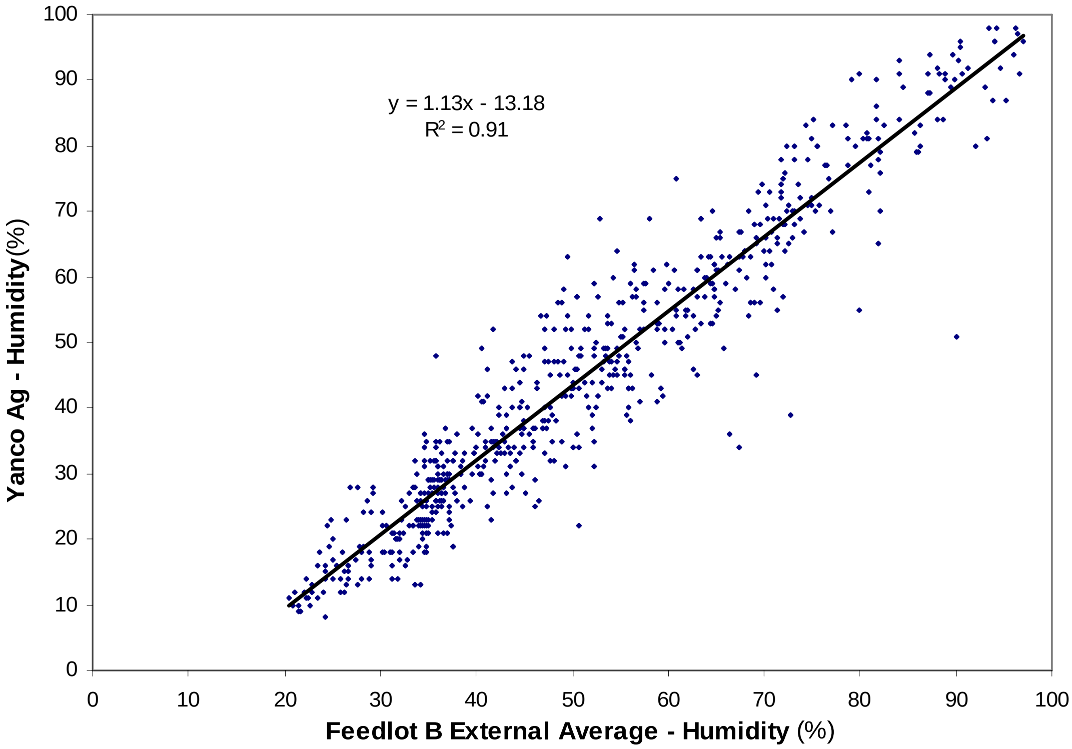

Figure 4.10. Relative humidity values recorded 3 hourly at Yanco Agricultural Institute plotted against corresponding values from the average external data at Feedlot B (n = 641).

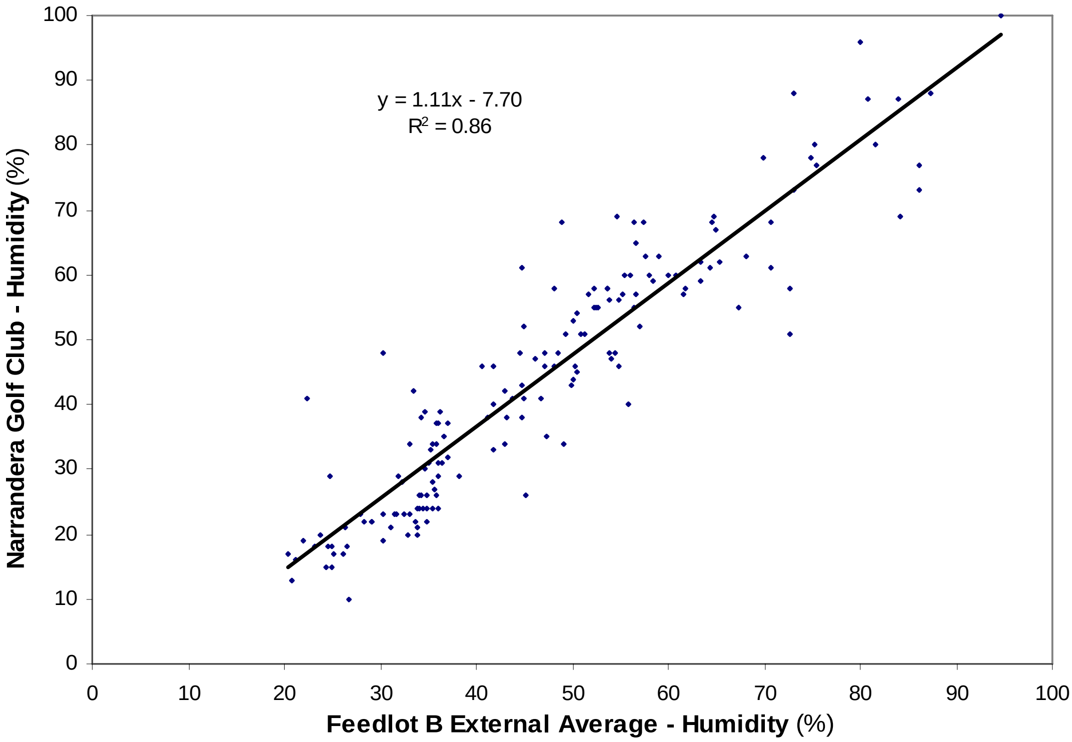

Figure 4.11. Relative humidity values recorded at 9am & 3pm at Narrandera Golf Club plotted against corresponding values from the average external data at Feedlot B (n = 162).

The plots presented above show that the y-intercept in each case is negative, indicating that the relative humidity values recorded at the BoM stations are generally lower than those of the Feedlot B external data set. Based on the line of best fit equations provided, relative humidity levels at Yanco are greater than those of Feedlot B for humidity values between 0 and 99%. The plotted data for Narrandera Golf Club suggests the range is 0 to 70%.

In order to examine the diurnal variation of this anomaly between the relative humidity values between the BoM stations and Feedlot B, a plot of average hourly humidity values from Yanco Agricultural Institute and Feedlot B was produced for the 3 month period. These data are presented in Figure 4.12 below.

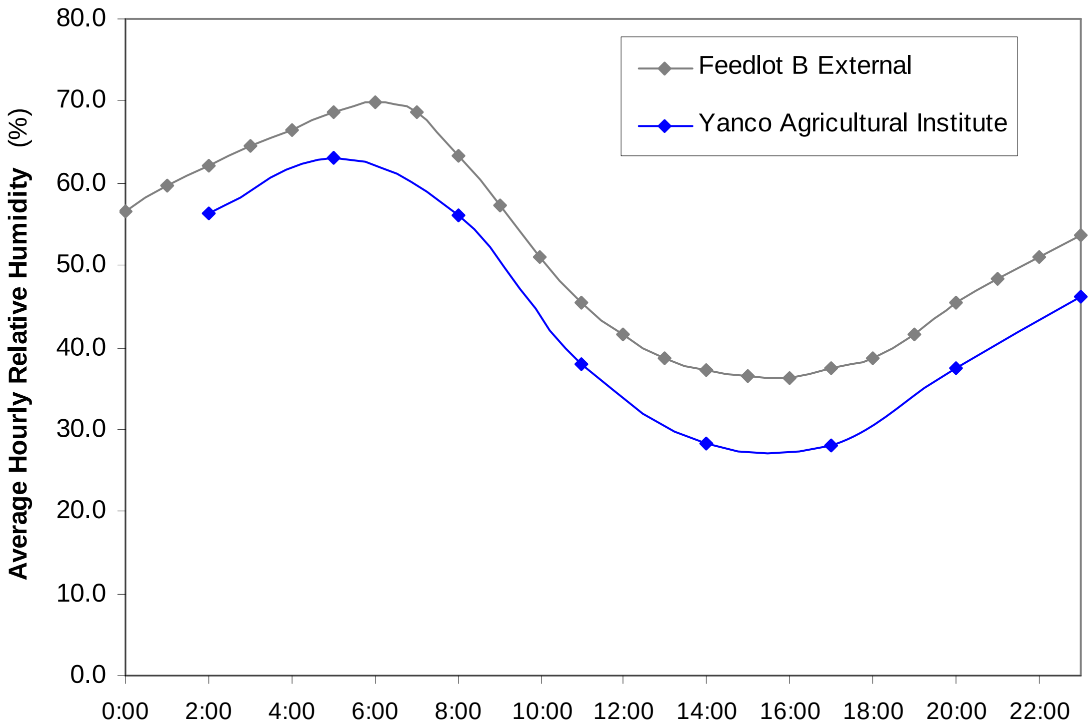

Figure 4.12. Average hourly (EST) relative humidity values for Feedlot B and Yanco Agricultural Institute for the period 1 January to 31 March 2001.

The above plot clearly shows that on average the relative humidity was consistently higher at Feedlot B than that recorded at Yanco Agricultural Institute. These differences were in the order of 5 to 7% from the hours of midnight to 5am and increased to 8 to 9% from midday to 6pm.

Possible reasons for the anomaly between the relative humidity data from Feedlot B and the BoM stations include potential errors in the data from Feedlot B; variation due to the measurement methods used for this project and the methods used by BoM; or simply that Feedlot B did experience higher humidity levels than the nearby BoM stations. These potential reasons are discussed below.

The possibility of errors in the relative humidity data derived from the external data set of Feedlot B is minimal. During the compilation process for Feedlot B, the individual data from the four external stations was scrutinised before being incorporated into the final data set. Any data from the individual external stations that appeared erroneous was excluded from this data set. This process meant that for the final data set to be unrepresentative of the external feedlot conditions, all the external stations had to record similar erroneous relative humidity values. The fact that four external stations were used, and individual sensors were replaced with new factory calibrated sensors as required throughout the data recording period, makes this situation highly unlikely. It is noted that the averaging of the external station data to produce a single data set can induce some errors; however the magnitude of these errors would certainly not produce the variation noted between Feedlot B and the BoM stations.

Relative humidity was recorded at the feedlot sites using a 'Monitor Sensors μ-smart series model HU1 Relative Humidity sensor'. As detailed by the manufacturer these sensors utilise an active polymer capacitor as a sensing element. The di-electric constant of the element surface changes with the absorption of atmospheric moisture. As a result the absorbed moisture causes a change in capacitance that is detected and converted to a relative humidity reading. The manufacturer notes that in conditions where relative humidity exceeds 90%, readings may vary significantly as relatively minor changes in temperature cause condensation on the sensor.

By comparison, the Bureau of Meteorology stations determine relative humidity values through a series of calculations that use direct measurements of wet and dry bulb temperature. The values of wet and dry bulb temperature are used (along with a correction for elevation) to derive a theoretical value of dew point. Oke (1987) defines dew point as "the temperature to which a given parcel of air must be cooled (at constant pressure and constant water vapour content) in order for saturation to occur". The calculated value of dew point and the measured air temperature are then used to determine relative humidity through the following equations.

$$\text{Relative Humidity} = \frac{\text{Vapour pressure}}{\text{Saturated vapour pressure}} \times 100 \qquad \textit{[Eq. 4.1]}$$

$$\text{Vapour pressure} = \exp\left[1.8096 + \frac{(17.269425 \times \text{Dew point})}{(237.3 + \text{Dew point})}\right] \qquad \textit{[Eq. 4.2]}$$

$$\text{Saturated vapour pressure} = \exp\left[1.8096 + \frac{(17.269425 \times \text{Air temp})}{(237.3 + \text{Air temp})}\right] \qquad \textit{[Eq. 4.3]}$$

The exact extent of the variation between readings that these two different methods of determining relative humidity would produce is not possible to be quantified in this project. It is noted however, that the different method employed by the BoM may be a viable reason for the minor variations between the measured humidity data from Feedlot A and the southern Queensland BoM sites. It is unlikely that the same factor can be attributed as the sole reason for the higher humidity values recorded at Feedlot B compared to those recorded at Yanco and Narrandera. It therefore concluded that Feedlot B did experience more humid conditions over the January to March 2001 period compared to the two BoM sites at Yanco and Narrandera.

This conclusion is supported when the management practises and features of the feedlot are considered. The southern NSW feedlot undertook ongoing dust suppression throughout the 2000/2001 summer period. This entailed daily watering of the internal unsealed roads of the facility using water trucks. This feedlot also watered cattle pens using spray irrigation water cannons mounted onto the top of the water trucks. This practice was undertaken every night throughout the summer. It is noted that the truck drivers turned off the cannons when driving past the shaded areas of the cattle pens so as not to exacerbate the already moist pen surface conditions under the shade. In addition to this, the on-going grounds maintenance involved regular watering of garden and grassed areas including a 7-hole golf course located within the feedlot premises. The farming area associated with the feedlot included 120 ha that was under centre pivot irrigation, 250 ha of flood irrigated crop production areas, and associated holding ponds, irrigation channels and water storages. It is feasible that these factors contributed to wetter antecedent conditions in the catchment resulting in greater evaporation of moisture from land surfaces and thus more humid conditions recorded at this feedlot site.

4.4.3 RAINFALL

4.4.3.1 SOUTHERN QUEENSLAND

Across the feedlot site there was some variation in the rainfall totals measured by the external stations. In general this variation was minor with the exception of one instance when the measured difference between two external stations was approximately 30% of the total recorded rainfall event. An averaging of the rainfall data from the four external stations minimised any significant anomalies.

The average monthly rainfall totals recorded by the external stations at Feedlot A are presented in Table 4.7 below. This table also includes the monthly totals recorded by the BoM stations located at Oakey Aero, Dalby Agricultural College, and Dalby Airport. The rainfall data show that over the three month period from January to March 2001, rainfall totals are similar. Whilst not generally the case for summer rainfall in the subtropical zone (due to mesoscale storm events); it is noted that the total rainfalls for the three months do show an increase moving geographically west from Oakey, through to Feedlot A, then Dalby.

Table 4.7. Monthly rainfall totals recorded at Feedlot A and the BoM stations Oakey Aero and Dalby Airport for January to March 2001.

Monthly Rainfall (mm)	Feedlot A External Average	Oakey Aero Station No. 41359	Dalby Ag College Station No. 41497	Dalby Airport Station No. 41522
January 2001	70.5	40.2	48.1	33.2
February 2001	68.9	130.0	124.6	140.8
March 2001	82.6	11.4	67.9	68.8
TOTAL	*222.0*	*181.6*	*240.6*	*242.8*

Comparison of the 2001 data recorded at Feedlot A with the long term average monthly rainfalls for the region is shown in Table 4.8. These data show that whilst the rainfall received at Feedlot A for the months of January and February 2001 was slightly below the long term average for the region, above average rainfall was received in March. As such, over the entire three month period the rainfall recorded at Feedlot A was similar to the long term average rainfall.

Table 4.8. Comparison of Feedlot A 2001 rainfall with long term average monthly rainfall totals for the BoM stations Oakey Aero (stn no. 41359) and Dalby Post Office (stn no. 41023).

Monthly Rainfall (mm)	Feedlot A External Average 2001	Oakey Aero Long Term Average 1970 - 2003	Dalby Post Office Long Term Average 1870 - 1992
January	70.5	75.2	84.8
February	68.9	86.0	77.2
March	82.6	46.2	65.7
TOTAL	*222.0*	*207.4*	*227.7*

4.4.3.2 Southern New South Wales

The variation in rainfall recorded by the four external stations at Feedlot B was less than that at Feedlot A. The most significant difference between monthly rainfall totals recorded by any two of the external stations was 9.6 mm for the month of February. On average the monthly range between the highest and lowest rainfall totals recorded by the external stations was 5.0 mm.

Monthly rainfall totals for Feedlot B and the nearby BoM stations are provided in Table 4.9 below. Rainfall recorded across the region over the data collection period was relatively consistent. A trend is noted with increasing rainfall moving geographically north from Narrandera Golf Club (73 mm), to Narrandera Airport (78.4 mm), Feedlot B (81.8 mm) and finally Yanco Agricultural Institute (87.2 mm).

Table 4.9. Monthly rainfall totals recorded at Feedlot B and the BoM stations Yanco Agricultural Institute, Narrandera Airport, and Narrandera Golf Club for January to March 2001.

	Feedlot B External Average	Yanco Agricultural Institute Station No. 74037	Narrandera Airport Station No. 74148	Narrandera Golf Club Station No. 74221
January 2001	16.0	22.0	26.2	19.3
February 2001	36.2	28.4	29.2	27.2
March 2001	29.7	36.8	23.0	26.5
TOTAL	*81.8*	*87.2*	*78.4*	*73.0*

Comparison of the 2001 data to the long term Bureau of Meteorology monthly averages show that in the Riverina district, January 2001 was a particularly dry month, however February and March received average rainfalls. These data are presented in Table 4.10 below.

Table 4.10. Comparison of Feedlot B 2001 rainfall with long term average monthly rainfall totals for the BoM stations Narrandera Airport (stn no. 74148) and Narrandera Golf Club (stn no. 74221).

Monthly Rainfall (mm)	Feedlot B External Average 2001	Narrandera Airport Long Term Average 1967 - 2003	Narrandera Golf Club Long Term Average 1969 - 2003
January	16.0	35.1	38.8
February	36.2	34.3	39.5
March	29.7	30.3	31.6
TOTAL	*81.8*	*99.8*	*109.9*

4.4.4 WIND SPEED

4.4.4.1 SOUTHERN QUEENSLAND

The average monthly wind speeds recorded at Feedlot A and the nearby BoM stations are presented in Table 4.11. These data include both the average 2 metre and 10 metre wind speeds from the external data set of Feedlot A. As expected, the 2 metre wind speeds at Feedlot A are lower than those measured at 10 metres. As detailed by AS 2923 (1987) “the average wind speed in undisturbed flow increases with height in an approximately logarithmic manner”.

Compared to the BoM station data, on average, wind speeds at Feedlot A were lower than those recorded at Oakey and similar to the average data recorded at the closer site of Dalby Airport. It is noted that at Dalby Airport the wind speed is estimated by an observer four times daily, whilst at Oakey Aero wind is measured every 3 hours at a height of 10 metres using a synchrotac anemometer (Farrell, A. BoM, 2004, pers comm. 28 January). The same 3 hourly observations from Feedlot A were used in the comparisons as opposed to the entire hourly average data set.

Table 4.11. Average monthly wind speeds recorded at Feedlot A (at 2 and 10 metres) and the BoM stations Oakey Aero and Dalby Airport for January to March 2001.

Average Wind Speed (km/h)	Feedlot A External Average (2 metres)	Feedlot A External Average (10 metres)	Oakey Aero Station No. 41359 (10 metres)	Dalby Airport Station No. 41522 (Observations)
January 2001	10.9	13.3	18.1	11.0
February 2001	11.2	13.5	17.8	8.7
March 2001	9.6	11.4	17.6	7.9
Total Observations	*720*	*720*	*719*	*359*
90 Day Average	**10.5**	**12.7**	**17.8**	**9.2**

The wind observations from each site were categorised into the standard wind speed ranges adopted by the Bureau of Meteorology. These data are plotted in Figure 4.13. It is noted that the four external automatic weather stations at each feedlot site recorded wind data readings every 10 minutes. The data set for Feedlot A in Figure 4.13 was composed of hourly averages obtained from these 10 minute records. The BoM station data are from single observations. As such, to produce a calm reading for the feedlot external data, all six 10 minute observations from the external feedlot stations had to be less then 1 km/hour. This situation was observed on only a few occasions at each feedlot site. It is for this reason that the data plot shows minimal calm readings for Feedlot A.

The data in Figure 4.13 show that the distribution of wind speeds recorded at both 2 and 10 metres at Feedlot A were similar to the wind speed distribution at the nearby BoM sites. Some variations are noted, with the data showing higher wind speeds observed at Oakey Aero compared to the other sites. Whilst less wind observations were recorded for the BoM site at Dalby, the available data indicate that these wind speeds were most similar to Feedlot A. This is expected due to the significantly closer proximity of this BoM site to Feedlot A.

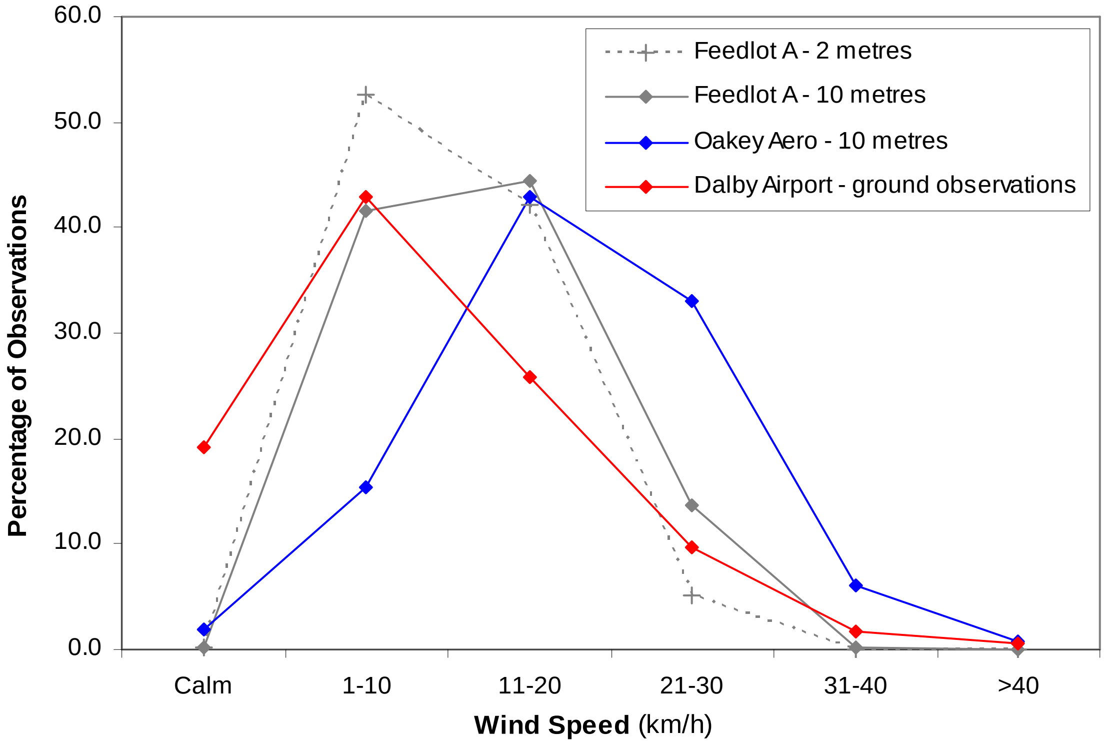

Figure 4.13. Distribution of wind speed observations recorded at Feedlot A and the BoM stations Oakey Aero and Dalby Airport for the period January to March 2001.

4.4.4.2 Southern New South Wales

Table 4.12 below shows the average monthly wind speeds recorded at Feedlot B and the BoM stations situated at Yanco and Narrandera. It is noted that the total number of observations at Feedlot B is less than those of Feedlot A and the Yanco BoM station. This is due to the fact that the external stations at Feedlot A were not fully operable until 10 January 2001. The data from Narrandera Golf Club are derived from daily 9am and 3pm readings only.

Table 4.12. Average monthly wind speeds recorded at Feedlot B (at 2 and 10 metres) and the BoM stations Yanco Agricultural Institute and Narrandera Golf Club for January to March 2001.

Average Wind Speed (km/h)	Feedlot B External Average (2 metres)	Feedlot B External Average (10 metres)	Yanco Agricultural Institute Station No. 74037 (10 metres)	Narrandera Golf Club Station No. 74221 (10 metres)
January 2001	8.6	13.9	17.0	11.4
February 2001	8.3	12.9	16.3	11.7
March 2001	8.7	13.2	16.4	10.9
Total Observations	*651*	*651*	*706*	*180*
90 Day Average	**8.6**	**13.3**	**16.6**	**11.3**

The above data show that wind speeds recorded at the three sites were similar. The primary difference being the higher values observed at Yanco. Comparison of the wind speed distribution for each site over the 3 month period is presented in Figure 4.14. This again shows the higher wind speeds observed at Yanco Agricultural Institute. Of note, is the very similar trend between the 10 metre wind speed data at Feedlot B and the wind speeds recorded at Narrandera Golf Club. Similar to the data for Feedlot A, the 2 metre wind speeds at Feedlot B were lower than the other sites.

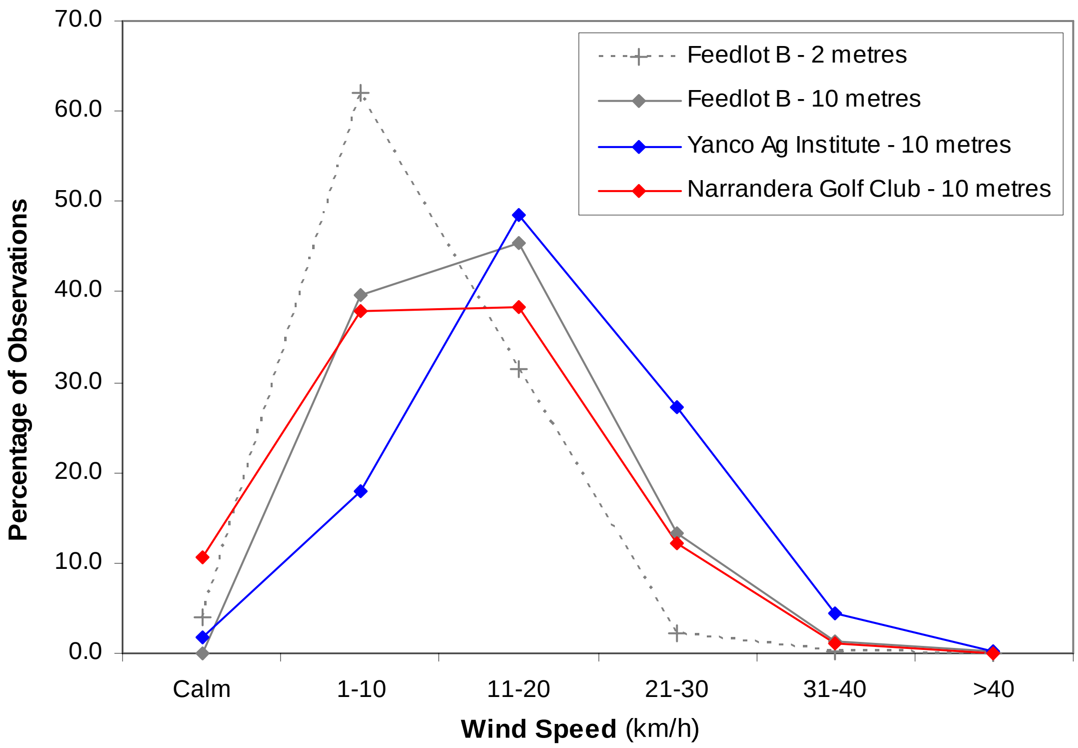

Figure 4.14. Distribution of wind speed observations recorded at Feedlot B and the BoM stations Yanco Agricultural Institute and Narrandera Golf Club for the period January to March 2001.

4.4.5 *WIND DIRECTION*

4.4.5.1 SOUTHERN QUEENSLAND

A summary of the 3 hourly wind direction observations from the external data set at Feedlot A is shown in the distribution plot below (Figure 4.15). This plot shows the percentage of wind direction observations across 16 points of the compass. It is noted that the wind direction sensors of the automatic weather stations located at the feedlot sites recorded wind direction values to a precision of 0.1°. In order to produce the summary plot presented below, the decimal data was compiled into a spreadsheet with formulas that rounded the values to the nearest 22.5°. This was done to enable straight forward comparison to the wind direction data of the BoM stations, which are recorded based on the 16 point compass.

The data in Figure 4.15 show that at Feedlot A easterly wind patterns prevailed over the data recording period of January to March 2001. Comparison of these data with similar plots produced from the data recorded by the BoM stations at Oakey Aero and Dalby Airport (Figure 4.16 and Figure 4.17 below) show that similar wind patterns were observed at all three sites.

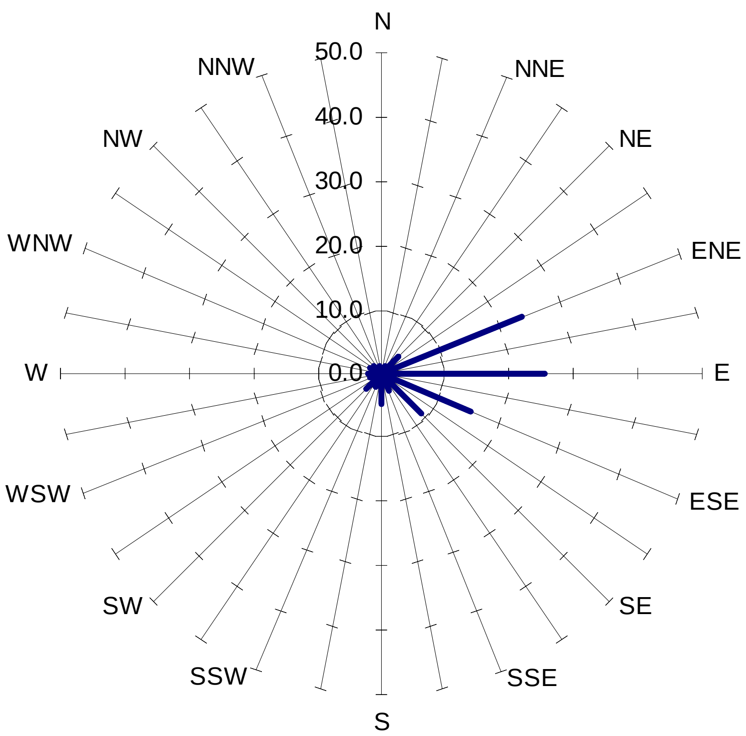

Figure 4.15. Percentage distribution of wind direction observations (n = 720) from the external data set for Feedlot A for January to March 2001.

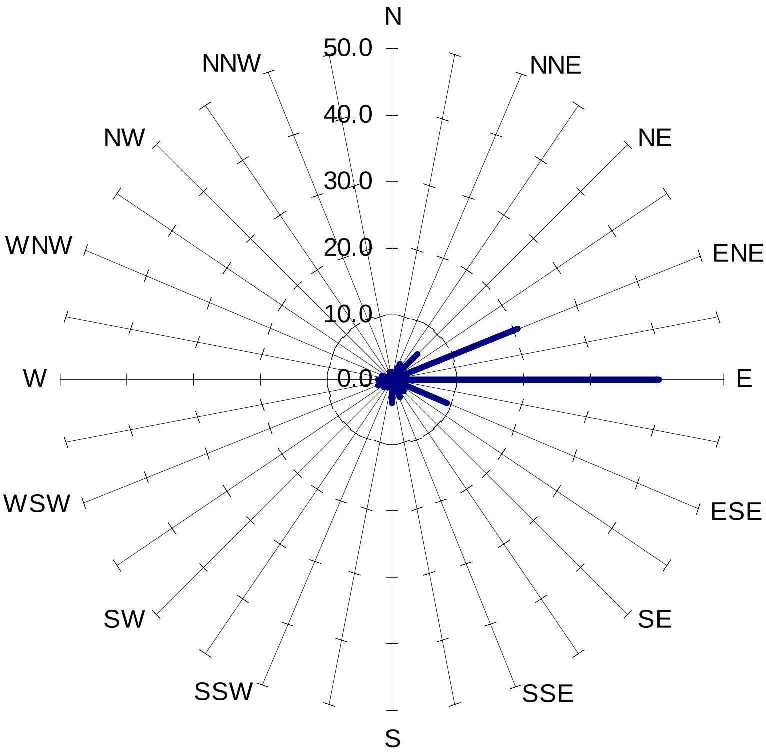

Figure 4.16. Percentage distribution of wind direction observations (n = 720) recorded at Oakey Aero (BoM station: 41359) for January to March 2001 (1.9% calm observations).

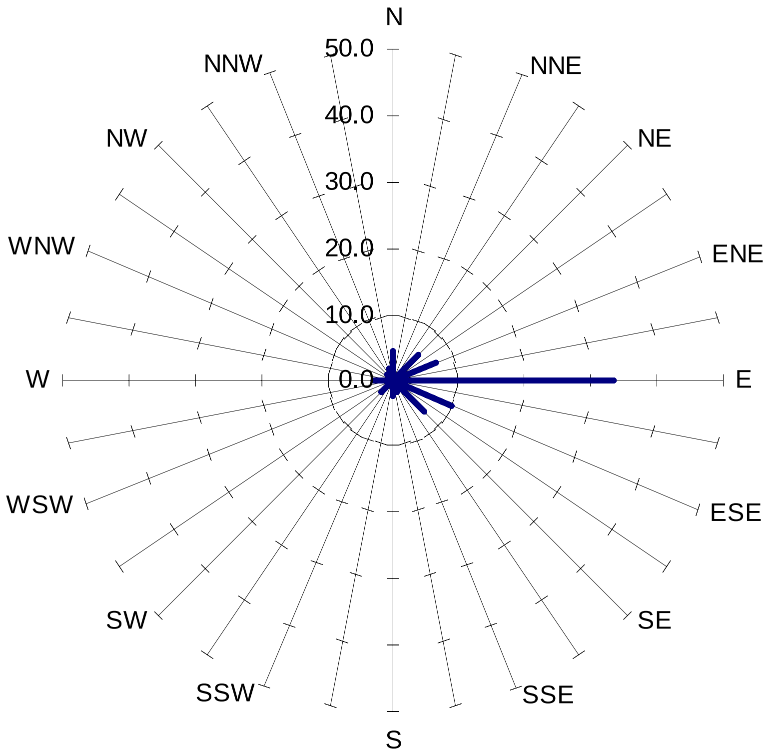

Figure 4.17. Percentage distribution of wind direction observations (n = 359) recorded at Dalby Airport (BoM station: 41522) for January to March 2001 (19.2% calm observations).

4.4.5.2 SOUTHERN NEW SOUTH WALES

The wind direction distribution plot for Feedlot B (see Figure 4.18 below) shows that, compared to Feedlot A, the wind observations were significantly more variable. Over the 90 day period the majority of observed winds were from either the north eastern quadrant (39.3%) or the south western quadrant (38.8% of observations).

A summary of the wind direction data recorded by the BoM stations is presented in Figure 4.19 and Figure 4.20 below for Yanco Agricultural Institute and Narrandera Golf Club respectively. These plots show similar variability in observed wind directions. Similar to Feedlot B the dominant wind directions recorded at the BoM stations were from the north eastern and south western quadrants. However, at both BoM sites winds were more common from the north eastern quadrant (51.4% and 42.2% of observations for Yanco and Narrandera respectively) compared to the south western quadrant (29.5% for Yanco Agricultural Institute and 35.0% for Narrandera Golf Club). This increased variation in wind data at Feedlot B, compared to the observations of the southern Queensland site, was expected due to the varied landscape (in particular increased undulations) of the surrounding area at Feedlot B (as described in section 3.2.1 of Chapter 3).

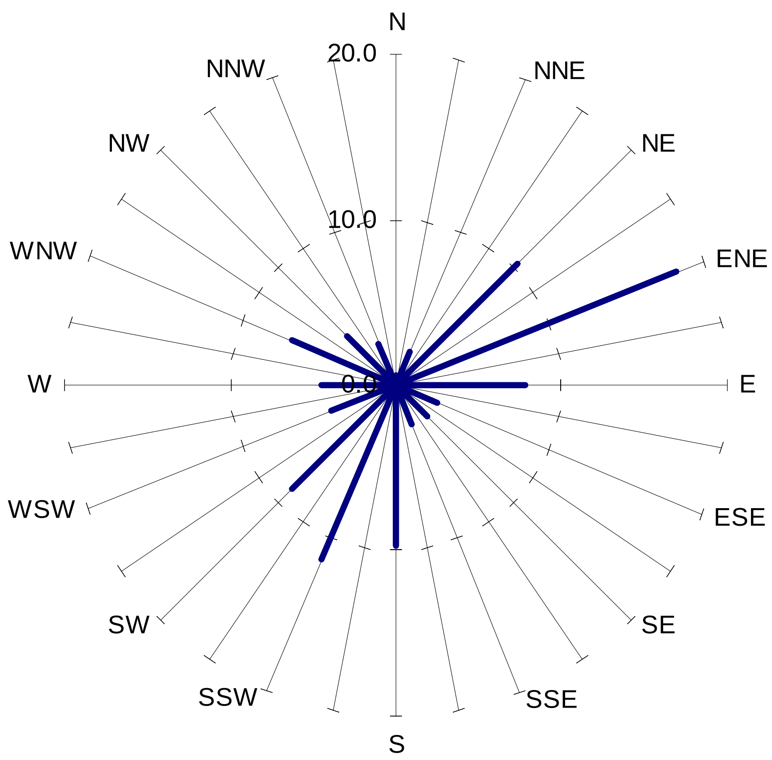

Figure 4.18. Percentage distribution of wind direction observations (n = 652) from the external data set for Feedlot B for January to March 2001.

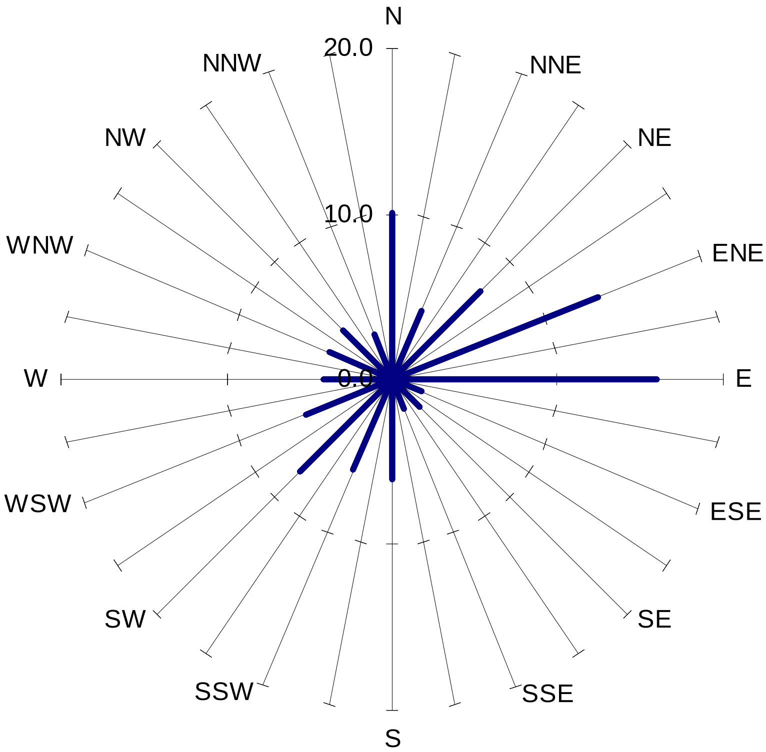

Figure 4.19. Percentage distribution of wind direction observations (n = 706) recorded at Yanco Agricultural Institute (BoM station: 74057) for the period January to March 2001 (1.7% calm observations).

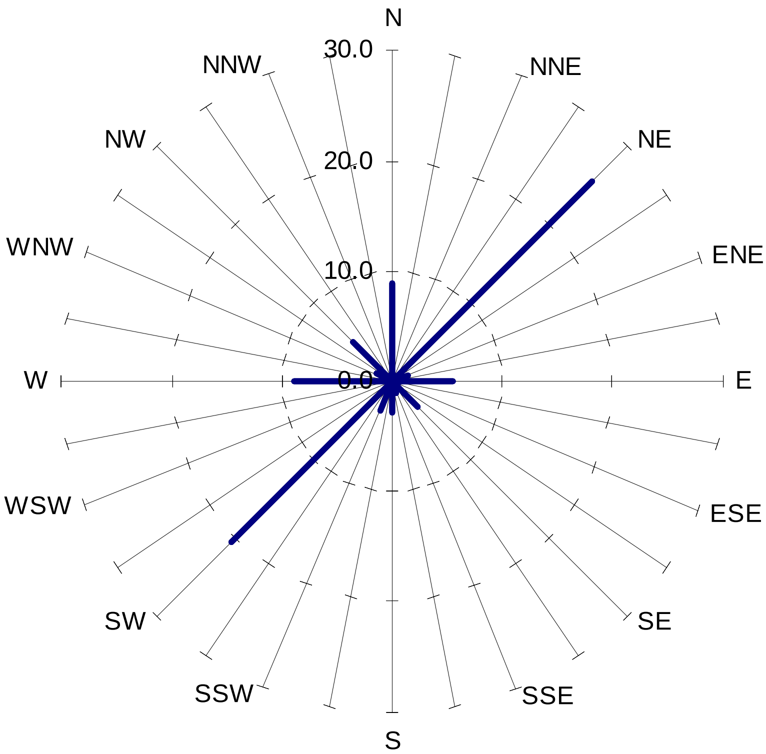

Figure 4.20. Percentage distribution of wind direction observations (n = 180) recorded at Narrandera Golf Club (BoM station: 74221) for the period January to March 2001 (10.6% calm observations).

4.5 CONCLUSIONS

This chapter has demonstrated that the data collected at each of the feedlot sites is representative of the climate experienced for those regions. In particular the data analyses have shown a strong correlation between the air temperatures recorded at the BoM stations and those compiled in the average external data set for each feedlot site.

Comparison of relative humidity data also revealed good correlations although it is noted that these were not as strong as those for air temperature. As discussed, the variation observed in relative humidity values at Feedlot A compared to those of the nearby BoM stations could potentially be attributed to the different method adopted by the BoM to measure relative humidity compared to that used in this project. A greater variation was observed with the relative humidity data recorded at Feedlot B compared to the southern NSW BoM stations. Specifically, the data showed that on average humidity levels at Feedlot B were around 5 to 9% higher than those of the BoM sites. This difference was attributed to the 'wetter' environment of the feedlot caused by management practices such as pen and road watering, garden and grass maintenance, and crop irrigation.

The comparison of rainfall data collected at each feedlot site and the BoM stations showed no unexpected variations. The rainfall that was recorded over the January to March 2001 period is noted as being average for the southern Queensland site and below average for southern New South Wales.

Wind data recorded at the feedlot sites were similar to those observed by the BoM stations. The 10 metre wind speeds recorded by the external stations were in the same order of magnitude as those of the BoM stations and as expected, 2 metre wind speeds were slightly less. Wind directions recorded at the feedlots were also observed to follow similar patterns to those of the BoM stations. The winds at Feedlot A were predominately from the east, whilst at Feedlot B the predominant wind directions were from the north east or south west.

The comparison of the external feedlot data set to the available climatic data from the nearby BoM stations has shown strong similarities for a range of climatic variables. As such, it is concluded that the project data collected by the external automatic weather stations at each feedlot site was in fact representative of the climate experienced by the region.

CHAPTER 5 FEEDLOT DATA ANALYSIS AND RESULTS

5.1 INTRODUCTION

The previous chapter outlined the data collection and compilation process and presented a detailed comparison between the external feedlot climate data for each site and the data recorded by nearby Bureau of Meteorology stations. These analyses demonstrated that the data collected at the feedlot sites were representative of the regional climatic data and that a high level of confidence can be placed in this result. This main variation that was noted between the feedlot data and the BoM data was in relation to the relative humidity values recorded at Feedlot B. As outlined in the previous chapter, this phenomenon is most likely due to the fact that the site layout of the feedlot and the management and farming practices undertaken at the site contribute to a 'wetter' and more humid environment.

This chapter presents detailed analyses of the climatic data collected within the feedlot sites. Specifically, comparisons are made between the data of the external feedlot environment, and the climatic data collected within the unshaded and shaded feedlot cattle pens. The purpose of these comparisons is to identify and quantify the microclimatic variations that are caused by, and occur within, the feedlot environment. The following sections detail these variations for each climatic variable that was measured during the data collection period of this project.

5.2 FEEDLOT OVERVIEW

The average monthly values for the nine climatic parameters measured at the two feedlot sites are presented in Table 5.1 and Table 5.2 below. These tables show the average values from the external feedlot area, as well as those recorded within the shaded and unshaded cattle pens at each site. Variations in the climatic parameters between the three environments are highlighted by these summary data. These variations are discussed in the following sections.

Table 5.1. (a) Average monthly climate data recorded at Feedlot A.

	January 2001			February 2001			March 2001		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot 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
Black Globe (°C)	28.4	26.9†‡	28.6	26.0	24.3†‡	26.2	25.6	23.9†‡	25.5
Ground Temperature (°C)	28.3	24.9†‡	31.1†	25.3	22.9†‡	29.4†	25.6	23.0†‡	29.9†
Relative Humidity (%)	62.9	71.7†‡	63.5	69.1	77.5†‡	69.5	67.7	76.2†‡	68.7
Incoming Solar Radiation (W/m^2)	322.5	71.0†‡	300.0	304.8	76.0†‡	288.7	247.8	51.7†‡	235.6
Outgoing Solar Radiation (W/m^2)	49.9	9.2†‡	44.0†	60.6	10.8†‡	37.7†	48.6	9.4†‡	31.4†
2 metre Wind Speed (km/h)	11.0	7.8†‡	8.7†	11.1	7.7†‡	8.8†	9.5	6.3†‡	7.0†
10 metre Wind Speed (km/h)	13.4	n/a	13.6	13.4	n/a	13.9	11.3	n/a	11.9
Wind Direction (°)	113.2	108.1	118.3	99.0	90.4	107.3	145.2	139.9	149.9

† - Highly significant difference ($P < 0.01$) between feedlot pen and external environment (based on two sample t-test).

‡ - Highly significant difference ($P < 0.01$) between shaded and unshaded feedlot pens (based on two sample t-test).

Table 5.1. (b) Differences in average monthly climate data recorded at Feedlot A.

	January 2001			February 2001			March 2001		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen
Air Temperature (°C)	24.4	+0.2	+0.7	22.8	+0.4	+0.6	22.7	+0.3	+0.6
Black Globe (°C)	28.4	-1.5	+0.2	26.0	-1.8	+0.2	25.6	-1.6	-0.1
Ground Temperature (°C)	28.3	-3.4	+2.8	25.3	-2.5	+4.1	25.6	-2.6	+4.3
Relative Humidity (%)	62.9	+8.8	+0.6	69.1	+8.5	+0.4	67.7	+8.5	+1.0
Incoming Solar Radiation (W/m^2)	322.5	-251.4	-22.4	304.8	-228.9	-16.2	247.8	-196.1	-12.2
Outgoing Solar Radiation (W/m^2)	49.9	-40.7	-5.8	60.6	-49.8	-22.9	48.6	-39.2	-17.1
2 metre Wind Speed (km/h)	11.0	-3.2	-2.4	11.1	-3.4	-2.4	9.5	-3.2	-2.6
10 metre Wind Speed (km/h)	13.4	n/a	+0.3	13.4	n/a	+0.5	11.3	n/a	+0.6
Wind Direction (°)	113.2	-5.2	+5.0	99.0	-8.7	+8.3	145.2	-5.3	+4.7

Table 5.2. (a) Average monthly climate data recorded at Feedlot B.

	January 2001			February 2001			March 2001		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen
Air Temperature (°C)	27.3	27.7	27.5	25.2	25.8	25.4	20.1	20.6	20.1
Black Globe (°C)	30.6	28.9	30.4	28.5	27.0	28.3	23.3	22.1	23.3
Ground Temperature (°C)	33.0	19.5†	no data	28.3	16.6†‡	30.6#	24.5	12.4†‡	25.1#
Relative Humidity (%)	42.7	45.9#*	43.2	53.0	56.9#*	52.2	56.6	61.8#*	56.3
Incoming Solar Radiation (W/m^2)	330.6	101.7†‡	329.3	281.7	85.6†‡	299.4	244.9	76.1†‡	267.5
Outgoing Solar Radiation (W/m^2)	83.8	23.5†‡	55.8†	67.4	18.5†‡	46.6†	58.4	20.6†‡	44.8†
2 metre Wind Speed (km/h)	8.7	8.1	8.3	8.3	7.6	7.6	8.7	7.8	7.7
10 metre Wind Speed (km/h)	14.0	n/a	12.7†	12.8	n/a	9.1†	13.1	n/a	10.0†
Wind Direction (°)	166.0	157.8	184.3	153.1	142.5	137.5	168.1	167.8	158.0

† - Highly significant difference ($P < 0.01$) between feedlot pen and external environment (based on two sample t-test).
# - Significant difference ($P < 0.05$) between feedlot pen and external environment (based on two sample t-test).
‡ - Highly significant difference ($P < 0.01$) between shaded and unshaded feedlot pens (based on two sample t-test).
* - Significant difference ($P < 0.05$) between shaded and unshaded feedlot pens (based on two sample t-test).

Table 5.2. (b) Differences in average monthly climate data recorded at Feedlot B.

	January 2001			February 2001			March 2001		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen
Air Temperature (°C)	27.3	+0.4	+0.1	25.2	+0.6	+0.2	20.1	+0.6	0.0
Black Globe (°C)	30.6	-1.7	-0.3	28.5	-1.5	-0.2	23.3	-1.3	-0.1
Ground Temperature (°C)	33.0	-13.5	no data	28.3	-11.7	+2.3	24.5	-12.1	+0.5
Relative Humidity (%)	42.7	+3.2	+0.4	53.0	+4.0	-0.8	56.6	+5.2	-0.3
Incoming Solar Radiation (W/m^2)	330.6	-229.0	-1.3	281.7	-196.1	+17.7	244.9	-168.8	+22.6
Outgoing Solar Radiation (W/m^2)	83.8	-60.2	-27.9	67.4	-48.9	-20.8	58.4	-37.8	-13.6
2 metre Wind Speed (km/h)	8.7	-0.6	-0.5	8.3	-0.7	-0.7	8.7	-0.9	-0.9
10 metre Wind Speed (km/h)	14.0	n/a	-1.3	12.8	n/a	-3.6	13.1	n/a	-3.2
Wind Direction (°)	166.0	-8.1	+18.3	153.1	-10.5	-15.5	168.1	-0.3	-10.1

It is noted that similar data tables to those above were presented in the MLA FLOT.310 project report (Petrov *et al.*, 2001). Comparison of these two data sets shows some differing values. These differences can be attributed to the more extensive data screening process undertaken for this project as detailed in section 4.3. The primary variations exist in the external feedlot data. It is noted that the data presented in Petrov *et al.* (2001) was the average data of all four external stations. By comparison, the data presented above is the average monthly data derived from the external data set produced from the four stations at each feedlot site. Furthermore, these data do not include any individual station data that was determined to be erroneous.

Table 5.1 and Table 5.2 highlight the data that demonstrate a notable difference between the climatic parameters recorded within the feedlot pens and external environment. Comparison of the average monthly data does not permit determination of the exact extent or nature of these variations. As such detailed analyses of the individual parameters are set out in the remaining sections of this chapter. General observations derived from the data in Table 5.1 and Table 5.2 may be summarised as follows.

a. Black globe temperatures recorded in the shaded pens were on average lower than those recorded in the unshaded pen and external feedlot environment.

b. Ground temperatures were lower under shade compared to the unshaded pens.

c. Ground temperatures recorded in the manure pad of the unshaded feedlot pens were higher than those recorded in the soil of the external feedlot environment.

d. Higher relative humidity levels were recorded in the shaded feedlot pen than in the unshaded pen and external feedlot environment.

e. The shade structures in the feedlot pens significantly reduced incoming and outgoing solar radiation levels.

f. Outgoing solar radiation levels measured in the unshaded feedlot pen were on average lower than those of the external feedlot environment.

g. The 2 metre wind speeds measured in the external feedlot environment were greater than those measured in the feedlot pens. This same trend was noted in the 10 metre wind speeds at Feedlot B.

h. At Feedlot A, the 2 metre wind speeds were less in the shaded pen compared to the unshaded pen.

5.3 AIR TEMPERATURE

5.3.1 OVERVIEW

The average monthly air temperatures shown in Table 5.1 and Table 5.2 show minimal difference between the monthly average values recorded for the external feedlot environment, the shaded feedlot pen, and the unshaded feedlot pen. However a comparison of the average monthly maximum and minimum air temperature data for both feedlot sites shows some notable variations. These data are presented in Table 5.3 and Table 5.4 below for Feedlot A and Feedlot B respectively.

Table 5.3. Differences in monthly average air temperatures recorded at Feedlot A for January to March 2001.

Monthly Air Temperatures	January			February			March		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen
Minimum (°C)	17.9	+0.6	+1.0	16.8	+0.7	+0.7	16.8	+0.8	+0.9
Maximum (°C)	31.2	+0.0	+0.6	28.8	+0.3	+1.0	29.0	+0.1	+0.6
Average (°C)	24.4	+0.2	+0.7	22.8	+0.4	+0.6	22.7	+0.3	+0.6

Table 5.4. Differences in monthly average air temperatures recorded at Feedlot B for January to March 2001.

Monthly Air Temperatures	January			February			March		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen
Minimum (°C)	20.0	+0.4	+0.1	18.9	+0.8	+0.4	13.9	+0.7	+0.1
Maximum (°C)	34.2	+0.4	+0.3	31.7	+0.4	+0.1	26.2	+0.5	+0.2
Average (°C)	27.3	+0.4	+0.1	25.2	+0.6	+0.2	20.1	+0.6	+0.0

Table 5.3 shows that at Feedlot A, a notable difference is observed in the average minimum air temperatures recorded at the external station compared to those of the feedlot pens. Specifically, the average monthly minimum temperatures of the external station data set were 0.6 to 1.0°C lower than those recorded within the

feedlot pens. The same trend was observed in the data from Feedlot B however the difference ranged from 0.1 to 0.8°C over the three month period.

5.3.2 *DISTRIBUTION OF AIR TEMPERATURE OBSERVATIONS*

The variations in minimum air temperature values between the three feedlot areas can be better observed through comparison of the distribution of the entire temperature observation data set. Figure 5.1 and Figure 5.2 below show the distribution of the hourly air temperature observations for Feedlot A and Feedlot B respectively. These plots present all common hourly observations collected at the three areas of each feedlot site. Where an observation was missing from one data set, the hourly record was removed from all three data sets. The data collected from each area was then individually sorted in ascending order and plotted as shown.

These data plots allow a comparison of the air temperatures measured external to the feedlot, in the unshaded pen, and in the shaded pen. The data from Feedlot A shown in Figure 5.1 indicate that air temperatures recorded by the external stations were generally lower than those observed within the feedlot pens. This figure highlights an interesting observation of the shaded pen air temperature data; that is, the lower air temperatures recorded in the shaded pen at Feedlot A were similar to those recorded in the unshaded pen. However, for the higher measured air temperatures, those recorded in the shaded pen are cooler than those of the unshaded pen and lie closer to those recorded by the external stations.

The distribution data for Feedlot B shown in Figure 5.2 shows a different trend. These data suggest that at Feedlot B, the shaded pen environment was warmer than that of the unshaded pen and external environment. This observed trend was unexpected and may be due to sensor error.

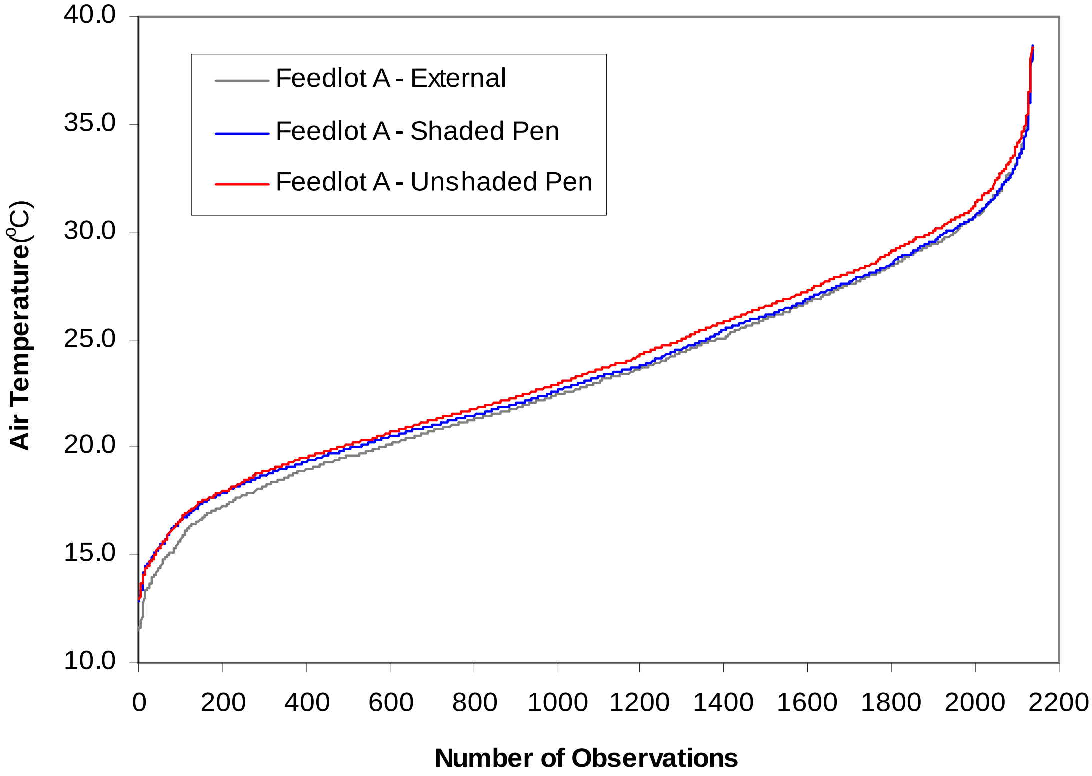

Figure 5.1. Ascending distribution of air temperature observations from Feedlot A for the period January to March 2001 (n = 2136).

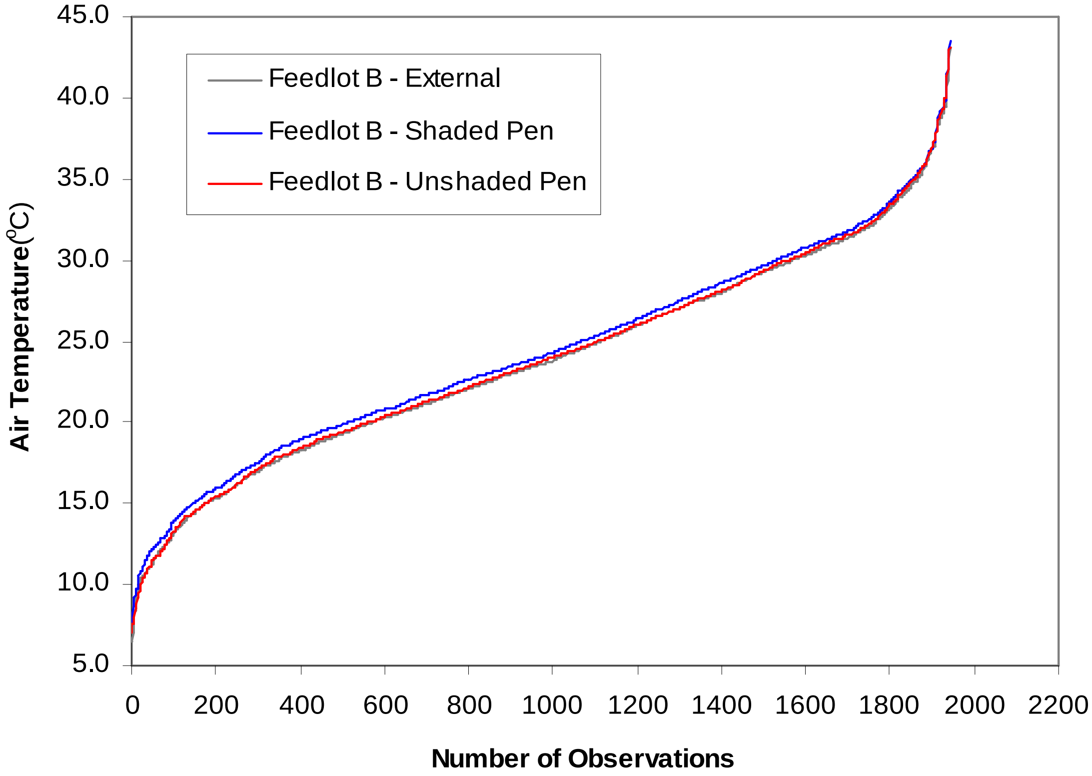

Figure 5.2. Ascending distribution of air temperature observations from Feedlot B for the period January to March 2001 (n = 1942).

As only single air temperature sensors were used in each of the shaded pens at the feedlot sites, it is not possible to determine if the data recorded by the sensor in the shaded pen at Feedlot B is erroneous. However, it is noted that the air temperature sensor initially installed in this automatic weather station at Feedlot B provided continuous hourly readings without fail throughout the entire data recording period. A similar trend to that observed and described above was also found in an MLA funded study of feedlot microclimates undertaken in 2002 which incorporated the same two feedlot sites. This study determined that the difference in air temperatures between unshaded and shaded feedlot pens was notably less significant at Feedlot B (0.0°C) compared to Feedlot A, where on average the unshaded pen was 0.3°C warmer (Petrov *et al.*, 2002).

From the project data it is not possible to determine whether or not the observed trend of warmer air temperatures in the shaded pen at Feedlot B is erroneous; or if in fact it is correct, what was the exact cause of this trend. Notwithstanding this, potential causes of the observed trend are discussed in Chapter 6.

5.3.3 *Diurnal Variation of Air Temperatures*

As outlined in section 5.3.1, the average monthly minimum temperatures of the external station data set at Feedlot A were 0.6 to 0.8°C lower than those recorded within the feedlot pens. The same trend was observed in the data from Feedlot B with the difference ranging from 0.1 to 0.4°C over the January to March period.

The average diurnal variations of air temperatures for the 3 month recording period are shown in Figure 5.3 and Figure 5.4 below for Feedlot A and B respectively. These plots follow the approximately sinusoidal form that is expected from daily air temperature oscillations as described by Rosenberg (1974), with the minimum occurring in the early morning hours and the maximum occurring after peak solar and net radiation.

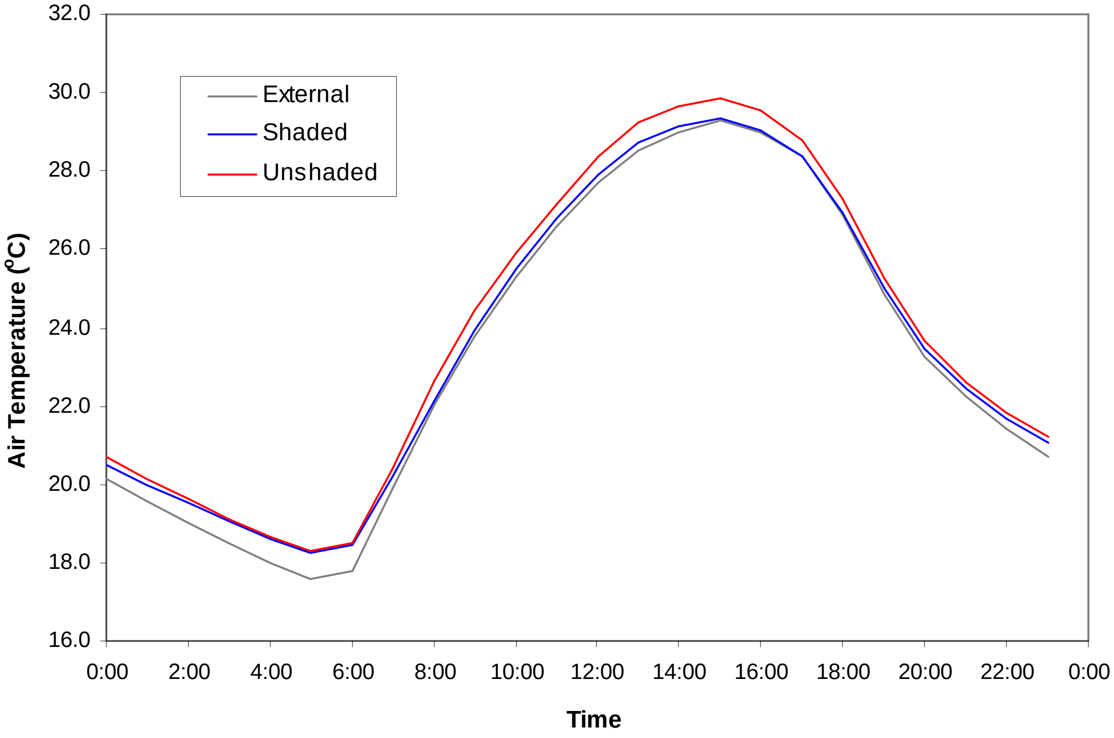

Figure 5.3. Average hourly air temperatures recorded at Feedlot A for the period 1 January to 31 March 2001.

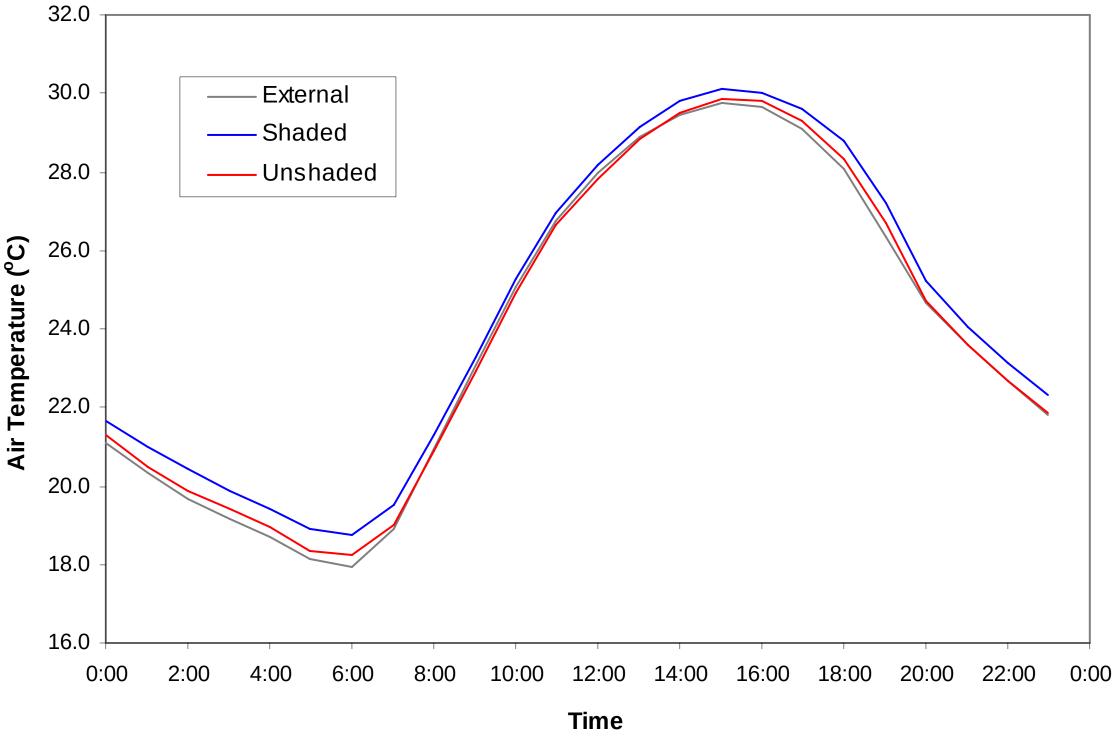

Figure 5.4. Average hourly air temperatures recorded at Feedlot B for the period 9 January to 31 March 2001.

The reason for the lower average monthly minimum temperatures reported above is highlighted by these average diurnal plots. The data show that during the cooler periods of the day (4 to 6am) the air temperatures recorded by the external stations at each feedlot site were clearly lower than those recorded within the feedlot pens. Analyses of these data show that between 4am and 6am the difference in air temperatures between the shaded pen and the external feedlot environment averaged 0.7 ± 0.02°C (mean ± s.e.; n = 540). Over the same pre-dawn period, the air temperatures of the unshaded pen were 0.5 ± 0.03°C (mean ± s.e.; n = 537) warmer than the external feedlot environment. The plots presented in Figure 5.3 and Figure 5.4 show that as the day warmed, this difference in air temperatures between the external stations and those within the feedlot pens was significantly reduced.

Similar to the air temperature distribution data presented and discussed in section 5.3.2, the data from Feedlot B presented in Figure 5.4 indicates that the air temperatures recorded in the shaded pen were slightly higher than those of the unshaded pen and the external stations. This is contrary to the trend at Feedlot A where the average hourly data show that air temperatures within the unshaded pen were generally warmer than those of the shaded and external sites. In particular, at Feedlot A this difference was most pronounced during the warmest periods of the day (generally 12 to 5pm). Again, as outlined in section 5.3.2, the reasons for the observed trend at Feedlot B are unclear.

5.3.4 *KEY OBSERVATIONS*

The data analyses of the recorded air temperature data highlight the following key observations:

1. Air temperatures recorded in the feedlot pens (both unshaded and shaded) were slightly higher than corresponding air temperatures recorded outside the feedlot environment;

2. The increase in air temperatures within the feedlot pens was most pronounced during the cooler overnight periods, in particular between the hours of 4am and 6am when it was found the shaded and unshaded feedlot pens were on average 0.7°C and 0.5°C warmer than the external feedlot environment;

3. At Feedlot A, the shade structure within the feedlot pen provided a reduction in maximum daily air temperatures compared to the unshaded pen;
4. The reduction in maximum daily air temperatures caused by the presence of shade saw that maximum air temperatures recorded in the shaded pen were only slightly higher than the maximum temperatures recorded in the external feedlot environment;
5. At Feedlot B the shade structures did not provide any notable reduction in air temperatures compared to the unshaded pen, in fact, over the entire data collection period, the average air temperatures recorded in the shaded pen at Feedlot B were slightly higher than those of the unshaded pen.

The possible reasons and effects of these observations are discussed in Chapter 6.

5.4 HUMIDITY

5.4.1 OVERVIEW

The average monthly data presented in section 5.2 highlighted that relative humidity levels recorded in the shaded feedlot pen were higher than those from the unshaded pen and external feedlot environment. The average monthly relative humidity data are presented in Table 5.5 and Table 5.6 below. These data show that the difference in average monthly relative humidity values between the shaded pen and those measured in the unshaded pen and the external stations ranged from 7.5 to 8.8% for Feedlot A and 2.7 to 5.5% for Feedlot B.

Table 5.5. Monthly average relative humidity values recorded at Feedlot A for January to March 2001.

	Feedlot External			Unshaded Pen			Shaded Pen		
	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Average Relative Humidity (%)	62.9	69.1	67.7	63.5	69.5	68.7	71.7	77.5	76.2
Difference from Shaded Pen (%)	-8.8	-8.4	-8.5	-8.2	-8.0	-7.5	n/a	n/a	n/a

Table 5.6. Monthly average relative humidity values recorded at Feedlot B for January to March 2001.

	Feedlot External			Unshaded Pen			Shaded Pen		
	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Average Relative Humidity (%)	42.7	53.0	56.6	43.2	52.2	56.3	45.9	56.9	61.8
Difference from Shaded Pen (%)	-3.2	-3.9	-5.2	-2.7	-4.7	-5.5	n/a	n/a	n/a

5.4.2 *Diurnal Variation of Relative Humidity*

Plots of average hourly relative humidity values recorded over the data collection period show that the diurnal variation of humidity over a 24 hour period mirrors the trend observed with the air temperature data; that is, highest humidity readings were generally observed during the cool early morning periods, and humidity levels were at their lowest during the afternoon period when temperatures were at their maximum. This trend is expected due to the high dependence of relative humidity on temperature which means that if the amount of moisture in the air remains essentially constant, relative humidity will vary inversely with the temperature.

The average diurnal variation of relative humidity is shown in Figure 5.5 and Figure 5.6 below for Feedlot A and Feedlot B respectively. These figures clearly highlight the significant difference in the average hourly humidity levels observed in the shaded feedlot pen compared to those of the unshaded pen and external feedlot environment over the data collection period. The data show that at both feedlot sites average hourly humidity levels in the shaded pens were higher throughout the entire day.

Comparison of the relative humidity levels measured by the external stations and the unshaded feedlot pens shows that during the daylight hours the unshaded pens were only slightly more humid than the feedlot surrounds. Analyses of the hourly data showed that averaged over the period from 8am to 6pm the humidity levels within the unshaded pens exceeded those of the external environment by only $1.1 \pm 0.08\%$ (mean ± s.e.; n = 977) and $0.5 \pm 0.06\%$ (mean ± s.e.; n = 893) respectively for Feedlot A and Feedlot B.

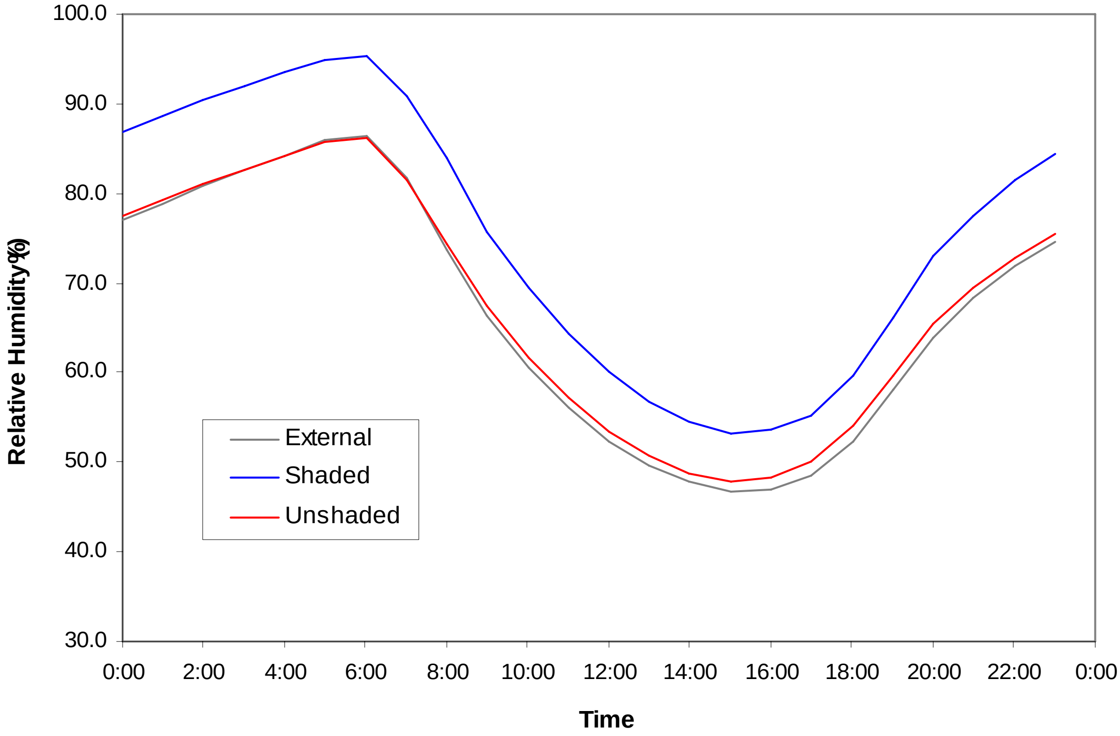

Figure 5.5. Average hourly relative humidity recorded at Feedlot A for the period 1 January to 31 March 2001.

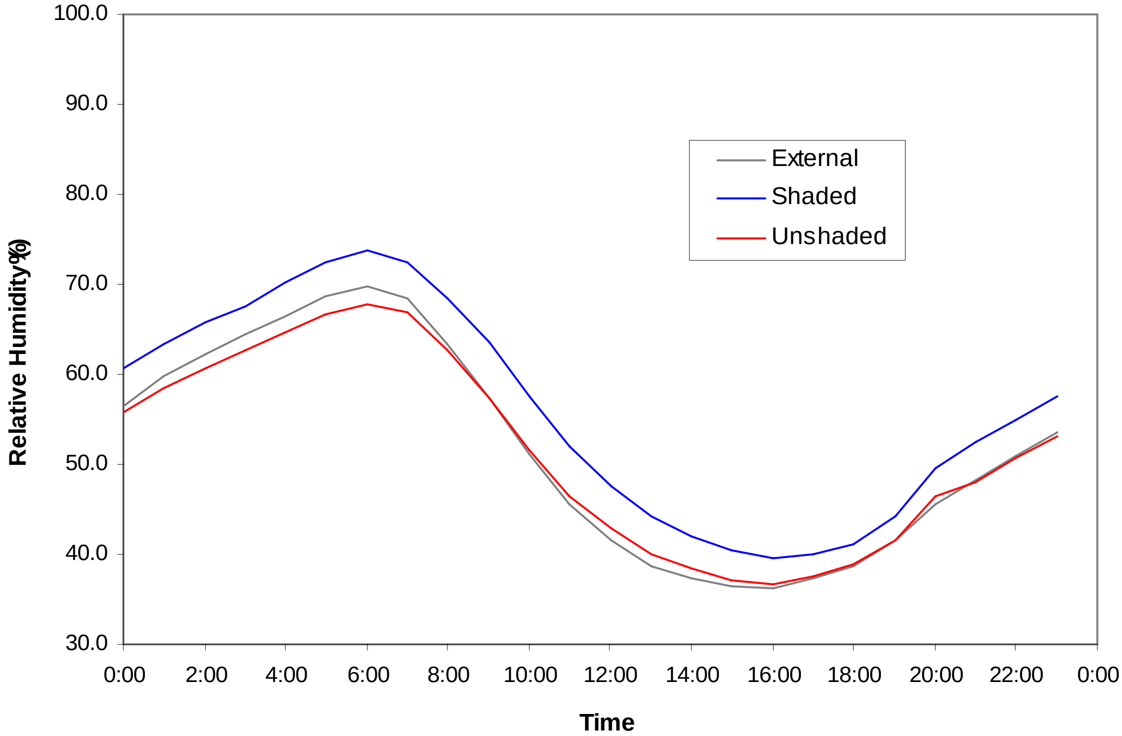

Figure 5.6. Average hourly relative humidity recorded at Feedlot B for the period 9 January to 31 March 2001.

The diurnal plots for humidity show that at Feedlot B, between midnight and 8am, the external feedlot environment was more humid than the unshaded pen area. At Feedlot A the unshaded pen and external station data show minimal difference in humidity levels over this same period. This observed trend at Feedlot B may be attributed to the management factors of the feedlot as detailed in Chapter 4. Specifically, the external area of Feedlot B featured numerous garden and grassed areas (including a 7-hole golf course) which were regularly watered at any hour of the day. The 120 ha centre pivot irrigation area was also frequently watered over full 24 hour periods. The night-time watering of these areas in close proximity to some of the external stations at Feedlot B may be the cause for the observed higher humidity levels.

5.4.3 *EFFECT OF SHADE ON HUMIDITY*

The average monthly and average hourly relative humidity data show that recorded humidity levels in the shaded pen at each feedlot site were higher than those of the unshaded pen. The trend can be quantified from plots of the recorded humidity levels from the shaded pen against the data from the unshaded pen. These data are shown below in Figure 5.7 and Figure 5.8 for Feedlot A and Feedlot B respectively.

The plots show that at both feedlot sites a very strong correlation exists between the relative humidity levels recorded in the unshaded and shaded feedlot pens ($R^2 = 0.97$ for Feedlot A and $R^2 = 0.99$ for Feedlot B). Analyses of the data found that for Feedlot A the humidity levels recorded in the shaded pen were on average 11.7 ± 0.11% (mean ± s.e.; n = 2,134) greater than those recorded in the unshaded pen. At Feedlot B the difference in relative humidity levels between the unshaded and shaded pen averaged 8.5 ± 0.11% (mean ± s.e, n = 1,906).

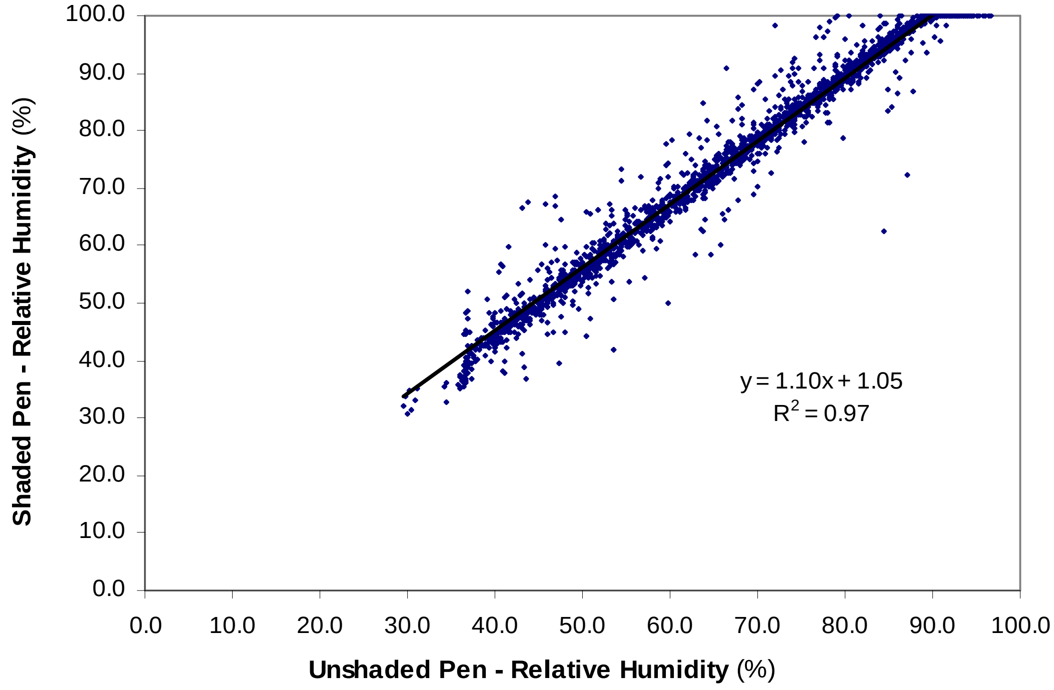

Figure 5.7. Hourly relative humidity recorded within the shaded pen at Feedlot A against corresponding relative humidity recorded in the unshaded pen for the period 1 January to 31 March 2001 (n = 2,134).

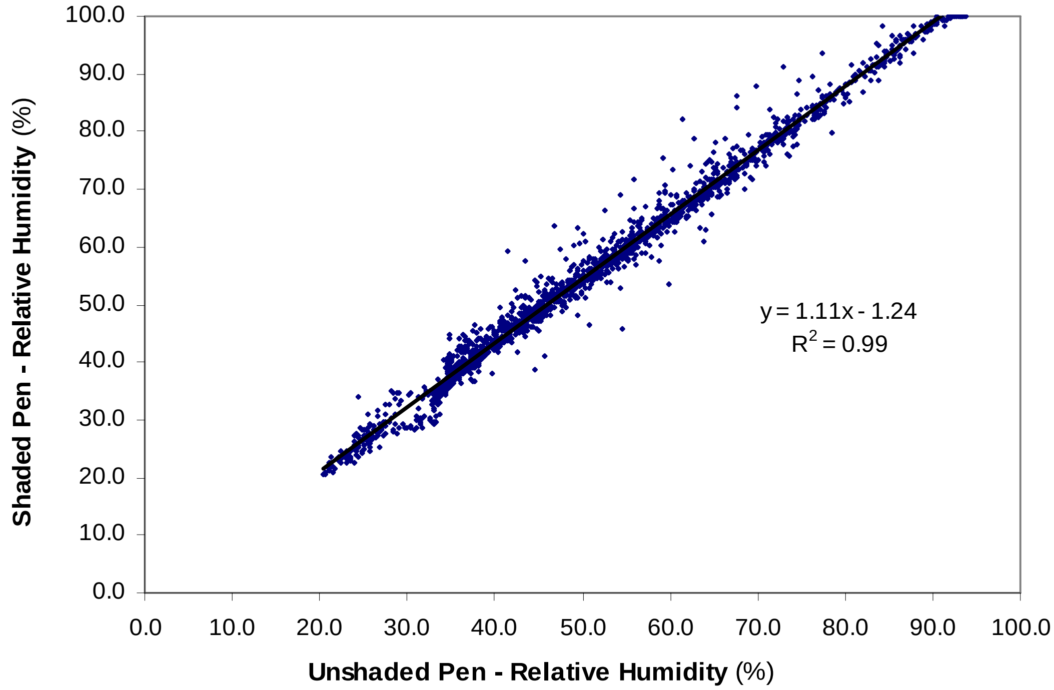

Figure 5.8. Hourly relative humidity recorded within the shaded pen at Feedlot B against corresponding relative humidity recorded in the unshaded pen for the period 9 January to 29 March 2001 (n = 1,906).

5.4.4 KEY OBSERVATIONS

In summary the analyses of the relative humidity data has shown:

1. The humidity levels in the shaded pens at both feedlot sites were on average found to be 8 to 12% greater than those recorded in the unshaded pens;
2. Humidity levels recorded in the unshaded feedlot pen were only slightly higher than those of the external feedlot environment;
3. At both feedlot sites the difference in humidity levels between the unshaded feedlot pens and the external environment was most pronounced between the hours of 8am to 6pm;
4. At Feedlot B humidity levels of the external environment were generally higher than those recorded within the unshaded pen between the hours of 12am to 8am. No significant difference was observed at Feedlot A.

5.5 GROUND TEMPERATURE

5.5.1 OVERVIEW

In section 5.2 it was noted that ground temperatures recorded in the shaded pens were lower than those recorded in the unshaded pen. It was also observed that ground temperatures recorded in the manure pad of the unshaded feedlot pen were higher than those recorded in the soil of the external feedlot environment. The average monthly maximum and minimum ground temperature data for both feedlot sites are presented in Table 5.7 and Table 5.8 below.

Table 5.7. Differences in monthly average ground temperatures recorded at Feedlot A for January to March 2001.

Monthly Ground Temperatures	January			February			March		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen
Minimum (°C)	25.1	-1.3	+3.6	23.2	-1.3	+4.1	23.5	-1.1	+4.6
Maximum (°C)	31.9	-5.9	+2.5	27.8	-4.0	+4.3	28.1	-4.5	+4.1
Average (°C)	28.3	-3.4	+2.8	25.3	-2.5	+4.1	25.6	-2.6	+4.3

Table 5.8. Monthly average ground temperatures recorded at Feedlot B for January to March 2001.

Monthly Ground Temperatures	January			February			March		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen
Minimum (°C)	29.6	-13.8	no data†	24.6	-10.3	+3.1‡	21.6	-11.2	+0.6
Maximum (°C)	36.9	-13.3	no data†	32.7	-13.3	+2.1‡	27.9	-12.8	+0.7
Average (°C)	33.0	-13.5	no data†	28.3	-11.7	+2.3‡	24.5	-12.1	+0.5

† - No data available due to sensor failure.
‡ - Average data for period of 22 to 28 February 2001 only.

5.5.2 *Diurnal Variation of Ground Temperature*

Plots of average hourly ground temperature values recorded over the three month period are shown in Figure 5.9 for Feedlot A and Figure 5.10 for Feedlot B. The diurnal variation of ground temperatures indicate that at both feedlot sites the shade structures within the feedlot pens provided a significant reduction in ground temperature throughout the entire 24 hour period.

It is not possible to make direct comparisons between the ground temperatures recorded at the external feedlot sites and the unshaded feedlot pen due to variations in the depths at which the temperature sensors were located. Whilst ground temperature sensors were buried to a depth 50 to 100 mm, varying ground and pen surface conditions prevented each sensor being accurately buried to identical depths. Notwithstanding this, the recorded data does show that the manure and clay composition of the feedlot pen surface was generally warmer than the grass covered soil of the external weather station sites. This difference was most notable at Feedlot A and can be attributed to the fact that the external stations at the southern Queensland site were located in black clay soils that allowed the ground temperature sensors to be easily buried at maximum depth (ie. 100 mm) which would have provided cooler temperatures than sensors located closer to the surface.

Comparison of the average hourly data plots show that the shade cloth structures at Feedlot B would appear to provide a greater reduction in ground temperatures than the spaced galvanised sheeting at Feedlot A. However it is noted that other factors such as the use of water cannons at night at Feedlot B and differing stocking densities of the feedlot pens may also contribute to these observed variations in ground temperatures between the feedlot sites.

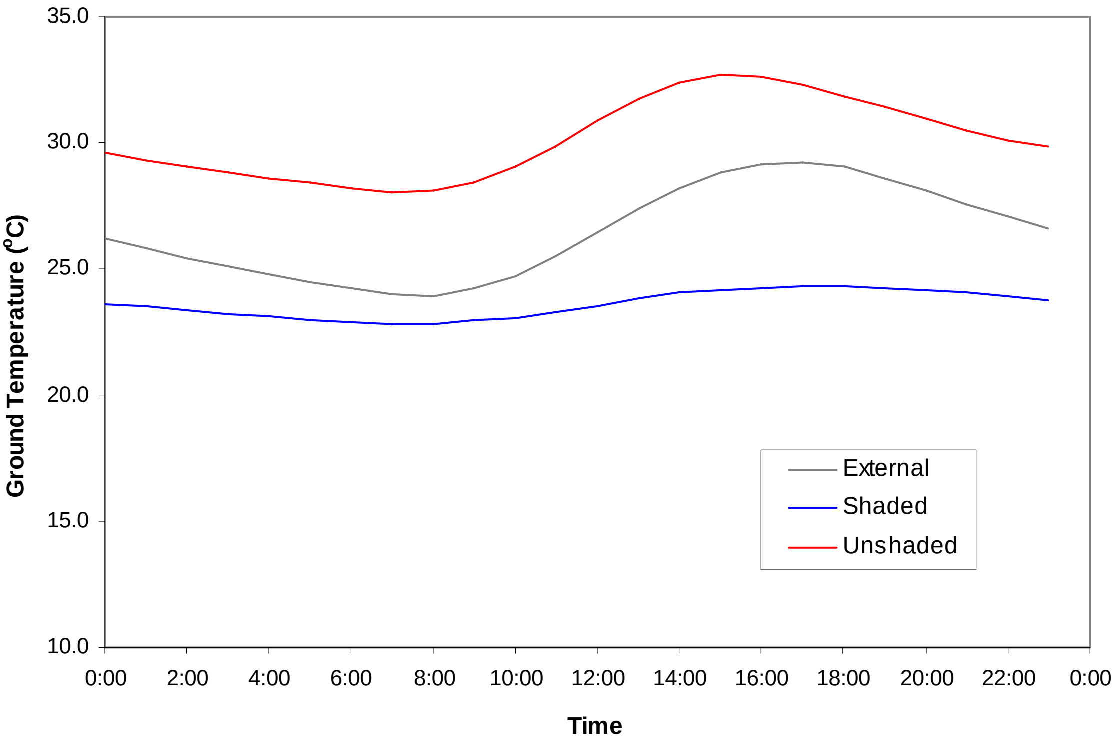

Figure 5.9. Average hourly ground temperatures recorded at Feedlot A for the period 1 January to 31 March 2001.

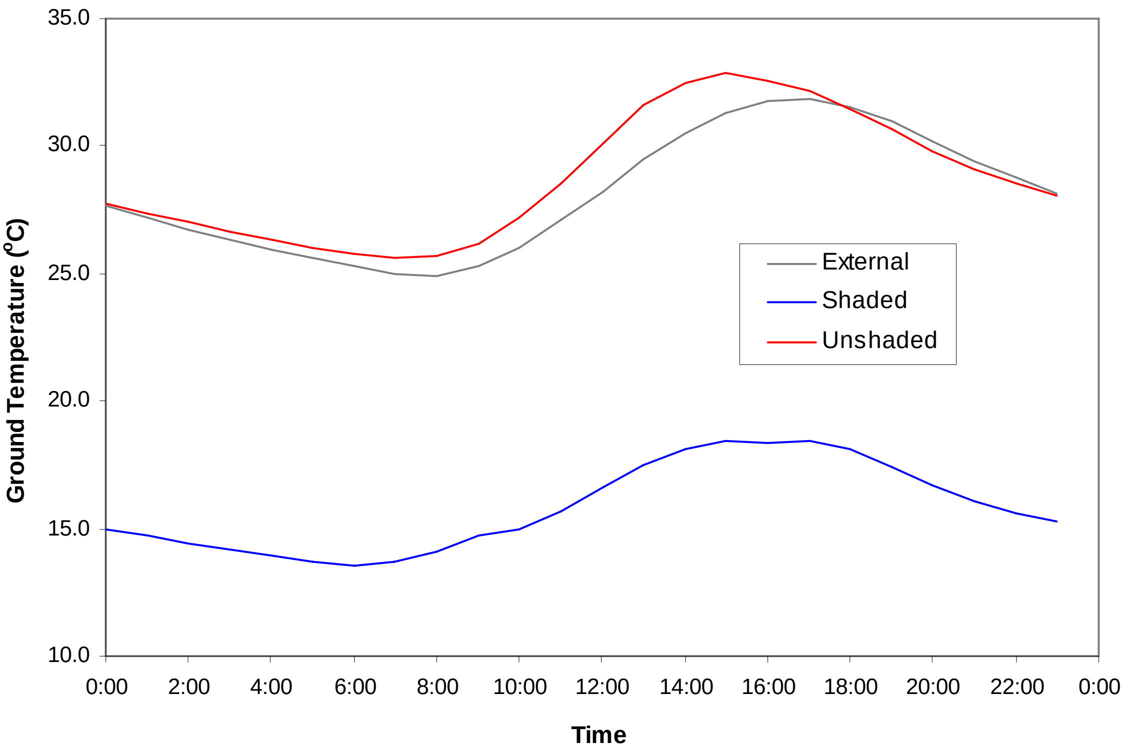

Figure 5.10. Average hourly ground temperatures recorded at Feedlot B for the period 9 January to 31 March 2001.

5.5.3 EFFECT OF SHADE ON GROUND TEMPERATURES

Plots of the recorded ground temperature data from the shaded pen against the data from the unshaded pen are shown in Figure 5.11 for Feedlot A and Figure 5.12 for Feedlot B. Whilst limited data are available for Feedlot B due to a failing sensor in the unshaded pen up until the 22 February 2001, the plots presented below highlight some key points.

Firstly, comparison of the data from the two feedlot sites show that the plot for Feedlot B has a much stronger correlation (R^2 = 0.94) compared to that for Feedlot A (R^2 = 0.44). This can be attributed to the shade cloth structure at Feedlot B that provides constant shade compared to the spaced galvanised sheeting at Feedlot A. The differences between these shade structures are discussed in more detail in section 5.6.

The lines of best fit for the data plotted in Figure 5.11 and Figure 5.12 can be used to calculate approximate shaded ground temperatures based on a range of unshaded pen ground temperatures. For example, using the above line of best fit equations, for the ground temperature range of 20 to 40°C in the unshaded pen, it can be calculated that at Feedlot A the ground temperature under the galvanised shade structure would be in the range of 19 to 28°C (ie. a reduction of approximately 5 to 30% compared to the unshaded pen); whilst under the shade cloth at Feedlot B, ground temperature would range from 8 to 25°C (a reduction of 58 to 38% respectively). These calculated percentages show that the galvanised shade structures at Feedlot A provide increased surface cooling with increased temperature, whilst the shade cloth at Feedlot B does the opposite, with a decreased difference in ground temperatures as temperatures increase. Notwithstanding these differences in trends, overall the shade cloth structures at Feedlot B were observed to provide a much greater reduction in surface temperature for all conditions compared to the galvanised shade cover at Feedlot A.

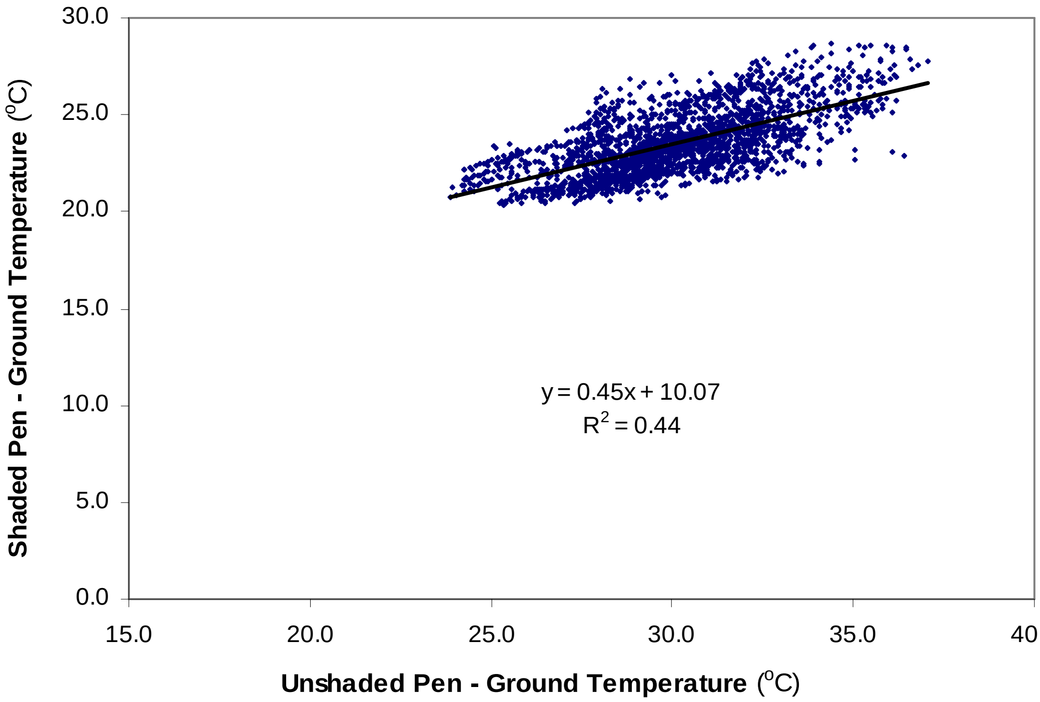

Figure 5.11. Hourly ground temperatures recorded within the shaded pen at Feedlot A against corresponding ground temperatures recorded in the unshaded pen for the period 1 January to 31 March 2001 (n = 2,136).

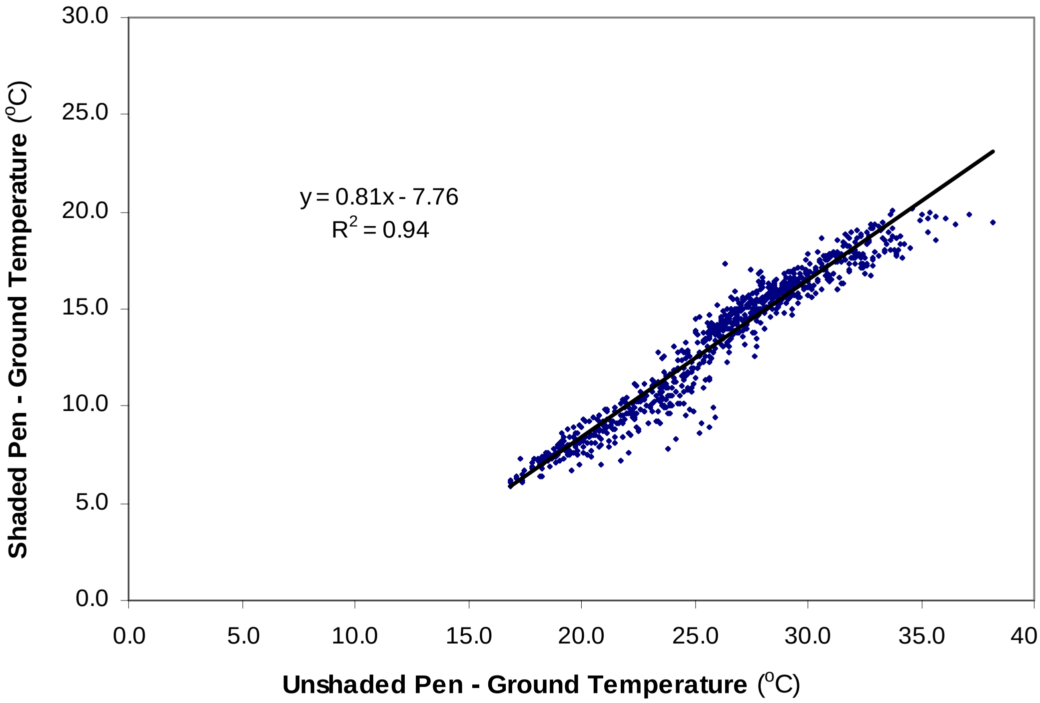

Figure 5.12. Hourly ground temperatures recorded within the shaded pen at Feedlot B against corresponding ground temperatures recorded in the unshaded pen for the period 22 February to 29 March 2001 (n = 845).

5.5.4 KEY OBSERVATIONS

As a result of the ground temperature data analyses the following observations were made. These are further discussed in Chapter 6.

1. Ground temperatures recorded in the manure pad of the unshaded feedlot pens were higher than those recorded in the soil of the external feedlot environment;
2. At both feedlot sites ground temperatures in the shaded pens were lower than those of the unshaded pens over the entire day;
3. The magnitude of reduction in ground temperatures caused by the presence of shade structures within the feedlot pens is dependant on the shade type;
4. The galvanised iron sheeting at Feedlot A provided increased cooling with increased temperatures whilst the shade cloth structures at Feedlot B had a reduced cooling effect as temperatures increased.

5.6 SOLAR RADIATION AND ALBEDO

5.6.1 OVERVIEW

The solar radiation data presented in section 5.2 shows the average monthly values of incoming and outgoing solar radiation calculated from all hourly observations. Table 5.9 and Table 5.10 below present the average monthly solar radiation data calculated from the daylight hours only (6am to 6pm EST) for Feedlot A and Feedlot B respectively. It is noted that the complete set of solar radiation sensors were not installed and operable at Feedlot A until 16 January 2001 due to a delay in the supply of the equipment from the manufacturer. For similar reasons the solar radiation readings at Feedlot B were not commenced until 9 January 2001.

Table 5.9. Average monthly solar radiation values recorded at Feedlot A (calculated from 6am to 6pm EST readings).

6am to 6pm Averages	Incoming Solar Radiation (W/m^2)			Outgoing Solar Radiation (W/m^2)		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen
January 2001	593.9	130.1†	553.9†	91.6	17.4†	81.3†
February 2001	561.6	139.5	532.5	111.5	19.5	69.6
March 2001	456.0	92.9	433.4	88.5	16.4	58.1
All Months	*535.1*	*118.3*	*496.2*	*96.4*	*17.8*	*67.4*

† - Average data for period of 16 to 31 January 2001 only.

Table 5.10. Average monthly solar radiation values recorded at Feedlot B (calculated from 6am to 6pm EST readings).

6am to 6pm Averages	Incoming Solar Radiation (W/m^2)			Outgoing Solar Radiation (W/m^2)		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen
January 2001	601.3†	183.5†	598.5†	150.7†	41.3†	100.9†
February 2001	519.3	157.8	538.1	124.2	33.3	84.2
March 2001	452.1	140.1	494.7	107.8	36.0	83.0
All Months	*516.3*	*158.2*	*538.3*	*125.3*	*36.5*	*88.4*

† - Average data for period of 9 to 31 January 2001 only.

The average monthly data show that the shade structures in the feedlot pens significantly reduced both incoming and outgoing solar radiation levels. It is also noted that outgoing solar radiation levels measured in the unshaded feedlot pen varied slightly from those of the external feedlot environment. The expected result was that the incoming solar radiation measured by the external stations should be equal to that measured by the automatic weather stations located within the unshaded feedlot pens. The differences in average incoming solar radiation values between the unshaded feedlot pens and external stations can be attributed to two factors. These are imprecise readings caused by individual sensor cleanliness, and variations between readings due to the accuracy of the solar radiation sensors.

During maintenance of the automatic weather stations over the data collection period it was noted that dust and fly spots would accumulate on the solar radiation sensors. The fact these sensors were located at a height of 10 metres on both the unshaded and external stations limited the practicality of cleaning these stations regularly (in particular the stations located within the feedlot cattle pens). Accumulation of dust and fly spots would contribute to lower than normal solar radiation values being recorded.

It is noted that the manufacturer's specification sheets for the solar radiation sensors states that these sensors record to within an accuracy of ±5% (refer Appendix B). Comparison of the average monthly incoming solar radiation values shows that the external station and unshaded pen data fall within this margin of error for both feedlot sites.

5.6.2 DIURNAL VARIATION OF SOLAR RADIATION

The average diurnal variation of incoming and outgoing (reflected) solar radiation measured in the shaded pen, unshaded pen and external feedlot environment are shown graphically in Figure 5.13 and Figure 5.14 below for Feedlot A and Feedlot B respectively. These data show that the measured incoming solar radiation of the unshaded pen and external feedlot environment at both feedlot sites follow the expected trend with incoming radiation reaching a peak of approximately 850 to 950 W/m^2 around midday. As detailed by Oke (1987), the pattern of incoming solar radiation is controlled by the azimuth and zenith angles of the sun relative to the horizon. As such, peak solar radiation occurs at the solar noon when the sun is located directly above the receiving surface.

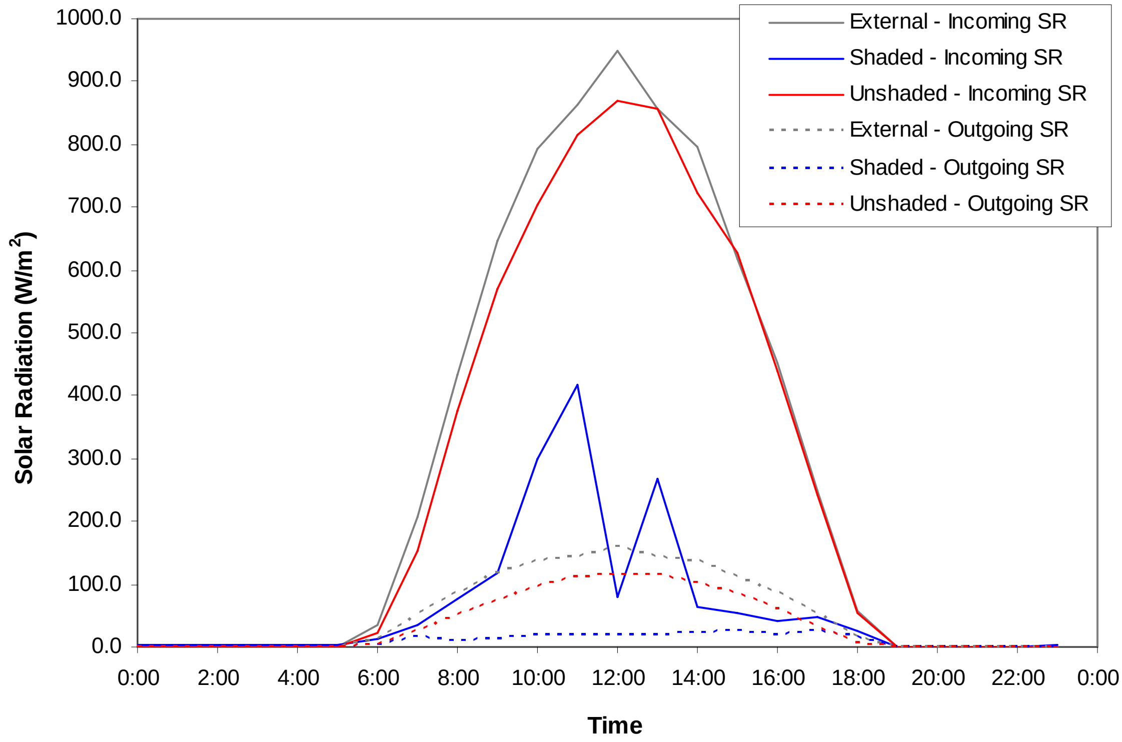

Figure 5.13. Average hourly solar radiation values (incoming and outgoing) recorded at Feedlot A for the period 16 January to 31 March 2001.

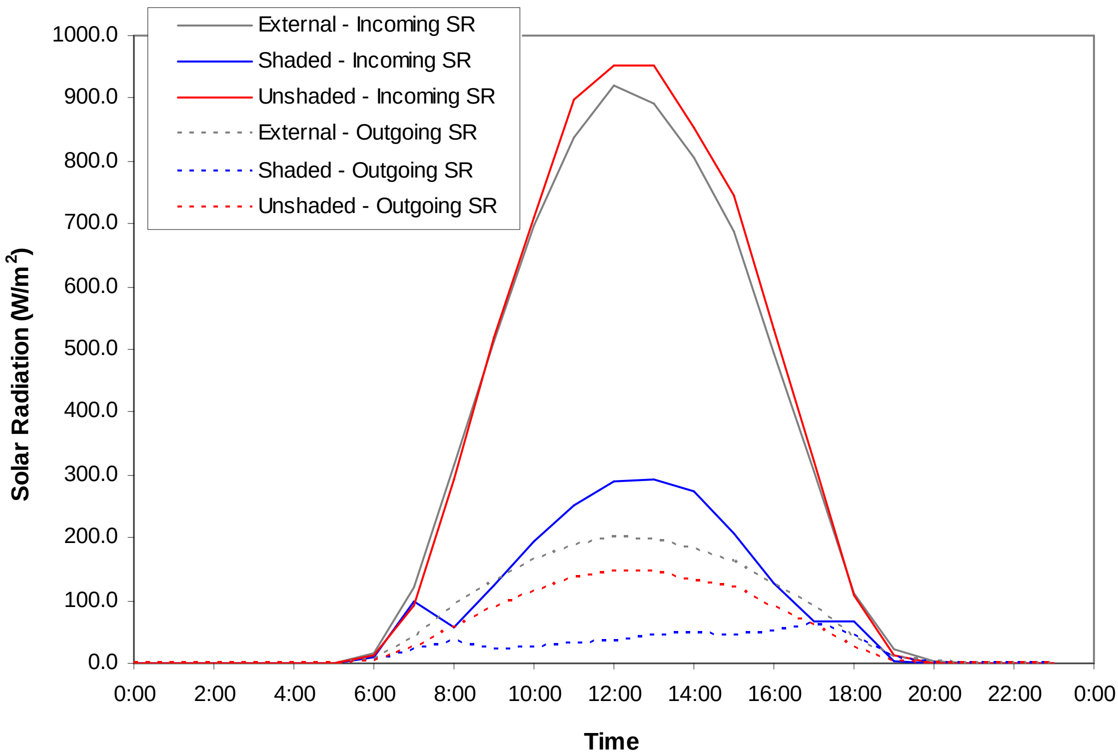

Figure 5.14. Average hourly solar radiation values (incoming and outgoing) recorded at Feedlot B for the period 9 January to 29 March 2001.

The shade cloth at Feedlot B provides a generally constant reduction in incoming solar radiation due to its semi transparent nature. The increased values of incoming solar radiation observed at 7am and 6pm was a result of the sun directly penetrating gaps present at the end of the shade sheets (as shown in Plate 5.1 below). Similarly the incoming solar radiation readings in the shaded pen at Feedlot A were influenced by the gaps present in the galvanised iron sheeting of the shade structure. Specifically, the average hourly data for the three month period indicate that the gaps in the sheeting allowed significantly more radiation through to the automatic weather station from 10 to 11am, and also at 1pm. It is presumed that sunlight penetrated one of the larger (approx. 300 mm) end gaps in the sheeting around 10 to 11am and then one of the 100 mm gaps for a shorter period around 1pm (as shown in Plate 5.1 below). The efficiency of the shaded structures at each feedlot site is discussed in section 5.6.3 below.

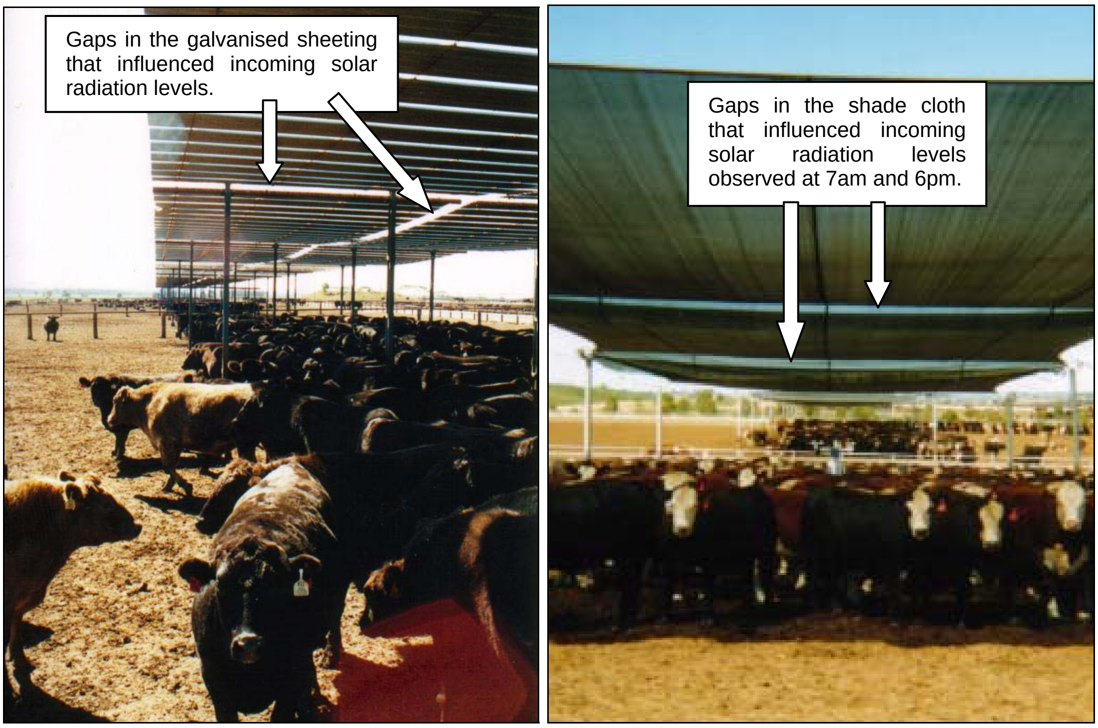

Plate 5.1. Shade structures at Feedlot A (left) and Feedlot B (right).

5.6.3 *Effectiveness of Shade Structures*

Through comparison of the incoming solar radiation values recorded in the shaded and unshaded pen, a general assessment of the effectiveness of the shade structures utilised at each feedlot site can be obtained. The two types of shade systems widely used in the feedlot industry are either iron sheets attached to metal cabling, or shade cloth that is either permanently fixed or furlable (Binns *et al.*, 2003). Feedlot A utilised the first of these shade types, and Feedlot B had established shade cloth that could be pulled back over the winter months.

Table 5.11 below presents the percentage reduction in incoming solar radiation calculated using the monthly average 6am to 6pm (EST) radiation data from the shaded and unshaded pen at each feedlot site. These data show that the shade structures at each feedlot site provided a similar overall reduction in incoming radiation with the galvanised sheeting at Feedlot A providing a slightly greater average reduction than the shade cloth at Feedlot B.

Table 5.11. Calculated percentage reduction in incoming solar radiation caused by the presence of shade structures in the cattle pens at Feedlot A and Feedlot B.

Incoming Solar Radiation (W/m^2)	Feedlot A			Feedlot B		
	Unshaded Pen	Shaded Pen	Percentage Reduction	Unshaded Pen	Shaded Pen	Percentage Reduction
January 2001	553.9	130.1	76.5%	598.5	183.5	69.3%
February 2001	532.5	139.5	74.8%	538.1	157.8	70.7%
March 2001	433.4	92.9	78.5%	494.7	140.1	71.7%
All Months	*496.2*	*118.3*	*76.2%*	*538.3*	*158.2*	*72.3%*

Plots of calculated daily shade reduction values for each feedlot site show that whilst overall the iron sheeting structure at Feedlot A provided a better reduction, over the three month period the daily reductions were more variable compared to the shade cloth structures at Feedlot B. These data are presented in Figure 5.15 and Figure 5.16 below for Feedlot A and Feedlot B respectively. The plots present the daily shade reduction percentage derived using the total incoming solar radiation differences between the shaded pen and both the unshaded pen and external station data. Undertaking these separate calculations based on both the unshaded and external station data showed minimal variation between the values.

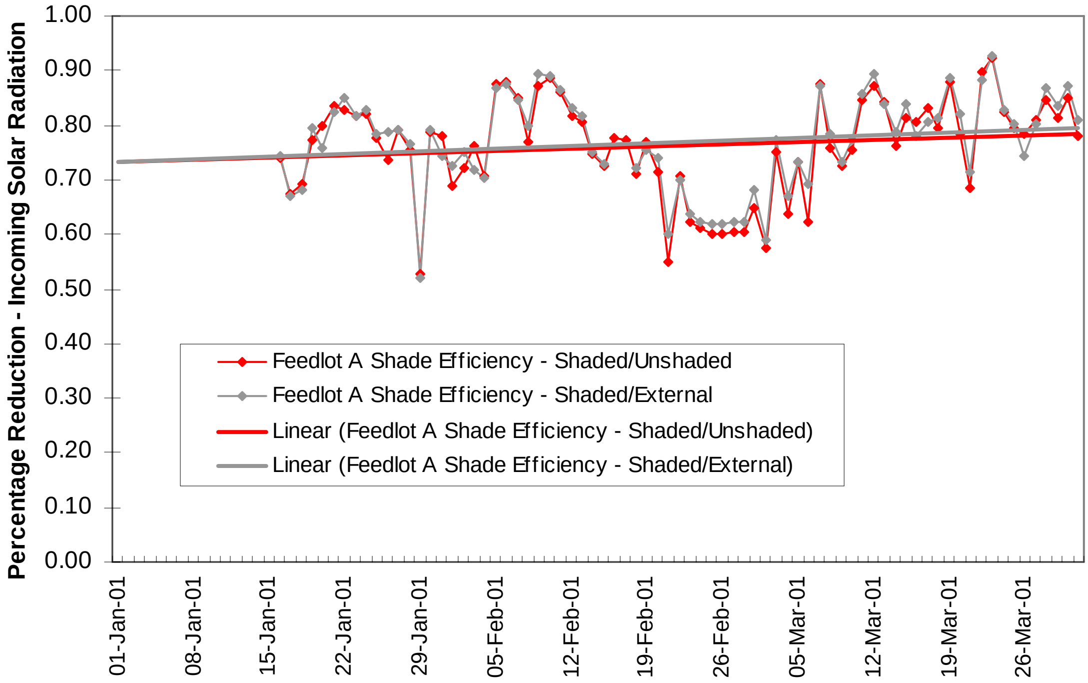

Figure 5.15. Plot of calculated daily shade reduction percentages for the galvanised iron sheet structure at Feedlot A for the period 16 January to 31 March 2001.

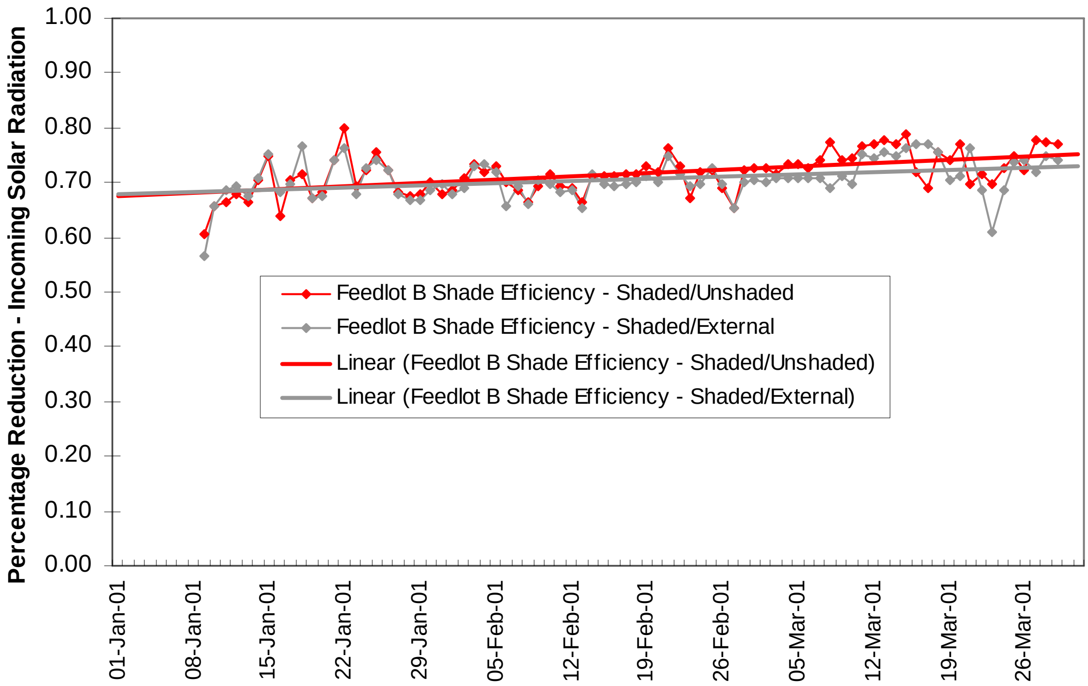

Figure 5.16. Plot of calculated daily shade reduction percentages for the shade cloth structure at Feedlot B for the period 9 January to 29 March 2001.

The increased variation in daily shade reduction values of Feedlot A compared to Feedlot B can be attributed to the type of shade structure. Whilst the complete (but semi-transparent) coverage provided by the shade cloth structures delivers a generally constant reduction in sunlight throughout the day, the reduction provided by iron sheeting is dependant on several factors including the altitude and azimuth of the sun (which varies both daily and seasonally) and also the size and orientation of the sheeting spacing.

The lines of best fit for the above plots indicate that shade efficiency at both sites marginally increased over the project data collection period. The reasons for this could be due to a number of factors. Over time it is expected that the shaded cloth at Feedlot B would accumulate dust which may assist in providing an increased reduction in the amount of sunlight passing through the fabric. Also both shade structures may become slightly more effective as the solar azimuth changes over the summer.

5.6.4 ALBEDO

As detailed in Chapter 2, the 'albedo' (α) of a surface is defined as the ratio of upwards to downwards radiation fluxes (Linacre and Hobbs, 1977). Albedo values range between 0 and 1 with lower number representing surfaces that have less reflectivity. The measurement of both incoming and outgoing solar radiation values allowed the albedo of the three areas at each feedlot site to be determined. The albedo values calculated from the average monthly 6am to 6pm (EST) solar radiation data are presented in Table 5.12 below.

Table 5.12. Average monthly albedo values for Feedlot A and Feedlot B.

Albedo (α)	Feedlot A			Feedlot B		
	Feedlot External	Unshaded Pen	Shaded Pen	Feedlot External	Unshaded Pen	Shaded Pen
January 2001	0.15	0.13	0.15	0.25	0.23	0.17
February 2001	0.20	0.14	0.13	0.24	0.21	0.16
March 2001	0.19	0.18	0.13	0.24	0.26	0.17
All Months	*0.18*	*0.15*	*0.14*	*0.24*	*0.23*	*0.16*

It is important to note that the moisture content of a surface can significantly vary its albedo value. This is observed when the calculated daily albedo values are plotted along with rainfall. These data are shown in Figure 5.17 for Feedlot A and Figure 5.18 and for Feedlot B. Two key points can be observed from the data presented in these daily albedo plots.

Firstly, it is noted that compared to the unshaded pen and external data, the daily albedo values calculated for the shaded pens at each site were highly variable. This variability is further demonstrated by examining mean daily albedo values and the standard deviations of these means as shown in Table 5.13 below. The possible reasons for this variability of the unshaded pen daily albedo values are discussed in Chapter 6.

Table 5.13. Mean and standard deviation of the daily albedo values for Feedlot A and Feedlot B.

	Feedlot A			Feedlot B		
	Feedlot External	Unshaded Pen	Shaded Pen	Feedlot External	Unshaded Pen	Shaded Pen
Mean	0.18	0.13	0.17	0.24	0.16	0.23
Standard Deviation	0.026	0.030	*0.071*	0.010	0.024	*0.041*
Number (n)	88	75	75	80	82	80

Secondly, and in contrast, the daily albedo values from the unshaded pen and external feedlot environment are relatively consistent. The plotted data show that significant variation in consecutive daily albedo values is related to rainfall events. In particular, the albedo values of the unshaded pen surface vary notably after a rainfall event. This is expected as the change in surface colour caused by a rainfall event is more dramatic on a bare manure pad compared to grass covered soil. The daily albedo plots presented above also show that after each rainfall event, the daily albedo values gradually increase as the manure pad surface dries.

The average albedo values of the unshaded manure pad and external feedlot environment are presented in Table 5.14 along with typical albedo values obtained from current literature. These data show the albedo values determined from the project data are similar to published values.

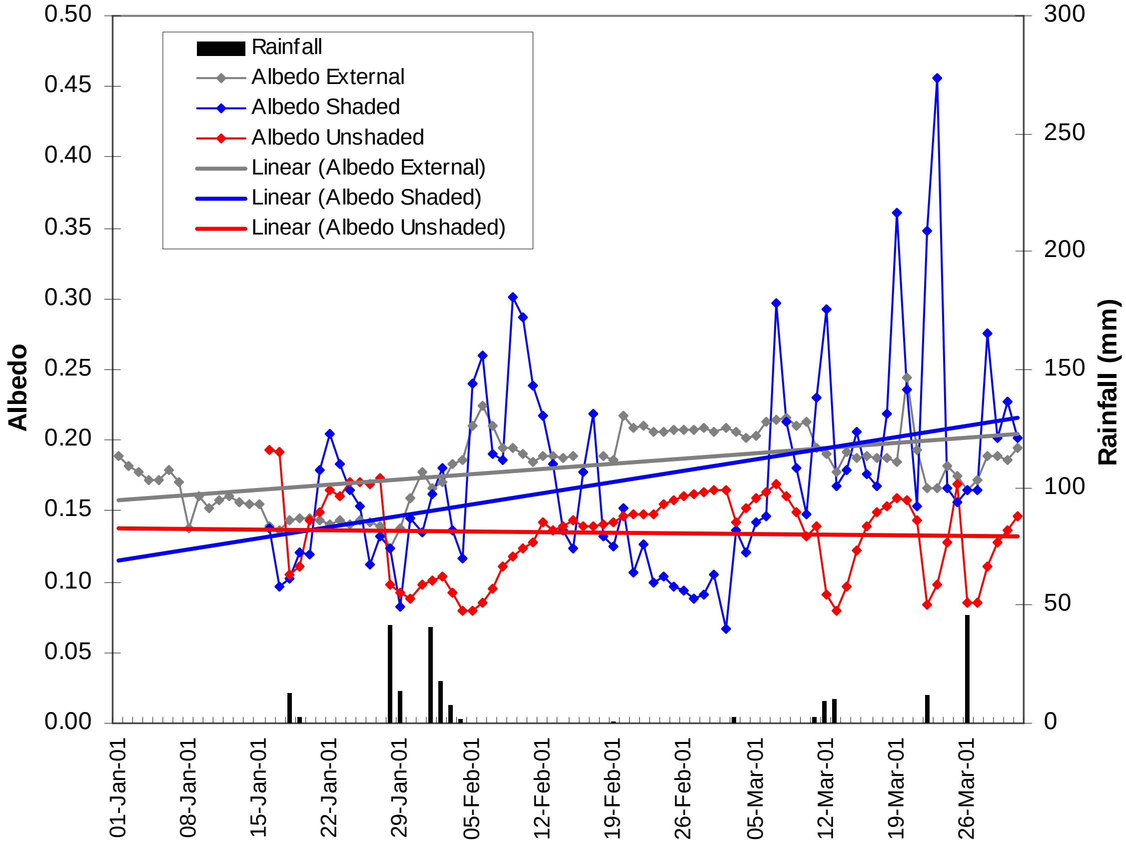

Figure 5.17. Daily albedos from Feedlot A for the January to March 2001 period.

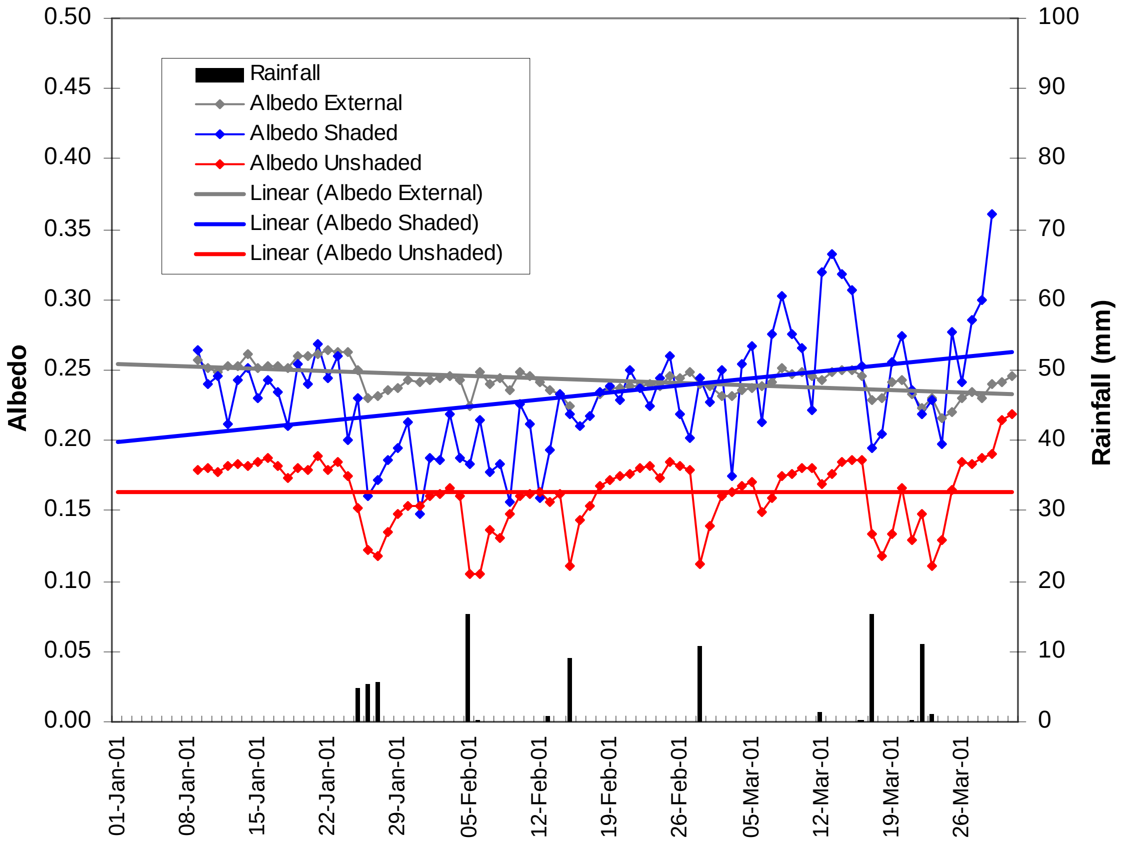

Figure 5.18. Daily albedos from Feedlot B for the January to March 2001 period.

Table 5.14. Comparison of calculated albedo values with typical published data.

Surface Type	*Albedo, α*	*Source*
Feedlot A - unshaded pen surface (dry average)	0.15	
Feedlot A - unshaded pen surface (wet average†)	0.10	
Feedlot A - external surface (grass and/or bare soil)	0.18	
Feedlot B - unshaded pen surface (dry average)	0.17	
Feedlot B - unshaded pen surface (wet average†)	0.13	
Feedlot B - external surface (grass and/or bare soil)	0.24	
Manure surface (wet average)	0.05	Lott, 1998
Manure surface (dry average)	0.11	Lott, 1998
Dry clay soil	0.20 - 0.30	Rosenberg, 1974
Dry sandy soil	0.25 - 0.45	Rosenberg, 1974
Soil (wet to dry)	0.05 - 0.40	Oke, 1987
Grass (short to long)	0.16 - 0.26	Oke, 1987

† - wet average based on a rainfall event of 10 mm or more.

5.6.5 *KEY OBSERVATIONS*

The observations arising from the analyses of the solar radiation and albedo data can be summarised as follows:

1. The presence of shade structures within feedlot pens provides a significant reduction in incoming and outgoing short wave solar radiation levels;

2. The reduction in short wave radiation levels caused by the two types of shade structures at each feedlot site were similar, although it is noted that the galvanised iron sheeting at Feedlot A provided a slightly greater reduction than the shade cloth at Feedlot B;

3. Daily albedo values of the manure pad under shade were highly variable for both feedlot sites, whilst the daily albedo values for the unshaded pen manure pads and the external feedlot environment were relatively consistent;

4. Rainfall events caused a significant decrease in the albedo values of the unshaded pen and to a lesser extent the external feedlot environment.

5.7 BLACK GLOBE TEMPERATURE

5.7.1 OVERVIEW

Black globe temperature is a measure of radiant heat. The sensor itself consists of an air temperature sensor enclosed within a 160 mm diameter copper globe that is coated with a matt black finish. This configuration provides an indication of the integrated effect of solar and terrestrial (long wave) radiation exchange on an exposed surface. It was expected that the shade structures within the feedlot pens would ensure that significantly lower black globe temperatures were recorded.

As shown by the average monthly data in Table 5.15 and Table 5.16 for Feedlot A and Feedlot B respectively, this trend was observed. These data also show minimal variation between the average monthly black globe temperatures recorded by the external stations and the stations located within the unshaded feedlot pens.

Table 5.15. Differences in monthly average black globe temperatures recorded at Feedlot A for January to March 2001.

Monthly Black Globe Temperatures	January			February			March		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen
Minimum (°C)	19.1	+0.9	+0.5	15.9	+1.2	+0.7	15.9	+1.2	+0.8
Maximum (°C)	39.9	-3.5	+0.1	37.5	-3.5	+0.7	37.8	-4.0	-0.9
Average (°C)	28.4	-1.5	+0.2	26.0	-1.8	+0.2	25.6	-1.6	-0.1

Table 5.16. Differences in monthly average black globe temperatures recorded at Feedlot B for January to March 2001.

Monthly Black Globe Temperatures	January			February			March		
	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen	Feedlot External	Shaded Pen	Unshaded Pen
Minimum (°C)	20.3	-0.1	+0.4	18.2	+1.3	+0.5	13.2	+1.2	+0.4
Maximum (°C)	43.1	-5.9	-0.5	41.3	-6.2	-0.5	36.4	-5.9	-0.7
Average (°C)	30.6	-1.7	-0.3	28.5	-1.5	-0.2	23.3	-1.3	-0.1

5.7.2 *Diurnal Variation of Black Globe Temperature*

The diurnal variation of black globe temperatures shown in the plots of average hourly values recorded over the three month period highlight the strong influence of incoming short wave solar radiation on black globe temperatures. These plots are shown below in Figure 5.19 for Feedlot A and Figure 5.20 for Feedlot B.

These data show that from 6am the black globe temperatures significantly increase. As shown from the solar radiation data in section 5.6.2, this corresponds with significant increase in incoming solar radiation. The data plots for both feedlot sites show a slight decrease in black globe temperatures at 2pm. This decrease can be attributed to the siting of the black globe sensor on the station. Limited space on the 2 metre cross arm of each automatic weather station resulted in the black globe sensor being positioned in a location that was partially shaded by the solar panel for a short period at around 2pm each day.

The average hourly black globe temperature plots shown in Figure 5.19 and Figure 5.20 show that during the 'non-daylight' hours, the black globe temperatures recorded in the shaded pen remain slightly higher than those of the unshaded pen and external stations. This observed trend is examined in Chapter 6.

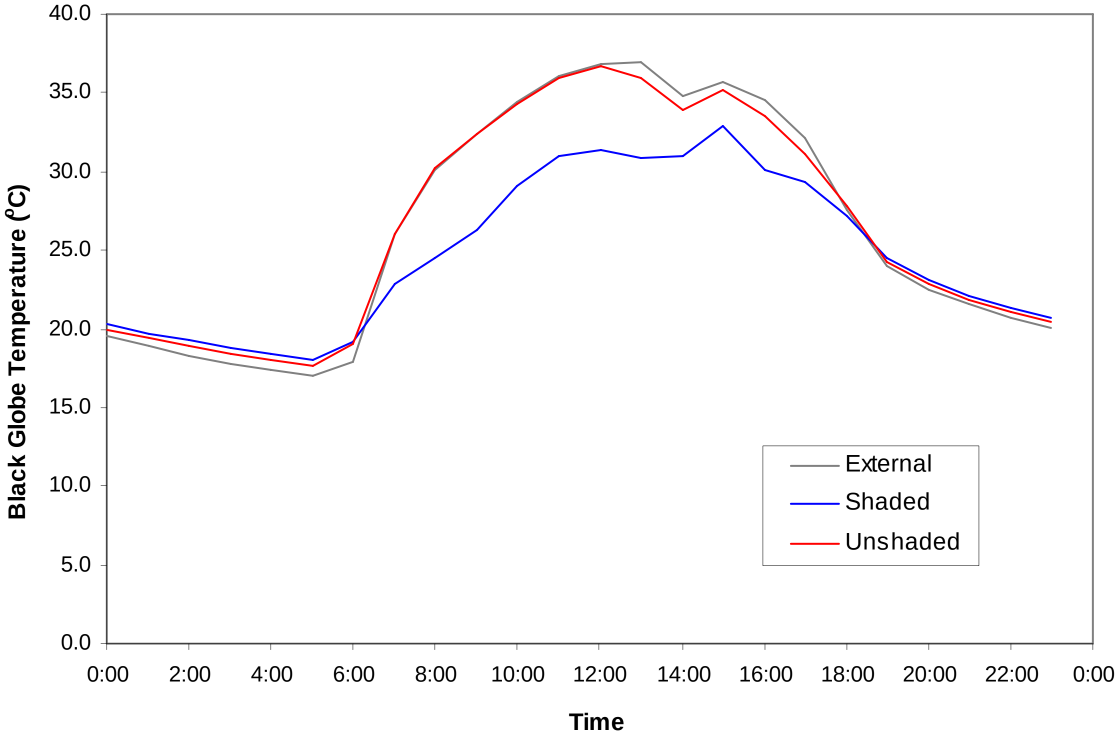

Figure 5.19. Average hourly black globe temperatures recorded at Feedlot A for the period 16 January to 31 March 2001.

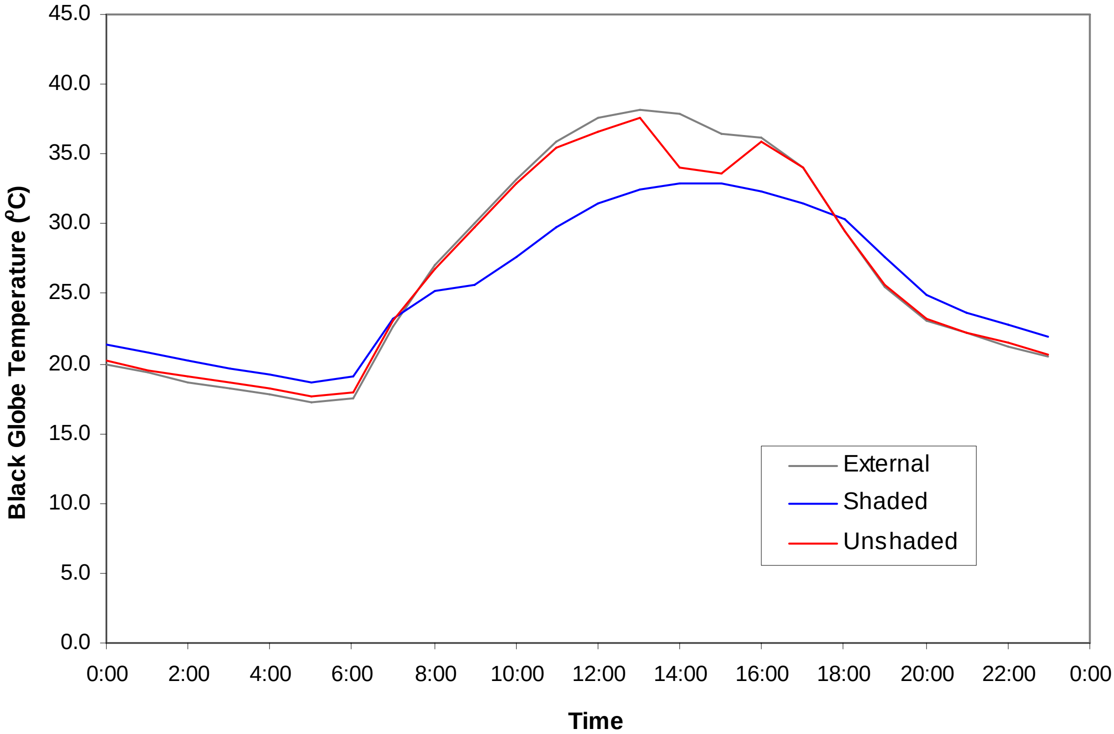

Figure 5.20. Average hourly black globe temperatures recorded at Feedlot B for the period 19 January to 31 March 2001.

5.7.3 CUMULATIVE BLACK GLOBE TEMPERATURES

In order to examine the total reduction in radiant heat loading that the shade structures at each feedlot provided over the data collection period, cumulative black globe temperatures were plotted over time. These plots are shown in Figure 5.21 and Figure 5.22 for Feedlot A and Feedlot B respectively.

As expected, the plots show that at the end of the data collection period the cumulative black globe temperatures recorded by the automatic weather stations located within the shaded pens at each feedlot site were significantly less than those recorded within the unshaded pen and by the stations external to the feedlot. Specifically, at Feedlot A the cumulative black globe temperatures recorded by the shaded pen at the end of the 75 day recording period were 6.8% and 6.5% lower than those of the unshaded pen and external stations respectively. Similarly, over the 70 day period that black globe temperatures were recorded in the shaded pen at Feedlot B, the cumulative temperature was 4.7% lower than that of the unshaded pen, and 5.4% lower than the cumulative black globe temperature of the external station data set. These data demonstrate the significant contribution that shade structures provide in reducing radiant heat loadings.

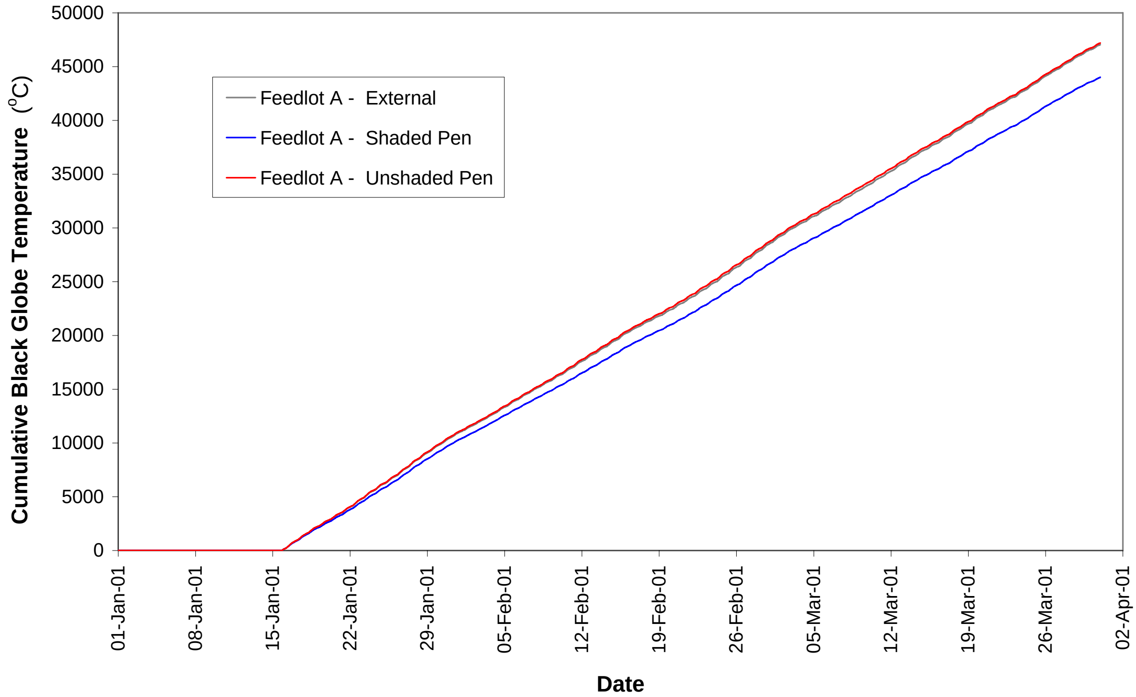

Figure 5.21. Plot of cumulative black globe temperatures recorded at Feedlot A for the period 15 January to 31 March 2001 (n = 1,804).

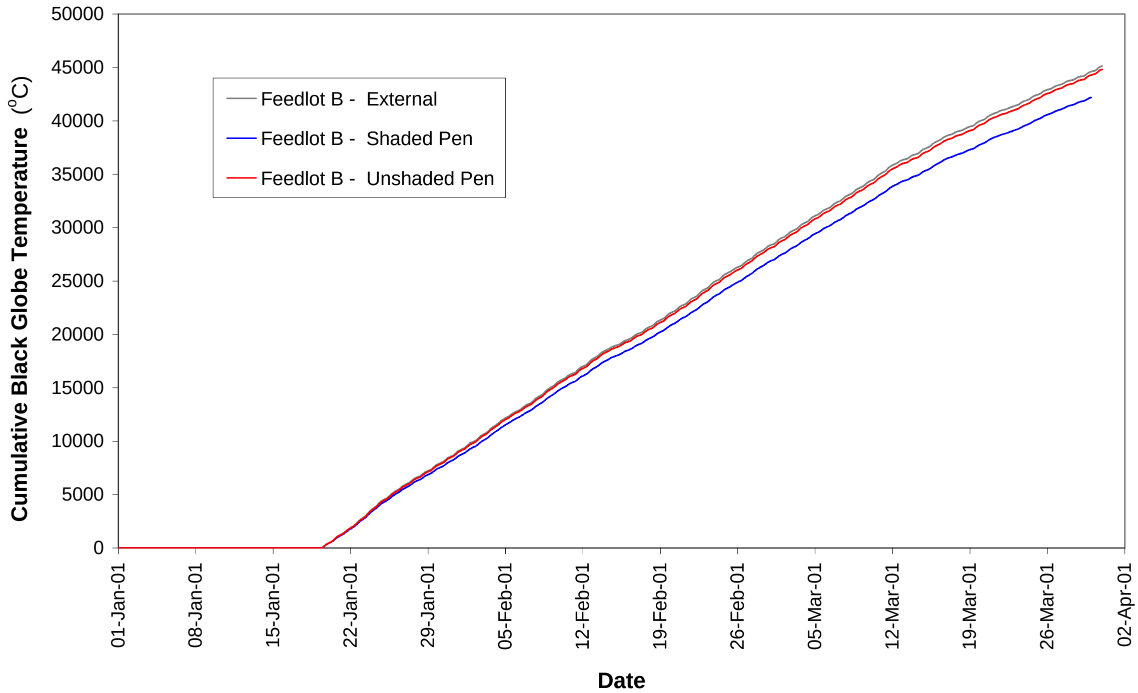

Figure 5.22. Plot of cumulative black globe temperatures recorded at Feedlot B for the period 19 January to 31 March 2001 (n = 1,717).

5.7.4 CALCULATION OF BLACK GLOBE TEMPERATURE

A predictive black globe equation was developed by Petrov *et al.* (2002) for the purpose of calculating black globe values representative of those within feedlot pens from climatic data recorded outside the feedlot area. These equations were developed as part of the industry project MLA FLOT.317 conducted over the 2001/2002 summer period. Over this summer period the project collected climatic data from four feedlot sites located in eastern Australia. This provided a large climatic data set representative of eastern Australian feedlots that could be used in conjunction with animal observation studies to develop a cattle stress index. As outlined in section 4.1.5 of the FLOT.317 final report (Petrov *et al.*, 2002) which is presented in Appendix D; black globe temperature is a useful parameter in the assessment of cattle heat stress that is not always recorded by standard climatic stations. Collecting climatic data from four separate feedlot sites provided sufficient data to enable general equations to be developed for eastern Australian feedlots that allow predictive black globe temperatures to be calculated for both shaded and unshaded pens from temperature and solar radiation data recorded outside the feedlot pen area. These equations are (Petrov *et al.*, 2002):

$$T_{BG\ (unshaded)} = 1.33T_A - 2.65\sqrt{T_A} + 3.21[\log(SR+1)] + 3.50 \qquad \textit{[Eq. 5.1]}$$

$$T_{BG\ (shaded)} = 1.21T_A - 2.44\sqrt{T_A} + 2.43[\log(SR+1)] + 5.26 \qquad \textit{[Eq. 5.2]}$$

where T_{BG} = predicated black globe temperature (°C)
T_A = air temperature recorded by external station (°C)
SR = incoming solar radiation recorded by external station (W/m^2)

The above equations were applied to the feedlot climate data recorded for this project. The air temperature and incoming short wave solar radiation values from the external data sets of each feedlot site were used to calculate predicted black globe temperatures for both the unshaded and shaded feedlot pens. Plots of the predicted black globe temperatures against the actual black globe temperatures are presented below. Figure 5.23 and Figure 5.24 present the unshaded pen data for Feedlot A and Feedlot B respectively. The shaded feedlot pen data is presented in Figure 5.25 for Feedlot A and Figure 5.26 for Feedlot B.

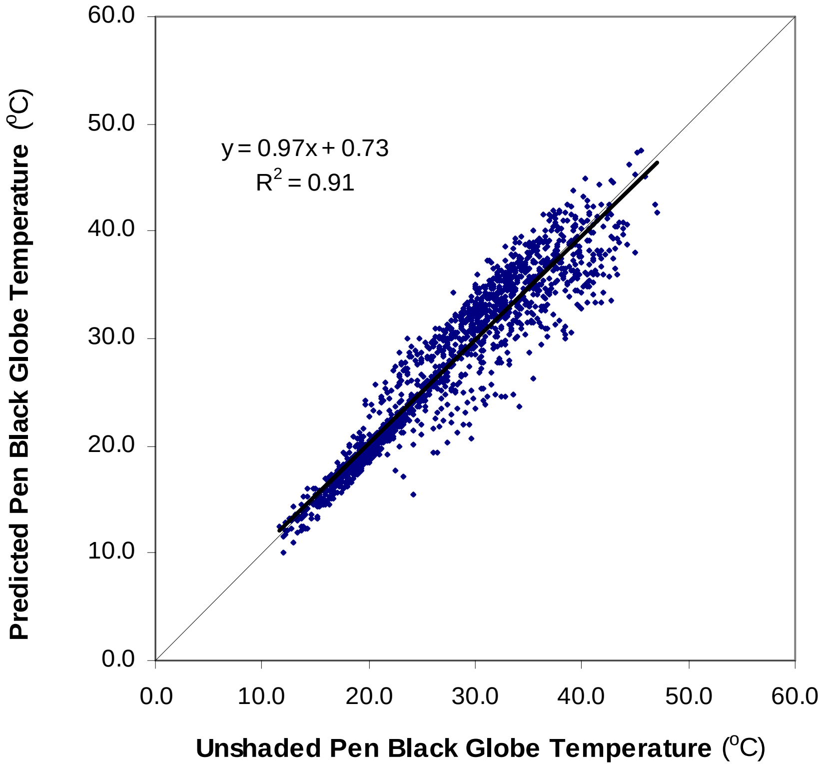

Figure 5.23. Predicted black globe temperatures for the unshaded pen at Feedlot A derived using the external feedlot data against the actual black globe temperatures recorded from 15 January to 31 March 2001 (n = 1,803).

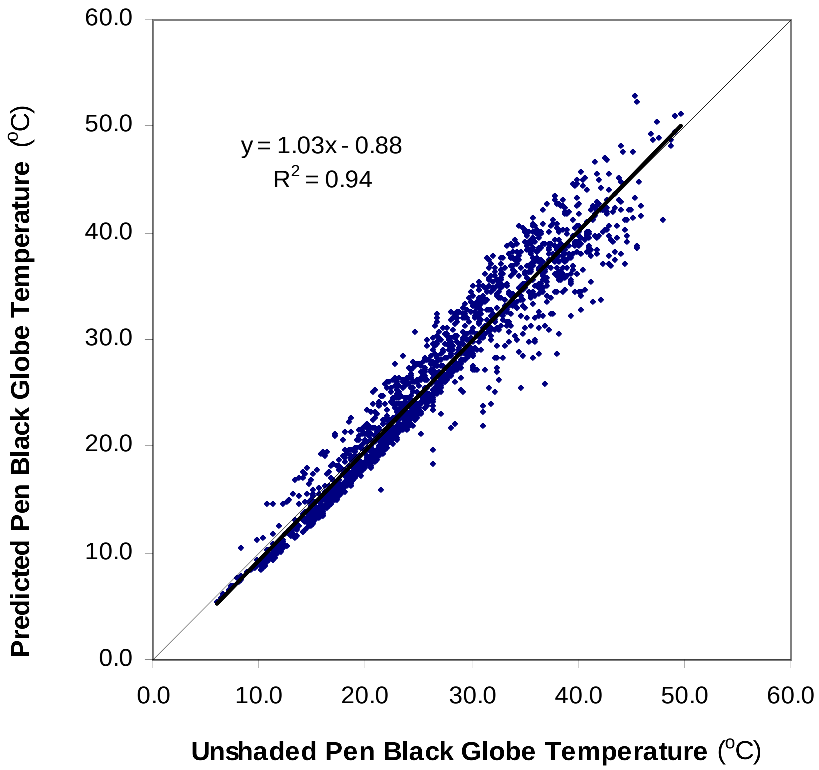

Figure 5.24. Predicted black globe temperatures for the unshaded pen at Feedlot B derived using the external feedlot data against the actual black globe temperatures recorded from 19 January to 31 March 2001 (n = 1,694).

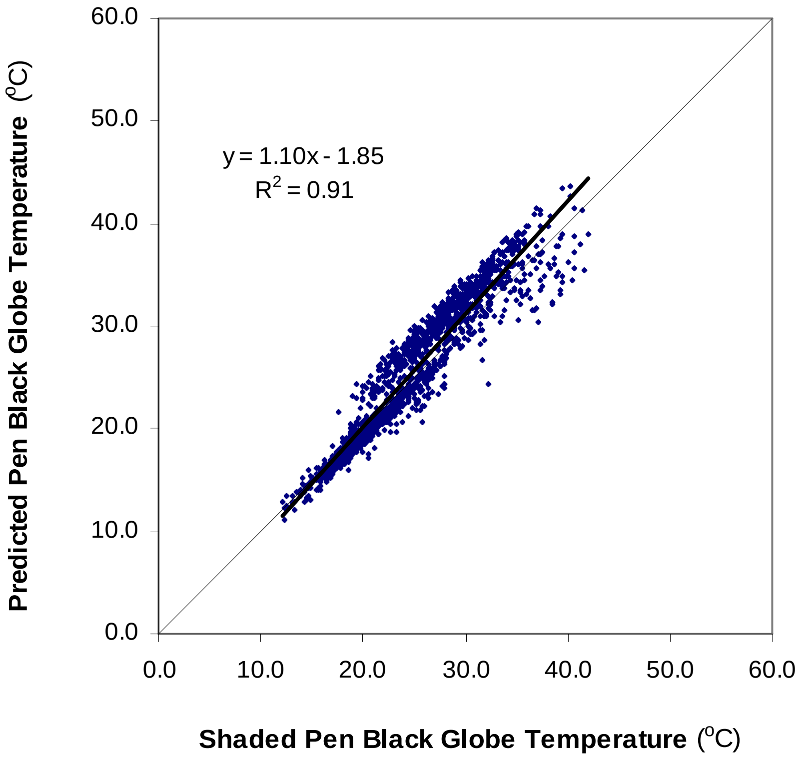

Figure 5.25. Predicted black globe temperatures for the shaded pen at Feedlot A derived using the external feedlot data against the actual black globe temperatures recorded from 15 January to 31 March 2001 (n = 1,807).

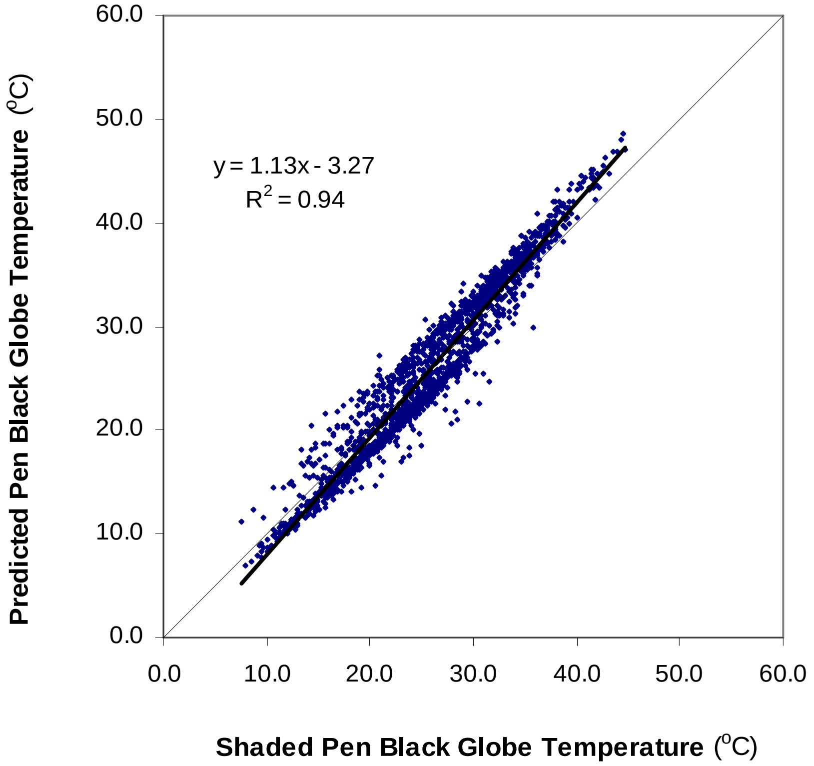

Figure 5.26. Predicted black globe temperatures for the shaded pen at Feedlot B derived using the external feedlot data against the actual black globe temperatures recorded from 9 January to 29 March 2001 (n = 1,905).

These plots show that based on the data set collected over the 2001 summer period, the above equations do accurately predict the black globe temperatures within shaded and unshaded feedlot pens using air temperature and solar radiation data recorded outside the feedlot area. The correlation of predicted and actual values is strong for each pen type at both feedlot sites, with the plots for Feedlot B ($R^2 = 0.94$) showing a slightly stronger correlation than Feedlot A ($R^2 = 0.91$). Close inspection of these plots do show a few anomalies worth noting.

The data for the unshaded pens do closely follow a 1:1 relationship but it is noted that as values of black globe temperature increase, the predicted values do become more variable. For the shaded pen data, the plots for both feedlot sites show two almost separate clusters of data sets. For black globe temperatures around 25 to 30°C and below, the predicted values at both sites generally are more conservative than the actual recorded values. The second data cluster for values over this 25 to 30°C region, shows that the predicted values of black globe temperature within shaded pen are higher than the actuals at both feedlot sites. This division of data can be attributed to daylight and night time values.

The data show that during the day, when incoming solar radiation causes higher black globe temperatures, the predicted values are overestimated. At night when incoming solar radiation is zero, the equation appears to underestimate black globe temperatures. As detailed in section 5.7.2, it was found that during the 'non-daylight' hours the black globe temperatures of the shaded pen remained slightly higher than those of the unshaded pen and external feedlot environment. It would appear that the current predictive equation for black globe temperatures of the shaded feedlot pen whilst accurate, does not fully model this observed diurnal effect.

5.7.5 KEY OBSERVATIONS

The following key observations can be drawn from the black globe temperature data analyses:

1. Shade structures within feedlot cattle pens provide a reduction in day time black globe temperatures;

2. During the ‘non-daylight’ hours the black globe temperatures recorded in the shaded pens remained slightly higher than those of the unshaded pens and external feedlot areas;
3. Notwithstanding the increased night time black globe temperatures, over the three month data collection period, the shade structures at each feedlot site provided a significant reduction in cumulative black globe temperatures (or radiant heat load);
4. Black globe temperature values representative of those within feedlot pens can be accurately calculated from climatic data recorded outside the feedlot area using the equations developed by Petrov *et al.* (2002).

5.8 WIND SPEED

5.8.1 OVERVIEW

The 10 minute wind observations from each feedlot site were categorised into the standard wind speed ranges adopted by the Bureau of Meteorology. The frequency of these wind speed categories are plotted in Figure 5.27 for Feedlot A and Figure 5.28 for Feedlot B.

These data show that for both feedlot sites the wind speeds recorded at a height of 10 metres were higher than those recorded at 2 metres. This is an expected result due to the reduction in wind speeds caused by the increased influence of surface features at lower heights. The data from Feedlot A show minimal difference between the 10 metre wind speeds recorded by the external stations compared to those measured within the unshaded feedlot pen. At Feedlot B, the data show that 10 metre wind speeds recorded within the unshaded pen were slightly lower than those recorded by the external stations. This trend is most likely due to the layout of the feedlot pen area rather than any influence caused by pen structures or cattle. As outlined in Chapter 3, the cattle pen area at Feedlot B was located within an ‘amphitheatre’ layout caused by the surrounding ridgelines. This topography is expected to have provided some degree of shelter from wind.

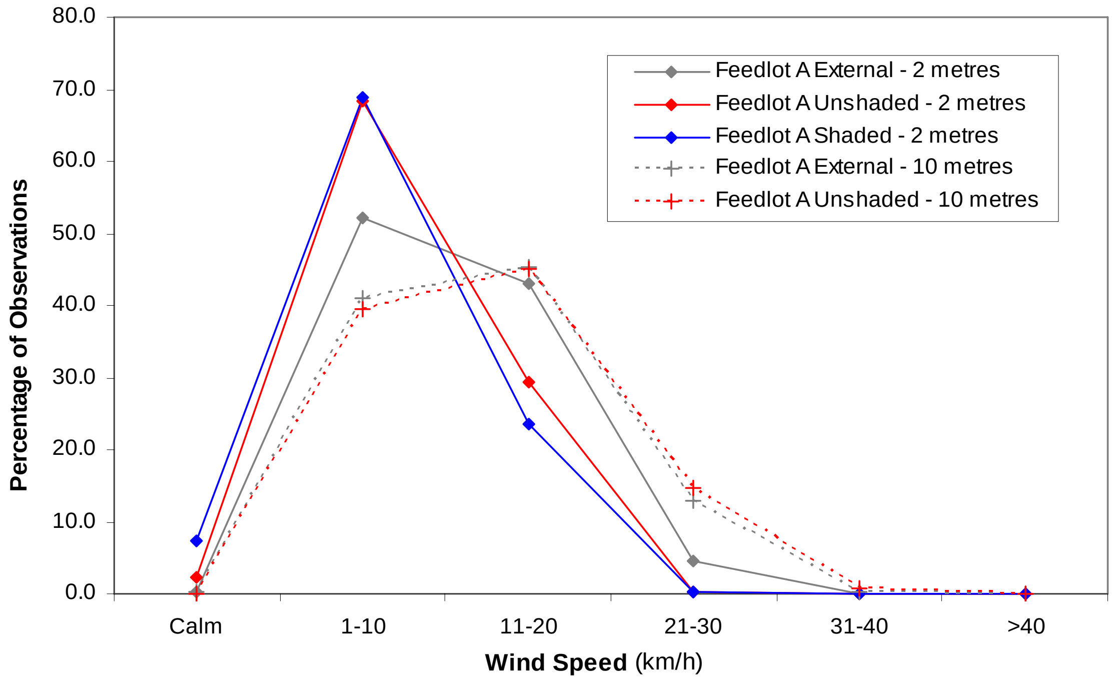

Figure 5.27. Distribution of wind speed observations recorded at Feedlot A for the period January to March 2001.

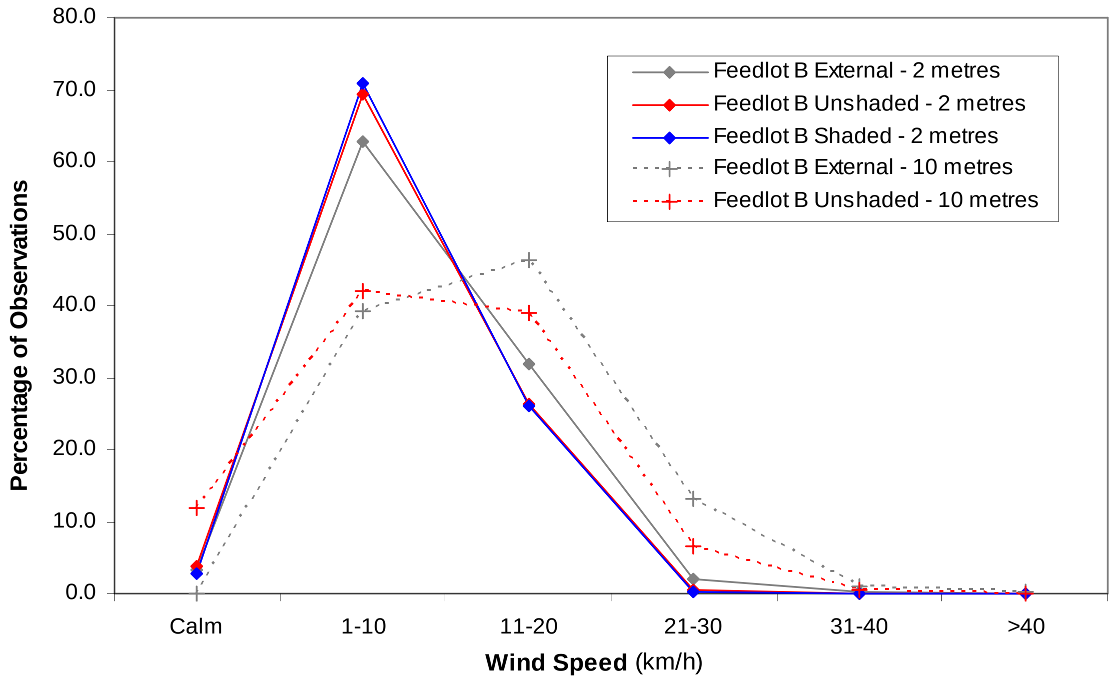

Figure 5.28. Distribution of wind speed observations recorded at Feedlot B for the period January to March 2001.

The 2 metre wind speed data show that at Feedlot A, wind speeds were lower in the shaded pen compared to those recorded in the unshaded feedlot pen. The 2 metre wind speeds recorded by the external stations were significantly higher than those recorded in both of the feedlot pens. This indicates that the presence of pen infrastructure such as fences, feed and water troughs, and cattle themselves provide a reduction in wind speeds at lower heights. The data from Feedlot B show minimal difference between the shaded and unshaded pen, but indicate that the external wind speeds were greater than those measured from within the feedlot. The fact that the data from Feedlot B shows minimal difference between 2 metre wind speeds of the unshaded and shaded pen may be attributed to the nature of the shade cloth which may provide better ventilation than the solid galvanised structures. This trend may also be due to the siting of the automatic weather stations at Feedlot A which, due to the smaller cattle pens at this site, were located closer to both pen fences and shade support structures.

5.8.2 *DIURNAL VARIATION OF WIND SPEED*

The diurnal variation of wind speed data obtained through plots of average hourly 2 metre and 10 metre wind speeds show similar trends to those obtained from the wind speed frequency plots. These average hourly diurnal plots are presented below in Figure 5.29 and Figure 5.30 for Feedlot A and Feedlot B respectively.

Analyses of the hourly data for Feedlot A shows that the 10 metre wind speeds recorded within the unshaded pen averaged 13.2 ± 0.14 km/hr (mean ± s.e.; n = 2,136) which was marginally higher than the average of 12.7 ± 0.14 km/hr (mean ± s.e.; n = 2,160) recorded by the external stations. At Feedlot B the wind speeds in the unshaded pen were significantly lower than those of the external station data set. Specifically, the data analyses showed that the average 10 metre wind speed in the unshaded pens was 10.0 ± 0.18 km/hr (mean ± s.e.; n = 1,504) compared to the average of 13.2 ± 0.15 km/hr (mean ± s.e.; n = 1,954) recorded by the external stations. This difference can be attributed to the site topography.

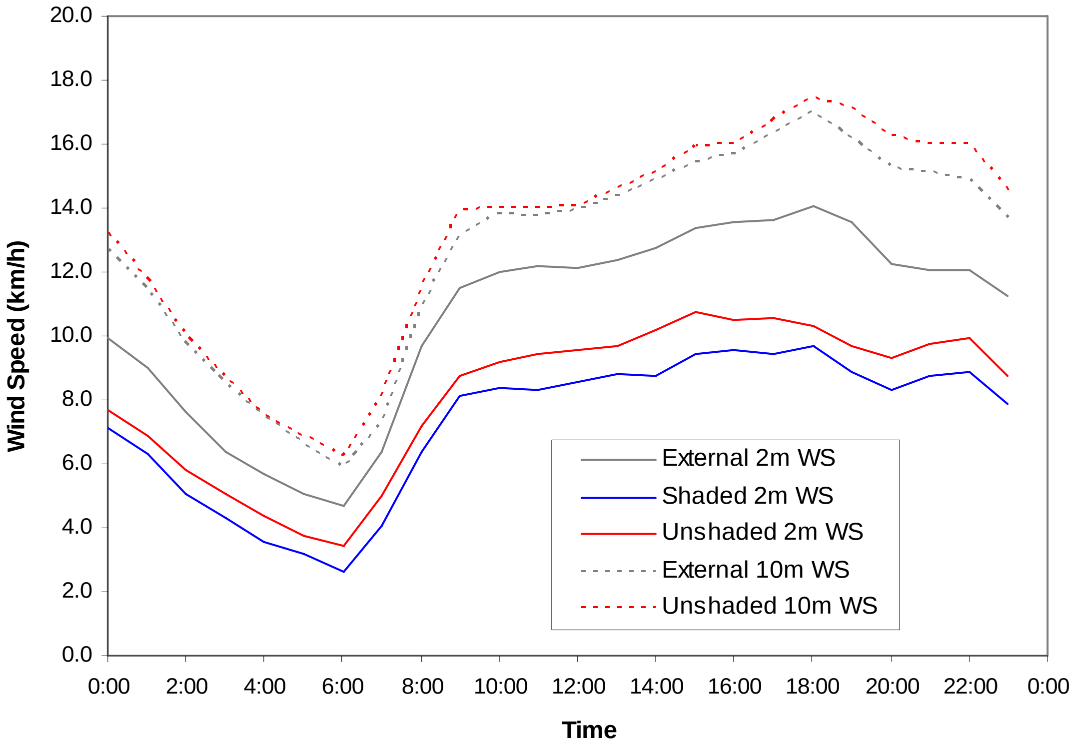

Figure 5.29. Average hourly wind speeds recorded at Feedlot A for the period 1 January to 31 March 2001.

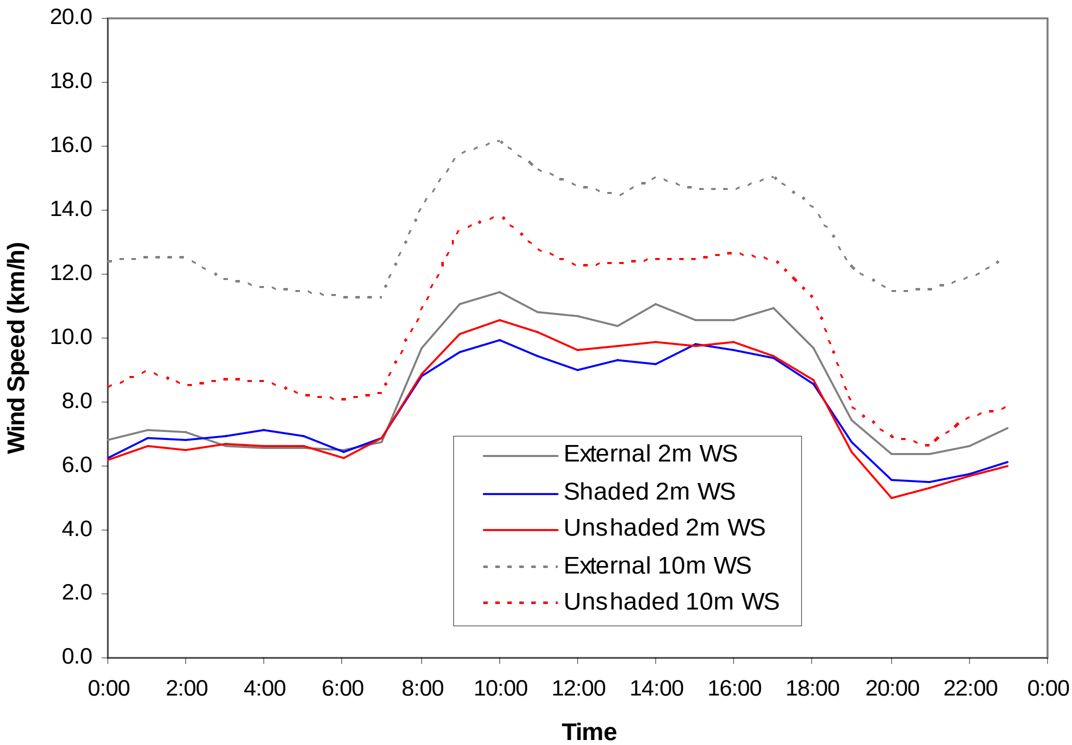

Figure 5.30. Average hourly wind speeds recorded at Feedlot B for the period 9 January to 31 March 2001.

The 2 metre wind speed data for both feedlot sites showed similar trends, although the trend was more significant at Feedlot A. That is, at both feedlot sites, higher 2 metre wind speeds were recorded by the external stations compared to those within the feedlot pens. At Feedlot A, the 2 metre wind speeds recorded by the external station averaged 10.6 ± 0.12 km/hr (mean ± s.e.; n = 2,160). This was 29% greater than the average of 8.2 ± 0.09 km/hr (mean ± s.e.; n = 2,136) measured in the unshaded pen. The data from Feedlot B show that the average 2 metre wind speed of 8.5 ± 0.12 km/hr (mean ± s.e.; n = 1,954) recorded by the external stations was 9% greater than the average unshaded pen wind speed of 7.8 ± 0.10 km/hr (mean ± s.e.; n = 1,952).

Analyses of the hourly wind speed data from the shaded pens showed that at Feedlot A the 2 metre wind speeds averaged 7.3 ± 0.10 km/hr (mean ± s.e.; n = 2,160). At Feedlot B the average 2 metre wind speed under shade was 7.8 ± 0.10 km/hr (mean ± s.e.; n = 1,955). Comparison of the data from the shaded pen with those from the unshaded pens shows that wind speed averages under shade were 11% and 0.5% lower than the averages in the neighbouring unshaded pens for Feedlot A and Feedlot B respectively.

It is noted that under the shade structure at Feedlot A, 7.4% of the total 2 metre wind speed hourly observations were calm (less than 1 km/hr). In the unshaded pen only 12 of the 720 hourly observations (2.2%) were calm. At Feedlot B, 2.9% of the hourly 2 metre wind observations were calm in the shaded pen. This was found to be less than the number of calm observations in the unshaded pen (3.8%).

Comparison of average hourly data for the shaded and unshaded pens shows that at Feedlot A the 2 metre wind speeds were constantly higher within the unshaded pen. At Feedlot B, the unshaded pen had slightly higher wind speeds but generally this occurred only during the hours of 7am to 6pm. The reasons for these observations are discussed in Chapter 6.

5.8.3 KEY OBSERVATIONS

The wind speed data analyses have demonstrated that:

1. At both feedlot sites the 10 metre wind speeds were greater than those recorded at a height of 2 metres;

2. At Feedlot A there was minimal difference between the 10 metre wind speeds recorded by the automatic weather stations located outside the feedlot pen area and the station located within the unshaded cattle pen;
3. At Feedlot B the 10 metre wind speeds recorded in the unshaded pen were generally lower than those of the external feedlot environment;
4. At both feedlot sites the 2 metre wind speeds recorded in the unshaded and shaded feedlot pens were notably lower than those measured outside the feedlot pen area;
5. At Feedlot A, the 2 metre wind speeds measured within the shaded pen were consistently lower than those recorded in the neighbouring unshaded cattle pen;
6. The data from Feedlot B showed that 2 metre wind speeds in the shaded pen were generally only lower than those of the unshaded pen between the daylight hours of 7am to 6pm.

5.9 WIND DIRECTION

5.9.1 FEEDLOT A OVERVIEW

The wind direction data from Feedlot A show that the observations from the external data set are very similar to those recorded by the automatic weather stations located within the shaded and unshaded feedlot pens. Distribution plots of these wind direction observations are shown in Figure 5.31, Figure 5.32, and Figure 5.33 for the external station data set, the unshaded pen, and the shaded pen respectively. Whilst the wind direction sensors recorded to a precision of 0.1°, these data plots show the percentage distribution of hourly wind directions rounded to the nearest 22.5° (ie. a 16 point compass). This rounding is assumed to negate the effect of errors within the manual alignment of the sensors which would reduce the accuracy of the readings to approximately ±5°. The data plots below show that the predominant wind direction recorded at the external site and within the feedlot pens at Feedlot A was from the eastern quadrant. The data also show minimal variation between locations at the feedlot. This is expected due to the flat topography at Feedlot A.

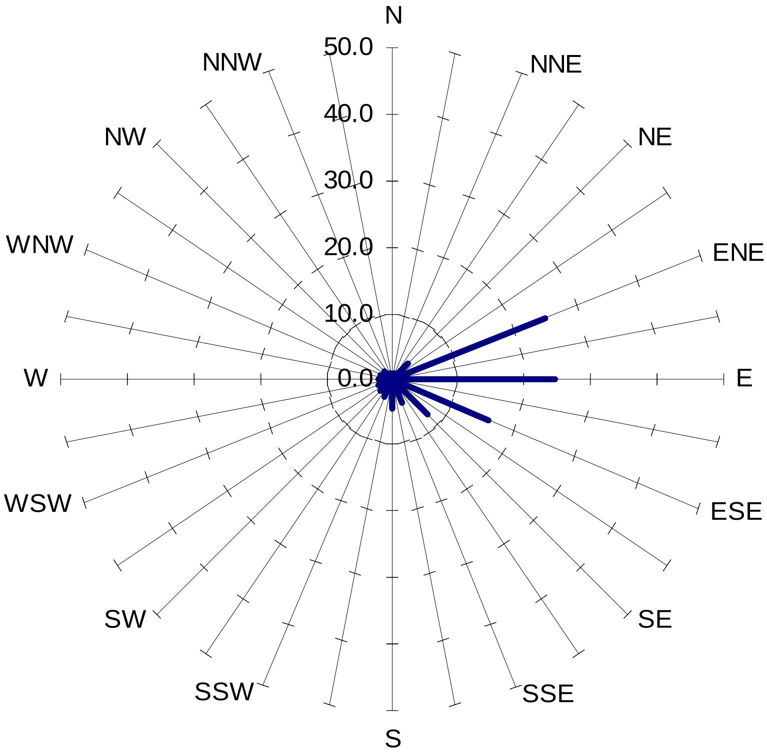

Figure 5.31. Percentage distribution of wind direction observations (n = 2,160) from the external data set for Feedlot A for the period January to March 2001.

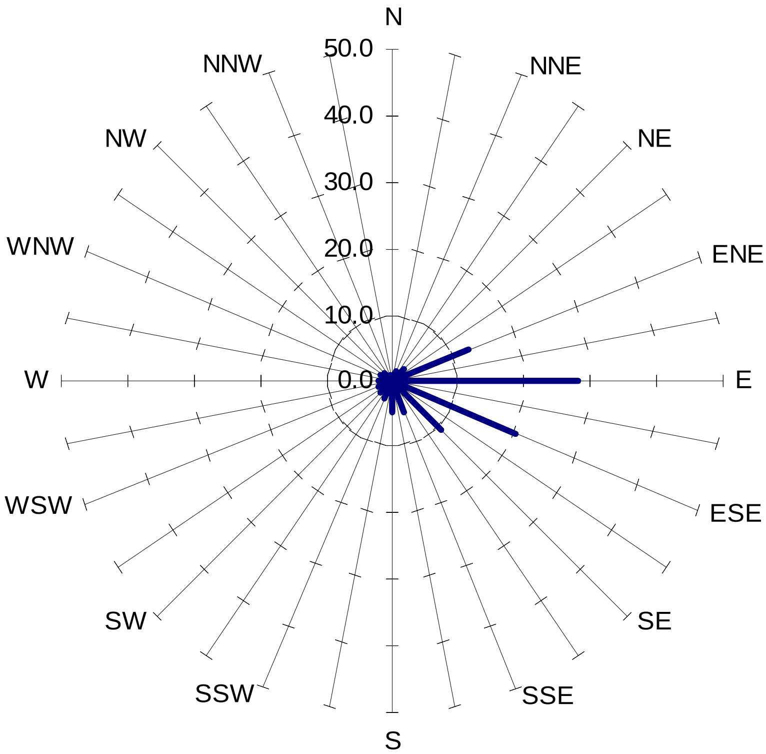

Figure 5.32. Percentage distribution of wind direction observations (n = 2,132) from the unshaded pen at Feedlot A for the period January to March 2001.

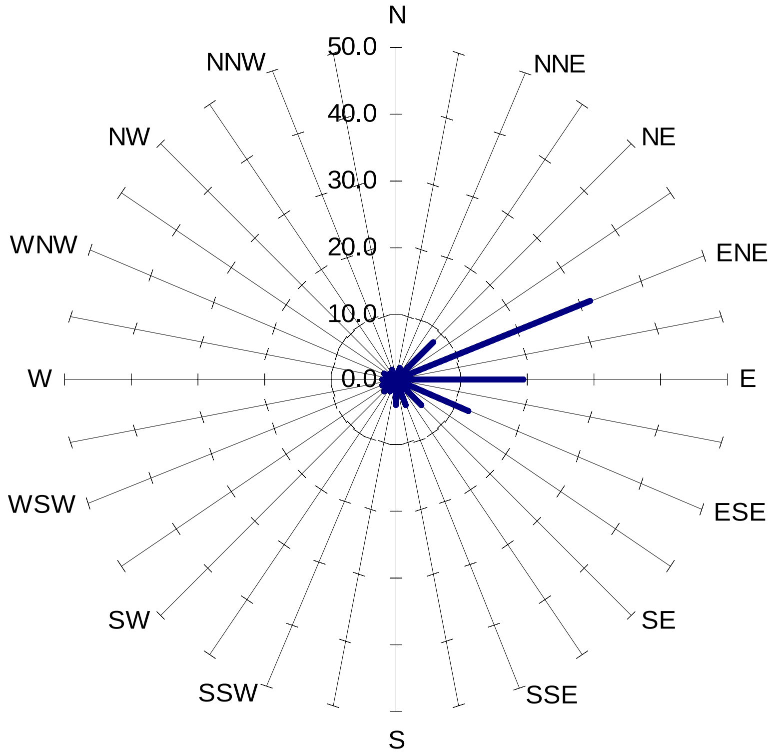

Figure 5.33. Percentage distribution of wind direction observations (n = 2,160) from the shaded pen at Feedlot A for the period January to March 2001.

5.9.2 *FEEDLOT B OVERVIEW*

The data from Feedlot B also show that wind directions recorded at the three locations were very similar. A summary of the wind direction data recorded at Feedlot B are presented in Figure 5.34, Figure 5.35 and Figure 5.36 below. These plots show the distribution of hourly wind direction observations recorded by the external stations, and within the unshaded and shaded feedlot pens respectively.

Winds at Feedlot B typically came from either the north east or south western quadrants. Examination of the hourly data showed that winds from the south west were most common in the afternoon/evening hours of 12 to 8pm. At all other times winds were predominantly from the north east to east.

Compared to the wind direction distribution data for Feedlot A, wind directions recorded over the three locations at Feedlot B, whilst still consistent, were slightly more variable. This can be attributed to the nature of the topography at Feedlot B, which as described in Chapter 3, varies due to the location of several small hills located immediately around the feedlot pen area.

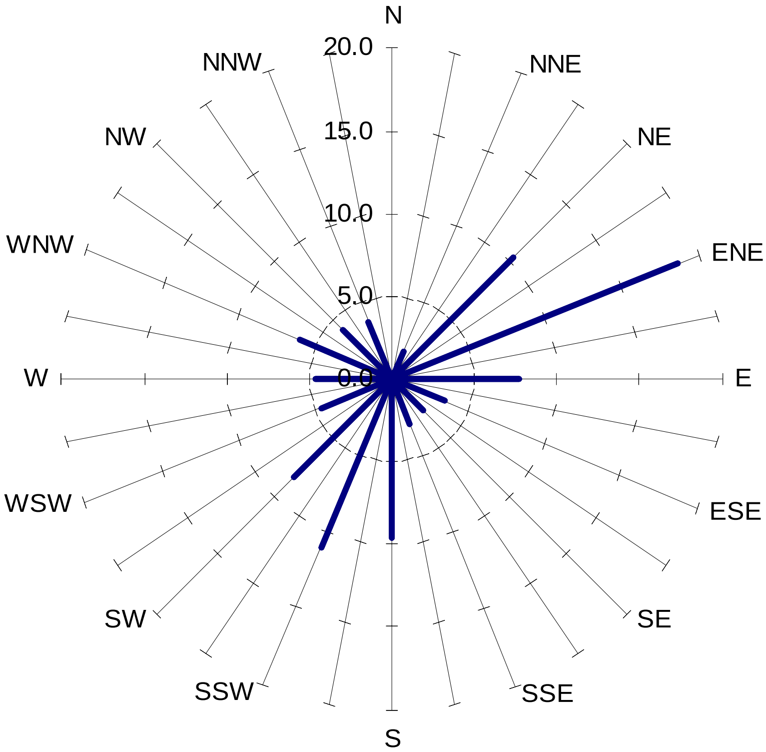

Figure 5.34. Percentage distribution of wind direction observations (n = 1,957) from the external data set for Feedlot B for the period January to March 2001.

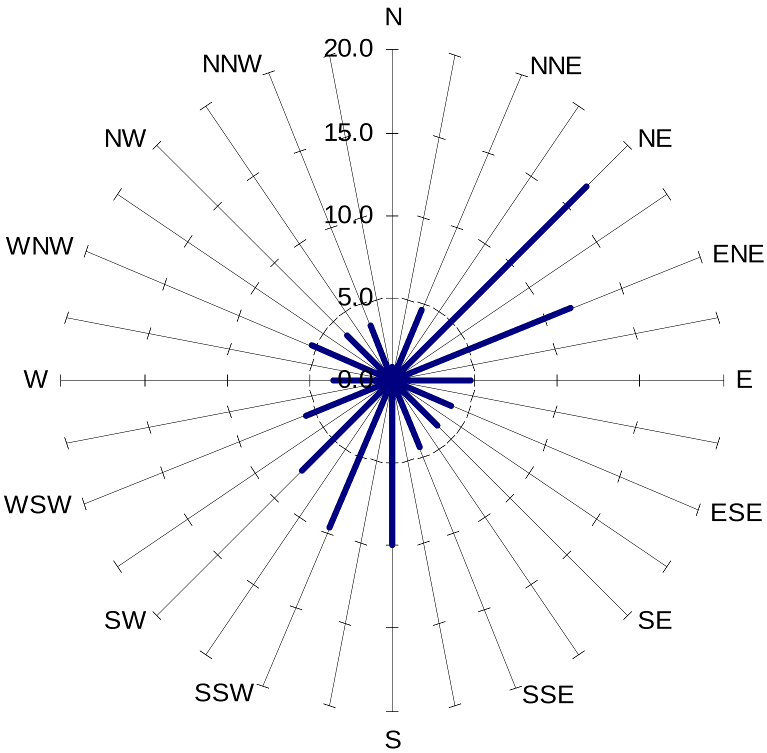

Figure 5.35. Percentage distribution of wind direction observations (n = 1,925) from the unshaded pen at Feedlot B for the period January to March 2001.

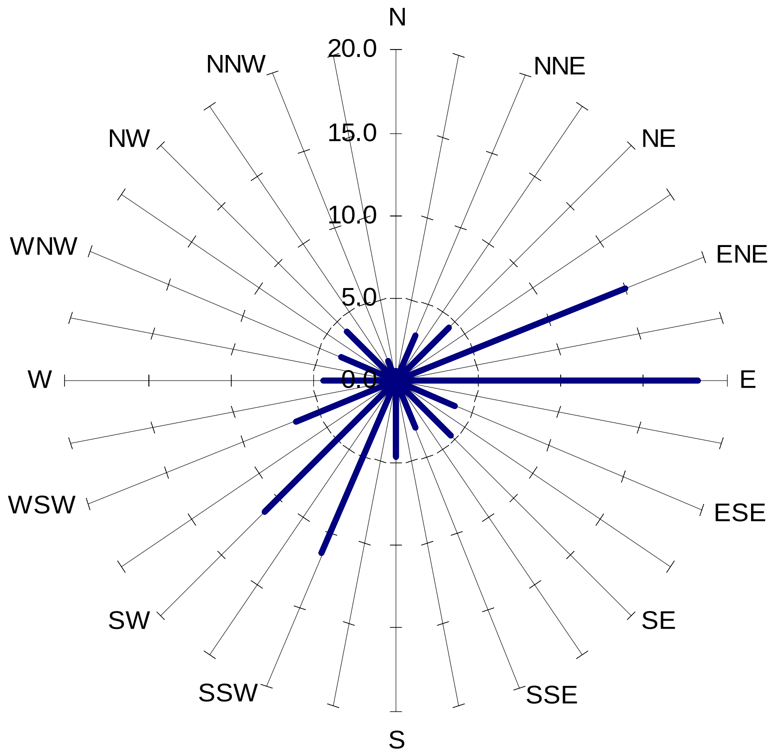

Figure 5.36. Percentage distribution of wind direction observations (n = 1,731) from the shaded pen at Feedlot B for the period January to March 2001.

5.10 SUMMARY

The detailed analyses of the climatic data collected at each feedlot site have highlighted the microclimatic variations that are caused by, and occur within, the feedlot environment. As outlined in this chapter, the climatic measurements have shown that the external feedlot environment exhibits lower minimum air temperatures than those within the unshaded and shaded feedlot pens. The data also show that generally the feedlot pens have slightly higher daily maximum temperatures than the surrounding feedlot areas.

It has been shown that relative humidity levels measured under the shade of feedlot cattle pens are significantly higher than those in an unshaded pen or outside the feedlot pen area. Shade structures have also been shown to reduce pen surface temperatures significantly. The data analyses demonstrated that the manure/clay pen surfaces are warmer than the natural vegetated surfaces of the surrounding feedlot environment.

The reduction in incoming short wave solar radiation provided by both galvanised sheeting and cloth shade structures is significant. Measurement of the outgoing (or reflected) short wave radiation enabled albedo values of the surfaces to be calculated. These data showed that for wet manure pad surfaces, albedo values were in the order of 0.10 to 0.13. For dry feedlot pen surfaces the albedo values increased to around 0.15 to 0.17. The albedo values of the external feedlot surfaces were found to be approximately 0.18 to 0.24. These albedo data were found to be consistent with those values published in current literature.

Shade structures also caused a reduction in measured black globe temperatures. Over the entire data collection period, the presence of shade structures within the feedlot pens was found to reduce cumulative black globe (or total radiant heat) by around 5 to 7%.

The analyses of the wind data showed that wind speeds recorded at a height of 2 metres were lower in the feedlot pen areas compared to the surrounding feedlot environment. The data also indicated that wind speeds were reduced by the presence of shade structures. Measured wind directions were found to be relatively consistent across the monitoring locations at each feedlot site.

These observed microclimatic variations outlined in this chapter are discussed in further detail in Chapter 6.

CHAPTER 6 DISCUSSION AND OPTIMISATION OF FEEDLOT MICROCLIMATE

6.1 INTRODUCTION

Chapters 4 and 5 have provided detailed analyses of the climatic data collected for this project. Chapter 4 presented a comparison of the data recorded by the automatic weather stations located outside the feedlot pen area to the climatic data recorded by the nearby Bureau of Meteorology (BoM) stations over the same period. It was determined that the data collected by the external stations at the two feedlot sites were representative of the climate experienced within those regions.

Chapter 5 highlighted the significant differences that were found through comparisons of the external station data to those data recorded by the stations located within shaded and unshaded feedlot pens. Those climatic differences caused by the presence of shade structures within feedlot pens were also identified. These variations were presented and discussed on a parameter by parameter basis.

The present chapter draws together those observed climatic variations in order to discuss the probable causes of these differences. The chapter aims to highlight the overall effects on microclimate caused by the both presence of a feedlot and also by the presence of shade structures within feedlot cattle pens. Finally, this chapter discusses possible planning and design considerations that may assist in optimising the feedlot microclimate.

6.2 THE PHYSICAL MICROCLIMATE OF CATTLE FEEDLOTS

Through the establishment of a feedlot facility the natural surface is transformed from its pre-existing state (typically crop or pasture areas in rural Australia) to bare clay pen surfaces that over time accumulate a compacted manure layer. These physical variations change the surface albedo. Oke (1987) describes albedo as a fundamental surface property that governs the daytime net radiation balance, which in turn controls the thermal and moisture climate of the surface and the adjacent air and soil layers. In addition to surface changes, the establishment of cattle pens requires significant infrastructure such as the establishment of adequate fencing, feeding and water supply systems. Large numbers of cattle are held within the pens in much higher concentrations than the pre-existing crop or pasture areas. It is expected that the physical presence of the infrastructure and cattle, and the climate of the animals themselves, would cause changes in the microclimate of the immediate area.

As outlined in the following sections the climatic data collected for this project has allowed a direct quantification of some of these changes. In particular, the comparison of climatic data presented in Chapter 5 highlighted notable differences in the temperature, humidity and wind speed data between the external feedlot environment and the unshaded pens. The following sections discuss these variations caused by the presence of a feedlot, both on a surface level and in relation to the microclimate.

6.2.1 THE UNSHADED FEEDLOT SURFACE

Chapter 5 demonstrated that the feedlot pen manure surfaces had significantly different albedo values compared to the grassed/soil areas of the external feedlot area. The data showed that albedo values of the dry unshaded manure pads were in the order of 0.13 to 0.19. By comparison the albedo values for the grass/soil surfaces of the external feedlot areas generally ranged from 0.15 to 0.25.

It was highlighted that albedo values were affected by variations in surface moisture content, and in particular a change in albedo values after rainfall events was most notable in the unshaded pen data. This is expected as the bare manure pad surface of the unshaded pen undergoes the most considerable physical change after rainfall. After a heavy rainfall event it was observed that the generally dry, powdery, lightly coloured manure pad surface of the unshaded pen became more plastic and changed to a very dark, almost black colour. Specifically the project data showed that the albedo values of the dry unshaded feedlot pen surfaces which typically ranged from 0.13 to 0.19, decreased to around 0.07 to 0.14 after a rainfall event.

The changes in the surfaces around the external feedlot stations were not as dramatic due to the fact that these areas remained vegetated over the data collection period. It was observed that after a rainfall event the change in colour of this vegetation was not as striking as the change in colour of the dry manure pen surface.

The albedo value directly determines the absorptivity of the surface, and for a given solar input, it regulates the surface short wave radiation absorption (Oke, 1987). The albedo data presented above indicate that on average the short wave radiation reflection from the external feedlot surfaces was 4% to 10% greater than that from unshaded feedlot pen surfaces under dry and wet conditions respectively. This increased reflectivity of the external feedlot surface. Inversely, the greater adsorption of incoming short wave solar radiation by the unshaded feedlot pens was the primary cause of the differences in ground temperatures that were observed. Specifically, the ground temperature data analyses demonstrated that the manure pad surfaces of unshaded feedlot pens were on average 2 to 4°C warmer than those of the grassed soil areas surrounding the feedlot.

It should be noted that aside from the increased adsorption of short wave solar radiation by the unshaded feedlot pens, other factors may have influenced the variation in ground temperatures between the unshaded feedlot pens and the external feedlot environment. These include differences in the properties of the manure pad and soil surfaces, and microbial activity. Whilst these factors were not measured as part of this project it is worth noting their probable influences. In particular, it is assumed that the manure pad surface of the feedlot pens generally had higher moisture contents than that of the external feedlot environment due to the additional water inputs from cattle urine and faeces. An increase in soil moisture content leads to an increase in the thermal conductivity and heat capacity of a soil (Oke, 1987). Additionally, the manure pad surface would have had a much higher organic matter content compared to the soils of the external feedlot environment. Watts *et al.* (1994b) state that the organic content of pen manure is in the order of 82%. By comparison, soil organic matter concentrations commonly range between 0% and 25% with most Australian soils containing less than 9% (NRM, undated)[6]. It is expected that this higher quantity of organic matter in the manure pad, would in turn

[6] Soil organic matter values converted from published organic carbon values using the equation: organic matter = 1.72 × organic carbon.

cause an increase in microbial respiration which may have contributed in part to the observed higher ground temperatures.

6.2.2 *Unshaded Feedlot Microclimate - Air Temperature*

The air temperature data analyses showed that the external feedlot environment was generally cooler than that within the unshaded pens. In particular, the difference in air temperatures between the external feedlot environment and the unshaded pens was most pronounced overnight. The data showed that during the coolest periods of the day (4 to 6am) the air temperatures recorded by the external stations at each feedlot site were lower than those recorded within the cattle pens. It was noted that as the day warmed, the difference in air temperatures between the external stations and those within the feedlot pens was significantly reduced.

As described by Petrov *et al.* (2001) the higher overnight temperatures recorded within the feedlot pens may be attributed to the nature of the manure pen surfaces. Specifically, the manure pad surface has a greater ability to store energy/heat compared to the soil of the external environment. As demonstrated by the ground temperature data discussed in section 6.2.1, the manure pad surface can store a greater amount of heat energy during the day compared to that of the soil surface outside the feedlot area. During the night the pen surface re-radiates heat, resulting in reheated air over the surface and thus maintenance of generally higher air temperatures.

6.2.3 *Unshaded Feedlot Microclimate - Energy Exchange*

The black globe temperature data presented in Chapter 5 showed that the unshaded pen and external station data were similar at both feedlot sites. However, from the plots of average hourly data it was noted that from 10am to 4pm the black globe temperatures recorded by the external stations were on average slightly higher than those of the unshaded pens at each feedlot site.

Whilst these differences are slight, they are worth noting as the trend does show that whilst the external sites recorded generally similar or even lower incoming solar radiation levels, slightly higher black globe temperatures were observed. This variation from a direct relationship between incoming solar radiation and black globe temperature can be attributed to the influence of reflected radiation and specifically, the effect of modifying the surface albedo (as discussed in section 6.2.1).

The calculation of albedo values in Chapter 5 produced average albedo values of the external areas at both feedlot sites that were notably higher than the albedo values of the unshaded pen surfaces in both dry and wet conditions. From these albedo data, it was concluded that the manure pad surface of the feedlot pens were less reflective than the surfaces of the external environment surrounding the feedlots. Hence, the resultant reduced amounts of reflected short wave solar radiation in the unshaded feedlot pen areas caused the comparatively lower black globe temperatures that were observed. This is an example of how a surface effect caused by the presence of feedlots caused a measurable micro-scale atmospheric effect.

6.2.4 UNSHADED FEEDLOT MICROCLIMATE - HUMIDITY

The comparison of the BoM climate data with the local climate data external to the feedlot presented in Chapter 4 highlighted that whilst the external environment at Feedlot A did not experience humidity conditions of notable difference to the surrounding area; at Feedlot B, the external feedlot environment experienced more humid conditions than the BoM sites located at Yanco Agricultural Institute and Narrandera Golf Club. Specifically, comparison of the average hourly external feedlot data with average three hourly data from Yanco Agricultural Institute showed that humidity levels at Feedlot B were in the order of 5 to 7% higher from midnight to 5am, and 8 to 9% higher from midday to 6pm. The higher relative humidity at Feedlot B was attributed to wetter antecedent conditions at the feedlot site caused by the irrigation storages, infrastructure and practices associated with the 370 ha of crop production areas linked to the feedlot.

Strong correlations were found between the relative humidity data recorded by the external stations and the unshaded pen at both feedlot sites. Data analyses previously presented showed that humidity levels recorded in the unshaded feedlot pen were only marginally higher than those of the external feedlot environment.

The analyses did show that at both feedlot sites the difference in humidity levels between the unshaded feedlot pens and the external environment was most pronounced between the hours of 8am to 6pm. It is this period of the day that evapotranspiration is most significant. It is expected that a feedlot pen manure surface has a higher rate of evapotranspiration compared to the soil of the external feedlot environment for two reasons. Firstly, the data analyses have demonstrated that the manure pad surface had a lower albedo value than that of the external feedlot areas. Related to these albedo values are the observed higher ground temperatures caused by increased short wave absorptivity of the manure pen surface compared to the soils of the external feedlot environment. These increased temperatures and the greater availability of energy results in an increased rate of evapotranspiration from the surface (Oke, 1987). Secondly, the feedlot pen surface would generally have an increased soil moisture content compared to the external feedlot environment due to additional water inputs from urine and faeces deposited by cattle housed within the pen. The higher evapotranspiration rates and the increased soil moisture content of the unshaded feedlot manure pen surface are the likely reasons that slightly higher humidity levels were recorded in the unshaded pens at both feedlot sites during the daylight hours.

Chapter 5 noted that at Feedlot B, humidity levels of the external environment were generally higher than those recorded within the unshaded pen between the hours of 12am to 8am. By contrast, no significant difference was observed at Feedlot A. The slightly higher humidity of the surrounding feedlot environment at the southern NSW site could be attributed to the wetter environment caused by the irrigation activities undertaken in the feedlot surrounds and farming areas.

6.2.5 Unshaded Feedlot Microclimate - Wind Speed

The wind speed data analyses showed that at Feedlot A the 10 metre wind speeds recorded within the unshaded cattle pen were only slightly higher (on average 4%) than those of the external feedlot environment. At Feedlot B, there was a significant difference in 10 metre winds speeds between the unshaded pen area and the external environment. The data presented in Chapter 5 showed that the average 10 metre wind speed within the unshaded pen was 24% lower than the average recorded by the external stations.

These data demonstrate the substantial influence of the immediate topography on the air movement within a feedlot facility compared to any effects caused by the presence of the feedlot itself. The feedlot site descriptions detailed in Chapter 3 show that

Feedlot A was located within a flat landscape, and by contrast, the cattle pen area at Feedlot B was located within an ‘amphitheatre’ layout caused by the surrounding ridgelines. It was found that the topography at Feedlot B provided a significant degree of shelter from wind, as quantified by the 10 metre wind speed observations. The fact that at Feedlot A, the 10 metre wind speeds recorded by the stations located external to the feedlot pen area were lower than those recorded within the unshaded feedlot pen, indicates that the presence of cattle and pen infrastructure do not inhibit wind movement at a height of 10 metres.

The analyses of the 2 metre wind speed data clearly show this is not the case for wind movement at lower heights. The data from both feedlot sites show that wind speeds measured at a height of 2 metres within the unshaded feedlot pens were significantly lower than those recorded external to the feedlot. Specifically, at Feedlot A, the average 2 metre wind speed recorded by the external stations was 29% higher than that of the unshaded pen. The data from Feedlot B show that the presence of feedlot pens reduced 2 metre wind speeds by around 9%. These data demonstrate that both the infrastructure used to establish feedlot pens (such as fences and troughs) and the presence of cattle within the pens themselves do inhibit wind movement at lower heights.

The depth of frictional influence on horizontal wind speed is dependant on the roughness of the surface the wind passes over (Oke, 1987). The above observations from the 2 and 10 metre wind speed data indicate that the effect of pen infrastructure and cattle on wind speeds is limited to a boundary layer of less than 10 metres.

6.3 THE PHYSICAL MICROCLIMATE OF SHADED FEEDLOT PENS

The previous section has drawn together and discussed the microclimatic variations that are caused through the establishment of a feedlot facility. This section examines the microclimatic variations inside the feedlot pen areas that arise from the presence of shade structures within individual cattle pens. It discusses the microclimatic changes caused by shade structures separately, firstly as regards to the surface state and secondly, with respect to meteorological variables.

6.3.1 The Shaded Feedlot Surface

Chapter 5 demonstrated that in comparison with the unshaded pen surface and the external feedlot environment, the daily albedo values of the shaded pen surface were highly variable. This variability can be attributed to the reduction and deviation of the solar radiation values caused by the shade structures as described in Chapter 5. Another reason for this variation could be due to changes in pen surface conditions that result indirectly from the presence of shade structures. During the data collection period it was observed that cattle congregated under the shade, and due to their curiosity they generally crowded in close proximity to the panels protecting the automatic weather stations. This congestion of cattle caused the pen surface in the immediate area surrounding the automatic weather stations to become rough, pugged and uneven. The regular traffic of cattle saw that the surface of these areas varied on a daily basis. These changes in surface condition, combined with variations in moisture content, were likely to have influenced the amount of reflected radiation and therefore the calculated albedo values.

It was found that the shade structures at each feedlot site were effective in providing a significant reduction in incoming short wave solar radiation levels. The data analyses further showed that whilst the reduction in short wave radiation levels caused by the two types of shade structures at each feedlot site were similar, the galvanised iron sheeting at Feedlot A provided a slightly greater reduction than the shade cloth at Feedlot B. This is due to the fact that the shade cloth at Feedlot B is semi-transparent compared to the galvanised sheeting at Feedlot A that blocks the sunlight completely. However it was also found that the daily reduction values provided by the shade cloth was significantly less variable than the daily reductions provided by galvanised iron sheeting due to the spacing between sheets. Overall, the data demonstrated that the typical shade structures adopted by feedlots provide significant reductions in incoming solar radiation compared to unshaded pens (76% for the galvanised sheeting at Feedlot A and 72% for the shade cloth at Feedlot B).

The shade structures provided a significant reduction in ground temperatures of the manure pad surface. The data analyses have demonstrated that the temperatures of the manure pad under shade were significantly lower than those of the unshaded pens at each feedlot site. At both feedlot sites it was found that ground temperatures in the shaded pens were lower than those of the unshaded pens over the entire day and that the magnitude of reduction in ground temperatures was dependant on the shade type. That is, the more effective the shade was at reducing incoming short wave solar radiation, the lower the observed ground temperatures.

This was an expected result due to the significant reduction in incoming short wave radiation that the shade structures provided. In comparison to the other factors that affect ground temperature (such as the thermal and biological properties of the surface itself) the reduction in radiant heat energy was the most influential effect and primary cause of the lower ground temperatures that were observed in the shaded pen manure surfaces.

6.3.2 *SHADED FEEDLOT MICROCLIMATE - AIR TEMPERATURE*

In relation to the air temperatures measured under the shade compared to those in the unshaded pen, Chapter 5 outlines that differing trends were observed at each feedlot site. The data from Feedlot A showed that for higher air temperatures, those recorded in the shaded pen were cooler than those of the unshaded pen. Conversely, the air temperature data recorded at Feedlot B indicated that the shaded pen environment was warmer than that of the unshaded pen. As detailed in Chapter 5 these differing trends may have been caused by sensor error, however it was noted that a similar microclimate study undertaken at the same feedlot sites in 2002 observed a similar trend (Petrov *et al.*, 2002).

Assuming that the observed warmer temperatures of the shaded pen at Feedlot B are not a result of sensor error, then the trend may possibly be contributed to the effectiveness of the shade structure at Feedlot B. It also may possibly be caused by heating influences from the cattle.

The data would indicate that the black shade cloth structures at Feedlot B caused an increased heating effect compared to the spaced galvanised sheeting at Feedlot A which provided lower air temperatures compared to the unshaded pen. Section 6.3.1 outlined that both shade structures at each feedlot provided a reduction in short wave radiation levels however, the galvanised iron sheeting at Feedlot A provided a slightly greater reduction than the shade cloth at Feedlot B. It was also noted that the more effective the shade was at reducing incoming short wave solar radiation, the lower the observed ground temperatures with the shaded pen at each feedlot site. It is probable that as the shade cloth at Feedlot B was slightly less effective at reducing ground temperatures, this in turn may have provided an increase in the amount of heat energy radiated from the manure surface.

Another possible reason may be not due to the nature of the shade structures themselves but their configuration and the relative location of the automatic weather stations. Specifically, at Feedlot B the station was located under the centre of the shade structure and as a result it was observed that more cattle congregated around the station compared to Feedlot A, where the station was located closer to the edge of the shade near two support poles. It is possible that the body temperatures (long wave radiation) from the greater density of cattle may have contributed to a warming of the air in the immediate vicinity of the station.

It is noted that these possibilities can only be treated as hypotheses and it is not possible to scientifically and statistically determine the exact cause of the warmer air temperatures in the shaded pen at Feedlot B; or in fact, whether or not the observed trend is erroneous.

6.3.3 SHADED FEEDLOT MICROCLIMATE - ENERGY EXCHANGE

Black globe temperature is a measure of the effects of direct solar radiation on an exposed surface. Based on this definition it was expected that the trends in black globe temperatures would be similar to those of recorded incoming short wave solar radiation. This was the observed case when comparing the unshaded and shaded feedlot pen data during the day time hours, with the recorded data showing that the presence of shade structures within feedlot cattle pens provides a reduction in black globe temperatures. The reduced black globe temperatures are a result of the fact that the shade structures provided a significant reduction in the amount of incoming short wave solar radiation that reached the exposed surface.

When the data were examined for the 'non-daylight' hours, it was found that at both feedlot sites the black globe temperatures recorded in the shaded pen remained slightly higher than those of the unshaded pen. This phenomenon may be attributed to re-radiation of long wave radiation from the pen surface and possibly reflection of this radiation off the bottom side of the shade structures. It is noted that long wave radiation was not measured in this project and as such it is not possible to quantify these effects.

The cumulative black globe temperature data presented in Chapter 5 demonstrated that notwithstanding the slightly higher night-time black globe temperatures, the reductions that shade structures provide in radiant heat loads were significant. Specifically, the data showed that over the three month data collection period the cumulative black globe temperatures recorded in the shaded pens were approximately 5 to 7% lower than the cumulative temperatures for the unshaded pens for both feedlot sites.

6.3.4 *Shaded Feedlot Microclimate - Humidity*

It was found that at both feedlot sites the relative humidity values recorded by the automatic weather station located under the shade structure within the feedlot pens were notably higher than those observed in the unshaded pens. This increase in humidity values under the shade structures within the feedlot pen may be attributed to several factors.

Firstly, it is commonly known that cattle congregate under the shade structures within feedlot pens as was observed during the site visits undertaken over the project period (this can be seen in the shade structure photos presented in Chapter 3). This congregation of cattle increases the stocking densities of the feedlot pen areas under the shade. The increase in cattle numbers means more manure and urine is deposited per unit area of pen surface, which creates a wetter pen surface compared to the unshaded pen areas. As these wetter areas are shaded for the majority of the daylight hours, drying of the manure pad is inhibited. The higher density of cattle and the presence of the shade structures themselves also restrict air movement and ventilation, which again inhibits surface drying. These factors create the more humid conditions that were recorded under the shade structures at each feedlot site.

The fact that Feedlot A experienced a greater difference in humidity levels between the shaded pen and unshaded pen compared to Feedlot B may be attributed to the varying types of shade structures employed at each feedlot site. The 5 metre high shade cloth structures utilised at Feedlot B possibly provided some degree of increased air movement and ventilation compared to the 4 metre high galvanised iron sheeting structures at Feedlot A. This can be further examined by comparing the 2 metre wind speed data.

6.3.5 *Shaded Feedlot Microclimate - Wind Speed*

The wind data analyses showed that the presence of shade structures within feedlot pens caused a notable reduction in wind speeds. The data also suggested that the 4 metre high galvanised iron sheeting at Feedlot A inhibited 2 metre wind speeds more than the 5 metre high shade cloth structures at Feedlot B.

Compared to the solid galvanised sheeting structures at Feedlot A, the semi-transparent nature of the shade cloth structures at Feedlot B would provide less resistance to vertical air movement. Other characteristics of the Feedlot A shade structure such as an increased number of support structures, and the lower height would all contribute to greater impairment of air movement that resulted in the lower wind speeds observed.

The diurnal plots of wind speed presented in Chapter 5 highlighted that at Feedlot A, the 2 metre wind speeds were consistently lower in the shaded pen compared to the unshaded pen. At Feedlot B, the data showed that the most significant reduction in wind speeds occurred under the shade during the daylight and early evening hours (typically 7am to 6pm). This suggests that the congregation of cattle under the shade had a more influential effect on 2 metre wind speeds compared to the presence of the shade structure itself.

6.4 Potential Microclimate Optimisation Measures

The most significant differences in climatic variables that occurred due to the presence of a feedlot facility and also the presence of shade structures within feedlot pens have been discussed in the previous sections. In order for feedlots to operate in an efficient and cost effect manner they must create conditions that are favourable to animal welfare and production. Research into cattle heat stress has concluded that increased air temperatures, increased humidity, and restricted air movement can have an adverse effect on cattle health (Hahn 1985; Bucklin, Bray & Beede 1991; Mader 1996; Gaughan *et al.*, 1996; Mader *et al.*, 2006). This section explores the variations in microclimate that may potentially have an adverse effect on animal welfare and discusses possible methods to mitigate their effects.

The project data has demonstrated that the establishment of a feedlot changes the surface albedo, which in combination with the increased thermal conductivity and heat capacity of the manure pad generates higher ground temperatures. The data indicate that these higher ground temperatures may assist in the maintaining of slightly higher overnight air temperatures within the feedlot pens. It was also determined that the higher ground temperatures and greater moisture content of the pen surface contribute to increased evapotranspiration from the manure pad, and hence higher daytime relative humidity levels within the feedlot pens.

6.4.1 *MAINTENANCE OF PENS*

Ultimately it is the nature of the feedlot pen surface (ie. the manure pad) that creates higher overnight air temperatures and higher daytime humidity levels compared to the external environment. Effective pen manure management can minimise these variations. By maintaining minimal quantities of manure on the pen surface as economically and practically possible, the pen surface will maintain lower ground temperatures and hold less moisture. This will inhibit the re-radiation of heat and evapotranspiration from the pen surface.

6.4.2 *MAINTENANCE OF ADEQUATE VENTILATION*

It was found that feedlot pen infrastructure and the presence of cattle significantly inhibit wind speeds at a height of 2 metres. The project also determined that this frictional influence on horizontal wind movement was limited to a depth of below 10 metres. At a height of 10 metres the data showed that the immediate topography surrounding the feedlot can dramatically reduce wind speeds.

Air movement within feedlot pens is important in order to provide ventilation, assist convective cooling of cattle, and removal of potentially harmful gases (eg. ammonia, methane). The planning and design of a feedlot should consider methods of maintaining adequate air flow. This may include siting of the facility in areas where topography does not inhibit wind, and infrastructure design that maximises air movement (such as wire fence panels rather than solid steel panels).

6.4.3 *Design of Shade Structures*

By examining the effects that the two main types of shade structures utilised in Australian feedlots have on microclimate it was found that both shade structures were effective in reducing solar radiation and ground temperatures. In addition to this it is noted that the shade structures exhibited potentially adverse effects on cattle as they reduced 2 metre wind speeds and contributed to higher humidity levels.

Design of shade structures should aim at minimising these potentially adverse effects. It was found that the shade cloth structure inhibited wind movement less than the galvanised sheeting structure. There are several reasons for this. Firstly, the shade cloth material was semi-transparent and allows some degree of vertical wind movement. Secondly, the shade cloth structure was one metre higher than the galvanised sheeting structure. Finally, the galvanised sheeting structure had significantly more support structures located in the feedlot pen.

It is noted that in addition to the reduction in wind speeds caused by the structures themselves, air movement was also restricted by the cattle that congregate under the shade. This has a significant consequence to the design of feedlot shade structures. For this reason, shade structures within feedlot pens should supply a sufficient shadow to ensure that cattle stocking densities are minimised. Shade structures should also be of adequate height to allow sufficient spacing for air movement in the immediate area below the structure and above the cattle. In addition to the shadow size and structure height, other design considerations should be the minimisation of support poles, and maximisation of vertical air movement.

Higher humidity levels were recorded under the shade structures as a result of the wetter pen surface conditions and the restricted air movement which impedes surface drying. To mitigate this, shade structures should aim to provide dryer pen surfaces. This can be done by minimising restrictions on air movement as outlined above, and also by providing a shadow that moves sufficiently over the day to allow as much of the pen area under the structure to receive direct sunlight. Providing sufficient shadow to minimise cattle stocking densities will also assist in maintaining a dryer pen surface.

CHAPTER 7 CONCLUSIONS

7.1 ACHIEVEMENT OF OBJECTIVES

The installation of six automatic weather stations in strategic locations at both a feedlot in southern Queensland and a feedlot in southern New South Wales enabled data to be collected over a three month period that was used to examine the microclimatic variations caused by the presence of feedlots. The data also enabled determination of the variations that occur within cattle pens due to the presence of shade structures.

Compilation of the data from the four stations located around each of the feedlot sites provided single data sets for each site that were representative of the external feedlot environment. These external feedlot climate data sets were validated through comparison with data obtained from regional Bureau of Meteorology (BoM) stations for the same period. As outlined in Chapter 4 this comparison showed that air temperature, humidity and wind observation data from both feedlot sites were strongly correlated to the data from the regional BoM stations. The one noted exception to this was the higher humidity levels recorded at Feedlot B compared to the nearby BoM stations.

It was concluded that the project data collected by the external automatic weather stations at each feedlot site were representative of the climate experienced by the region. From the information presented in Chapters 3 and 4, it is clear that the first two objectives of this project, being, to install and maintain a series of automatic weather stations at two separate feedlot sites representing 'typical' Australian feedlot operations; and collating and analysing the microclimatic data collected from these two Australian feedlots, were achieved.

7.2 UNSHADED FEEDLOT MICROCLIMATE

The third objective of the project was to examine the specific differences between the microclimate within a cattle feedlot and that of the surrounding 'external' environment. The project also aimed to describe these microclimatic differences that are caused by the presence of feedlots.

The analyses of the climatic data presented in Chapter 5 clearly demonstrated that the presence of a feedlot does create microclimatic variations. It was found that the establishment of clay based manure covered feedlot pens creates surfaces with lower albedo values than the vegetated surfaces of the feedlot surrounds. The albedo values of these pen surfaces are further decreased under wet conditions.

These changes in surface albedo result in an increased adsorption of short wave solar radiation which in turn causes warmer ground temperatures within the unshaded feedlot pens compared to those of the grassed areas surrounding the feedlot. The study found that air temperatures recorded in the feedlot pens were slightly higher than corresponding air temperatures recorded outside the feedlot environment and in particular, minimum overnight temperatures within the feedlot were higher than those of the external environment. It was concluded that this increase in overnight air temperatures was the result of re-radiated heat energy from the manure pad. An increase in radiant heat loads was noted in the surrounding feedlot areas as a result of the higher reflectivity of the external surface (due to higher albedo values) compared to the unshaded feedlot pens.

The data analyses demonstrated that the relative humidity levels within the unshaded feedlot pen were higher than those of the feedlot surrounds with the most pronounced differences observed between the hours of 8am and 6pm when evapotranspiration is most significant. It is the higher rates of evapotranspiration from the manure pad due to the increased temperatures and greater soil moisture content that caused these variations.

Feedlot pen infrastructure and the presence of cattle were found to create frictional effects that reduced 2 metre wind speeds within the feedlot pens. However it was determined that this frictional influence on horizontal wind movement was limited to a height of below 10 metres within the feedlot pens. It was also highlighted that the immediate topography surrounding a feedlot site can significantly effect air movement within feedlot pens.

7.3 SHADED FEEDLOT MICROCLIMATE

The final objectives of the project were to determine microclimatic variations caused by the presence of artificial shade structures within feedlot pens; and to describe the microclimatic differences between shaded and unshaded feedlot pen environments.

The data analyses presented in Chapter 5 demonstrated that shade structures do affect the microclimate within feedlot pens. Further, it was found that these microclimatic differences were influenced by differing shade structure types.

Specifically it was observed that the albedo values of the feedlot pen surface under the shade structures varied significantly. This is due to the reduction and deviation of solar radiation caused by the shade structures, and also the increased congestion of cattle under the shade that creates rough and uneven pen surfaces. It was found that shade structures are effective in significantly reducing the amount of incoming solar radiation. The total reduction of incoming solar radiation was found to be dependant on the type of shade structure, and varied both hourly and daily according to the orientation and arrangement of the shade construction. It was the reduction in incoming solar radiation provided by the shade structures that caused both lower ground temperatures of the manure pad surface under the shade and a significant reduction in black globe temperatures during the daylight hours.

The congregation of cattle was found to create more humid conditions under the shade structures compared to the unshaded feedlot pens. This was a result of the wetter pen surface conditions and restricted air movement which impeded surface drying. Whilst it was noted that wind speeds measured at a height of 2 metres were lower in the shaded pens compared to the unshaded pens at both feedlot sites, it was found that the four metre high galvanised iron sheeting structures at Feedlot A inhibited 2 metre wind speeds more than the five metre high shade cloth structures at Feedlot B. It was also determined that the reduction in wind speeds under the shade at Feedlot B was influenced more by the congregation of cattle under the shade rather than direct effects of the shade structure itself.

7.4 RECOMMENDATIONS

The project has identified microclimatic variations that may potentially have an adverse effect on animal welfare. In order to mitigate these effects it is recommended that the following management and design concepts be considered.

7.4.1 RECOMMENDATIONS FOR FEEDLOT DESIGN

The planning and design of a feedlot should consider methods of maintaining adequate air flow. This may include siting of the facility in areas where topography does not inhibit wind. As demonstrated by this project, locating a feedlot within an area sheltered by the immediate landscape can significantly reduce wind movement within the cattle pens. Feedlot infrastructure design should also aim to maximise air movement. One example of how this can be achieved is through the use of wire fence panels rather than the solid steel panels that are present in some Australian feedlots.

Where shade structures are to be included within feedlot pens, they should be designed to inhibit air movement as little as possible. Specifically, shade structures should be of adequate height to allow sufficient spacing for air movement in the immediate area below the structure and above the cattle. It is suggested that shade structures be higher than 4 metres above the surface and preferably closer to 5 metres in height (Binns *et al.*, 2003; Petrov & Lott, 2001). In addition to the height of the structure, other design factors such as the minimisation of support poles, and maximisation of vertical air movement should be considered.

The design of shade structures should aim to provide dryer pen surfaces in an effort to reduce relative humidity levels. This can be done by minimising restrictions on air movement as outlined above, and by providing a large enough shadow to minimise cattle stocking densities, whilst still ensuring that over the day the shadow moves sufficiently to allow as much of the pen area under the structure to receive direct sunlight.

7.4.2 Recommendations for Feedlot Management

Differences between the microclimate within a cattle feedlot and that of the surrounding environment have been identified. The microclimatic variations that are created by the presence of shade structures have also been described. The identification of these variations could potentially benefit Australian feedlot industry as it allows climate data collected outside the feedlot pen area to be manipulated to provide an understanding of the microclimatic conditions within the feedlot pens. Specifically, this would allow feedlot operators to determine the conditions that the cattle housed within the feedlot are experiencing. This would provide an additional and useful management tool and is further discussed in section 7.4.3.

The project has demonstrated that a significant number of microclimatic variations resulted from the surface conditions of feedlot pens. Adoption of appropriate feedlot management can minimise these variations. Specifically, the pen cleaning operations should aim to reduce the quantities of manure on the pen surface as economically and practically possible. This will provide a surface with lower heat capacity and less moisture. Doing this will assist in maintaining lower ground temperatures, lower daytime relative humidity levels, and potentially lower overnight air temperatures within the feedlot pens.

7.4.3 Recommendations for Further Research

This project has compiled, analysed and discussed a large set of climatic data collected over the 2000-2001 summer period at two typical feedlot sites. This data set is one of the most comprehensive data sets of climatic conditions for both the feedlot surrounds and within feedlot pens. It is noted that a similar MLA funded project collected a second large data set over the 2001-2002 summer period. The collection of this data was undertaken at the same two feedlot sites as the previous year's data plus an additional two feedlot sites located in eastern Australia (Petrov *et al*., 2002). Some deficiencies highlighted by the experimental procedure of the 2000-2001 data collection were addressed for the collection of this second data set. Of particular note was the fact that remote communications were established with the automatic weather stations to ensure that individual sensor failures could be rectified promptly. This ensured that the occasional large data gaps that were noted in the 2000-2001 data sets were minimised. These two years of consecutive data provide a thorough representation of the climatic conditions within eastern Australian feedlots. It is suggested that further data collection is not required at present; however it is recommended that more detailed analyses of these data sets be undertaken. In particular the 2001-2002 data has not been examined in as much detail as the data analysed as part of this project.

Both data sets should be used to develop predictive equations for climatic conditions within feedlot pens. An example was presented in section 5.7.4 which demonstrated that data collected from the external feedlot environment could be used to accurately predict the climatic conditions within both the shaded and unshaded feedlot pens. In this example, the predictive equation allowed black globe temperatures within feedlot pens to be calculated from air temperature and solar radiation data recorded outside the feedlot. Further work in this area would enable equations to be determined for additional climatic variables.

These equations could then be used to develop a microclimate model for Australian feedlots. The data collected over the 2000-2001 and 2001-2002 summer periods provide significant data sets that could be used in the production, calibration, and validation of this feedlot model. The model should aim to predict the climatic conditions of the animal environment (ie. within feedlot pens) by using data recorded outside the feedlot area. As previously discussed, the external feedlot area is an environment much better suited for sensitive electronic equipment than within the feedlot pens. As such, the external feedlot environment is the most common location where automatic weather stations are sited within Australian feedlots.

Producing a model that is able to incorporate the variations that arise from the presence of shade, differing shade types, and ranging cattle stocking densities would enable it to be customised and utilised by most eastern Australian feedlot operators. Incorporated with an on-site automatic weather station, or even data recorded by a nearby BoM station, this model would provide an extremely useful tool that could be used by feedlots in the management of cattle performance and welfare. It would also serve as an informative planning tool in the early stages of feedlot development, in that it could enable climatic modelling of a variety of feedlot pen environments based on pen layout, shade type and cattle stocking densities.

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