HotStuff V5 Addendum

Calculations within the Live Export Heat Stress Risk Assessment Method

Project code: W.LIV.0277

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Date published: February 2017

PUBLISHED BY

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Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

The 'HotStuff' software for the assessment of heat stress risk on livestock voyages west from Australia has been revised, updated and expanded. This addendum records the formulae and input data which form the core of the HotStuff risk calculations. It addresses the issue of providing complete transparency of the method's calculations. All of the material, except for the revised voyage wet bulb figures, is gathered from earlier reports.

Executive summary

The HotStuff software implements an approach to the assessment of heat stress risk on live export voyages from Australia. It combines animal heat tolerance, weather statistics and vessel parameters to give a scientifically defendable estimate of the numerical risk of mortality in each line of livestock to be loaded. It is used as a risk management tool through the assessment of planned voyages so that unacceptable risk can be avoided well ahead of the loading.

The method has been established and augmented through successive projects since 2000. Previous LiveCorp/MLA reports document the formulae and input data. This addendum repeats in one place, the formulae which mathematically represent the understanding of heat stress risk. Information already in the primary LIV.0277 report is not repeated here. The calculations and inputs are essentially the same as those applied in earlier versions of HotStuff. The principal change affecting risk estimates in Version 4 was in the weather data, the analysis of which is well described in the main report, which also gives the discharge port weather data. The revised voyage weather data are tabulated in this addendum.

Contents

1 Background on HotStuff

In 2000, the basic thermodynamics of livestock housing had been clearly documented. Among the outcomes was a new measure of ventilation rate; the Pen Air Turnover or PAT which is the ratio of the fresh air supply rate to the pen area. This measure differed from the previous volumetric air turnover measure in that the airflow was compared only to the pen area. It is the pen area, not the volume, which determines the animal mass housed, and hence the metabolic heat evolved.

Version 1.0 of HotStuff was released in final form in May 2003. In version 1.0, the closed deck risk assessment was substantially in its current form. The open deck issues were treated by giving guidance as to what the crosswind the captain needed to be certain of while sailing and before proceeding into port. While that approach on open decks was not really suitable for a regulatory role on risk, the introduction of a robust treatment of closed deck risks was a major step forward for the industry. Continued development, mainly on the software operation rather than the risk numbers, led to Version 2.0 in September 2003. Further interaction with users and with MLA and LiveCorp led to Version 2.3 in February 2005. It is version 2.3 which has been in use up until the Version 4.0 release.

Version 3 was produced in April 2009 but not released in its developed form for use by the industry. It included a new approach to reducing the ship-sourced weather data to voyage weather statistics. That approach was further refined in producing Version 4. Version 3 also included an assessment of the risk when tied up in the discharge port, as a separate assessment to that of the risk when sailing. That important feature responded to several lower level incidents and near misses on vessels while in port.

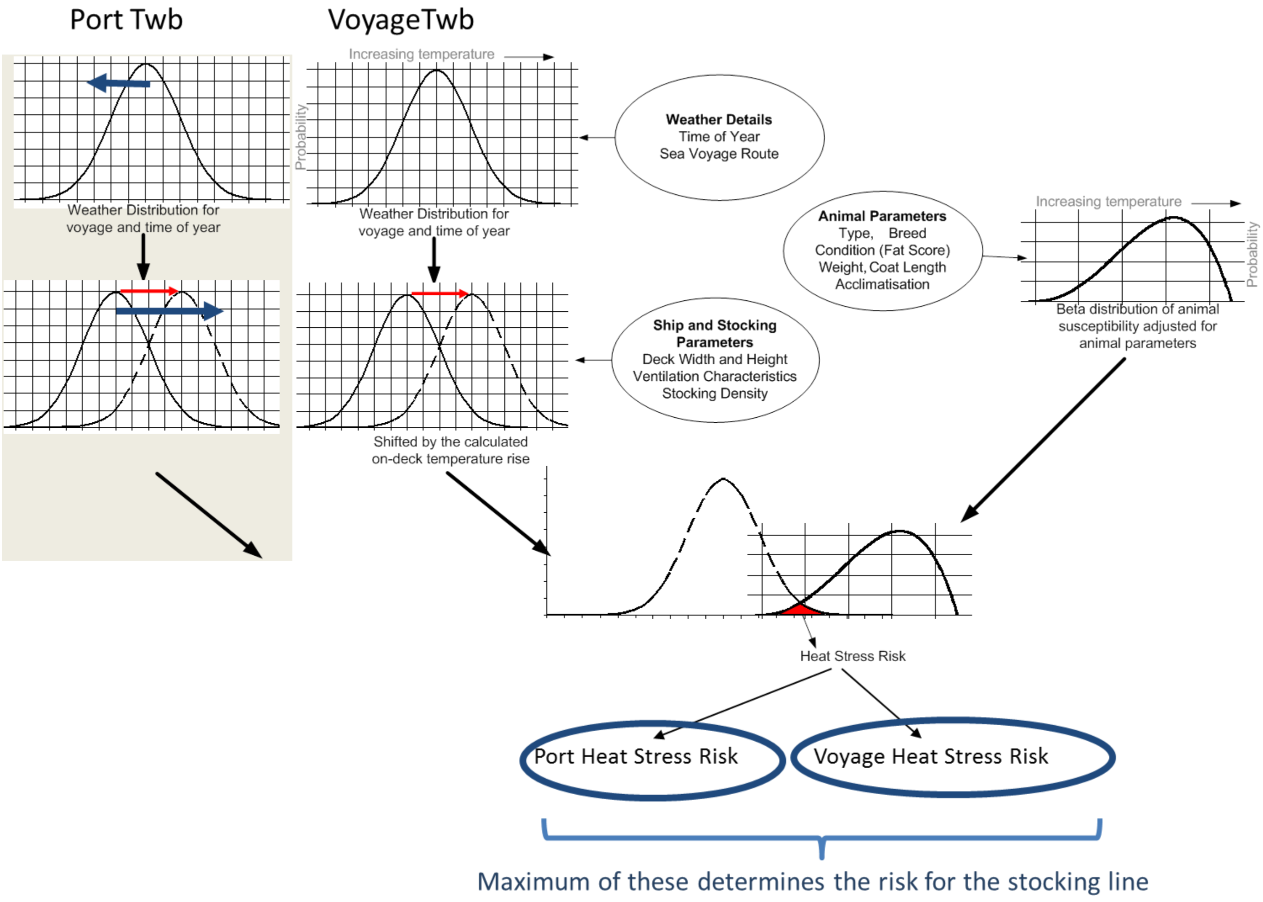


Figure 1.1 below describes the approach schematically. Version 3 did not include the recently added ports or routes and was superseded by Version 4.

Version 5.0 is the current development described in this report. The version number has been incremented to describe a migration of the software platform to allow continued maintainability. No new risk functionality was introduced between versions 4.0 and 5.0. It includes all previous HotStuff developments, plus those noted in the following sections. The voyage weather data has been re-analysed yet again for Version 5, with a close focus on the data and temperature distribution integrity. The method is summarised briefly as follows.

The probability of animal mortality is described statistically as a function of wet bulb temperature by a distribution which is a function of the animal's breed, condition, weight, coat and acclimatisation. The likelihood of reaching any given wet bulb temperature on a deck is also described by a probability distribution. First, the probability distribution of ambient wet bulb temperature has been assessed from weather observations for every voyage route for all twelve calendar months. Second, the ambient distribution is shifted hotter by an amount corresponding to the rise in wet bulb temperature on the deck. That rise is calculated from the heat output of the animals diluted by the fresh air flow rate. The result is probability distributions for both the deck wet bulb temperature (local environment) and the animal tolerance to the environment (mortality limit). The intersection between the hot end of the deck wet bulb probability distribution and the cool end of the animal mortality limit gives the risk level. This is done for each line of livestock, on each deck of the vessel, for the particular discharge date. The risk must be below the industry accepted level of 2% chance of a 5% mortality event.

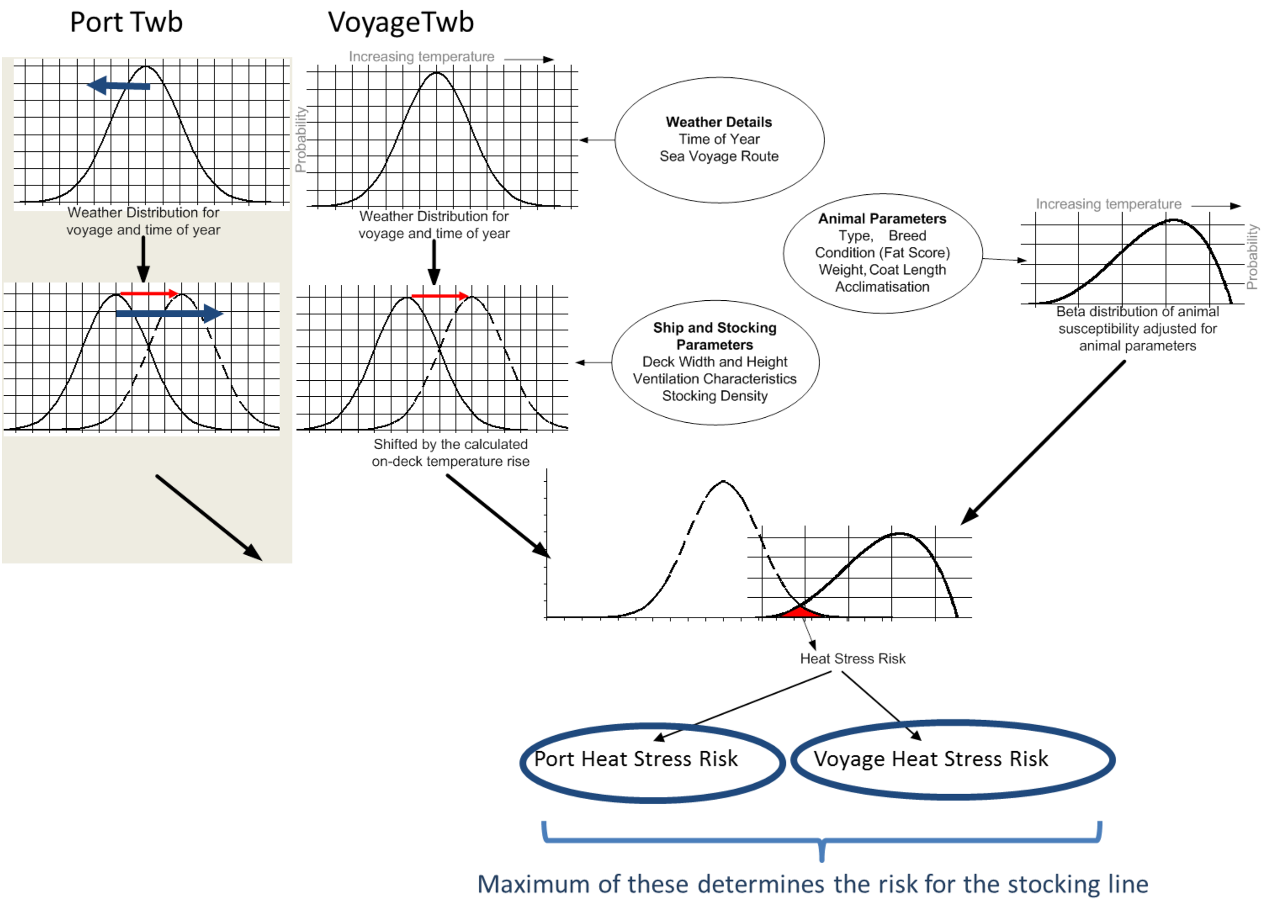


Figure 1.1. Flowchart of the heat stress assessment, with the shaded area being added since Version 2.3.

The above text describes the risk assessment while sailing. It uses the hottest wet bulb temperature distribution anywhere along the particular route. The shaded areas in

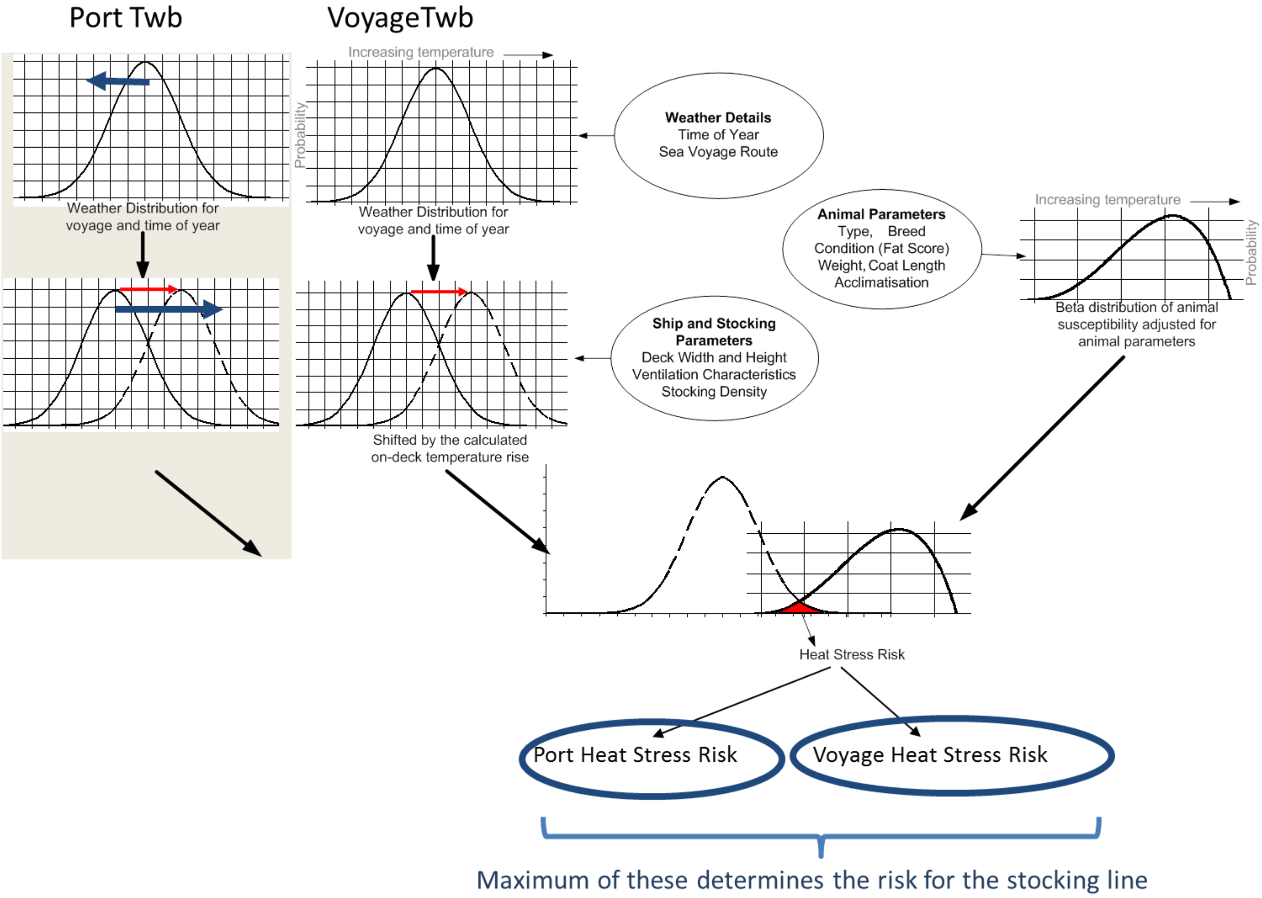


Figure 1.1 indicate that since Version 2.3, the same process is repeated for the discharge phase risk (the "port risk") being the risk while the vessel is stationary alongside the wharf. Because the ventilation effects on open decks are very different when the vessel is stationary, a separate risk assessment was called for. In assessing port risk, only the port weather data are used and the crosswind for open decks is taken to be zero. The risk must be seen as acceptable in both sailing (voyage) and port calculations. Version 5.0 calculates the port risk for all destination ports.

2 Port Weather

Port weather is described by the 98th percentile wet bulb temperatures for each month. These are tabulated in the main report. The monthly data are assigned to the 15th day of the month, with the figure relevant to a particular day being found by interpolation between the values for the “15th“ dates either side of the date in question.

3 Voyage Weather

The date for the voyage weather is taken as being the day of arrival at the first discharge port. The voyage weather statistics were established by aggregating by month, with the data assigned to the 15th day of each month. Interpolation is then as for the port weather data. Other analysis details are given in the main report. The 98th percentile wet bulb temperatures applied are given in **Error! Reference source not found.** below.

Journey Name	Origin	January	February	March	April	May	June	July	August	September	October	November	December
Agadir via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	25.38	25.78	26.508	26.37	27.052	27.53
Agadir via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	25.38	25.78	26.508	26.37	27.052	27.53
Al Latakya via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Al Latakya via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Al Latakya via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	27.172	28.86	26.508	26.37	27.052	27.53
Al Latakya via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	27.172	28.86	26.508	26.37	27.052	27.53
Alexandria via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Alexandria via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Alexandria via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	27.172	27.2	26.508	26.37	27.052	27.53
Alexandria via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	27.172	27.2	26.508	26.37	27.052	27.53
Antalya via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Antalya via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Antalya via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	27.172	27.4723	26.508	26.37	27.052	27.53
Antalya via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	27.172	27.4723	26.508	26.37	27.052	27.53
Aqaba from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Aqaba from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Bahrain from North	North	27.814	29.24	29.4586	28.472	30.6023	30.9	31.64	31.9211	32.33	29.632	28.2	28.2
Bahrain from South	South	26.2	26.44	27.201	28.3638	30.6023	30.9	31.64	31.9211	32.33	29.2275	27.26	26.36
Beirut via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Beirut via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Beirut via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	27.172	28.76	26.508	26.37	27.052	27.53
Beirut via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	27.172	28.76	26.508	26.37	27.052	27.53
Benghazi via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Benghazi via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Benghazi via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	26.4125	27.68	26.508	26.37	27.052	27.53
Benghazi via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	26.4125	27.68	26.508	26.37	27.052	27.53
Casablanca via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	25.38	25.78	26.508	26.37	27.052	27.53
Casablanca via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	25.38	25.78	26.508	26.37	27.052	27.53
Dharan from North	North	27.814	29.24	29.4586	28.472	30.6023	30.9	31.64	31.9211	32.33	30.1636	28.2	28.2
Dharan from South	South	26.2	26.44	27.201	28.3638	30.6023	30.9	31.64	31.9211	32.33	30.1636	27.26	26.36
Doha from North	North	27.814	29.24	29.4586	28.472	30.6023	30.9	32.68	33.0085	33.084	29.632	28.2	28.2
Doha from South	South	26.2	26.44	27.201	28.3638	30.6023	30.9	32.68	33.0085	33.084	29.5061	27.26	26.36
Dubai - Jebel Ali from North	North	27.814	29.24	29.4586	28.472	29.76	30.9	31.64	31.8341	32.46	29.632	28.2	28.2
Dubai - Jebel Ali from South	South	26.2	26.44	27.201	28.3638	29.76	30.9	31.64	31.8341	32.46	29.1929	27.26	26.36
Fujairah from North	North	27.814	29.24	29.4586	28.472	29.328	30.75	31.2	31.2452	30.68	29.632	28.2	28.2
Fujairah from South	South	26.2	26.44	27.201	28.3638	29.328	30.75	31.2	31.2452	30.68	29.1929	27.26	26.36
Istanbul via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Istanbul via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Istanbul via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	28.1008	30.6614	26.508	26.37	27.052	27.53
Istanbul via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	28.1008	30.6614	26.508	26.37	27.052	27.53
Izmir via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Izmir via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Izmir via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	27.172	27.7251	26.508	26.37	27.052	27.53
Izmir via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	27.172	27.7251	26.508	26.37	27.052	27.53
Jeddah from North	North	27.814	29.24	29.4586	28.7496	30.1467	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Jeddah from South	South	27.9295	29.05	28.58	28.7496	30.1467	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Karachi from North	North	27.814	29.24	29.4586	30.2	30.2	32.2	28.72	28.2043	27.928	30.56	28.2	28.2
Karachi from South	South	26.4954	26.6722	27.8163	30.2	30.2	32.2	28.72	27.9533	27.908	29.4532	27.4067	27
Kuwait from North	North	27.814	29.24	29.4586	28.472	30.6023	30.9	31.64	31.9211	32.33	29.632	28.2	28.2
Kuwait from South	South	26.2	26.44	27.201	28.3638	30.6023	30.9	31.64	31.9211	32.33	29.2275	27.26	26.36
Mersin via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Mersin via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Mersin via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	27.172	28.86	26.508	26.37	27.052	27.53
Mersin via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	27.172	28.86	26.508	26.37	27.052	27.53
Muscat from North	North	27.814	29.24	29.4586	28.472	29.216	30.62	30.2	29.6907	28.604	29.632	28.2	28.2
Muscat from South	South	26.2	26.44	27.201	28.3638	29.216	30.62	30.2	29.6907	28.604	29.1929	27.26	26.36
Novorossiysk via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Novorossiysk via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Novorossiysk via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	28.2	32.0124	26.508	26.37	27.052	27.53
Novorossiysk via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	28.2	32.0124	26.508	26.37	27.052	27.53
Odessa via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.349	30.924	30.56	28.2	28.2
Odessa via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.349	30.924	29.814	29.36	27.2
Odessa via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	28.2	32.349	26.508	26.37	27.052	27.53
Odessa via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	28.2	32.349	26.508	26.37	27.052	27.53
Samsun via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Samsun via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Samsun via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	28.2	31.0687	26.508	26.37	27.052	27.53
Samsun via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	28.2	31.0687	26.508	26.37	27.052	27.53
Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Tekirdag via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Tekirdag via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Tekirdag via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	27.9818	30.6614	26.508	26.37	27.052	27.53
Tekirdag via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	27.9818	30.6614	26.508	26.37	27.052	27.53
Trabzon via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Trabzon via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Trabzon via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	28.2	31.0687	26.508	26.37	27.052	27.53
Trabzon via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	28.2	31.0687	26.508	26.37	27.052	27.53
Tripoli via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Tripoli via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Tripoli via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	27.0656	26.2094	26.508	26.37	27.052	27.53
Tripoli via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	27.0656	26.2094	26.508	26.37	27.052	27.53
Ust Luga via Suez from North	North	27.814	29.24	29.4586	28.7496	30.1122	31.344	30.788	32.1277	30.924	30.56	28.2	28.2
Ust Luga via Suez from South	South	27.9295	29.05	28.58	28.7496	30.1122	31.344	30.788	32.1277	30.924	29.814	29.36	27.2
Ust Luga via West Africa	North	27.2	26.56	27.936	27.364	25.958	26	25.38	25.78	26.508	26.37	27.052	27.53
Ust Luga via West Africa	South	27.2	26.56	27.936	27.364	25.958	26	25.38	25.78	26.508	26.37	27.052	27.53

4 Animal parameters

4.1 Base heat tolerance

The model of animal response to heat is well described in earlier reports. The base data are gathered here with minimal explanation.

Table 4.1. Base Heat Stress Threshold and Mortality Limit Values for the 'Standard' Animals

Base Parameter	Bos taurus		Bos indicus			Merino		Awassi	
	beef	dairy	beef	25%	50%	adult	lamb	adult	lamb
Weight (kg)	300	300	300	300	300	40	40	40	40
Core Temperature (degrees C)	40	40	40	40	40	40	40	40	40
Condition (Fat Score)	3	3	3	3	3	3	3	3	3
Coat	mid	mid	N/A	N/A	N/A	shorn	shorn	hairy	hairy
Acclimatisation WB Temp	15	15	15	15	16	15	15	15	15
Base HST (degrees C)	30	28.2	32.5	31.25	31.875	30.6	26.7	31.9	28.6
Base ML (degrees C)	33.2	32.9	36.0	34.60	35.30	35.5	35.20	36.1	35.90
Beta distribution lower limit (degrees C)	30.31	29.88	34.30	32.30	32.30	33.58	33.17	34.52	34.15
Beta distribution upper limit (degrees C)	34.74	34.51	36.90	35.82	35.82	36.52	36.29	37.03	36.83

Figure 4.1. Beta Function Probability Distribution – Bos taurus - dairy

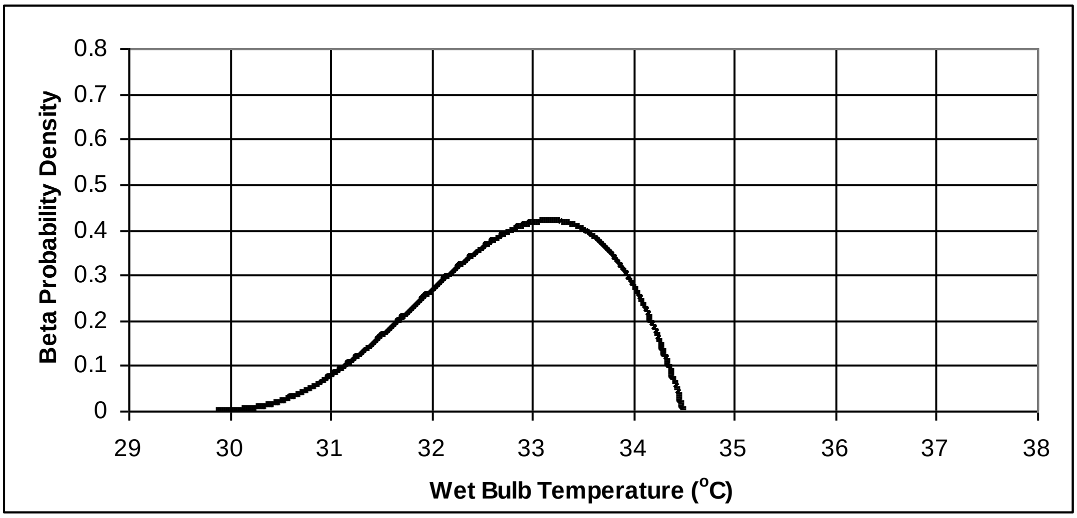


Figure 4.2. Beta Function Probability Distribution – Bos indicus

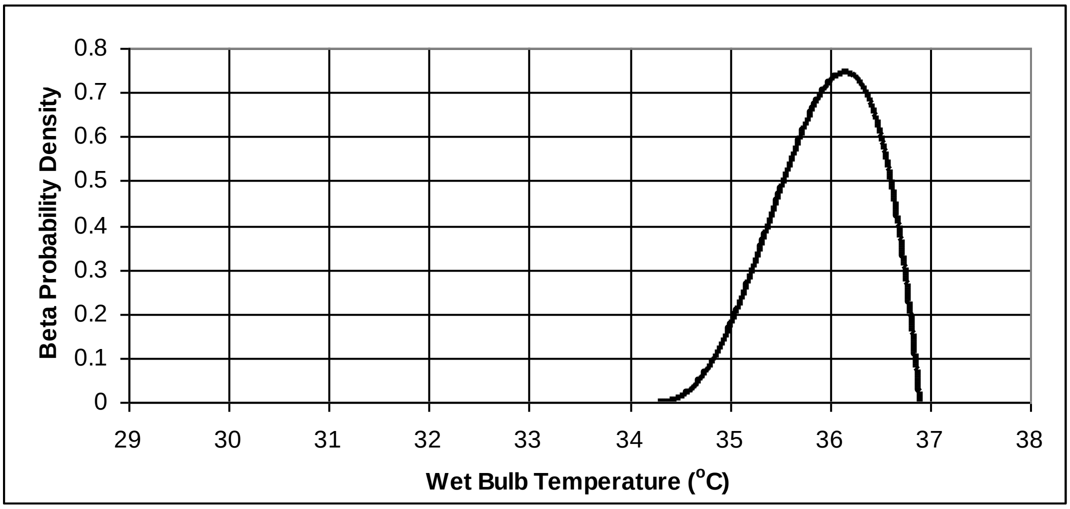


Figure 4.3. Beta Function Probability Distribution – 25% Bos indicus

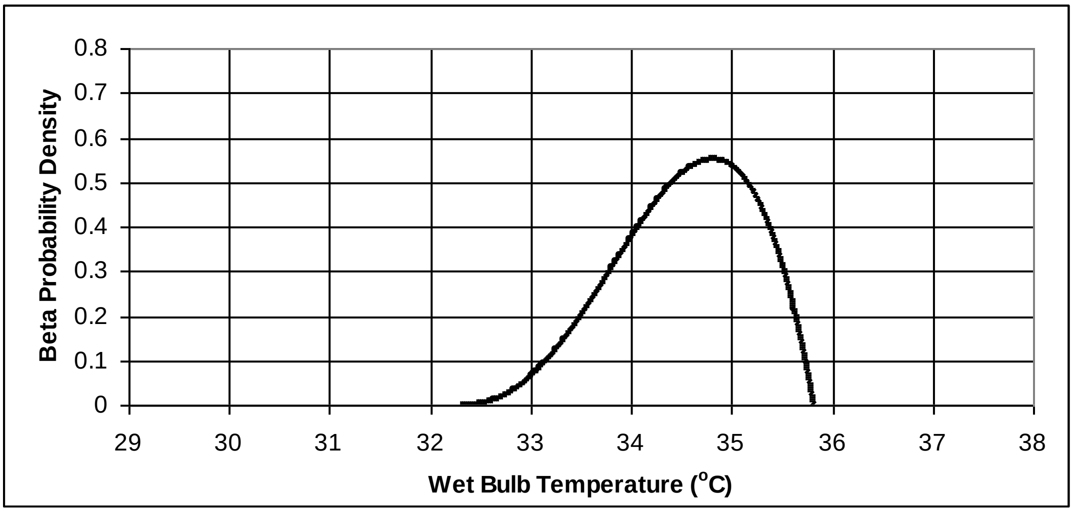


Figure 4.4. Beta Function Probability Distribution – 50% Bos indicus

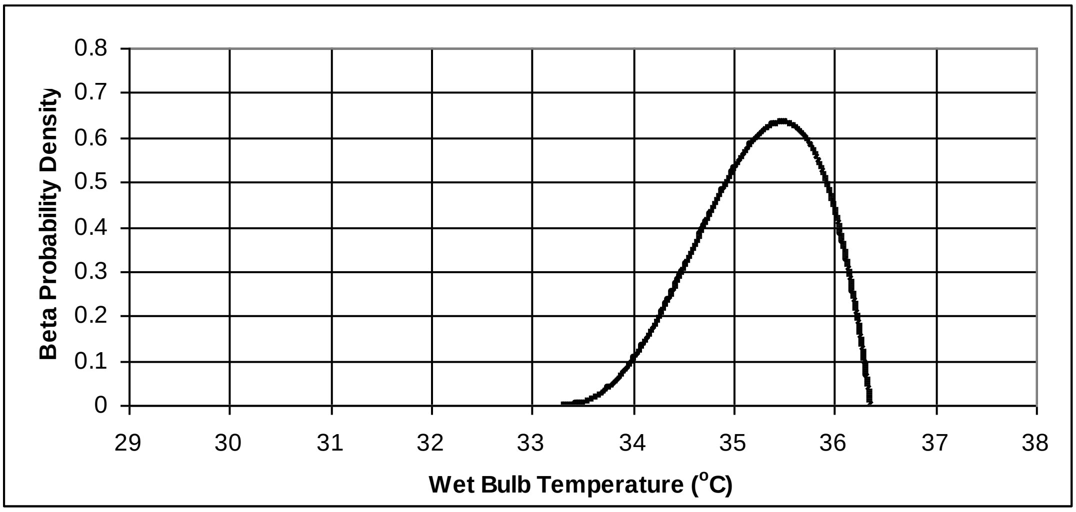


Figure 4.5. Beta Function Probability Distribution – Merino - Adult

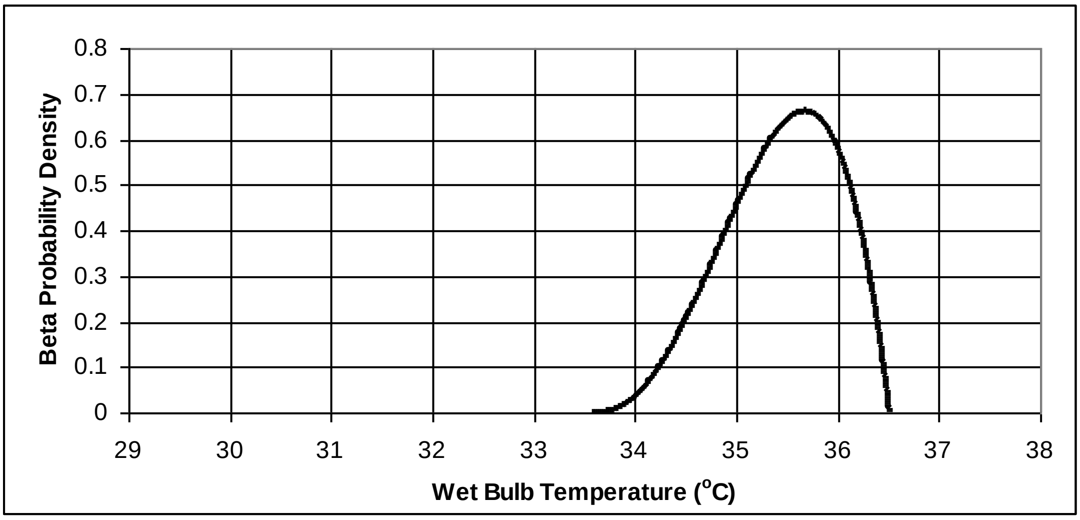


Figure 4.6. Beta Function Probability Distribution – Merino - Lamb

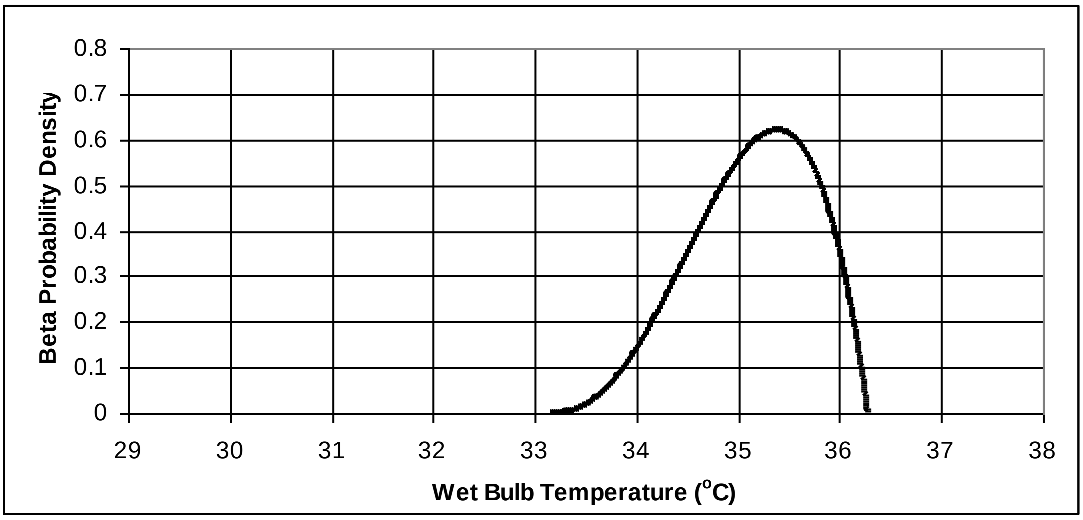


Figure 4.7. Beta Function Probability Distribution – Awassi - Adult

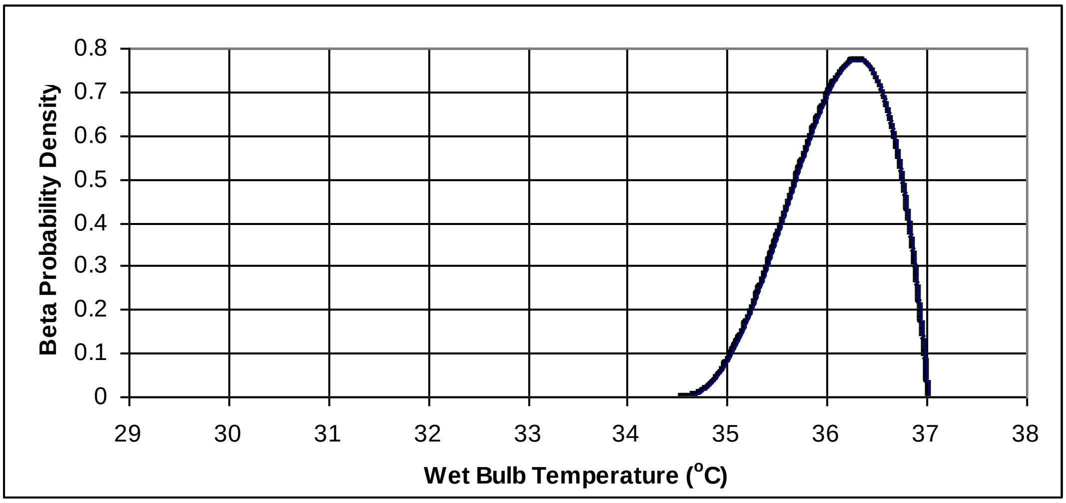
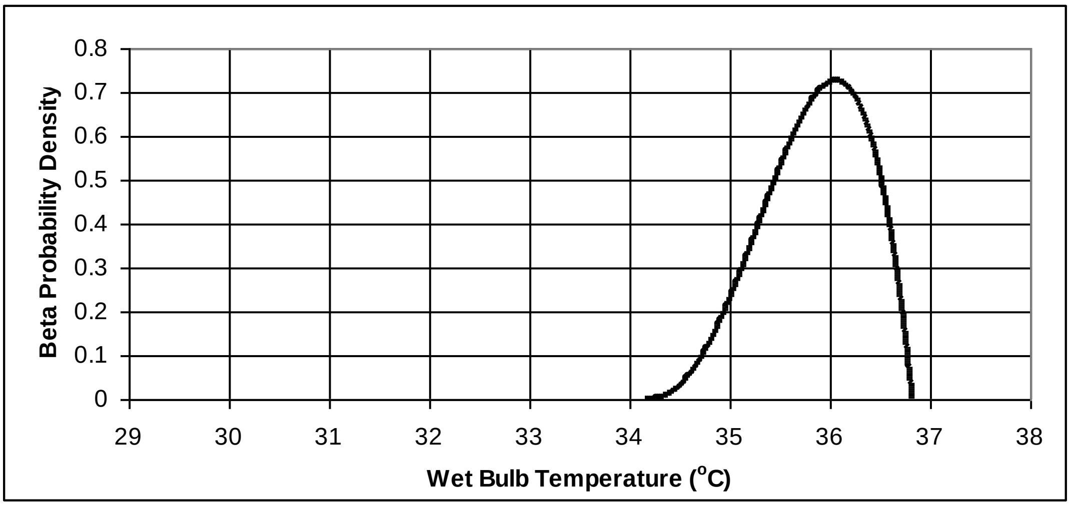


Figure 4.8. Beta Function Probability Distribution – Awassi - Lamb



4.2 Scaling the mortality limit

The mortality limit for any given line of animal is estimated by scaling the values from those of a standard animal of the same type. The various physical characteristics (weight, acclimatisation, coat and condition) will affect the temperature difference required between the animal and its environment for rejection of metabolic heat. The factors assigned to each feature act in the model to modify this temperature difference. That is; using T_{CORE} as the animal's core temperature, and adjustment factors F for each characteristic, the difference between the core temperature and the wet bulb that is the animal's mortality limit (ML) can be modified as:

$(T_{CORE} – ML) = F_{ACC} \times F_{WEIGHT} \times F_{COAT} \times F_{CONDITION} \times (T_{CORE} – \text{base ML})$

As the probability beta distribution of ML for any one animal type is uncertain, the scaling of the beta distribution limits with animal characteristics cannot be any more certain. Following again the principle that the difference between core and ambient wet bulb temperatures gives the controlling temperature scale, the spread of the beta distribution is adjusted in proportion to that difference. That is; 'softer' lines of animals, with a lower ML, will also have a wider spread of ML within the line. The shape parameters (P and Q) which determine the skewness of the beta distribution were set by judgement and have been kept constant across all animals. For the record, we have used P = 3.50 and Q = 2.00. For a 50th percentile of 35.09˚C, the minimum and maximum of the beta distribution are 33˚C and 36.2˚C respectively. Other distributions, including those in Figure 4.1 to Figure 4.8, are scaled from this as described above.

The following sections describe the development of each adjustment factor.

4.2.1 Weight Scaling

The initial estimate of the weight factor is based on geometry. We make the simplifying assumption that animals of one breed are geometrically similar. This gives a surface area proportional to the two-thirds power of body mass. If the rate of production of metabolic heat per unit mass is constant (a fair approximation) then obviously the heat generated is proportional to mass. Assuming further, that the coefficients of heat transfer are independent of body mass, the required minimum temperature difference between core and wet bulb temperatures goes as the one-third power of mass. That is;

$$\Delta T_{CRIT} \propto m^{1/3} \qquad (m \text{ is animal mass})$$

This gives the first estimate of the weight factor as

$$F_{WEIGHT} = \left(\frac{m}{m_{STANDARD}} \right)^{\frac{1}{3}}$$

or, if we believe that the one-third power may not be quite right;

$$F_{WEIGHT} = \left(\frac{m}{m_{STANDARD}} \right)^{n}$$

When an animal of a given frame puts on weight, it does not follow the geometric rules above, with surface area growing more slowly with mass than described. This has the effect of increasing the exponent *n*, above, beyond 0.33. Animals with lots of weight for their frame may also attract a high condition factor and so we must be careful not to 'double count' the weight influence in both weight factor and condition factor.

We have also not seen a strong weight influence in moderately sized (up to 60kg) sheep. For now we have settled on $n = 0.33$ for cattle and somewhat arbitrarily decreased this to $n = 0.2$ for sheep.

4.2.2 Acclimatisation

The form of the acclimatisation factor is shown in Figure 4.9. Wet bulb limits of 5°C and 25°C are taken as causing animals to be cold acclimatised or hot acclimatised respectively. There is no physiological basis for this however the rarity of wet bulb temperatures outside that range prevents it being a problem anyway. The calibration of acclimatisation within the range between 5°C and 25°C wet bulb is based on Voyages 3 and 4 of the SBMR.002 cattle ship ventilation project. Voyage 3 left from Townsville with Bos indicus weighing around 420 kg and acclimatised to around 12°C wet bulb. Voyage 4 left from Darwin with apparently similar animals also weighing around 420 kg but acclimatised to 23°C wet bulb. The difference in response between these two groups is the basis for the acclimatisation factor as plotted in Figure 4.9. The break points of the plotted curve are also in Table 4.3.

Figure 4.9. Variation of acclimatisation factor with acclimatising wet bulb temperature.

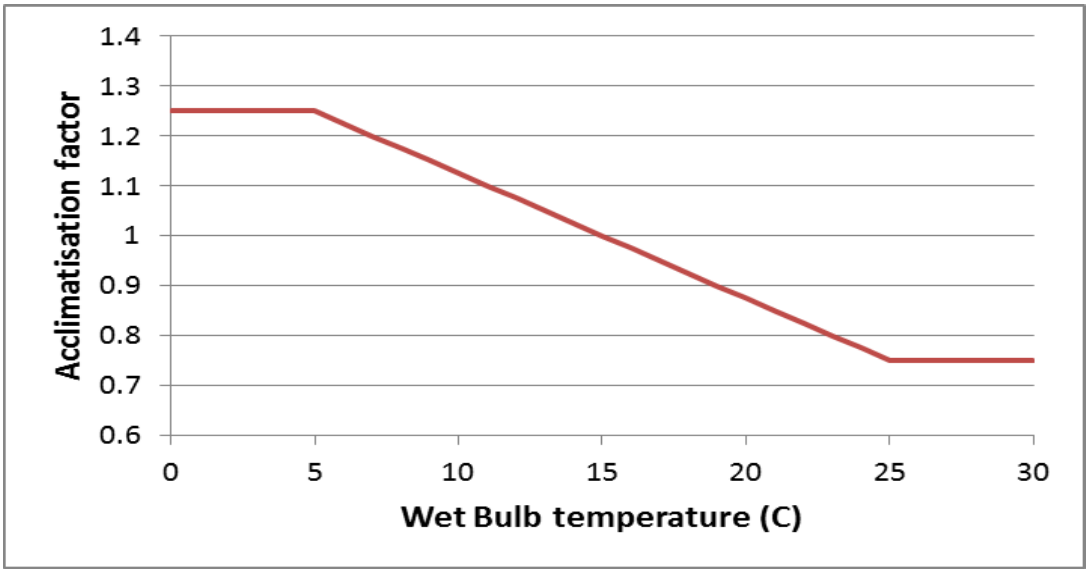


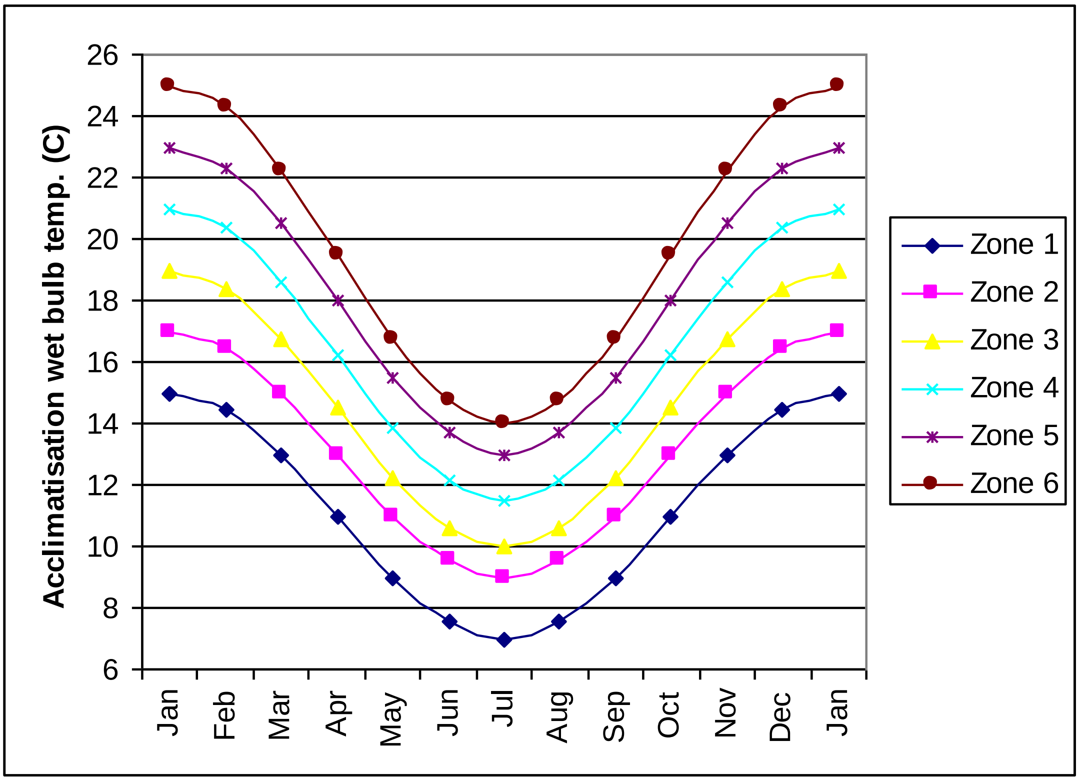
Table 4.2 gives the adopted wet bulb temperatures for acclimatisation for each month and zone. The same data are shown graphically in Figure 4.10.

The monthly wet bulb temperatures for acclimatisation are taken as applying to the 15th of each month, with the wet bulb temperature applicable to the departure date being linearly interpolated between the adjacent 15ths.

Table 4.2. Acclimatisation Wet Bulb Temperatures by Zone and Month.

	ZONE					
	1	**2**	**3**	**4**	**5**	**6**
Jan	**15**	**17**	**19**	**21**	**23**	**25**
Feb	14.5	16.5	18.4	20.4	22.3	24.3
Mar	13	15	16.8	18.6	20.5	22.3
Apr	11	13	14.5	16.3	18	19.5
May	9	11	12.3	13.9	15.5	16.8
Jun	7.54	9.54	10.6	12.1	13.7	14.7
Jul	**7**	**9**	**10**	**11.5**	**13**	**14**
Aug	7.54	9.54	10.6	12.1	13.7	14.7
Sep	9	11	12.3	13.9	15.5	16.8
Oct	11	13	14.5	16.3	18	19.5
Nov	13	15	16.8	18.6	20.5	22.3
Dec	14.5	16.5	18.4	20.4	22.3	24.3

Figure 4.10. Acclimatisation Wet Bulb Temperatures by Zone and Month



4.2.3 Scaling factor summary

The parameters used to establish the scaling, including condition and coat factors, are tabulated below.

Table 4.3. Scaling Factors

Factor		**Bos taurus**	**Bos indicus**	**Sheep**
Base Weight (kg)		300	300	40
Weight Index n		0.33	0.33	0.2
Core Temperature (˚C)		40	40	40
F Condition	Fat Score 0	9	9	9
	Fat Score 1	0.9	0.9	0.9
	Fat Score 2	0.95	0.95	0.95
	Fat Score 3	1	1	1
	Fat Score 4	1.1	1.1	1.1
	Fat Score 5	1.2	1.2	1.2
F Coat	Mid	1	-	-
	Summer (shiny)	0.93	-	-
	Winter (hairy)	1.1	-	-
	Normal	-	1	-
	Hairy (Awassi only)	-	-	1
	Mid (10 to 25mm)	-	-	1.08
	Shorn	-	-	1
	Woolly (over	-	-	1.12
F Acclimatisation	Hot Acclimatised	0.75	0.75	0.75
	Cold Acclimatised	1.25	1.25	1.25
	Slope	-0.025 (per degree)	-0.025 (per degree)	-0.025 (per degree)
T_{WB} Break	Hot Acclimatised	25	25	25
	Cold Acclimatised	5	5	5

5 Vessel parameters

5.1 Closed decks and PAT

The environmental parameters relevant to the animals are not the ambient conditions but the conditions in the pens. Following previous work (SBMR.002), the average rise in wet bulb temperature in closed decks between ambient and exhaust flows is given by:

$$\triangle Twb = 3.6 \times C \times M \times h / (\rho \times PAT)$$

where: $\triangle$Twb is the wet bulb temperature increase (°C)

C is the ‘constant’ of proportionality relating $\triangle$Twb to the internal energy rise. We have taken this as 0.23°C/(kJ/kg)

M is the liveweight in the particular ventilation zone (kg/m^2) (M = beast weight ÷ area per head) (275 kg/m^2 for cattle, 180 kg/m^2 for large sheep, etc.)

h is the ‘per mass’ rate of metabolic heat. This is variable however here we will take 2 W/kg for Bos indicus cattle, 2.4 W/kg for Bos taurus cattle and 3.2 W/kg for sheep.

ρ is the density of air (1.2 kg/m^3)

PAT, the pen air turnover in m/hr, is the ratio of the fresh air flowrate (Q) in m^3/hr to the pen area (A) in m^2

The factor 3.6 at the front corrects units from W to kW and hours to seconds.

Rearranging to do the reverse calculation for the PAT required to meet an allowable risk level and wet bulb temperature rise on open decks:

$$PAT = 3.6 \times C \times M \times h / (\rho \times \triangle Twb)$$

Alternatively, to find the stocking rate for a given PAT and allowable wet bulb temperature rise:

$$M = PAT \times \rho \times \triangle Twb / (3.6 \times C \times h)$$

5.2 Open decks

The wet bulb environment in open decks is determined by all the influences applying to closed decks, but is commonly dominated by the ambient wind flowing across the deck through the open sides. In still air, there is still a problem with reingestion of air from lower decks into the upper decks. Earlier work defined a reingestion fraction and Computational Fluid Dynamics (CFD) simulation was used to estimate relationships between prevailing crosswind and the resulting Pen Air Turnover (PAT) on open decks. The relationship between crosswind and PAT was expressed in two equations, one for high (cattle) decks and one for double-tier sheep decks. The equations have a form based on dimensional analysis and were then fitted to the CFD results. Assuming that the crosswind is sufficient to prevent reingestion on the upwind side, the equation for cattle decks is:

$PAT = (250/1.5) \times V \times (10H/W)^{1.5} – 234$, with the reverse to find required crosswind being:

$V = (PAT + 234) / (250/1.5) / (10H/W)^{1.5}$

where PAT is in m/hr, crosswind V is in m/s, deck height H and deck width W are in metres.

For double-tier sheep decks, the relevant equation is:

$PAT = (60/2) \times V \times ((24H)/(1.3W))^{1.5} + 10$ with the variables as above and the reverse as:

$V = (PAT - 10) / (60/2) / ((24H)/(1.3W))^{1.5}$

In still conditions when in port, air leaving the sides of a lower open deck will be partially reingested into those above. A reingestion fraction, R, was defined, which is the fraction of air arriving on a deck which was exhausted from the deck(s) below. CFD and scaling arguments presented in LIV.116 project arrived at an empirical equation for R, for a given mechanically supplied pen air turnover (MPAT), deck width and height:

$R = 0.405 – 0.000294(MPAT \times W/H)$ with a lower limit of zero.

To avoid the sudden change in behaviour when reingestion cuts in, and to implement the lower limit of zero, a combined limiting and smoothing function is applied in the software. It effectively limits R to values of zero or above and blends out the ‘corner’ where the function above meets R = 0. It is:

Smoothed $R = 0.25 \log_{10}(10{,}000^{R} + 1)$

Numbering the open decks from the lowest being 1, and assuming that all open decks have similar mechanical ventilation, the PAT in still air for the N^{th} open deck, PATN, is:

$PATN = PAT1 \times (1-R)/(1-R^{N})$

This is then used to estimate both the PAT due to natural convection and the resulting PAT with some mechanically supplied PAT (MPAT). The equations are:

Natural convection on cattle decks:

$PAT = 72(24/W)^{2/3}(H/2.4)(1-R)/(1-R^{N})$

Mechanical supply to cattle decks:

$PAT = MPAT \times (1-R)/(1-R^{N})$

Natural convection on double-tier sheep decks:

$PAT = 42(24/W)^{2/3}(H/1.3)(1-R)/(1-R^{N})$

Mechanical supply to double-tier sheep decks at low PAT:

Effective $PAT = (60.MPAT/110 + 18) \times (1-R)/(1-R^{N})$

The form of this equation is fine for very low PAT decks, but clearly, as the PAT figure gets very high, there is still a de-rating applied by the ratio 60/110. The problem of how to treat double-tier decks with very high PAT is a theoretical one, in that there are no such decks. Nevertheless, in the software, the equation for the effective PAT from mechanical supply to decks less than 1.6 m high is modified so that effective PAT rises at the same rate as mechanical PAT when PAT is high. The two terms are 'blended' by use of the exponents as below, such that one equation applies over all PAT:

$$\text{Effective PAT} = [(60 \times \text{MPAT}/110 + 18)^{10} + (\mathit{MAX}(0, \text{MPAT}-50))^{10}]^{0.1} \times (1-R)/(1-R^N)$$

The crosswind estimated as sufficient to prevent any reingestion on the upwind side of single-tier decks is:

$$V = 1.2((2.4W)/(24H))^{1.5} \text{ m/s}$$

The crosswind estimated as sufficient to prevent any reingestion on the upwind side of double-tier sheep decks is:

$$V = 1.2((1.3W)/(24H))^{1.5} \text{ m/s}$$

Because of the interest in the generation of PAT by crosswind on double-tier decks, the tables below give effective PAT as a function of crosswind and deck width. Each table is for a different deck height. In the tables, "R" means that the crosswind is insufficient to avoid reingestion.

Table 5.1. PAT on 1.20 m high double tier decks as a function of deck width and crosswind.

Crosswind		Deck Width (m)									
knots	m/s	20	22	24	26	28	30	32	34	36	38
0	0	R	R	R	R	R	R	R	R	R	R
1	0.514	R	R	R	R	R	R	R	R	R	R
2	1.029	R	R	R	R	R	R	R	R	R	R
3	1.543	64	57	51	46	R	R	R	R	R	R
4	2.058	82	72	65	59	53	49	R	R	R	R
5	2.572	100	88	78	71	64	59	54	51	47	R
6	3.087	118	104	92	83	75	69	63	59	55	51
7	3.601	136	119	106	95	86	79	72	67	62	58
8	4.116	154	135	119	107	97	88	81	75	70	65
9	4.630	172	150	133	119	108	98	90	83	77	72
10	5.144	190	166	147	131	119	108	99	91	85	79

Table 5.2. PAT on 1.22 m high double tier decks as a function of deck width and crosswind.

Crosswind		Deck Width (m)									
knots	m/s	20	22	24	26	28	30	32	34	36	38
0	0	R	R	R	R	R	R	R	R	R	R
1	0.514	R	R	R	R	R	R	R	R	R	R
2	1.029	47	R	R	R	R	R	R	R	R	R
3	1.543	65	58	52	47	R	R	R	R	R	R
4	2.058	84	74	66	60	55	50	46	R	R	R
5	2.572	102	90	80	72	66	60	56	52	48	R
6	3.087	121	106	94	85	77	70	65	60	56	52
7	3.601	139	122	108	97	88	80	74	68	63	59
8	4.116	158	138	122	110	99	90	83	77	71	66
9	4.630	176	154	136	122	110	100	92	85	79	73
10	5.144	194	170	150	134	121	110	101	93	86	80

Table 5.3. PAT on 1.30 m high double tier decks as a function of deck width and crosswind.

Crosswind		Deck Width (m)									
knots	m/s	20	22	24	26	28	30	32	34	36	38
0	0	R	R	R	R	R	R	R	R	R	R
1	0.514	R	R	R	R	R	R	R	R	R	R
2	1.029	51	R	R	R	R	R	R	R	R	R
3	1.543	71	63	56	51	47	R	R	R	R	R
4	2.058	91	80	72	65	59	54	50	47	R	R
5	2.572	111	98	87	78	71	65	60	56	52	49
6	3.087	132	116	103	92	83	76	70	65	60	56
7	3.601	152	133	118	106	96	87	80	74	69	64
8	4.116	172	151	133	119	108	98	90	83	77	72
9	4.630	193	168	149	133	120	109	100	92	86	80
10	5.144	213	186	164	147	132	120	110	102	94	87

Table 5.4. PAT on 1.40 m high double tier decks as a function of deck width and crosswind.

Crosswind		Deck Width (m)									
knots	m/s	20	22	24	26	28	30	32	34	36	38
0	0	R	R	R	R	R	R	R	R	R	R
1	0.514	R	R	R	R	R	R	R	R	R	R
2	1.029	55	49	R	R	R	R	R	R	R	R
3	1.543	78	69	62	56	51	47	R	R	R	R
4	2.058	101	89	79	71	65	59	55	51	48	R
5	2.572	123	108	96	86	78	72	66	61	57	53
6	3.087	146	128	113	102	92	84	77	71	66	62
7	3.601	169	148	131	117	106	96	88	82	76	71
8	4.116	191	167	148	132	119	109	100	92	85	79
9	4.630	214	187	165	148	133	121	111	102	94	88
10	5.144	237	207	182	163	147	133	122	112	104	97

6 Risk calculation

With the wet bulb temperature probability distribution calculated as above for each line of animal on each deck, the mortality statistics are estimated as follows.

6.1.1 Probability of 5% Mortality

The ‘expected mortality’, while being the usual statistical measure, is not necessarily the preferred measure for those seeking to judge acceptability of risk. The emphasis is normally on the likelihood of mortality exceeding a limiting level. The current reporting limits are 1% mortality for cattle and 2% for sheep. At these levels, it is difficult to verify from voyage reports, the importance of heat stress relative to other causes. It is preferable, for comparing future outcomes, to look at a higher mortality level with an appropriately lower likelihood (reduced probability). A 5% mortality figure has been chosen. At this level and above, if heat stress is not a major cause, the alternative explanation will be obvious (fire, sinking, etc.). We also note that adopting a probability measure at a higher mortality level does not imply acceptance of greater risk. A single voyage will have different probability of 1% and 5% mortalities, but both will be a snapshot of the same risk profile. We note that the adoption of risk standards is not the role of this report, neither do we comment on the variation of risk standard with mortality level.

The calculation of probability for a given mortality level in one stocking entry is more straightforward than the calculation of expected mortality. The drawback is that combined results, to give a voyage average across different lines, are not necessarily meaningful. Consequently, these figures are given only for each stocking entry and not for the voyage as a whole.

To find the probability of exceeding 5% mortality, the cumulative distribution of animal response is first used to find the wet bulb temperature corresponding to 5% mortality. This wet bulb temperature is then compared to the cumulative probability curve for wet bulb temperature on the particular deck to find the probability of wet bulb temperature exceeding the 5% mortality value. As before, the wet bulb probability on the deck is taken as the ambient wet bulb probability shifted along the wet bulb scale by the deck wet bulb temperature rise.

7 Method Enhancements in HotStuff 4.0 and later

7.1 Wet bulb temperature synthesis

Many of the Voluntary Observing Ships (VOS) observation records had no value entered for the wet bulb temperature. The wet bulb temperature is central to the HotStuff method and without a wet bulb value the records cannot be used. For the observations where no direct wet bulb temperature was recorded, wet bulb temperatures were synthesised, where possible, from the available dew point and relative humidity measurements. Lookup tables were generated using standard psychrometric equations to allow wet bulb values to be added to the database. The form of the equations used is given in "Environmental Engineering in South African Mines", published by the Mine Ventilation Society of South Africa, 1982.

Table 7.1. Numbers of observations with each of the psychrometric parameters.

Reading	Number of points with reading	Number of points without reading
Wet Bulb	176,300	229,573
Relative Humidity	210,244	195,629
Dew Point Temperature	2,905	402,968

The calculated wet bulbs were added as new parameters in the database, to allow later distinction between the three 'sources' of wet bulb values. In the subsequent analysis, recorded wet bulbs were used wherever available, with wet bulb calculated from dew point used as the second option, and wet bulb from relative humidity used if the other two were not available.