On farm

Applied Scientific Evaluation of Feedlot Shade Design

FLOT.315
Final Report prepared for MLA by:

Mr Peter Binns, Mr Ryan Petrov, Mr David Wood
E.A. Systems Pty Limited
PO Box W1029, ARMIDALE NSW 2350

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

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FEEDLOTS

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Applied Scientific Evaluation of Feedlot Shade Design

Feedlot .315

Prepared by:

Mr Peter Binns, B.App.Sc.M.Env.Man
Principal Scientist (Ag)
E.A. Systems Pty Limited

Mr Ryan Petrov, B.E.(Env)
Environmental Engineer
E. A. Systems Pty Limited

Mr David Wood
University of Southern Queensland

Date: 22.May 2003

Reviewed by:

Dr Simon Lott, BE(Ag)(Hons), PhD, CPEng, CPAg
Principal Environmental Engineer
E.A. Systems Pty Limited

Date:22 May 2003

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EXECUTIVE SUMMARY

Hot weather conditions such as those experienced over an Australian summer can cause a loss of production and in extreme cases, catastrophic losses amongst lot fed cattle. These losses in production are due to levels of heat stress in lot fed cattle that results when the thermal loads on an animal are greater than the animals ability to lose heat by normal metabolic means. These levels of heat stress can vary from causing discomfort to the animal that results in panting, through to death. Rises in thermal loads leading to heat stress events may result from energy derived through the ingestion and digestion of feed and water, incident radiation from the atmosphere and the ground, and direct heating by surrounding air mass.

Ambient temperatures in excess of body temperature typically induce behavioral and physiological changes in cattle that are intended to reduce the animal's heat load by adjusting its radiative, convective, conductive and evaporative exchanges with its environment. In hot climates, shade can be utilised by cattle to provide relief from radiant energies by intercepting direct beam, shortwave solar radiation that may otherwise induce excess body temperatures. The lack of shade in some feedlots has been implicated as restricting the ability of cattle to reduce their radiative energy load.

Although shade is a useful tool for reducing heat loads and stress in livestock, if incorrectly designed and poorly maintained, shade can at times lead to increased levels of stress and cattle discomfort. This can occur due to a reduction in localised wind speeds and an increase in localised levels of humidity. Wind speeds may be reduced by shade structures that in turn results in a reduction in the capacity of the animal to be cooled through convective and evaporative means. An increase in localised levels of humidity will result when the capacity of the feed yard pad to dry out is reduced. This in turn can also result in a reduced capacity to lose heat via evaporative means and can lead to other issues such as a greater build up of ammonia gas and increases in odour generation

The effectiveness of shade is largely dependant on the following factors:

- The thermal properties of the shade material;
- The height of the shade structure;
- Size of shadow;
- The slope of the shade;
- Location of shadow;
- Shadow orientation; and
- The level of ventilation.

Current feedlot shade designs have evolved over time. Most are of simple designs to minimise capital and ongoing maintenance costs. However, even though the structures are agricultural, structures of such size should be engineer-designed and certified. This includes the structural connection details, especially where tensioned cables are involved, and the fixing details for the corrugated iron sheeting.

This report has completed an investigation of current shade designs and has made recommendations to the feedlot industry based on these observations and available literature. A summary of this report suitable for industry is attached in Appendix F.

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1. INTRODUCTION

Ambient temperatures in excess of body temperature typically induce behavioural and physiological changes in cattle that are intended to reduce the animal's heat load by adjusting its radiative, convective, conductive and evaporative exchanges with its environment. Concerns have been raised that when compared to grazing animals cattle in feedlots may be restricted in the extent to which they are able to express some of these adaptive characteristics. Consequently, the welfare of lot fed cattle may be readily compromised under certain conditions.

In particular, the lack of shade in feedlots has been implicated as restricting the ability of cattle to reduce their radiative energy load (Blackshaw & Blackshaw, 1994 quoted in Binns, Petrov & Lott, 2002). In hot climates, shade can be utilised by cattle to provide relief from the ambient temperatures that induce excess body temperatures. Owen (1994) describes the benefits of shade (reduction in heat load) to animals exposed to both high temperatures and high solar radiation with the effectiveness of shade being dependant upon the following key factors:

- Size of shadow;
- Location of shade;
- Shade orientation;
- Type of shade material.

Notwithstanding the perceived need to provide shade in feedlots that are likely to experience extended periods of hot weather conditions, the benefits, both in regard to animal productivity and physiological stress indicators, have not been conclusively established (Esmay, 1978; Curtis, 1983; Rinehart & Tucker, 1994; Mader *et al*., 1999 and Sparke *et al*., 2001). Curtis (1983) suggests that the lack of conclusive evidence is due to the design of shade being a very complex matter that invokes a diverse range of interactions between the animal and its environment. Further, the nature and magnitude of these interactions may also be dependent on the climatic conditions.

This report summaries the finding of an applied scientist evaluation of feedlot shade design. The reader is referred to a detailed literature review completed as part of this study. The review is attached in this report as Appendix G. The report thus summarises the literature review and incorporates additional findings obtained through observations of industry practice and detail design of shade structures.

2. THE NEED FOR SHADE

Hot weather conditions such as those experienced over an Australian summer can cause a loss of production and in extreme cases, catastrophic losses. Heat stress of lot fed cattle can be defined as a condition where the thermal loads on an animal are greater than the animals ability to lose heat by normal metabolic means. These levels of heat stress can vary from causing discomfort to the animal that results in panting, through to death. Rises in thermal loads may result from energy derived from the ingestion of feed and water, digestion of a ration, incident radiation from the atmosphere and the ground, and direct heating by surrounding air mass.

A shade structure is utilised to minimise cattle stress levels by ensuring that ambient temperatures do not reach level in excess of their typical body temperature. Ambient temperatures in excess of those experienced by lot fed cattle are typically reduced by behavioural and physiological changes that reduce an individual animals temperature by adjusting its radiative, convective, conductive and evapoartive exchanges with its environment (Binns, Petrov & Lott, 2002).

Management strategies such as the use of shade can minimise the rise of ambient temperatures and then assist to cool the individual beast as quickly as possible. A number of factors can strongly influence these ambient temperatures and the rate in which heat can be gained or lost by an animal.

2.1 Solar Radiation

The principal function of a shade structure is to intercept direct beam, shortwave solar radiation (Binns, Petrov & Lott, 2002). Binns, Petrov and Lott (2002) provide two figures to explain the radiant energy flows that are experienced by an animal with and without shade. Figure 1 shows that an unshaded animal is affected by shortwave radiation that is diffused by reflection off the ground, clouds, dust and other airborne matter as well as off structures and other animals (Binns, Petrov & Lott, 2002). Some long wave radiant energy is also exchanged between the animal and it's surrounds (Binns, Petrov & Lott, 2002). Therefore, depending on the surrounding temperatures of the ground and air, the animal is either an emitter or absorber of radiation.

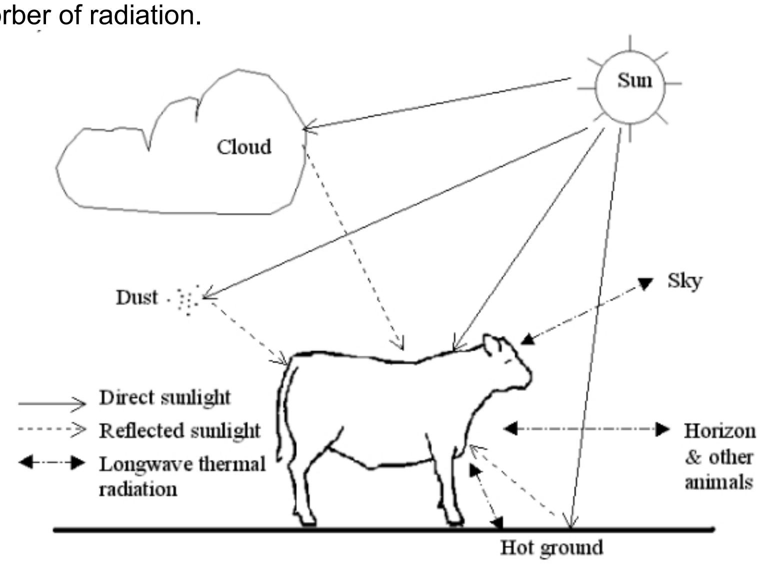

Figure 1. Main radiant energy flows for an animal without shade (Curtis, 1983 presented in Binns, Petrov & Lott, 2002).

The interactions of an animal with its thermal environment when under shade are more complex than those seen in an animal without shade (Figure 2). Although the animal is affected by less direct solar radiation, to a lesser extent it is still largely affected by reflected shortwave radiation (Binns, Petrov & Lott, 2002). The surfaces of the shaded ground and the shade itself also provide additional radiative surfaces for the animal to interact with and hence to increase heat loss (Binns, Petrov & Lott, 2002).

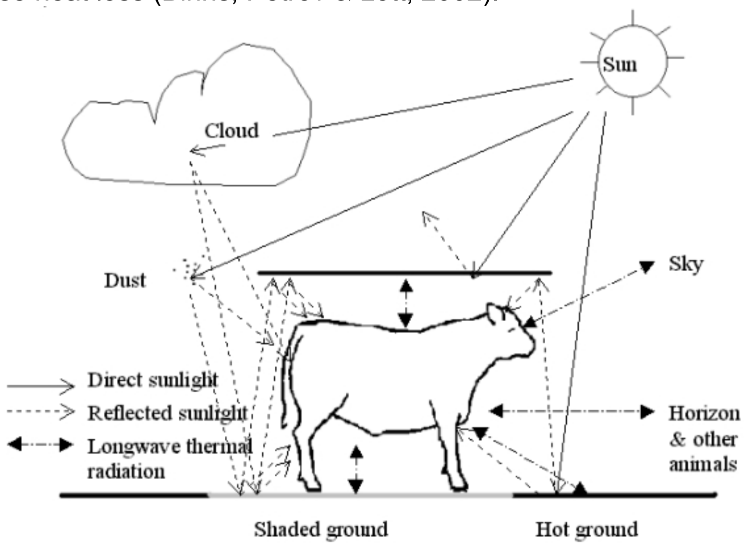

Figure 2. Main radiant energy flows for an animal with shade (after Curtis, 1983 presented in Binns, Petrov & Lott, 2002).

2.2 Energy Balance of a Feedlot Steer

A basic analysis of the energy balance and heat transfer systems of an animal in the feedlot environment identifies the key issues related to minimising heat loads. A MLA funded study in the summer of 2000/2001 undertook an assessment of the energy transfer systems of a lot fed steer in the feedlot environment (Petrov, Lott & Cork, 2001). The primary transfer systems were identified by computing the relative energy inputs and losses. These inputs and losses were calculated by using data collected over the study period and formulae described by Sparke *et al.* (2001). The primary transfer systems identified are shown in Figure 3 and were:

- Metabolic heat production (heat released from the digestion of food);
- Water consumption (heat transfer from animal to consumed water);
- Radiant heating (direct heating from solar radiation);
- Evaporative losses (cooling processes such as panting and to a lesser extent sweating);
- Radiant heat loss (heat transfer from the animal to the surrounding environment);
- Convective heat transfer (loss of heat from animal to surrounding air).

Estimates on energy transfers were made for varying climatic scenarios by quantifying some of the above transfer systems using the formula described by Sparke *et al.* (2001). The calculations were based on four separate climatic scenarios (varying only temperature and wind speed) applied to a shaded pen and an unshaded pen. A summary of the energy transfers (calculated over a 24 hour period) for the different scenarios are presented in Table 1.

Table 1. Calculated Daily (24 hours) Energy Transfers (MJ) under Different Climatic Scenarios.

	Cold and windy		Cold and still		Hot and windy		Hot and still		Very Hot
	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Unshaded
Metabolic Heat Production	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+104 MJ
Incoming Radiation	+ 10 MJ	+ 39 MJ	+ 10 MJ	+ 39 MJ	+ 10 MJ	+ 39 MJ	+ 10 MJ	+ 39 MJ	+39 MJ
Radiant Heat Loss	- 141 MJ	- 141 MJ	- 141 MJ	- 141 MJ	-22 MJ	-22 MJ	-22 MJ	-22 MJ	+ 6 MJ
Water Consumption	- 6.0 MJ	- 6.0 MJ	- 6.0 MJ	- 6.0 MJ	- 3.5 MJ	- 3.5 MJ	- 3.5 MJ	- 3.5 MJ	-3.5 MJ
Convective Loss	- 360 MJ	- 360 MJ	- 104 MJ	- 104 MJ	- 138 MJ	- 138 MJ	- 103 MJ	- 103 MJ	0 MJ
Net Energy Change	**-393 MJ**	**-364 MJ**	**-137 MJ**	**-108 MJ**	**-49.5 MJ**	**-20.5 MJ**	**-14.5 MJ**	**+14.5 MJ**	**+145.5 MJ**

Cold - T_{air} = 10°C, T_{water} = 15°C
Hot - T_{air} = 35°C, T_{water} = 25°C
Very Hot - T_{air} = 40°C, T_{water} = 25°C
Still - Wind speed = 0 km/hr
Windy - Wind speed = 10 km/hr

Some formula used above are empirical and are not accurate for some situations. For instance, the loss of energy by convective means should approach zero as conditions become hotter (ie, approaching animal body temperature) and wind conditions reduce to still. It has also been assumed in the calculations that shade has not had an effect on wind speeds. Despite some equations and thus results being of questionable quality, the tabulated data highlights trends in relation to the energy balance and the effects of shade. Key issues are;

- The largest single variable in the energy balance is the excess energy derived from digestion of the ration. It contributes 73% of the input energy to the animal.
- Shade has large impact on the energy balance by reducing the radiant heat load on cattle.
- Convective heat loss is the largest and main means of heat loss, even in hot conditions.

Convective losses occur through the transfer of heat from one body of a gas or liquid to another and subsequent movement of the heated and less dense medium. For a steer, heat is transferred from the coat to the surrounding air and subsequent wind movement around the body moves the heat away. When ambient air temperatures exceed body temperature, heat gain increases because convective losses and radiant losses reduce to zero or become energy/heat inputs. In this case shade does not prevent heat gain or increasing heat load, but it can assist in slowing the rate of gain.

Reducing the gross energy intake of the cattle during heat stress events will also have a direct effect on the energy balance of the animals. The normal reduction in appetite observed during hot weather is the result of the animal's natural satiety control mechanisms acting to reduce gross energy intake. However, where the onset of the stress event is rapid this physiological mechanism may not occur within sufficient time. Clearly if a stress event is forecast, altering the feeding regime to reduce gross energy intake can be a key mitigation measure for avoiding heat stress. Unlike metabolisable energy (ME), the gross energy (GE) value of feeds is relatively constant across common feedstuffs and reductions in gross energy intake normally necessitate reducing actual feed (dry matter) intakes rather than changing the composition of the diet. There is some evidence that increasing the fibre or protein content of the feed (reducing ME but not DE) without substantially decreasing feed intake may actually decrease the animals' upper critical temperature, effectively increasing their susceptibility to heat stress.

Because the major heat loss mechanism is through convection, design of shade structures and management of cattle must ensure that wind speeds are maximised in the feedlot pen, and that where possible, air temperatures are kept below body temperature. While the animal appears to lose only a small amount of energy in warming water to body temperature, the presentation of cool water (15°C) is likely to play a pivotal role in reducing heat loads at times of heat stress.

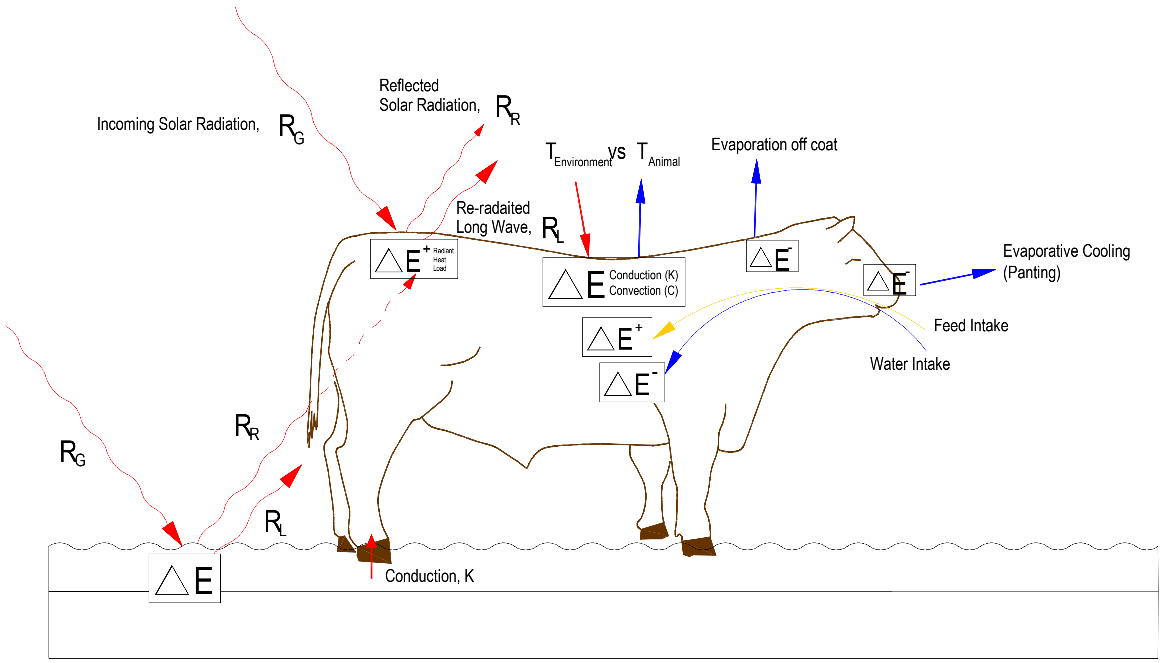

Figure 3. The energy balance of a lot fed steer.

Cattle have thick hides and hair for the regulation of the animal's metabolism that is geared to managing heat loss in cool temperatures. It is designed to limit heat loss through conduction from the inner body to the skin and then loss of heat by convective means. The hide also limits water loss by sweating that varies as a function of hide type and thickness. Bos Indicus cattle are reputedly able to sweat more than Bos Taurus cattle as they have thinner hides that provides better exchange of body heat with the atmosphere as blood is able to circulate close to the hide surface.

The equations used for determination of convective energy loss in the above analysis do not account for energy transfers associated with the loss of energy from the animal through sweat (water) on the coat, thus providing energy for evaporation. While some energy used for evaporation would be supplied by the surrounding air, most would come from the animal hide. The energy loss from such evaporative cooling is a function of animal size and thus hide surface, the amount of water spread over the hide as sweat, the temperature of the animal hide, the ambient dry bulb temperature of the surrounding air mass and the amount of moisture in the air.

The calculation of energy loss given these variables is theoretically simple and uses equations well utilised in atmospheric physics and thermodynamics. Unfortunately few data are available that accurately define the hide and sweating characteristics of lot fed Bos Taurus animals housed in Australian conditions. These data need to be obtained to provide better definition of the energy balance through physical determinations. Appendix C provides a description of the relationships between ambient air temperatures and relative humidity.

2.3 Summary

Through a number of processes, shade can be utilised to reduce the overall heat stress of an animal or herd of animals. One of the most significant processes is by reducing the incidence of shortwave radiation to the individual which in turn results in a reduction in the amount of energy in the form of heat impacting upon the animal. Radiation is most obviously reduced by installing shade structures that reduce the impact of incidence of solar radiation. Modifying feed rations to low energy rations and by ensuring that stock water is kept cool can further reduce heat load.

Although shade is a useful tool for reducing heat loads and stress in livestock, if incorrectly designed and poorly maintained shade can at times lead to increased levels of stress and cattle discomfit. This can occur due to two main factors. The first is simply due to the presence of the shade structures reducing wind speed. An investigation completed by Petrov, Lott and Cork (2001) into microclimate variations in cattle feedlots showed that shade may greatly reduce localised wind speeds. This in turn reduces the capacity for cattle to be cooled through convective and evaporative means.

Stresses to cattle can also be increased due to increased levels of humidity experienced under shade structures that are not designed appropriately. If orientated incorrectly, shade structures can prevent the feedlot pad from drying out following rainfall which can in turn lead to an increase in localised humidity and can result in other issues such as increases in the production of ammonia gas. It is therefore important that shade structures are designed and constructed appropriately to ensue that levels of heat stress are reduced and not increased.

3. FACTORS INFLUENCING SHADE DESIGN

The effectiveness of shade provided to an animal exposed to both high temperatures and high levels of solar radiation is dependant upon a number of factors. These can be broadly defined as the following:

- The thermal properties of the shade material;
- The height of the shade structure;
- Size of shadow;
- The slope of the shade;
- Location of shadow;
- Shadow orientation; and
- The level of ventilation.

These factors are discussed in depth within the literature review completed by Binns, Petrov and Lott (2002) that is attached as Appendix G.

3.1 Thermal Properties of the Shade Material

The properties of shade materials that affect their efficiency include the radiative properties (sorptivity and emissivity) of the upper and lower surfaces, the thermal conductivity or conversely, thermal resistance of the material and its thermal capacity (Binns, Petrov & Lott, 2002).

Two types of systems are widely used in the feed lot industry; the use of iron sheets attached to cables (Figure 4) or shade cloth that is either permanently fixed or furlable (Figure 5). The improvements that have been made to these systems over time are largely the result of trial and error and considerable practical experience from feedlot operators.

Figure 4. A sheet & cable feedlot shade structure with a variety of spatial configurations of sheeting.

Figure 5. A shade cloth covered feedlot shade structure.

The importance of shade material selection is demonstrated by Kelly and Bond (1958 quoted in Binns, Petrov & Lott, 2002), and more importantly they demonstrated the importance of having a white coating on the upper surface and black coating on the lower. The purpose of the upper white surface is to reflect incoming beam radiation whilst the black underside allows for adsorption of reflected radiation from the ground. A summary of the effectiveness of shade materials based on black globe temperatures and related to new, untreated aluminium is shown in Table 2. As well as highlighting the importance for variations in top and bottom colour, this table also highlights the loss of efficiency due to weathering of the material over time.

Table 2. The relative effectiveness of various shade materials when compared to new aluminium (Kelly & Bond, 1958 quoted in Binns, Petrov & Lott, 2002)

Material	Treatment	Relative effectiveness
Aluminium	Top white, bottom black	1.103
Galvanised iron	Top white, bottom black	1.066
Galvanised iron	Top white, bottom natural	1.053
Aluminium	Top white, bottom natural	1.049
Aluminium	New, untreated	1.000
Aluminium	One year old	0.994
Galvanised iron	New, untreated	0.992
Galvanised iron	One year old	0.985
Aluminium	Ten years old	0.969
Shade cloth	92% solid	0.926
Shade cloth	90% solid	0.839

The use of corrugated iron sheeting that is shown in Figure 4 is often utilised with gaps between the individual sheets to facilitate clamping, improve airflow an enhance drying of the manure pad (Binns, Petrov & Lott, 2002). It is not possible to provide definitive conclusions as to the benefits or otherwise of these sheet and cable systems (Binns, Petrov & Lott, 2002).

Shade cloth is generally less expensive than solid roofing material and the supporting structure required for shade cloth need not be as substantial due to the reduced load it must carry (Figure 5). However, as shown in Table 2, shade cloth is not as effective in terms of protection from solar radiation and the durability may not be as good as that of solid roofing materials. Natural air movement under a shade structure is affected by the ease with which air can move through the structure. As such, shade cloth does have the advantage of allowing some air to pass directly through the material, whilst structures constructed from galvanised sheeting require openings to assist air movement. There is a lack of comprehensive data on the relative benefits and disadvantages of shade cloth and discontinuous sheeting in regard to air movement and effective shade (reductions in solar radiation levels).

3.2 Shade Height

Shade height has no impact upon the size of the shadow due to the unidirectional nature of solar radiation (Binns, Petrov & Lott, 2002). Shade height can however have impacts on air movement and the diffuse and radiative load on cattle (Binns, Petrov & Lott, 2002). Shade less that four metres in height can result in a significant reduction in air movement (Petrov, Lott & Cork, 2001) which in turn can limit the amount of heat energy that an animal can lose through convection.

Increasing the height of shade structures and allowing stock more space to spread out can combat restricted air flow. While increasing the height of a shade structure will improve ventilation, it wall also result in increased wind loads on the structure and, depending on the location of the shade, increased rate of movement of the shadow over the ground surface. Although the height of the structure does not impact upon shadow size, it does effect the rate at which the shadow will move along the surface.

3.3 Shadow Size

Binns, Petrov and Lott (2002) found little consensus regarding the minimum optimum area of shade that should be provided for cattle, although obviously the minimum area should be sufficient to shade all housed animals. Based on current literature, Binns, Petrov and Lott (2002) suggested that a minimum shade allocation should be around 3.5 m^2 per head but may be increased to an area as large as 6.0 m^2. The size of the shadow is most affected by the slope of the shade material.

3.4 Shade Slope

According to Binns, Petrov and Lott (2001), there are four potential advantages to sloping shade structures, however much of the current literature is unable to provide substantial evidence of the advantages and disadvantages of each. These four potential advantages are the chimney or stack effect, the increasing of the shadow size, the increasing of the animal's exposure to "cool" sky and the changing of the angle of incidence of solar radiation to the shade surface (Binns, Petrov & Lott, 2001).

The chimney or stack effect relates to the convective movement of thermal buoyant currents. As the air under a shade structure is heated, it will rise and escape from the raised side of the shade, hence drawing cooler air in from the bottom. Although it is know that this process does occur, there is little current literature available that outlines what slope the shade should be angled at (Binns, Petrov & Lott, 2001). It is generally recommended that slopes of around 18 degrees be used.

According to Binns, Petrov and Lott (2001), correct shade slope can result in a number of potential advantages, however more information is needed regarding how shade slope will impact upon shadow size. It is known that increasing latitudes will increase the mean size of the shadow throughout a day, but it is not known how this variation changes for individual moments throughout the day (Binns, Petrov & Lott, 2001).

3.5 Shade Orientation

Orientation of a shade structure along an east-west axis will result in a maximisation of shadow directly under the shade throughout the day. This has the main benefit of reducing the temperature of the ground that the animal is exposed to, however it reduces the evaporation from the shaded surface (Binns, Petrov & Lott, 2001). Reducing the evaporation from the feedlot pad my result in increased accumulation of wet manure and levels of odours, and according to Petrov, Lott and Cork (2001) may lead to an increase in the production of ammonia gas as well as an increase in humidity beneath the shade. The increased humidity will impact upon the level of cattle comfort experienced by the livestock as this will reduce convective and evaporative losses from the animal.

3.6 Ventilation

According to the information presented in Table 1, air movement is an important factor driving the lowering of pen temperatures and in the relief of cattle heat stress. Design of shade structures should ensure that ventilation is not restricted. Air movement under a structure is influenced by the height and size of the shade structure, its slope and the ease with which air may move through the shade material and between the shade structure.

4. REVIEW OF CURRENT SHADE STRUCTURES

Current feedlot shade designs have evolved over time. Most are of simple designs to minimise capital and ongoing maintenance costs. However, even though the structures are agricultural, structures of such size should be engineer-designed and certified. This includes the structural connection details, especially where tensioned cables are involved, and the fixing details for the corrugated iron sheeting.

4.1 Industry Observations

A structural engineer made detailed inspections of three shade systems during this project. A number of observations were made regarding the practicality, durability and effectiveness of these current shade structures. Other shade structures were reviewed by E.A. Systems staff.

4.1.1 Feedlot A

Two types of livestock shade structures were observed at Feedlot A, those using shade cloth and those using corrugated iron sheeting. The iron sheets were aligned north-south, to allow for a high traverse of shade. Figure 6 shows the shade structures at Feedlot A that utilise corrugated iron sheeting.

Figure 6. Shade structure at Feedlot A utilising corrugated iron sheeting.

The oldest structures at Feedlot A had been erected for more than ten years with few visual signs of aging. The design had incorporated concrete pillars to protect the bases of the main steel posts. If the steel had been left unprotected, the harsh environment of the feedlot pad could have accelerated corrosion of these structures.

Due to the high performance of the early structure in terms of low cost and minimal maintenance, subsequent shade structures at Feedlot A were modeled on this one. Several slight changes were made to the design for later structures. The first structure had utilised two layers of steel sheets in a staggered pattern that could be adjusted to vary the amount of shade provided. The position of the steel sheets was rarely adjusted, so this option was not included in later structures.

The use of shade cloth to provide shade was largely replaced by corrugated iron sheeting throughout Feedlot A. This was a cost reducing measure as although the shade cloth had performed reasonably well in terms of effectiveness, the stitching had failed after about five years resulting in long term durability issues.

4.1.2 Feedlot B

The shade structures observed at Feedlot B were part of a new extension to the feedlot that had seen new shaded pens constructed (Figure 7). These pens are typically 40 to 60 metres wide. The roof of the structure was sloped to maximise the area of shade in the hottest part of the day.

Three individual posts supporting the shade structure extended down the middle of each of the pens. These posts located inside the pens were mounted on concrete plinths that stood 1.2 metres proud of ground level. As with Feedlot A, this lifted the post bases out of the damp and corrosive area of the pen floor. Shade cloth had been investigated as an option, but even though it was half the price of the corrugated iron, the 20 year life span of the corrugated iron outweighed the anticipated five year life of the shade cloth (based on past industry experience).

Figure 7. New shade structures constructed at Feedlot B.

The shade structures at Feedlot B were secured with an arrangement of seven sets of wires that held the corrugated iron sheets in place. The sheets of corrugated iron were inserted between the wires where they were secured into place by clamping the wires together. There were screw piles at each end of the structure. Steel SHS tension members were attached to the main structure to provide restraint and tensioning at one end, whilst at the other end the cables were secured and tensioned with the system shown in Figure 8. The cables were strained to 2 tonnes, and the tension was held at one end using chains that were secured in slots cut into a steel beam. The beam was held to ground using screw piles.

Figure 8. Anchorage and cable tensioning system seen for the shade structures at Feedlot B.

4.1.3 Feedlot C

The shade structures at Feedlot C were older than those seen at Feedlots A and B with one of the shade cloth structures installed ten years ago. The shade cloth covering had had major repairs three times in that period, mostly due to deterioration of the stitching. Hail damage and damage caused by birds chewing cloth stitching resulted in deterioration of the cloth, whilst hot exhaust fumes from machinery had resulted in holes being burnt through the cloth. Conversely, shade structures that utilised corrugated iron sheets were considered to be in the same condition as when they had been erected.

The corrugated iron shade structures are shown in Figure 9. The gaps in the corrugated iron sheets had been rationalised to 100 mm which allowed the sheets to be clamped and allowed some movement of the air through the shade that assisted in cooling animals and in drying the feedlot pad. The shade had a slope of eight degrees.

The iron sheets were fixed in a similar fashion to that seen at Feedlots A and B using several pairs of tensioned cables. The corrugated iron sheets were mounted between the pairs of cables and were clamped into place.

The positioning of the iron sheets between the cables had to be exact. If there was too much overhang at the end of the sheet, it could break off. Long overhangs of iron at one pen had been bent during a severe windstorm. Too little overhang could allow the sheet to shake loose of the cable. Overhangs of at least 250 millimeters appear to be the most suitable.

The main columns were again encased in concrete plinths to provide protection from corrosion. It was stated that the concrete plinths would be made taller in future, up to the cattle's hip. The older structures displayed an innovative array of structural material that had been used to build the structure. Old drill stem and steel pipe had been utilised.

Figure 9. The shade structures observed at Feedlot C.

4.1.4 Feedlot D

The shade structures at Feedlot D consisted of an older design and a more conventional design similar to that observed a feedlot C. The older design is reviewed in this section. It is shown in the plated presented in Figure 10.

The older design is innovative and it aimed to provide a large amount of shade per animal, shade spread through out the pen and a high degree of ventilation. The shade is supported by main cables strung from posts on the corner of pens to a central higher post in a "pavilion" fashion. Lighter cables are then passed from main cable to main cable in conjunction with the shade cloths.

The design was developed with input from a structural engineer and failure of the structure per se has not occurred. Shades have had to be replaced.
The character of the structure is such that the shades are more difficult to fix and therefore the cost of replacement is higher than other shade structures.

Figure 10. The original innovative shade structures observed at Feedlot D.

4.2 Summary

Discussions with staff at the investigated feedlots revealed that an ideal shade structure would have no posts in the pens, would be durable, cheap, and would be able to be taken down easily and folded for storage in winter.

Shade cloth is not the preferred choice of material due to levels of deterioration seen in stitching that requires replacing every three to five years. Shade cloth can also be damaged by hail, birds and machinery exhaust. Another problem with shade cloth occurs during winter storage when it has been prone to damage by vermin.

Use of corrugated iron has been found to be more durable for longer periods of time. However, corrugated iron has resulted in safety issues when it has broken free of attachments during strong winds.

There are metal meshes, which could solve the storage problems, because vermin wouldn't nibble them. They would be more durable in service, stitching would last longer and the mesh would not be damaged by the heat from a loader's exhaust pipe. However, these metal meshes are expensive, and would not be able to compete in terms of cost with plain corrugated iron.

Most current designs incorporate concrete pillars to protect the bases of the main steel support posts from corrosion. These posts are particularly susceptible to corrosion due to the aggressive environment of the feedlot pad.

Maintenance of pen floors under shade was recognised as a major problem. The shaded areas obviously do not dry out as well as the unshaded areas which can contribute to greater wear on the pen surface and increased maintenance costs associated with holes forming in the pad that can trap water and become odorous. Increasing the height of shade structures would assist to reduce this problem by allowing greater movement of shade and greater airflow beneath the structure.

The design of the existing shade structures has proven itself in the time that they have been in use. The improvements that have been made and are planned are the result of observation, and trial and error.

Throughout the Australian feedlot industry a number of alternative designs for shade structures that have been developed. These have been developed with varying levels of success and have typically utilised sloped sails to provide protection from solar radiation (Figure 11). Typically the costs involved for design, construction and maintenance are greater than those associated with the designs investigated in the study.

Even though the structures are agricultural, structures of this size should be engineer designed and certified. This includes the structural connection details, especially where tensioned cables are involved, and the fixing details for the corrugated iron sheeting. The galvanized iron sheets could be very dangerous if they worked loose in a high wind or a storm.

Figure 11. An effective current design of a shade structure utilised in Australia constructed from sloped shade cloth.

5. STRUCTURAL DESIGN OF SHADE SYSTEMS

5.1 Dead Loads

A "dead load" is the load supported by a structure which is equivalent to the mass of the materials held by the structure. The load is applied vertically downward due to gravitation force. This means that the load is passed either vertically down ward through a support column or is resisted by systems such as tension cables (Figure 12).

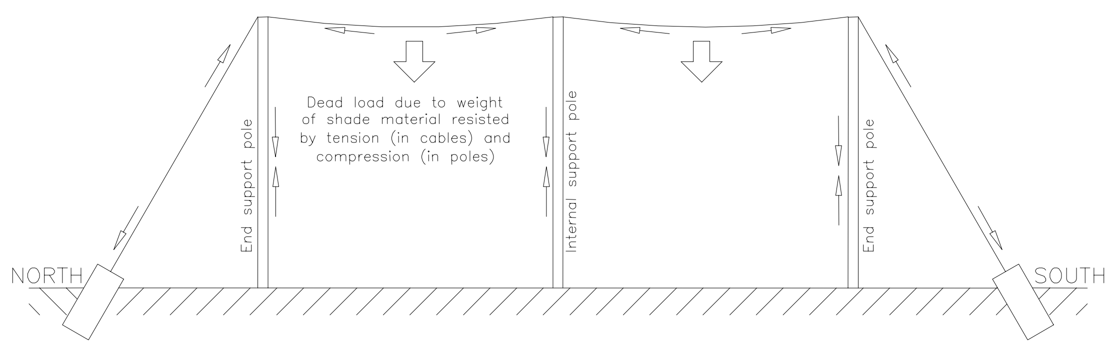

Figure 12. Columns and tension cables to resist dead loads.

The dead load of galvanised sheeting is greater than that of shade cloth. Consequently, the support structures holding up galvanised iron shading need to be more substantial than that needed for cloth based shades.

5.2 Live Loading

A live load is a load that varies in character. It typically results from movement of a structural member or other variable, intermittent or oscillating force. Wind gusts are the most common live loading on structures. In the case of shade structures, wind driven movement of the shade will cause dynamic loading of the structure through swinging of the structure, or alternating uplift or down draft loads on the structure.

The movement of wind against a solid structure results in directional loads. If wind is moving against a wall it causes a side load. As wind moves up and over a roof structure it causes a down load on the front face of the roof and an upload on the downwind face as a result of an induced area of low pressure over the inclined surface. These forces must be taken into account when designing a shade structure; especially if the shade itself is sloped to obtain advantages in shading and ventilation. A sloping shade structure will act as an aerofoil depending upon the direction of the wind. These directional forces are shown in Figure 13.

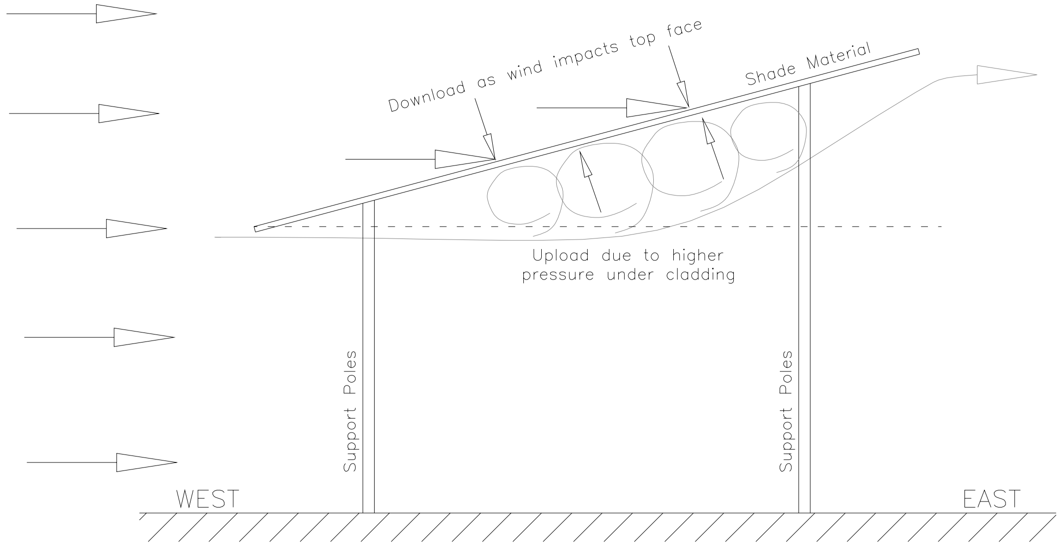

Figure 13. Live loading on shade material from wind

The ability of the structure to shed load and dampen out oscillations becomes important when taking account of dynamic loads. The weight of the moving section is also of critical importance as the energy contained in movement of the part is related to its mass and the square of its velocity. Consequently, a heavy moving structure becomes difficult to constrain.

5.3 Design Standards

Basic pressure wind loadings for 'canopy' and free-standing structures is covered in AS1170.2 Section 2.4.3 and 2.4.4. This standard accounts for both the upward and downward pressures that are discussed in sections 5.1 and 5.2. AS1170 also accounts for variations in loads dependant upon the type of roof cladding utilised in the structure.

5.4 Shade Structure Designs

5.4.1 Existing Design

During this research project and industry review completed for this report, the shade design at Feedlot A proved to be one of the most effective conventional systems in terms of meeting environmental and structural recommendations. The shade designs from Feedlot A are shown in Appendix A.

5.4.2 Improved Design

The research undertaken during this project allowed a new generation of shade structure to be designed. This design was based on the premise that feedlot pens were 60 metres in depth and 63 metres wide with a capacity to contain 250 bullocks at a stocking density of 15 m^2/head. A conceptual design is presented in Figure 14 and Figure 15. Detailed structural designs for the improved shade designs are shown in Appendix B.

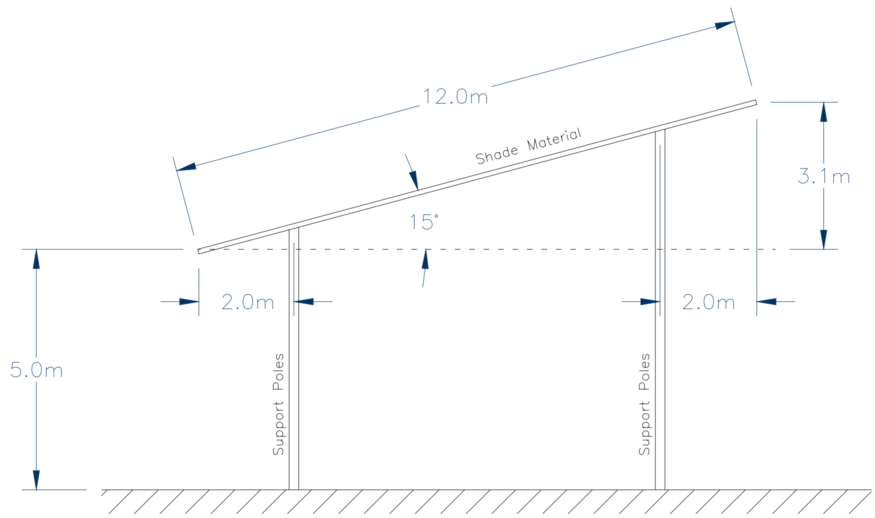

Figure 14. Conceptual Shade Design (Elevation).

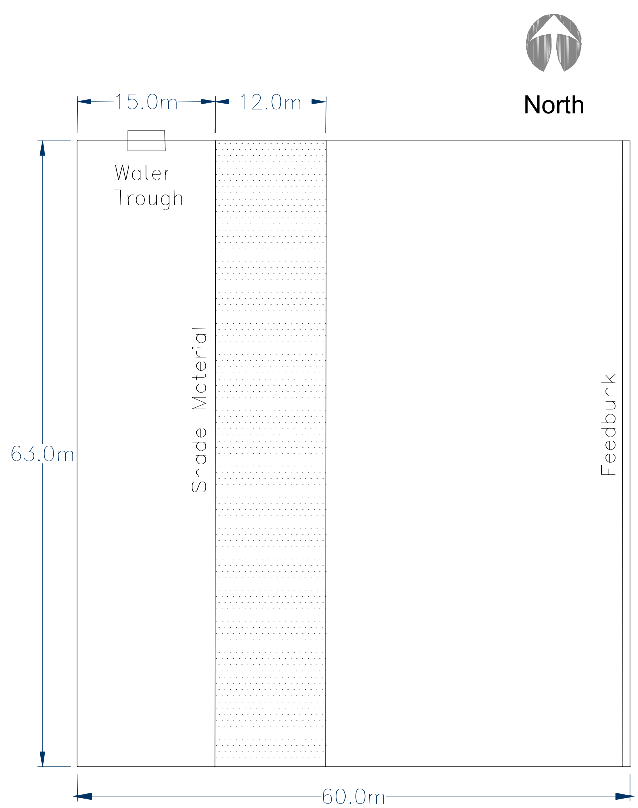

Figure 15. Conceptual Shade Design (Plan).

It is proposed that the shade is located as a strip that runs across the feedlot pens in a north-south direction. The shade is pitched with the 'eave' towards the west. The upper side of the material is white and the bottom side is matt black. It is assumed that the material is a heavy duty shade cloth that will allow high winds and rainfall to pass through the material.

Because the shade is on an angle its profile to winds will make it act as an aerofoil. Structural design of the structure to counter these aerodynamic features becomes important and the pervious nature of shade cloth and its lightness assists in obtaining design efficiencies over that for shade that utilises coloured galvanised sheeting.

The western ‘eave’ is at least five metres off the ground to improve side ventilation. Many existing shade structures are about four metres high and it is likely that this restricts air movement beneath the structure. Petrov, Lott and Cork (2001) showed that existing four metre high shade structures at two Australian feedlots significantly reduced wind speeds beneath the shade structure.

The shade is 12 metres wide, which should allow for effective use of materials as most are provided in six metre lengths. If the pitch is 15°, the top of the shade is 3.1 metres above the lower eave of the shade. If the slope is 10° the upper edge is two metres higher than the western edge. The 12 metre wide strip of shade will have a 11.6 or 11.8 metre planer width, given the pitch of 15 or 10 degrees respectively. This equates to a shade cover of 2.92 m^2/hd or 2.97 m^2/hd if the sun were immediately overhead.

In the afternoon an increase in shaded area due to the western pitch will become available to cattle. Based on the position of the sun at Toowoomba on the 20th of January between 3 and 4pm, the average increase (over the hour) in shaded area is 28.5% (15°) or 18.4% (10°). Therefore the shaded area increases to 3.75 m^2/hd or 3.51 m^2/hd respectively.

Because the shade material is high and pitched, the shade will move across the pen quickly. Shade providing the largest area per animal is most important late in the afternoon when stock have been accumulating heat for longest and day time temperatures are at their greatest. Petrov, Lott and Cork (2001) found that the highest day time temperatures often occurred between 2 and 4pm EST and that typically stress occurred in the period between 2 and 6pm, with cattle often showing most stress in the period between 3 and 5pm EST.

Some care needs to be taken in the location of the shade to ensure that the shade is kept within the pen during the afternoon. By 4pm (EST) on the 20th of January, the throw of the shade from the 15° shade will be 10.75 metres (9.3 metres for 10°), by 6pm (EST) the throw will be 41.2 metres (36 metres for 10°). This gives reason to place the shade on the western side of the pen.

Conflict with the placement of the water trough needs to be avoided because the water trough is an area where moisture accumulates. It is recommended that in earth based yards that they are located away from shaded areas to limit the build up of wet manure. Figure 15 shows a simple plan of the position of the shade as described. It is located 15 metres off the western fence line that allows for sufficient room to place a water trough on the dividing fence line whilst providing some distance between the pen gate and the trough, and the trough and shade structure. The throw of the shade at 6pm would result in the shade being cast onto the feed bunk if the pitch of the shade was 15°.

The above shade design will result in an area beneath the shade that will become moist. This area, if not well managed to limit manure accumulation and moisture build up, will result in increased humidity and elevated ammonia levels within the pen and beneath the shade. Repair and maintenance of the pen surface will also be high in this area. It is strongly recommended that areas beneath shade structures be regularly cleaned of wet manure. It is noted that an increased height of the proposed shade structure will provide both a greater exposure of the pen to drying by morning to midday sun, and a greater movement of shade which will act to limit the occurrence of shade related wet pen conditions.

6. CONCLUSIONS

When exposed to ambient temperatures in excess of body temperature, the productivity and welfare of lot fed cattle can be severely compromised and extreme cases can lead to cattle death. The provision of shade for cattle will provide a medium to improve the capacity of an individual beast to increase excess heat loss and hence reduce losses in production and issues of cattle welfare. This report investigated a number of current shade designs and incorporated additional findings to present a new generation of shade design.

It is know from previous investigations and readings of current literature that the effectiveness of shade is largely dependant on the following factors:

- The thermal properties of the shade material;
- The height of the shade structure;
- Size of shadow;
- The slope of the shade;
- Location of shadow;
- Shadow orientation; and
- The level of ventilation.

Each of these factors were considered during the development of the improved feedlot shade structures shown in Appendix B. A review of several current shade structure designs utilised in Australia were surveyed in regards to those factors outlined above. The survey results found that:

- Shade cloth is not preferable due to levels of deterioration, however it would be satisfactory if longevity and durability were increased and improved fixing systems were developed.
- Corrugated iron has a much longer life span in most environments although may be dangerous if not attached appropriately and is removed by wind.
- Concrete pillars should encase the bases of steel posts to guard against corrosion.
- Shade should be constructed to allow easy pen maintenance beneath and most importantly, promote the drying of the pen pad.
- Removal of shade during winter is desirable, although stored material must be protected from damage.
- An ideal shade structure would have no posts in the pens, would be durable, cheap and would be able to be taken down easily for winter storage.

Although it is not possible to incorporate all of these limitations into a feasible shade design, such as the absence of posts within the pen, many of these recommendations were incorporated into the new design presented in Appendix B.

The improved shade design shown in Appendix B is based on a pen of 60 metres by 63 metres with a holding capacity of 250 bullocks. It is proposed that the shade will run north-south with the shade eave pitched towards the west. The material should be a heavy duty shade cloth to allow high winds and rainfall to pass through, and have a white upper and matt black surface.

The improved shade design has the western eave at least five metres off the ground to improve ventilation with the entire structure around 12 metres wide to allow for effective use of materials. The shade is to be pitched between 10 and 15 degrees. Care has been taken to ensure that the positioning of the shade structure ensures that the shade remains in the pen for much of the afternoon. The shade structure is also designed to be positioned so that it will impinge on feed bunks and watering troughs as little as possible.

This new shade design results in limited impact to feed yard operations whilst providing maximum protection to penned livestock. The position of the shade is designed to ensure that drying of the yard pad is promoted and hence further production losses and cattle welfare issues are reduced.

The use of shade is important for obtaining reductions in the heat load suffered by animals lot fed in hot climates. Care needs to be exercised in the design of shade systems to ensure that pen conditions are improved and the reduction in heat load is optimised.

6.1 Recommendations

1. Further investigation and modeling is required to determine how shade slope will impact upon shadow size.
2. Areas where excessive heat loads are expected should be identified.
3. The risk of heat load in lot fed animals at specific sites within these areas should be determined once the areas of expected heat loads have been identified.
4. The technologies identified in this project should be extended to industry.

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APPENDIX A - CURRENT SHADE DESIGN

APPENDIX B - IMPROVED SHADE DESIGN

APPENDIX C - PSYCHROMETRY AND HEAT STRESS

1. DEFINITIONS

1.1 Ambient Air Temperature

Ambient air temperature is the temperature of the surrounding environment (Oke 1978), measured with a standard thermometer. This is the standard temperature measurement in most applications. Ambient air temperature is also referred to as the dry bulb temperature.

1.2 Wet Bulb Temperature

Wet bulb temperature is measured using a standard thermometer covered with a wet wick (Oke 1978). Due to evaporative cooling from the wet wick, the wet bulb thermometer reads temperatures lower than ambient temperatures (Oke 1978). By measuring the ambient temperature and the relative humidity, the wet bulb temperature can be calculated using psychrometry methods, or conversely wet bulb and dry bulb temperatures are often used in calculating the relative humidity. The measurement of wet bulb temperature assumes that in the absence of external energy, all the energy used to evaporate the water from the wick is supplied by cooling the air (Oke 1978).

1.3 Relative Humidity

Relative humidity is the ratio of the mass of water vapour actually present in a unit volume of air to that required to saturate it at the same temperature (Department of Science and Technology & the Bureau of Meteorology 1975). Oke (1978) also defined humidity as the ratio of the mass of water vapour to the mass of moist air, or quite simply is a measure of the water content of the air. Relative humidity can change with only a change in ambient temperature, while the water content remains consistent and vice versa.

1.4 Psychrometry

Psychrometry is based on wet and dry bulb temperatures and their use to determine humidity (Oke 1978). The differences in the measured wet and dry bulb temperatures provide the relationship that determines the value for humidity. The methods used by psychrometry to determine humidity involve the use of thermodynamic methods for measuring temperature (Oke 1978). Psychrometric charts include wet and dry bulb temperatures, relative humidity, dew point temperature, enthalpy and water content of the air.

1.5 Latent Heat Transfer

Latent heat is the heat released or adsorbed per unit mass by a system when changing phase (Oke 1978). The term ‘phase’ is used to describe a specific state of matter such as a solid, liquid or gas (Young & Freedman 1996:9). Latent heat transfer will see no variation in temperature, it is simply a measurement of the energy absorbed or emitted to change phase (Oke 1978; Young & Freedman 1996:9). An example of latent heat transfer occurs when water is vapourized through an evaporative process. For this change of state to occur, energy must be added to the system, but if added slowly enough so that the liquid water and water vapour remain in thermal equilibrium, no temperature change will occur (Young & Freedman 1996:9).

1.6 Sensible Heat Transfer

Sensible heat transfer occurs when the addition or subtraction of energy to a body results in a rise or fall in the temperature of that body (Oke 1978). Sensible heat transfer is therefore the change in heat seen between phase changes.

2. IMPLICATIONS OF MEASURING PSYCHROMETRY AND HEAT STRESS

Psychrometry and the principles associated with it may provide a strong relationship between climatic conditions and the likely hood of cattle heat stress events. As suggested, psychrometry provides an indication of climatic conditions dependant upon both ambient temperatures and humidity.

Previous studies have attempted to determine climatic conditions leading to potential heat stress events in cattle by measuring wet bulb temperatures only (Barnes et al 2002). Barnes et al (2002) suggested that wet bulb temperature is a simple measurement that accounts for dry bulb temperature and humidity, and it is considered to provide adequate information while being easy to measure. The measurement of wet bulb temperature with respect to heat stress in animals may be used as an index of degree of comfort as wet bulb temperature combines both the ambient temperature and the relative humidity into a single number. However, with neither ambient temperature nor relative humidity recorded as well this information can only be used as a relative index and is of limited value.

Heat stress is a function of both ambient temperature and relative humidity (Petrov, Lott & Cork 2001), and a rise in one if not mirrored in the other is less likely to cause heat stress events. For example, if the ambient temperature is increased while the relative humidity remains constant or is reduced, the likely hood of a heat stress event is less than if both ambient temperature and humidity see a similar rate of increase. Normally heat stress events are due to a combination of increased ambient temperatures and relative humidity.

As heat stress occurs, an animal losses its ability to dissipate heat. This is because many warm blooded animals use latent heat and the change of state from liquid to a gas to remove heat from the body by using it to evaporate water from the tongue (panting) or skin (sweating) (Young & Freedman 1996:9). If either ambient temperature or relative humidity increase, then the ability of the animal to lose heat through evaporative cooling is lessened as the potential for latent heat transfer is reduced. A rise in humidity will cause this reduction in heat loss as the air becomes increasingly saturated and the potential to transfer water to air is reduced. Therefore the potential for energy transfer and thus for evaporative cooling is reduced. Increases in ambient temperatures reduce the potential for convective heat transfer from the animal due to a decrease in the level of sensible heat loss between the animal and the atmosphere.

Dealing with two factors may become complicated, however it is the combination of these numbers that determines the significance of the heat stress. For example an ambient temperature of 33^{o}C doesn't indicate whether heat stress might be a problem. But if we know the relative humidity is 10%, we can determine that heat stress isn't likely. Alternatively for that same ambient temperature, if the relative humidity was 95%, heat stress may become an issue.

With the lack of information presented by Barnes et al (2002), an appropriate management strategy cannot be determined. To determine management strategies effectively, both relative humidity and ambient temperature need to be known so that the appropriate heat loss mechanism can be used. The two heat loss mechanisms that can be determined by relative humidity and ambient temperature are latent and sensible heat transfer. As it is a convective process, latent heat transfer is dependent upon relative humidity whilst sensible heat transfer is dependent on ambient temperature.

So while the wet bulb temperature is simple to measure, it has limited applications when attempting to determine potential levels of heat stress and possible mitigation strategies (such as spray cooling, misting and wetting), and can only be used as a relative index. Thus wet bulb temperatures alone do not provide adequate information to be able to adopt an appropriate management solution that may reduce levels of heat stress.

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APPENDIX D - CONTACTS INTERVIEWED

Rob Donovan
Myola Feedlot
Croppa Creek Rd
North Star NSW 2408
Ph: (02) 6754 5333

Peter Paradice
Rockdale Beef Pty Ltd
PO Box 42
Yanco NSW 2703
Ph: (02) 6951 1199

Graham Flynn
Rockdale Beef Pty Ltd
PO Box 42
Yanco NSW 2703
Ph: (02) 6951 1199

Richard Sturgess
Beef City Feedlot
Australian Meat Holdings
PO Box 886
Toowoomba QLD 4350
(07) 4691 4301

Jim Cudmore
Kerwee Lot Feeders
PO Box 29
Jondaryn QLD 4403
Ph: (07) 4692 2277

Warren Salter
Sandalwood Feedlot
Dalby QLD 4405
Ph: (07) 4663 7739

APPENDIX E - TERMS OF REFERENCE

FLOT.315 - APPLIED SCIENTIFIC EVALUATION OF SHADE DESIGN

TERMS OF REFERENCE

THE CONSULTANCY SERVICES

BACKGROUND

There are a number of practical examples where the provision of shade has been effective in reducing feedlot cattle mortalities associated with excessive heat load during periods of very hot, humid weather.

An examination of the actual form and design of 'shade' employed in commercial operations reveals a wide range in terms of material type, area allocated per animal, size, shape, height, orientation, pen position, construction material and construction technique. Not surprisingly, the construction and maintenance costs associated with these various shade designs are also highly variable as is their effectiveness in providing protection to the feedlot cattle that utilise them.

The recent MLA funded project, 'FLOT.310 – Measuring Microclimate Variations in Two Australian Feedlots', identified both positive and negative effects of shade on the physical environment and concluded that shade design can be altered to reduce the negative effects and enhance the positive aspects, thereby contributing to an improved animal environment.

This project aims to examine the shade design issue, from the perspective of basic physical and engineering principles and applied experience, with the objective of developing an optimum practical cost effective shade structure that can be incorporated into both new and existing facilities, when required. It is also anticipated that the project will identify enhancements that can be made to improve the performance of shade structures currently in use within the industry.

OBJECTIVES

1. Review all aspects of shade design and construction on the basis of the findings of the FLOT.310 project report, information available in the scientific literature and industry experience with existing shade structures and designs.
2. Provide key design principles to be addressed in the development of an optimum practical cost effective shade structure. Parameters to be assessed when developing design principles include, but are not limited to:
    a. The physical attributes of the shade structures, including type of material used; area allocated per animal; size, shape and height of individual shade structures; ability to break the pen animal population into groups; and, orientation and position of structures within the pen area.
    b. Engineering aspects, including the ability to promote air movement and manure drying; ease of pen cleaning; and construction material and technique.
    c. Economic considerations, including construction and maintenance costs and useful life of structures.

3. Based on the key design principles developed, obtain engineering advice and input into the design of a new generation of shade structures that can be incorporated into both existing and new developments, if required. Recommendations should also be developed detailing enhancements that can be employed to improve the performance of existing shade structures.
4. Presentation of the information developed as a result of this project in a format acceptable for extension to operators within the feedlot industry, in addition to the MLA reporting requirements set out below.

REQUIREMENTS UNDER THE CONSULTANCY

Scope and Methodology

It is envisaged that this project will involve a number of components; including collection of relevant information from industry operators in addition to desk study and development components. The Australian Lot Feeders' Association (ALFA) and Meat and Livestock Australia (MLA) will assist the successful consultant with industry contacts able to assist with supply of information.

Consultants need to define their proposed methodology and work plan for addressing the project objectives.

Project Management

This project is a component of the MLA Feedlot Program, which has an Advisory Committee of Industry operators that will oversight the project and provide an ongoing guidance.

The outcome of this project will be referred to the Advisory Committee for endorsement prior to acceptance of the Final Report.

Output

The output of the project will be a Report that will be presented, in the first instance, as a Draft Final Report for the consideration and comments of MLA and the Advisory Committee.

The Report will be revised to address comments made on the Draft Final Report and be re-presented to MLA as a Final Report.

Two (2) bound copies, and one (1) unbound copy, of the Draft Final and Final Reports will be provided to MLA, as well as an electronic copy of the Final Report using agreed software. MLA has guidelines for presentation of Final Reports, which will be provided to the successful Consultant at the commencement of the project.

Notwithstanding the requirements set out in the MLA guidelines, the Final Report will contain:

- An Executive Summary (2-8 pages), which will, as far as possible, read as a stand-alone document that effectively summarises the full document in a form suitable for Industry.

- A section detailing the implications to Industry of the findings of the report and conclusions drawn.
- An appendix detailing a list of contacts interviewed during the course of the project.
- An appendix containing the Terms of Reference for the project.

If the Consultant has access to commercial-in-confidence data, germane to the project outcome, MLA would not require this to be presented in the Final Report, nor sources identified. Subject to agreement between the parties involved, such commercial-in-confidence data may be presented in an unpublished, Part 2 document.

Consultants should be aware that the Final Report may be reproduced in MLA format with due acknowledgment to their involvement in its preparation.

Access to Information

Where information is available which may assist the Consultant in meeting the requirements of this project, such information will be provided to the Consultant on a confidential, or other basis as indicated, by MLA. Confidential information would not be reproduced in the Report, consistent with the caveats mentioned under 'Output'.

Timing

MLA is anticipating that a contract to proceed with the project will be finalised with the Consultant by 12 October 2001. Contractors need to provide clear timelines for conduct of the various phases of the project.

Within the first fortnight of the project, the Consultant will deliver a brief Inception Report detailing suggestions (if any) on fine-tuning of the project scope and potential outcomes for consideration by MLA and the Advisory Committee.

Experience/Qualifications of Researcher(s)

The successful applicant(s) will have significant experience in this area of work, and a demonstrated record of high quality review achievements. Documentation supporting the credentials and experience of the review team should accompany the project proposal.

Costing

MLA seeks a quotation for the complete project to be conducted under these Terms of Reference. The quotation will provide details of the proposed methodology for conduct of the project and costing of each project component.

The details of costing provided to MLA will include professional fees, calculated on a daily rate for each person, or party involved, and will cover professional services of the Consultant, provision of office facilities, electricity, local telephone and facsimile calls, postage, clerical/secretarial services and indirect costs (overheads).

Out-of-pocket expenses will be reimbursed at cost for travel and accommodation, long distance telephone and facsimile calls and external costs of report preparation. Air travel costs will be reimbursed at a maximum of full economy rates. Estimates of expenses will be provided in the project proposal.

The details of the project content, methodology and costing may be adjusted with the agreement of MLA, following initial assessment of the project proposal. The project proposal should be submitted in the format outlined in the Research Proposal Preparation Guidelines attached.

Consultative Group Meetings

Consultants need to make provision for two (2) half-day meetings, if required, with the Advisory Committee. The initial meeting will be held at the commencement of the project and the second at Draft Final Report delivery stage. These will be separately identified and costed within the project proposal. Costings should be based on attendance at meetings in Brisbane.

Industry Presentations

Consultants also need to make provision for presentation of the project findings to an appropriate forum, if so requested by MLA. The costing of such presentation will be separately identified and costed within the project proposal. Allowance of one (1) day and travel to Sydney should be provided for.

Payment

MLA will make progress payments against completion of the components of the project identified, with milestones agreed to by MLA.
Final payment for the project will be subject to written acceptance of the Report by MLA. All payments will be subject to receipt of invoices and appropriate supporting documentation from the Consultant.

Subcontracting

The Consultant may wish to subcontract certain activities and analyses to other parties. In this case full details of the party or parties to be subcontracted, their capabilities and background and the activities or analysis that they would perform in the context of this project will also be provided to MLA. Notwithstanding this, the responsibility for the performance of the subcontractor will rest completely with the Consultant, with whom MLA would be contracted.

Reporting and Liaison

The Consultant will report to MLA through Mr. Des Rinehart. In addition to the Inception Report at the end of the first fortnight, the Consultant will provide a brief statement of progress with the project (by letter or facsimile) at the end of each month.

Confidentiality

The Consultant may divulge that the project is being undertaken at the request of MLA. Otherwise, the specification of the project, contents and conclusions of the project and the Report produced are strictly confidential. The Consultant may not disclose any details or information in respect of the project to any party without the prior consent of MLA.

Proposals may be lodged by post or electronically:

Des Rinehart
Feedlot Program Coordinator
Meat & Livestock Australia
9 Girral Road
THAGOONA QLD 4306

Email: rinehart@gil.com.au

Proposals must be received by **COB 21 September 2001**.

APPENDIX F - INDUSTRY SUMMARY PAPER

Feedlot Shade Structures

Dr Simon Carl Lott [1,2] Mr Peter Binns [3] Mr Ryan Petrov [4]

1 Principal Engineer, E.A. Systems
2 Honorary Associate, School of Natural Resources and Rural Science, UNE
3 Principal Scientist, E.A. Systems
4 Environmental Engineer, E.A. Systems

1. KEY RECOMMENDATIONS

a) Use shade in areas prone to high temperatures and radiation loads
b) In all dry arid areas place the shade on a north-south axis
c) The shade should be constructed to maximise ventilation, afternoon shade and a cool aspect
d) Management of the shaded pen area is needed to limit potential increases in repairs and maintenance and environmental problems
e) Seek engineering advice on the design of the shade structure.

2. THE NEED FOR SHADE

2.1 Heat Load

Over the Australian summer heat stress can cause a loss of production and in extreme cases, catastrophic stock losses. Heat stress of lot feed cattle can be defined as a condition where the thermal loads on an animal exceed its ability to lose heat by normal metabolic means. Excessive heat loads stress the animal.

The level of stress ranges from some discomfort (eg. panting) to death. The thermal loads arise from energy derived from ingestion of feed and water, digestion of a ration, incident radiation from the atmosphere and the ground, and direct heating by the surrounding air mass.

A range of factors influence the rate of heating of an animal. These include;

- type of ration (energy level and character of constituents);
- temperature of drinking water;
- magnitude of some atmospheric variables (eg. radiation, ambient air temperature);
- interactions between atmospheric conditions (eg. between ambient air temperature, relative humidity, and wind speed); and
- a number of ground characteristics (eg. ground temperatures, re-radiation of heat from the ground, moisture content of the pen surface).

A ‘stress event’ is considered to be a situation where atmospheric and ground conditions combine to create a microclimate in a feedlot which is unfavourable to animal production. Stress events are also linked to large numbers of cattle exhibiting discomfort, potentially an increase in health problems following the event, or possibly death.

2.2 Feedlot Animal Energy Balance

A basic analysis of the energy balance and heat transfer systems of an animal in the feedlot environment identifies the key issues related to minimising heat loads. It is possible to crudely compute relative energy inputs and losses using data collected over the study period. The primary transfer systems were identified and are illustrated in Figure 1. They are:

- Metabolic heat production (heat released from the digestion of food);
- Water consumption (heat transfer from animal to consumed water);
- Radiant heating (direct heating from solar radiation);
- Evaporative losses (cooling processes such as panting and to a lesser extent sweating);
- Radiant heat loss (heat transfer from the animal to the surrounding environment);
- Convective heat transfer (loss of heat from animal to surrounding air).

Estimates of energy transfers and the balance for varying climatic scenarios are presented in Table 1 below. The calculations are based on four separate climatic scenarios (varied temperature and wind speed) applied to a shaded pen and an unshaded pen.

Table 1. Calculated Daily (24 hours) Energy Transfers (MJ) under Different Climatic Scenarios.

	Cold and windy		Cold and still		Hot and windy		Hot and still		Very Hot
	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Unshaded
Metabolic Heat Production	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+ 104 MJ	+104 MJ
Incoming Radiation	+ 10 MJ	+ 39 MJ	+ 10 MJ	+ 39 MJ	+ 10 MJ	+ 39 MJ	+ 10 MJ	+ 39 MJ	+39 MJ
Radiant Heat Loss	- 141 MJ	- 141 MJ	- 141 MJ	- 141 MJ	-22 MJ	-22 MJ	-22 MJ	-22 MJ	+ 6 MJ
Water Consumption	- 6.0 MJ	- 6.0 MJ	- 6.0 MJ	- 6.0 MJ	- 3.5 MJ	- 3.5 MJ	- 3.5 MJ	- 3.5 MJ	-3.5 MJ
Convective Loss	- 360 MJ	- 360 MJ	- 104 MJ	- 104 MJ	- 138 MJ	- 138 MJ	- 103 MJ	- 103 MJ	0 MJ
Net Energy Change	**-393 MJ**	**-364 MJ**	**-137 MJ**	**-108 MJ**	**-49.5 MJ**	**-20.5 MJ**	**-14.5 MJ**	**+14.5 MJ**	**+145.5 MJ**

Cold - T_{air} = 10°C, T_{water} = 15°C
Hot - T_{air} = 35°C, T_{water} = 25°C
Very Hot - T_{air} = 40°C, T_{water} = 25°C
Still - Wind speed = 0 km/hr
Windy - Wind speed = 10 km/hr

Some formula used above are empirical and are not accurate for some situations. For instance, the loss of energy by convective means should approach zero as conditions become hotter (ie., approaching animal body temperature) and still. It has been assumed in the calculations that shade has not had an effect on wind speeds. Despite some data being of questionable quality, the tabulated data highlights trends in relation to the energy balance and the effects of shade.

- The largest single variable in the energy balance is the excess energy derived from digestion of the ration. It contributes 73% of the input energy to the animal.
- Shade has large impact on the energy balance by reducing the radiant heat load on cattle.
- Convective heat loss is the largest and key means of heat loss - even in hot conditions.

Convection losses occur through the transfer of heat from one body of a gas or liquid to another and subsequent movement of the heated and less dense medium. For a steer heat is transferred from the coat to the surrounding air and subsequent wind movement around the body moves the heat away. When ambient air temperatures exceed body temperature, heat gain increases because convective losses and radiant losses reduce to zero or become energy/heat inputs. In this case shade does not prevent heat gain or increasing heat load, but it can assist in slowing the rate of gain.

Cattle have thick hides and hair. These are for regulation of the animal's metabolism which is geared to managing heat loss in cool temperatures. It is designed to limit heat loss through conduction from the inner body to the skin and then loss of heat by convective means.

Reducing the gross energy intake of the cattle during heat stress events will also have a direct effect on the energy balance of the animals. The normal reduction in appetite observed during hot weather is the result of the animal's natural satiety control mechanisms acting to reduce gross energy intake. However, where the onset of the stress event is rapid this physiological mechanism may not occur within sufficient time. Clearly if a stress event is forecast, altering the feeding regime to reduce gross energy intake can be a key mitigation measure for avoiding heat stress. Unlike metabolisable energy (ME), the gross energy (GE) value of feeds is relatively constant across common feedstuffs and reductions in gross energy intake normally necessitate reducing actual feed (dry matter) intakes rather than changing the composition of the diet. There is some evidence that increasing the fibre or protein content of the feed (reducing ME but not DE) without substantially decreasing feed intake may actually decrease the animals' upper critical temperature, effectively increasing their susceptibility to heat stress.

Because the major heat loss mechanism is through convection, design of shade structures and management of cattle must ensure that wind speeds are maximised in the feedlot pen, and that where possible, air temperatures are kept below body temperature. While the animal appears to lose only a small amount of energy in warming water to body temperature, the presentation of cool water (15°C) is likely to play a pivotal role in reducing heat loads at times of heat stress.

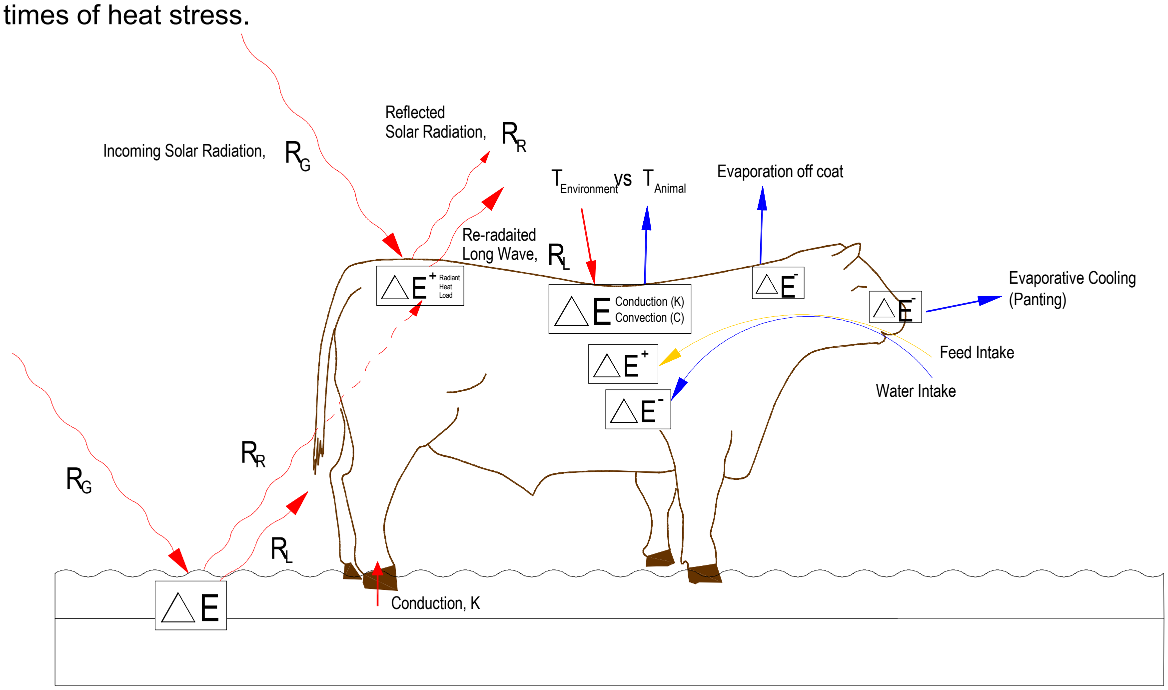

Figure 1. The Energy Balance of a Lot Fed Steer.

3. PRINCIPLES OF SHADE DESIGN

The benefits of shade to animals exposed to both high temperatures and high solar radiation are influenced by a number of factors. These are;

- Size of shadow;
- Location of shade;
- Shade orientation;
- Type of shade material.

3.1 Practical Design Constraints

Lot feeders have considerable practical experience in the design and installation of shade. The design of the existing shade structures has proven itself in the time they have been in use. The improvements that have been made over time are the result of observation, and trial and error.

Two types of system are used by industry; iron sheets attached to cables (see Figure 2) or shade cloth that is either permanently fixed or furlable (see Figure 3).

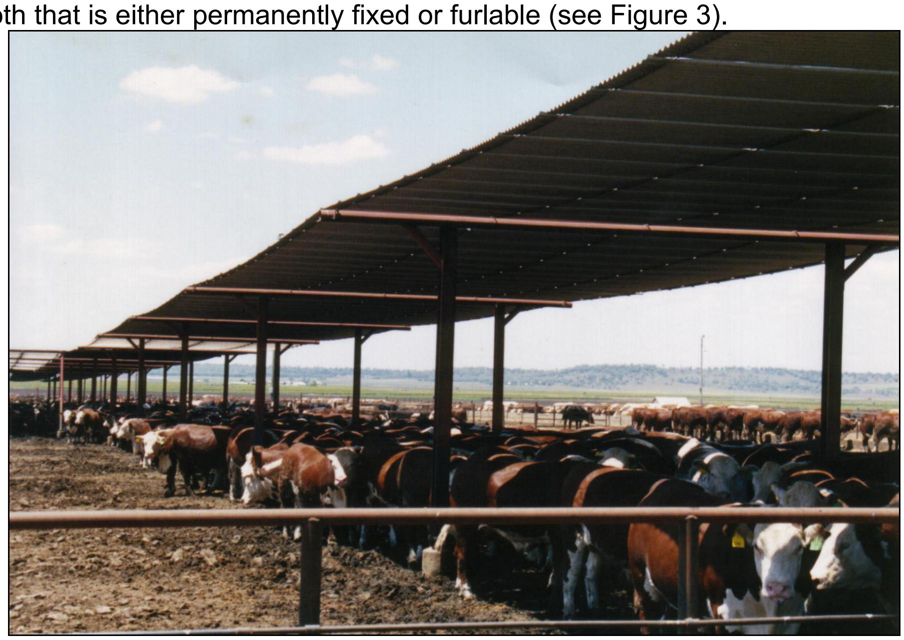

Figure 2. A sheet & cable feedlot shade structure with a variety of spatial configurations of sheeting.

Shade cloth is generally less expensive than solid roofing material and the supporting structure required for shade cloth may not be as substantial. However, shade cloth does not provide as much protection from solar radiation and the durability may not be as good as that of solid roofing materials. Natural air movement under a shade structure is affected by the ease with which air can move through the structure. As such shade cloth does have the advantage of allowing some air to pass directly through the material, whilst structures constructed from galvanised sheeting require openings to assist air movement. There is a lack of comprehensive data on the relative benefits and disadvantages of shade cloth and discontinuous sheeting in regard to air movement and effective shade (reductions in solar radiation levels).

Figure 3. A shade cloth covered feedlot shade structure.

Practical design issues noted in a survey of industry shade systems are;

- Shade cloth is not the preferred choice of material because it has been found to deteriorate. Mostly problem has been with deterioration of the stitching with replacement of the cloth or stitching needed every 3-5 years. New technologies are now offering life spans of up to 10 years.
- Shade cloth had been affected by hail damage, birds chewing it, and machinery that clean the pen floors having burned holes in the cloth with the exhaust pipes. This means that cloth must be placed well above machinery.
- Even after 5 years the corrugated iron sheets on some shade structures were considered to be in the same condition as when they had been erected. It is noted that ammonia levels increase with manure moisture content and that ammonia is corrosive agent particularly in more humid climates which suggests that the life of corrugated iron will be reduced in wet humid climates.
- Galvanized iron sheets have been proven to be very dangerous when they have worked loose in a high wind or a storm. Some stock have been killed by flying sheet metal. Consequently, robust methods of fixing the sheets to roof structures are required.
- Designs have incorporated concrete pillars to protect the bases of the main steel posts from corrosion caused by the manure on the pen floor
- Maintenance of pen floors under shade can be problematic. The shaded areas do not dry out as well as the unshaded areas and this can contribute to greater wear on the pen surface and increased maintenance costs aside from problems such as holes being formed which can trap water and become odourous.
- If shade cloths are removed one of the problems with storing the cloth during winter is that mice can destroy the stored material

An ideal shade structure would have no posts in the pens, would be durable, cheap, and would be able to be taken down easily and folded for storage in winter.

Current feedlot shade designs have evolved over time. Most are of simple design to minimise capital and ongoing maintenance costs. However, even though the structures are agricultural, structures of such size should be engineer-designed and certified. This includes the structural connection details, especially where tensioned cables are involved, and the fixing details for the corrugated iron sheeting.

3.2 Sizing of Shade Structures

A relationship between shaded area, stocking density, and cattle performance has not been defined in the available literature. General recommendations have been made by some researchers.

Obviously the minimum is that the shade structures must create a shadow on the ground of sufficient size to cover all animals. Guidelines relating to the ideal amount of shade that should be provided vary. Recommendations derived from US research undertaken in the dairy industry suggests that cattle should be provided with anywhere from 20 to 65 square feet (1.9 to 6.0 m^2) of shade per head.

The size of the shadow is most affected by the angle (or slope) of the shade material. The height of the structure does not change the size of the shadow, but does effect the rate that the shadow moves across the ground. Higher shade structures also provide more cool air that cattle can be exposed to and studies have shown that cattle show a preference for higher shade structures. However, higher structures typically cost more to construct as they are subject to greater wind loads.

3.3 Positioning of Shade Structures

It is important to locate shade structures so that the shadow provided covers an area of the ground that is easily accessible by the animals. This is the primary reason that shade structures are typically erected towards the centre of feedlot pens. This ensures that cattle are able to occupy the shaded area as it moves across the pen over the day.

The orientation of shade structures will also affect their performance. Structures orientated with the long axis in a north-south direction have the advantage of providing drier pen surfaces as the shadow provided by the shade moves over a greater area than that of structures orientated east-west. However, structures with an east-west orientation cause some areas of the feedlot pen to be permanently in shade which has the advantage of creating cooler pad temperatures. The advantage of this is that lowering the ground temperature in the immediate vicinity of the shade will decrease the gross radiant heat load on the animal. Determining the ideal orientation also requires consideration of the prevailing winds, which should be utilised to assist in ventilation and cooling.

As a general rule, shade structures in hot dry climates should be located on a north-south axis while those to be used in hot humid (wet) climates should be located on an east-west axis.

3.4 Shade Materials

At present there is a wide range of materials that are utilised in the construction of shade structures. The most common materials used in Australian feedlots are galvanised sheeting or shade cloth. This is due to availability and relatively low cost of these materials. The effectiveness of shade structures is highly dependent on the type of materials used.

Any material that intercepts direct solar radiation will heat up. If the lower side of the shade material becomes hot it will then radiate heat to the air and the animals below. An advantage can be gained by having shade structures that are reflective on the top surface, absorptive on the bottom surface, and allow free airflow. In relation to dairies, it has been suggested that the most effective shade roof is an aluminium or white coloured galvanised metal roof that is fitted with insulation directly beneath the metal roofing that will reduce the radiation heat load. Figure 4 below shows the radiation energy balance for an artificial shade structure.

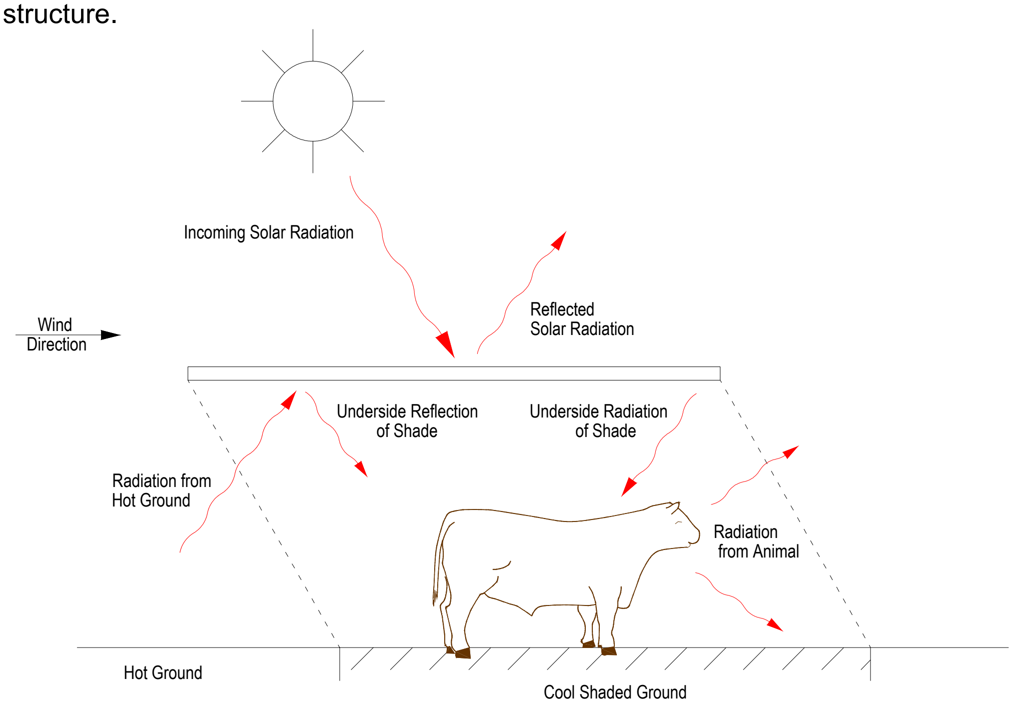

Figure 4. Radiation energy balance of a horizontal shade structure. (adapted from Owen, 1994 and Esmay, 1978).

3.5 Ventilation

Air movement is an important factor in the relief of heat stress. The data in Table 1 above shows that wind velocity and direction can change the total heat balance effect on the animal.

The design of shade structures should ensure that ventilation is not restricted. Natural air movement under a shade structure is affected by its size (height and width), the slope of the roof, and the ease with which air can move through the structure. For example shade cloth has the advantage of allowing air to pass directly through the material, whilst structures constructed from galvanised sheeting require openings to assist air movement.

The heating of shade material by incoming solar radiation causes the air immediately beneath the shade material to become considerably hotter than the surrounding air and therefore it rises. This 'buoyancy' can be used to passively create air movement beneath shade structures by allowing hot air to slide upwards on the inside of a sloping roof. As this air moves upward, it draws air in from the side of the structure. Rate of upward movement is related to the slope of the roof, buoyancy of the air, and roughness of the material it is in contact with. It is generally recommended that slopes of 3 horizontal to 1 vertical be used. This equates to a slope of 18 degrees. It is known that for larger roof structures slopes of 10 to 15 degrees will utilise this phenomenon to similar effect. It is important to note that shade slopes over 15-20% may have a net negative effect on shaded areas.

3.6 Height

MLA funded research projects have proven that many existing shade structures restrict air movement beneath the structure. Most existing structures are about 4 metres high. These effects can be profound. To combat the restricted ventilation the structures should be higher and have the stock more spaced out to allow air movement in and around the cattle.

While increasing the height of the structure will improve ventilation it will also result in increased wind loads.

3.7 Management of Shaded Areas

The use of shades will result in an area beneath the shade becoming moist with the concentrated deposition of urine and faeces. This area, if not well managed to limit manure accumulation and moisture build up, will result in increased humidity and elevated ammonia levels within the pen and beneath the shade.

Repair and maintenance of the pen surface will also be high in this area. It is strongly recommended that areas beneath shade structures be regularly cleaned of wet manure to limit odour production and ammonia emissions. An increased height of the proposed shade structure will provide both a greater exposure of the pen to drying by morning to midday sun, and a greater movement of shade which will act to limit the occurrence of shade related wet pen conditions.

4. STRUCTURAL DESIGN OF SHADE SYSTEMS

4.1 Dead Loads

A “dead load” is the load supported by a structure which is equivalent to the mass of the materials held by the structure. The load is applied vertically downward due to gravitation force. This means that the load is passed either vertically down ward through a support column or is resisted by systems such as tension cables (Figure 5).

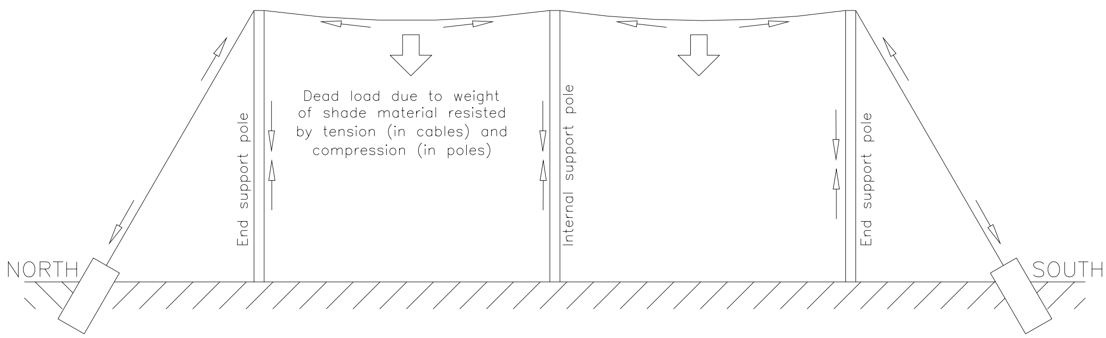

Figure 5. Columns and tension cables to resist dead loads.

The dead load of galvanised sheeting is greater than that of shade cloth. Consequently, the support structures holding up galvanised iron shading need to be more substantial.

4.2 Live Loading

A live load is a load that varies in character. It typically results from movement of a structural member or other variable, intermittent or oscillating force. Wind gusts are the most common live loading on structures. In the case of shade structures, wind driven movement of the shade will cause dynamic loading of the structure through swinging of the structure, or alternating uplift or down draft loads on the structure.

The movement of wind against a solid structure results in directional loads. If wind is moving against a wall it causes a side load. As wind moves up and over a roof structure it causes a down load on the front face of the roof and an upload on the downwind face as a result of an induced area of low pressure over the inclined surface. These forces must be taken into account when designing a shade structure; especially if the shade itself is sloped to obtain advantages in shading and ventilation. A sloping shade structure will act either as a wing or as an aerofoil depending upon the direction of the wind. These forces are shown in Figure 6.

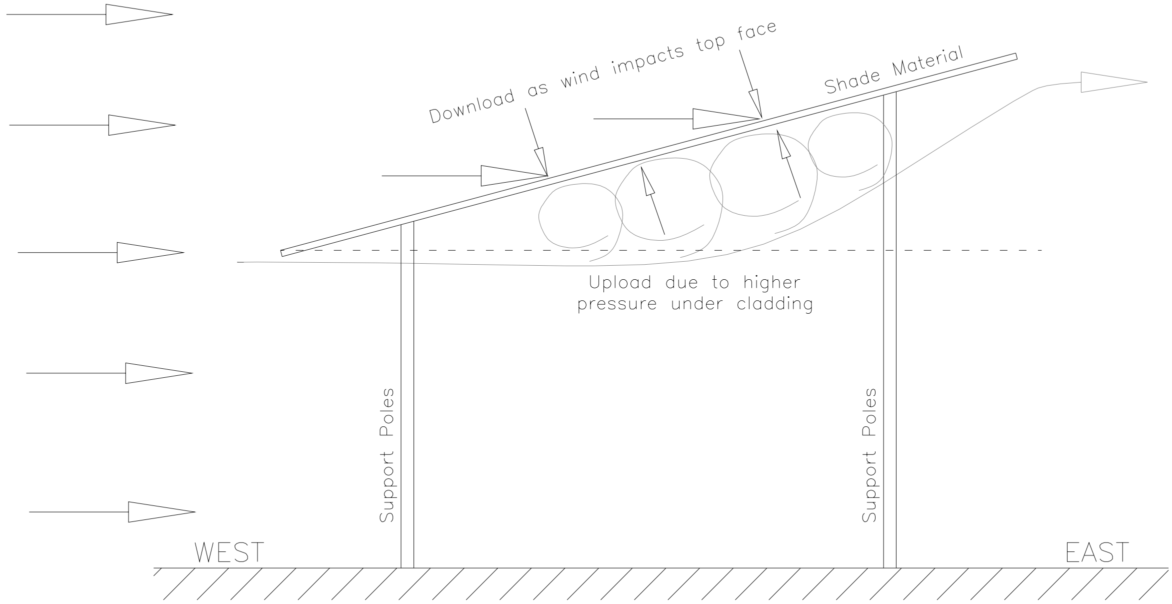

Figure 6. Live loading on shade material from wind

The ability of the structure to shed load and dampen out oscillations becomes important when taking account of dynamic loads. The weight of the moving section also is of critical importance as the energy contained in movement of the part is related to its mass and the square of its velocity. Consequently, a heavy moving structure becomes difficult to constrain.

5. THE IDEAL DESIGN

By drawing on the theoretical outcomes of research and practical experience, a new generation of shade structure can be formulated. A conceptual design is presented in Figures 7.

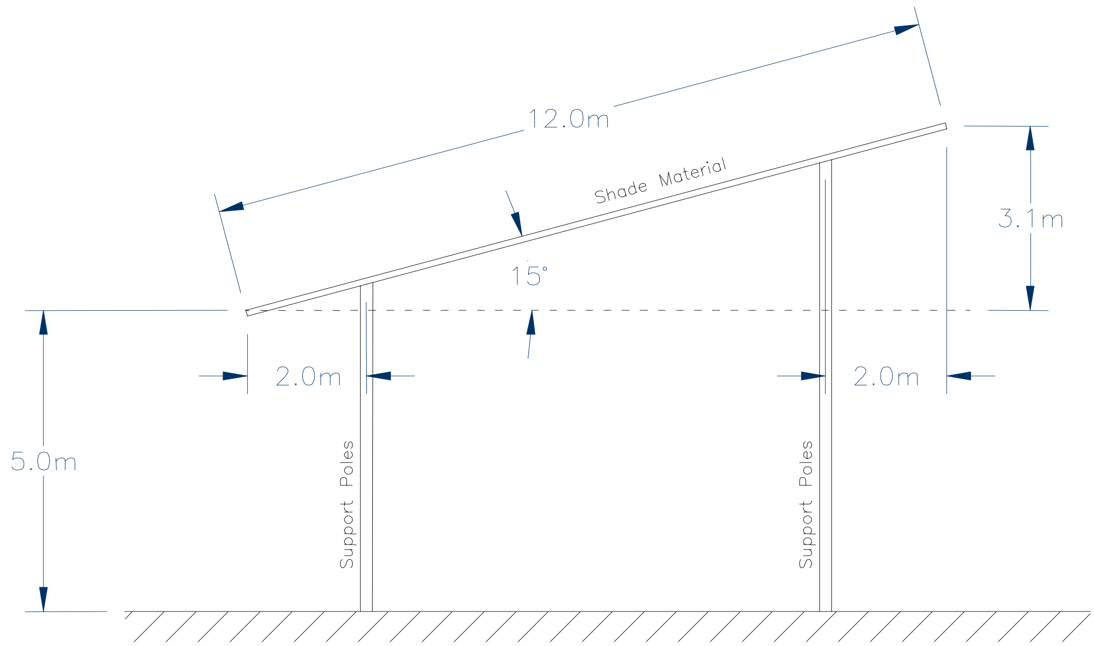

Figure 7. Conceptual Shade Design (Elevation).

The design is based on a feedlot pens 60 metres in depth and 63 metres wide that contain 250 bullocks at a stocking density of about 15 m^2/head.

The shade is located as a strip that runs across the feedlot pens in a north-south direction. The shade is pitched with the lower edge towards the west. The upper side of the material is white and the bottom side is matt black. It is assumed that the material is a heavy duty shade cloth that will allow high winds and rainfall to pass through the material.

Because the shade is on an angle its profile to winds will either make it an aerofoil or wing. Structural design of the structure to counter these aerodynamic features becomes important and the pervious nature of shade cloth and its lightness assists in obtaining design efficiencies over that for coloured galvanised iron shade. The use of galvanised iron in this type of structure will result in significant increases in loading rates and thus size of support structures.

The western 'eave' is 5 metres (or higher) off the ground to improve air flow through the side of the shade system.

The shade is 12m wide, which allows for effective use of materials as most are provided in 6m widths or lengths. If the pitch is 15°, the top of the shade is 3.1 metres above the lower eave of the shade. If the slope is 10° the upper edge is 2 metres higher than the western edge. The 12 metre wide strip of shade will have a 11.6 or 11.8 metre planar width, given the pitch of 15 or 10 degrees respectively. This equates to a shade cover of 2.92 m^2/hd or 2.97 m^2/hd if the sun were immediately overhead.

In the afternoon an increase in shaded area due to the western pitch will become available to cattle. Based on the position of the sun on the 20 January at Toowoomba between 3pm and 4pm the average increase (over the hour) in shaded area is 28.5% (15°) or 18.4% (10°). Therefore the shaded area increases to 3.75 m^2/hd or 3.51 m^2/hd respectively.

Because the shade material is high and pitched, the shade will move across the pen quickly. Shade providing the largest area per animal is most important late in the afternoon when stock have been accumulating heat for longest and day time temperatures are at their greatest. Research has found that the highest day time temperatures often occurred between 2 and 4pm EST and that typically stress occurred in the period between 2 and 6pm, with cattle often showing most stress in the period between 3 and 5pm EST.

Some care needs to be taken in the location of the shade to ensure that the shade is kept within the pen during the afternoon. By 4pm (EST) on the 20 January the throw of the shade from the 15° shade will be 10.75 metres (9.3 metres for 10°), by 6pm (EST) the throw will be 41.2 metres (36 metres for 10°). This gives reason to place the shade on the western side of the pen.

Conflict with the placement of the water trough needs to be avoided because the water trough is an area where moisture accumulates. It is recommended that in earth based yards that they are located away from shaded areas to limit the build up of wet manure.

8 shows a simple plan of the position of the shade as described. It is located 15 metres off the western fence line that allows for sufficient room to place a water trough on the dividing fence line whilst providing some distance between the pen gate and the trough, and the trough and shade structure. The throw of the shade at 6pm would result in the shade being cast onto the feed bunk if the pitch of the shade was 15°.

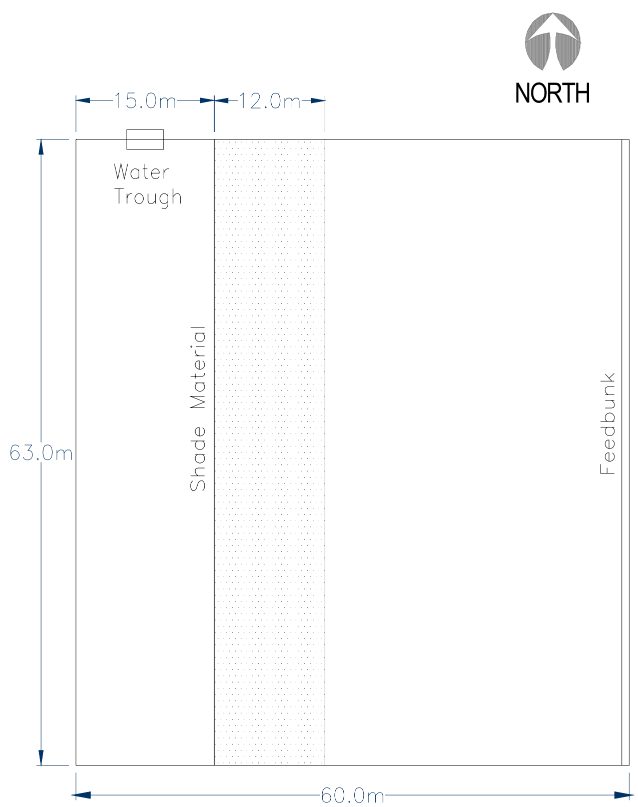

Figure 8. Conceptual Shade Design (Plan).

APPENDIX G - FEEDLOT SHADE DESIGN LITERATURE REVIEW

Report Number: 20008

FEEDLOT SHADE DESIGN
- Literature Review -

Version 1.0

March, 2002

MEAT & LIVESTOCK
AUSTRALIA

Prepared by: Peter Binns, Ryan Petrov & Simon Lott
E.A. SYSTEMS Pty Limited
Environmental and Agricultural- Science and Engineering
PO Box W1029
ARMIDALE NSW 2350
Phone: (02) 6771 4864
Fax: (02) 6771 4867

1. INTRODUCTION

Ambient temperatures in excess of body temperature typically induce behavioural and physiological changes in cattle that are intended to reduce the animal's heat load by adjusting its radiative, convective, conductive and evaporative exchanges with its environment. Concerns have been raised that when compared to grazing animals cattle in feedlots may be restricted in the extent to which they are able to express some of these adaptive characteristics and, consequently, that their welfare might be more readily compromised under such conditions. In particular, the lack of shade in feedlots has been implicated as restricting the ability of cattle to reduce their radiative energy load (Blackshaw & Blackshaw, 1994).

Notwithstanding the perceived need to provide shade in feedlots that are likely to experience extended periods of hot weather conditions, the benefits, both in regard to animal productivity and physiological stress indicators, have not been conclusively established (Esmay, 1978; Curtis, 1983; Rinehart & Tucker, 1994; Mader *et al*., 1999 and Sparke *et al*., 2001). Curtis (1983) suggests that the lack of conclusive evidence is due to the design of shade being a very complex matter that invokes a diverse range of interactions between the animal and its environment. Further, the nature and magnitude of these interactions may also be dependent on the climatic conditions.

This report provides a review of literature pertaining to the design of shade structures for livestock with particular emphasis on the provision of shade in beef cattle feedlots. While it would appear that the design of existing feedlot shade structures have a sound, substantive basis derived in part from anecdotal or experiential information (Rinehart & Tucker, 1994), the aims of the report are to identify a robust scientific basis for evaluating their design and to identify critical design criteria to be considered in the construction of new feedlot shade structures.

2. RADIANT ENERGY TRANSFERS

2.1 Radiant Energy

Every object emits thermal radiation. According to the Stefan-Bolzmann law the radiative power (*E*) emitted (or the radiant energy emitted per unit of time) increases exponentially with an increase in the object's absolute temperature[1] (*T*) such that:

$$E \propto T^4$$

However, the wavelength at which the object's emissive power is at its maximum is proportional to the inverse of its absolute temperature and is given by Wein's displacement rule. That is:

$$\lambda_{max} = \frac{2898}{T}$$

where λ_{max} = wavelength (μm), and
T = absolute temperature (°K).

Consequently, the sun, with a surface temperature of around 5 800°K (~5 500°C) emits predominantly shortwave[2] radiation with a λ_{max} value of 0.5 μm (around 47% of solar energy being in the visible spectrum of 0.4 to 0.8 μm). In comparison, a relatively cool object at a temperature of 300°K (27°C) would emit predominantly longwave[3] radiation with a λ_{max} value of 9.7 μm (in the mid-infrared spectrum).

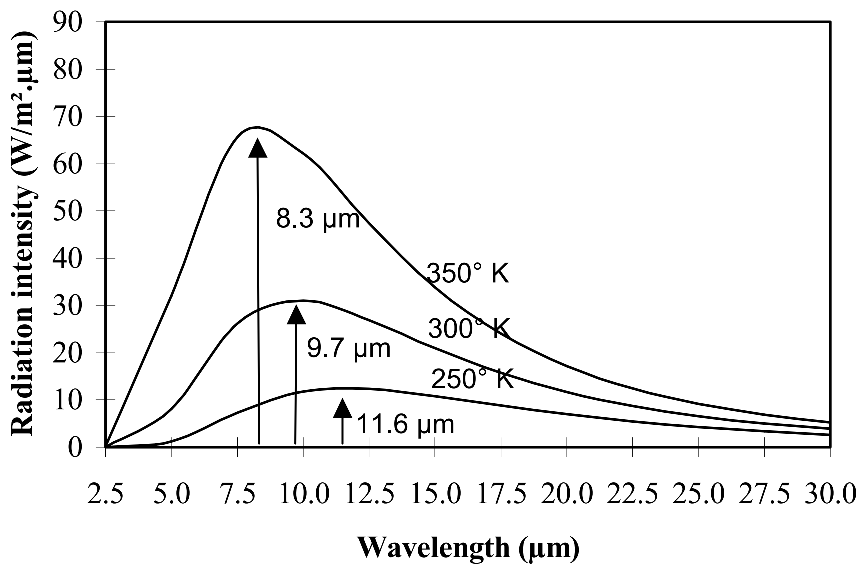

Figure 1. The emissive power spectrum of a blackbody at various temperatures (according to Plank's law) and the wavelengths at which the emissive power are at a maximum (according to Wein's displacement rule).

[1] Measured in degrees Kelvin (°K) and equivalent to degrees Celsius (°C) + 273.15
[2] Shortwave radiation has a wavelength less than 3 μm
[3] Longwave radiation has a wavelength greater than 3 μm

Figure 1 (above) shows the emissive power spectrum of a theoretical blackbody[4], the total power radiated (the area under the curve) and the corresponding λ_{max} value at various temperatures (equivalent to -23°C, 27°C & 77°C). Based on these relationships it can be seen that the λ_{max} value decreases as the amount of energy transmitted increases exponentially. Consequently, the greatest efficiencies in reducing the radiant energy intercepted by a body might be gained by reducing exposure to shortwave solar radiation (eg. by shading it).

Notwithstanding the above, a blackbody is a theoretical abstraction. Real bodies both emit and absorb radiant energy with somewhat less efficiency than a blackbody. The actual efficiency with which energy of various wavelengths is emitted or absorbed is specific to particular molecules.

Radiant energy is absorbed by matter when its frequency (which is inversely related to its wavelength) is similar to the various frequencies of an intrinsic range of molecular oscillations occurring specifically in that matter. Long wave (low frequency) radiation in the mid-infrared spectrum (3 to 10 μm) is readily absorbed by most kinds of matter and is highly effective in transferring energy to objects that it strikes. It is such frequencies and their absorbance that provide the sensory perception of radiant heat. From Figure 1 it can be seen that as the temperature of an object increases above 300°K (27°C), both the amount and proportion of radiation emitted in these wavelengths increases significantly. This explains why an animal, whose body temperature is around 312°K (39°C), can readily dissipate heat when its environs are at temperature of less than 300°K (27°C) and alternatively, why as the temperature of its environs rise above this level the animal's ability to dissipate heat decreases markedly and it may even become a net absorber of radiant heat.

2.2 Radiant Energy Flows and Shade

The principal function of a shade structure is to intercept direct beam, shortwave solar radiation. The radiant energy flows experienced by an animal without and with shade are shown in Figure 2 and Figure 3 respectively (Bond *et al*., 1967; Esmay, 1978; Barth, 1982; Curtis, 1983 and Owen, 1994). For an unshaded animal, the effects of direct shortwave solar radiation are accentuated by diffuse shortwave solar radiation reflected off the ground, clouds, dust and other airborne matter as well as other animals and structures in the animal's environs. There will also be longwave radiant energy exchanged between the animal and the various physical elements of its environs. The net radiant flux[5] will depend on the absolute temperature, interfacial area and sorptivity[6] and emissivity[7] of the exposed radiative surfaces of the animal and these different environmental elements. Consequently, while the unshaded animal is liable to be a net absorber of radiation when it is interacting with the large area of hot unshaded ground, it may be a net emitter when it is interacting with an open, clear and relatively cool sky. It is this phenomena that explains how an animal (with a body temperature of 312°K) is able to readily dissipate heat when its environs are relatively cool (< 300°K) and conversely why it is unable to loose heat at greater temperatures.

[4] A theoretical abstraction for an object that is a perfect emitter (and absorber) of radiant energy
[5] The net flow of radiant energy per unit of cross sectional area
[6] The ratio of the radiative power absorbed by a surface relative to that of a theoretical black body (a perfect absorber) having the same surface area
[7] The ratio of the power radiated by a surface relative to that of a theoretical black body (a perfect emitter) at the same temperature and having the same surface area

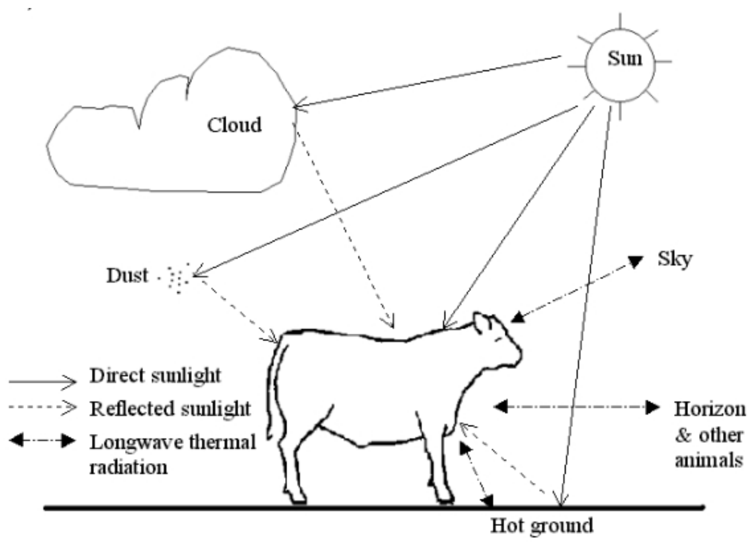

Figure 2. Main radiant energy flows for an animal without shade (after Curtis, 1983).

The relative complexity of the shaded animal's interaction with its thermal environment is evident in Figure 3. While the shaded animal no longer has to deal with direct beam solar radiation, it is still affected, albeit to as lesser extent, by reflected shortwave radiation including that reflected off the lower surface of the shade structure. Also, the underside of the shade and the shaded ground provide additional radiative surfaces for the animal to interact with. Other complicating factors may include changes in the spatial distribution of other animals induced by the provision of the shade and changes that affect the animal's ability to dissipate heat through convective or evaporative means.

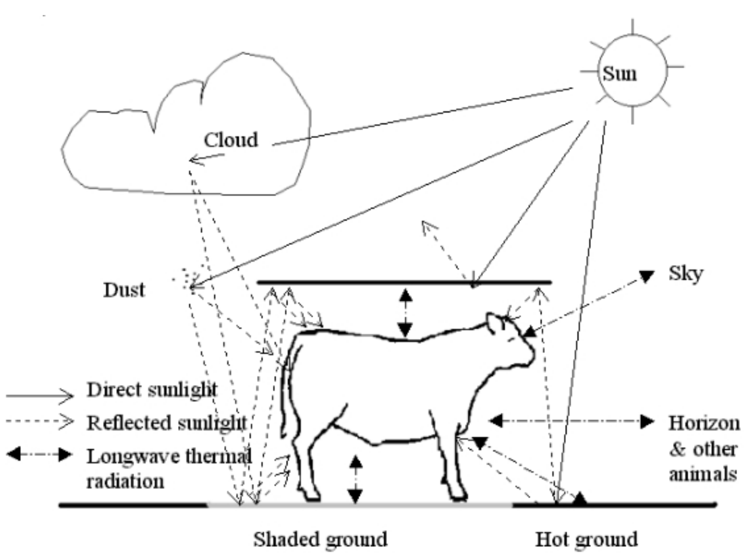

Figure 3. Main radiant energy flows for an animal with shade (after Curtis, 1983).

The magnitude of the specific, interactive, radiant energy flows and their corresponding importance to the shaded animal is influenced by various shade design factors including the thermal properties of the shade material, the shade height, the shadow size, the slope of the shade and the orientation of the shade.

3. SHADE DESIGN

3.1 Thermal Properties of the Shade Material

The properties of shade materials that affect their efficacy include the radiative properties (sorptivity and emissivity) of the upper and lower surfaces, the thermal conductivity or conversely, thermal resistance of the material and its thermal capacity[8] (Kelly & Bond, 1958; Esmay, 1978; Curtis, 1983; Buffington *et* al., 1983; Esmay & Dixon, 1986, Barre *et al*., 1988 and Owen, 1994). Data on the relative effectiveness of various shade materials, derived using a black globe thermometer based estimate of radiant heat load, was provided by Kelly & Bond (1958). This seminal work is still extensively cited in contemporary literature and an abridged list is provided in Table 1. These data demonstrate the magnitude of the improvement that can be gained by having a white coating on the upper surface and a black coating on the under surface; the loss of efficacy with the weathering of the surface and, the marked difference in efficacy between 92% and 90% shade cloth (most feedlots using shade cloth probably use the 80% material). While Vladimirova *et al*. (1996) found no significant difference in efficacy between various grades of shade cloth (47%, 63%, 80% & 91%), they measured air temperatures under shades rather than black globe temperatures.

Black globe temperatures can be considered more representative of the thermal load on an animal in that they provide a reasonable man-made analogy to the blackbody abstraction (Bond & Kelly, 1955). Consequently, they provide a better indicator of the actual flux density of radiant energy through having a greater sorptivity (and more uniform absorption spectrum) than the gaseous molecules (principally N_2, O_2 and H_2O) that are present in the air and whose sorptivity is reflected in air temperature. The MLA funded study of feedlot microclimate found that black globe temperatures were lower in shaded pens (shade cloth and galvanised iron) compared to pens with no shade and the external feedlot environment (Petrov *et al.* 2001).

Table 1. The relative effectiveness of various shade materials when compared to new aluminium (Kelly & Bond, 1958)

Material	Treatment	Relative effectiveness
Aluminium	Top white, bottom black	1.103
Galvanised iron	Top white, bottom black	1.066
Galvanised iron	Top white, bottom natural	1.053
Aluminium	Top white, bottom natural	1.049
Aluminium	New, untreated	1.000
Aluminium	One year old	0.994
Galvanised iron	New, untreated	0.992
Galvanised iron	One year old	0.985
Aluminium	Ten years old	0.969
Shade cloth	92% solid	0.926
Shade cloth	90% solid	0.839

The shortwave (<3μm) sorptivity and longwave (>3μm) emissivity of various surfaces relative to a theoretical blackbody are provided in Table 2. From these data it can be seen that while white paint and new, unpolished aluminium both reflect substantial amounts (around 70 to 80%) of incident shortwave solar radiation, the relative advantage provided by white coatings in Table 1 is derived from the substantially higher longwave emissivity (ε = 0.91) of this surface. However, the advantages of the black underside coatings in Table 1 are more

[8] The energy required to increase the temperature of a given mass of a material by one degree Celsius

complex. Curtis (1983) and Esmay & Dixon (1986) explain that the advantages can be attributed to the (undesirable) higher emissivity of the black surface being more than offset by the (desirable) reduced reflection of diffuse solar radiation. The radiative qualities of the various surfaces also explain the relative efficacy of aluminium and galvanised iron and the relative effects of weathering on these materials.

Table 2. Solar energy sorptivity and emissivity at ordinary temperatures of various surfaces relative to a theoretical blackbody (Esmay & Dixon, 1986)

Surface	Condition	Sorptivity	Emissivity
Aluminium	New, unpolished	0.32	0.10
Aluminium	0.43 mm white paint	0.20	0.91
Aluminium	0.43 mm black paint	0.94 - 0.98	0.88
Galvanised iron	New	0.65	0.13
Galvanised iron	Oxidised	0.80	0.28

The thinness, high thermal conductivity and limited thermal capacity of metal sheeting results in the upper and lower surface temperatures of these materials being similar irrespective of the surface coatings (Esmay, 1978). The use of insulating materials, such as polystyrene board to polyurethane foam, in conjunction with the various metal sheetings can substantially reduce conductivity and the temperature of the underside of a shade cover (Buffington *et al*., 1983 and Bucklin *et al*., 1991). However, disadvantages of using these materials may include a reduced durability and an increased cost. Whether such costs are sustainable depends on a variety of factors.

Sheet metal and cable roofing systems (refer Figure 4), wherein the metal sheeting is suspended and clamped between high-tension cables, are a variation on solid roof shades that are commonly found in feedlots and dairies in the USA and feedlots in Australia (Buffington *et al*., 1983 and Rinehart & Tucker, 1994). Gaps are usually left between individual sheets to facilitate clamping, improve airflow and enhance drying of the manure pad. The spatial configuration of the sheeting that is utilised is highly variable. However, typically there is a gap of 0.2 to 2.0 metres between sheeting materials having a width of about 0.9 metres. In some instances alternating narrow and wide gaps are utilised with a view providing a shadow width commensurate with size of the stock housed. Providing the same effective area of shadow (m^2/head) is available, the performance of sheet and cable systems in intercepting direct beam solar radiation will be similar to structures with a solid cover of sheeting. However, these sheet and cable systems will increase reflected radiation loads and may increase the mean radiant flux density exchanged with the ground due to an increased mean temperature of the exposed soil surface. The benefits, if any, in terms of air movement will depend on a large number of factors including ambient wind speed, direction and turbulence, the length, depth, height and orientation of the shade structure and the spatial configuration of the sheeting. Given the complexity of these considerations it is not possible to provide a definitive conclusion as to the benefits or otherwise of sheet and cable systems.

Figure 4. A sheet & cable feedlot shade structure with a variety of spatial configurations of sheeting.

Shade cloth is generally less expensive than solid roofing material and the supporting structure required for shade cloth may not be as substantial (refer Figure 5). However, shade cloth does not provide as much protection from solar radiation and the durability may not be as good as that of solid roofing materials (Barth, 1982; Buffington *et al*., 1983; Bucklin *et al*., 1991; Bucklin *et al.*, 1992 and Shearer *et al*., 1999). Natural air movement under a shade structure is affected by the ease with which air can move through the structure. As such shade cloth does have the advantage of allowing air to pass directly through the material, whilst structures constructed from galvanised sheeting require openings to assist air movement (Petrov & Lott, 2001).

Figure 5. A shade cloth covered feedlot shade structure.

There has been some suggestion that due to the process of transpiration, natural shade provided by foliage might be more effective than artificial shade in controlling an animal's thermal load (Blackshaw & Backshaw, 1994). Valtorta *et al*. (1997) investigated the provision of alternatively, one of two forms of tree shade, an 80% shade cloth structure 2.5 m high, or no shade in concrete floored pens. They found no difference in black globe temperatures under the different forms of shade and no difference in a range of physiological parameters assessed in the animals kept under the different forms of shade. Consistent with a significant difference in the associated black globe temperatures, there were significant differences in all of the physiological parameters between shaded and unshaded animals. Goodwin *et al*. (1997), in a study where green lotted dairy cows were able to select between no shade and different forms of shade including natural tree shade and structures 3 m high covered with either galvanised iron, 80% shade cloth or a vine; found no preference for shade in general when the air temperature was below 30° C. Above 30° C, dark coated cattle demonstrated a significant preference for the galvanised iron clad structure. Light coated cattle did not seek shade.

The differences in the shade seeking behaviours of dark and light coated cattle is readily explained by the relative differences in sorptivity of the variously coloured coats of cattle and the similarity in emissivity shown in Table 3.

Table 3. Sorptivity and emissivity of variously coloured coats of cattle relative to a theoretical black body (Sparke et al. 2001).

Coat colour	Sorptivity	Emissivity
Black	0.90	0.95
Red	0.80	0.95
White	0.50	0.95

3.2 Shade Height

At the earth's surface at any point in time, direct solar radiation is effectively unidirectional. As a consequence, shade height has no impact on the size of the shadow cast.

The direct and indirect effects attributed to variations in shade height in literature vary markedly.

Givens (1965), working in Georgia, assessed black globe temperatures under galvanised iron shades 1.8 m, 2.7 m and 3.6 m above a grass groundcover. Givens concluded that there was no apparent advantage in having shade heights greater than 1.8 m. However, he indicated that afternoon conditions at the site were characterised by substantial amounts of white, cumulus clouds that may have been a significant factor in the results obtained. Consequently, he suggested that the amount, frequency and type of clouds should be considered in determining the optimum height of shade in a specific locality. Notwithstanding this, the direct applicability of these results to cattle feedlots is limited by the study being undertaken in an area with a grass groundcover. The difference in sorptivity and emissivity of grass, bare soil and concrete surfaces is shown in Table 4. Based on this, it could be expected that in this instance reflected solar energy would be higher and thermal radiation levels lower than that experienced under typical feedlot conditions.

Table 4. Solar energy sorptivity and emissivity at ordinary temperatures of various grassed and bare soil surfaces relative to a theoretical blackbody (Esmay & Dixon, 1986).

Surface	Condition	Sorptivity	Emissivity
Grass	Dry & high	0.68	0.90
Grass	Green	0.67	0.98
Ground	Dry, ploughed	0.78	0.90
Ground	Dark, moist	0.90	0.95
Concrete	Natural	0.60	0.88

Reviewing earlier studies, Buffington *et al*. (1983) and Bucklin *et al*. (1991), all working in Florida, suggested that optimum shade height needs to be determined on the basis of two opposing criteria; the higher the shade the greater the air movement under the shade and, the lower the shade the smaller the diffuse and reflected radiative load on the cattle. They suggested an optimum height of around 3.6 metres.

Air movement is an important factor in the relief of heat stress (Bucklin *et al.,* 1992). Wind velocity and direction can change the total heat balance effect on the animal (Esmay, 1978). Considering specifically the matter of air movement under shades, Petrov *et al.* (2001) found air velocities were significantly reduced under shade structures less than 4 metres in height. This has important implications for heat loss by the animals as poorly designed shade structures that reduce air movement and ventilation can limit the amount of heat energy that an animal can loose through convection.

Based on directional radiometer studies undertaken in California, Bond *et al*. (1967) found the influence of shade height is likely to depend in part on the animal's displacement relative to the shade and shadow. They suggested that an animal under a low (1.8 m) shade is liable to intercept less diffuse solar radiation than one under a high (3.6 m) shade. However, while an animal directly under the centre of a low shade is likely to receive less radiant energy from its environs that one under the centre of a high shade, the situation was reversed for animals at the centre of the shadow rather than under the centre of the shade. Consequently, they concluded that the comparative heat load experienced by animals under high or low shades would depend on their displacement in relation to the shade and shadow and the proportional contribution of diffuse shortwave solar radiation and the longwave thermal radiation emitted by their environs. The relative contribution of these forms of radiant energy will be site specific and depend on factors such as the sun's altitude and azimuth, climate, atmospheric dust and particulate levels and the character of the animal's immediate environs.

Muller & Botha (1997), working in a Mediterranean climate in South Africa, found no significant difference in black globe temperatures measured under shades 1.75 m and 3.15 m high. They also found no difference in various production and physiological parameters assessed in dairy cattle kept under either shade. They suggested that while temperature sensors in the high structures might have been subject to more indirect solar radiation, those under the low structures might have been subject to a commensurately higher level of thermal radiation from the low, unpainted galvanised iron roof. This would suggest that the optimum height of shade might also depend on the thermal properties of the shade material.

In a review of the subject, Ansell (1981) suggested that the higher the shade the lower the radiative load due to more "cool" sky being exposed for the animals to interact with. However, he noted that as the height of shades increased, the rate at which the shadow traversed the ground increased proportionally. As a result the shaded ground may be comparatively hotter with a resultant increase in the longwave thermal radiation from this source. He noted that this effect is likely to be of more significance where the surface is without a grass groundcover. Esmay (1978) expressed similar conclusions in regard to both the "cool" sky exposure and the rate of traverse. However, he suggested that with any "appreciable" air velocity, the shaded ground would cool rapidly and that the higher rate of traverse of the shadow cast by a high shade is unlikely to be a significant factor.

In a feedlot pen constant shade will result in a wet pen area. This wet area is dark with an albedo of 0.05 (Lott, 1997). By comparison the albedo of dry manure is a lot higher being in 0.11. These data indicate that wet manure will absorb a lot of energy in comparison to dry manure surfaces. Despite the evaporative cooling offered by water loss from wet manure, temperature differences between wet shaded manure and dry unshaded manure are small (Petrov *et al.* 2001).

While concurring with Ansell (1981) in regard to the rate of traverse of the shadow, Curtis (1983) suggested that a shade height of ~2 m was optimal in humid regions having a prevalence of cumulus cloud and that one of 3.5 m or greater was optimal in more arid areas where the air was drier and the sky relatively free of clouds ("cool").

Bucklin *et al*. (1992) and Shearer *et al*. (1999), offering advice to Florida dairy farmers, emphasise the importance of shade height on natural air movement under the shade and suggest optimum air movement will occur at a height of 3.6 m for shades less than 12 m wide and at a height of 4.2 m for wider shades.

Other factors need to be considered in designing the height of shade structures. These include having sufficient clearance for pen cleaning equipment and the cast distance of the shade which may throw to water and feed troughs.

Considering the above body of published information, it is evident that it is not possible to provide unequivocal recommendations solely on the basis of this material. It would appear that the optimum shade height is best determined by a multi-variate analysis that considers shade height in relation to the diverse range of factors discussed above. Notwithstanding this, climatic and or weather conditions appear to be factors of paramount importance when considering the height of shade structures. These factors combined with the practical considerations (such as allowing adequate clearance for pen cleaning operations) indicate that shade heights of greater than 4 metres are required in Australian feedlots.

3.3 Shadow Size

The shadow provided on a level surface by a thin, horizontal shade will have the same dimensions as the shade. However, the surface of feedlot pens typically slopes with a gradient in the range of 2 to 5%. Consequently, the size of the shadow cast by a horizontal shade in a sloping feedlot pen will vary with the aspect and magnitude of the pen gradient. The size of the shadow provided by a sloping shade will additionally vary with the solar altitude and azimuth.

There does not appear to be a strong consensus in the literature as to the minimum or optimum area of shade that needs to be provided for cattle.

Owen (1994) simply states that the area of shade needs to be sufficient to shade all of the housed animals.

A large proportion of published information pertains to the provision of shade for dairy cattle. In South Carolina, Barth (1982) suggested that a shaded area of 3.7 to 4.6 m² per head was desirable but did not state the basis for these stocking densities. Similarly Buffington *et al*.

(1983), working in Florida, recommended a minimum of 4.2 m² per head but suggested a shaded area equivalent to 5.6 m² per head might need to be considered. Further, they suggested that the 1.4 to 2.3 m² per head commonly provided on Florida dairy farms caused overcrowding (and higher thermal loads) that offset any benefit accruing from the provision of shade. In reviewing this topic, Bucklin *et al*. (1991) indicated that while allocations of 1.8 to 2.5 m² per head may be suitable in dry arid climates, in hot humid climates the 4.2 to 5.6 m² per head recommended by Buffington *et al*. (1983) is necessary to provide the ventilation rates required under these climatic conditions. Armstrong *et al*. (1993) indicated that they saw no benefit in providing more than 4.5 m² per head but recommended a minimum allocation of 3.5 m² per head based on the incidence of teat injuries at higher stocking densities. Teat injuries are unlikely to be a significant concern in a beef cattle feedlot.

Looking specifically at cattle feedlots, Mader *et al.* (1997) assessed feed and water intake and cattle behaviour when no shade, 1.5 m², 2.5 m² and >3.5 m² of shade per head were provided for cattle in four commercial feedlots in Australia. Their findings suggested that a shade allocation of at least 3.5 m² per head was needed to reduce the incidence of stress symptoms and that there was a possible interaction with the accessibility of drinking water (in terms of the allocation of trough space per head of stock).

Based on the above recommendations, which appear to largely have an experiential or empirical basis, a shade allocation of around 3.5 m² per head would seem to be a minimum requirement with the possibility that up to 5.6 m² may be required in hot, humid climates. However, there would appear to be a need to attempt to validate these recommendations using a more theoretical or analytical approach. Ideally, such an approach would be able consider not only the effects of the spatial distribution of cattle on their radiative load but also the associated interactions with convective, conductive and evaporative heat transfer.

3.4 Shade Slope

Four potential advantages are attributed to sloping shade structures in literature. These are the chimney or stack effect; the increasing of the shadow size; the increasing of the animal's exposure to "cool" sky; and the changing of the angle of incidence of solar radiation to the shade surface.

The chimney or stack effect relates to the utilisation of thermal buoyancy, induced by the convective heating of the air under the lower surface of the shade, to generate air movement. This air movement results from the convectively heated air rising along the lower surface of the shade and being discharged at the upper eave of a sloping shade structure. As a result, relatively cooler air is drawn under the shade at the lower eave. Bucklin *et al*. (1992) state, without substantiation, that the stack effect is only significant where shades have a slope greater than 18°. They recommend a maximum slope of around 26°, although this limitation is based on practical constraints associated with constructing and maintaining steeper structures. They also point out that the stack effect only increases air movement at the respective eaves and not at the height of the sheltered animals. Accordingly, the nature of the benefit gained will depend on the extent to which the heat load on the sheltered animal is reduced by this enhanced convective heat loss from the lower surface of the shade. There is no data in the literature specifically quantifying convective heat loss from the lower surface of shade structures although information on the effect in other structures (Barre *et al*., 1988 and Cooper *et al*., 1997) would suggest the effect could be significant.

Bond *et al*. (1976) undertook an extensive study of the effect of shade slope on shadow size under North American conditions. Based on their findings, significant increases in the mean size of the shadow cast throughout the day by variously sloping shades relative to that cast by a horizontal shade would only occur at latitudes greater than 50° (south of Tasmania). In midsummer, at latitudes less than 30° (Walgett and Bourke in New South Wales), the mean shadow area under sloping shades was reduced relative to that under horizontal shades (refer Figure 6). However, it should be noted that this study looked at the mean shadow size throughout the day rather than the shadow cast at specific and potentially critical times such as early to mid afternoon. More information is needed on this aspect of shade slope.

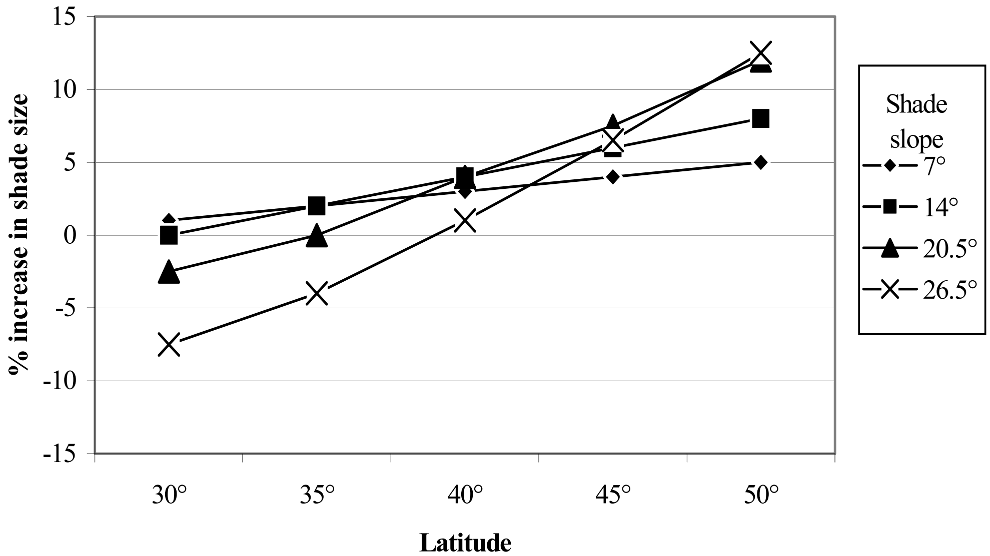

Figure 6. Percentage increase throughout the day in the mean shadow sizes of variously sloped shades (7°, 14°, 20.5° & 26.5°) over a horizontal shade structure at the summer solstice (adapted from Bond et al., 1976).

Bond *et al*. (1976) also considered that orientation of sloping shades relative to the cardinal points[9]. Based on their findings, under southern hemisphere conditions the maximum benefit would be gained by orientating sloping shades so that the higher side faces the southeast therefore exposing the shaded animal to a greater area of "cool" sky. However, they concluded that any benefit was relatively modest and only occurred under clear sky conditions where the humidity was low. They considered that such "cool" sky conditions were only likely to occur in summer at latitudes greater than about 38° (south of Melbourne). Consequently, there may not be any benefits in terms of this aspect of the sloping of shade structures for feedlots operating in mainland Australia. However, more information is needed to draw firm conclusions on the benefits likely to accrue under Australian conditions.

The intensity of direct solar radiation on a sloping surface is equivalent to the product of the direct normal solar radiation (as intercepted by a surface perpendicular to the sun's rays) and the cosine of the angle of solar incidence to the sloping surface. The cosine of the angle of solar incidence is the sum of the product of the cosine of the solar altitude, the cosine of the solar azimuth and the sine of the shade slope angle (refer Figure 7) and the product of the sine of the solar altitude and the cosine of the shade slope angle (Curtis, 1983 and Esmay & Dixon, 1986). Consequently, from this perspective sloping shades would need to have the highest side facing the west to reduce the intensity of solar radiation onto the shade surface during the hottest part of the day. Conversely, shades whose higher side faced the east or southeast would intercept the maximum amount of solar radiation in the early afternoon when the radiation load on the shaded animal from other sources is likely to be at its highest.

[9] North, south, east & west

Therefore, it is possible that sloping shades might be at least in part counterproductive when the net heat load on the shaded animal is considered, particularly in the middle latitudes where majority of the feedlots in Australia are located.

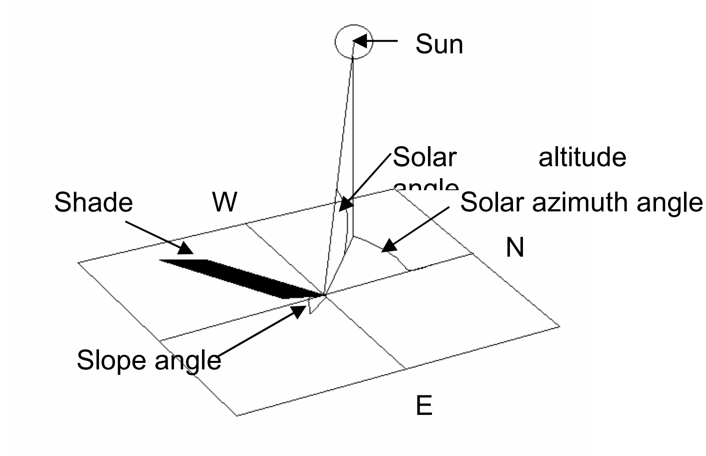

Figure 7. Solar angles with respect to a sloping shade.

The magnitude of the net effect resulting from the interaction of the above factors associated with sloping shade structures is a complex matter dependent upon the angle of inclination of the shade structure, its cardinal orientation, the shade material used, the latitude, the time of year and the climatic and weather conditions. Based on the above it is not possible to provide precise recommendations on the sloping of shade structures. In terms of the increasing of the animal's exposure to "cool" sky; and the changing of the angle of solar incidence it would appear the benefits, if any, could be relatively small and specific to a region or feedlot.

In regard to the chimney or stack effect there is insufficient data published to quantify the net effect under shade structures although based on evidence in other structures it may be significant. The effects of sloping shades on mean shadow size throughout the day depend in part on the latitude at which the feedlot is located. However, more information is required on the specific benefits to be derived from sloping shades at times of critical heat load such as in the early to mid afternoon.

3.1 Shade Orientation

The orientation of the long axis of the shade structure relative to the cardinal points determines the percentage of the shadow directly under the shade.

By orientating the shade structure so that its long axis runs east west, the percentage of the shadow directly under the shade throughout the day is maximised. This has the benefits of reducing the absolute temperature and radiant flux of the shaded ground that the animal is exposed to and reducing the number of times animals must move to remain in the shadow. However, it also minimises the area of relatively "cool" sky the shaded animal is exposed to and reduces evaporation from the shaded surface (Ansell, 1981; Barth, 1982; Buffington *et al*., 1983; Curtis, 1983; Bucklin *et al*., 1991 and Bucklin *et al*., 1992). Nevertheless, it has been suggested that reducing the evaporation from the shaded surface may result in high moisture levels in the feedlot manure pad with resultant increases in odour emissions (Sparke *et al*., 2001) and more fouling of the animals' coats (Curtis, 1983). Bucklin *et al*. (1991) notes that such undesirable effects are likely to be more pronounced in winter when there are likely to be no benefits from the shade. Consequently, if the objective is to maintain the surface of the manure pad as dry as possible, a north south orientation is preferable.

3.6 Summary

Consideration of the net effect different shade materials, shade height, shadow size, shade slopes and orientation have on the thermal load on shaded animals is a complex matter often involving conflicting interactions. This is particularly so when matters other than the radiant heat load, such as convective, conductive and evaporative heat loss, are to be considered. This complexity is further increased when the dynamic and complex spatial arrangement of animals under the shade is considered. As a result, it is difficult to provide unequivocal recommendations in regard to shade design solely on the basis of general design information provided in the published literature. There is however sufficient information published to undertake some elementary modelling that might provide some broad indication of importance of the different aspects of shade design.

Based on the available data it can be surmised that shades greater than 4 metres height, possibly with a slope and located on a north-south axis will offer best results. Heat load computations for various combinations of some of these factors are provided in Section 4.

4. ESTIMATING SHADE EFFECTS

4.1 Black Globe Thermometer

Bond & Kelly (1955) initiated the use of the black globe thermometer, together with measurements of air temperature and air movement, in the development of indices for the heat load on domestic animals. As such, the black globe thermometer is analogous to a theoretical black body that has perfect sorptivity (α = 1) and emissivity (ε = 1). In practice, a black globe thermometer has a sorptivity and an emissivity less than unity (~0.94 (Esmay & Dixon, 1986)). Nevertheless, black globe temperature has proved to be a useful parameter in attempts to incorporate radiant heat into indices of heat stress in cattle over the intervening period (Givens, 1965; Bond *et al.*, 1967; Esmay, 1978; Barth, 1982 and Esmay & Dixon, 1986).

Under steady state conditions the heat gained or lost by radiative flows between a black globe thermometer and its surrounds must be equivalent to that lost or gained by convection. The convective heat transfer can be expressed as (Esmay, 1978 and Esmay & Dixon, 1986):

$$q_c = 13.46\, v^{0.5} \left(t_g - t_a\right)$$

where q_c = convective heat transfer (W/m²),
v = air velocity (m/s),
t_g = black globe temperature (°C), and
t_a = air temperature (°C).

The radiative heat transfer can be expressed as (Esmay, 1978, Esmay & Dixon, 1986 and Barre *et al.*, 1988):

$$q_r = \varepsilon\, \sigma \left(T_m^4 - T_g^4\right)$$

where q_r = radiant heat transfer (W/m²),
ε = emissivity of the globe surface (0.94),
σ = Stefan-Boltzmann constant (5.67×10^{-8} W/m².K^4),
T_m = mean radiant temperature (°K), and
T_g = black globe temperature (°K).

Assuming steady state conditions where convective and radiant heat transfers are equivalent, then the above relationships can be equated and rearranged to determine the mean radiant temperature. This is expressed as (Esmay, 1978 and Esmay & Dixon, 1986):

$$T_m = 100\left[2.50\, v^{0.5} \left(t_g - t_a\right) + \left(\frac{T_g}{100}\right)^4\right]^{0.25}$$

Conceptually, the mean radiant temperature is the temperature of a theoretical, uniform black enclosure with which a black globe thermometer will exchange the same amount of energy as it would with the actual environment (Esmay & Dixon, 1986). Applying the Stefan-Boltzmann law of radiation, the radiant heat load can be related to the mean radiant temperature by the expression:

$$\mathrm{RHL} = \sigma\, T_m^4$$

Unfortunately, the mean radiant temperature can only be determined by the above methods using *in situ* measurements of black globe temperature, air temperature and air velocity. *A posteriori* observation of these parameters is not the most efficient means of designing shade structures.

4.2 Radiant Heat Load Estimation

It is possible to make *a priori* estimates of the radiant heat load if the radiant flux density, or alternatively the absolute temperature and emissivity, of each element in the animal's environs is known or can be estimated. Accordingly, the radiant heat load can be expressed as (Bond *et al*., 1976 and Esmay & Dixon, 1986):

$$\mathrm{RHL} = \sigma \sum_{i=1}^{n} \varepsilon\, T_i^4 F_i$$

where RHL = radiant heat load,
σ = Stefan-Boltzmann constant (5.67×10^{-8} W/m².K^4),
ε = emissivity of the surface of each environmental element,
T_i = absolute temperature of each element surface (°K),
F_i = shape factor of each surface in respect to the receiving body, and
n = the number of surfaces.

When using this relationship as an analytical tool for comparing different forms of shade design, computations are typically simplified by calculating radiation received by the black globe rather than the net radiative exchange.

The absolute temperature of the exposed radiative surfaces of environmental elements can be estimated using sol-air temperatures. Sol-air temperatures can be calculated from weather data using the relationship (Esmay & Dixon, 1986 and Barre *et al*., 1988):

$$t_c = t_a + \left(\frac{\alpha\ I}{f_c} \right)$$

where t_c = sol-air temperature (°C),
t_a = air temperature (°C),
α = sorptivity of the surface,
I = incident solar radiation (direct, diffuse & reflected) (W/m²), and
f_c = convective film coefficient.

As an alternative to calculating sol-air temperatures, the radiant flux of each surface ($q = \sigma\, \varepsilon\, T$) can be estimated from empirical data and the respective shape factors applied in a summation to derive the net radiant heat load (Bond *et al*., 1976 and Esmay, 1978).

The shape factor, F_i, is the view angle with respect to the black globe of each element in its environs and as such is the ratio of the area of the globe surface subtended by that element as a proportion of the surface area of the black globe. For elements distributed uniformly around the circumference of the globe, such as the "horizon" (fences, troughs, feed bunks, trees etc.), the shape factor can be simplified to (sin ϕ)/2 (Esmay & Dixon, 1986).

$$F_i = \frac{\text{area of zone } i}{\text{area of sphere}} = \frac{2\,\pi\, r\, h}{4\,\pi\, r^2} = \frac{2\,\pi\, r^2\, \sin\phi}{4\,\pi\, r^2} = \frac{\sin\phi}{2}$$

where ΣF_i = 1,
r = radius of sphere,
h = altitude of zone *I*, and
ϕ = angle the zone radius makes with the diameter.

For more spatially complex but regularly shaped elements, in particular planar surfaces such as the shade and the shadow, the shape factor can be calculated from the ratios (L_1/D & L_2/D) of the displacement of two edges of the element perpendicular to a point normal to the location of the receiving body (L_1 & L_2) and the displacement of the receiving body from the element (D). The resultant shape factor can then be read from the diagram provided in the Cornell University Experiment Station Bulletin 32 (1943).

For irregularly shaped elements such as the sky or the unshaded ground, their shape factors can often be estimated by subtracting the previously determined shape factors for all the other elements in their respective hemispheres from 0.5.

4.3 Interpretations of Shade Design

While detailed modelling of shade structures is beyond the scope of this report, some limited modelling can be undertaken to illustrate the influence of the various factors discussed in Section 3 (above) on the radiant heat load (RHL) on feedlot cattle.

At 2 pm on 14 January at latitude 27°S (Dalby, Queensland), the sun will have an altitude of 64° and an azimuth of 84°. A shade 30 metres long and 6 metres wide, 4 metres off of the ground and orientated north south would cast a shadow lying 1.94 metres to the east and 0.2 metres to the south of the shade (refer Figure 8).

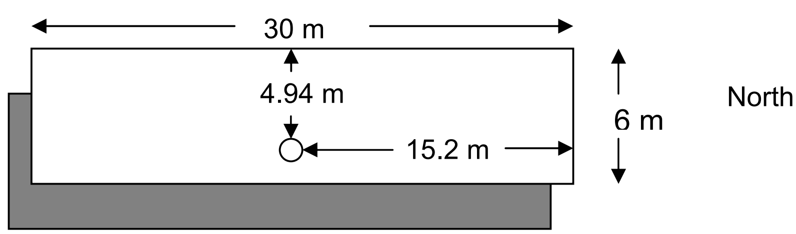

Figure 8. Displacement of an animal located at the centre of the shadow cast by a shade 30 m long and 6 m wide, 4 m off of the ground and orientated north south at 2 pm on 14 January at 27°S.

There would appear to no published measurements of the radiant flux density associated with the environmental elements found specifically in feedlots and, in particular, in feedlots under Australian conditions. Esmay (1978) provided estimates of the radiant flux for various environmental elements based on measurements made at an experimental field site at El

Centro, California when the air temperature was 38°C. These estimates included 500 W/m² for the shaded ground in the shadow, 660 W/m² for the hot, unshaded ground, 675 W/m² for the horizon, 660 W/m² for the underside of the shade and 425 W/m² for the exposed sky. Using these estimates (in the absence of any better data) and *F* factors determined for the spatial configuration of the various elements as shown in Figure 2, the total radiant load one metre above the ground (corresponding to the centre of mass of a standing feedlot steer) in a dry climate can be calculated and is provided in Table 5.

Table 5 RHL in centre of shadow, 1 m above ground, under a 30 m × 6 m galvanised iron shade, 4 m above the ground, in a dry climate.

Element	Radiant flux (W/m²)	F_i	q_i (W/m²)
Shadow	500	0.40	200
Hot ground	660	0.10	66
Horizon	675	0.09	61
Shade	660	0.21	139
Sky	425	0.20	85
	Total	**1.00**	**551**

The radiant flux between the shaded animal and the sky is dependent on the humidity, and airborne dust and particulate levels. Various methods have been proposed for estimating the incoming diffuse solar radiation (Esmay, 1978; Curtis, 1983 and Esmay & Dixon, 1986). However, the relatively simple relationship from Esmay & Dixon (1986) shown in Figure 9is sufficient to illustrate the effect of humidity.

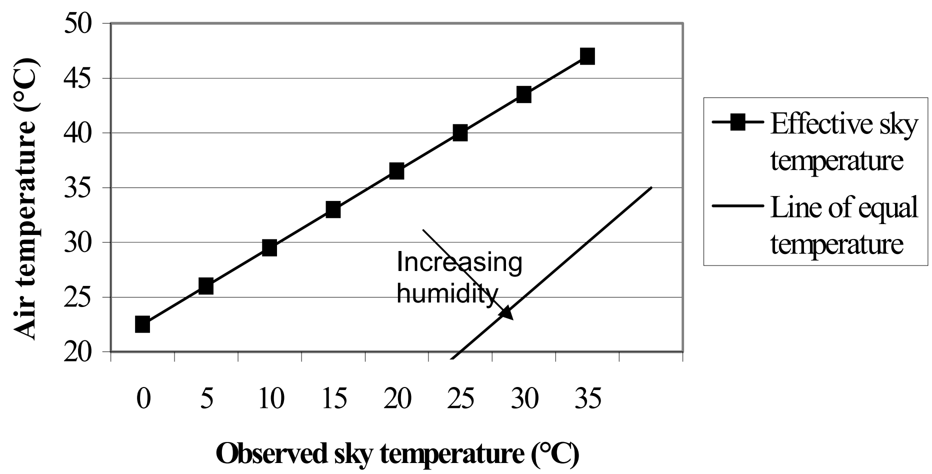

Figure 9. The effective northern sky temperature 60° above the horizon in relation to ambient air temperature at ground level at El Centro, California (Esmay & Dixon, 1986).

At an air temperature of 38°C under the relatively arid conditions at El Centro, the effective sky temperature would be around 22°C (Figure 9). All other things being equal, as the humidity of the atmosphere increases the effective sky temperature (mean radiant temperature) approaches the ambient air temperature at ground level. Accordingly, in a humid environment the radiant flux associated with the sky might be expected to be around 25% greater than that in an arid environment. Adjusting the radiant flux with the sky in Table 5 to reflect this effect, the radiant heat load can be recalculated and is shown in Table 6.

Table 6. RHL in centre of shadow, 1 m above ground, under a 30 m × 6 m galvanised iron shade, 4 m above the ground, in a humid climate.

Element	Radiant flux (W/m²)	F_i	q_i (W/m²)
Shadow	500	0.40	200
Hot ground	660	0.10	66
Horizon	675	0.09	61
Shade	660	0.21	139
Sky	530	0.20	106
	Total	**1.00**	**572**

The resultant increase in radiant heat load on an animal kept in a humid environment would appear relatively minor (<4%) but even an increase of this small magnitude may be critical, particularly if other mechanisms for controlling body temperature, such as convective or evaporative heat loss, are impeded under such conditions.

Applying insulation to the shade material can reduce the radiant flux associated with the lower surface of the shade. Assuming a conservative 15% reduction in the radiation from the underside of an insulated shade, the estimated radiant heat load experienced by an animal in a dry climate (Table 7) can be reduced by around 4% to 528 W/m². A percentage reduction of about the same magnitude can be expected in a humid climate.

Table 7. RHL in centre of shadow, 1 m above ground, under a 30 m × 6 m insulated shade, 4 m above the ground, in a dry climate.

Element	Radiant flux (W/m²)	F_i	q_i (W/m²)
Shadow	500	0.40	200
Hot ground	660	0.10	66
Horizon	675	0.09	61
Shade	550	0.21	116
Sky	425	0.20	85
	Total	**1.00**	**528**

To illustrate the effects of shade height on radiant heat load (but not other heat transfer mechanisms) the estimates in Table 5 were recalculated to reflect the effect of reducing shade height to 2.5 m (Figure 10) as compared to the original 4.0 m (Figure 8). The results for a dry climate are provided in Table 8.

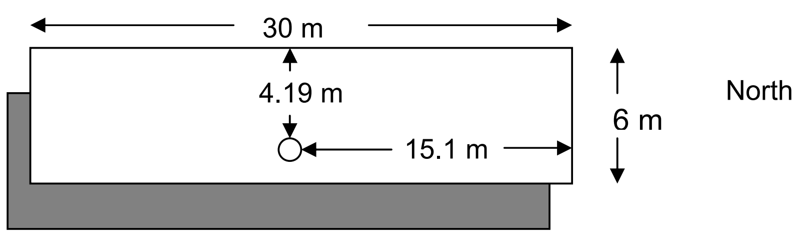

Figure 10. Displacement of an animal located at the centre of the shadow cast by a shade 30 m long and 6 m wide, 2.5 m off of the ground and orientated north south at 2 pm on 14 January at 27°S.

Table 8. RHL in centre of shadow, 1 m above ground, under a galvanised iron shade 30 m long and 6 m wide, 2.5 m above the ground, in a dry climate.

Element	Radiant flux (W/m²)	F_i	q_i (W/m²)
Shadow	500	0.40	200
Hot ground	660	0.10	66
Horizon	675	0.09	61
Shade	660	0.34	224
Sky	425	0.07	30
	Total	**1.00**	**581**

From Table 8 it can be seen that reducing the shade height might increase the radiant heat load on a shaded animal from around 550 W/m² to 580 W/m², an increase of over 5%. This increase is a result of the animal's increased exposure to the relatively hot underside of the lower shade structure. When the unquantified effects of reducing air movement and increasing humidity likely to result from a reduction in shade height are considered, it would appear likely that animals under a lower shade are liable to be at a significant disadvantage relative to that under a 4 metre high shade.

The increase in the radiant heat load under a 2.5 metre high shade in a humid climate (Table 9) relative to that in an arid climate (Table 8) is small in comparison that under the 4 metre shade reflecting the substantially reduced exposure to the sky (Table 9 F_i = 0.07, Table 6 Fi = 0.20).

Table 9. RHL in centre of shadow, 1 m above ground, under a galvanised iron shade, 2.5 m above the ground, in a humid climate.

Element	Radiant flux (W/m²)	F_i	q_i (W/m²)
Shadow	500	0.40	200
Hot ground	660	0.10	66
Horizon	675	0.09	61
Shade	660	0.34	224
Sky	530	0.07	37
	Total	**1.00**	**588**

Doubling the width of the shade to 12 metres will result in the changes in the location of an animal standing in the centre of the shaded area as shown in Figure 11.

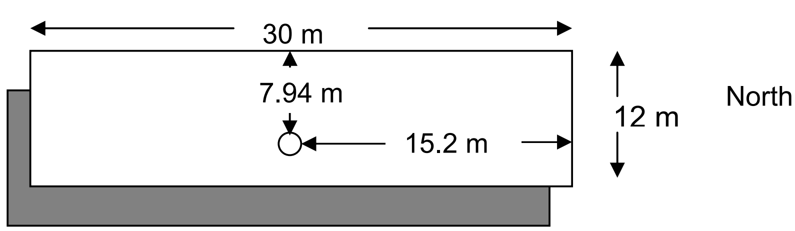

Figure 11. Displacement of an animal located at the centre of the shadow cast by a shade 30 m long and 12 m wide, 4 m off of the ground and orientated north south at 2 pm on 14 January at 27°S.

As the shadow is larger under the larger shade, on average the ground will remain shaded for a longer time during the day. Consequently, the mean radiant temperature of the shaded ground might be expected to be less than under the smaller shade. Assuming a 10%

reduction in the radiant temperature of the shaded ground under the larger shade, the radiant heat load on the animal can be estimated and is provided in Table 10. Despite the doubling of the shaded area, the radiant heat load is only estimated to be about 2% less. However, this estimate is very sensitive to the radiant temperature of the shaded ground. If there were no change in the mean radiant temperature of the shaded ground under the larger shade, the estimated load under the larger shade would actually increase to 563 W/m², slightly higher than that under the smaller shade (Table 5). This is due to the animals increased exposure to the underside of the larger shade. It should be noted that the above estimates do not take account of the potential changes in the radiant load that might arise if there was a greater dispersion of individual animals under the larger shade.

Table 10. RHL in centre of shadow, 1 m above ground, under a 30 m × 12 m galvanised iron shade, 4 m above the ground, in a dry climate.

Element	Radiant flux (W/m²)	F_i	q_i (W/m²)
Shadow	450	0.48	216
Hot ground	660	0.02	13
Horizon	675	0.09	61
Shade	660	0.32	211
Sky	425	0.09	38
	Total	**1.00**	**539**

Insulating the larger shade (Table 11) results in a radiant heat load of 504 W/m². This represents a reduction of over 8% when compared to the uninsulated larger shade. The effect of insulating the larger shade is greater than that associated with the smaller insulated shade (Table 6 and Table 7) due to the animal's increased exposure to the underside of the larger shade. Again, if there were no reduction in mean radiant temperature of the shaded ground there would be no change in the radiant heat load under the larger shade (552 W/m²) compared to that under the smaller shade (Table 5). In this later case the reduced exposure to heat from the hot unshaded ground outside the shadow of the larger shade is matched by the increased exposure to radiation from the underside of the larger shade. Similarly, this estimate takes no account of the spatial distribution of the other animals under the shade.

Table 11. RHL in centre of shadow, 1 m above ground, under a 30 m × 12 m insulated shade, 4 m above the ground, in a dry climate.

Element	Radiant flux (W/m²)	F_i	q_i (W/m²)
Shadow	500	0.48	240
Hot ground	660	0.02	13
Horizon	675	0.09	61
Shade	550	0.32	176
Sky	425	0.09	38
	Total	**1.00**	**528**

A 30 metre by 12 metre sheet and cable structure having a 50% cover would provide the same area of shadow as a 30 metre by 6 metre solid cover. Under a sheet and cable structure it might be assumed that the surface temperature of the shadow area would be higher than that under a solid shade. Table 12 provides an estimate of the radiant heat load on an animal at the centre of the shadow area under such a structure in a arid climate assuming the surface of the shaded ground is 10% hotter than under a solid structure. The resultant heat load of 577 W/m² is more than 4% greater than that under a solid structure providing the same shadow area (Table 5).

Table 12. RHL in centre of the area of shadow, 1 m above the ground, under a 30 m × 12 m galvanised sheet and cable structure (50% shade cover), 4 m above the ground in a dry climate.

Element	Radiant flux (W/m²)	F_i	q_i (W/m²)
Shadow	550	0.24	132
Hot ground	660	0.26	172
Horizon	675	0.09	61
Shade	660	0.16	106
Sky	425	0.25	106
	Total	**1.00**	**577**

Table 13 provides an estimate of the heat load under the same sheet cable structure in a humid climate. The resultant heat load of 604 W/m² is about 5% greater than that under the solid structure providing the same shadow area in a humid climate (Table 6). This increase is due to the greater exposure to the relatively hot sky under such climatic conditions.

Table 13. RHL in centre of the area of shadow, 1 m above the ground, under a 30 m × 12 m galvanised sheet and cable shade (50% cover), 4 m above the ground in a humid climate.

Element	Radiant flux (W/m²)	F_i	q_i (W/m²)
Shadow	550	0.24	132
Hot ground	660	0.26	172
Horizon	675	0.09	61
Shade	660	0.16	106
Sky	530	0.25	133
	Total	**1.00**	**604**

A summary of the general effects discussed above is provided in Table 14. It should be noted that the estimates used to ascertain these effects are not based in feedlot specific measurements made under Australian conditions. Also, the derived estimates of radiant heat load are also sensitive to the magnitude of the estimates of radiant flux associated with the underside of the shade structure and the shadow area on the ground. Consequently, the predicted effects should be treated with due caution in the absence of any verification of the radiant flux densities likely to be experienced in Australian feedlots. Notwithstanding this, the predicted effects are generally consistent with reports in literature as discussed in Section 3 above.

Table 14. Summary of general effects attributable to variables associated with shade design.

Shade design variables	General effect
Higher shade	Lower RHL
Lower shade	Higher RHL
Larger shade	Small & variable
Arid climate	Lower RHL
Humid climate	Higher RHL
Insulation	Lower RHL
Sheet & cable structure	Higher RHL

5. CONCLUSIONS

The complexity of the multifarious aspects of subject precludes conclusive recommendations for shade design in Australian feedlots being developed on the basis of this literature review. Notwithstanding this, the basic radiant heat load (RHL) estimations outlined in section 4.2 has shown that the factors that assist in reducing the RHL include higher shade, an arid climate, and provision of insulation to the shade material.

While some elementary modelling of the radiant heat load confirms a number of general principles, the basic nature of the modelling, the unverified input data and the range of untested assumptions that the modelling is based, mean that it is neither rigorous nor robust when applied to feedlots operating under Australian conditions.

Based on the findings of the literature review, it is recommended that consideration be given developing a suitable thermodynamic model that can deal with the complex factors associated with radiant heat in shade design. Such a model would also need to consider other aspects of the heat load on cattle, including convective, conductive and evaporative heat fluxes between groups of penned cattle and their environs.

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