On farm

Measuring the Microclimate of Eastern Australian Feedlots

Project number FLOT.317
Final Report prepared for MLA by:

E.A. Systems Pty Limited
PO Box W1029
16 Queen Elizabeth Drive
ARMIDALE NSW 2350

Meat and Livestock Australia Ltd
Locked Bag 991
North Sydney NSW 2059

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Feedlots

This Report has been prepared by:

Mr Ryan Petrov

Dr Simon Lott

Mr Peter Binns

Mr Robert Cork

of **E.A. Systems Pty Limited**.

Mr Charles MacFarlane

of **The University of Southern Queensland**.

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Thanks must go to the management & staff at the five cooperator feedlots.

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ABSTRACT

Over the summer of 2001 a study was undertaken to define the micrometeorological characteristics of two feedlots. The study aimed to characterise the microclimate of the feedlots, including the internal environment (both shaded and unshaded pens) and also the microclimate of the feedlot surrounds. The study also investigated potential sources of heat load on cattle held within feedlots.

A further study was undertaken over the 2002 summer with three work areas that aimed to address some of the key recommendations derived from the 2001 study. These work areas included the collection of another data set of intense micrometeorological variables to better define relationships between internal feedlot environments and their surrounds, and variations caused by the presence of shade within feedlot pens. The second work area aimed to better define the extents of ammonia generation from feedlot pens. The final work area involved measurements to investigate the relationship between trough design and water temperature.

The study confirmed previous findings that significant variations occur between the micrometeorology of the external and internal feedlot environments. The key differences noted were that air temperatures were found to be slightly higher in unshaded pen areas than those of the external environment. Shade provides a minor reduction in air temperatures and a large reduction in solar radiation, soil temperatures, and black globe temperatures. Humidity levels are higher under shade. Both horizontal and vertical wind speeds are reduced in shaded pens, however the extent is variable and dependent on the type of shade structure and geographic position of the feedlot in the landscape.

Due to the differences in individual micrometeorological variables between the external environment (where most standard weather stations are located), and the pen environ, it is possible that such variations might be reflected in a calculated stress index. To best manage heat stress events it is important that a stress index calculated from data collected outside of the feedlot pens, be representative of conditions within the feedlot pens. The variations that occur between indices calculated from internal and external data was examined. This highlighted significant variability in stress indices calculated from within shaded and unshaded pens, and outside the feedlot area. The project has demonstrated that stress index equations can be adjusted accordingly so that data recorded outside the feedlot area can be used to calculate indices representative of pen conditions in a feedlot.

1. INTRODUCTION

1.1 Project Background

The project FLOT.317 “Measuring the Microclimate of Eastern Australian Feedlots” was funded by Meat and Livestock Australia, with support from E.A. Systems Pty Limited and the University of Southern Queensland.

The project FLOT.317 aimed to address recommendations that arose from the outcomes of project FLOT.310. Project FLOT.310, titled “Measuring the Microclimate of Two Australian Feedlots” was undertaken over the 2000/2001 summer. The project aimed to measure microclimate variations within two feedlot sites representative of operations in southern and northern Australia.

By placing micrometeorological instrumentation at both feedlot sites, measurements were made outside the feedlot area and within the feedlot pens (shaded and unshaded). Over the same period, cattle observations were undertaken for the purpose of relating cattle behaviour to microclimate variations, and manure samples were collected from the feedlot pens in order to define pen surface conditions. A series of ammonia measurements was also undertaken using hand held gas sensors. These sensors were used to collect data on ammonia levels within the feedlot pen areas over the summer period.

The outcomes of the data collection, analysis and interpretation was presented to MLA in a final report for project FLOT.310 (Petrov *et. al.* 2001). The report made several key research recommendations as detailed below:

1. Undertake further field studies by collecting another record of data over a summer period with intense measurements of micro-meteorological variables and other ambient conditions inside a feedlot pen. The aim of these studies would be to;
   a. Duplicate the studies undertaken so far but with more focused measurements to expand the available data sets and in particular determine vertical wind movement (ie. circulation) in feedlots. These studies should aim at examining the relationships between horizontal and vertical wind movement, and also determine the differences between shaded and unshaded areas.
   b. Increase the level of measurements of atmospheric ammonia to better define the extents of ammonia generation in feedlot pens and the profile concentration over the pen surface and consequent effects on stock.
2. Develop a stress index based on the existing data and trial it in the field over the coming summer. The information can be used as an early warning system for the feedlot industry on a ‘trial’ basis. The “stress index” must be cognitive of the key outcomes of the literature review projects (FLOT.307-309) and outcomes of FLOT.310 and subsequent industry review.
3. Review shade design on the basis of the findings of the project report and provide key design principals as a prelude to obtaining advice on the structure design of a “new generation” of shade structures.
4. Undertake simple thermodynamic studies to investigate the relationship between trough design and water temperature. These studies should define those systems that limit heating of water.
5. Define the effects of ammonia (NH_3) on lot fed cattle.

After considering the recommendations and findings from both project FLOT.310 and the literature review project FLOT.307-309, Meat and Livestock Australia Limited (MLA) commissioned the following studies to be undertaken over 2001/2002:

a) **FLOT.312** – Heat stress software development.

b) **FLOT.313** – Forecasting feedlot thermal comfort.

c) **FLOT.315** – Applied scientific evaluation of feedlot shade design.

d) **FLOT.316** – Development of an excessive heat load index for use in the Australian feedlot industry.

e) **FLOT.317** – Measuring the microclimate of eastern Australian feedlots.

The aim of these integrated projects was to obtain a holistic approach to addressing heat stress issues in the lot feeding industry.

Project FLOT.317 involved three separate work areas. These included:

1. The undertaking of further field measurements of microclimate over the 2001/2002 summer;

2. The collection of intense ammonia emission measurements from feedlot pen surfaces;

3. Defining the thermodynamics and characteristics of feedlot cattle troughs and their effect on water delivery and temperature.

This report presents the findings of these three work areas.

1.2 Project Objectives

The general objectives for project FLOT.317 are defined below:

a) Establish a series of weather stations at four feedlot sites (including sites in both NSW and Queensland) by the end of December 2001.

b) Collect meteorological data on conditions in both shaded and unshaded pens and the surrounding ammonia emissions, cattle stress, and pen conditions over the 2001/2002 summer period.

c) Verify, collate, and interpret this data to determine the feedlot pen microclimate, and the effects of climate, shade and manure characteristics on both pen conditions and cattle comfort/stress.

d) Undertake intensive measurements of ammonia generation within feedlot pens to define the relationship between atmospheric conditions, feedlot pen conditions, and ammonia generation and subsequent atmospheric concentrations.

e) To define the thermodynamics and characteristics of feedlot cattle troughs and their effect on water delivery and temperature.

2. METHODOLOGY

The methodology of each specific work area is detailed in the following sections.

2.1 Work Area 1 - The Microclimate of Four Feedlots in Eastern Australia

Work Area 1 undertook detailed microclimate measurements at four separate feedlot sites. This work was conducted in a similar manner to that performed for project FLOT.310 and reported by Petrov *et. al.* 2001. Work Area 1 aimed to expand the available data sets of microclimatic measurements whilst also examining the relationships between horizontal and vertical wind movement, and determining differences between shaded and unshaded areas.

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

2.1.1 Site Descriptions

Four feedlot sites were selected for the measurement of microclimatic conditions over the 2001/2002 summer period. Two of the sites were feedlot sites involved in project FLOT.310. Two additional sites, one each in Queensland and New South Wales, were added to these for data collection in FLOT.317. Site selection aimed at ensuring that the feedlots were representative of operations in eastern Australia. The four feedlots that were selected for the study are described below.

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

Feedlot A has a capacity of 18,000 head. Four individual pens were used for the cattle measurements. Two of the selected pens contain permanent 15 metre wide shade structures composed of galvanised iron sheets (see Plate 1). These two shaded pens had an average area of 2750 m^2 and were stocked at an average density of 18 m^2/head over the study. The two unshaded pens were slightly larger, with their pen areas of approximately 3100 m^2 providing average stocking densities of 22 m^2/head over the study. All four pens used for the study are on a slope of about 2.5% with a westerly aspect.

Feedlot B is also located in southern Queensland on the Darling Downs. This feedlot is situated approximately 45 km to the south east of Feedlot A, and 14 km west of Oakey (151°43' E, 27°26' S). The closest BOM stations located to the feedlot site are Dalby Airport (station no. 041522) and Oakey AMO (station no. 041359). This site is located on the side of a hill sloping toward a stream and thence a creek.

The capacity of Feedlot B is 7,100 head. The area of the feedlot pens within which the automatic weather stations were installed were 3000 m^2. During the study period the stocking density of these pens averaged 19 m^2/head. During early January, shade structures were constructed in newly developed pen areas and as such one of these shaded pens was utilised later in the study period. The shade structures consist of galvanised sheets with a minimum height of 4.8 metres, angled at approximately 5° with the low side to the west (see Plate 1).

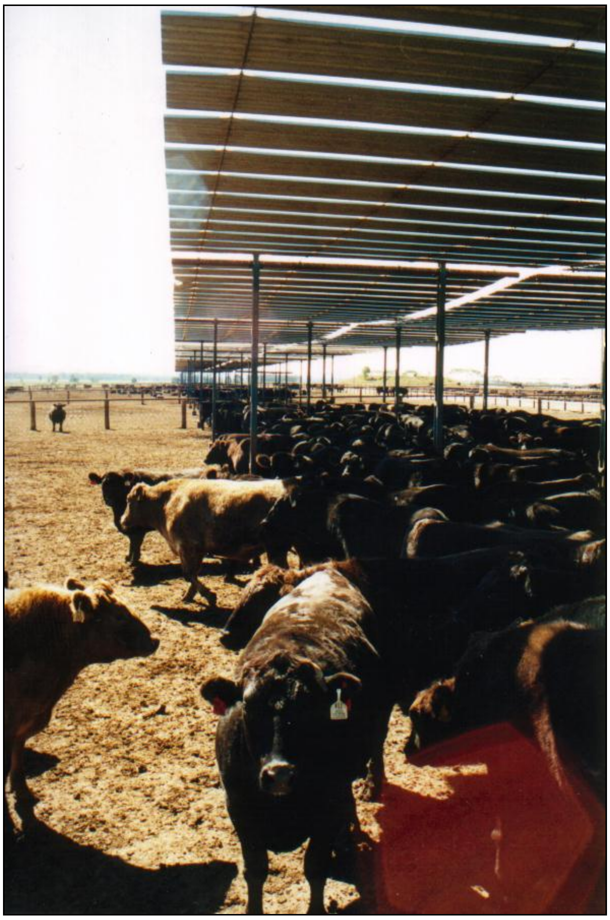


Plate 1. Shade Structures at Feedlot A (left) and Feedlot B (right).

Feedlot C is situated on the north west slopes and plains of NSW. The feedlot is located 65 km south west of Tamworth (150°56' E, 31°05' S) and 50 km south of Gunnedah (150°15' E, 30°54' S). The nearest BOM stations that record climatic data additional to rainfall are Tamworth Airport (station no. 55054), Gunnedah Airport (station no. 55202) and Barraba Post Office (station no. 54003). The site located on top of a ridge that is part of a formation of the edge of a large catchment. As such it is situated well above the valley floor.

This feedlot has an operating capacity of 25,000 head. The pens used for the cattle measurements had areas of 4,680 and 4,950 m^2 and were stocked at an average density of 14 to 15 m^2/head. The pens had a slope of 3 to 4% with pens located on a ridge above a valley floor.

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

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

Plate 2. Shade cloth structures at Feedlot D.

2.1.2 Project Duration

The data collection period for the microclimatic measurements focused on the summer period from January to March 2002. The installation of the weather stations commenced in early December 2001 (see Table 1). During this time the station infrastructure was assembled and the majority of sensors and communication systems installed. Some delays were experienced in the supply of the vertical wind sensors and as a result these particular instruments were not installed until early to mid January 2002. Notwithstanding this, climatic data collection had commenced by the end of December 2001 at all feedlot sites.

The cattle measurements undertaken at the feedlot sites occurred during the months of January, February, and March as detailed in Table 1. These measurements also included the collection of pen surface observation data. The dismantling of the automatic weather stations from within the feedlot pens commenced in early April 2002. The external stations were left on site in order to collect data to assist in the trialing of the forecasting software developed as part of project FLOT.313 by Katestone Scientific. Dismantling of the external stations commenced in late May 2002.

Specific activity dates for the four feedlot sites are detailed in Table 1 below.

Table 1. Progress Outline of Field Measurements.

Activity	*Feedlot A*	*Feedlot B*	*Feedlot C*	*Feedlot D*
Commencement of Weather Station Installation	12 Dec 2001	13 Dec 2001	10 Dec 2001	13 Dec 2001
Commencement of Climatic Data Recording	14 Dec 2001	22 Dec 2001	30 Dec 2001	31 Dec 2001
Commencement of Cattle Comfort Measurements	2 Jan 2002	2 Jan 2002	9 Jan 2002	7 Jan 2002
Completion of Cattle Comfort Measurements	19 Mar 2002	23 Mar 2002	2 April 2002	27 Mar 2002
Dismantling of Internal Weather Stations	2 April 2002	3 April 2002	22 April 2002	1 May 2002
Dismantling of External Weather Station	27 May 2002	27 May 2002	23 May 2002	Still on site

It should be noted that the period over which micrometeorological data collection and analysis for FLOT.317 was concentrated was from January to March 2002. The cattle comfort measurements and pen surface observations were undertaken by feedlot staff over this time as detailed in section 2.1.9.

2.1.3 General Microclimatic Measurements

Project FLOT.317 aimed to expand on the microclimatic dataset recorded as part of project FLOT.310 conducted over the 2000/2001 summer. For the 2001/2002 summer period, another two feedlot sites were selected in addition to the two sites used for FLOT.310.

Three automatic weather stations were located at each of the feedlot sites, with the exception of Feedlot C where only two stations were installed. At each site, two ten metre automatic weather stations were installed, with one positioned outside the feedlot area (referred to as the external station) and the second located within a feedlot pen. At three of the four feedlot sites (Feedlots A, B, and D) a two metre automatic weather station was also positioned under the shaded area of pen that contained some type of shade structure. The purpose of these 11 automatic weather stations was to measure the climatic conditions both outside, and within each of the four feedlot environments.

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

The purpose of locating a station outside of the feedlot was to characterise the external climate of the feedlot which would allow the differences in the external and pen (internal) climates to be defined. The two internal stations were used to define microclimatic differences between shaded and unshaded pens. The study aimed to define the climate of the feedlot by recording the climatic variables as outlined below in Table 2. The weather station configuration was kept consistent between the four feedlot sites. The automatic weather stations used in the study were configured so that all sensors logged readings every 10 minutes. The exception to this was the rain gauges on the external stations which logged data hourly, and the evapotranspiration calculation that was performed daily.

Table 2. Sensor Configuration for the 'External' Weather Stations.

Sensor Type	*Units of Measure*	*- Sensor Location -*
Air Temperature	0.001 °C	1.2 metres
Humidity	0.01 %	1.2 metres
Black Globe	0.001 °C	2 metres
Vertical Wind Speed	0.001 m/s	2 metres
Wind Speed	0.01 km/h	2 & 10 metres
Wind Direction	0.01 °	10 metres
Soil Temperature	0.001 °C	Ground
Rain Gauge	0.2 mm	Ground
Incoming Solar Radiation	0.1 W/m^2	10 metres
Outgoing Solar Radiation	0.1 W/m^2	10 metres
Evapotranspiration	0.01 mm/day	Calculation

For the purpose of the project specialist vertical wind speed sensors were manufactured. The purpose of these sensors was to define the extent of uplift and vertical mixing. The specific nature of these sensors required them to be custom made and as such the sensors were not available at the start of the project. The delayed supply of the vertical wind sensors saw that the sensors were not installed at all feedlot sites until mid January 2002. As detailed in the above table, these sensors were installed at a height of 2 metres.

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

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

2.1.4 Feedlot Microclimate Measurements

Microclimatic conditions within the feedlot were measured by installing two weather stations in separate pens at three of the four feedlot sites. The feedlot pens selected at these sites included one pen with shade structures, and a separate pen that either contained no shade (Feedlots A and B) or had the shade removed for the purpose of the study (Feedlot D). At the remaining feedlot site (Feedlot C) a 10 metre station was installed in an unshaded pen only. Pen selection was aimed at ensuring that the study pens were representative of the general feedlot conditions at each site and that they were comparable across the sites. It was also important to ensure that the location of the pens were not in close proximity to the edge of the feedlot area (in order to prevent variations caused by boundary effects).

At Feedlots A, B and C, a 10 metre station was positioned close to the boundary fence adjoining the two unshaded pens that were selected for the study. This was done to enable the collection of data that would be representative of both pens at each site. It also enabled existing fences to be utilised for additional protection of the stations from cattle.

At Feedlot D, the internal posts that are typically used for the securing of shade cloth could be utilised to support the 10 metre station. As such the station was positioned within the centre of a single pen and was protected from cattle using portable fence panels fixed to star posts (see Plate 3 below). This pen (6,000 m^2) was significantly larger than the unshaded pens at the other three sites (3,000 to 4,950 m^2).

Plate 3. Automatic weather station in the unshaded pen at Feedlot D.

The weather stations located in the unshaded pens at the three feedlot sites (Feedlots A, B, and D) were 2 metres in height which enabled them to be placed under the existing shade structures. These stations were situated as close to the centre of the shade structure as possible whilst still allowing any existing shade support posts to be utilised as braces for the fence panels that were erected to prevent cattle from damaging the stations. Plate 4 below shows the 2 metre station located within the shaded pen at Feedlot A.

Plate 4. Automatic weather station in the shaded pen at Feedlot A.

The climatic variables recorded at the stations positioned within the feedlot pens are outlined in Table 3 below. The weather station configuration was kept consistent between the three 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 D had to be relocated at 2 metres rather than 10 metres during the project when damage occurred to the extension cable at 10 metres. The internal stations were used to record climatic data for a shorter period than the external stations (primarily the three months from January to March 2002, as outlined in Table 1 of section 2.1.2).

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

Sensor Type	*Units of Measure*	*- Sensor Location -*	
		Shaded Pens	*Unshaded Pens*
Air Temperature	0.001 °C	1.2 metres	1.2 metres
Humidity	0.01 %	1.2 metres	1.2 metres
Black Globe	0.001 °C	2 metres	2 metres
Vertical Wind Speed	0.001 m/s	2 metres	2 metres
Wind Speed	0.01 km/h	2 metres	2 metres & 10 metres
Wind Direction	0.01 °	2 metres	10 metres
Soil Temperature	0.001 °C	Ground	Ground
Incoming Solar Radiation	0.1 W/m^2	2 metres	10 metres
Outgoing Solar Radiation	0.1 W/m^2	2 metres	10 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 and therefore determine the amount of re-radiated energy that may affect the air in the feedlot pens. The purpose of the vertical wind speed sensors was to define the extent of uplift and vertical mixing of the air within the feedlot pens.

2.1.5 Sensor Calibration

All sensors used in the project had undergone standard calibration by the manufacturer prior to delivery. Sensors that had been used in the previous study FLOT.310 were checked and calibrated against sets of new sensors to ensure their accuracy before being utilised for project FLOT.317. Calibration of these sensors involved placing a number of similar sensors in the same conditions and logging a period of data to define variances in measurements. These readings were graphed and visually compared to ensure that no significant variation occurred between the sensors across a range of operating conditions and the variance checked to ensure that it was less than 1%. Any sensors found to be providing variable data were returned to the manufacturer for re-calibration or replacement.

2.1.6 Communications

In order to ensure that the collected data was of quality and remained accurate throughout the study period, mobile communications were established at all stations to allow daily data downloads and verification. The establishment of mobile communications involved the installation of a modem/telephone (GSM) and antenna in the weather stations. The establishment of mobile communications with the stations ensured that any problems in data collection were quickly identified and remedied. It was important to collect reliable and uninterrupted data from both the internal and external stations, as the stations were not replicated. The mobile communication systems were used to check the stations on a regular basis (typically daily) for both changes in weather conditions and sensor integrity. Daily data downloads were also required so that data could be regularly supplied to the research bodies undertaking projects FLOT.312 to 316.

At one of the feedlot sites (Feedlot C) it was found that the digital phone coverage was inadequate for the GSM systems to operate. In order to allow regular mobile communications with the two stations located at this feedlot site CDMA systems had to be utilised. Weather station manufacturers had not utilised CDMA communication systems prior to this project. Consequently, delays were experienced while appropriate phone and communication systems were obtained, configured, and tested. These delays saw the mobile communications with the stations at Feedlot C established on 22 February 2002.

2.1.7 Data Collection and Collation

The mobile communications were used to undertake daily downloads of the recorded climatic data. The previous days data recorded by each of the 11 weather stations was downloaded on weekday mornings from the E.A. Systems office. Collected data from the external stations was supplied to the researchers undertaking projects FLOT.312 to 316 on a daily basis. Data collected from the internal stations was collated and supplied to the researchers as required.

2.1.8 Weather Station Maintenance

As the majority of the recorded climatic data was collected using the mobile communications the fortnightly visits undertaken by E.A. Systems staff were primarily used to maintain the stations. During these visits all stations were checked, cleaned and serviced to ensure that all sensors were fully operable. The visits were also used to verify station measurements and to identify and remedy any faults. From time to time these visits were necessitated to reset GSM communication systems that may have temporarily stopped operating.

Verification of the sensor readings involved the checking of spot measurements 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. In most cases, 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 including the verification of temperature and humidity sensors using a hand held sling psychrometer.

It should be noted that due to the typically dustier and harsher conditions within the feedlot pens, significantly more cleaning of the internal stations was required during the fortnightly site visits to ensure sensor and data integrity.

2.1.9 Cattle Measurements

Throughout the months of January to March 2002, daily measurements were recorded in order to monitor cattle behaviour. The project aimed to undertake these measurements in a similar manner to those conducted as part of FLOT.310 and previous studies conducted by Dr Lloyd Fell (1994) and Dr Ross Clarke (1996). The monitoring involved the observation of cattle behaviour in both the unshaded and shaded study pens where climatic monitoring was undertaken. This observational study conformed to the Australian code for the care and use of animals for scientific purposes (6th edition, 1997). The cattle were purchased and managed under commercial feedlot operations, and were not subjected to any differences in management due to the study.

This monitoring of cattle behaviour was undertaken by the staff of the four feedlots. The feedlot staff undertook the observations at three separate periods throughout the day, five days per week. Recordings were collected as close as possible to the hours of 0600, 1200 and 1700 EST.

A number of variables were monitored relating to both cattle behaviour and comfort. These observations were designed to provide an indication of when cattle become stressed and to provide data on their behaviour corresponding to these stress periods. To assist the recording of cattle measurements, a simple check sheet was supplied to the staff that could be used to record animal behaviour in the monitored pens. This check sheet (provided in Appendix B) was developed by the University of Queensland as part of Project FLOT.316.

The observations that were recorded on the check sheets are shown in Table 4 below.

Table 4. Observations that were recorded with the Cattle Measurements.

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

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

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

To assist the staff undertaking these observations, the following terms were defined as shown in Table 5.

Table 5. Definition of Terms for the Cattle Observations.

Term	*Definition*
Pulls	The number of individuals removed from a pen.
Number around water trough	The number of cattle standing as close as they can to the water trough, even if not actually drinking.
Number of cattle at feed	The number of cattle in the process of ingesting feed at the feed trough.
Panting Score	As defined in Table 6 below.

Table 6. Cattle Observations - Breathing Condition, Respiration Rate and Panting Score.

Breathing Condition	Respiration Rate [A] (bpm)	Panting Score
No panting	Less than 40	0
Slight panting, mouth closed	40 to 70	1
Fast panting, occasional open mouth	70 to 120	2
Open mouth + some drooling	120 to 160	3
Open mouth, tongue out + drooling	< 160[B]	4

[A] - Respiration rate should be counted for at least 2 minutes
[B] - At this stage, RR may decrease due to change to deep phase breathing.

The pen surface condition was also recorded at each of the three periods. The check sheet allowed the feedlot staff to select the most appropriate description of the pen surface from the following classifications:

- Dry Dusty;
- Smooth;
- Compact;
- Pugged;
- Saturated (Slurry).

The collection of all data was benchmarked to ensure that data collected at one feedlot could be compared to another. The completed data collection sheets were supplied to University of Queensland for compilation and analysis as part of Project FLOT.316.

2.2 Work Area 2 - Ammonia Measurements from Feedlot Pen Surfaces

A series of intensive ammonia measurements was undertaken for Work Area 2. These measurements were undertaken over two periods with a consecutive 8 day period from 22 to 31 January 2002 being of most note. The measurements were undertaken at Feedlot A and involved the collection of continuous ammonia level readings from within both the shaded pen and unshaded pen that were being used for the micrometeorological studies. The ammonia measurements were undertaken during a protracted dry period at the site. As a consequence the data set is limited to recording the profile of ammonia concentrations over a dry pen surface.

Data on ammonia levels within the feedlot pens were collected using several hand held gas monitors. The monitors used included two ‘QRAE PGM-2020’ and a ‘VRAE PGM-7800’ multi gas monitor, all fitted with an ammonia sensor. These two types of meters allow continuous measurements of ammonia levels to be recorded with data automatically logged at a user defined interval. For this study ammonia levels were recorded every 10 seconds. A fourth monitor was also used to undertake spot measurement checks. This ‘QUEST’ monitor did not have data logging capabilities and as such was primarily used to verify readings.

Continuous ammonia measurements were collected by positioning the hand held monitors on a metal stand with platforms that could be set at any height between 0.1 and 1.7 metres (see Plate 5 below). Within both of the feedlot pens used for the study the stand and monitors were set up within the porta panel enclosure surrounding the automatic weather station. This was done to ensure that cattle could not damage the gas monitors.

For the study duration the monitors were either set at the same height (generally 1 metre above surface) for calibration purposes, or at set height intervals (0.25, 1.0 and 1.5 metres) in order to define the ammonia gradient above the pen surface. The monitors were set to automatically log the ammonia levels at a specified interval (generally once every 10 seconds) until they were either removed, or ran out of battery power. The battery life of the monitors was found to be in the order of 10 to 13 hours. Readings were generally started between the morning hours of 6 to 8 am and completed by 6 to 7 pm. Some overnight recordings were also undertaken. A summary of the recording intervals is presented in Table 7 below.

Plate 5. Hand held gas monitors (QRAE top and bottom, VRAE middle left, QUEST middle right) used to collect ammonia measurements.

Table 7. Summary of ammonia measurement data collection undertaken at Feedlot A

Date/s	Period	Pen	Monitor Height			Comments
			VRAE	QRAE 1	QRAE 2	
22 Jan	9:50 to 18:20	Unshaded	0.30 m	0.30 m	0.30 m	Missing VRAE data 11:00 to 14:30
23 Jan	6:30 to 18:30	Unshaded	1.0 m	1.5 m	0.25 m	-
24 Jan	6:00 to 18:40	Unshaded	1.0 m	1.0 m	1.0 m	-
25 Jan	6:50 to 19:00	Shaded	1.0 m	1.0 m	1.0 m	Monitors knocked to ground by cattle
26 Jan	8:25 to 19:00	Shaded	1.0 m	1.0 m	1.0 m	-
27/28 Jan	15:50 to 7:00	Shaded	1.0 m	1.0 m	1.0 m	-
29 Jan	7:30 to 18:00	Shaded	1.5 m	0.25 m	1.0 m	-
30/31 Jan	7:00 to 7:00	Shaded	1.5 m	0.25 m	1.0 m	-

2.3 Work Area 3 - The Thermodynamic Characteristics of Feedlot Troughs

2.3.1 Site Descriptions

The feedlots located on the Darling Downs of Southern Queensland were used in the study of trough temperatures in Work Area 3. These sites included Feedlots A and B (as described in section 2.1.1) and a third feedlot site also located on the Darling Downs in close proximity to Feedlots A and B (referred to as Feedlot E in this report).

The three feedlots were selected due to their comparable size and general management systems, their relative proximity to each other, and the availability of good quality on-site meteorological data. Importantly, they provided a diverse range of water trough designs and reticulation systems that were representative of the stock water delivery systems typically used in the Australian feedlot industry (Watts and Tucker, 1994). The studied feedlots also displayed small, but potentially important differences in feedlot pen design and management systems that again are characteristic of the diversity of designs and systems to be commonly found in the Australian feedlot industry. A comparison of the various stockwater delivery systems, feedlot pen designs and management systems is provided in Table 8.

Table 8. Comparison of various characteristics of the studied feedlots.

Parameter	Feedlot A	Feedlot B	Feedlot E
No. cattle in pen	117 head	146 head	350 head
Cattle breed	Angus	Angus	Angus
Market supplied	Jap Ox (200 d)	Jap Ox (200 d)	Jap Ox (200 d)
Stockwater source	Groundwater	Surface water	Groundwater
Water troughs per pen	1	1	2
Water trough construction materials	Fibreglass in concrete frame	Concrete	Concrete Fibreglass
Water trough length	2.80 m	4.65 m	4.60 m 4.73 m
Trough guard length	0.60 m	0.84 m	0.70 m 0.70 m
Effective trough length †	2.20 m	4.61 m	3.90 m 4.03 m
Trough space / head ‡	0.0376 m/hd	0.0632 m/hd	0.0227 m/hd
Trough volumes	210 L	405 L	425 L 265 L
Location in pen	Freestanding, opposite feedbunk	Freestanding, opposite feedbunk	On pen partition On pen partition
Shared toughs	No	No	No

† - The effective trough length is the length of the trough minus the length of the trough guard, since the cattle cannot access the water under the trough guard.

‡ - Trough space per head is based on the effective trough length. For a trough on the pen partition, it is equal to the effective trough length divided by the number of head in the pen. For a freestanding trough, it is equal to twice the effective trough length divided by the number of head in the pen (as cattle can access both sides of the trough).

Plate 6 below shows the trough types at Feedlots A and B. The study pens at Feedlot A contained fibreglass troughs housed in a concrete frame with a storage capacity of around 210 L. In comparison, the troughs at Feedlot B were longer concrete troughs with a larger capacity (405 L).

Plate 6. Fibreglass trough in concrete frame at Feedlot A (left); and the larger concrete trough at Feedlot B (right).

The study pen used at Feedlot E contained two troughs, being a larger (425 L) concrete trough situated near the southern pen fence, and a smaller (265 L) fibreglass trough mounted on the northern pen fence (see Plate 7).

Plate 7. Large concrete trough (left); and the smaller fibreglass trough (right) at Feedlot E.

Time and practical constraints meant that it was not possible to undertake trough water temperature measurements concurrently at each of the three feedlots or to use *in situ* temperature data loggers resident in the troughs for the entire study period. As a consequence, trough temperatures were recorded periodically over the study period by using hand held digital thermometers[1] fitted with Type K thermocouples. Where possible, data was recorded using both thermometers to provide an acceptable level of data quality and integrity. To account for situations where one of other of the thermometers was not operational, a calibration curve was developed to allow standardisation of data recorded by the two thermometers.

[1] A Fluke™ 53II thermometer and a brand name™ & model thermometer.

2.3.2 Study Duration

The troughs were inspected and some sample temperature measurements were taken on Friday 1 March, 2002. This inspection enabled a better appreciation of the design and layout of the troughs and feedlot pens. The sample temperature measurements were taken using a hand held thermometer fitted with a thermocouple. The data collected during these inspections provided general idea of the in-trough temperature variations at each site and were used to provide direction to the detailed study.

The detailed study was conducted over a 5 day period of unseasonably warm temperatures in March 2002. During this period air temperatures on each day were in the range of 12°C to 37°C. Hourly recordings were made over a 12 hour period between 0600 hours and 1800 hours on Friday 15 March (Feedlot B), Monday 18 March (Feedlot A) and Tuesday 19 March (Feedlot E). Ambient air temperatures and incoming solar radiation at 2 metres were recorded by automatic weather stations situated in or adjacent to the feedlot pens where the water trough temperature measurements were made.

It was recognised that activity near the stockwater troughs during each recording period might influence animal behaviour patterns and consequently the same temperature sampling frequency and methods were used in each of the feedlots.

From the preliminary temperature measurements that were taken, it was evident that sufficient in-trough variation existed to warrant taking cross-sectional data in each trough. The typical cross-section that was used is illustrated in Figure 1.

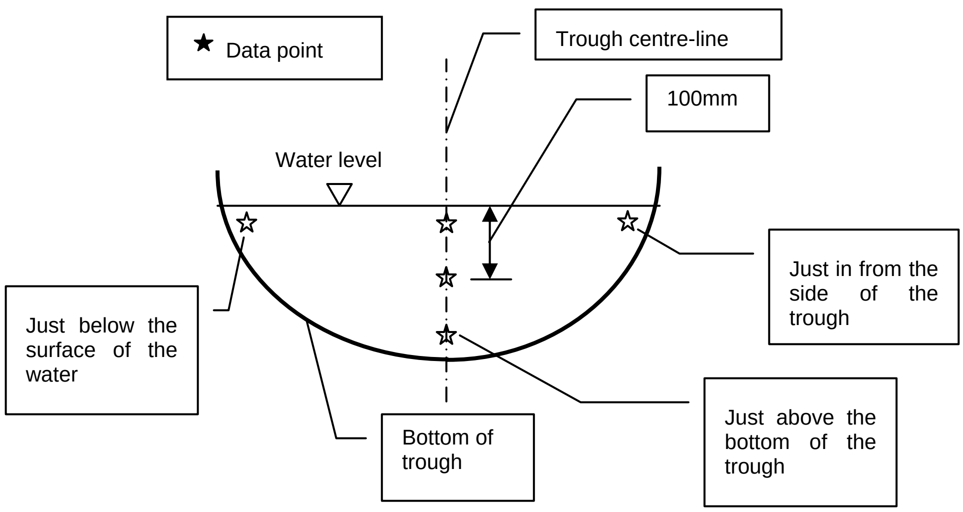

Figure 1. Typical cross-section on which temperature measurements were taken within the troughs.

Temperatures were taken on the cross-section pattern shown in Figure 1 approximately every metre along the length of the trough. The temperatures were measured and recorded to a 0.1°C accuracy. However, it was considered that temperature changes less than about 0.5°C were not significant.

Depth measurements were also taken with each cross section along the length of each trough. This enabled a limited picture of the drinking patterns of the cattle throughout the day. It showed whether the cattle were drinking heavily or not. This enabled an appreciation of how strong the inflow into the trough was at the time of measurement.

Two troughs were measured at each site. At Feedlot A and B, measurements were made at a second trough that was located in an unstocked pen. This enabled a better appreciation for how the thermodynamics of the trough worked throughout the day without any inflow of water into the trough. At these feedlots the troughs in the unstocked pens were the same design as the troughs in the respective stocked pens and were used as a control. This was not possible at Feedlot E, as no empty pens were available at the time of the study. The two troughs used at Feedlot E were located in the same pen, but were of different design.

3. RESULTS

3.1 Work Area 1 - The Microclimate of Four Feedlots in Eastern Australia

3.1.1 Summary of Climatic Measurements

For the purpose of this study the climatic measurements presented primarily consist of data collected over the period January to March 2002 although some climatic data was recorded at all feedlot sites before and after this period.

A summary of the climatic data recorded at the four feedlot sites over these months is presented in Table 9 to Table 12 below. These tables show average monthly values recorded at the external station of each feedlot site compared to the long term average monthly data obtained from nearby Bureau of Meteorology (BOM) stations.

The long term BOM data presented in Table 9 and Table 10 are the long term average values recorded at Dalby Airport and the Dalby Post Office. The long term average BOM data in Table 12 is sourced from Gunnedah SCS and Tamworth Airport and the data presented in Table 13 is the average long term values from Narrandera Airport, Narrandera Council Depot and Narrandera Post Office.

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

	January		*February*		*March*	
	Recorded	BOM Long Term Average	Recorded	BOM Long Term Average	Recorded	BOM Long Term Average
Air Temperature (°C)	24.9	25.4	24.0	24.7	22.2	22.9
Relative Humidity (%)	58.5	58.0	66.6	59.0	65.2	55.0
Total Rainfall (mm)	14.4	86.6	44.2	84.2	69.0	52.4
Soil Temperature (°C)	31.6	-	29.4	-	27.9	-
Incoming Solar Radiation (W/m^2)	318.2	-	272.4	-	266.7	-
Outgoing Solar Radiation (W/m^2)	90.3	-	55.2	-	51.0	-
Black Globe (°C)	27.5	-	26.6	-	24.5	-
2m Wind Speed (km/hr)	7.2	-	5.7	-	5.9	-
10m Wind Speed (km/hr)	11.1	-	9.6	-	9.7	-
Wind Direction (°)	229.7	-	232.5	-	252.2	-

In terms of temperature and rainfall, the conditions at Feedlot A over the period 1 January to 31 March 2002 were generally below average. In particular, well below average rainfalls were experienced in the months of January and February. Temperatures were also below the long term average values for the area. A significant difference in the recorded values of humidity and the BOM long term average values was observed. This trend was also noted in the comparison of the data collected as part of project MLA FLOT.310 where the recorded humidity levels at the feedlot sites was higher than the BOM long term averages.

Similarly, the data presented in Table 10 shows that over the study period Feedlot B experienced a very similar summer climate as Feedlot A. This would be expected due to the relatively close proximity of the two feedlot sites. Feedlot B experienced a very dry summer compared to the long term average for the region and recorded air temperatures were below the long term monthly average.

Table 10. Recorded Monthly Average Climate Data for the study period compared with Average Long Term Monthly Averages for nearby Climate Stations – Feedlot B.

	January		*February*		*March*	
	Recorded	BOM Long Term Average	Recorded	BOM Long Term Average	Recorded	BOM Long Term Average
Air Temperature (°C)	24.6	25.4	23.2	24.7	21.4	22.9
Relative Humidity (%)	60.2	58.0	70.2	59.0	64.4	55.0
Total Rainfall (mm)	4.6	86.6	26.2	84.2	80.8	52.4
Soil Temperature (°C)	27.7	-	27.7	-	25.7	-
Incoming Solar Radiation (W/m^2)	269.9	-	235.3	-	249.0	-
Outgoing Solar Radiation (W/m^2)	63.9	-	58.7	-	47.3	-
Black Globe (°C)	28.2	-	26.0	-	23.8	-
2m Wind Speed (km/hr)	10.5	-	7.7	-	7.7	-
10m Wind Speed (km/hr)	11.6	-	10.6	-	10.2	-
Wind Direction (°)	135.1	-	135.1	-	114.4	-

The data in Table 11 show that Feedlot C also experienced a dry but mild summer. The total rainfall received over the three months from January to March 2002 was only 42% of the long term average for the region. The average monthly air temperatures recorded at the site were slightly below average for the months of February and March. Again a similar trend was noted in the recorded humidity readings being slightly higher than the long term average for all three months.

Table 12 shows that over the study period Feedlot D also experienced a relatively mild summer. On average the monthly air temperatures recorded at the site were 2.6°C below the long term average. As was noted at the other three sites, recorded humidity levels were generally higher than the long term averages with the exception of the month of January. For the month of January the significantly low rainfall (3.2 mm) saw that the average monthly humidity was around 3% lower than the long term average. In February the recorded average monthly humidity level was 16.1% above the long term average which can be attributed to the monthly rainfall (114.8 mm) that was 3.7 times greater than the long term average.

Table 11. Recorded Monthly Average Climate Data for the study period compared with Average Long Term Monthly Averages for nearby Climate Stations – Feedlot C.

	January		*February*		*March*	
	Recorded	BOM Long Term Average	Recorded	BOM Long Term Average	Recorded	BOM Long Term Average
Air Temperature (°C)	25.7	24.8	23.2	24.4	21.5	22.3
Relative Humidity (%)	56.8	53.0	64.2	55.5	57.3	53.0
Total Rainfall (mm)	0	90.2	41.6	70.5	43.8	44.7
Soil Temperature (°C)	28.4	-	25.8	-	24.9	-
Incoming Solar Radiation (W/m^2)	372.2	-	270.3	-	248.9	-
Outgoing Solar Radiation (W/m^2)	93.2	-	64.5	-	56.2	-
Black Globe (°C)	29.3	-	26.1	-	24.4	-
2m Wind Speed (km/hr)	7.3	-	6.4	-	5.7	-
10m Wind Speed (km/hr)	10.0	-	8.5	-	7.8	-
Wind Direction (°)	146.9	-	174.9	-	140.2	-

Table 12. Recorded Monthly Average Climate Data for the study period compared with Average Long Term Monthly Averages for nearby Climate Stations – Feedlot D.

	January		*February*		*March*	
	Recorded	BOM Long Term Average	Recorded	BOM Long Term Average	Recorded	BOM Long Term Average
Air Temperature (°C)	22.8	24.8	20.4	24.4	20.0	22.3
Relative Humidity (%)	44.6	53.0	65.1	55.5	55.9	53.0
Total Rainfall (mm)	3.2	90.2	114.8	70.5	18.6	44.7
Soil Temperature (°C)	29.8	-	25.7	-	25.7	-
Incoming Solar Radiation (W/m^2)	290.2	-	267.2	-	254.9	-
Outgoing Solar Radiation (W/m^2)	118.0	-	63.0	-	65.6	-
Black Globe (°C)	27.0	-	23.5	-	23.3	-
2m Wind Speed (km/hr)	7.3	-	9.6	-	8.3	-
10m Wind Speed (km/hr)	9.5	-	12.6	-	11.4	-
Wind Direction (°)	170.8	-	137.4	-	133.3	-

Additional climatic data were sourced from the Bureau of Meteorology in order to compare the measurements recorded at each feedlot site with climatic data recorded in surrounding areas. The closest climate stations to Feedlot A and Feedlot B with available data for the period January to March 2002 were found to be Oakey Aero (station no. 41359) and Dalby Airport (station no. 41522). The average monthly data for these stations are presented in Table 13 and Table 14 along with the average monthly data recorded at the external station of each feedlot site.

These data show that the recorded climatic data external to both Feedlot A and Feedlot B were very similar to the BOM recorded climate of the surrounding areas for the period January to March 2002. Variation occurred in recorded monthly rainfall values. This was expected due to the spatial variability of rainfall.

Table 13. Comparison of Recorded Data at Feedlot A with BOM Stations Oakey Aero and Dalby Airport for January to March 2002.

	Air Temperature (°C)			*Relative Humidity* (%)			*Total Rainfall* (mm)		
	Recorded Averages	BOM Averages		Recorded Averages	BOM Averages		Recorded Totals	BOM Totals	
		Oakey Aero[a]	Dalby Airport[b]		Oakey Aero[a]	Dalby Airport		Oakey Aero	Dalby Airport
January	24.9	24.7	26.2	58.5	56.8	-	14.4	12.2	13.2
February	24.0	23.8	25.8	66.6	67.1	-	44.2	70.8	80.6
March	22.2	22.1	23.9	65.2	64.5	-	69.0	87.0	106
Ave./Total	*23.7*	*23.5*	*25.3*	*63.5*	*62.3*	-	*127.6*	*170.0*	*199.8*

[a] - calculated from hourly readings
[b] - calculated from daily maximum and minimums

Table 14. Comparison of Recorded Data at Feedlot B with BOM Stations Oakey Aero and Dalby Airport for January to March 2002.

	Air Temperature (°C)			*Relative Humidity* (%)			*Total Rainfall* (mm)		
	Recorded Averages	BOM Averages		Recorded Averages	BOM Averages		Recorded Totals	BOM Totals	
		Oakey Aero[a]	Dalby Airport[b]		Oakey Aero[a]	Dalby Airport		Oakey Aero	Dalby Airport
January	24.6	24.7	26.2	60.2	56.8	-	4.6	12.2	13.2
February	23.2	23.8	25.8	70.2	67.1	-	26.2	70.8	80.6
March	21.4	22.1	23.9	64.4	64.5	-	80.8	87.0	106
Ave./Total	*23.0*	*23.5*	*25.3*	*64.9*	*62.3*	-	*111.6*	*170*	*199.8*

[a] - calculated from hourly readings
[b] - calculated from daily maximum and minimums

Table 15 below presents the average monthly data recorded at Feedlot C along with the data recorded at the BOM stations Gunnedah Airport (station no. 55202) and Barraba Post Office (station no. 54003). The closest BOM stations to Feedlot D with available data were Yanco Agricultural Institute (station no. 74037) and Narrandera Golf Club (station no. 74221). Table 16 presents a summary of the average monthly data for these stations and the data recorded at Feedlot D.

Table 15. Comparison of Recorded Data at Feedlot C with BOM Barraba Post Office and Gunnedah Airport for January to March 2002.

	Air Temperature (°C)			*Relative Humidity* (%)			*Total Rainfall* (mm)		
	Recorded Averages	BOM Averages Barraba PO[a]	BOM Averages Gunnedah Airport[b]	Recorded Averages	BOM Averages Barraba PO[c]	BOM Averages Gunnedah Airport[b]	Recorded Totals	BOM Totals Barraba PO	BOM Totals Gunnedah Airport
January	25.7	23.9	25.3	56.8	39.5	52.3	0	42.6	11.4
February	23.2	23.8	24.3	64.2	56.9	69.6	41.6	49.0	77.6
March	21.5	21.4	22.2	57.3	48.3	61.4	43.8	79.6	45.4
Ave./Total	*23.4*	*23.0*	*23.9*	*59.5*	*48.0*	*60.9*	*85.4*	*171.2*	*134.4*

[a] - calculated from daily maximum and minimums
[b] - calculated on 3 hourly readings
[c] - calculated on 0900 and 1500 readings

Table 16. Comparison of Recorded Data at Feedlot D with BOM Stations Yanco Agricultural Institute and Narrandera Golf Course for January to March 2002.

	Air Temperature (°C)			*Relative Humidity* (%)			*Total Rainfall* (mm)		
	Recorded Averages	BOM Averages Yanco Ag[a]	BOM Averages Narran. Golf[b]	Recorded Averages	BOM Averages Yanco Ag[a]	BOM Averages Narran. Golf[c]	Recorded Totals	BOM Totals Yanco Ag	BOM Totals Narran. Golf
January	22.8	24.3	23.9	44.6	35.8	36.5	3.2	3.0	19.8
February	20.4	21.7	21.8	65.1	60.2	61.0	114.8	96.2	132.3
March	20.0	21.6	20.9	55.9	48.1	48.9	18.6	22.2	29.7
Ave./Total	*21.1*	*22.5*	*22.2*	*55.2*	*47.7*	*48.3*	*136.6*	*121.4*	*181.8*

[a] - calculated on 3 hourly readings
[b] - calculated from daily maximum and minimums
[c] - calculated on 0900 and 1500 readings

The data presented in the above tables shows that the recorded climate data external to the feedlot only varied slightly from that of surrounding areas as recorded by the BOM. The most significant variation was noted in the recorded humidity levels at the feedlot sites. Feedlot D exhibited the greatest variance with recorded relative humidity levels being 7 to 8 % higher than the levels measured at the surrounding BOM stations. The reasons for this can be attributed to the significantly high rainfall experienced at this site in February, and the generally 'wetter' conditions of the feedlot environment caused by dust minimisation activities such as road and pen surface watering, and irrigation of grassed areas.

Table 17 below presents a comparison of the monthly and minimum temperatures recorded at each feedlot site. This table shows the maximum and minimum temperatures recorded by the air, black globe, and soil temperature sensors. Comparison of the four feedlot sites shows that Feedlot D generally experienced a greater range of climatic variation than that of the other three feedlots (around 5 to 7°C). Whilst the temperature ranges experienced at Feedlots A, B and C were very similar, the ranges recorded at Feedlot C were slightly below (approx. 1 to 2 °C) those of Feedlots A and B. Average black globe temperatures were highest in January, whilst black globe maximum temperatures generally peaked in January and February.

Table 17. Comparison of Average Monthly Temperatures recorded at each Feedlot Site.

		Feedlot A			*Feedlot B*			*Feedlot C*			*Feedlot D*		
		Monthly Max.	*Monthly Min.*	*Monthly Average*	*Monthly Max.*	*Monthly Min.*	*Monthly Average*	*Monthly Max.*	*Monthly Min.*	*Monthly Average*	*Monthly Max.*	*Monthly Min.*	*Monthly Average*
Air Temp (°C)	*Jan*	40.3	13.4	24.9	39.3	11.9	24.6	35.2	16.8	25.7	40.5	6.4	22.8
	Feb	34.7	12.8	24.0	34.9	11.9	23.2	36.9	9.6	23.2	36.2	8.8	20.4
	Mar	36.7	11.3	22.2	36.2	10.4	21.4	38.3	11.0	21.5	37.0	6.6	20.0
Black Globe (°C)	*Jan*	49.0	11.8	27.5	48.8	10.9	28.2	48.8	15.8	29.3	56.7	5.9	27.0
	Feb	51.2	10.3	26.6	51.6	11.4	26.0	51.6	7.8	26.1	50.4	9.0	23.5
	Mar	50.7	9.0	24.5	49.7	9.2	23.8	51.9	10.0	24.4	49.1	5.5	23.3
Soil Temp (°C)	*Jan*	40.7	24.6	31.6	38.0	16.5	27.7	35.8	22.2	28.4	42.5	19.8	29.8
	Feb	41.3	21.6	29.4	36.4	21.8	27.7	36.8	19.7	25.8	42.0	14.2	25.7
	Mar	39.2	18.9	27.9	34.4	19.0	25.7	34.1	15.6	24.9	36.6	15.2	25.7

3.1.2 Microclimate Measurements

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

A summary of the climatic variables recorded at both the internal and external stations is presented in Table 18 to Table 21 for the four feedlot sites. These tables show the average monthly values for all recorded climatic parameters for both the unshaded and shaded pens and also the average data sourced from the external station at each site.

Table 18. Average Monthly Climate Data Recorded outside the Feedlot, and within both an Unshaded and Shaded Pen – Feedlot A.

	January			*February*			*March*		
	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen
Air Temperature (°C)	24.9	24.9	25.1	24.0	23.9	24.1	22.2	22.4	22.8
Relative Humidity (%)	58.5	59.0 [b]	57.7	66.6	67.7 [ab]	66.9	65.2	65.1 [b]	64.2
Soil Temperature (°C)	31.6	27.3 [ab]	30.8	29.4	26.8 [ab]	28.5	27.9	24.5 [ab]	27.9
Incoming Solar Radiation (W/m^2)	318.2	121.9 [ab]	309.3	272.4	113.1 [ab]	263.8	266.7	106.7 [ab]	263.2
Outgoing Solar Radiation (W/m^2)	90.3	18.7 [ab]	49.8 [a]	55.2	14.4 [ab]	32.7 [a]	51.0	14.5 [ab]	36.5 [a]
Black Globe (°C)	27.5	26.8 [b]	28.4 [a]	26.6	25.8 [b]	27.3 [a]	24.5	24.1 [b]	26.0 [a]
2m Wind Speed (km/hr)	7.2	7.8 [b]	8.9 [a]	5.7	6.2 [b]	7.8 [a]	5.9	6.2 [b]	7.2 [a]
10m Wind Speed (km/hr)	11.1	-	13.7 [a]	9.6	-	12.0 [a]	9.7	-	11.6 [a]
Wind Direction (°)	229.7	-	164.0	232.5	-	128.5	252.2	-	130.2

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

Table 19. Average Monthly Climate Data Recorded outside the Feedlot, and within both an Unshaded and Shaded Pen – Feedlot B.

	January			*February*			*March*		
	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen
Air Temperature (°C)	24.6	24.3	24.7	23.2	24.1	24.3	21.4	22.3	22.3
Relative Humidity (%)	60.2	-	61.0	70.2	65.5	66.7	64.4	67.5 [ab]	65.9
Soil Temperature (°C)	27.7	27.8 [b]	28.2	27.7	26.7 [ab]	27.1	25.7	24.0 [ab]	24.9
Incoming Solar Radiation (W/m^2)	269.9	204.8 [ab]	279.6	235.3	152.9 [ab]	245.9	249.0	136.2 [ab]	242.0
Outgoing Solar Radiation (W/m^2)	63.9	35.1 [ab]	45.5 [a]	58.7	22.3 [ab]	37.4 [a]	47.3	22.2 [ab]	41.8 [a]
Black Globe (°C)	28.2	26.9 [b]	27.3	26.0	25.7 [b]	26.4	23.8	24.0	24.1
2m Wind Speed (km/hr)	10.5	8.1 [b]	9.1	7.7	7.2 [b]	8.3 [a]	7.7	11.9 [b]	7.5
10m Wind Speed (km/hr)	11.6	-	12.9 [a]	10.6	-	11.7 [a]	10.2	-	11.2 [a]
Wind Direction (°)	135.1	-	110.3	135.1	-	56.2	114.4	-	75.8

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

Table 20. Average Monthly Climate Data Recorded outside the Feedlot, and within both an Unshaded and Shaded Pen – Feedlot C.

	January		*February*		*March*	
	External	Unshaded Pen	External	Unshaded Pen	External	Unshaded Pen
Air Temperature (°C)	25.7	24.6 [a]	23.2	22.9 [a]	21.5	20.9 [a]
Relative Humidity (%)	56.8	57.6 [a]	64.2	64.7	57.3	59.0 [a]
Soil Temperature (°C)	28.4	27.2	25.8	26.2	24.9	24.1
Incoming Solar Radiation (W/m^2)	372.2	373.1	270.3	275.0	248.9	249.7
Outgoing Solar Radiation (W/m^2)	93.2	60.9 [a]	64.5	45.9 [a]	56.2	43.0 [a]
Black Globe (°C)	29.3	28.0	26.1	25.9	24.4	23.8
2m Wind Speed (km/hr)	7.3	11.6 [a]	6.4	8.9 [a]	5.7	8.2 [a]
10m Wind Speed (km/hr)	10.0	14.7 [a]	8.5	11.3 [a]	7.8	10.5 [a]
Wind Direction (°)	146.9	130.6	174.9	175.6	140.2	134.5

[a] – Significant difference between feedlot and external.

Table 21. Average Monthly Climate Data Recorded outside the Feedlot, and within both an Unshaded and Shaded Pen – Feedlot D.

	January			*February*			*March*		
	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen
Air Temperature (°C)	22.8	23.7 [a]	23.7 [a]	20.4	21.4 [a]	21.5	20.0	21.1 [a]	21.1 [a]
Relative Humidity (%)	44.6	42.5	41.5	65.1	63.3	62.2	55.9	52.8	52.8
Soil Temperature (°C)	29.8	25.2 [ab]	26.9	25.7	24.6 [ab]	26.2	25.7	23.5 [ab]	25.4
Incoming Solar Radiation (W/m^2)	290.2	107.8 [ab]	343.0	267.2	80.4 [ab]	280.2	254.9	59.2 [ab]	264.8
Outgoing Solar Radiation (W/m^2)	118.0	36.3 [ab]	76.1 [a]	63.0	21.6 [ab]	49.6 [a]	65.6	19.7 [ab]	53.8 [a]
Black Globe (°C)	27.0	25.2 [ab]	26.6	23.5	22.5 [ab]	24.3	23.3	22.2 [ab]	23.9
2m Wind Speed (km/hr)	7.3	9.3 [a]	9.1 [a]	9.6	8.0 [a]	8.2 [a]	8.3	7.0 [a]	7.0 [a]
10m Wind Speed (km/hr)	9.5	-	13.7	12.6	-	12.4	11.4	-	10.8
Wind Direction (°)	170.8	-	-	137.4	-	-	133.3	-	-

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

From the data in Table 18 to Table 21 it can be seen that some differences occurred in the microclimate between the external environ and the unshaded pens. In particular, significant variations are noted between the average monthly values of soil temperatures and outgoing radiation values. These trends were also observed in the data recorded as part of MLA project FLOT.310 and the reasons for the trends are presented in the final report for FLOT.310 (refer Petrov *et. al.*, 2001).

The data presented in Table 18 to Table 21 provides an overview of the general microclimatic differences between the external and internal feedlot environments. However, the data is based on average monthly data compiled using data from the automatic weather stations that were logging as often as every 10 minutes for most parameters. In order to better define the microclimatic variations between the external and internal feedlot environment and also between the microclimate of an shaded and unshaded pen, a more detailed analysis of the climatic data was undertaken than that for project FLOT.310.

This data analysis involved compiling the 10 minute readings into average hourly data. This hourly data was then examined on a daily and monthly basis in order to define both the diurnal and nocturnal variations and also to determine any differences in these variation across the months. The results of this detailed analysis are presented in summary form and discussed in section 4.1.

3.2 Work Area 2 - Ammonia Measurements from Feedlot Pen Surfaces

The period over which the ammonia measurements were undertaken can be described as extremely dry. The data were collected over the period 22 to 31 January 2002. The rainfall recorded at Feedlot A for the month of January totalled 14.4 mm. Of this, 8.6 mm was received on the 1 January, 3.8 mm fell on the 6/7 January, and the remaining 2 mm was received on the 17 January. February also experienced below average rainfall and as such it was not possible to undertake ammonia measurements during wet conditions. The climatic conditions experienced during the recording period are summarised in Table 22.

Table 22. Climatic data recorded during ammonia measurements at Feedlot A.

Date	Air Temperature (^oC)			Black Globe (^oC)			2m Wind Speed (km/h)	Humidity (%)
	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Ave.
22/01/02	24.7	33.2	16.5	28.8	47.7	14.5	5.2	55.5
23/01/02	25.0	31.8	19.5	28.2	45.8	18.1	5.8	57.3
24/01/02	23.6	31.0	16.0	26.9	43.8	14.1	6.6	61.3
25/01/02	23.4	30.4	18.5	25.4	42.3	16.3	7.4	62.2
26/01/02	23.8	31.7	16.1	26.8	42.9	14.3	7.1	58.1
27/01/02	24.5	32.4	15.5	27.7	44.2	12.9	6.3	55.4
28/01/02	25.0	33.9	14.8	28.1	45.9	12.4	5.9	53.6
29/01/02	25.7	34.4	16.8	29.0	47.7	14.7	6.2	58.4
30/01/02	25.7	35.1	16.0	28.8	46.4	14.0	7.0	58.3
31/01/02	23.1	-	-	21.7	-	-	4.3	69.0

These data show that the recording period was hot, with maximum temperatures in the range of 30 to 35°C and humidity levels in the mid range (53 to 69%). The wind data shows that recorded wind speeds were generally low.

Comparisons of ammonia levels recorded at a height of 1 metre from the unshaded pen on the 24 January and the shaded pen on 26 January show similar concentrations were recorded. The data indicate that whilst the readings measured by the two QRAE monitors did follow similar trends, actual ammonia levels recorded at the same height were different. The reason for this can be attributed to instrument calibration errors. The VRAE monitor recorded readings in the range of 0 to 140 ppm. These levels were found to be erroneous and due to a calibration error. The fourth ammonia meter that was used for data checks provided readings similar to those of the two QRAE monitors. Spot measurements undertaken with this QUEST meter showed peak readings of 17 ppm in the unshaded pen (24 January) and 21 ppm in the shaded pen (26 January).

Further data analyses were undertaken in order to quantify the noted calibration errors to enable the data to be modified accordingly. The ammonia data collected from the four measurement periods when the ammonia meters were set at identical heights were examined to determine the variance between meters. Statistical analyses of this data showed that on average the VRAE meter was providing readings that were 9.87 times higher than those of the meter referred to as QRAE1. Similarly, the ammonia levels recorded by the QRAE2 meter were 1.80 times greater than the reading from QRAE1.

It was decided to scale the data from the VRAE and QRAE2 meters to bring them to a similar magnitude to the readings recorded by the QRAE1 meter. The reason for this was that the ammonia levels recorded by the QUEST meter were most similar to those recorded by the QRAE1. It is noted that factory calibration was unable to determine which meter was providing the most accurate results, and as such this data adjustment assumes that the levels recorded by QRAE1 were correct. This meter generally recorded the lowest levels, hence the adjusted data is most likely conservative. However the data manipulation has allowed comparison of the ammonia data recorded at different heights (ie. the ammonia profile above the feedlot surface).

The adjusted ammonia data collected from the unshaded pen and the shaded pen has provided the results presented in Figure 2 and Figure 3 below.

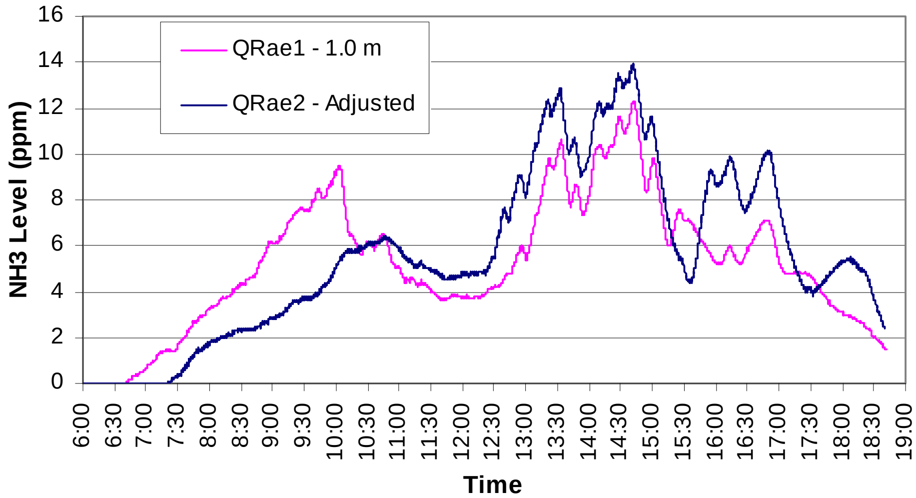

Figure 2. Adjusted data collected from the unshaded pen at Feedlot A on 24 January 2002.

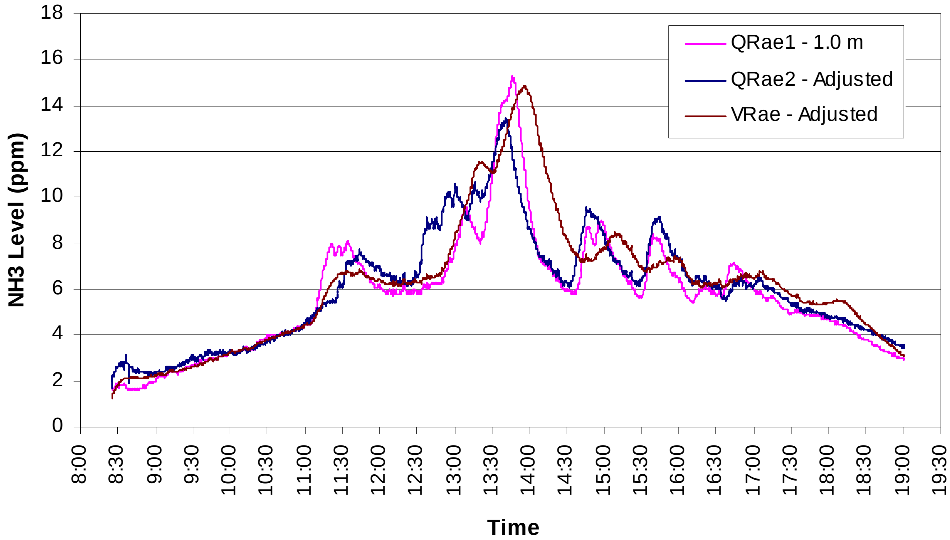

Figure 3. Adjusted data collected from the shaded pen at Feedlot A on 26 January 2002.

Figure 4 below presents the ammonia levels recorded by the two QRAE monitors at a height of 0.3 metres above the surface of the unshaded pen. These data show that significantly higher ammonia levels were recorded when compared to those measured at 1 metre (see Figure 2). These data are discussed in section 4.2.

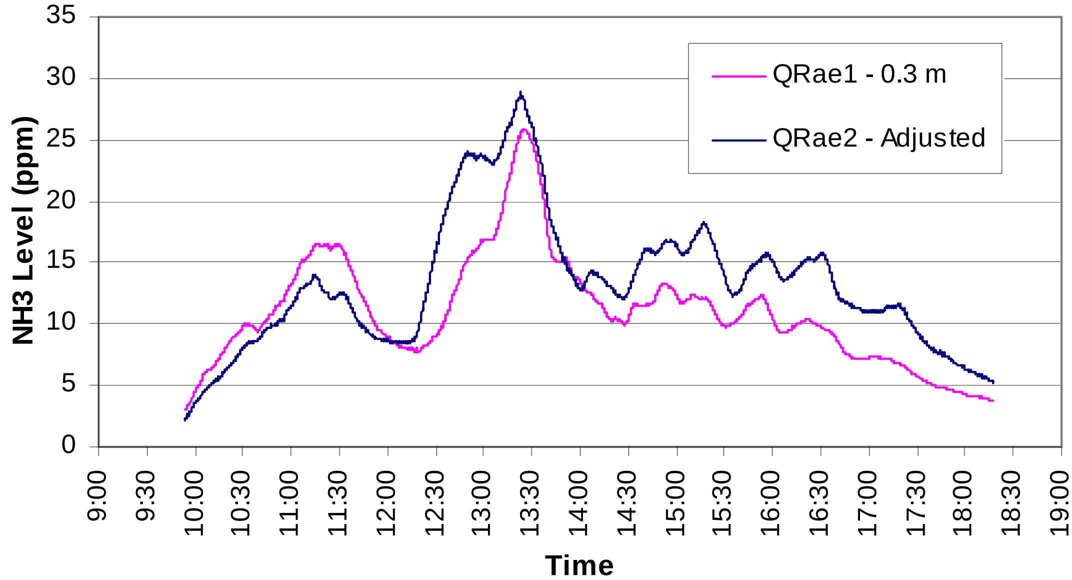

Figure 4. Ammonia levels recorded in the unshaded pen at Feedlot A on 22 January 2002.

The data collected on days when the three handheld meters were located at differing heights has highlighted the profile of ammonia levels that increases with proximity to the pen surface. The data presented in Figure 5 and Figure 6 below shows the ammonia levels recorded at heights of 0.25, 1.0 and 1.5 metres in the unshaded and shaded pens.

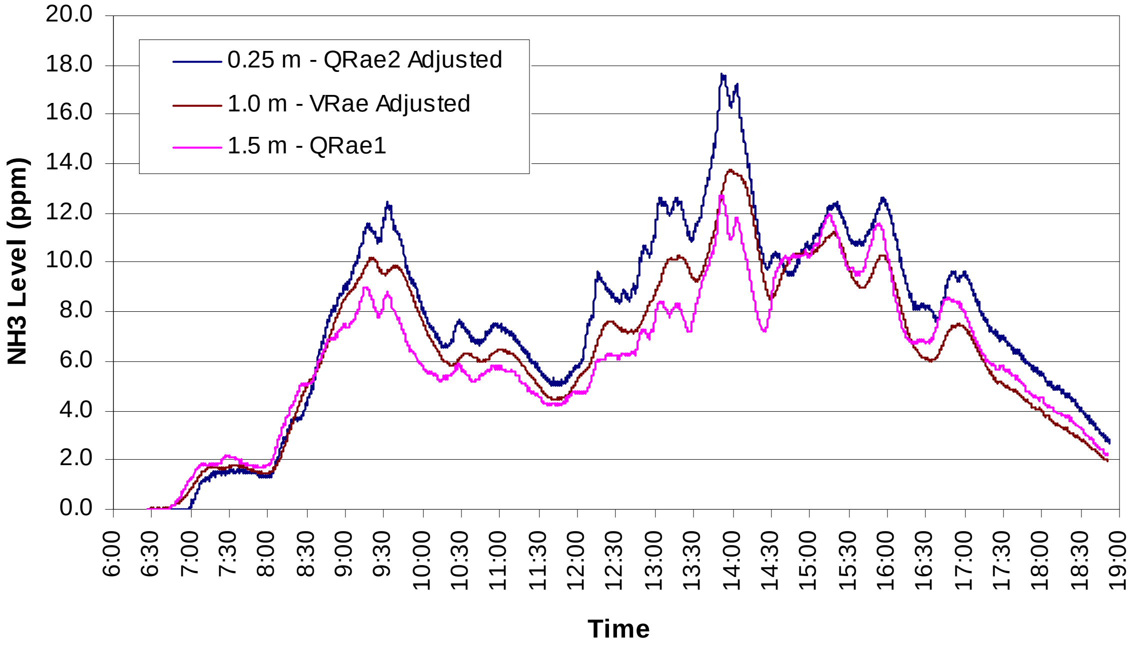

Figure 5. Ammonia levels recorded at varying heights in the unshaded pen on 23 January 2002.

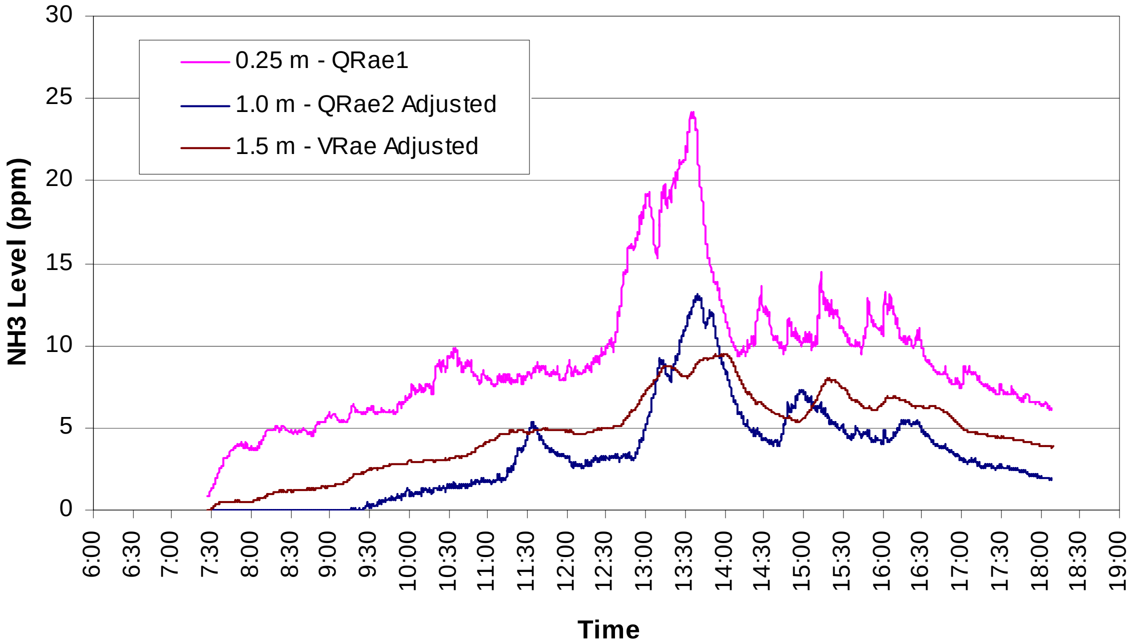

Figure 6. Ammonia levels recorded at varying heights in the shaded pen on 29 January 2002.

The data presented in Figure 5 and Figure 6 shows that a distinct ammonia profile exists above the pen surface with ammonia concentrations decreasing with height. The data also show that the moister pen surface conditions that were noted under the shade caused higher ammonia levels at 0.25 metres above the pen surface compared to those recorded at the same height in the unshaded pen.

3.3 Work Area 3 - The Thermodynamic Characteristics of Feedlot Troughs

3.3.1 Climatic Conditions During Trough Water Temperature Study

The trough water temperature study was undertaken over the period 15 to 19 March 2002. During this time the climate experienced on the Darling Downs of Southern Queensland can best be described as unseasonably hot. Trough temperature measurements were made on 15 March at Feedlot B, 18 March at Feedlot A, and 19 March at Feedlot E. The temperatures recorded at the feedlot sites on these days are shown graphically in Figure 7. These data show that over the 12 hour period that trough measurements were undertaken, temperatures at the three sites were in the range of 13ºC to 37ºC. The hottest day was experienced at Feedlot A where temperatures were generally 7ºC and 2.5ºC higher than those recorded at Feedlots B and E respectively for the 12 hour study period (see Figure 7).

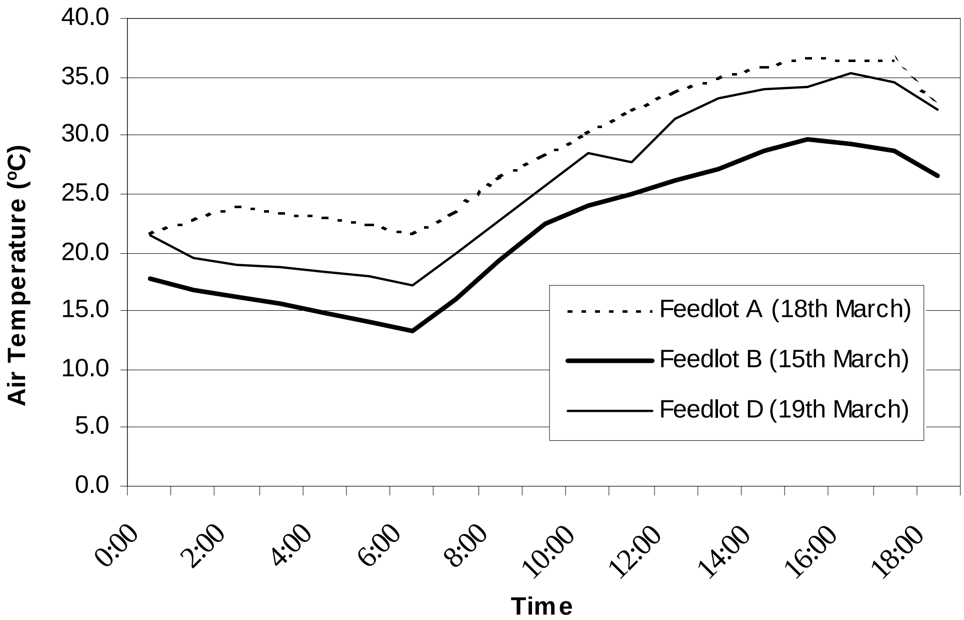

Figure 7. Temperatures recorded at each feedlot site during the trough studies.

Using the average and maximum daily temperature values presented in Table 23 an estimation of cattle daily water intakes can be made. These water consumption values can be used to calculate the number of times the water in a trough is replaced ('turnovers') each day at each feedlot site. These data are presented in Table 23. The significance of trough turnovers is discussed in section 4.3.4.

Table 23. Comparison of various characteristics of the studied feedlots.

Parameter		Feedlot A	Feedlot B	Feedlot E
Air Temperature (ºC)	Average (6 am to 6 pm)	31.5	24.3	29.8
	Minimum (12 am to 6 pm)	21.7	13.3	17.3
	Maximum (12 am to 6 pm)	36.6	29.6	35.3
Daily Water Intake (L/day)	Calculated based on average daily temperature †	75	46	64
	Calculated based on maximum daily temperature ‡	44	39	43
	Number of cattle in pen	117	146	350
	Total trough volume in pen (Litres)	210	405	690
	Total water consumption† (Litres/day)	8775	6716	22400
	Number of trough turnovers over day	42	17	32

† - Based on formula from Winchester and Morris (1956) and assuming Dry Matter Intake = 10 kg/day.
‡ - Based on formula from Hicks *et al.* (1988) and assuming Dry Matter Intake = 10 kg/day and making no adjustment for dietary salt intake.

3.3.2 Summary of Trough Water Temperature Data

The data presented in Figure 8 to Figure 10 below show the variability of water temperatures throughout the day measured in both the trough of a stocked and an unstocked pen. It should be noted that the trough in the unstocked pen at Feedlot B was empty at the start of the recordings and was filled prior to the commencement of measurements. The data in Figure 9 show that the water that was used to fill the trough was relatively warm (28ºC) compared to the resident water in the trough in the stocked pen (20ºC).

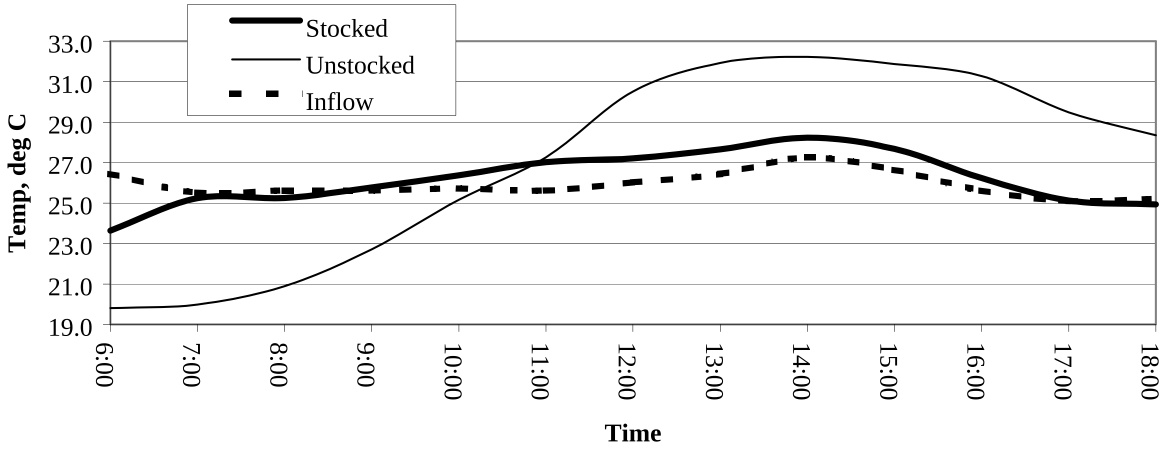

Figure 8. The comparison of temperatures recorded in the two troughs at Feedlot A.

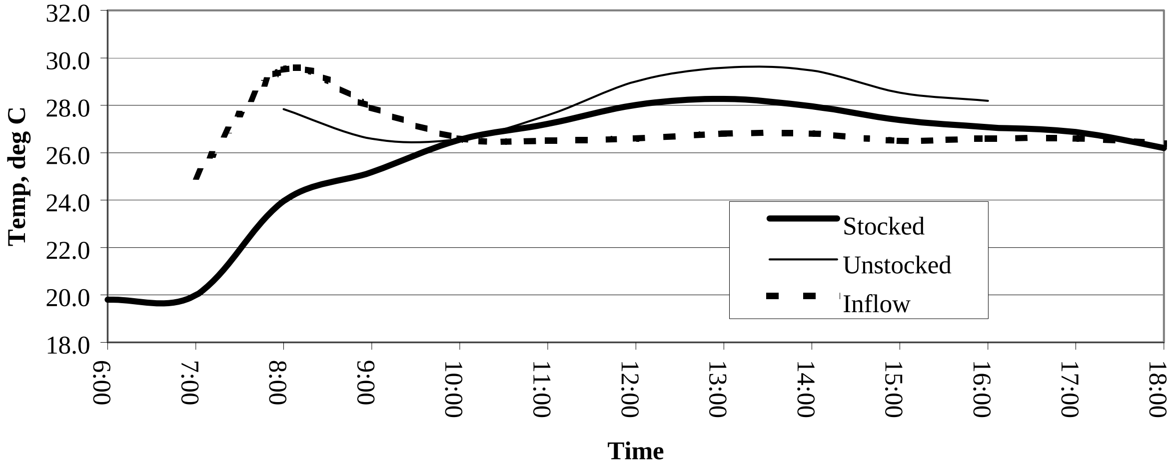

Figure 9. The comparison of temperatures recorded in the two troughs at Feedlot B.

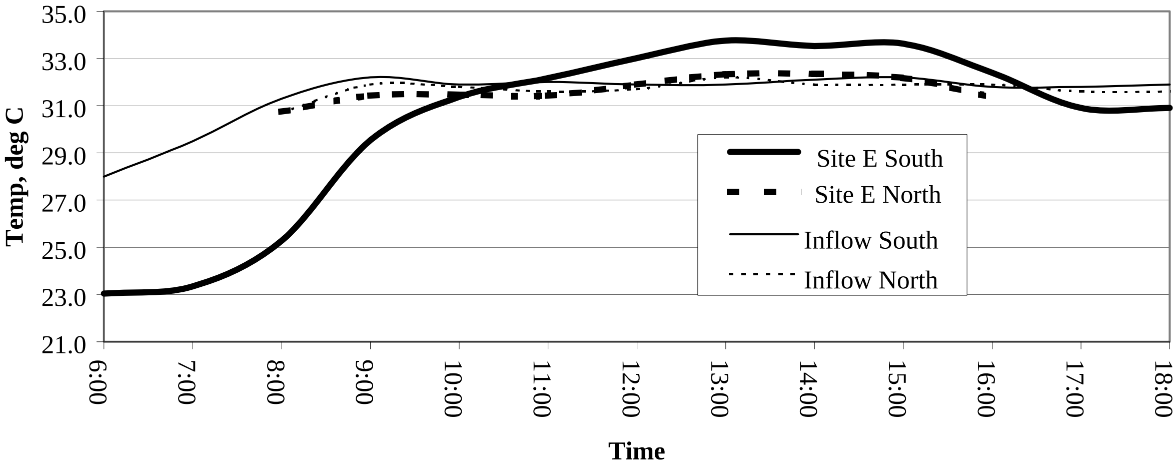

Figure 10. The comparison of temperatures recorded in the two troughs at Feedlot E.

Figure 11 below shows a comparison of the trough water inflow temperatures recorded throughout the day at the three feedlot sites. The effects of trough water temperatures are discussed in section 4.3.5 of this report.

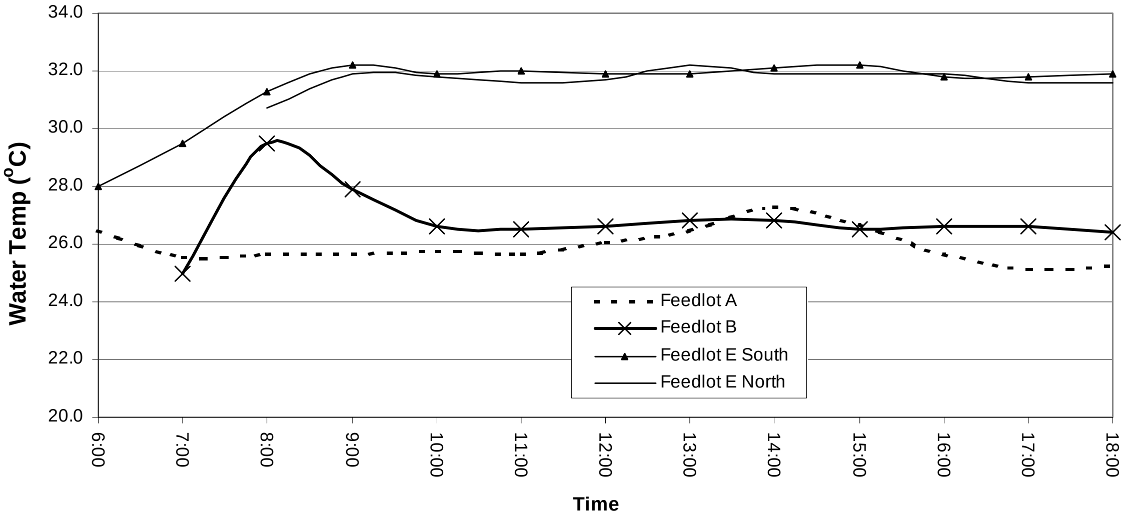

Figure 11. Comparison of trough inflow temperatures at the three feedlot sites.

3.3.3 Case Studies

The range of trough types investigated in the study allows some comparison of the effects caused by varying trough size and construction materials. Figure 12 below presents the average hourly difference in temperature between the water stored in the trough and the inflow water recorded at the three feedlot sites.

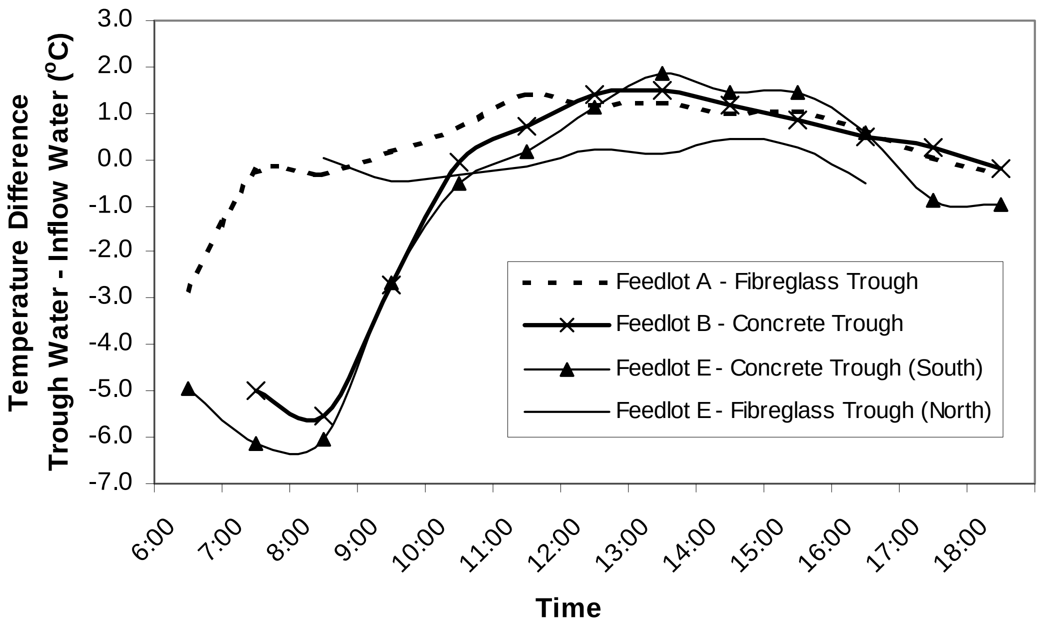

Figure 12. Average hourly temperature differences between trough water and inflow water recorded at the three feedlot sites.

The data presented in Table 8 shows the difference between the trough water temperature and inflow water temperature recorded in the four troughs examined at the three feedlot sites. Presenting the data in this manner allows some comparisons to be made on the performance of each trough, as the data is crudely normalised to negate the effect of the varying inflow temperatures that were observed between sites. Negative values in this figure show that the trough water was cooler than the inflow water, whilst positive values indicate the trough water was of a higher temperature than the inflow water at that time.

Several key points are highlighted by these data. The two larger concrete troughs (Feedlots B and E) appear to provide a cooling effect of the water during the morning hours (6 to 10 am). It is presumed that cool overnight temperatures and the habit of cattle to not drink late at night allowed the trough and the resident water to cool. The cooled and substantial thermal mass of the concrete trough provides further cooling of water as it enters the trough until mid-morning. This cooling effect is also noted (to a lesser extent) in the fibreglass trough at Feedlot A between the hours of 6 to 8 am. The data also show that the water temperature in the smaller fibreglass trough at Feedlot E does not vary significantly from the inflow temperature throughout the day. Comparison of the two troughs at Feedlot E shows during the later periods of the day (10 am to 4 pm), the water in the fibreglass trough remained slightly cooler compared to the concrete trough. Further discussion on these observed trends are presented in section 4.3.4.

4. DISCUSSION

4.1 Work Area 1 - The Microclimate of Four Feedlots in Eastern Australia

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

4.1.1 Air Temperature

As shown by the average monthly data in Table 18 to Table 21 of section 3.1.2, the air temperatures recorded within the unshaded pens were generally slightly higher than those of the external feedlot environment (with the exception of Feedlot C). It was noted in the final report for project FLOT.310 (Petrov *et. al.*, 2001) that there was a significant difference between the minimum overnight temperatures recorded within the feedlot pens compared to the values obtained from the external feedlot stations. The study found that over the three month study period in 2001 the difference in minimum temperatures between the external and internal feedlot environment averaged around 1.2°C and 0.9°C for the two feedlot sites.

By comparing the data recorded from January to March 2002 on an average hourly basis this noted nocturnal variation can be seen. The data presented in Figure 13 shows the average hourly difference in air temperature between the station located in the unshaded pen and that of the external station. The most significant difference is noted at Feedlot D.

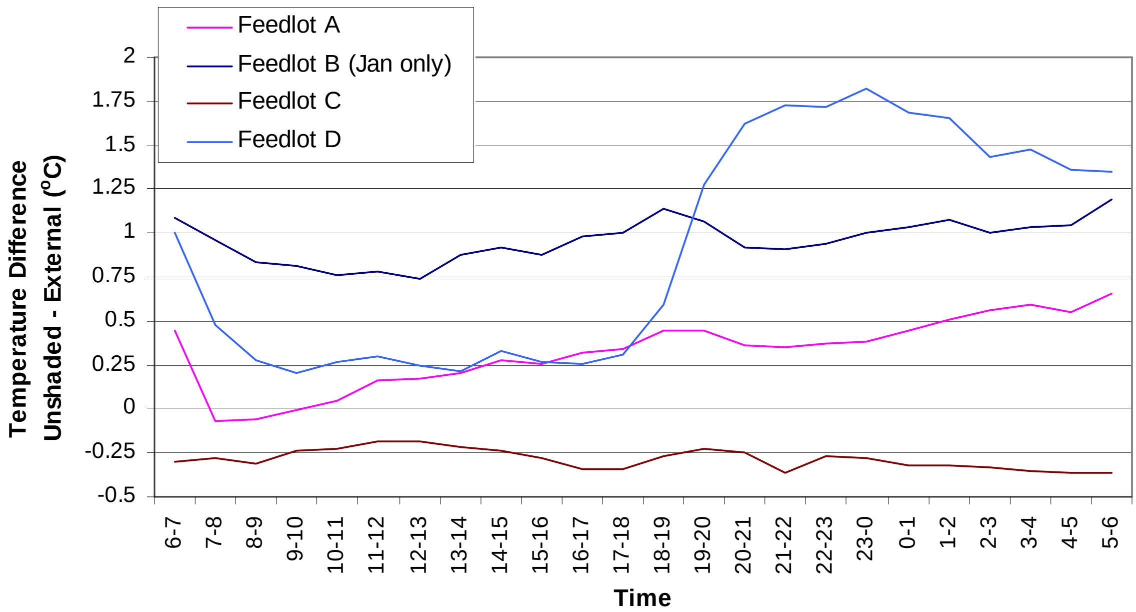

Figure 13. Average hourly differences in air temperature between the unshaded and external stations at the four feedlot sites.

The data from Feedlot D shows that whilst the difference in air temperatures recorded between 7am and 7pm is minor (around 0.25°C), between 7pm and 6am this difference significantly increases with the climate in the unshaded pen typically being 1 to 2 °C warmer than that of the external feedlot environment. A similar trend is also noted for the data collected at Feedlot A and Feedlot B, although the increase is more gradual throughout the 24 hour period. The data from Feedlot C does not follow this trend. As can be seen in Figure 13, calculating the average hourly differences between the unshaded and external station at this feedlot site shows that the unshaded station was cooler by around 0.25°C. The geographic position of this feedlot on the side and top of the ridge appears to result in an upslope movement of air that causes thorough mixing of the air over the site. This results in the minor differences noted between the feedlot environs.

FLOT.310 (Petrov *et. al.* 2001) found that the higher overnight temperatures recorded within the feedlot pens could be attributed to the nature of the pen surfaces. The pen surface is primarily composed of manure which is generally dark and moist and has a greater ability to store energy/heat compared to soil. As a consequence pen surfaces heat up more than the soil. During the night the pen surface re-radiates heat, resulting in reheated air over the surface and thus maintenance of generally higher air temperatures.

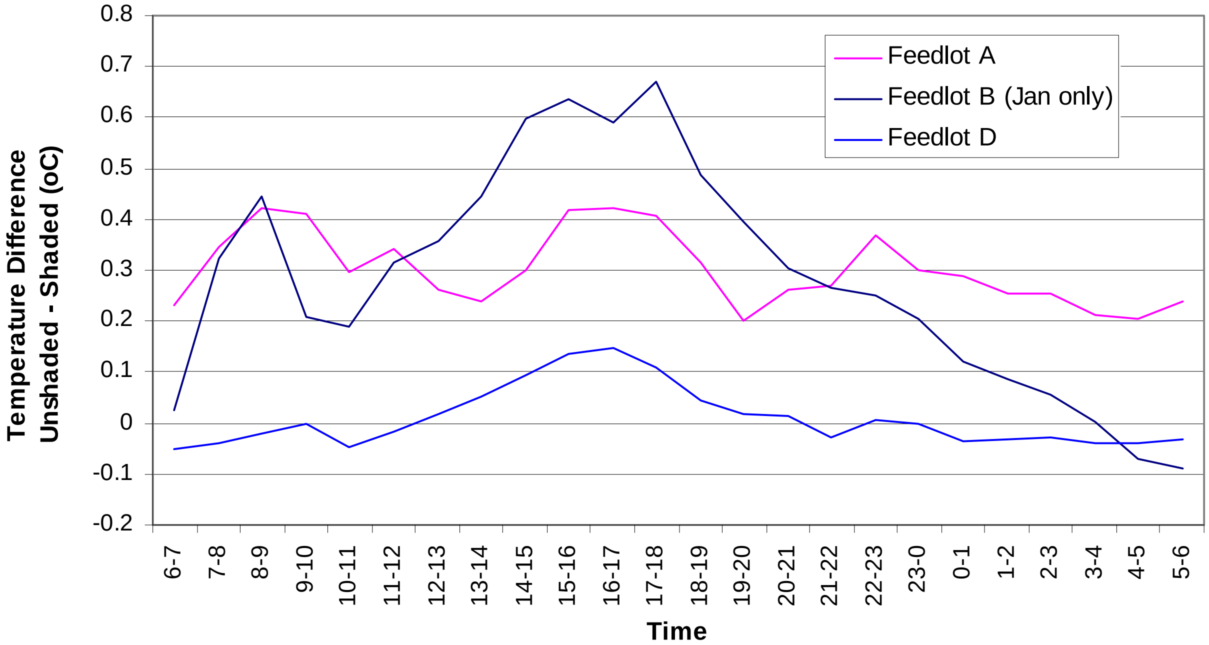

Figure 14. Average hourly differences in air temperature between the unshaded and shaded stations at three feedlot sites.

Figure 14 above shows the average hourly difference in air temperature between the station located in the unshaded pen and that of the station in the shaded pen. Compared to the differences noted between the external and internal feedlot environment, the differences between the unshaded and shaded pen are more subtle. A general trend is noted with the unshaded pen being hotter than the shaded pen from around midday through to the afternoon. The extent of this difference is in the order of 0.2 to 0.7°C. These minor differences can be attributed to the cooling effects of the shade and moister pen surfaces.

4.1.2 Humidity

Analyses of the data collected as part of FLOT.310 showed a significant difference in humidity levels in the shaded pens at the two feedlot sites compared to the levels recorded in the unshaded pen and the external stations. The average monthly data showed that the humidity levels under the shade in the shaded pens were typically 8 to 9% higher at Feedlot A and 4 to 6% higher at Feedlot D. This trend was again noted in the analysis of the data collected over the 2002 summer study period.

Figure 15 presents data on the average hourly difference in humidity between the unshaded pen and that of the station in the shaded pen. This was negative at Feedlot A and also at Feedlot D with the exception of the hours from 2 am to 9 am where the difference was close to zero, which is to be expected at cooler temperatures that approach dew points. The negative difference shows that the humidity levels within the shaded pen ranged from around 0.5 to 2.5 % higher than those recorded in the unshaded pen. Data for Feedlot B was too patchy for detailed analysis and as such a representative average could not be derived. A weather station was not included in a shaded pen at Feedlot C.

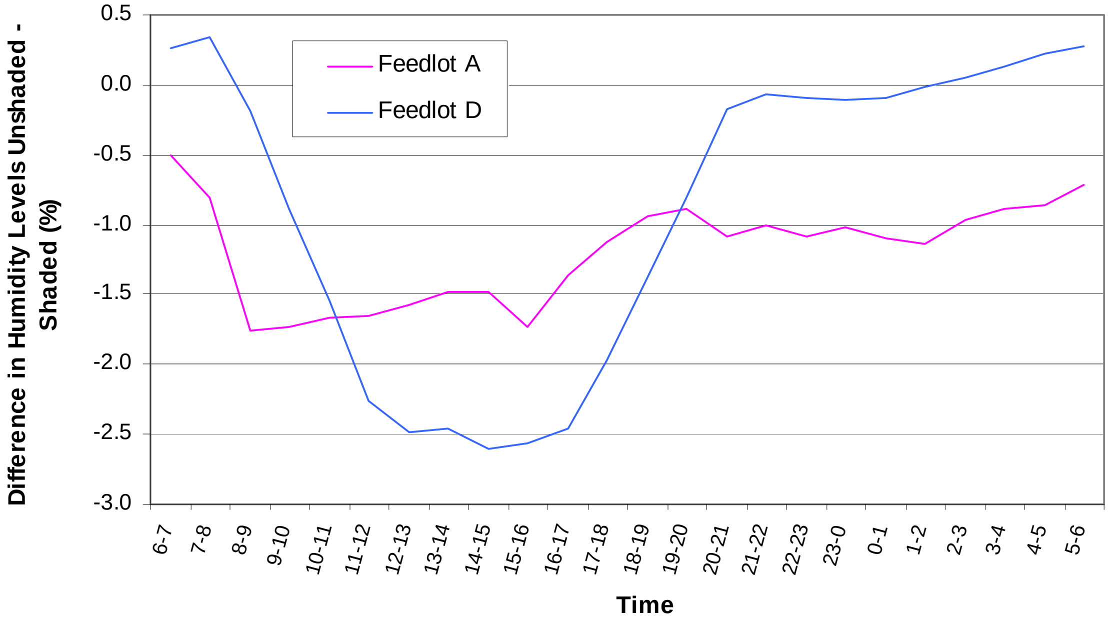

Figure 15. Average hourly differences in humidity levels between the unshaded and shaded stations at two feedlot sites.

Whilst the data collected over the 2001 summer showed average monthly humidity levels to be up to 9% higher under the shade, the data collected during the 2002 summer showed the difference to be in the order of 2 to 3% on average. This difference in magnitude can be attributed to the drier summer experienced in 2002 compared to that of 2001. The effect of rainfall on humidity levels is demonstrated in Figure 16 below. The monthly data from Feedlot D shows that the wettest month, February (114.8 mm), provided the greatest difference in humidity levels between the unshaded pen, shaded pen and the external environment.

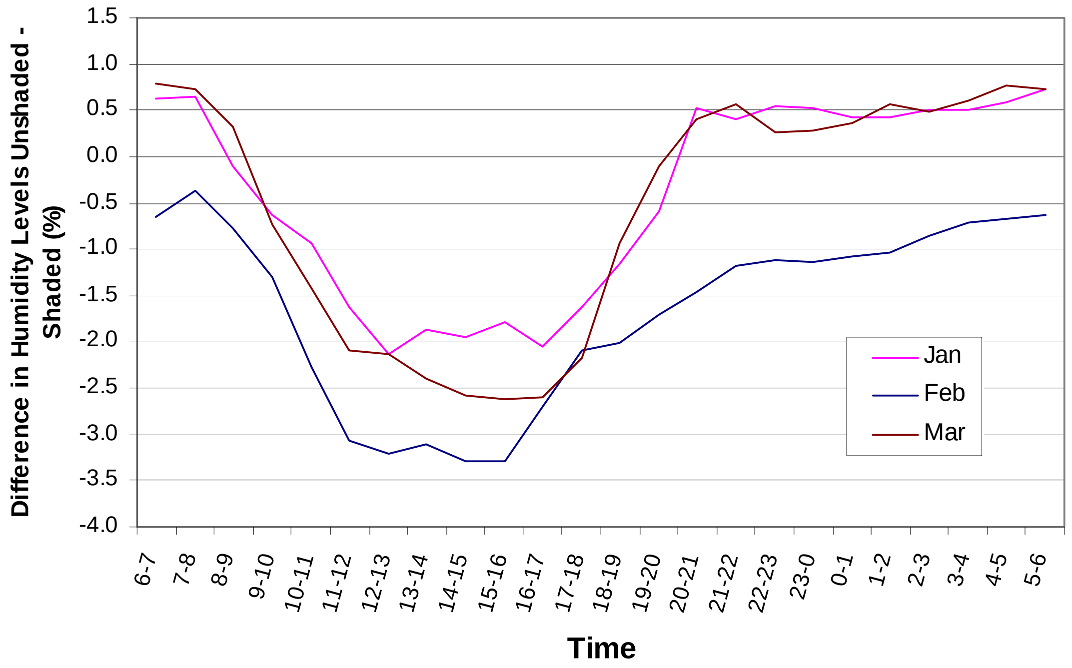

Figure 16. Average hourly differences in humidity levels between the unshaded and shaded station at Feedlot D for the months of January, February and March 2002.

4.1.3 Soil Temperature

As was the case over the 2001 summer period, the data from 2002 show that soil temperatures recorded in the shaded pens were lower than those of the unshaded pen and outside areas. This can be attributed to the fact that the shade structures provide a reduction in the amount of direct sunlight (ie. solar radiation and heat energy) that reaches the pen surface.

This is demonstrated by the data in Figure 17 below that shows the average hourly difference in soil temperatures between the station located in the unshaded pen and that of the station in the shaded pen. These data show that during the daylight hours the soil temperatures in the unshaded pen increase to levels that on average are around 6°C higher than those recorded in the shaded pen. During the night this difference is reduced, and in the case of Feedlot B and Feedlot D, the unshaded pen temperatures actually fall 1 to 4°C below those of the shaded pen. This can be attributed to the larger build up of manure that occurs under the shaded areas of feedlot pens. This manure accumulation would assist in maintaining some heat around the soil temperature sensors compared to the dry and thinner layer of manure over the sensors within the unshaded pen.

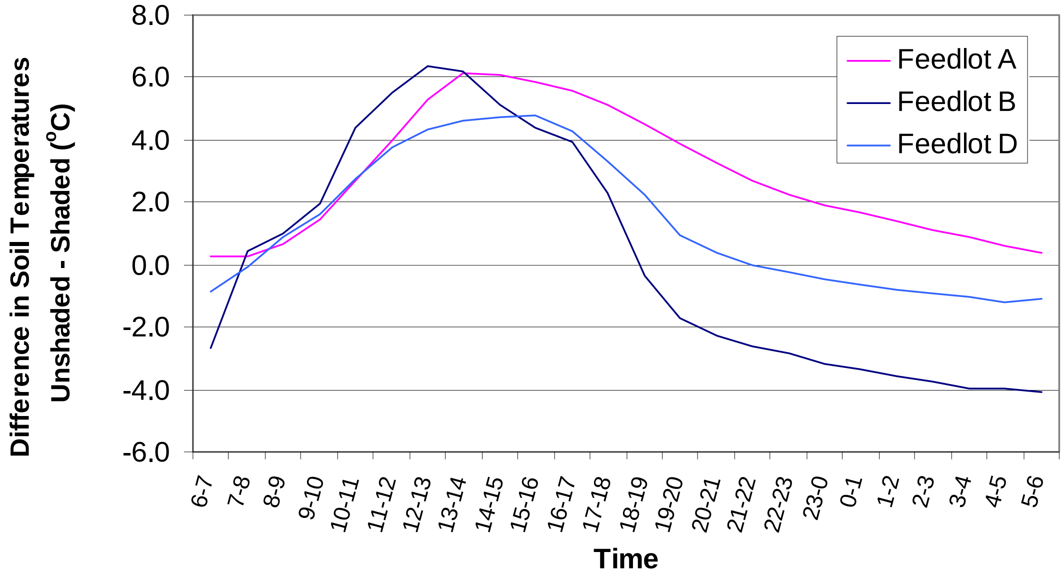

Figure 17. Average hourly differences in soil temperature between the unshaded and shaded stations at three feedlot sites.

4.1.4 Solar Radiation (Incoming and Outgoing)

Gross incoming solar radiation differed across the sites. This occurred as a function of the amounts of cloud cover at each site. The presence of shade structures significantly reduces the amount of incoming solar radiation incident on the pen surface beneath the shade. This in turn reduces the amount of solar radiation that is reflected from the pen surface (referred to as outgoing radiation). Another significant factor that effects the level of outgoing radiation is the condition and type of ground surface.

Using the average monthly data presented in Table 18, Table 19, and Table 21 of section 3.1.2 the approximate effectiveness of each shade structure can be determined. This is calculated by comparing the incoming solar radiation levels of the external and unshaded station to the incoming solar radiation of the shaded station. The difference in recorded values can be assumed to be the amount of solar radiation that is adsorbed or reflected by the shade structures. Expressing these values as a solar radiation reduction percentage enables a simple comparison of the effects of the different shade structures. These data are presented in Table 24 below. It should be noted that these calculated values are only crude indications of shade structure effectiveness. They have only been used to provide a general comparison between the effects of the different shade structures at each feedlot site. It is noted that these data show that the structures at Feedlot B provide the lowest shade reduction percentages. This can be attributed to the fact that this shade structure is not fully covered, with large spacings present between the galvanised iron sheeting (as shown in Plate 1, section 2.1.1).

Table 24. Comparison of Monthly Average Incoming Solar Radiation Levels (in W/m^2) and Approximate Shade Reduction Percentages.

Incoming Solar Radiation (W/m^2)	*Feedlot A - Unshaded Pen*			*Feedlot B - Unshaded Pen*			*Feedlot D - Unshaded Pen*		
	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
	309.3	263.8	263.2	279.6	245.9	242.0	343.0	280.2	264.8
Shaded Pen	121.9	113.1	106.7	204.8	152.9	136.2	107.8	80.4	59.2
% Reduction	61%	57%	59%	27%	38%	44%	69%	71%	77%

The outgoing radiation measurements recorded by the weather stations can be used to determine the 'albedo' of the feedlot pen and external ground surfaces. Albedo is a number between 0 to 1 that indicates the proportion of energy reflected off a surface. For example an albedo value of 0.25 indicates that 25% of incoming solar radiation is reflected and 75% would be absorbed by the surface. Using the average monthly solar radiation values the albedo of the feedlot pen surfaces and the external feedlot surface can be calculated. These data are presented in Table 25 to Table 28 below.

Table 25. Average Monthly Solar Radiation Data and Calculated Albedo Values – Feedlot A.

	January			*February*			*March*		
	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen
Incoming Solar Radiation (W/m^2)	318.2	121.9	309.3	272.4	113.1	263.8	266.7	106.7	263.2
Outgoing Solar Radiation (W/m^2)	90.3	18.7	49.8	55.2	14.4	32.7	51.0	14.5	36.5
Albedo	0.28	0.15	0.16	0.20	0.13	0.12	0.19	0.14	0.14

Table 26. Average Monthly Solar Radiation Data and Calculated Albedo Values – Feedlot B.

	January			*February*			*March*		
	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen
Incoming Solar Radiation (W/m^2)	269.9	204.8	279.6	235.3	152.9	245.9	249.0	136.2	242.0
Outgoing Solar Radiation (W/m^2)	63.9	35.1	45.5	58.7	22.3	37.4	47.3	22.2	41.8
Albedo	0.24	0.17	0.16	0.25	0.15	0.15	0.19	0.16	0.17

Table 27. Average Monthly Solar Radiation Data and Calculated Albedo Values – Feedlot C.

	January		*February*		*March*	
	External	Unshaded Pen	External	Unshaded Pen	External	Unshaded Pen
Incoming Solar Radiation (W/m^2)	372.2	373.1	270.3	275.0	248.9	249.7
Outgoing Solar Radiation (W/m^2)	93.2	60.9	64.5	45.9	56.2	43.0
Albedo	0.25	0.16	0.24	0.17	0.23	0.17

Table 28. Average Monthly Solar Radiation Data and Calculated Albedo Values – Feedlot D.

	January			*February*			*March*		
	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen	External	Shaded Pen	Unshaded Pen
Incoming Solar Radiation (W/m^2)	290.2	107.8	343.0	267.2	80.4	280.2	254.9	59.2	264.8
Outgoing Solar Radiation (W/m^2)	118.0	36.3	76.1	63.0	21.6	49.6	65.6	19.7	53.8
Albedo	0.41	0.34	0.22	0.24	0.27	0.18	0.26	0.33	0.20

The data presented are consistent with those calculated from the FLOT.310 data (see Petrov *et. al*. 2001) and those detailed by Lott (1998) for albedos of wet and dry manure surfaces. It should be noted that the albedo values for the shaded pens are based on a proportion of the incoming radiation that has already passed through the shade, which is generally only 20 to 30% of the global incoming values used to calculate the albedo of the unshaded pens. This difference may incur some deviation for the true albedo values of the open surface. Other factors that influence albedo values include the potential re-radiation of energy from beneath the shade structures, the temperature of the pen surface, and the stocking density of cattle under the shade. With the exception of the albedo recorded in January at Feedlot D (0.41), the albedo of the external environment is relatively similar ranging from 0.19 to 0.28.

4.1.5 Black Globe Temperature

Black globe temperature is an integrated measure of radiant heating. It is best described as a combined measure of temperature and the heat effects of solar radiation (or radiant heat load). Black globe temperature readings are strongly influenced by solar radiation and as expected the measurements undertaken during the study show that the black globe temperatures were lower in the shaded pens compared to the unshaded pens and external feedlot environment.

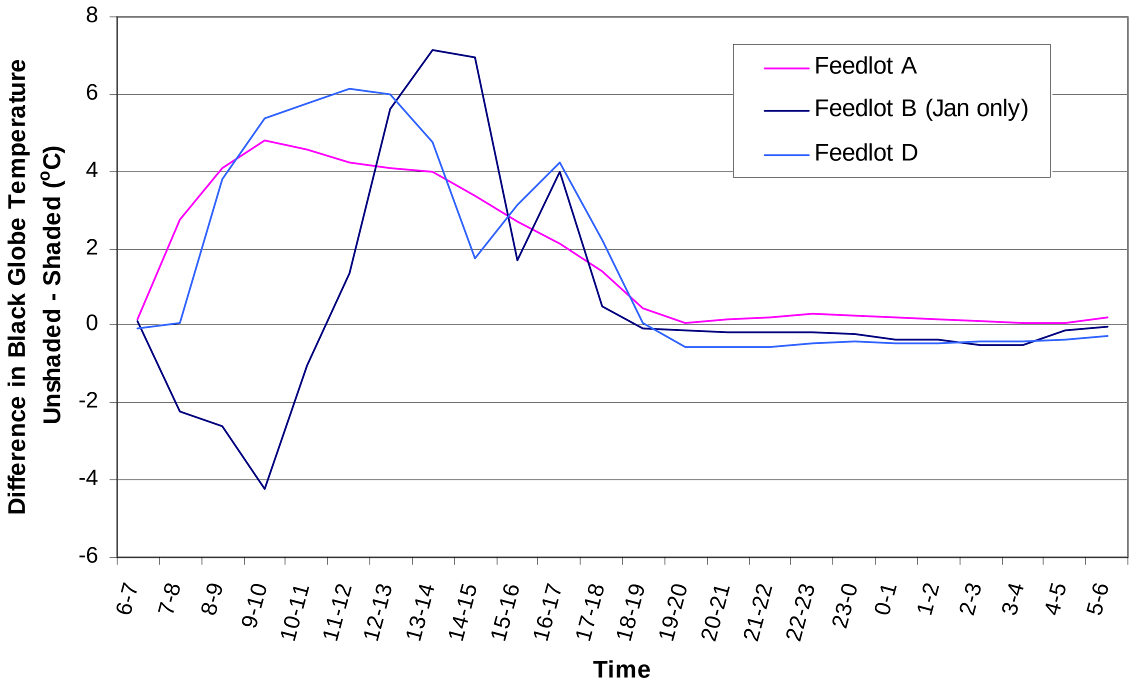

Figure 18. Average hourly differences in black globe temperature between the unshaded and shaded stations at three feedlot sites.

The average hourly comparison data presented in Figure 18 above clearly shows that radiant heat contributed by solar radiation significantly increases black globe readings in the unshaded pen during the daylight hours to temperatures well over those recorded in the shaded pen. However, as is expected, during the night when solar radiation levels are zero, there is little to no difference between the black globe temperature and the black globe temperatures recorded in the unshaded and shaded pen.

While black globe temperature is a useful parameter in the assessment of cattle heat stress, most standard climatic stations do not always record it. Air temperature and solar radiation are more commonly recorded. Therefore as part of the study, the relationship between black globe temperature, air temperature, and solar radiation was examined. The purpose of this was to investigate whether it is possible to develop a predictive equation for black globe temperature using recorded air temperature and solar radiation values.

Using data collected from the external stations at the four feedlot sites, regression analyses were undertaken using the parameters black globe temperature, air temperature, and solar radiation. This enabled various predictive equations of black globe temperature to be examined using the input climatic variables of air temperature and solar radiation.

The most accurate predictive equation for black globe temperature is described below:

$$T_{BG} = X_1\sqrt{T_A} + X_2T_A + X_3(\log(SR+1)) + b \qquad \textbf{(1)}$$

where T_{BG} = Black Globe Temperature (ºC)

T_A = Air Temperature (ºC)

SR = Solar Radiation (W/m^2)

$X_{1,2,3}$ = X Variables

b = Intercept

Multivariate regression analyses were undertaken in order to determine the X variables for each site. The results of this analyses is presented in Table 29 below.

Table 29. External station 'X Variables' for the predictive Black Globe equation.

	Feedlot A	**Feedlot B**	**Feedlot C**	**Feedlot D**	***Average***
Intercept	-6.47	2.24	-0.73	10.07	*1.28*
X Variable 1	-1.03	-4.08	-1.23	-5.87	*-3.05*
X Variable 2	1.27	1.65	1.22	1.78	*1.48*
X Variable 3	4.38	3.57	3.37	2.76	*3.52*

Based on the above coefficients derived from the external station at the four feedlot sites a general predictive equation for black globe temperature would be:

$$T_{BG} = 1.48T_A - 3.05\sqrt{T_A} + 3.52(\log(SR+1)) + b$$

where T_{BG} = Black Globe Temperature (ºC)

T_A = Air Temperature (ºC)

SR = Solar Radiation (W/m^2)

b = Intercept

It is noted that significant variability occurred in the intercept values between the feedlot sites. This variable should be in the range of -5 to 10. The higher the intercept value the more conservative the equation, with higher black globe values predicted.

Data analysis was also undertaken to examine the relationship between air temperature and solar radiation values measured outside the feedlot with black globe temperatures recorded within the feedlot pens. The analyses undertaken has shown that it is possible to use data collected from outside the feedlot area to predict black globe temperatures within the feedlot pens with some accuracy.

Using the external station values for air temperature and solar in equation **(1)** and black globe temperatures recorded in the feedlot pens as 'y' values, regression analyses has allowed the site specific X variables for each feedlot to be determined. The results of these analyses are presented in Table 30 and Table 31 for the unshaded and shaded pen respectively.

Table 30. Unshaded pen 'X Variables' for the predictive Black Globe equation using external data.

	Feedlot A	**Feedlot B**	**Feedlot C**	**Feedlot D**	***Average***
Intercept	-3.25	18.10	-7.15	6.31	*3.50*
X Variable 1	-0.26	-10.60	2.83	-2.56	*-2.65*
X Variable 2	1.05	2.36	0.65	1.26	*1.33*
X Variable 3	4.00	2.91	3.37	2.55	*3.21*

Table 31. Shaded pen 'X Variables' for the predictive Black Globe equation using external data.

	Feedlot A	**Feedlot B**	**Feedlot D**	***Average***
Intercept	14.10	-7.43	9.10	*5.26*
X Variable 1	-6.47	2.20	-3.05	*-2.44*
X Variable 2	1.64	0.72	1.26	*1.21*
X Variable 3	2.18	4.13	0.97	*2.43*

Substituting the variables derived in the above tables into the predictive black globe equation **(1)** allows external air temperature and solar radiation data to be used to calculate the black globe temperature within both the unshaded and shaded pen. Plots of calculated black globe temperature (using air temperature and solar radiation values recorded by external stations) against actual black globe temperatures are presented in Figure 19 for the unshaded pen at Feedlot B and Figure 20 for the shaded pen at Feedlot D.

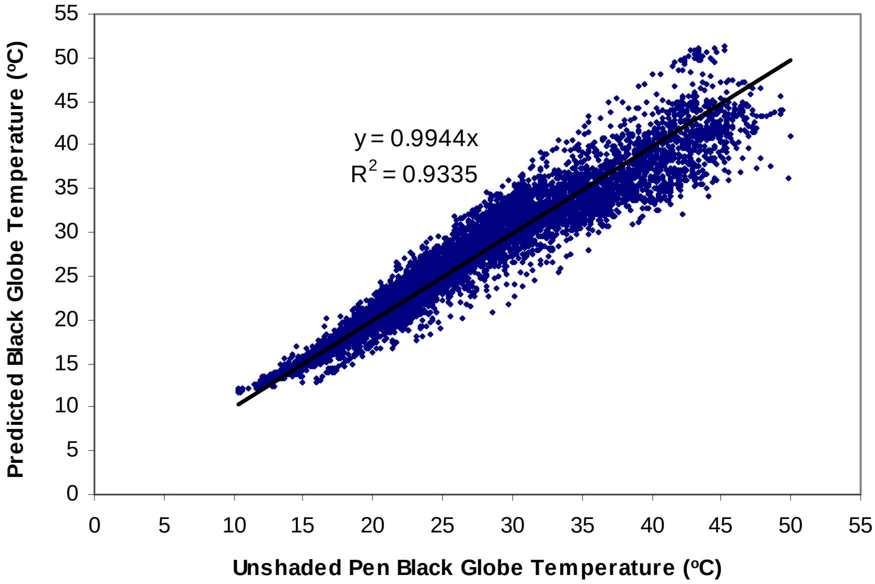

Figure 19. Predicted black globe temperatures for the Feedlot B unshaded pen derived using external data in comparison with actual black globe temperatures (n = 9,388).

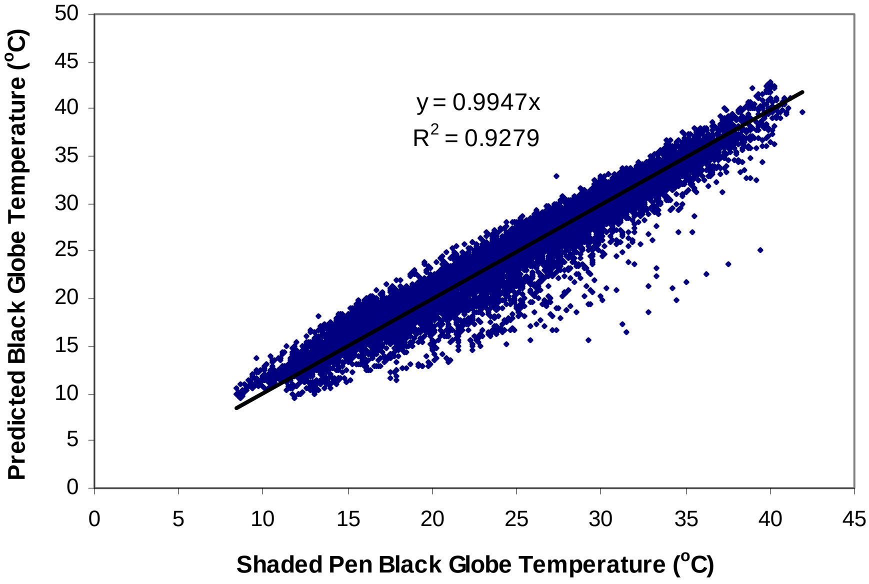

Figure 20. Predicted black globe temperatures for the Feedlot D shaded pen derived using external data in comparison with actual black globe temperatures (n = 12,876).

It is noted that the calculated black globe temperatures presented in Figure 19 and Figure 20 were derived using the site specific X variables presented in Table 30 and Table 31 above. It is possible to use the average X variable values presented in these tables, however is should be noted that the variance between sites results in the predicted black globe temperatures for both the unshaded and shaded pens being somewhat conservative.

This is shown when using the following general equations for predicting black globe temperatures in both the unshaded and shaded pen.

$$T_{BG\ (unshaded)} = 1.33T_A - 2.65\sqrt{T_A} + 3.21(\log(SR+1)) + 3.50$$

$$T_{BG\ (shaded)} = 1.21T_A - 2.44\sqrt{T_A} + 2.43(\log(SR+1)) + 5.26$$

where T_{BG} = Predicted Black Globe Temperature (ºC)

T_A = Air Temperature recorded by external station (ºC)

SR = Solar Radiation recorded by external station (W/m^2)

The general equations above were used to calculate the predicted black globe temperatures for the unshaded and shaded pens at each site. Plots of calculated black globe temperatures against actual recorded values were made and lines of best fit were applied. This allowed the accuracy of the equations to be determined. This data in Table 32 below presents the equations for the line of best fit derived from these plots.

Table 32. Lines of best fit derived from predicted versus actual black globe plots.

	Unshaded Pen			Shaded Pen		
	a	**b**	**R^2 Value**	**a**	**B**	**R^2 Value**
Feedlot A	0.89	3.57	0.94	0.92	2.74	0.91
Feedlot B	0.84	4.29	0.93	0.79	4.53	0.90
Feedlot C	0.90	2.36	0.94	-	-	-
Feedlot D	1.03	-1.67	0.92	1.12	-3.01	0.90

Line of best fit: y = **a**x + **b**

where y = predicted BG,
x = actual BG.

The above data show that, with the exception of Feedlot D (a>1), the predicted black globe values at the Feedlot sites were generally slightly lower than the actual recorded values (a<1). Therefore while it has been possible to predict the black globe temperatures within the feedlot pens (both unshaded and shaded) with a relatively high degree of accuracy, care must be taken as high black globe temperatures may be underestimated. This may reduce the likelihood of predicting extreme stress events using a modelled value of black globe temperature.

4.1.6 Wind Speed and Direction

Varying trends were observed in the wind measurements at each weather station. The data in Figure 21, Figure 22, and Figure 23 below show the average hourly difference in horizontal wind speeds between the stations located in the unshaded pens and that of the external stations and the stations in the shaded pens.

Figure 21 shows the difference in 2 metre wind speeds recorded in the unshaded and shaded pens. These data show that at Feedlot B the recorded wind speeds in the unshaded pen were on average consistently higher (2 to 4 km/hr) than those measured in the shaded pen. This trend is also noted at Feedlot A however the difference average only around 0.5 to 1.5 km/hr and between midnight and 6 am the recorded wind speeds at the unshaded and shaded pen are virtually identical. The reduction in wind speeds noted in the shaded pens of Feedlot A and Feedlot B may be attributed to higher stocking densities that occur with the congregation of cattle under the shade structure.

The data from Feedlot D shows little variance in the recorded wind speeds of the unshaded and shaded pens. This was also the case for this feedlot over the 2001 summer period. It is noted that Feedlot D has shade cloth covers that are higher than the galvanised iron covers at Feedlot A.

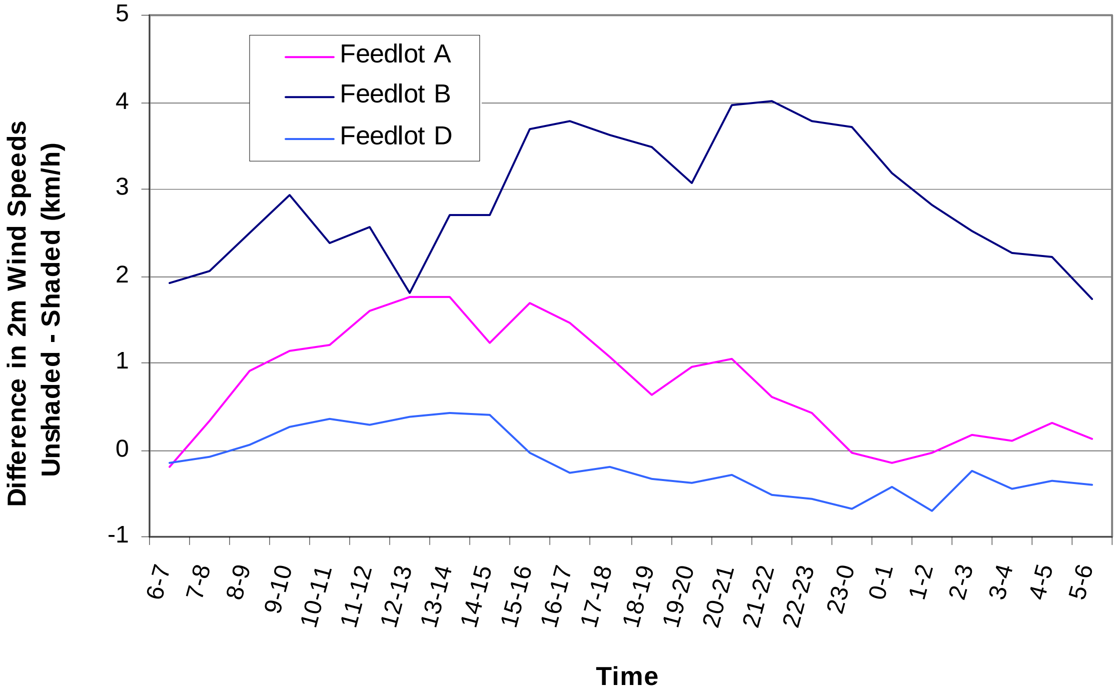

Figure 21. Average hourly differences in 2 metre wind speeds between the unshaded and shaded stations at three feedlot sites.

The data in Figure 22 shows that the 2 metre wind speeds were generally lower outside the feedlot area compared to those recorded in the pens at Feedlots A, B and C. This could be due to the stubble and grass cover outside of the feedlot and also the relatively closer proximity of the external stations to trees. The data from Feedlot D shows the opposite trend with the 2 metre wind speeds recorded in the unshaded pen being around 0.5 to 1.5 km/hr slower than those recorded at the external station.

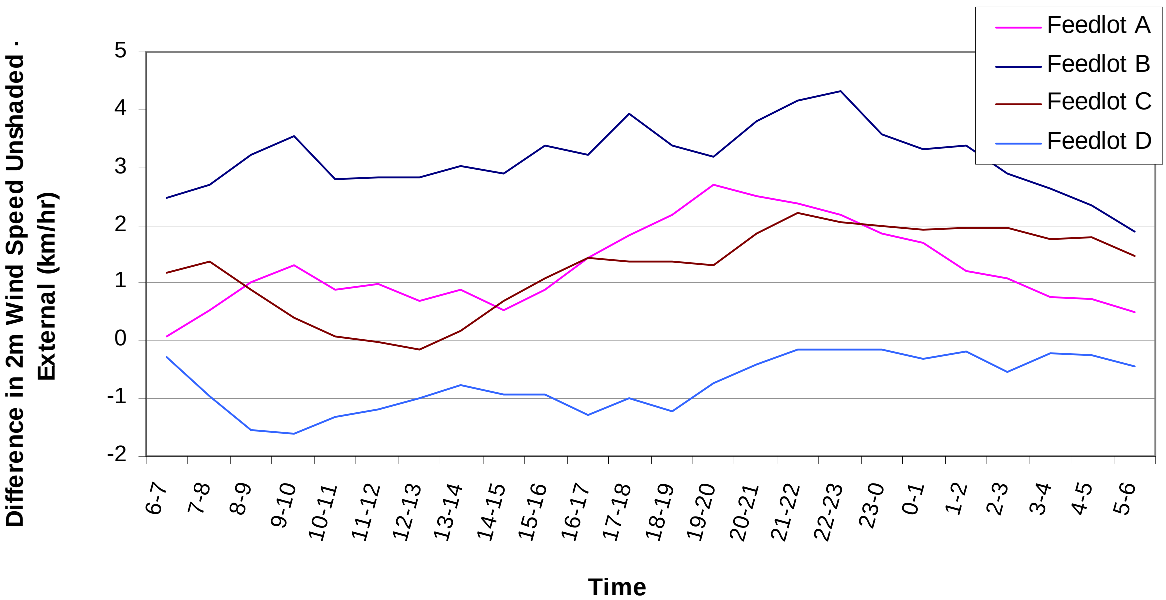

Figure 22. Average hourly differences in 2 metre wind speeds between the unshaded and external stations at four feedlot sites.

The data in Figure 23 shows that similar to the 2 metre wind speeds, at Feedlots A and C the recorded 10 metre wind speeds were generally lower outside the feedlot area compared to the unshaded pen. Little variation was noted at Feedlot D, and the data from Feedlot B shows that 10 metre wind speeds were 3 to 5 km/hr higher outside the feedlot area. This contradicts the trend noted in the 2 metre wind speed data recorded at this site and may be due to site topography and station siting or possibly sensor errors.

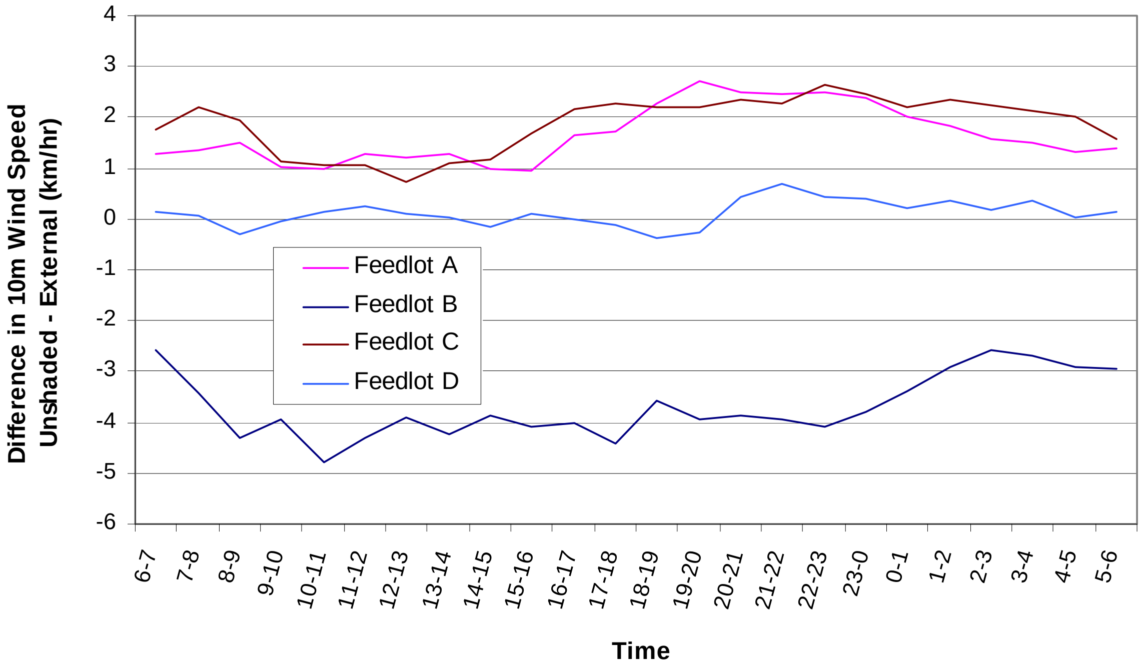

Figure 23. Average hourly differences in 10 metre wind speeds between the unshaded and external stations at four feedlot sites.

4.1.7 Vertical Wind Speed

As part of the study vertical wind sensors were used in order to obtain data on the vertical movement of air both within the feedlot pens and outside the feedlot area. The vertical wind sensors were located at a height of 2 metres on the automatic weather stations used for the project.

In order to examine the differences in vertical wind measured outside the feedlot, and within both the shaded and unshaded feedlot pens, the relationship between horizontal and vertical wind was examined. Plots of horizontal versus vertical wind were made to examine this relationship. For the purpose of the data analyses absolute values of vertical wind were used as opposed to both the positive and negative values that were recorded depending on the direction of rotation of the sensor. The resultant plots for the external and internal stations at Feedlot A are presented in Figure 24 to Figure 26 below.

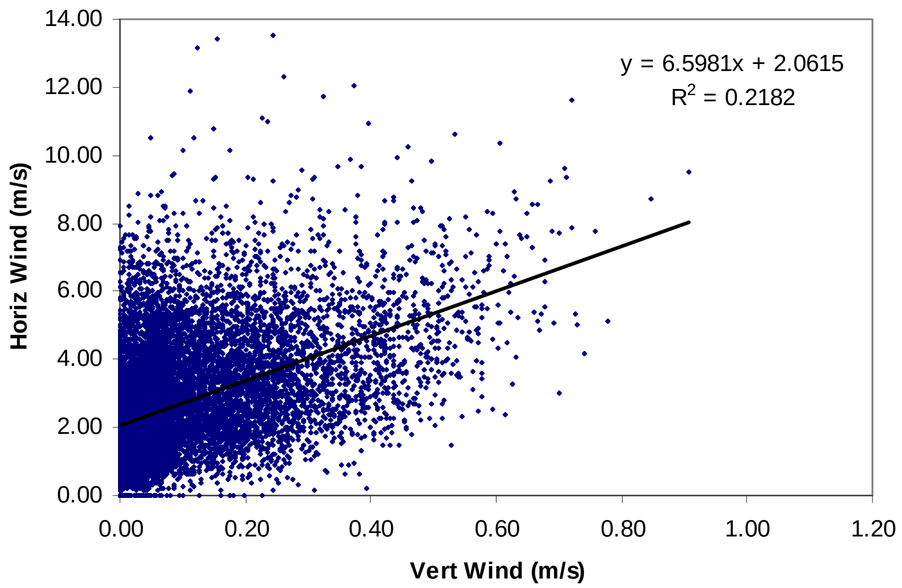

Figure 24. Relationship between horizontal and vertical wind measured at external station Feedlot A.

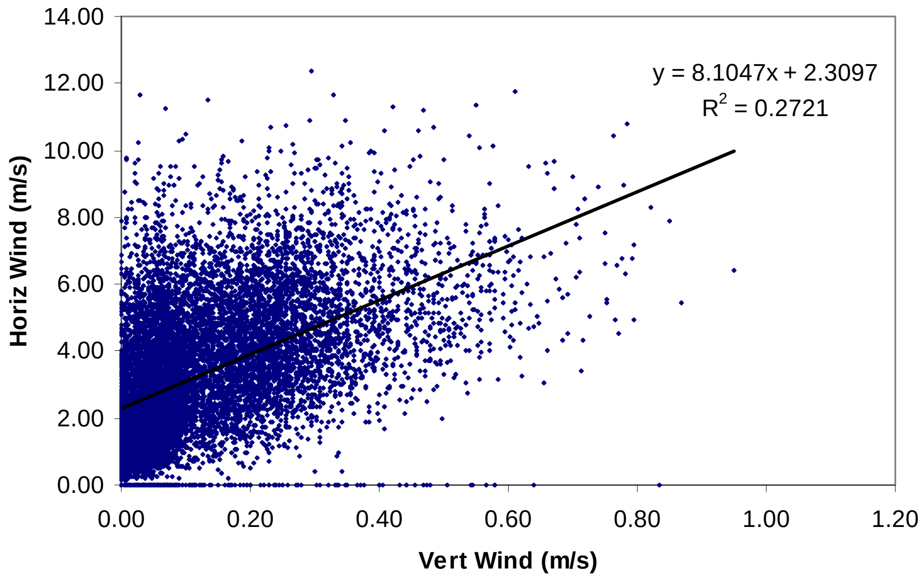

Figure 25. Relationship between horizontal and vertical wind measured in the unshaded pen at Feedlot A.

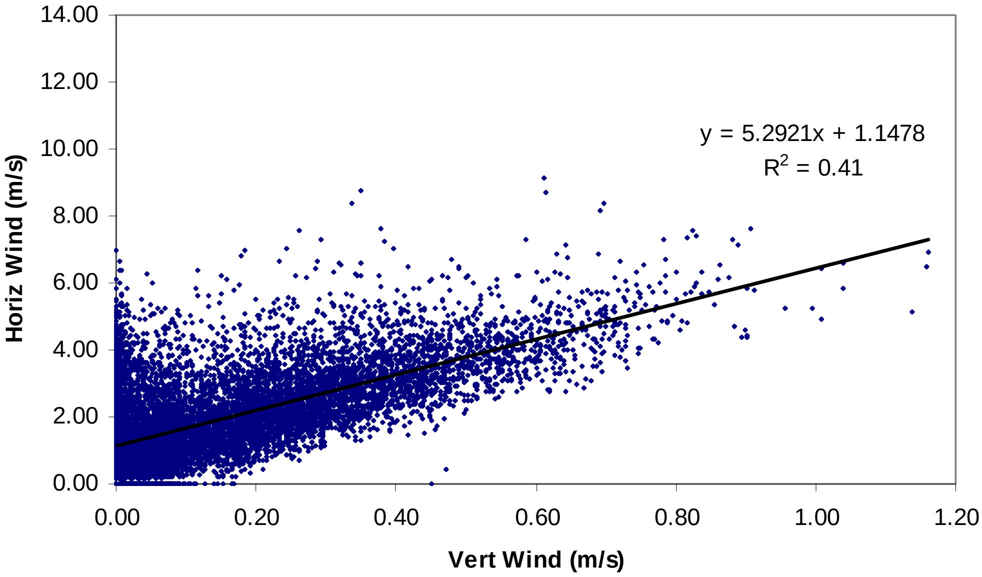

Figure 26. Relationship between horizontal and vertical wind measured in the shaded pen at Feedlot A.

Applying a linear best fit to the above data has allowed the magnitude of the relationship between horizontal and vertical wind to be assessed. The x-coefficients obtained from plots of horizontal versus vertical wind for all feedlot sites are presented in Table 33 below.

Table 33. X-coefficients obtained from plots of horizontal versus vertical wind speed.

	External	Unshaded Pen	Shaded Pen
Feedlot A	6.60	8.10	5.29
Feedlot B	7.15	(Faulty sensor)	6.96
Feedlot C	6.03	8.76	-
Feedlot D	7.85	7.70	7.93†
Average	*6.90*	*8.19*	*6.73*

† - Limited data points available.

The above data highlights some key points. It shows that at Feedlot A, the vertical wind speed as a proportion of horizontal speed in the shaded pen was significantly greater than that recorded in the unshaded pen. This would indicate that the presence of shade structures results in impediments to smooth flow of air and results in turbulence beneath the shade. However it must be remembered that horizontal speeds are less beneath shades than outside and as a result there is generally less air movement beneath shades. This trend is also noted at Feedlot B, however the difference is not as great and this may be attributed to the shade structures at Feedlot B that are higher, have greater spacing, and sloped (thus providing less restrictions to horizontal wind movement). The data from Feedlot D does not follow this trend however limited data points were available from the shaded pen. Notwithstanding this, it is noted that Feedlot D contains shade cloth as opposed to the iron shade structures at Feedlots A and B.

Comparing the external data to the data from the unshaded pens shows that generally there is more vertical wind movement within the feedlot pens compared to outside the feedlot. This trend is most significant at Feedlot C, which would be expected due to the topography of the site and the location of the station within the feedlot pen at the top of the slope.

At the start of the project it was hypothesised that shade structures may impede vertical air movement. These data would initially suggest otherwise. However, if constraints are placed on the analyses so that only low horizontal wind speeds are considered (because this removes the issue of the effects of surface roughness) a different result is derived. When data relating to horizontal wind speeds of less than 1 m/s are considered then vertical wind speeds are least beneath the shades. This is a critical finding as it is under such scenarios that the possibility of stress is greatest. Shade structures at Feedlot B (high spaced galvanised sheeting) and Feedlot D (shade cloth) offered the least impediment to vertical wind movement under low horizontal wind speed conditions.

4.1.8 Stress Indices

A variety of stress indices exist that use climatic variables in order to calculate a single number that can be used to provide an indication of potential stress conditions. The most common of these uses recorded air temperature and relative humidity values to calculate what is referred to as a 'Temperature Humidity Index' (THI). However, many other indices exist that use other climatic variables such as black globe temperatures, solar radiation, and wind speed.

A major component of project FLOT.316, which is being undertaken by the University of Queensland, is to better define a heat stress index equation that can be used to indicate potential cattle stress periods. At the time of writing, this project was still being finalised.

As part of the data analyses undertaken for Project FLOT.317 several of the existing stress indices were examined. The purpose of this was to determine the variations that exist in indices calculated from data collected outside the feedlot area, compared to those calculated using measurements recorded within both an unshaded and shaded feedlot pen. Due to the difference in micrometeorological variables that were noted between the external and internal feedlots environments, and also between feedlot sites, it is possible that these variations might carry through to any calculated stress index. Being able to use meteorological data collected outside of the feedlot pens has a number of practical benefits. However, it is important that a stress index calculated from this actual data be representative of conditions within the feedlot pens. The majority of feedlots in Australia which record site specific climatic data, collect this data from outside the pen areas. Whilst this data is useful, the variations between the external and internal feedlot environments highlighted in this report, means that the conditions experienced by the cattle may not be accurately represented using external data.

The variations that occur between indices calculated from internal and external data was examined as part of this project. The following existing indices were examined:

$$\mathrm{THI} = 0.8 \times T_A + RH(T_A - 14.4) + 46.4$$

$$\mathrm{BHI} = 0.8 \times T_{BG} + RH(T_{BG} - 14.4) + 46.4$$

where T_A = Air Temperature (ºC)

RH = Relative Humidity (decimal form eg. 0.55 for 55%)

T_{BG} = Black Globe Temperature (ºC)

Preliminary results of the FLOT.316 project have suggested some 'Heat Load Index' (HLI) equations which were also examined as part of this report. It is noted that at the time of writing these equations were yet to be finalised and were included as part of this report primarily to examine equations that included wind speed. The HLI equations examined were:

$$\mathrm{HLI}_{(1)} = 33.2 + 0.24 \times RH + 1.2 \times T_{BG} - 0.62 \times WS$$

$$\mathrm{HLI}_{(2)} = [(1.8 \times T_{BG}) + 32] - [\{0.55 - (0.55 \times RH/100)\} \times \{(1.8 \times T_{BG}) - 26\}] - 0.589 \times WS$$ which simplifies to

$$= (0.81 \times T_{BG}) - (0.143 \times RH) + (0.0099 \times T_{BG}RH) - (0.589 \times WS) + 46.3$$

where RH = Relative Humidity (%)

T_{BG} = Black Globe Temperature (ºC)

WS = Wind Speed (km/hr for $\mathrm{HLI}_{(1)}$; m/s for $\mathrm{HLI}_{(2)}$)

The above indices were calculated using the 10 minute data collected from the 11 automatic weather stations located at the four feedlot sites. The data was then analysed to determine how often certain threshold values were exceeded at each station. The thresholds used were 78 for THI and BHI, and 79 for the two HLI equations. This data is summarised in Table 34 below.

Table 34. Stress Index Hours above Threshold Values for the Four Feedlot Sites.

Stress Index		*Total Hours Above Threshold Level* †			*Available Index Data Period*	
		External	Unshaded	Shaded	Total Hours	Total Days
Feedlot A	THI	166.2	192.2	181.2	2052.2	85.5
	BHI	784.2	789.0	576.3	2052.3	85.5
	$HLI_{(1)}$	663.0	603.8	471.0	2051.5	85.5
	$HLI_{(2)}$	671.3	652.5	418.0	2051.5	85.5
Feedlot B	THI	49.5	68.7	60.5	835.3	34.8
	BHI	162.8	177.5	149.8	616.5	25.7
	$HLI_{(1)}$	104.7	123.8	105.3	615.0	25.6
	$HLI_{(2)}$	122.2	134.2	105.0	615.0	25.6
Feedlot C	THI	130.0	114.8	-	2024.5	84.4
	BHI	639.0	616.0	-	1754.5	73.1
	$HLI_{(1)}$	520.8	436.3	-	1754.2	73.1
	$HLI_{(2)}$	545.8	500.5	-	1754.2	73.1
Feedlot D	THI	102.3	107.7	119.5	2142.3	89.3
	BHI	614.2	567.7	326.5	2141.7	89.2
	$HLI_{(1)}$	400.8	387.2	183.3	2066.5	86.1
	$HLI_{(2)}$	463.2	436.7	203.7	2066.5	86.1

† Threshold Level - 78 for THI and BHI, 79 for HLI.

The above table highlights the variability in stress index levels calculated from data recorded outside the feedlot and within the feedlot pens. The data show some general trends, which are noted below:

- At the Queensland sites (Feedlots A and B), the indices that do not include wind speed exceed the threshold values more frequently in the unshaded pens compared to the external environment.
- At Feedlot C the above trend is reversed with all the indices calculated from the unshaded pen data showing the thresholds are exceeded less than those calculated from the external station.
- The THI calculated from the shaded pen data provides higher values than that calculated from outside the feedlot environment. This trend is noted at all three sites and can be attributed to the higher humidity levels noted within the shaded pen areas.
- The BHI and HLI values calculated from the shaded pen data are generally consistently lower than those calculated from the external data at the three feedlot sites. This is expected due the reduction in black globe temperatures caused by the presence of shade.

The key issue that is highlighted from this data is the variability in stress indexes calculated from within shaded and unshaded pens, and outside the feedlot area. As such, using data recorded from outside the feedlot to assess conditions within the feedlot pens is not likely to be entirely accurate. Using the microclimatic data recorded from this project allows stress index equations to be adjusted accordingly so that data recorded outside the feedlot area can be used to calculate indices representative of pen conditions.

Whilst the stress indexes derived from project FLOT.316 are not yet finalised, the derivation of a revised BHI formula is presented below to demonstrate how an existing index can be modified so that external data can be used to estimate pen conditions.

By collating the calculated BHI values from the data collected within the shaded pen at the three feedlot sites (dependent variables), and the black globe and humidity values recorded at the corresponding external stations (independent variables), statistical analysis can be undertaken to determine revised BHI equations. Multivariate regression analysis was used to determine if the existing variables of the BHI equation can be modified so that data collected outside the feedlot can be used to more accurately derive BHI values that better represent what was recorded in the shaded pens. The data in Table 35 below presents the results from this regression analysis.

Table 35. Modified BHI coefficients to better predict BHI values of shaded pens from external data.

Variables †	Existing BHI Equation	Revised Feedlot A	Revised Feedlot B	Revised Feedlot D	*Revised Average*
X_1	0.8	0.5	0.4	0.3	*0.4*
X_2	14.4	11.9	21.5	21.8	*18.4*
b	46.4	57.4	56.3	61.1	*58.3*

† - where BHI = $X_1 \times T_{BG} + RH(T_{BG} - X_2) + b$

The coefficients derived in Table 35 above show notable difference from those presented in the original BHI equation. The regression analysis that was undertaken has shown that when using data recorded outside the feedlot environment to calculate BHI values that are representative of conditions within a shaded feedlot pen, the following equation may provide more accurate data:

BHI $= 0.4 \times T_{BG} + RH(T_{BG} - 18.4) + 58.3$

where T_{BG} = Black Globe Temperature (ºC)

RH = Relative Humidity (in decimal form eg. 0.55)

Regression analysis was also undertaken on the preliminary HLI equations derived from project FLOT.316. The external station parameters of black globe temperature, humidity, and 2 metre wind speed were used as independent variables, whilst the calculated HLI values for the shaded and shaded pens were used as the dependent variables. The results of the regression analysis are presented in Table 36 to Table 39 below.

Table 36. Results of $HLI_{(1)}$ regression analysis for unshaded pens.

Variables †	**Existing HLI Equation**	Feedlot A	Feedlot B	Feedlot C	Feedlot D	*Average*
b	**33.2**	36.8	38.5	34.2	31.6	*35.3*
X_1	**0.24**	0.24	0.19	0.23	0.26	*0.23*
X_2	**1.2**	1.0	1.1	1.1	1.1	*1.1*
X_3	**-0.62**	-0.45	-0.41	-0.52	-0.18	*-0.39*
R^2 Value	-	0.76	0.84	0.78	0.76	*0.78*
No. observations	-	12309	3690	10525	12399	-

† - where $HLI_{(1)} = (X_1 \times RH) + (X_2 \times T_{BG}) + (X_3 \times WS) + b$

Table 37. Results of $HLI_{(1)}$ regression analysis for shaded pens.

Variables †	**Existing THI Equation**	Feedlot A	Feedlot B	Feedlot D	*Average*
b	**33.2**	45.4	38.6	38.4	*40.8*
X_1	**0.24**	0.18	0.23	0.22	*0.21*
X_2	**1.2**	0.8	1.0	0.8	*0.8*
X_3	**-0.62**	-0.40	-0.40	-0.19	*-0.33*
R^2 Value	-	0.63	0.72	0.62	*0.66*
No. observations	-	12309	3690	12399	-

† - where $HLI_{(1)} = (X_1 \times RH) + (X_2 \times T_{BG}) + (X_3 \times WS) + b$

Table 38. Results of $HLI_{(2)}$ regression analysis for unshaded pens.

Variables †	**Existing THI Equation**	Feedlot A	Feedlot B	Feedlot C	Feedlot D	*Average*
b	**46.3**	50.5	47.0	47.3	55.0	*49.9*
X_1	**-0.143**	-0.113	-0.088	-0.140	-0.238	*-0.145*
X_2	**0.81**	0.70	0.92	0.71	0.41	*0.69*
X_3	**-0.589**	-0.574	-0.318	-0.531	-0.246	*-0.418*
X_4	**0.0099**	0.0085	0.0052	0.0104	0.0145	*0.0097*
R^2 Value	-	0.95	0.97	0.95	0.92	*0.94*
No. observations	-	12309	3690	10525	12399	-

† - where $HLI_{(2)} = (X_1 \times RH) + (X_2 \times T_{BG}) + (X_3 \times WS) + (X_4 \times T_{BG}RH) + b$

Table 39. Results of $HLI_{(2)}$ regression analysis for shaded pens.

Coefficients †	**Existing THI Equation**	Feedlot A	Feedlot B	Feedlot D	*Average*
b	**46.3**	55.8	57.0	60.0	*57.6*
X_1	**-0.143**	-0.100	-0.224	-0.215	*-0.180*
X_2	**0.81**	0.57	0.40	0.30	*0.42*
X_3	**-0.589**	-0.474	-0.682	-0.296	*-0.484*
X_4	**0.0099**	0.0055	0.0134	0.0104	*0.0098*
R^2 Value	-	0.87	0.90	0.86	*0.88*
No. observations	-	12309	3690	12399	-

† - where $HLI_{(2)} = (X_1 \times RH) + (X_2 \times T_{BG}) + (X_3 \times WS) + (X_4 \times T_{BG}RH) + b$

The data presented in the above tables highlights several key points. Firstly, the data show that whilst variability does occur between the HLI values calculated using data from the unshaded and shaded pens, it is possible to derive correlations between these values. As such, it is possible to modify the HLI equations so that external data can be used to calculate HLI values representative of conditions within the feedlot pen to a reasonable degree of accuracy. The R^2 values derived from the analysis show that stronger correlations are obtained from the HLI equation that includes the additional variable ($HLI_{(2)}$). The R^2 values also show that the correlation between external data and unshaded pen HLI values is stronger than that of external data and shaded pen HLI values. This is expected due to the fact (as highlighted by this report) that the variations in microclimate are greater under shade, particularly the parameters of black globe temperature, relative humidity, and wind speed.

The anlaysis undertaken and presented above is based on preliminary HLI equations from project FLOT.316. Once revised calculations are derived, they should be checked against the cattle measurement data recorded as part of FLOT.316 to ensure that potential cattle stress events are accurately predicted. It is strongly recommended that similar regression analysis be undertaken on the final heat stress formulae that are derived from project FLOT.316.

4.2 Work Area 2 - Ammonia Measurements from Feedlot Pen Surfaces

The ammonia measurements undertaken during the day time periods showed that recorded ammonia levels generally followed similar diurnal trends. Data presented in section 3.2 showed that ammonia generation rates are dependent on temperature with peak readings occurring during the warmer periods of the day (typically between 1 and 3 pm).

The collected data has shown that the readings measured by the three monitors did follow similar trends but actual ammonia levels recorded at the same height were different. The study has found that a notable concentration gradient exists immediately above the pen surface with ammonia concentrations decreasing with height.

Peak readings were found to be in the order of 12 to 16 ppm when measured at a height of 1 metre above a dry pen surface. The readings recorded at 0.3 metres above the pen surface showed peak readings to be in the order of 25 to 30 ppm.

Comparison of the ammonia levels within the shaded and unshaded pens show similar levels were recorded at a height of 1 metre. During the data collection period the surface of both pens were noted as dry. Whilst the areas under the shade were slightly moister when compared to the unshaded pen surface, differences in ammonia concentrations between the shaded and unshaded pens were only noted at lower heights (less than 0.3 m above surface). It is expected that this difference would be more significant under wetter pen conditions.

Comparing the recorded ammonia data to the measurements undertaken as part of project FLOT.310 shows that the recorded levels were consistent with those previously measured. The project FLOT.310 stated that ammonia levels measured at heights less than 50 cm were 10 to 20 ppm in an unshaded pen, and 20 to 30 ppm in the shaded pen. It remains unknown whether these levels affect the health and welfare of stock in the pens. The duration of ammonia exposure of people working continuously in pens needs to be examined.

4.3 Work Area 3 - The Thermodynamic Characteristics of Feedlot Troughs

4.3.1 Vertical Temperature Gradient of Trough Water

Cattle drink very little water during the night, which results in very little water inflow into the trough. This, together with the overnight cooling of the trough materials and the resident trough water, results in a temperature stratification within the trough. The recorded temperature data showed that the three sample points at the surface of the water are warmer than the points below the surface in the morning. It is surmised that any inflow water is warmer than the resident trough water, and appears to flow along the surface of the trough water and stay at the surface.

This vertical temperature gradient remains in place until there is significant ‘turnover’ of the water in the trough. Cattle drink heavily in the early morning (just after sunrise), prior to being fed and again just after being fed. This drinking results in the emptying and refilling of the water trough (turnover). When the trough is refilled, the resident water is initially the same temperature as the inflow temperature. However, if the trough material is still relatively cool (from overnight cooling), it exchanges energy (and thus heat loads) with the water, thereby cooling the water that is in contact with the trough (the water at the bottom of the trough) and also heating the trough materials.

By 0900 hours or 1000 hours, the trough has been emptied and refilled a number of times, and the water temperatures become consistent throughout the trough, thus removing the vertical temperature gradient.

4.3.2 Horizontal Temperature Gradient of Trough Water

In the early morning, the inflow temperature is warmer than the resident water in the trough which has cooled overnight. Therefore the valve end of the trough heats up faster than the drain end of the trough. This results in a horizontal temperature gradient within the trough, where the points “Under valve” and “End of guard” are warmer than the point “End of trough”. This gradient remains in place until there is significant turnover of the water in the trough, which occurs between 0900 hours and 1000 hours. The significant turnover of water at this time results in a relatively consistent water temperature throughout the trough.

In the heat of the day (1200 hours to 1500 hours), the inflow water temperature is cooler than that of the resident trough water. This results in the valve end of the trough being cooler than the drain end of the trough. However, cattle drink very little at this time of the day, which means the inflow of water at this time is small. Therefore the temperature difference between the valve end of the trough and the drain end of the trough is relatively small.

4.3.3 Stocked vs. Unstocked Pens

The vertical and horizontal temperature gradients within the troughs indicate that the temperature of the resident water in the trough tends towards the inflow temperature over the course of the day. In the unstocked pens, there is no inflow. So, the temperature variations over the course of the day reflect the heating of the trough materials and the trough water through radiation (solar) and convection (ambient air temperature).

In the cool of the morning, the inflow water heats the resident water in the troughs (in the stocked pen), but, in the heat of the afternoon, the inflow water cools the resident water in the troughs (in the stocked pens).

4.3.4 Effects of Trough Size and Construction Materials

The data presented in Figure 12 of section 3.3.3 provides a comparison on the performance of feedlot troughs by highlighting the difference between the trough water temperature and inflow water temperature recorded in the four troughs examined at the three feedlot sites. As outlined in section 3.3.3, several key points are highlighted by these data.

The data have shown that the two larger concrete troughs investigated in the study appeared to provide a cooling effect on the resident trough water during the morning hours. This is most likely due to the fact that the concrete itself, being relatively cool (from overnight cooling), exchanges energy with the water, thereby cooling the water that is in contact with the trough. The study results showed that the concrete troughs at Feedlots B and E both provided trough water temperatures that were 2 to 6ºC lower than the inflow water temperatures between the hours of 6 to 10 am. Although the large thermal mass of the concrete troughs does provide this cooling benefit, it also results in concrete troughs heating up more over the day which may provide warmer trough temperatures during afternoon periods. This was observed in the study data, however the extent of heating was less than the morning cooling benefit.

A similar cooling effect was also noted to a lesser extent in the smaller fibreglass trough at Feedlot A. The data recorded at this site has shown that between the hours of 6 to 8 am, trough water temperatures were 1 to 3ºC lower than the inflow water temperatures. However, this cooling benefit was quickly removed due to the high turnover rate of water within the smaller trough and the troughs small thermal mass.

It appears that the high turnover rate of the smaller fibreglass trough at Feedlot E provided stored water temperatures that did not vary significantly from the inflow temperature throughout the day. It is not possible to determine the actual turnover rate of this trough during the study period due to the fact that two troughs were contained in the same pen. However, as shown in Table 23 of section 3.3.1 the total number of trough turnovers for this pen was estimated to be 32. Whilst this is the estimated combined turnover for both the larger concrete (425 L) and smaller fibreglass trough (265 L), during the study it was noted that cattle showed a preference of using the smaller trough. This may be due to a number of reasons, including the fact that the fibreglass trough was located on a common pen fence where cattle from the neighbouring pen were also drinking from an adjoining trough. As such the cattle from both pens may have simply preferred to congregate in this area for social reasons. The observed effect of this behaviour is that the smaller trough was used more frequently than the larger trough and as a result the number of turnovers of this trough would have been considerably more than that of the larger trough. It is for this reason that the resident water within the trough consistently stayed at a similar temperature to the inflow water (31 to 32ºC) throughout the day.

4.3.5 Trough Inflow Temperatures

As detailed in the FLOT.310 report, water consumption by cattle is an important variable in energy transfers and the energy balance. The consumption of water by cattle can act as a ‘heat sink’ that provides potential cooling effects through the absorbtion of energy. Petrov *et. al.* (2001) calculated that to increase 60 L of water at 15°C to body temperature (39°C) required 6.03 MJ/day, whilst the same volume of water presented at 25°C absorbed 3.5 MJ/day from the animal as it was increased to body temperature. As such to assist in reducing the potential for heat stress feedlot operators should be aiming to present good quality water at the lowest possible temperature, especially in the latter part of the day when heat loads on the animal peak.

The data presented in section 3.3.1 shows that at the three feedlot sites water was presented at temperatures in the range of 25 to 33°C. These feedlots are representative of other feedlots in the industry and therefore highlight the fact that the issue of water supply temperatures needs to be addressed across the whole industry. The study clearly showed that during the study period all the different trough types and reticulation systems failed to present water below 25°C.

The study showed that water temperatures in the troughs tended towards that of the inflow into the trough. This is due to the short residence time of the water in the trough (the high turnover of trough water). Therefore, in order to cool the trough water down, the inflow water needs to be cool. The study has shown that undertaking measures to reduce trough water temperature should focus on how to cool the water in the source/storage (usually a turkey nest or dam) and in the reticulation system before it is presented to stock. Water storages should be designed and constructed to keep water as cool as possible. Water drawn from bores may be hot and it should be cooled before supply to stock over the summer period.

5. CONCLUSIONS

Project FLOT.317 has met the objectives described in section 1.2. The weather stations placed in the four feedlots have provided a dataset in addition to that obtained in Project FLOT.310. Together these data have allowed the microclimates of feedlot pens (unshaded and shaded) to be defined and compared to that of external stations. Based on these data it is possible to develop predictive models of stress and heat load in pens using data from stations external to a feedlot. Though further work on these equations is required. Project FLOT.317 has measured ammonia levels in air above pens, and water trough temperatures. Specific conclusions are detailed in the following sections.

5.1 Micrometeorological Variations

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

- Air temperatures were found to be higher in the pen areas of the feedlot compared to the external environment;
- The presence of shade provides only a minor reduction in air temperatures (on average less than 0.7°C);
- Humidity levels were found to be higher in the shaded pens compared to the levels recorded in the unshaded pens and external feedlot environment;
- During the daylight hours soil temperatures in unshaded pens generally increased to levels 4 to 6°C higher than those measured under shade;
- Black globe temperatures under shade are reduced by 4 to 7°C during the day compared to unshaded pens (little variation occurs at night);
- Typically wind speeds are reduced in shaded pens however the extent is variable and dependant on, among other factors, the type of shade structure;
- The variations in the micrometeorology of the internal and external feedlot environment will influence values derived from stress indices. Using the data collected for this project it is possible to redefine existing stress indices so that data collected from outside the feedlot can be used to predict potential stress events within the cattle pens. It is recommended that heat stress indexes developed as part of project FLOT.316 undergo a mutivariate regression analysis using data from this project.

5.2 Ammonia Measurements

The study has found that:

- Ammonia generation from pen surfaces is directly affected by temperature, with higher ammonia levels measured during the warmer parts of the day;
- Little difference was noted between ammonia levels recorded at a height of 1 metre within the shaded and unshaded pens. This can be attributed to the dry weather conditions experienced during the ammonia measurements. At lower heights (less than 0.3 m above surface) higher ammonia concentrations were noted in the moister areas under shade compared to the unshaded pens;

- A notable profile of ammonia concentrations exists above the pen surface. Peak concentrations were found to be in the order of 12 to 16 ppm when measured at a height of 1 metre above the surface. Peak concentrations measured at a height of 0.3 metres were 25 to 30 ppm.

5.3 Trough Temperatures

The trough study undertaken at three feedlot sites has provided an overview and understanding of the factors affecting trough water temperatures. The data analysed to date has highlighted the following:

- Due to overnight atmospheric cooling and thus cooling of stored water (cattle water consumption is low at night), a vertical temperature gradient occurs in troughs. This gradient is removed by mid morning due to the cattle water consumption rates that are notable around morning feed times.

- A horizontal temperature gradient is formed by the inflow of warmer water during early morning periods. This temperature gradient is also removed by the number of trough turnovers that have occurred by mid morning.

- The study has shown that concrete troughs do provide better cooling of water during the morning periods than that provided by fibreglass troughs.

- Due to the high turnover rates of water stored within a trough over the day, resident water temperatures are highly dependent on the inflow water temperature. This becomes more critical with smaller trough sizes. The study has shown that the water temperature in troughs with a small capacity (and high turnover rate) is equivalent to the temperature of the inflow water.

- The best means of maintaining lower trough water temperatures is to reduce the temperature of the water supply.

- The study has shown that trough inflow temperatures were typically high (25 to 33ºC), which will reduce the ability of cattle to shed heat through consumption of water.

6. RECOMMENDATIONS

1. No further field studies on feedlot microclimates are required.

2. Further analyses should be undertaken on the predictive ability of heat stress equations once project FLOT 316 is completed.

3. These equations, once rectified, should be used to forecast heat loads/stress on cattle for Australian feedlots.

4. The effects of ammonia exposure on cattle and feedlot personnel should be defined.

5. Mechanisms for keeping stored supply water cool must be examined to provide industry with an opportunity to reduce the incidence of heat stress.

7. REFERENCES

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APPENDIX A

Cattle Measurement Data Sheet and Panting Scores

Cattle Comfort Measurements for Shaded Pens (Please Print Clearly)

Pen N^o:_______________ **Pulls:** ___________ **Mortalities:**_____________ **Food intake:**______________

Date:_________________ **Name of Recorder:**_______________________ **Sick Returns:**___________ **Average Weight:**_________

6AM EST

N^o. Head in pen__________ **Pen Surface Condition:** Dry Dusty / Smooth / Compact / Pugged / Saturated (Slurry)

N^o. outside shade									N^o. using shade							Observations/Comments:
N^o. around water trough:	N^o. at feed:	N^o with each panting score					N^o. Lying:	N^o. Standing:	N^o with each panting score					N^o. Lying:	N^o. Standing:	
		0	1	2	3	4			0	1	2	3	4			

12Noon EST

N^o. Head in pen__________ **Pen Surface Condition:** Dry Dusty / Smooth / Compact / Pugged / Saturated (Slurry)

N^o. outside shade									N^o. using shade							Observations/Comments:
N^o. around water trough:	N^o. at feed:	N^o with each panting score					N^o. Lying:	N^o. Standing:	N^o with each panting score					N^o. Lying:	N^o. Standing:	
		0	1	2	3	4			0	1	2	3	4			

5PM EST

N^o. Head in pen__________ **Pen Surface Condition:** Dry Dusty / Smooth / Compact / Pugged / Saturated (Slurry)

N^o. outside shade									N^o. using shade							Observations/Comments:
N^o. around water trough:	N^o. at feed:	N^o with each panting score					N^o. Lying:	N^o. Standing:	N^o with each panting score					N^o. Lying:	N^o. Standing:	
		0	1	2	3	4			0	1	2	3	4			

Definitions:

Pulls	Number of individuals removed from pens
N^o around water trough	Standing close to water trough including those not drinking
N^o at feed	In the process of ingesting feed at feed trough
Panting Score	See Table 1

Table 1. Breathing Condition, Respiration Rate and Panting Score.

Breathing Condition	Respiration Rate [A] (bpm)	Panting Score
No panting	Less than 40	0
Slight panting, mouth closed	40 – 70	1
Fast panting, occasional open mouth	70 – 120	2
Open mouth + some drooling	120 – 160	3
Open mouth, tongue out + drooling	< 160[B]	4

[A] Count respiration rate for at least 2 minutes
[B] At this stage, RR may decrease due to change to deep phase breathing

SEE PHOTO SHEET FOR PANTING SCORES

Cattle Comfort Measurements for Unshaded Pens (Please Print Clearly)

Pen N^{o}:_______________ **Pulls:** ___________ **Mortalities:**_____________ **Food intake:**______________
Date:_________________ **Name of Recorder:**_______________________ **Sick Returns:**___________ **Average Weight:**_________

6AM EST

N^{o}. Head in pen__________

Pen Surface Condition: Dry Dusty / Smooth / Compact / Pugged / Saturated (Slurry)

N^{o}. around water trough:	N^{o}. at feed:	N^{o} with each panting score					N^{o}. Lying:	N^{o}. Standing:	**Observations/Comments:**
		0	1	2	3	4			

12Noon EST

N^{o}. Head in pen__________

Pen Surface Condition: Dry Dusty / Smooth / Compact / Pugged / Saturated (Slurry)

N^{o}. around water trough:	N^{o}. at feed:	N^{o} with each panting score					N^{o}. Lying:	N^{o}. Standing:	**Observations/Comments:**
		0	1	2	3	4			

5PM EST

N^{o}. Head in pen__________

Pen Surface Condition: Dry Dusty / Smooth / Compact / Pugged / Saturated (Slurry)

N^{o}. around water trough:	N^{o}. at feed:	N^{o} with each panting score					N^{o}. Lying:	N^{o}. Standing:	**Observations/Comments:**
		0	1	2	3	4			

Definitions:

Pulls	Number of individuals removed from pens
N^{o} around water trough	Standing close to water trough including those not drinking
N^{o} at feed	In the process of ingesting feed at feed trough
Panting Score	See Table 1

Table 1. Breathing Condition, Respiration Rate and Panting Score.

Breathing Condition	Respiration Rate [A] (bpm)	Panting Score
No panting	Less than 40	0
Slight panting, mouth closed	40 – 70	1
Fast panting, occasional open mouth	70 – 120	2
Open mouth + some drooling	120 – 160	3
Open mouth, tongue out + drooling	< 160[B]	4

[A] Count respiration rate for at least 2 minutes
[B] At this stage, RR may decrease due to change to deep phase breathing

SEE PHOTO SHEET FOR PANTING SCORES

Panting Score 1

Panting Score 2

Panting Score 3

Panting Score 4