VESSEL HEAT STRESS TECHNOLOGY TRIAL PROGRAM – SHEEP

Predicting the effect of dehumidification technology in mitigating heat stress in exported sheep

Summary

Australia exports sheep to and through the Middle East and North Africa region via sea, which requires voyages through and into areas where there is a risk that heat and humidity will reach high levels. Sheep also generate heat and moisture that can increase the temperature on the deck of a livestock transport ship higher than outside temperatures. The combination of these factors can increase the risk of heat stress for sheep.

To mitigate this risk, the industry currently uses high-powered ventilation systems to move fresh air through the decks and remove heat. However, there is an ongoing need to assess the efficacy of alternate, or complementary, technologies to continue making improvements to the forecasting and management of heat stress, and ultimately, to the welfare of exported sheep.

In 2018, LiveCorp began a project to explore technologies that could reduce the risk of hot and humid conditions on livestock transport ships from exceeding the heat stress thresholds of sheep and could also provide an environment that supports acclimation to destination country conditions. In 2019, with funding from the Australian Government, LiveCorp initiated a trial to assess the effect of dehumidification on reducing the risk of heat and humidity under field conditions. Dehumidification focuses on the removal of moisture in the air that creates humidity. The assessment of commercial dehumidification equipment under realistic livestock export operating conditions represented the first field study conducted of its kind.

A multi-disciplinary team of experts in heating, ventilation and air conditioning, scientific research trial methodology, statistical modelling, animal physiology / veterinary science, epidemiology and engineering was responsible for developing the scientific protocols to assess the commercial dehumidification technology.

A livestock transport ship was used for the trial while it was docked in Dubai with no sheep present on board. Commercial dehumidifiers were installed on the wharf to produce a combined theoretical flow rate of dehumidified air. Two decks of the ship were used and dehumidifiers that operate at varying capacity were run in combination with existing ship ventilation systems.

As the field trial was conducted in real-world conditions, it was not surprising that practical issues were encountered throughout the project, including containment of air flow, heat load of the ducted air systems and maintaining the steady performance of the dehumidifiers. However, the results from this trial demonstrated that the dehumidifiers were able to consistently reduce heat and humidity (wet bulb temperature) on both decks. With the ventilation fans turned off and the dehumidifiers turned on, reductions in relative humidity of up to 12% and in wet bulb temperature of up to 3.0°C were recorded within 20 minutes across both decks. Data from the trial also showed that ventilation fan rates and air temperature on an empty ship influenced the effect of dehumidification. At higher temperatures, more positive effects may be seen when the dehumidifiers alone are used (i.e. without the ventilation fans).

The field trial provided a successful proof of concept for the use of dehumidifiers to reduce the heat and humidity within an empty livestock transport ship. The data from this trial, in combination with estimates of sheep heat load generation, were used to develop a model to predict the effect of a range of variables on the risk of sheep developing heat stress during transport by sea. The model was used to simulate a range of 'what if' scenarios applying dehumidification and ventilation fan capacities across a range of conditions far beyond what was tested in the field. These simulations predicted that to meaningfully and effectively reduce stress risk for sheep on board, the dehumidification capacity used in the field trial would need to be tripled. However, current technology does not appear to be able to achieve this capacity in air flow.

Further, there are several practical and commercial implementation considerations that must be incorporated to develop a successful dehumidification option for industry adoption. More research is also needed to improve the underlying assumptions used in the model, including how much heat is generated by sheep, as estimates in current literature vary widely.

While further refinements to the model would be beneficial, the cross-disciplinary skills and expertise of the project team and the outcomes from the trial have resulted in the development and verification of a thermal model of the deck space – including simulating the presence of sheep under different conditions. This significant outcome allowed the study to evaluate the performance of the dehumidifiers and conduct this trial without requiring the use of live sheep.

The outcomes from the modelling demonstrated that by combining off-the-shelf dehumidification products, it was possible to lower heat and humidity in situations where such a decrease could not be achieved using ventilation fans alone. While the significant commercial and logistical constraints are very real challenges, this finding still provides valuable information to guide the design or identification of technologies that may deliver a feasible option for industry.

- **Wet bulb temperature (Twb)**
  Air can be cooled when water is evaporated. Twb is the lowest possible temperature that can be achieved by evaporative cooling. It is different to 'dry bulb' temperature, which is a measure of the amount of heat in the air.
- **Relative humidity (RH)**
  Relative humidity is a measure of the moisture in the air relative to the temperature of the air.

Introduction

The combination of outside heat and humidity with naturally generated heat from sheep can increase the risk of heat stress for animals during transport on a livestock transport ship. To mitigate this risk, the industry currently uses ventilation systems to blow fresh air through the decks to draw heat away from the sheep. However, there is an ongoing need to assess the efficacy of alternate, or complementary, technologies to continue making improvements to the forecasting and management of heat stress, and ultimately welfare, for exported sheep.

At present, the livestock export industry uses a heat stress risk assessment (HSRA) model developed by LiveCorp and Meat & Livestock Australia. The HSRA model combines voyage variables such as weather (e.g. heat and humidity conditions), animal (e.g. class of livestock) and ship related data (e.g. ventilation fan output). The data is applied within a framework of logical assumptions, estimations and accepted risk thresholds to determine the risks to the animals that may be associated with a particular voyage. If the HSRA predicts that the risk thresholds will be exceeded, exporters are required to decrease the number of animals exported or are prevented from exporting under those voyage conditions.

In 2018, LiveCorp began a challenge-led Open Innovation project to explore existing technologies that could reduce the risk of hot and humid conditions on livestock transport ships. Phase 2 of the project was to assess the effect of dehumidification on mitigating heat and humidity under field conditions using an empty livestock ship (Figure 1). Temperature can be lowered by the evaporation of water, however, high humidity reduces the amount of evaporation possible. Dehumidification technology can be used to remove water from the air and increase the potential for evaporation. This trial to assess commercial dehumidification equipment under realistic livestock export operating conditions represented the first field study conducted of its kind. Importantly, the outcomes of the field trial informed development of a model, reflective of the HRSA model, to predict the combined effect of heat generation by sheep with variations in ventilation and dehumidification.

	PHASE 1 Pre Trial	PHASE 2 Static Trials			PHASE 3 Dynamic Trials		PHASE 4 Reporting
Trial	**Pre Trial**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Post Trial**
Details	Pre Trial Planning	Route Planning	Network Trial	Static Dehumidification Trial	Dynamic Chamber Trial	Dynamic Sea Trial	Final Report

Figure 1. The phases planned for the vessel heat stress technology trial program. This summary report relates to Phase 2, Trial 3.

Challenge statement

To find a proven and scalable solution for managing the on-board environment of sheep being transported by sea to reduce the risk of heat stress, optimise stocking rates and maintain license to operate.

A multi-disciplinary team ensured the trial outcomes would inform industry practice

The project team comprised of experts in heating, ventilation and air conditioning, scientific research trial methodology, statistical modelling, animal physiology / veterinary science, epidemiology and engineering. To ensure the trial was scientifically feasible within the constraints of a working ship and dockyards, engineers from the University of Sydney advised, supported and observed the development of the trial methodologies and their delivery.

This multi-disciplinary approach to planning, project management, data assessment and reporting ensured the trial outcomes were valid and could reliably inform industry practice and the development of a model to predict the effect of dehumidification in mitigating the risks of heat stress in sheep being transported by sea.

Figure 2. The four dehumidifiers used in the trial.

Realistic operating conditions were created for the trial

The trial was conducted on a commercial livestock transport ship in Dubai in June, during the northern hemisphere summer. The ship was dockside in the water orientated in a west north westerly direction, with the starboard side in the full sun for the majority of the day. Data relating to the standard operation of the ship, including the ventilation system, were obtained from the ship's owner.

Two HCU3000 and two HCU6000 'DryCool' dehumidifiers were installed on the western side of the ship (Figure 2), with single unit flow rates of 5,000m^3/hr and 10,000m^3/hr, respectively. Ducts from the units to two decks were set up for this trial. One of each type of dehumidifier was ducted directly into each of the decks to produce a combined theoretical flow rate of 15,000m^3/hr. To avoid compromising the quality of the data, modifications were made to the set-up of the ducting and the units to avoid the lag time between when they were turned on and when they reached full output. Further, the two decks were sealed (with the exception of the ventilation fan outlets) to isolate the test zones to prevent cold air from sinking and accumulating on lower decks, and hot air rising to higher decks.

Environmental data loggers were used to record the temperature and humidity at various locations throughout the ducts, the decks and ship. Air velocity and thermal imaging data were also collected. Where required, validation of the data collected by the loggers was conducted prior to the trial and all equipment was tested before the trial commenced to determine baseline operating conditions.

Dehumidifiers were able to reduce the heat and humidity on an empty livestock export ship during summer in the Middle East

While not surprising that practical issues were encountered (including containment of air flow, heat load of the ducted air systems and maintaining the steady performance of the dehumidifiers), the results from this trial demonstrated that the dehumidifiers were able to reduce the heat and humidity consistently on both decks. Further, the results indicated that the performance of the dehumidifiers increased as the heat and humidity increased.

There was a reduction of relative humidity, averaged across the deck, of 12% and a reduction in wet bulb temperature of 3.0^{0}C recorded within 20 minutes with the ventilation fans turned off and the dehumidifiers turned on (Figure 3).

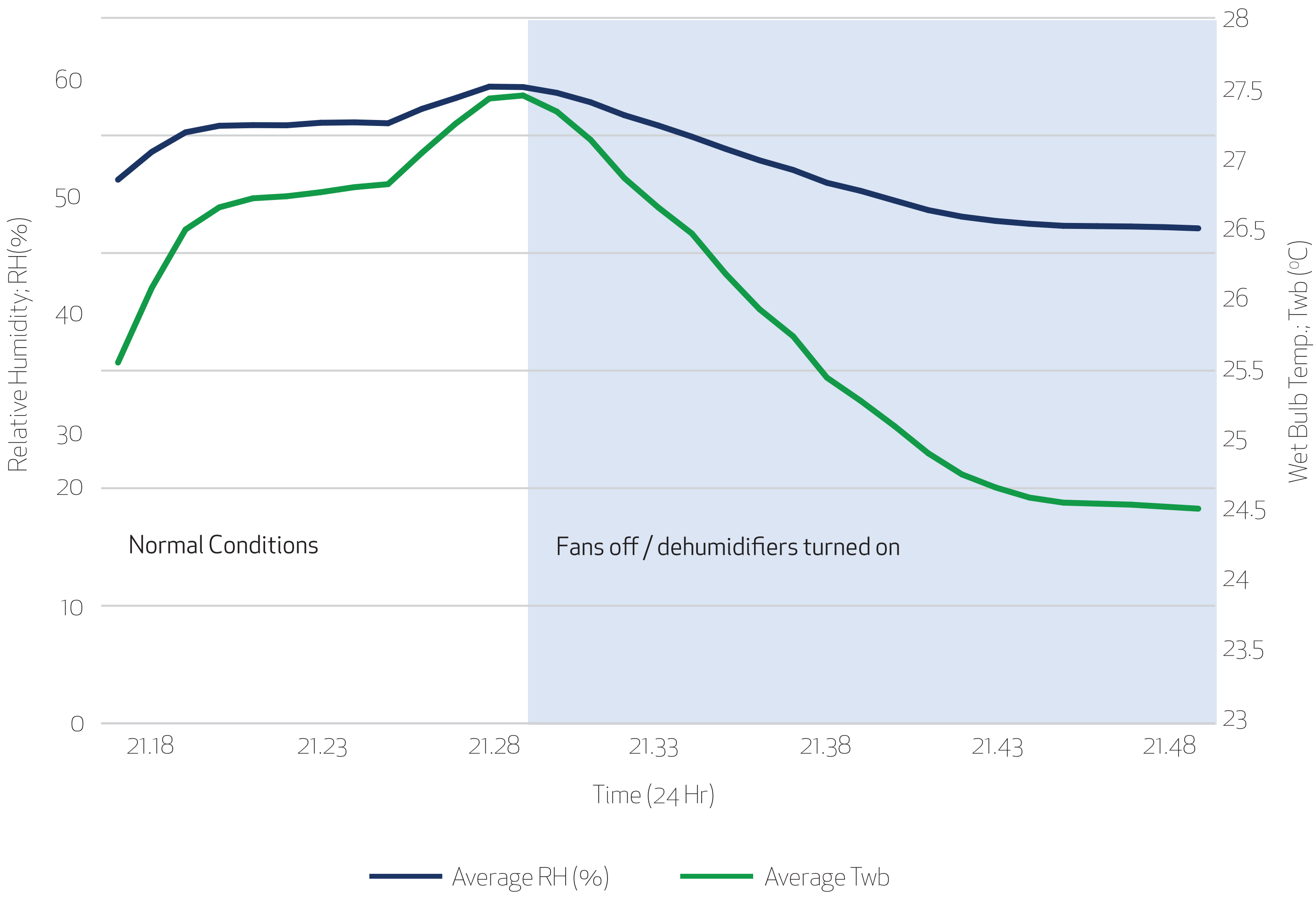

Figure 3. The average Relative Humidity (RH) and Wet Bulb Temperature (Twb) rate response on Deck 2 with dehumidifiers delivering 15,000 m³/hr of dehumidified air, before and after the ventilation fans were turned off.

More work is needed to determine how to operate heat mitigation technologies simultaneously

Ventilation fans are currently used by the industry to blow fresh air from the outside through the deck to remove heat and other pollutants (such as ammonia and carbon dioxide). Data from the trial indicated that the effect of the dehumidifiers was diluted by air flow from the ventilation fans on an empty vessel. This suggests that dehumidifiers may provide more positive effects in reducing the heat and humidity on the decks when the ventilation fans are turned off, but it is not yet known how this would be influenced by the presence of sheep.

The average relative humidity in both decks decreased once the dehumidifiers were switched on, with a 9% decrease in relative humidity observed within 20 minutes when no fans were operating (Figure 4). There was a 7% increase in relative humidity within 20 minutes when fans were operated at 25%. This reflected the same pattern in temperature.

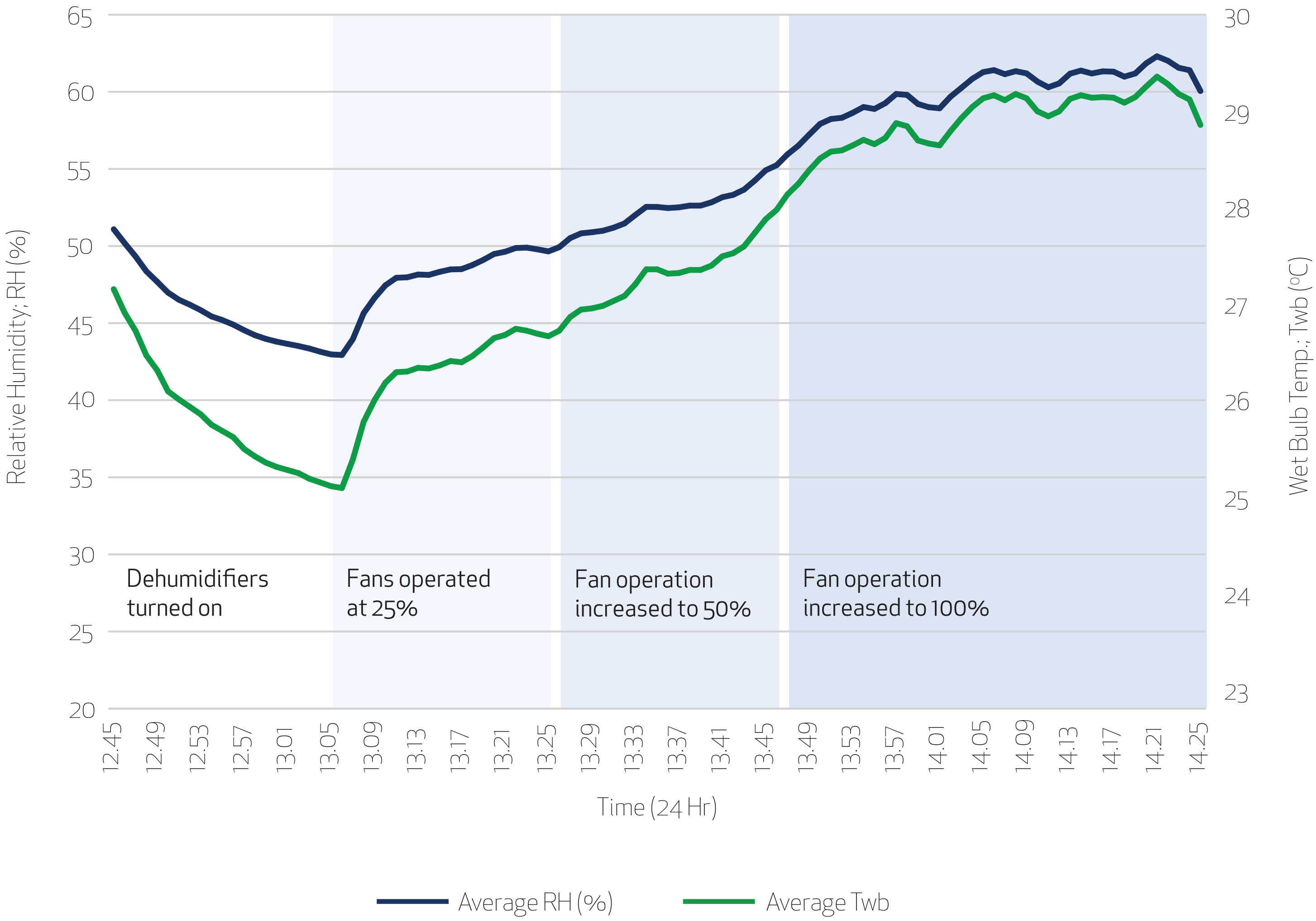

Figure 4. The average Relative Humidity (RH) and Wet Bulb Temperature (Twb) rate response on Deck 2 with dehumidifiers delivering 15,000 m³/hr of dehumidified air, with ventilation fans increasing in capacity over time.

The developed model highlighted technological improvements are required

The field trial provided a successful proof of concept for the use of dehumidifiers to reduce the heat and humidity within an empty livestock transport ship. The data from the field trial, in combination with estimates of sheep heat load generation, was used to develop a model to predict the effect of combinations of variables on the risk of sheep developing heat stress during transport by sea. The model was used to simulate a range of 'what if' scenarios across a range of conditions far beyond what was tested in the field and various modelling scenarios were verified by comparison with existing data.

It was concluded that the model provided accurate predictions of deck conditions across a range of combinations of livestock class and type, stocking density, air temperatures, fans and dehumidifier use. Generally, the use of ventilation fans had a stronger influence in reducing the heat and humidity at lower air temperatures, and dehumidification had a stronger influence in reducing heat and humidity at higher air temperatures, which supported the findings of the field trial.

The model predicted that to meaningfully and effectively reduce heat stress risk for sheep on board, the dehumidification capacity used in the field trial would need to be tripled. However, current technology is not able to achieve this capacity in air flow.

There remains a gap between the outcomes of the modelling and identifying an implementable solution for industry

The outcomes of the field trial and modelling have highlighted that the management of the environmental conditions on a livestock transport ship are complex and multi-faceted. This study has helped to identify where the performance of various interventions, such as fans and dehumidification, are greatest and where their application alone or in combination may have an impact.

This project clarified improvements required to on-board dehumidification technology, and also highlighted the practical and commercial issues that need to be considered before dehumidification can be successfully used to manage the health and welfare of sheep transported by sea. These include:

- space and weight constraints
- energy use
- regulatory requirements
- maintenance
- redundancy or contingency arrangements
- effect on ship performance (speed, fuel consumption etc.)
- customisation
- wider costs / benefit considerations.

Future research required centres on improving available technologies

The outcomes from this project indicate that a commercial dehumidification unit would need to produce three times the current capacity of dehumidification to influence the temperature on a livestock transport ship when sheep are on board. It is not yet clear how this will be achieved, but may involve increasing the air volume capacity from smaller units, or the introduction of cooling in conjunction with dehumidification.

To narrow the technological specifications required for effective dehumidification while the sheep are on board, improved clarity is required for key assumptions used in the model. For example, there is significant variation in current literature regarding the amount of heat that sheep generate and the volume of air movement needed to remove this heat and maintain air quality. There is also a need to further understand how each of the elements of heat and humidity interact and what their individual and combined influences are on animal welfare. To ensure adoption by industry, any dehumidification technology developed would need to be effective under a wide range of varying field conditions.

Clarification of the challenges to be addressed provides a framework for the direction of the research to be conducted in the future stages of the 'vessel heat stress technology trial program'.

Outcomes for industry

The cross-disciplinary skills and expertise of the project team and the outcomes from the trial have resulted in the development and verification of a thermal model of the deck space. Importantly, this model was able to simulate different conditions if sheep were to be present, meaning an assessment of the dehumidification technology could be conducted without the use of live animals. Further, the model allowed for simulation of a range of 'what if' scenarios across a range of conditions far beyond what was tested in the field.

The outcomes from the modelling demonstrated that by combining off-the-shelf dehumidification products, it was possible to lower heat and humidity in situations where such a decrease could not be achieved using ventilation fans alone. While the significant commercial and logistical constraints of achieving this (e.g. tripling the capacity used in the trial) are very real challenges, this finding still provides valuable information to guide the design or identification of technologies that may deliver a feasible option for industry.

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