live export

Wetting cattle to alleviate heat stress on ships

Final report – stage 2

Project number LIVE.219

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ISBN 1 74036 576 3

April 2005

THE UNIVERSITY OF QUEENSLAND

MEAT & LIVESTOCK AUSTRALIA

LIVECORP

The livestock export program is jointly funded by the livestock exporters and producers of Australia

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Abstract

This report details the results of a study commissioned by LiveCorp/MLA to investigate the effects of cooling Angus steers (mean live weight = 355 kg) with water on pen microclimate, feed intake, respiration rate, panting score, body surface temperature and behaviour when exposed to dry bulb temperatures (DBT) > 30 ^oC and wet bulb temperatures (WBT) > 30 ^oC for 4 days. The steers (n=18) were housed in groups of nine (1.427 m^2/hd) in an enclosed climate controlled room in a pen designed to replicate ship board conditions. Water was applied by (i) a hose, (ii) overhead sprinklers, (iii) sprinklers at leg height, or (iv) misting. Fans ensured adequate air movement. To replicate seawater conditions in the northern Indian Ocean water was heated to 30 ^oC and contained 3% salt. DBT, WBT, air pressure, and atmospheric ammonia concentration were recorded. Hose, overhead sprinklers and misting were successful in reducing cattle heat load. Leg wetting was ineffective because dominant cattle restricted sprinkler access. Misting used the most water (5483 L) and the hose the least (845 L). The application of water resulted in significant falls (> 3 ^oC) in DBT, and zero or < 1^oC increases in WBT. These result, show that wetting cattle as a method of reducing the effects of high heat load can be carried out in environments where WBT is high with little negative impact on the microclimate. It is necessary to remove bedding prior to or during wetting to ensure ammonia levels remain low.

1.0 Executive summary

Eighteen Angus steers exposed to high heat load conditions were used to assess the effectiveness of four spray cooling systems, on reducing the effects of high heat load on the animal, the impact on microclimate and water usage. The steers were housed in groups of nine in a fully enclosed climate controlled room and were exposed to high heat load conditions for four days. Each group of cattle was housed in a pen (12.84 m^2) designed to replicate a shipboard pen. Stocking rate was 1.427 m^2/hd. The cooling systems used were water applied via a hose, via overhead sprinklers, via sprinklers at leg height or via misters. Fans were used to ensure adequate air movement over the cattle. The animal parameters measured were feed intake, respiration rate, panting score and behaviour. Climatic factors measured were ambient temperature and wet bulb temperature. Ammonia levels were also measured. Data were analysed using; using analysis of variance, nonparametric analysis, correlation analysis, time series analysis, Chi-Square analysis and regression analysis. Data analysed included: Panting scores, feed intake, water intake, water usage (for cooling), number of times water was applied, climatic change (pre and post wetting) and behaviour. Treatment, day and treatment x day effects were also investigated. Generally the level of significance between treatment means is taken at the 95% or 99% confidence interval or where $P<0.05$ or $P<0.01$, however significance levels of $P<0.10$ are also included for some of the measured parameter while not normally taken as statistically significant may be of biological or financial importance. The hose, overhead sprinklers and misting were all successful in reducing heat load on the cattle. The leg wetting system did not work due to dominant cattle blocking access to the sprinklers. The misting system used significantly ($P<0.05$) more water (5483 L) than hose application (845 L). Cattle exposed to the hose and misting strategies had the smallest reduction in feed intake when exposed to hot conditions at 14.6% and 20.7% respectively. The reduction in feed intake was greatest ($P<0.05$) for the leg wetting option at 50.9%. There were no differences between treatments for mean daily water intake under thermoneutral or hot conditions, however across all treatments water consumption doubled under exposure to hot conditions. The application of water had minor impacts on wet bulb temperature, but resulted in significant falls in dry bulb temperatures.

1.1 Major findings

Within the confines of this study the following findings and recommendations are presented.

- Cooling heat stressed cattle with warm (30 ^{o}C) salt water was successful in terms of cooling the cattle for three of the four options investigated – hose, overhead sprinkler and large droplet misting.
- Use of sprinklers at leg level was not a viable option because access was easily blocked by dominant cattle, and therefore should not be considered.
- For all options no wetting was needed on day 1 of exposure to hot conditions.
- Application of water via a hose was the best in terms of the number of wettings needed (n = 10) over the hot period, followed by 22 for leg, 23 for overhead and 68 for misting.
- Water application by hose used the least water. Total water used for each option over 3 days of water application were: hose: 845 L, overhead: 2691 L, leg[1]: 3694 L and misting: 5483 L.

[1] Leg wetting was terminated on day 3 for animal welfare reasons. Wetting was for 2 days only.

- Total water application per steer was 94, 299, 410 and 609 (L/hd) respectively for the hose, overhead, leg and misting options.
- Bedding must be removed when wetting commences – or just prior to – failure to do so resulted in unacceptable levels of ammonia (up to 35 ppm).
- As the duration of exposure increased so does the frequency of water application.
- As the duration of exposure to hot conditions continues it appears as if the animals ability to cope (or adjust) is reduced i.e. they become more susceptible to heat stress.
- There were no negative effects of wetting cattle in terms of rise in wet bulb temperature. In most incidences the use of water to cool cattle also resulted in a reduction in air temperature, especially with the misting option where reductions of 1 ^{o}C were observed.
- Cattle appear to be more susceptible to even mild heat stress conditions following exposure to a major heat event.

1.2 Recommendations

- Hose wetting (water running off the cattle) should be used to cool heat stressed cattle. This method is especially effective for emergency cooling of cattle and where the heat event is of short duration. This is the simplest method to use because the infrastructure is already in place. However, labour costs need to be considered if prolonged wetting of a whole deck or multiple decks is required. Ship operators will need to determine if they have sufficient labour capacity to adequately cool single or multiple pens/decks at the same time.
- Overhead wetting (large droplet size, water running off the cattle) should be considered where possible. The cost of installation may be offset by savings in labour and would allow for rapid responses across a number of pens and decks at the same time. This option would give ship operators considerable flexibility.
- Leg wetting and fine droplet misting using small sprays should not be used.
- Bedding should be removed at first wetting, and not replaced until heat stress conditions abate. If this is not done atmospheric ammonia levels may reach unacceptable levels.
- Cattle observation remains the key to effective heat stress management. It is recommended that panting scores be used as the basis for assessment of cattle heat load status. Observation of panting scores should be done a least four times each day when environmental conditions are likely to induce heat stress. The ideal times are 0200 h, 0600 h, 1400 h and 2200 h. More frequent observations should be made if cattle are suffering from heat stress. Wetting should commence when more than 5% of cattle in a pen or deck have a panting score of 2.5. Other factors such as reductions in feed intake and increased water consumption can also be used as an indicator that cattle are having difficulty in coping. And may serve as a warning of impending problems.
- Climatic factors also need to be considered. Approaching heat waves or entry into known “hot spots” may be predicted two or three days prior. Increasing maximum daytime temperatures and increasing minimum night time temperatures are possible indicators of impending high heat load situations.
- A specific recommendation for time on/off for water application is difficult to make. The frequency and duration of water application is a function of the severity of the climatic conditions and animal condition. However, based on observations and results from this study and previous studies the following recommendations are made. Where heat stress effects are mild i.e. cattle with panting score 2 to 2.5, cattle may be wetted for 3 to 5 minutes every 45 to 50 minutes if there is a likelihood that climatic conditions will get worse. *However, provided that there is adequate*

observation of cattle with mild heat stress, and the likelihood of climatic conditions becoming more severe is low than wetting will not normally be need. When heat stress becomes more severe i.e. panting score 3 to 4, cattle will need to be wetted for 3 to 5 minutes every 15 to 25 minutes. If a situation exists where panting scores of 4.5 are observed cattle must be wetted for 5 to 8 minutes every 10 minutes. It is important to keep observing the cattle. If following wetting animal conditions do not improve more frequent and longer application may be necessary.
- Once wetting commences it must be carried out until the climatic conditions causing heat stress abate.

1.3 Future research

- The optimum frequency and duration of water application to cool heat stressed cattle needs further investigation, under a variety of climatic conditions, and genotypes (e.g. dairy cow verses beef cattle). This is essential to ensure that not only are cattle adequately cooled, but also to ensure the efficient use of labour and water use. This should be done under controlled conditions.
- The possible susceptibility of cattle to a mild heat stress events following a major heat episode needs to be further investigated. This has implications for cattle welfare after unloading into a hot environment.

2.0 Background

A literature review was undertaken for Part 1 of LIVE.219. From this review the following were determined to be important in regard to cooling cattle using water:

- Application of water via sprinklers is an effective method of cooling cattle,
- Large droplets should be used,
- Supply an intermittent spray,
- Cooling with water works best where there is air movement,
- Air movement on the animal needs to be maintained above 2 to 4 m/s, and,
- Application of cool water provides greater benefit than warm water.

2.1 Project objectives

The objectives are split into two stages.

Stage One
By 5 September 2003, determine the benefit of the emergency wetting of heat stressed cattle as feasible using current shipboard infrastructure, by measuring body temperature, respiration (panting), feed intake and live weight change.

Stage Two

a) By 30 January 2004, analyse the literature and the shipboard environment to explain the physical and physiological parameters involved in cooling both the air and the animal using water, and to recommend wetting options for evaluation in climate room experiments.

b) By 19 April 2004, undertake climate room experiments to test, document and demonstrate the results of wetting cattle to determine the most practical, physiologically effective and commercially viable means of using water to alleviate heat stress in cattle on ship.

c) By 30 April 2004, following identification of the means to wet cattle, communicate to industry the theory and practical application of this means, as directed by MLA.

Based on the review of literature and previous consultation with ship operators, four cattle wetting (cooling) systems using warm (30 °C) salt water and adequate air movement (pen air turn over 184 m/h to 194 m/h) were investigated.

Four wetting systems were evaluated using cattle (n=9 per treatment) housed in a 12.84 m^2 pen (1.427 m^2/hd) within the controlled climate facility at The University of Queensland, Gatton. The wetting options used were as follows:

(i) Wetting the body of cattle using a pressure hose (hose),
(ii) Wetting the body of cattle using large droplet overhead sprinklers (overhead),
(iii) Wetting the legs of cattle using large droplet sprinklers (leg), and,
(iv) Wetting the body of cattle using a large droplet misting system (misting).

The efficiency of each system was evaluated on the basis of cattle responses (i.e. change in respiration rate following water application), changes in cattle behaviour (i.e. standing, lying, eating and drinking) and daily feed intake.

The efficiency of each system was also evaluated on the basis of rate of water application (L/d), and the duration (minutes on) and frequency (minutes off) for each application that was needed to maintain cattle with a panting score below 2.5.

The pen microclimate effects resulting from each of the wetting system were also evaluated.

3.0 Materials and methods

3.1 Experimental design

The wetting water used for all treatments was heated to 30 °C and contained 3% NaCl. This was undertaken to simulate the conditions typically encountered in the northern Indian Ocean and Persian Gulf. The salt water system was previously described in Gaughan *et al.* (2003).

The cattle (Angus steers) were exposed to two days of thermoneutral conditions (TNC), followed by four days of hot conditions (HOT) during which there was no respite from the heat. The following parameters were set for TNC: Dry bulb temperature (DBT) set to be below 22 °C, relative humidity (RH) > 70% and wet bulb (WBT) to be below 24 °C.

The climatic conditions for HOT were determined by actual wet bulb temperature and pen air turnover recordings on ships travelling to the Middle East during the northern summer.

The following parameters were set for the four days of Hot:

Day 1*:* DBT = 28 °C (min) to 30 °C (max), RH = > 70%, WBT = 26 °C (min) to 28 °C (max).

Day 2: DBT = 30 ^{o}C (min) to 32 ^{o}C (max), RH = > 70%, WBT = 27 ^{o}C (min) to 29 ^{o}C (max).

Days 3 - 4: DBT = 33 ^{o}C (min) to 37 ^{o}C (max), RH = > 70%, WBT = 32 ^{o}C (min) to 34 ^{o}C (max).

Prior to the commencement of the study in the climate facility, the cattle (n = 18), were held at The University of Queensland Gatton feedlot in two groups of nine. The cattle remained within their respective group for the duration of the study. One group was allocated to hose and leg wetting, and the second group to overhead sprinklers and misting. While in the feedlot the cattle were accustomed to human handling and introduced to the "shipper" pellets. The cattle (one group of 9) (were then rotated through the climate facility and exposed to their allocated treatment. At the cessation of treatment the steers were returned to the feedlot and were observed for a further 4 days. The group remained at the feedlot for 24 days before being exposed to the next allocated treatment. Exposing the same 9 steers to two different treatments was undertaken to allow adjustment for animal variation in response to heat load. The 24 days between treatments ensured that there were no carry over effects between treatments.

3.2 Data collection

Hourly observations of cattle were undertaken during all days of HOT. During TNC observations were made hourly between 0600 h and 1800 h. All instrumentation was re-calibrated between treatments.

3.2.1 Climatic variables

The following climatic variables were recorded: dry bulb temperature (DBT; ^{o}C), wet bulb temperature (WBT; ^{o}C), air pressure (kPa), oxygen concentration (%) and atmospheric ammonia concentration (ppm). Relative humidity was calculated from DBT, WBT, air pressure and mean elevation (m) of the facility using the equations of Barnes (2001).

Dry bulb temperature and WBT were measured using thermistors located 300 mm outside of the cattle pen at a height of 1 m above the floor. The thermistors were positioned to ensure that there was no direct air movement over them. Air pressure was measured using a pressure transducer (PDS-Baro Barometric Pressure Transducer, Pacific Data Systems, Brisbane). Temperature and air pressure data were logged every 1 minute to a DT50 data logger (Data Electronics Australia P/L).

Oxygen concentration of the air (%) was measured using an oxygen analyzer (PK Morgan Ltd., Chatham, Kent, England). A hose attached to a vacuum pump sampled air 2 m above the cattle pen at 1 hour intervals. The vacuum pump was run for 5 minutes prior to readings being recorded to ensure accuracy of reading. This was undertaken to ensure that there was adequate air turnover in the climate facility.

Ammonia concentration (ppm) was measured for l minute each hour at the cattle pen (1.5 m above the floor and 3 m from the end of the pen) using an ammonia gas analyzer (VRAE Multi Gas Monitor, Model PGM-7800; RAE Systems Inc., Sunnyvale, CA USA).

Air speed (m/s) was measured twice daily at the cattle pen using an anemometer (TA 2; Airflow). In addition air speed was measured in the cattle pen at eight locations on four occasions.

Pen air turnover was calculated using the volume of air entering the facility.

3.2.2 Cattle measurements

The cattle were weighed at the start and finish of each wetting strategy.

Panting scores (Table 1), location in pen, behaviour and body surface temperature were measured and recorded hourly during HOT.

Table 1. Cattle Breathing Conditions and Panting Scores (PS).

Breathing Conditions	Panting Score
No panting – normal	0
Slight panting, mouth closed, no droll or foam	1
Fast panting, drool or foam present	2
As for 2 but with occasional open mouth	2.5
Open mouth + drooling, neck extended and head usually held up	3
As for 3 but with tongue out slightly	3.5
Open mouth tongue out + drooling, neck extended and head up	4
As for 4 but head down, drooling may cease, respiration rate may drop	4.5

Adapted from Mader et al. 2001 and Gaughan (2003)

Behaviour was classified as standing (not eating or drinking), lying, eating (head in or at trough) or drinking (muzzle in trough). Any agonistic behaviour (e.g. head butting or pushing) was also recorded.

Body surface temperature (ST) was measured on the ribs of four cattle each hour using an infrared thermometer with a laser sight (Raynger MX, Raytek, Santa Cruz, CA). In addition ST was measured on any obviously distressed cattle.

Feed intake (kg) was recorded daily on a pen basis.

3.2.3 Housing

The steers were housed as a group (9) in a 6 x 2.14 m pen (12.84 m^2), which was a stocking rate of 1.427 m^2/hd. This is consistent with LEAP recommendations (November 2002 amendment) for cattle weighing 355 kg that are to be exported from south of the 26^{th} parallel between 1 May and 31 October. Two metal feed troughs and two plastic water troughs were attached to the pen. The floor of the pen was concrete, and the pen structure was made up of 2 m high metal portable yard panels. A 400 mm high guard around the bottom of the panels was used to retain bedding (Photograph 1 and 2).

Air movement across the animals was provided via a fan located 1 m outside the cattle pen and 1 m from one end of the pen, and by ducted air located 600 mm from the opposite end of the pen.

3.2.4 Bedding

Sawdust bedding (Pine wood shavings; HYSORB) was provided. The sawdust used was similar to that used on live export vessels (Photograph 3). The bedding was placed in the pen to a depth of 200 - 300 mm and was removed after the first 7 days or as required. The impact of all wetting treatments on the bedding was assessed. To do this the pH content of the bedding was measured prior to and following wetting. A 100 gram sample of sawdust was collected each day at 0900 h and pH was measured. The 100 g sample was divided into two 50 g sub-samples which were paced in a 500 ml flask. Approximately 100 ml of distilled water was added to the sub-sample and was left at room temperature for 2 hours. The pH of each sub-sample was then measured. Cleanliness of cattle was also assessed using a 0 to 5 scale, where 0 was clean (no faeces on coat) and 5 was more than 4/5 of the animal covered in faeces.

3.2.5 Feeding

A commercial 8 mm "export" pellet was used (Better Blend Stockfeeds, Oakey, Qld.) throughout the study. The cattle were fed half of their daily allowance at 0800 h and again at 1600 h. The daily allocation was based on 2.5% of mean live weight of the 9 steers at the start of each treatment. Total feed allocation on days of HOT was made on the basis of actual consumption. For example if 20 kg of feed was not eaten on a particular day, feed allocated the next day was reduced. However cattle never ran out of feed. Drinking water was available *ad-libitum*.

Feed intake and water usage were recorded daily on a pen basis. Drinking water temperature was recorded twice daily at 0800 h and 1600 h, and two hourly when under 24 h HOT observation. Dry matter content of fresh feed was determined each day. All orts were collected, weighed and dry matter determined.

3.2.6 Animal care

This project was approved by the UQ animal ethics committee (SAS/112/03/Livecorp). When exposed to hot conditions the cattle were inspected at least hourly. When 1 steer had a panting score of 2.5 (equivalent to a respiration rate of approximately 120 bpm) the respective wetting strategy was imposed. No animals were removed during the course of the study. The cattle used in the study were inspected twice by the UQ Gatton animal welfare officer.

3.3 Wetting treatments

Based on the outcomes of stage one of this project (Gaughan *et al*., 2003), shipboard interviews and a review of literature (Gaughan *et al*., 2004), the cattle were subjected to four wetting treatments.

These treatments were designed to evaluate the impact of droplet size and different heat transfer mechanisms. The water application methods are commercially available and have been widely used in the dairy industry for cooling cattle. The temperature of the saline water applied to wet cattle remained constant and reflected the temperature of seawater used on ships in the northern

Indian Ocean and Persian Gulf during summer i.e. approximately 30 ^{o}C. The mean water output from the pump over the duration of the study was 32.5 ± 1.2 L per minute.

Water usage was timed, and was kept to a minimum – however animal welfare was also important – so the amount of water that was used ensured that cattle welfare was maintained. Adequate water coverage of the animal was defined as - *when water was running off the back and sides of the animal*.

When calculating ventilation requirements and assessing cattle comfort it is essential to distinguish between sensible and latent heat dissipation (Pedersen 2002).

Sensible heat will dissipate in accordance with the differential between an animals surface/core body temperature and ambient air temperature. Sensible heat loss will be zero when the air around the animal reaches an ambient temperature (dry bulb) of 39 to 40 ^{o}C, equivalent to the animal body temperature (Pedersen 2002). There is a curvilinear drop in the efficiency of sensible heat loss as ambient temperature approaches body temperature. At approximately 22 ^{o}C potential evaporative heat loss exceeds sensible heat loss, and by the time ambient temperature approaches 38 ^{o}C cattle are relying on evaporative (latent) heat loss to maintain body temperature (Maia *et al.,* 2005).

Latent heat dissipates from the animal by evaporation of water from a surface to the atmosphere. In order to maintain heat balance evaporative heat loss will generally increase with increasing ambient temperature (Pedersen 2002). However, if there is also a subsequent increase in relative humidity the efficiency of evaporative heat loss decreases. Recent work by Maia *et al.* (2005) showed a 66% reduction in the ability of cattle to lose body heat by evaporation when relative humidity approaches 50% and a 92% reduction in efficiency at 80 to 90% relative humidity. The reader should also refer to Gaughan *et al.* (2004a) for more detail on heat transfer.

3.3.1 Hose wetting (hose)

A 25 mm high volume high-pressure hose was used to wet cattle in this treatment. Water was applied so that the cattle were saturated i.e. water was running off the animals.

3.3.2 Cooling by sprinklers

This method used low-pressure high volume nozzle sprinklers that generated large water droplets (150 μm). This ensured that the cattle would be wetted through the hair layer to the skin. Two sprinkler options were used.

3.3.2.1 Overhead sprinkler (overhead)

A sprinkler line was located 2 m above the pen with two sprinklers attached. The spray from these two sprinklers was sufficient to cover the pen surface but was set so no spray entered the feed or water troughs (Photograph 4).

3.3.2.2. Leg sprinkler (leg)

A sprinkler line was installed in the lower rails of the pen in order to spray water towards the legs and feet of the cattle. Four sprinklers were used, two on each side of the pen. These sprinklers were identical to the overhead sprinklers and were located approximately 300 mm from the floor of the pen.

3.3.3 Misting with air flow (mist)

This method used 8 high-pressure misters to inject water vapour into the atmosphere above the pen. The misters (4) were located 1 m from each end of the pen. The water droplet size was small (mist droplets were less than 50 μm).

This method has several benefits as it shouldn't significantly have a negative effect on pen microclimate and could minimize potential waste management problems. When the floor is wetted, there may be an increase in relative humidity for a short period (and also allows heat to escape from the floor), however if bedding management is not optimal, the cattle may be stressed due to increased levels of ammonia, partially negating any benefits of cooling.

The possible negatives of this system are a rise in relative humidity which could be exacerbated if air flow is low.

3.4 Trial outline

Group 1: Steers at feedlot → Climate Facility (hose) 4 d TNC → 4 d HOT → Feedlot 4 d.
Group 2: Steers at feedlot → Climate Facility (overhead) 4 d TNC → 4 d HOT → Feedlot 4 d.
Group 1: Steers at feedlot → Climate Facility (leg) 4 d TNC → 4 d HOT → Feedlot 4 d.
Group 2: Steers at feedlot → Climate Facility (mist) 4 d TNC → 4 d HOT → Feedlot 4 d.

Note: (i) there were 9 steers per group, and (ii) there was a 24-day break between group 1's exposure to hose and leg wetting, and a 24-day gap between group 2's exposure to overhead and misting.

3.5 Statistical analysis

Data was analysed using the SAS computer program (SAS 1996). The following statistical procedures were used: analysis of variance, non-parametric analysis, correlation analysis, time series analysis, Chi-Square analysis and regression analysis. Data analysed included: Panting scores, feed intake, water intake, water usage (for cooling), number of times water was applied, climatic change (pre and post wetting) and behaviour. Treatment, day and treatment x day effects were also investigated. Treatment means were separated using Tukey's studentized range test. Generally the level of significance between treatment means was taken where $P<0.05$, however significance levels of $P<0.10$ are also included.

4.0 Results

Due to the failure of the leg wetting option to adequately cool cattle this part of the study was terminated at the end of day 3. All data presented for the leg wetting option is therefore based on 3 days of hot conditions. Data for the other wetting options are based on 4 days of hot conditions.

4.1 Climatic variables

4.1.1 Day length

During the study the cattle were exposed to 12 hours of white light (fluorescent light) and 12 hours of red lights. The white lights were turned on at 0700 h and switched off at 1900 h each day.

4.1.2 Dry bulb temperature, wet bulb temperature, relative humidity, oxygen concentration and ammonia concentration

At the feedlot the cattle were exposed to a mean dry bulb temperature of 24.6 ± 4.2 °C. During the thermonuetral periods in the climate facility the mean dry bulb temperature was 23.8 ± 2.6 °C, and the mean wet bulb temperature was 20.2 ± 1.4 °C.

The mean values for dry bulb temperature, wet bulb temperature, relative humidity, ammonia concentration and temperature humidity index during the hot periods (4 days) in the climate facility are presented in Table 2. The dry bulb and wet bulb temperatures for the leg wetting option are presented in Figure 1. Oxygen concentration remained constant throughout the study (20.9%).

While there were climatic differences between the various wetting options, daily variations within any wetting option were consistent.

The climatic conditions to which the cattle were exposed were sufficient to induce heat stress as seen by increased respiration rates and panting scores, and decreased feed intakes.

Table 2. Mean dry bulb temperature (DBT, °C), wet bulb temperature (WBT, °C), relative humidity (%), ammonia concentration (NH_3, ppm) and temperature humidity index (THI) for each of the imposed wetting methods (hose, overhead, leg and misting) during HOT.

	DBT	WBT	RH	NH_3	THI
Hose	31.4 ± 1.7	31.1 ± 0.9	91.6 ± 5.9	20.8 ± 5.6	85.7 ± 5.6
Overhead	33.7 ± 2.4	32.2 ± 1.9	90.6 ± 7.4	7.3 ± 7.0	89.7 ± 4.3
Leg	31.0 ± 1.7	30.2 ± 2.2	94.4 ± 6.1	5.3 ± 5.9	84.5 ± 4.3
Misting	32.3 ± 2.3	31.2 ± 2.4	91.4 ± 5.9	1.9 ± 2.9	88.1 ± 4.4

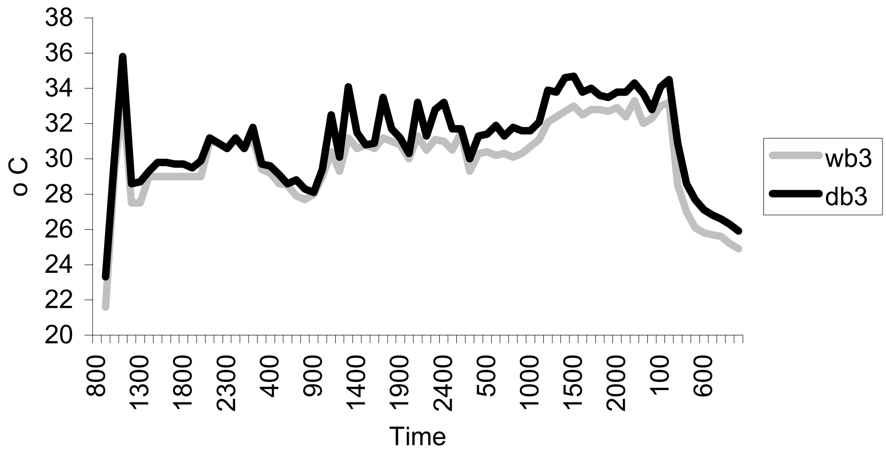

Figure 1. Dry bulb and Wet bulb temperature over three days of HOT - leg wetting option

4.1.3 Pen air turnover and air movement within the pen

Mean pen air turnover (PAT) across all treatments was approximately 186 m/h (ranged from 184 to 194 m/h). PAT was calculated by dividing air flow through the facility by pen area. Air flow through the facility was regulated at 2370 to 2500 m^3/h which resulted in the PAT range given above (e.g. 2370 m^3/h ÷ 12.84 m^2 = 184.6 m/h). Ventilation incorporating direct air jetting to the cattle pen was used. At a distance of 1 m from the air jet the air speed was 2.2 m/s. Jetted air movement cross the pen ranged from 0.8 to 2.2 m/s, which meets Marine Order 43 (Cargo & Cargo Handling Livestock) requirements (minimum of 0.5 m/s). Jetted air movement over the cattle varied from 2.2 m/s to 0 m/s depending on where the animal was in the pen. When cattle were laying direct air movement on the animal was 0.0 m/s.

4.1.4 Atmospheric ammonia concentration

Ammonia gas is generated by urease activity breaking down urea in urine, manure and bedding (Dewes and Goodall 1995; James *et al*., 1999; MAMIC 2000). Ammonia is an irritant pollutant within livestock buildings and ships, with comfort and animal health impacts on both cattle and people (Dewes and Goodall 1995; MAMIC 2000). The level at which ammonia concentration causes respiratory problems in cattle has not yet been determined. However, Dewes and Goodall (1995) reported that calves exposed to high levels of ammonia had significantly higher respiratory disease and higher death rates than those exposed to low levels.

Published values for housed cattle range from less than 2 ppm to 29 ppm (Groot Koekamp *et al.* (1998). Much higher values (50 ppm) have been reported for pig and poultry sheds (Groot Koerkamp *et al.*, 1998; Hinz and Linke 1998). The published allowable atmospheric ammonia concentration varies from 10 to 50 ppm with 25 being a common threshold value (Groot Koerkamp *et al.,* 1998; MAMIC 2000). Values in excess of 25 ppm have been reported on live export vessels (MAMIC 2001). The reader is referred to work by Nick Costa of Murdoch University in 2003 (LIVE.218).

In general ammonia concentration increased from 0 ppm on day 1 of the thermoneutral period to approximately 20 ppm on day 2 of thermoneutral. Although the change was not linear, or constant, the level of ammonia continued to increase over time, unless the bedding was removed. Ammonia levels also increased with cattle activity e.g. around feeding time, and then decreased slightly when activity decreased.

The highest concentrations ($P<0.05$) were measured during the hose wetting (washing) treatment. During this treatment ammonia levels quickly rose to 35 ppm (within a couple of hours of the first wetting). A level of 35 ppm is the threshold limit for short-term exposure by humans (Costa *et al*., 2003). The ammonia levels were significantly lower ($P<0.01$) in subsequent wetting options because bedding was removed when wetting commenced. The mean ammonia concentration levels for each treatment were: hose 20.75 ± 0.56 ppm, overhead 8.93 ± 0.56 ppm, leg 5.31 ± 0.64 ppm, and mist 1.97 ± 0.58 ppm.

Ammonia levels above approximately 6 ppm were noticeable (i.e. could be detected by smell). Levels above 20 ppm were uncomfortable i.e. made breathing somewhat difficult and caused throat irritation for humans working on the project. Costa *et al*., (2003) reported that the threshold limit for an 8 hour period is 25 ppm, and Luttrell (2002) reported throat and nose irritation of humans at 24 ppm. In general it was observed that as ammonia levels increased above 20 ppm so did the amount of coughing in the cattle. Increased respiration rate was also observed in the cattle, even under TNC when ammonia levels were high. Long term exposure to even low levels of ammonia may lead to respiratory damage in cattle (Dewes and Goodall 1995; Costa *et al.*, 2003), which will have a negative impact on their ability to deal with heat stress. Therefore atmospheric ammonia levels on ships should be kept as low as possible, and should not exceed 20 ppm if human and cattle welfare are to be met.

Wetting the bedding resulted in a substantial increase in ammonia concentration (all treatments). Bedding was removed once the ammonia concentration reached 20 ppm. The only effective method to reduce ammonia levels was to remove the bedding, and not replace bedding once wetting commenced. After removal of bedding the ammonia levels fell to 0 ppm, usually within an hour.

Bedding was removed and replaced four times during hose wetting. The change in bedding took place approximately at the peaks shown in Figure 2. The bedding was removed three times and replaced twice during overhead wetting. During the leg wetting option the bedding was removed twice and only replaced once. During the misting option the bedding was removed once and not replaced.

The increase in ammonia concentration was a function of increasing ambient temperature, increasing urine concentration of the bedding and pH levels (increasing alkaline) of the bedding (Dewes and Goodall 1995; Argo *et al.*, 2001; Costa *et al*., 2003; Zhao and Chen 2003). The pH levels in the bedding changed from a mean of 6.2 when first placed in the pen to means of 7.3, 8.4 and 9.1 on day 2 of TNC and days 1 and 2 of HOT. Similar results and trends were reported by Dewes and Goodall (1995) for bedding in calf rearing sheds, and by Zhao and Chen (2003) for dairy cow manure.

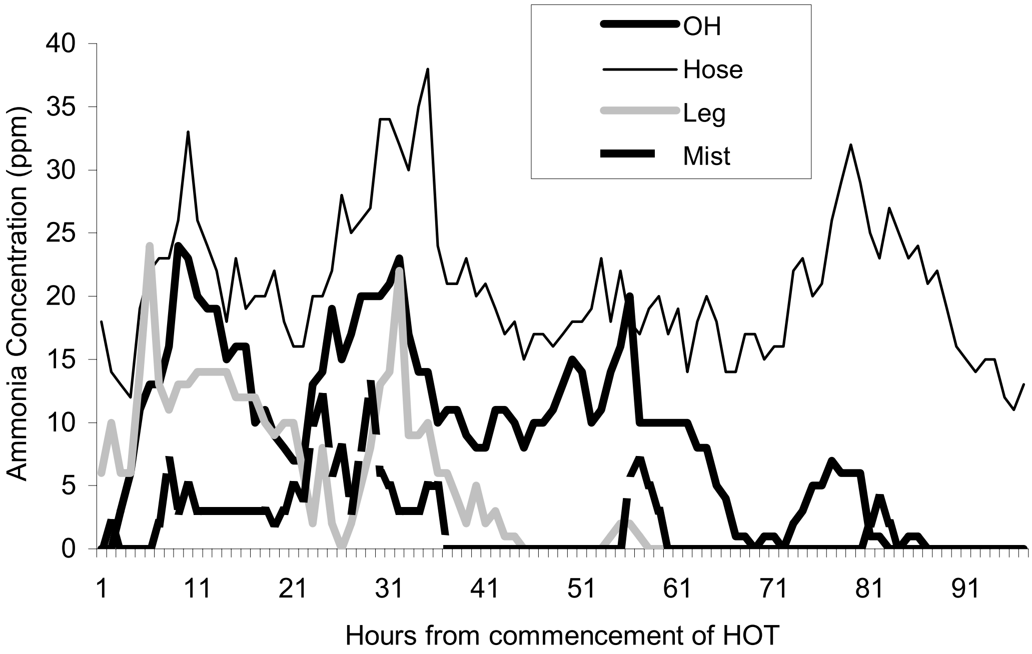

Figure 2. Hourly atmospheric ammonia concentration (ppm) for the four wetting options.

4.1.5 Microclimate effects

Microclimate changes in response to wetting were variable both within and between the strategies investigated. In most cases application of water had a two fold effect (i) a reduction in dry bulb temperature, and (ii) and a slight increase in wet bulb temperature. The changes were generally of limited duration usually less than 10 to 20 minutes.. The largest effect on air temperature occurred during the misting option where reductions of 2.5 ^{o}C dry bulb temperature were recorded within 3 minute of water application, and in the case of overhead sprinkling by 4 ^{o}C dry bulb temperature over about 20 minutes. Hose wetting only had a slight (0.5 ^{o}C reduction in dry bulb temperature) impact on air temperature. However the effect on cattle was pronounced with reductions in respiration rate and panting score seen within a couple of minutes of wetting. In general wet bulb temperature increased following wetting by 0.1 to 0.8 ^{o}C, however there were instances within all wetting options were wet bulb temperature did not increase. It was difficult to predict the effect of wetting on wet bulb temperature. In most cases the wet bulb temperature began to fall about 10 minutes after the post wetting peak. The slight increase in wet bulb temperature had little or no effect on the cattle as the associated drop in dry bulb temperature brought relief. The wet bulb temperature tended to increase with increasing dry bulb temperature. However under some conditions there were no changes in dry bulb temperature. For example, the following shows the response of wet bulb temperature (increased) and dry bulb temperature (decreased) for 6 minutes after misting (Table 3). A three-hour period on day 4 of HOT (overhead sprinkling option) during which time 4 water applications where made are shown in Figure 3. In this example dry bulb temperature was reduced by up to 4 ^{o}C and wet bulb temperature increased by up to 0.8 ^{o}C (ranged from 0.1 to 0.8 ^{o}C) following a wetting episode. Similar results were reported by Gaughan *et al*., (2003) for individually housed cattle. There is little published data on micro-climate effects of using water to cool cattle in confined situations.

Table 3. The impact of misting on wet (WBT) and dry bulb temperature (DBT) for 6 minutes after wetting ceased.

Time	WBT	DBT
Before misting	32.4	37.5
0320	33.5	33.2
0321	33.6	33.3
0322	33.6	33.1
0323	33.9	33.1
0324	32.5	33.3
0325	32.4	33.2

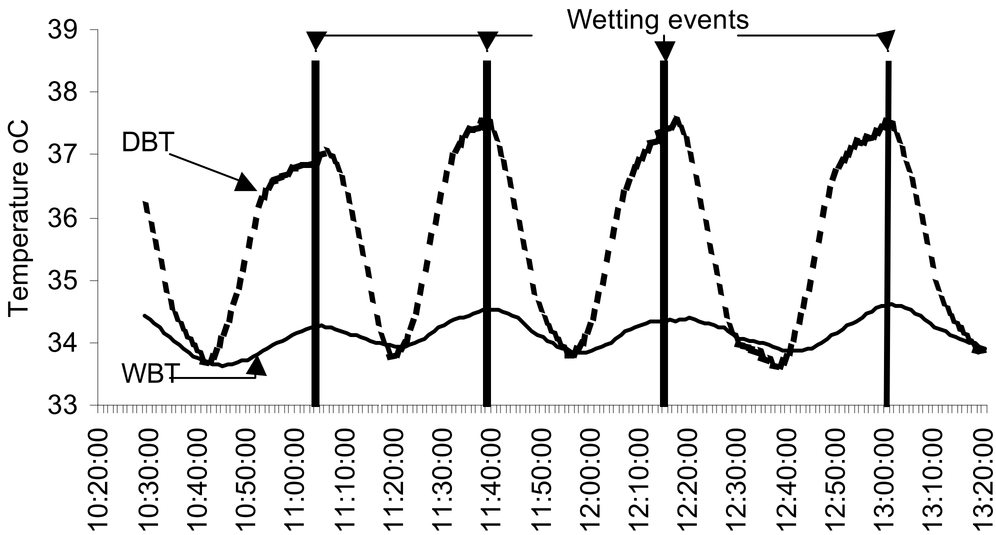

Figure 3. The effect on dry bulb temperature (DBT) and wet bulb temperature (WBT) following 4 x 5 minute wetting episode using overhead sprinklers over a 3 hours on day 4 of HOT.

There was some concern that the misting option would lead to undesirable changes in the micro-climate especially in situations where relative humidity is high and air movement is limited (Frazzi *et al.*, 1997; Correa-Calderon *et al*., 2004). Positive effects on cattle have however been reported in the dairy industry (Armstrong *et al*., 1993; Means *et al*., 1992). Under the climatic conditions imposed during the present study undesirable changes were not seen. Misting had a significant downward effect on dry bulb temperature, and a slight effect on wet bulb temperature. Throughout this option, dry bulb temperature fell within 1 minute of the commencement of misting and remained below the pre misting levels for 20 to 30 minutes (Figure 4). The fall in dry bulb temperature was normally in the range of 0.8 to 2.5 ^{o}C (Figure 5) when the relative humidity was approximately 90%. The increase in dry bulb temperature after the cessation of misting was expected as hot air, with low humidity and thus high evaporative potential, was being vented into the facility. The rate of increase in dry bulb temperature following the initial decrease in wet bulb temperature after wetting is a function of rate of air exchange and the number of cattle.

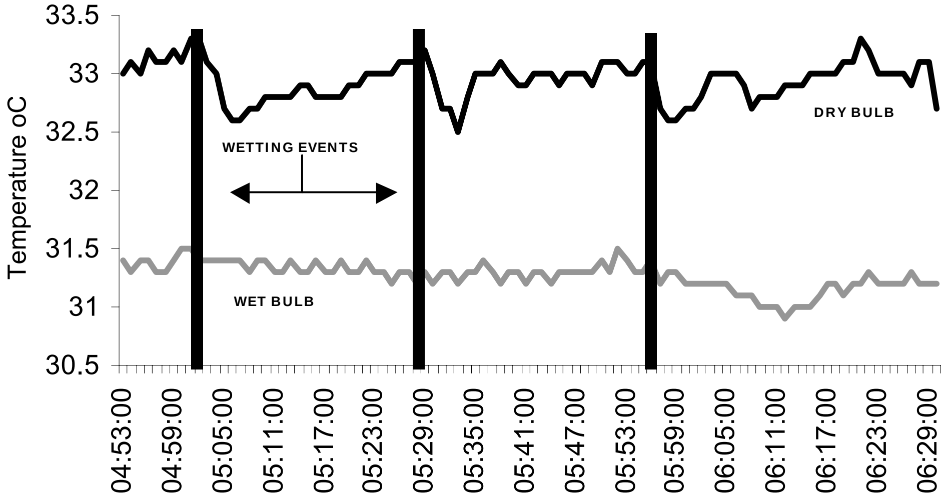

Figure 4. The effect on dry bulb temperature (DBT) and wet bulb temperature (WBT) following 3 x 3 minute wetting episode using misting sprinklers over a 1 hour period on day 3 of HOT.

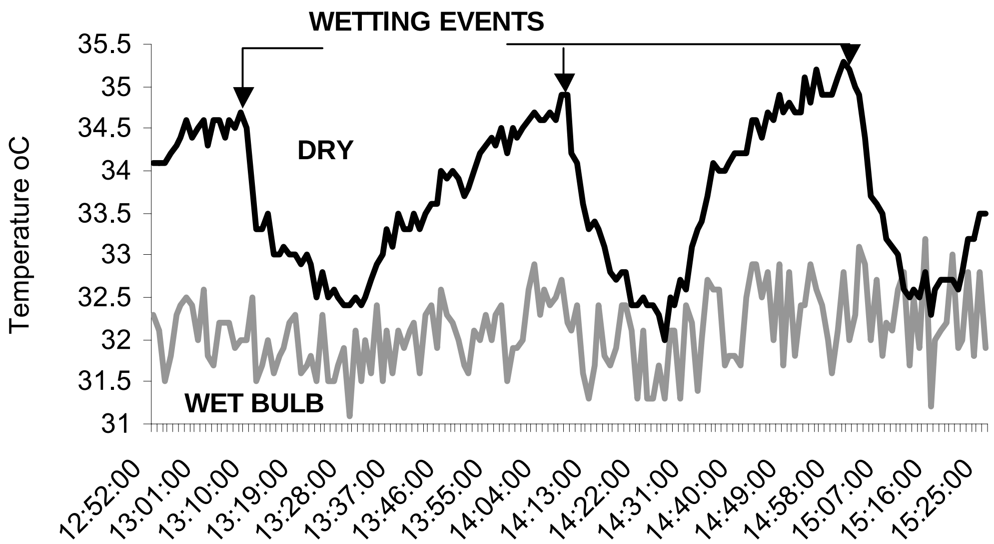

Figure 5. The effect on dry bulb temperature (DBT) and wet bulb temperature (WBT) following 3 x 3 minute wetting episode using misting sprinklers over a 3 hour period on day 3 of HOT.

4.2 Animal data

4.2.1 Behaviour

As expected there was considerable animal variation in response to HOT. While the majority of cattle showed classic symptoms of excessive exposure to high heat load (drooling and excessive panting, shifting weight from leg to leg and holding head down), others coped well, showing little or no response to the conditions imposed. Our observations suggest that those that coped best were the dominant animals in the group. This premise is largely based on animal location within the pen. It was obvious from the start of the study, and seen in all treatments, that one or two animals tended to remain in the “best” location in the pen, i.e. where air movement was greatest, at the water bowl or near the leg sprinklers (leg wetting option). Within the leg wetting option the dominant animal would stand or lie near the sprinkler, and would often place their head in the water spray. This effectively blocked wetting to other cattle. The dominant cattle actively “defended” their position in the pen and would push other cattle away. In addition these dominant animals were able to spend time lying down each day. At the lower end of the hierarchy one or two animals were pushed to the middle of the pen, away from water and good air movement. In this location much of the air movement was blocked by other cattle. These lower hierarchy cattle also spent little or no time lying. In two cases a steer spent 5 days standing.

Within and between treatments more cattle were observed standing (but not eating or drinking) than any other parameter for the hose, leg and overhead wetting. The only significant ($P<0.05$) difference for standing was between hose and misting. During the misting treatment there was no difference between the numbers observed standing or lying, however in the remaining strategies more ($P<0.05$) cattle were observed standing then lying (Table 4). Standing for long periods may be an indication that cattle are hot. Standing presents a larger surface area to air movement and thereby enhances cooling. When they are under thermoneutral conditions it is likely that cattle housed in non grazing situations e.g. feedlots and on board ship will spend (or attempt to spend) more time lying than standing, most likely because they do not need to graze. However, the number standing may also be an indicator of stocking density. Heat stressed cattle tend to have more meals but eat less feed over a 24 hour period then they would when not under thermal stress (Hahn 1995 & 1999). Therefore frequency of eating is not necessarily a good indicator of cattle coping or not coping with high heat load. Total intake is the major determinant of heat load status and is a useful measure of heat load status. Water intake is a function of both heat load and feed intake. The low water intake in the leg wetting option can be explained by the concurrent low feed intake (Table 6). The steers in the overhead option spent more time drinking, however this was not reflected in over all water intake.

Table 4. The percentage of cattle (n=9/treatment) observed standing, lying, eating and drinking for each hour over a 4 day HOT period for each wetting method (hose, overhead sprinkler, leg sprinkler and misting).

	Standing	Lying	Eating	Drinking
Hose	$55.10^{A,E}$	$36.66^{A,F}$	$5.73^{A,G}$	$2.52^{A,H}$
Overhead	$50.05^{A,B,E}$	$39.22^{A,F}$	$6.72^{A,G}$	$4.01^{B,H}$
Leg	$52.25^{A,B,E}$	$38.74^{A,F}$	$6.76^{A,G}$	$2.25^{A,H}$
Misting	$45.81^{B,E}$	$44.07^{A,E}$	$6.49^{A,G}$	$3.62^{A,B,H}$

^{A,B,C,D} Values in a column with different superscripts are significantly different ($P<0.05$).
^{E,F,G,H} Values in a row with a different superscript are significantly different ($P<0.05$).

These data are confounded by other factors. For example, when water was applied by hose or overhead sprinklers cattle that were lying would generally stand. The percentage of cattle standing is consistent with observations made for heat stressed cattle in outside feedlots, and in previous studies in the climate facility.

An important observation was made after cattle returned to the feedlot. Following each wetting option we observed cattle at the feedlot with high respiration rate, tongue out and drooling 2 to 4 days after exposure to the hot conditions in the climate room, even though conditions at the feedlot were not hot (about 30 ^{o}C and low humidity). This may be an indication that the cattle are “more” susceptible to heat after prolonged exposure. This needs to be further investigated as it may have implications for cattle once offloaded.

4.2.2 Respiration rate and panting scores

Both respiration rate and panting scores are useful indicators of heat stress in cattle (Gaughan 2003), and have been used in the feedlot industry in Australia. Panting scores provide a quick visual assessment of the heat load status of cattle, and should be used as part of heat stress management on live export vessels.

Under thermoneutral conditions the mean respiration rate across all wetting options was 42 $\pm$ 10 breaths per minute (bpm) and was in the normal range for cattle. Panting scores were 0 to 1. Within 1 hour of increased ambient temperature respiration rate became slightly elevated (mean 60 $\pm$ 10 bpm).

Within each of the wetting systems, the cattle were able to handle the conditions over the first two days of exposure to HOT. Respiration rates and panting scores increased on days 3 and 4 of exposure to heat.

Panting scores increased as exposure to hot conditions increased (Table 5 and Figure 6). There were only minor differences between treatments in terms of panting score. Differences between treatments or panting score in excess of 2.5 were not expected as cattle would generally be wetted before they reached this stage of heat stress. In all cases wetting resulted in a reduction in respiration rate by at least 30 bpm (panting score $\leq$ 2), and in many cases in excess of 70 bpm. Brouk *et al.* (2001) reported a respiration rate drop of 28 bpm when heat stressed dairy cows were wetted. However, the reductions (< 70 bpm) in the present study were more in line with previous finding from this facility (Gaughan *et al*., 2004b).

4.2.3 Key respiration rate observations

4.2.3.1 Hose wetting

Generally the cattle handled the first 2 days of exposure to HOT well. Respiration rates of up to 100 bpm were observed during this period, but there were only slight reductions in feed intake.

On days 3 and 4 of hose wetting, the cattle, in general, coped well. However occasional high respiration rates of 157 to 200 bpm were recorded. As expected the steers were not affected by the hot conditions to the same extent as the days of HOT progressed. Under similar climatic conditions one steer was observed with a respiration rate of 200 bpm while another had a respiration rate of 98 bpm.

4.2.3.2 Overhead wetting

Overhead sprinkling commenced at 1900 h on day 2 of hot conditions. Between 1800 to 2400 h on day 2 respiration rates of 105 to 149 bpm were observed. In general the cattle, coped well. On day 3 the respiration rate of steer 104 was 168 bpm at 1000 h, fell to 102 bpm following sprinkling, and later (1500 h) increased to 212 bpm (PS = 3.5). Following sprinkling at this time the respiration rate fell to 164 bpm (PS = 3.0). It was later observed that this steer had pink eye, and this may have contributed to its inability to handle the hot conditions. On day 3 and 4, maximum respiration rates ranged from 142 to 206 bpm prior to wetting and from 88 to 120 bpm approximately 30 minutes after wetting.

4.2.3.3 Leg wetting

During a 6 hour period (2400 to 0400 h) on day 2 of hot conditions respiration rates of between 135 and 157 bpm were observed

On day 3 over a 5 hour period (2100 to 0100 h) six steers had respiration rates of 149 to 175 bpm. The other three had respiration rates between 70 to 100 bpm. The later three were those that were able to lie or stand next to the leg wetting sprinklers. The respiration rate of these individuals fell by up to 50 bpm within 3 to 6 minutes of wetting. Due to concerns with cattle that were not able to access the leg sprinklers this option was terminated on day 3 of HOT.

4.2.3.4 Misting

The greatest mean and maximum respiration rates were observed within this option. On day 2 a steer recorded a respiration rate of 232 bpm and a panting score of 3.5. The other steers all had maximum respiration rate of between 155 to 189 bpm. Day 3 and 4 were hard days for the cattle again, respiration rate exceeded 155 and another maximum of 232 bpm was seen. On four occasions cattle were observed to have tongues out, and all had lots of drool. Following each misting event, the respiration rate fell by 50 to 90 bpm. Although dry bulb temperature fell considerably (see 3.1.5) the cattle did not appear to lose sufficient body heat, and quickly returned to pre misting respiration rates.

The difficulty with this system was in establishing the duration of time water was applied and the duration between application of water that was required to ensure cattle were cooled effectively (see 3.5). This was made even more difficult because the interval between sprinklings needed to cool the cattle was less as the duration of exposure to hot was extended.

Misting without direct air movement over the cattle cooled cattle when the misting was applied. However cattle quickly returned to pre misting panting scores and respiration rates. This option can not be recommended based on these results. More over, with high relative humidity, the positive effects of this method may be limited. Although this may be somewhat affected by PAT and air exchange rate.

Table 5. The mean number of steers (n=9) observed hourly over a 4 day HOT period with panting scores of <2, 2, 2.5, 3 or >3 for each of the wetting options.

	<2	2	2.5	3	>3
Hose	$8.45^{A} \pm 1.75$	$0.59^{A} \pm 1.81$	$0.10^{A} \pm 0.42$	$0.03^{A} \pm 0.17$	$0.01^{A} \pm 0.10$
Overhead	$8.78^{B} \pm 0.60$	$0.12^{B} \pm 0.44$	$0.55^{B} \pm 0.22$	$0.04^{A} \pm 0.20$	$0.01^{A} \pm 0.09$
Leg	$8.30^{A} \pm 1.74$	$0.49^{A} \pm 1.24$	$0.15^{A} \pm 0.49$	$0.05^{A} \pm 0.24$	$0.01^{A} \pm 0.12$
Mist	$8.53^{A} \pm 1.12$	$0.30^{C} \pm 0.68$	$0.06^{C} \pm 0.23$	$0.11^{B} \pm 0.35$	0

^{A,B} Values in a column with a different superscript are significantly different (P<0.05).

4.2.4 Body surface temperature

Under thermoneutral conditions, the mean body surface temperature was 36.4 ± 1.2 °C. When exposed to hot conditions body surface temperature increased by approximately 2 °C. The highest measure was 40 °C, which was measured in the hose treatment. There were differences between treatments. The hose and leg treatments had the highest mean surface temperatures at 38.3 ± 1.0 and 37.9 ± 1.7 °C respectively. The mean and standard error for the overhead option was 36.8 ± 1.5 °C, while the misting strategy resulted in the lowest mean body surface temperature (35.8 ± 1.6 °C). Within all treatments the application of water reduced body surface temperature by 1 to 2 °C (Figure 7). Brouk *et al*. (2003) also reported drops in body surface temperature of 1 to 2 °C. There was a direct correlation between body surface temperature and both respiration rate and panting score in the current study. However, it did appear that the greater reductions in respiration rate were in those cattle with exposure to direct air jetting. This demonstrates the importance of air movement in increasing mechanisms for heat loss and thus reducing heat stress.

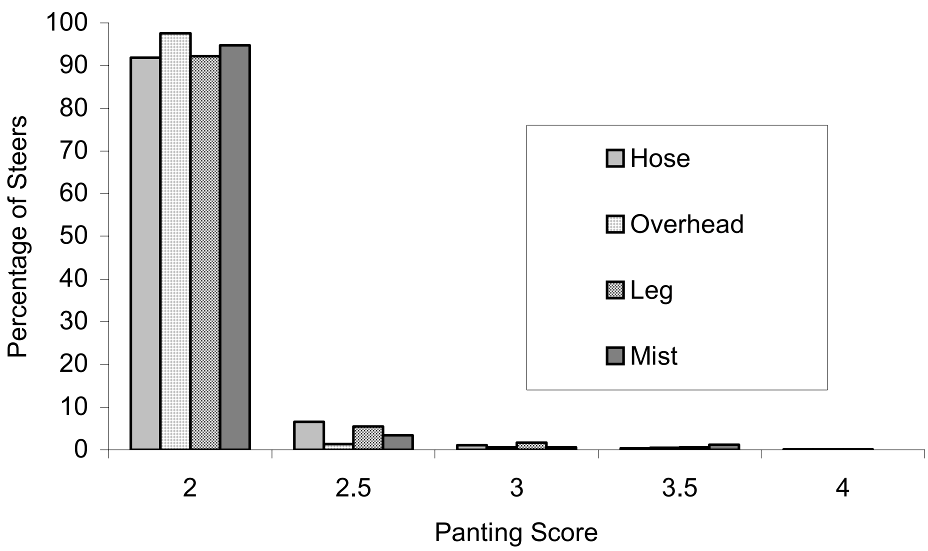

Figure 6. The percentage of steers with panting scores 2 to 4 over 4 days of exposure to hot conditions (3 days for leg wetting).

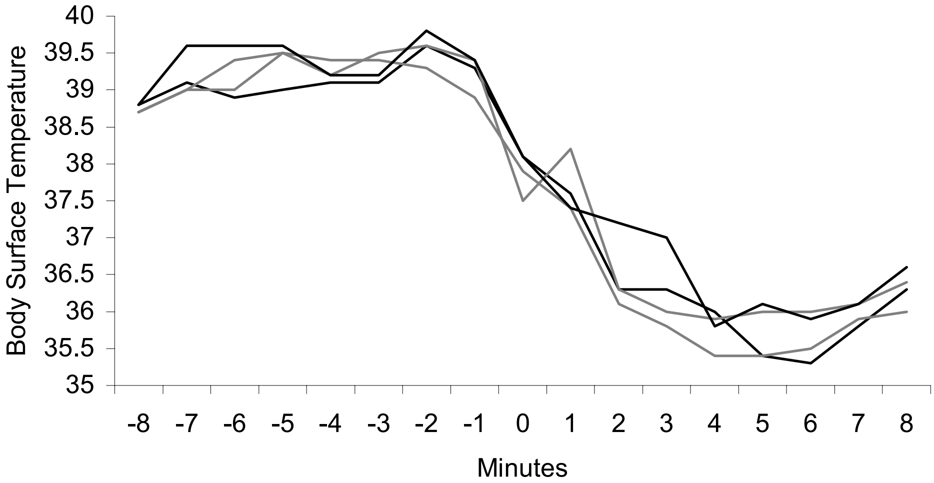

Figure 7. The change in body surface temperature of four steers over a 16 minute period on day 2 of HOT (hose wetting option). Water was applied at the 0 minute mark, for 1 minute 32 sec. The negative minutes are minutes prior to wetting, and the positive minutes are minutes post wetting.

4.3 Feed intake

Feed intake fell when cattle were exposed to hot conditions (Table 6). In addition, as duration of exposure to HOT increased further reductions in feed intake were observed. The mean reductions were not as great as expected for either the hose or misting option probably because the wetting options were sufficient for cattle to dissipate heat, and therefore cattle were able to retain intake levels. There was a 25.6 kg reduction in feed intake in the overhead wetting group and this was largely due to a single animal that was not observed to eat during the 4 days exposure to HOT. This animal was one that was continually pushed away from the feed and water trough. The steer in question had a weight loss of 25 kg.

The leg wetting option had the largest negative impact on feed intake – a reduction of 42.8 kg over 3 days. As mentioned previously the dominant steers blocked access to the water. This effectively resulted in a number of steers not being wetted, and therefore they did not have adequate opportunity to shed body heat. Under these conditions the only effective avenue to reducing heat load is to reduce feed intake.

Table 6. Average dry matter intake (kg/d) of 9 steers over 2 days of thermoneutral and 4 days of exposure to high heat load.

	TNC	Day 1	Day 2	Day 3	Day 4	Difference[2]
Hose	84.3	76.5	63.0	72.0	72.0	12.3[A]
Overhead	86.8	81.0	76.5	64.8	61.2	25.6[B]
Leg[1]	86.0	81.0	81.0	43.2	--	42.8[C]
Mist	85.6	73.8	69.8	67.7	67.9	17.7[B]

[1] Leg wetting option terminated at end of day3.
[2] Difference in feed intake (kg/d) between TNC and day 4 of HOT.
[A,B] Values in a column with a different superscript are significantly different (P<0.05).

4.4 Drinking water temperature and intakes

The mean drinking water temperature during the thermoneutral days was 22.9 ± 0.2 °C, and during the hot days mean temperature was 25.7 ± 0.4 °C. For all treatments water intake was greater ($P<0.05$) during exposure to HOT compared to exposure during the thermonuetral conditions (Table 7).

Table 7. Mean water intake (L/head/d) and the percentage change in water intake for 2 days prior to exposure to hot conditions (TNC) and for 4 days of exposure to hot conditions (Hot).

	TNC	Hot	% Change
Hose	20.13^{A}	46.13^{B}	229.16
Overhead	22.80^{A}	40.55^{B}	177.85
Leg[1]	16.79^{A}	38.85^{B}	231.39
Mist	19.52^{A}	38.97^{B}	199.64

[1]Leg wetting option terminated at end of day 3.
^{A,B} Values in a row with a different superscript are significantly different ($P<0.05$).

4.5 Number of wetting episodes

There were differences between treatments ($P<0.10$) in regard to the number of wetting episodes that were needed to ensure that the cattle were able to cope with the conditions imposed. The least wetting episodes occurred within the hose wetting option (n=10) and the most within the misting option (n=68). The differences between these two options were highly significant ($P = 0.01$). The differences between hose and leg, and overhead and misting were significant at the $P<0.10$ level.

No wetting for any treatments occurred on day 1 of HOT (Figure 8). For the overhead, leg and misting treatments the number of wettings needed to relieve the heat load on the steers increased as their exposure to heat load increased.

The lack of the need to wet cattle on day 1 is consistent with a number of studies that have shown that cattle are able to cope with high heat load conditions for at least some period of time (Hahn *et al*., 1993; Gaughan *et al*., 2004b). The duration of this coping period (hours to days) is dependant on a number of factors such as: the intensity of the head load, animal health, genotype, prior exposure to hot conditions, nutrition and housing.

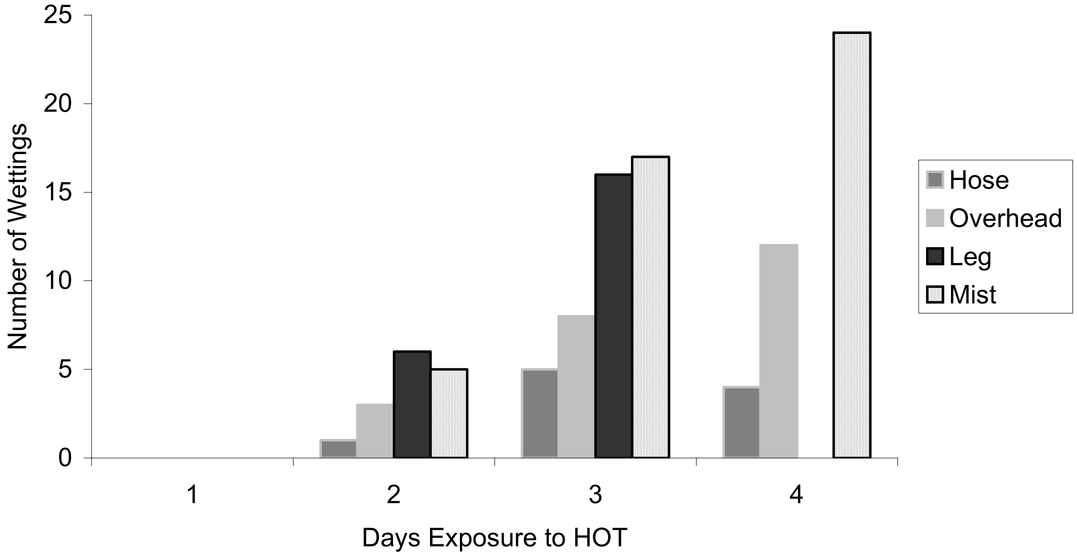

Figure 8. The number of wettings on each day of exposure to hot conditions for the four wetting options (NB. Leg wetting option terminated at end of day 3).

4.6 Amount of water used during wetting

The mean duration of water application and amount of water used per application for each option were: hose ~ 2 min 36 s (84.5 L); overhead ~ 3 min 36 s (117 L); leg ~ 5 min 10 s (167.9 L); misting ~ 3 min 40 s (119.2 L). These data equate to a per animal water application rate (based on 9 head) of 9.4 L/hd, 13 L/hd, 18.7 L/hd and 13.2 L/hd respectively for the hose, overhead, leg and misting options. Total water used for each wetting strategy over 3 days of water application were 845 L for hose, 2691 L for the overhead sprinklers, 3694 L (2 days) for the leg sprinklers and 5483 L for the misting option. Theses data are shown graphically in Figure 9. The letters above each bar graph denote a significant difference (P<0.05) between each strategy.

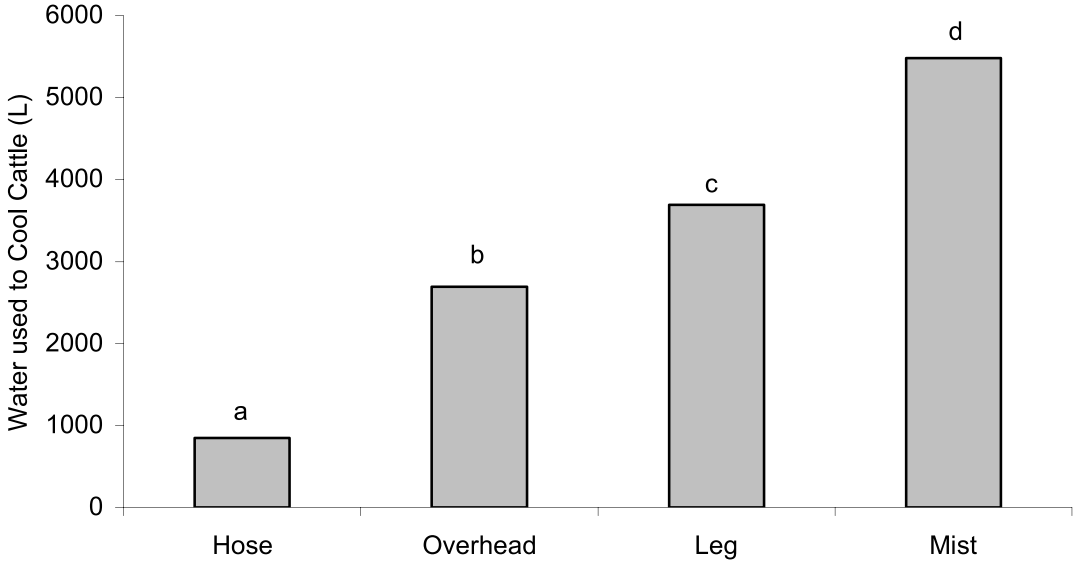

Figure 9. Total water used (L) to cool cattle for each of the four wetting strategies investigated.

Total water application per steer (L/hd) was 94, 299, 410 and 609 respectively for the hose, overhead, leg and misting options. The differences between treatments were due to the duration of water application (minutes) and the interval (minutes) between each application.

Within treatments application and interval were not consistent. The re-application of water was not solely driven by ambient conditions. There is some evidence that the diurnal rhythm in body temperature plays a part in the animal's ability to dissipate heat. It was noticeable across all treatments that respiration rate increased through the day (from 0800 to 2000 h) even when there was little change in wet bulb temperature and dry bulb temperature. The rise in respiration rate may also be due to the effect of feed intake, especially early in the day (i.e. between 0800 to 1200 h). Furthermore as the duration of exposure to hot conditions continues it appears as if the animals ability to cope (or adjust to the prevailing conditions) is reduced i.e. they become more susceptible to heat stress.

Therefore it is difficult to recommend a timed on/off wetting strategy. Animal observation remains the key to implementation of wetting practices. For example within the hose wetting a 2 minute water application followed by a 1 to 3 hour break before more wetting was required again. Within the misting option, 2 minutes on and 50 minutes off was sufficient to cool cattle on day 2. By the third day the best strategy was 5 minutes on 45 minutes off.

From these data the hose wetting option is clearly the most efficient in terms of water usage.

4.7 Cattle cleanliness score

The application of water resulted in a situation where bedding quickly became saturated. The hose treatment and overhead sprinkler treatments created major problems with bedding (Photograph 5 & 6), while the misting option, although not as bad still resulted in unfavourable conditions i.e. an increase in ammonia level and dirty coated cattle. Under these conditions cattle had a cleanliness score of 5 (i.e. 4/5 of body covered in faeces).

When bedding was removed and water applied to cattle the cleanliness score was 0. Bedding also had to be removed to ensure ammonia levels remained low (see 3.1.4)

5.0 Success in achieving objectives

All of the objectives of the study were achieved.

6.0 Impact on livestock industries now and in 5 years

This study has shown that water application can be used to successfully cool cattle under "heat wave" conditions similar to those that have been experienced on long haul vessels travelling from Australia to the Middle East during the northern summer. Adoption of hose wetting or overhead sprinklers – where feasible will reduce heat load on cattle and will improve cattle welfare in the event that heat wave conditions are experienced. This will have a positive impact on the public and government perception of the live export industry. In addition cattle that maintain greater feed intakes are less likely to lose weight.

7.0 Major findings and recommendations

The major findings and recommendations from this study are as follows.

- Cooling cattle with warm (30 ^{o}C) salt water was successful in terms of cooling the cattle for three of the four options investigated – hose, overhead sprinkler and large droplet misting.
- Use of sprinklers at leg level was not a viable option because access was easily blocked by dominant cattle, and therefore should not be considered.
- For all strategies no wetting was needed on day 1 of exposure to hot conditions.
- Application of water via a hose was the best in terms of the number of wettings needed (n = 10) over the hot period, followed by 22 for leg, 23 for overhead and 68 for misting. Hose wetting is a viable option, but in a situation were it is necessary to wet a large number of animals at the same time this option may not work.
- Use of overhead sprinklers should be considered. If overhead sprinklers are in place, a stockman would have the ability to wet a large number of cattle at the one time e.g. a whole deck. This has considerable merit if a major heat event occurs. Although there is a cost in installing and maintaining a sprinkling system, the ease of operation would save considerable labour hours.

- Total water used for each option over 3 days of water application were: hose: 845 L, overhead: 2691 L, leg[2]: 3694 L and misting: 5483 L. The total water applications per steer (L/h) were 94, 299, 410 and 609 respectively for the hose, overhead, leg and misting options.
- Bedding must be removed when wetting commences – or just prior to – failure to do so resulted in unacceptable levels of ammonia (up to 35 ppm). Removal of bedding for long periods may lead to problems with cattle feet. However we do not have any evidence from the current study to support this.
- As the duration of exposure to hot conditions continues it appears as if the animals ability to cope (or adjust) is reduced i.e. they become more susceptible to heat stress. This has implications for the frequency of water application (more frequent application is needed) and again this favours the overhead wetting option as this option would use less labour than hose wetting?
- There were no negative effects of wetting cattle in terms of rise in wet bulb temperature (or relative humidity). In most incidences the use of water to cool cattle also resulted in a reduction in dry bulb temperature, particularly with the misting option where 1 ^{o}C drops were observed. The only possible concern would be in the event of ventilation failure, which would lead to a rise in both wet bulb and dry bulb temperature – however we do not have any data to support or refute this statement.
- Cattle observation remains the key to effective heat stress management. It is recommended that panting scores be used as the basis for assessment of cattle heat load status. Observation of panting scores should be done a least four times each day when environmental conditions are likely to induce heat stress. The ideal times are 0200 h, 0600 h, 1400 h and 2200 h. More frequent observations should be made if cattle are suffering from heat stress. Wetting should commence when more than 5% of cattle in a pen or deck have a panting score of 2.5, especially if climatic conditions are expected to worsen. Other factors such as reductions in feed intake and increased water consumption can also be used as an indicator that cattle are having difficulty in coping. And may serve as a warning of impending problems.
- A specific recommendation for time on/off for water application is difficult to make. The frequency and duration of water application is a function of the severity of the climatic conditions and animal condition. However, based on observations and results from this study and previous studies the following recommendations are made. Where heat stress effects are mild i.e. cattle with panting score 2 to 2.5, cattle may be wetted for 3 to 5 minutes every 45 to 50 minutes if there is a likelihood that climatic conditions will get worse. *However, provided that there is adequate observation of cattle with mild heat stress, and the likelihood of climatic conditions becoming more severe is low than wetting will not be need.* When heat stress becomes more severe i.e. panting score 3 to 4, cattle will need to be wetted for 3 to 5 minutes every 15 to 25 minutes. If a situation exists where panting scores of 4.5 are observed cattle must be wetted for 5 to 8 minutes every 10 minutes. It is important to keep observing the cattle. If following wetting animal conditions do not improve more frequent and longer application may be necessary (Table 8).
- Once wetting commences it must be carried out until the climatic conditions causing heat stress abate.

[2] Leg wetting was terminated on day 3 for animal welfare reasons. Wetting was for 2 days only.

Table 8. Wetting strategies for various animal and climatic conditions.

Panting Scores (PS)	Climatic	Scenarios	Wetting Strategy[A]/Animal observation[B]
2 - 2.5	Assess deck climatic conditions ~ at least every 2 hours. Check weather predictions.	1. Climatic conditions are unlikely to worsen over next 24 h. 2. Panting scores have not changed. 3. Climatic conditions likely to worsen over next 12 h.	1. None. Observe panting score at 2 hour intervals. 2. None. Observe panting scores at 2 hour intervals. 3. Consider wetting cattle for 3 to 5 min. Observe PS at 45 min intervals. If PS increased wet again at this time.
3 - 4	Assess deck climatic conditions ~ at least every 30 minutes. Check weather predictions.	1. Climatic conditions are unlikely to worsen over next 24 h. 2. Panting scores have not changed. 3. Climatic conditions likely to worsen over next 12 h.	Wet cattle for 3 to 5 min. Observe cattle at 15 min intervals when PS is 4, and 30 min intervals when PS is 3 – 3.5. (This applies for all scenarios). Water application will need to continue until PS ≤ 2.5, or there is significant climatic change.
4.5	Assess deck climatic conditions ~ continual assessment is needed. Check weather predictions	1. Climatic conditions are unlikely to worsen over next 24 h. 2. Panting scores have not changed. 3. Climatic conditions likely to worsen over next 12 h.	Immediate action is needed. Wet cattle for 5 to 8 min. Observe PS at 10 min intervals. Cattle with PS 4.5 are in major distress. Water application will need to continue until PS ≤ 2.5, or there is significant climatic change.

[A] Bedding should be removed prior to or during first wetting to ensure no build up of ammonia.
[B] Cattle observation remains the key to good heat stress management.

7.1 Recommended research

- The optimum frequency and duration of water application to cool heat stressed cattle needs further investigation, under a variety of climatic conditions, and genotypes (e.g. dairy cows verses beef cattle). This is essential to ensure that not only are cattle adequately cooled, but also to ensure efficient use of labour and water.
- The possible susceptibility of cattle to even mild heat stress events following a major heat event needs further investigation. This has implications for cattle welfare after unloading into a hot environment.

8.0 Acknowledgements

We would like to thank the following people who worked on, and contributed to this project.

Dr Michael McCarthy, Ms Amy Tait, Mr Cesar Casteneda, Mr Yoichi Sakaguchi, Mr Robert Englebright and Mr Edward Qualichefski.

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10.0 Appendix

Photograph 1 Fresh sawdust in pen

Photograph 2   Cattle at feed trough (another two troughs and additional water bowl were located at the opposite end of the pen)

Photograph 3 Cattle in fresh pen

Photograph 4 Overhead sprinkler system (large droplet garden sprinkler)

Photograph 5 Pen floor after first application of hose wetting (second day of hot conditions)

Photograph 6 Cattle after two days of misting