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The Effect of Heat Stress on Milk Production and the Profitability of Investing in a Permanent Shade Structure

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Abstract

This paper details an economic analysis of investment in a permanent shade structure to minimise milk production losses as a result of heat stress. Using data over a seven year period from a northern Victorian dairy farm, the analysis found that annual milk production loss, due to heat stress, varied from 240 litres to 415 litres per cow per year. This variation was due to the number and severity of days that exceeded the Temperature Humidity Index threshold. Three future climate scenarios were developed for the next 20 years and these generated differing milk production losses. Net present values from different scenarios over the 20 year period showed that the level of profitability of investing in a shade structure was determined by the severity of temperatures experienced, with more extreme heat events increasing the profitability of the investment. The milk price received by the farmer also determined the time it took for the investment to become profitable. The minimum price required after 20 years to return a NPV of $0, ranged from of 35.7 to 24.6 cents per litre over the three climate scenarios.

Key words: dairy industry, heat stress, shade structures, investment analysis

Introduction

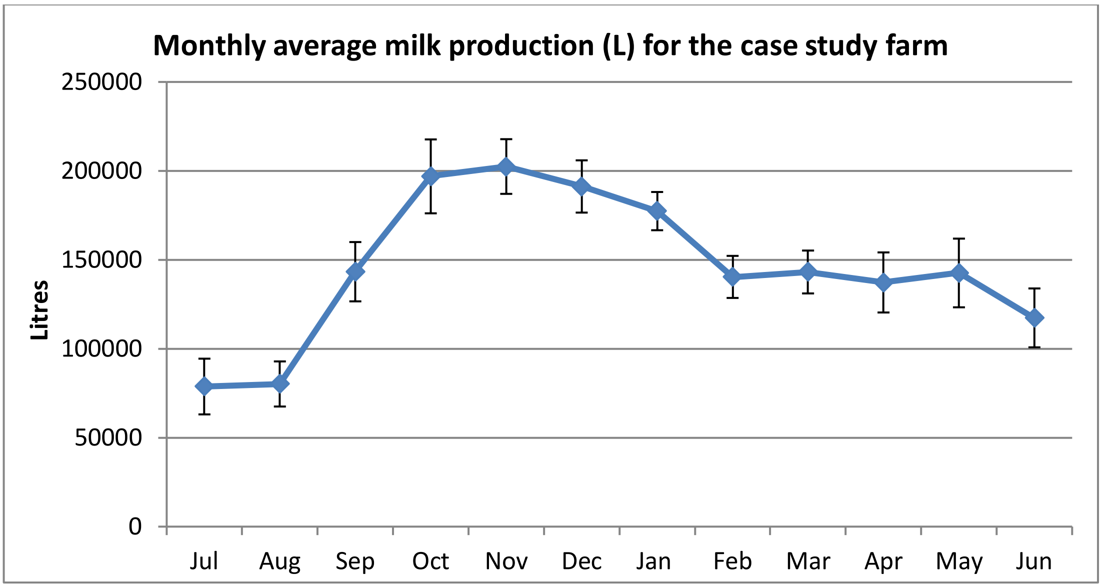
The Australian dairy industry contributes $13 billion to the Australian economy annually, with the Murray Dairy region contributing approximately $4.3 billion every year (MD, 2016). The dairy industry is a vital part of the Murray Dairy economy, which directly employs some 10,000 people in dairy farm and factory jobs (MD, 2016).

Globally, even more frequent and extreme hot weather is likely over the coming decades (IPCC, 2012). The IPCC also notes that Australia is likely to be particularly vulnerable. As a consequence, there is likely to be an increase in the incidence of heat stress on livestock in dairy production systems in Australia. Heat stress can decrease the milk yield of dairy cows by up to 50% in extreme cases (Dunshea et al., 2013). This loss of production is already costing Australian farmers a significant amount and will only get worse if predictions about the effects of climate change on southern Australia are accurate (Dunshea et al., 2013).

The Temperature Humidity Index (THI) is used as an indication of the degree of heat stress experienced by dairy cattle. The THI measures cattle body discomfort and the animals' progressive difficulty in cooling themselves as environmental temperature and/or relative humidity increases (Nidumolu et al., 2010; Sejian et al., 2015; Dunshea et al., 2013; Silanikove, 2000). A THI greater than 72 is considered mild heat stress, while at a THI greater than 78, cows experience moderate heat stress and markedly reduced milk production and other physiological effects are generally observed (Silanikove, 2000). When the THI rises above 82, very significant losses in milk production are likely; cows show signs of severe stress and are at risk of death (Dairy Australia, 2012a,c; Sejian et al., 2015).

A case study approach was used to investigate the cost of heat stress on milk production. The case study dairy farm was located in northern Victorian, near the town of Cohuna (35.8149° S, 144.2095° E). The operation involved a herd of 200 predominantly high production Holstein Fresians, averaging 8,000 litres per cow over a 300 day lactation. Production was at its lowest prior to calving in the winter and peaked in the spring (Figure 1). The summer months signalled a decreasing trend in litres produced. This was partly due to the stage of lactation being past peak production of the spring calving herd. However, production decreases were amplified due to extreme heat events during the warmer months.

Figure 1. Average monthly milk production on the case study dairy farm between 2009 and 2015
(bars are the standard deviation within each year)



To help dairy cows cope with hot weather, a simple and effective change is the construction of shaded areas under which cows can escape direct solar radiation. Being out of the sun significantly reduces the THI and heat stress experienced by the cow (Nidumolu et al., 2010).

The heat stress management strategies of the case study farm included keeping the herd in paddocks where shade from trees was available, allowing the herd to move into tree shaded laneways and moving the herd under water sprinklers in the milking shed yard. These strategies were implemented in response to weather forecasts and monitoring of animal health. There was no permanent shade structure.

The purpose of this analysis was to establish the milk production losses associated with heat stress on the case study farm and to assess whether a permanent shade structure would be a profitable investment.

Method

Meteorological data

Historic daily maximum temperature (°C) and daily dew point temperature (°C) data from the Kerang weather station (approximately 20 Km from the farm) dating back to 2000, was purchased from the Bureau of Meteorology (BOM, 2015b). This data was essential for calculating the Temperature Humidity Index (THI). As reported by Dairy Australia (2012c), Mayer et al. (1999) and Nidumolu et al. (2010) the formula to calculate THI is:

Temperature Humidity Index = temperature (°C) + 0.36 dew-point temperature (°C) + 41.2

THI based on the maximum daily temperature and the same day dew-point temperature recorded at 15:00 was used because this combination of daily recordings (dew-point temperature in Australia is only recorded at 9:00 and 15:00 daily) is a better predictor of production losses when compared to daily average temperature alone or any other combination (Mayer et al., 1999).

Production data

Production data from the case study farm was available from 2009 – 2015. The data were the total number of litres per milk tanker pick-up from the farm gate. Pick-up frequency varied between daily and every two days based on the time of the year. On average, the managers received 45 cents per litre of milk produced over the six year period.

Estimating production losses

To evaluate the effects of the frequency, intensity and duration of heat stress days on the case study farm, the susceptibility of the herd to heat stress was established. The impact of THI on dairy herd milk production was calculated using conversion factors for cows with different susceptibility to heat stress (Little and Campbell, 2008):

- Low susceptibility cows (i.e. a Brown Swiss Jersey producing less than 5,500 L of milk per year),
- Moderately susceptible cows (i.e. another European breed or cross breed producing 5,500 L to 8,000 L of milk per year),
- Highly susceptible cows (i.e. a large Holstein Friesian producing more than 8,000 L of milk per year).

Milk production losses were assumed to occur when daily THI values exceeded 75 (Nidumolu et al., 2010). When THI exceeded this threshold the amount of milk not produced due to heat stress, in litres per cow per day, was calculated by subtracting 75 from the daily THI value. The difference between the two values yielded a severity index. The severity index was then multiplied by Nidumolu et al.'s (2010) scaling factor to determine the susceptibility of the herd to heat stress. The cows on this farm were large Holstein Friesians so the scaling factor is 1 for these highly susceptible cows (Nidumolu et al., 2010).

For example, in 2009 the total amount of severity index points in Cohuna for the year was 507.8. Therefore:

Baseline production loss litres/cow/year = 507.8 x 1 (highly susceptible),
Baseline production loss litres/farm/year = 507.8 x 200 cows,
Baseline production loss for case study dairy in 2009 = 101,566 L.

Estimating the effectiveness of a shade structure

The baseline production losses assume that the herd was left in an open paddock during heat stress periods. Therefore, any benefit from the use of heat stress management techniques could be measured as a production gain.
Nidumolu et al. (2010) found that in northern Victoria, providing water spray through sprinklers during hot days decreased production losses by 21% and a shade structure with a concrete floor and high, well ventilated roof, decreased milk production losses by 72%. The case study farm used sprinklers as a major heat stress management tool but did not have a permanent shade structure. Therefore, this analysis assumed that of the total baseline production losses predicted by the severity index, only 21% was reduced by the sprinklers. The remaining loss was taken to be the farm production losses per year due to heat stress.

Using the same year 2009 data from the case study farm as above:
Baseline production loss litres/farm/year = 507.8 x 200 = 101,566 L,
Current farm production loss litres/farm/year = 101,566 – (0.21 x 101,566) = 80,237 L,
Estimated production gains from shade structure litres/farm/ year = 0.72 x 80,237 = 57,771 L.

Economic analysis

The profitability of building a permanent shade structure was measured using the Present Value (PV) of the benefits and costs involved to calculate the Net Present Value (NPV) over 5, 10 and 20 year periods. The PV and NPV were calculated using a 10% discount rate[1]. If the NPV is positive the shade structure is a sound investment. An Internal Rate of Return (IRR) was also calculated to determine the interest rate at which the NPV from the investment would equal zero. If the IRR is greater than the assumed 10% rate, then the shade structure is a sound investment.

As the effectiveness of the shade structure will be determined based on the level of hot days experienced, three future climate scenarios in Cohuna over a ten year period were modelled for the analysis: no change, nine additional days of heat stress (Moderate Change) and 17 additional days of heat stress (High Change) in conjunction with two different milk prices and shade structure sizes.

Results and Discussion

Climate risk and current production cost

Due to the location of the case study farm, in northern Victoria, the warmer months of the year are associated with a large risk of heat stress compared to other Victorian dairy regions. A temperature anomaly is the departure from the long-period average value for a particular location using the

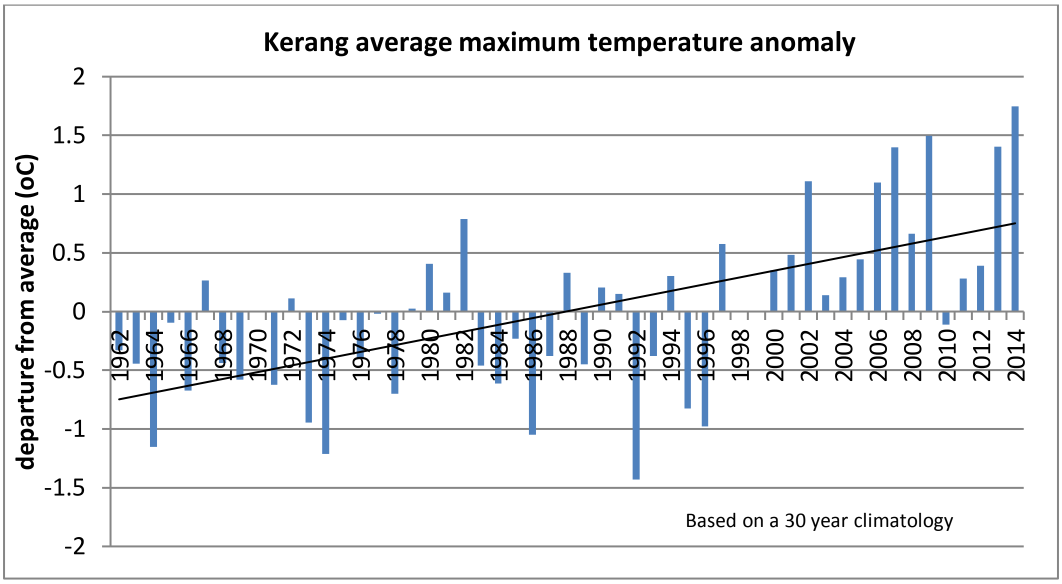
[1] The referee suggested that this rate was high given the current interest rate environment. This is correct if the discount rate is interpreted as the return the required capital could achieve if it had been invested in some alternative use. Such deposit rates are currently low. However if the structure had to be financed from borrowings, such rates are currently around 7.5% for agribusiness development loans and likely to increase in the future. Given the 20-year time horizon of the analysis, and the uncertainty around many of the assumptions, the authors chose to impose a relatively high discount rate.

international standard of a 30 year average as the long-term average (BOM, 2015a). Figure 2 highlights the warming trend of average annual maximum temperatures close to Cohuna.

Milk production losses are assumed when a daily Temperature Humidity Index (THI) rises above 75 (Nidumolu et al., 2010). To examine this assumption, milk production litres from the case study farm were plotted on the same time series as the daily number of THI points above 75, for two particular summer months in 2015.

Figures 3 and 4 demonstrate that the hypothesised relationship between milk production loss and high THI proposed by Nidumolu et al. (2010) is exhibited at the case study farm, where over periods of heat waves and high THI, milk production falls[2].

Figure 2. Departure from long term average maximum temperature per year in Kerang, 20 km from Cohuna (Source: BOM Climate Data)



The 2009-2015 meteorological data from the BoM weather station closest to Cohuna was compiled into the form of daily THI. Once the daily THI was established, the heat stress severity index (total number of THI points over 75) could be determined by subtracting 75 from the daily THI. Therefore,

[2] The referee asked whether the data set could be expanded over several years and a regression equation developed between milk production and the severity index, and perhaps including lagged production. This is a good idea but impractical given the data available. As milk production decreases over summer with stage of lactation, the milk production data moves from once a day tanker pick up to every two days. With less milk in the vat on the farm, the tanker only needs to come half as often. Data from pick ups every second day are not valid when considering heat effects as the recorded pick up is a combined production from two days of different THI's. For example, December in 2012-15 had daily pick ups on the case study farm, but December in 2009-2011 was every second day. This problem in the data occurs in most of the summer months. December 2015 and January 2015 were chosen for the graphs shown in Figures 3 and 4 due to the daily pick up data.

The daily THI was graphed against corresponding litres produced for the month of December for those years (2012-2015) when there was daily pick up (Appendix 1A). There is no trend, partly because production is in decline already due to the stage of lactation, and partly because of the lag of a few days before production picks up again after a heat wave when THI drops back under 70. If the THI is lagged by three days (Appendix 1B) there is a bit more shape, but the R^2 is still only 0.03.

if the daily THI was 78, the severity index was 3, and if the daily THI was less than 75 the severity index was 0. The yearly sum of all the daily severity indexes was then able to be calculated. According to the susceptibility of the herd, the yearly severity index was then multiplied by 1 and then multiplied by the number of cows in the herd for the corresponding year (Table 1).

Figure 3. Milk production (L) (blue) and daily severity index (Temperature Humidity Index points above 75) (red) recorded at the case study farm in January 2015 (Source: BOM Climate Data)

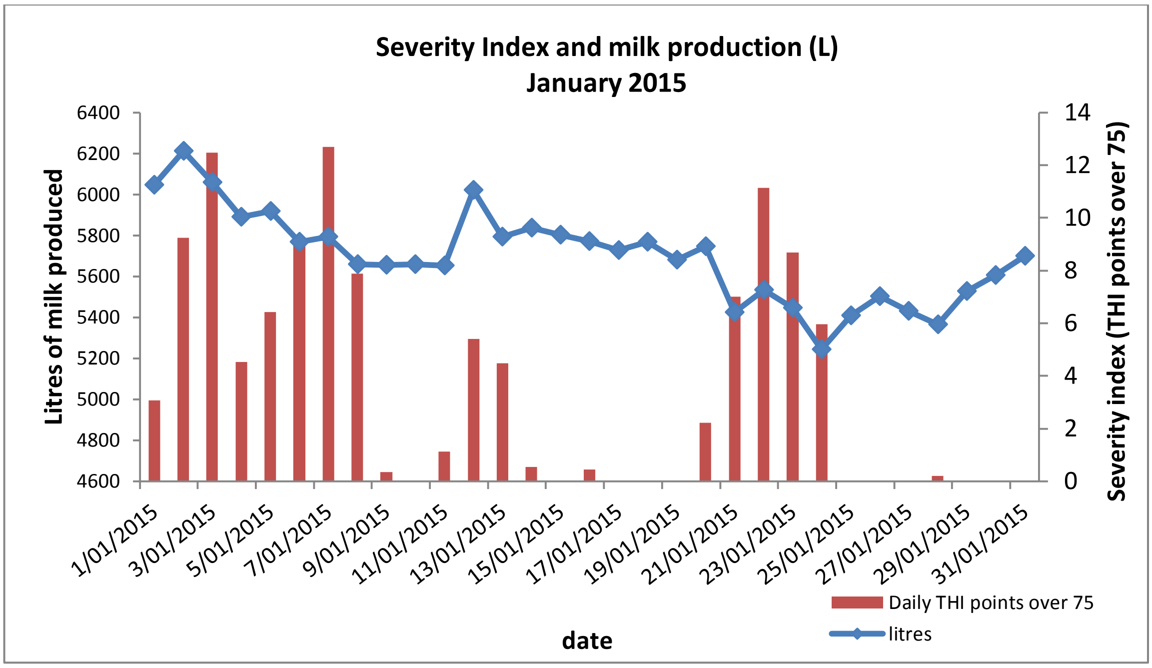


Figure 4. Milk production (L) (blue) and daily severity index (Temperature Humidity Index points above 75) (red) recorded at the case study farm in December 2015 (Source: BOM Climate Data)

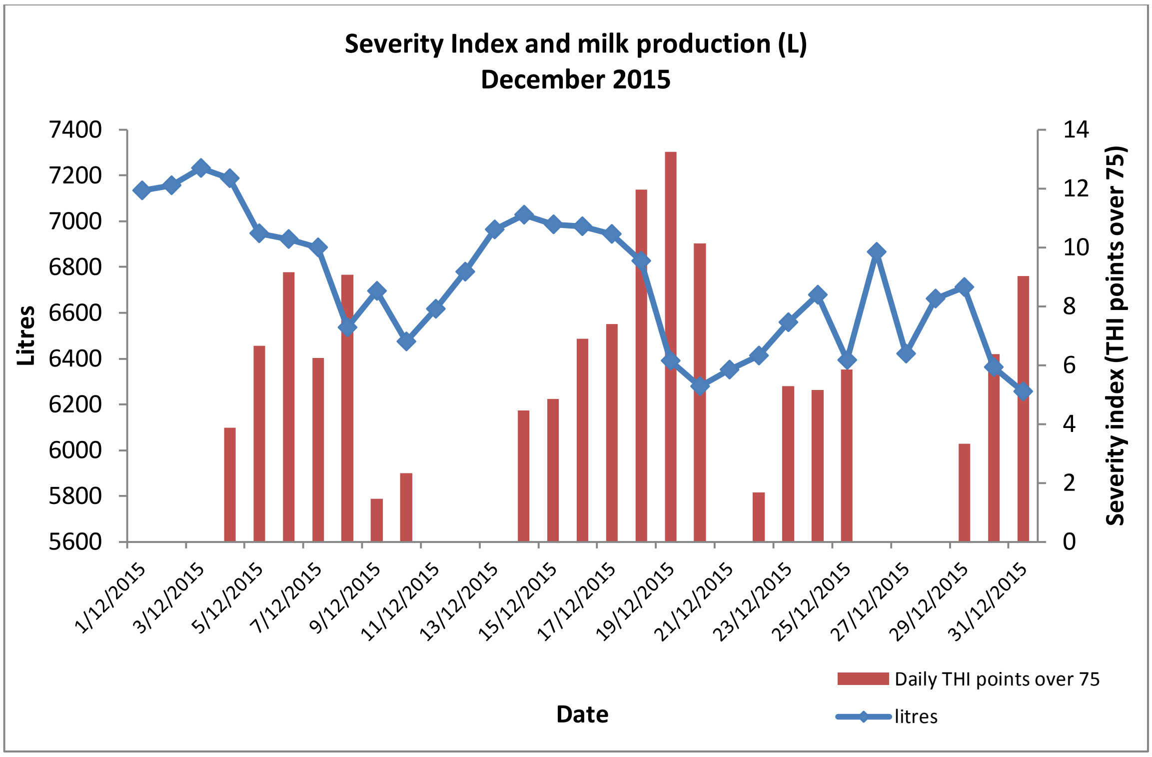


Table 1. Case study farm production data, susceptibility factors and heat stress production losses

Year	Annual litres produced	Number of cows milked	Litres produced/ cow/year	Suscep-tibility	Severity index (total annual points over 75 THI)	Baseline litres loss/year due to heat stress L/farm/year	Farm heat stress production losses, less the effect of sprinklers L/Farm/year
2009	1904931	200	9525	High	508	101566	80238
2010	1578821	200	7894	High	382	76393	60350
2011	1527892	200	7639	High	304	60808	48038
2012	1731442	200	8657	High	354	70786	55921
2013	1730909	200	8655	High	453	90654	71617
2014	1867514	200	9338	High	525	104917	82884
2015	1916390	200	9582	High	503	100653	79516

After establishing a baseline production loss, the current heat stress management strategy was taken into account to determine that the current production losses for the farm were 21% less than the baseline due to the use of sprinklers. This production loss is the estimated production cost of heat stress on the case study farm.

Table 2 details the production cost in litres and in dollars. Lost production due to heat stress in 2015 cost the farm $35 782 or approximately 398 litres per cow. Production losses ranged from 240 to 414 litres per cow, which at the average historical price of 45c/L resulted in financial losses for the farm of between $25,164 and $37,298 per year.

Table 2. Current loss of milk production and income due to heat stress on the case study farm

Year	Severity index (total annual points over 75 THI)	Current heat stress production loss (L)/ cow/year (Accounting for existing heat management)	Current heat stress production loss (L)/farm/year (Accounting for existing heat management)	Heat stress income losses ($)/farm/year*
2009	508	401	80237	-$36,106.86
2010	382	302	60350	-$27,157.64
2011	304	240	48038	-$21,617.24
2012	354	280	55921	-$25,164.28
2013	453	358	71617	-$32,227.50
2014	525	414	82884	-$37,297.92
2015	503	398	79516	-$35,782.21

*based on 45 c/L

While Table 2 highlights the substantial losses being currently experienced by the case study farm, the estimated losses are only that of lost milk income. If other symptoms of heat stress such as reduced in-calf rates, low milk protein and fat tests, liveweight loss, higher somatic cell counts, more clinical mastitis cases and reduced pasture growth are taken into account, the estimated income loss can often be doubled (DA, 2012a).

Effectiveness of a shade structure on current losses

Once the milk production and income losses due to heat stress were calculated for the case study farm, it was then possible to estimate how much of these losses could be avoided with a shade structure. A shade structure with a concrete floor and high, well ventilated roof, is estimated to reduce milk production losses by 72% (Nidumolu et al., 2010). Therefore, 72% of the current farm heat stress production loss is potentially reduced by a shade structure (Table 3).

The litres saved by a shade structure can be calculated on a daily basis and added to the actual litres produced for the corresponding day. This provides an indication of the total litres produced by the herd, and the corresponding increase in income, with the addition of a shade structure.

Table 3. Calculating the benefit in litres and income from a shade structure based on past temperature and production data

Year	Severity index (total annual points over 75 THI)	Baseline Litres lost/year due to heat stress L/farm/year	Current heat stress production losses (21% x Baseline) L/Farm/year	Heat stress litres saved with shed (72% x current production losses) L/farm/year	Income benefit of shed* ($)/farm/year
2009	508	-101566	-80237	57771	$25,997
2010	382	-76393	-60350	43452	$19,554
2011	304	-60808	-48038	34588	$15,564
2012	354	-70786	-55921	40263	$18,118
2013	453	-90654	-71617	51564	$23,204
2014	525	-104917	-82884	59677	$26,855
2015	503	-100653	-79516	57252	$25,763

*based on 45 c/L

Figure 5 plots actual litres, estimated litres with a shade structure and the severity index all on the same timeline. When the severity index increases, so does the estimated litres with shade. This rise and fall in production is accentuated because the calculated production losses only include the production lost *during* a heat stress event. It does not include lower production in the recovery time after a heat stress event.

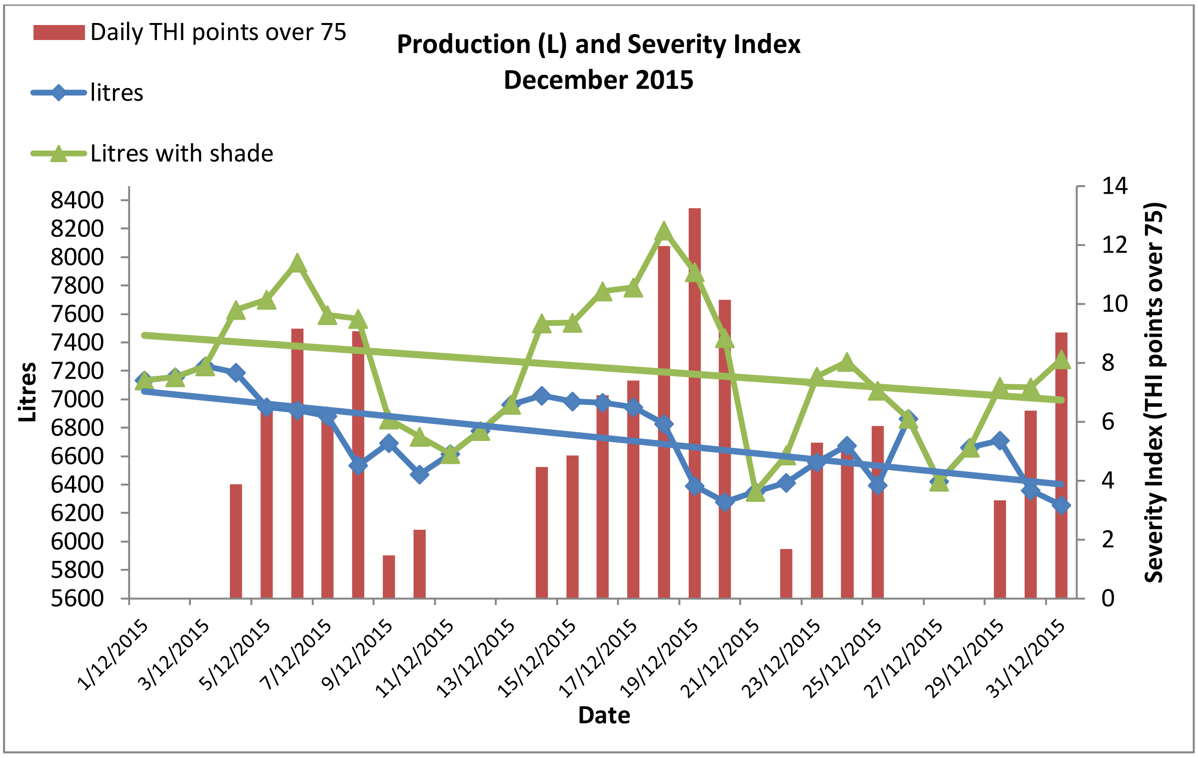
Therefore, litres with shade (green points) drops back to the actual litres (blue points) when the severity index is zero. The trend line slopes are driven predominantly by lactation stage but the distance between each trend line is the benefit given from a shade structure.

The above method of calculating the benefit of a shade structure in previous years on the case study farm can now be applied to three future Cohuna climate scenarios to determine the profitability of investing in a shade structure.

Different climate scenarios

With very high confidence under future climate scenarios, there will be increases in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells in the Murray Darling Basin (CCIA, 2015). For Cohuna and the Murray Dairy region, this amounts to increases in heat stress days across the region. Compared to the 1971 -2000 average, and based on the CSIRO Mk 3.5 model, 2025 is predicted to have an additional 5 days of heat stress for both the 75–78 THI range and 78–82 THI range, while it is expected to have an additional 5 to 10 days for the THI range >82 (Nidumolu et al., 2010; Nidumolu et al., 2014).

Figure 5. Actual milk production (blue), estimated milk production with a shade structure (green) and daily Severity Index (Temperature Humidity Index points above 75) (red) recorded at the case study farm in December 2015 (Source: BOM Climate Data)



Daily THI values were analysed over the 15 year period between 2000 and 2015 in Cohuna. The total number of heat stress days per year were added up, along with the total severity index points for each year in an attempt to set a baseline severity index (Table 4). According to Nidumolu et al. (2010) and Nidumolu et al. (2014), between 1971 -2000 Moama (75Km from Cohuna) had, an average of: 27 days in the 75–78 THI range; 26 days in 78–82 THI range; and 21 days in with the THI range >82. This is an annual average of 74 days above 75 THI in the 30 years between 1971 -2000.

More recently, as shown in Table 4, the observed and average amount of days in Cohuna that experienced the same thresholds from 2000 – 2015 are : 29 days in the 75–78 THI range; 28 days in 78–82 THI range; and 19 days in with the THI range >82. This is an annual average of 76 days above 75 THI in the last 15 years.

So from the observed changes in Cohuna over the last 15 years there has been a two day increase in the 75-78 and 78-82 THI ranges, compared with the 1971-2000 Moama averages, and a 2 day decrease in the 82<THI range.

Table 4. For the year 2000-2015, Total number of days that reach different THI thresholds per year, total number of days over 75 per year and the sum of Severity Index points (the total number of points over 75 per year)

Year	Number of days 75 -78 THI	Number of days 78 – 82 THI	Number days over 82 THI	Total days over 75 THI	Severity index (sum of total points over 75 THI/year)
2000	22	28	20	70	361
2001	22	32	14	68	343
2002	26	24	12	62	236
2003	29	32	11	72	295
2004	30	16	15	61	259
2005	27	21	13	61	271
2006	36	27	17	80	372
2007	28	28	25	81	409
2008	24	26	17	67	321
2009	29	26	33	88	508
2010	37	28	18	83	382
2011	30	28	15	73	304
2012	32	33	15	80	354
2013	31	30	28	89	453
2014	35	35	27	97	525
2015	29	38	29	96	503
2000-2015 Average	**29**	**28**	**20**	**77**	**369**

From the above predictions and observations, the following analysis will assume that for the next 10 years there could be three future climate scenarios:

1) No change: the severity index will remain the same as the average severity index calculated in Cohuna from 2000-2015. This produces an average severity index of 368 (Table 4).
2) Moderate change: an increase of three days in each of the three levels of THI from the 2000-2015 Cohuna averages. This produces an average severity index of 419 (increase of 51 on the 2000-2015 Cohuna averages) (Appendix 2).
3) High change: an increase of five days in the 75–78 THI range, an increase of five days in the 78–82 THI range and an increase of seven days in the THI range >82 from the 2000-2015 averages. This produces an average severity index of 475 (increase of 107 on the 2000-2015 Cohuna averages) (Appendix 2).

A year-by-year summary of each climate scenario impact is presented in Appendix 3.

Cost of shade structure

The structure is assumed to be built for a herd of 200 cows. However a farmer may well build a larger shed to allow for an increased capacity in the future.

A quote for an appropriate shade shed was provided by a local engineering company (www.swanhillengineering.com.au). The company had built several large scale shade structures in the area for the purpose of cooling dairy herds. The structures were built with either a concrete or an organic floor. They have a gabled roof with a ridge gap at the peak that runs the length of the roof. This acts as an exhaust, encouraging more airflow through the shed. According to this company, their structures are built to allow 10 m^2 of shade per cow. This is more than double the Dairy Australia (2012b) recommended amount of 2.5 – 3m^2 shade/cow, but is in line with the observations by Fisher et al. (2008) of cow preferences for larger (9.6 m^2) communal shaded areas.

At \$85/m^2, the cost of a shade structure at the company's recommended size for the case study herd of 200 will cost \$170,000. This analysis will also investigate for the benefits of 8m^2 shade/cow, which is less than the amount of shading the manufacturer suggests but double Dairy Australia's recommendations, at a cost of \$136,000. Once the structure is built, with no utilities attached, the on-going costs will include labour for the cleaning of the shed and any required maintenance. It is assumed that these costs total \$500/year.

Economic analysis of the shade structure

Analyses were conducted for each of the three climate scenarios described above. Further, the price received per litre of milk and the size of the shade structure were varied in the three climate scenarios. An additional scenario of the recovered milk income and avoided animal health problems were also included in the profitability analysis. The results are as follows.

a) Additional milk income only, 200 cows, 45 c/L, 10 m^2 shade/ cow

From Table 5, if milk prices remain the same as the historical average, then the upfront cost of constructing a shade structure is not matched by the benefits to milk production in any of the climate scenarios over 5 and 10-year time horizons. In each scenario, the net benefits of additional milk production from the shade structure returns a negative present value after 5 and 10 years. IRR in all climate scenarios at 5 and 10 years remained under 10%.

It is only over a 20-year time horizon that NPVs become positive and IRRs approach or exceed the threshold value of 10%. A general pattern, as expected, is that the benefits are greater as the climate change scenarios become more severe.

Table 5. The NPV from investing in a shade structure in three climate scenarios over 20 years when 200 cows are milked and receive 45 c/L, at a discount rate of 10%. The shade structure is built allowing 10m^2 shade/cow with a cost of $170,000

	Climate Scenario		
	No Change	Moderate	High
Assumptions			
Milk price (c/L)	45	45	45
Discount rate	10%	10%	10%
Number of cows	200	200	200
Allowed shaded area under shed per cow (m^2)	10		
Present value of shade benefit			
Additional milk income (5 years)	**$71,413**	**$81,690**	**$91,455**
Additional milk income (10 years)	**$115,755**	**$131,910**	**$149,243**
Additional milk income (20 years)	**$160,384**	**$195,331**	**$232,802**
Present value of shade costs			
Project costs (5 years)	**$156,269**	**$156,269**	**$156,269**
Project costs (10 years)	**$157,338**	**$157,338**	**$157,338**
Project costs (20 years)	**$158,415**	**$158,415**	**$158,415**
Net benefits (only additional milk income)			
5 years	**-$84,855**	**-$74,578**	**-$64,813**
10 years	**-$41,583**	**-$25,428**	**-$8,095**
20 years	**$1,969**	**$36,916**	**$74,387**
Internal Rate of Return (milk income only)			
5 years	**-18%**	**-15%**	**-12%**
10 years	**1%**	**4%**	**7%**
20 years	**9%**	**12%**	**14%**

b) Additional milk income only, 200 cows, 55 c/L, 10 m^2 shade/ cow

From Table 6, if milk prices rise to 55 c/L, then the NPV for a shade structure returns a positive value after 10 years in the moderate and high climate change scenarios. However, the positive NPV in the moderate scenario is quite small ($3 885), so still a risk in terms of investment. This is also reflected in the moderate IRR of 8%. The NPV in the high change scenario is a larger positive value ($25 070) with an IRR of 11%, suggesting that in these circumstances the shade structure would be an attractive investment for the case study farm based on additional milk income alone. After 20 years the investment becomes unambiguously profitable in all three climate scenarios.

Table 6. The NPV from investing in a shade structure in three climate scenarios over 20 years when 200 cows are milked and receive 55 c/L, at a discount rate of 10%. The shade structure is built allowing 10m^2 shade/cow with a cost of $170,000

	Climate Scenario		
	No Change	Moderate	High
Assumptions			
Milk price (c/L)	55	55	55
Discount rate	10%	10%	10%
Number of cows	200	200	200
Allowed shaded area under shed per cow (m^2)	10		
Present value of shade benefit			
Additional milk income (5 years)	**$87,283**	**$99,844**	**$111,779**
Additional milk income (10 years)	**$141,479**	**$161,224**	**$182,408**
Additional milk income (20 years)	**$196,025**	**$238,738**	**$284,536**
Present value of shade costs			
Project costs (5 years)	**$156,269**	**$156,269**	**$156,269**
Project costs (10 years)	**$157,338**	**$157,338**	**$157,338**
Project costs (20 years)	**$158,415**	**$158,415**	**$158,415**
Net benefits (only additional milk income)			
5 years	**-$68,986**	**-$56,425**	**-$44,490**
10 years	**-$15,860**	**$3,885**	**$25,070**
20 years	**$37,610**	**$80,323**	**$126,120**
Internal Rate of Return (milk income only)			
5 years	**-12%**	**-9%**	**-6%**
10 years	**5%**	**8%**	**11%**
20 years	**12%**	**15%**	**18%**

c) Additional milk income only, 200 cows, 45 c/L, 8m^2 shade/ cow

In Table 7, milk prices and herd size remain at 45 c/L and 200 respectively, while the size of the shade structure was reduced to 8m^2 shade/cow, with a subsequent reduction in capital cost to $136,000. This change in capital cost meant the NPV for both the moderate and high climate change scenarios returned positive figures at 10 years. However, similar to analysis b) only after 10 years does the shade structure become an attractive investment based on additional milk income alone. After 20 years the investment becomes profitable in all three climate scenarios.

Table 7. The NPV from investing in a shade structure in three climate scenarios over 20 years when 200 cows are milked and receive 45 c/L, at a discount rate of 10%. The shade structure is built allowing 8m^2 shade/cow with a cost of $136 000

	Climate Scenario		
	No Change	Moderate	High
Assumptions			
Milk price (c/L)	45	45	45
Discount rate	10%	10%	10%
Number of cows	200	200	200
Allowed shaded area under shed per cow (m2)	8		
Present value of shade benefit			
Additional milk income (5 years)	**$71,413**	**$81,690**	**$91,455**
Additional milk income (10 years)	**$115,755**	**$131,910**	**$149,243**
Additional milk income (20 years)	**$160,384**	**$195,331**	**$232,802**
Present value of shade costs			
Project costs (5 years)	**$125,359**	**$125,359**	**$125,359**
Project costs (10 years)	**$126,429**	**$126,429**	**$126,429**
Project costs (20 years)	**$127,506**	**$127,506**	**$127,506**
Net benefits (only additional milk income)			
5 years	**-$53,946**	**-$43,669**	**-$33,904**
10 years	**-$10,674**	**$5,481**	**$22,814**
20 years	**$32,878**	**$67,825**	**$105,296**
Internal Rate of Return (milk income only)			
5 years	**-12%**	**-9%**	**-5%**
10 years	**6%**	**9%**	**12%**
20 years	**12%**	**15%**	**18%**

d) All benefits counted, 200 cows, 45 c/L, 8m^2 shade/ cow

In Table 8, additional milk income from the shade structure is calculated and combined with the added benefit of the reduction of other animal health costs. These arise from heat stress (reduced in-calf rates, low milk protein and fat tests, live weight loss, higher somatic cell counts, more clinical mastitis cases) which Dairy Australia (2012a) estimate could be **as much as** the additional milk income from a shade structure. As a more conservative estimate this analysis will assume additional benefits from the shade structure to be 50% that of additional milk income. All NPVs are positive and all IRRs exceed 10% after 10 years when these additional animal health benefits are added to the additional milk income NPVs. Across all climate scenarios, 10 year NPVs are at least $47,000. A high change climate scenario NPV is $11,000, after 5 years. This analysis would suggest that more work needs to be done to estimate more accurately the costs of heat stress to animal health and therefore the additional benefit of a shade structure for the farm business.

Table 8. The NPV and IRR from investing in a shade structure in three climate scenarios over 10 years when 200 cows are milked and receive 45 c/L, at a discount rate of 10%, including estimates to the additional benefits to animal health (50% of additional milk income)

	Climate Scenario		
	No Change	Moderate	High
Assumptions			
Milk price (c/L)	45	45	45
Discount rate	10%	10%	10%
Number of cows	200	200	200
Allowed shaded area under shed per cow (m^2)	8		
Present value of shade benefit			
Additional milk income (5 years)	**$71,413**	**$81,690**	**$91,455**
Better animal health (5 years)	**$35,707**	**$40,845**	**$45,728**
Additional milk income (10 years)	**$115,755**	**$131,910**	**$149,243**
Better animal health (10 years)	**$57,878**	**$65,955**	**$74,622**
Additional milk income (20 years)	**$160,384**	**$195,331**	**$232,802**
Better animal health (20 years)	**$80,192**	**$97,666**	**$116,401**
Present value of shade costs			
Project costs (5 years)	**$125,359**	**$125,359**	**$125,359**
Project costs (10 years)	**$126,429**	**$126,429**	**$126,429**
Project costs (20 years)	**$127,506**	**$127,506**	**$127,506**
Net benefits (all benefits counted)			
5 years	**-$18,239**	**-$2,824**	**$11,823**
10 years	**$47,204**	**$71,436**	**$97,435**
20 years	**$113,070**	**$165,491**	**$221,697**
Internal Rate of Return (all benefits counted)			
5 years	**0%**	**5%**	**10%**
10 years	**15%**	**19%**	**23%**
20 years	**20%**	**24%**	**27%**

Sensitivity testing

To establish the minimum requirements needed to invest, a number of key variables were tested to find the point that net present values equal $0 over the three climate scenarios and three different time frames. A NPV of $0 represents the tipping point for the investment, if the variable in question becomes larger or smaller the investment will then either become profitable or unprofitable at a given target rate of return.

Table 9 highlights that the milk price and the amount of extreme heat experienced are the variables that most determine how long before a shade structure investment becomes profitable. A milk price of 35.77 c/L is required to return a $0 NPV over 20 years when the 'no change' scenario is assumed. In contrast, a milk price of 24.63 c/L is required to return a $0 NPV when the 'high change' scenario is assumed.

Table 9. The milk prices needed to return a NPV of $0 after 5, 10 and 20 years assuming a discount rate of 10%, 72% shed effectiveness and 8 m^2 shaded area allowed per cow

Assumptions

Discount rate	10%
Allowed shaded area under shed per cow (m^2)	8
Shed effectiveness	72%

	Climate Scenario		
Net benefits (only additional milk income)	No Change	Moderate	High
Milk price (c/L)	78.99	69.37	61.19
NPV 5 years	**$0**	**$0**	**$0**
Milk price (c/L)	49.14	43.17	38.07
NPV 10 years	**$0**	**$0**	**$0**
Milk price (c/L)	**35.77**	**29.43**	**24.63**
NPV 20 years	**$0**	**$0**	**$0**

Table 10 tests how large the shade structure could be to return a NPV of $0 after 10 years; prices based on the shed builder's estimates. Shade allowances vary from 7.31 m^2 per cow in the 'no change' scenario to 9.47 m^2 per cow in the 'high change'. The estimated structure costs are $124,270 and $160,990 respectively.

The effectiveness of the shade structure was tested under set assumptions to determine what the minimum amount of improved production losses from the shade needed to be to be profitable (Table 11). After 10 years, the minimum required shade effectiveness ranged from 60.92% (high change scenario) to 78.64% (no change scenario) to return a $0 NPV. These dropped to 39.41% and 57.24% respectively after 20 years.

Table 10. The amount of shade allowed needed to return a NPV of $0 after 10 years assuming a discount rate of 10%, 72% shed effectiveness and a milk price of 45 c/L

Assumptions

Discount rate	10%
Milk price (c/L)	45
Shed effectiveness	72%

	Climate Scenario		
Net benefits (only additional milk income)	No Change	Moderate	High
Allowed shaded area under shed per cow (m^2)	7.31	8.34	9.47
NPV 10 years	**$0**	**$0**	**$0**

Table 11. The minimum shed effectiveness needed to return a NPV of $0 after 5, 10 and 20 years, assuming a discount rate of 10%, 8m2 shaded area allowed per cow and a milk price of 45 c/L

Milk price (c/L)	45
Discount rate	10
Allowed shaded area under shed per cow (m2)	8

	Climate Scenario		
Net benefits (only additional milk income)	No Change	Moderate	High
Shed effectiveness (%)	126.39	111.01	97.92
NPV 5 years	**$0**	**$0**	**$0**
Shed effectiveness (%)	78.64	69.07	60.92
NPV 10 years	**$0**	**$0**	**$0**
Shed effectiveness (%)	**57.24**	**47.08**	**39.41**
NPV 20 years	**$0**	**$0**	**$0**

Limitations and Further Questions

The calculated production losses only include the production lost *during* a heat stress event. It does not include production losses in the recovery time after a heat stress event. Therefore, the additional income from a shade structure could be higher if this recovery time was also taken into account. The integration of the Dairy Heat Load Index as described by Dunshea et al. (2013) could be a means to measuring the accumulation of heat load over time and its effects on milk production loss following a heat stress event.

The effectiveness of a shade structure for this analysis was based almost entirely on the findings by Nidumolu et al. (2010), and shade structure effectiveness results were from one case study farm. More research is needed into the relationship between ambient THI and the THI under a shade structure and the differences between THI and other types of shade structures.

The results from the economic analysis d) above also demonstrates that farmer's wishing to make an informed decision on investing in a shade structure, require a deeper understanding of the costs of heat stress impacts on animal health.

Conclusion

Over the seven year period investigated, heat stress cost the case study dairy farm between 240 and 414 litres per cow per year. Building a shade structure to cool the case study dairy herd during days of heat stress could be a profitable investment for the farm based on the recovered milk production. However, this is dependent on the severity of climate change and the milk price received. Ultimately the question of the whether the shade structure is a good investment relies on the amount of extreme heat events that will be experienced.

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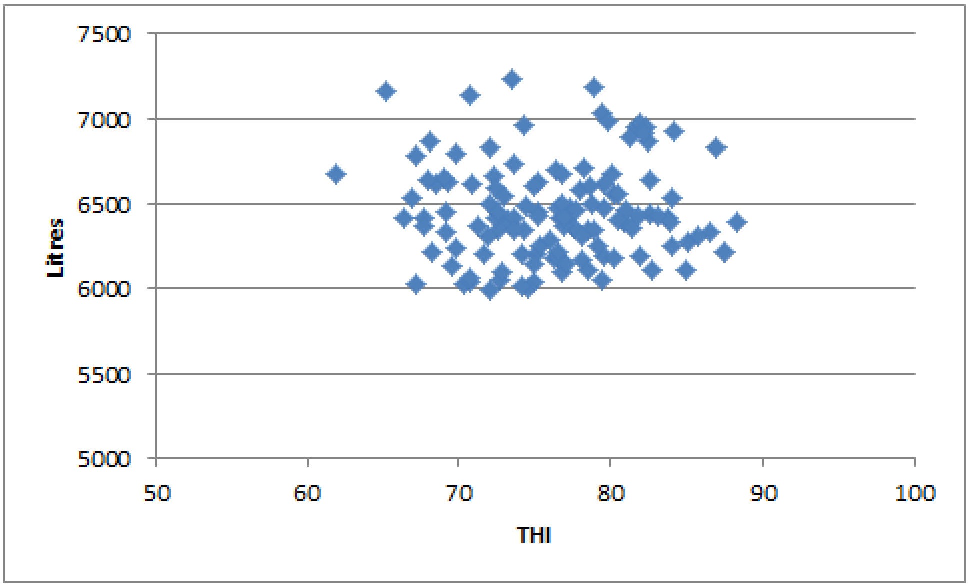
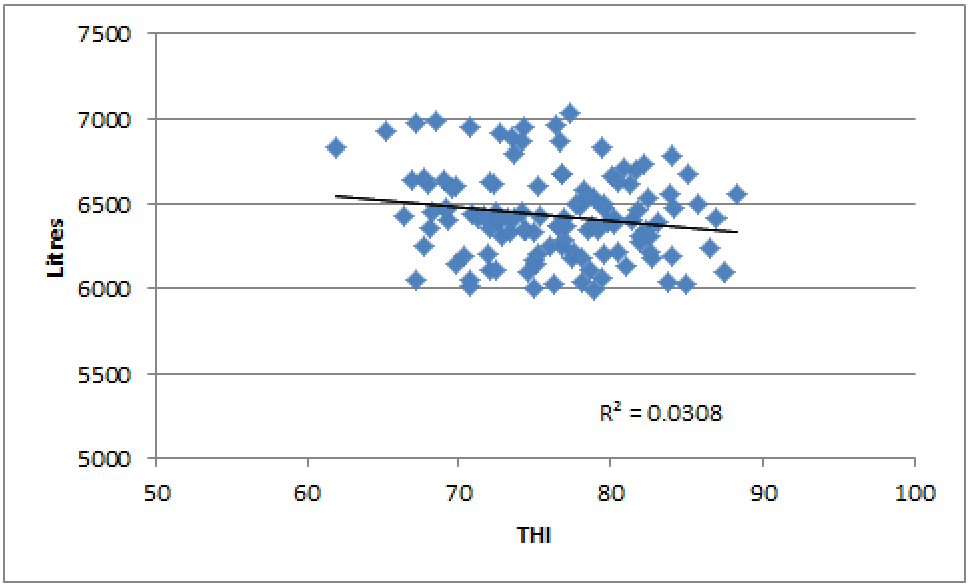
Appendix 1



Appendix 1A.



Appendix 1B.

Appendix 2. Calculating Severity Index for different levels of future climate change based on number of extra days (from 2000-2015 Cohuna averages) that experience different levels of THI. Moderate change: an increase of 3 days in the 75–78 THI range, 3days in 78–82 THI range and 3 days in with the THI range >82. High change: an increase of 5 days in the 75–78 THI range, 5 days in 78–82 THI range and 7 days in with the THI range >82.

THI	Severity index	Moderate change no. days	Moderate change severity index (severity index x moderate no. days)	High change no. days	High change severity index (severity index x high no. days)
76	1	1	1	2	2
77	2	1	2	1	2
78	3	1	3	2	6
79	4	1	4	2	8
80	5	1	5	1	5
81	6	1	6	2	12
82	7	0	0	0	0
83	8	0	0	2	16
84	9	1	9	0	0
85	10	1	10	1	10
86	11	1	11	2	22
87	12	0	0	2	24
	Total	9	51	17	107

Appendix 3. A year-by-year analysis of what each predicted climate scenario looks like over 10 and 20 years of the shade structures use.

		Climate scenario severity index		
Year	**Years after investment**	**No change**	**Moderate change**	**High change**
	0			
2016	1	368	419	475
2017	2	368	419	475
2018	3	368	419	475
2019	4	368	419	475
2020	5	368	419	475
2021	6	368	419	475
2022	7	368	419	475
2023	8	368	419	475
2024	9	368	419	475
2025	10	368	419	475
10 year average		**368**	**419**	**475**
2026	11	368	521	689
2027	12	368	521	689
2028	13	368	521	689
2029	14	368	521	689
2030	15	368	521	689
2031	16	368	521	689
2032	17	368	521	689
2033	18	368	521	689
2034	19	368	521	689
2035	20	368	521	689
20 year average		**368**	**470**	**582**