Study

Solar Cooling for Dairy Farms and Cold Stores in Victoria

Client: Sustainability Victoria

29th June 2009

provided by

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All costs in this study are Australian Dollars (AU$).

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Nomenclature/Units

Symbols

kW	Kilowatt
W	Watt
kWh	Kilowatthour
MWh	Megawatthour
COP	Coefficient of performance
Rt	tons of refrigeration
GHG	Greenhouse gas

Indices

el	electric
th	thermal
p	peak
r	refrigeration
h	heat

EXECUTIVE SUMMARY

This work provides a study of different solar cooling system configurations applied to four different sites, namely two dairy farms and two cold stores in Victoria. In the first part of the study the cooling and hot water loads have been analysed. Firstly, the loads have been calculated using metered electricity data for each site and annual average coefficients of performance (COP) for the installed refrigeration systems. Secondly, the cooling and hot water loads have been modelled using a commercial software package. The results show very good agreement between calculated and simulated data for the dairy farms with a variation of ± 10%. The results for the cold stores match within an average of 32%.

The second part of the study investigates the energy and GHG savings of the different solar cooling system configurations for each site. Time-dependent annual performance modelling has been carried out for each configuration to examine energy and water consumption as well as CO_2 emissions. Further, an economic analysis has been carried out with regard to investment and lifetime cost for each configuration, comparing to the existing conventional system.

The analysis shows that solar cooling can contribute up to 80% of the total cooling load and 57-65% of the hot water load for the dairy farms. Lifetime cost can be reduced between 9-16% compared to the existing conventional system. Greenhouse gas emissions can be reduced up to 23% in the dairy farms using solar cooling.

Solar contributions of 30% can be achieved towards the cooling loads of the two cold stores, resulting in energy and GHG savings of up to 4%. The cost reduction compared to the existing system is up to 7%.

It can be concluded that for the configurations investigated in this study the application of solar cooling in dairy farms looks much more promising than in cold stores. Significant reductions in lifetime cost, energy consumption and GHG emissions are possible.

SCOPE OF WORK

Task 1. Analyse for climate zone 3 & 4 the cooling and heating loads of two different sized dairy farms (Dairy 2 and Notman) and two cold stores (Cobram and Three Bridges) and calculate the air-conditioning/cooling load time series for every hour of the year based on simulations using TRNSYS

Task 2. Design models of cooling/heating technologies and provide information on suitable cooling/air-conditioning technologies that can be utilised or is suitable for the particular dairy farm/cold store.

Model options to include:

- Meeting peak load with solar
- Meeting average summer load with solar
- Meeting average annual load
- Minimal size conventional backup

A. Calculate all the energy and water consumption in the entire system and the realizable and the primary energy savings

B. Calculate the investment and O&M costs of the solar system and the auxiliary heating system

C. Provide NPV economic analysis for all systems above

Task 3. Report results and analysis in a report and include:

- Summary data and results
- Recommended technologies / configurations

1 BACKGROUND

Sustainability Victoria, CSIRO and The Energy Resources Institute (TERI) in India are collaborating in a joint research project on the development of renewable cooling and power generation systems. In this context, Sustainability Victoria investigates opportunities for solar cooling technologies in dairy farms and cold stores.

Sustainability Victoria commissioned Solem Consulting to undertake a study to examine options for solar cooling at four different sites, two cold stores for fruit storage and two dairy farms. This study is partially based on a previous report which analysed the electricity consumption of these sites as well as hot water load profiles [1].

This study is to consider various solar cooling designs to serve the heating and cooling needs of the dairy farms and cold stores. Such a solar cooling system runs from heat collected by solar collectors mounted on the roof or on nearby ground. The design is intended to reduce the electricity consumption associated with the provision of space/milk cooling and hot water provision to the sites. This is achieved by the substitution of electrically driven chillers by solar driven absorption chillers with the collateral benefit of reducing the exposure of the sites to peak electricity prices.

2 HEATING AND COOLING LOAD ANALYSIS

The first part of this study is to analyse the heating and cooling loads of the sites based on electricity consumption metering. Then a time-based simulation is to be conducted for each site to calculate the cooling and heating loads and compare the two.

2.1 General site descriptions

The two dairy farms are located in the Gippsland region, approx. 120 km south-east of Melbourne. The Dairy 2 dairy farm is a research institute however operates commercially and wishes to remain anonymous. The Notman dairy farm is a private dairy farm.
The two cold stores are used for fruit storage after the harvest. The Riverview cold store in Cobram is located in Victoria at the border to NSW, approx. 320 km north of Melbourne. The Sanders cold store is located in Three Bridges, approx. 75 km east of Melbourne. Table 1 shows details of the sites. Figure 1 shows the locations of the sites.

Table 1. Details of cold stores and dairy farms

Name	Address	Type	Annual milk production/ Annual fruit storage
Dairy 2	NA	Dairy farm	2690 kL
Notman	Nyora Rd, Poowong, VIC 3988	Dairy farm	2710 kL
Riverview	12 Schubert Street, Cobram VIC 3644	Cold store	3,400 tons
Three Bridges	930, Little Yarra Rd, Three Bridges, VIC 3797	Cold store	1,462 tons

It can be seen that the two dairy farms are of equal size, whereas the Riverview cold store has more than twice the annual storage capacity than the Three Bridges store.

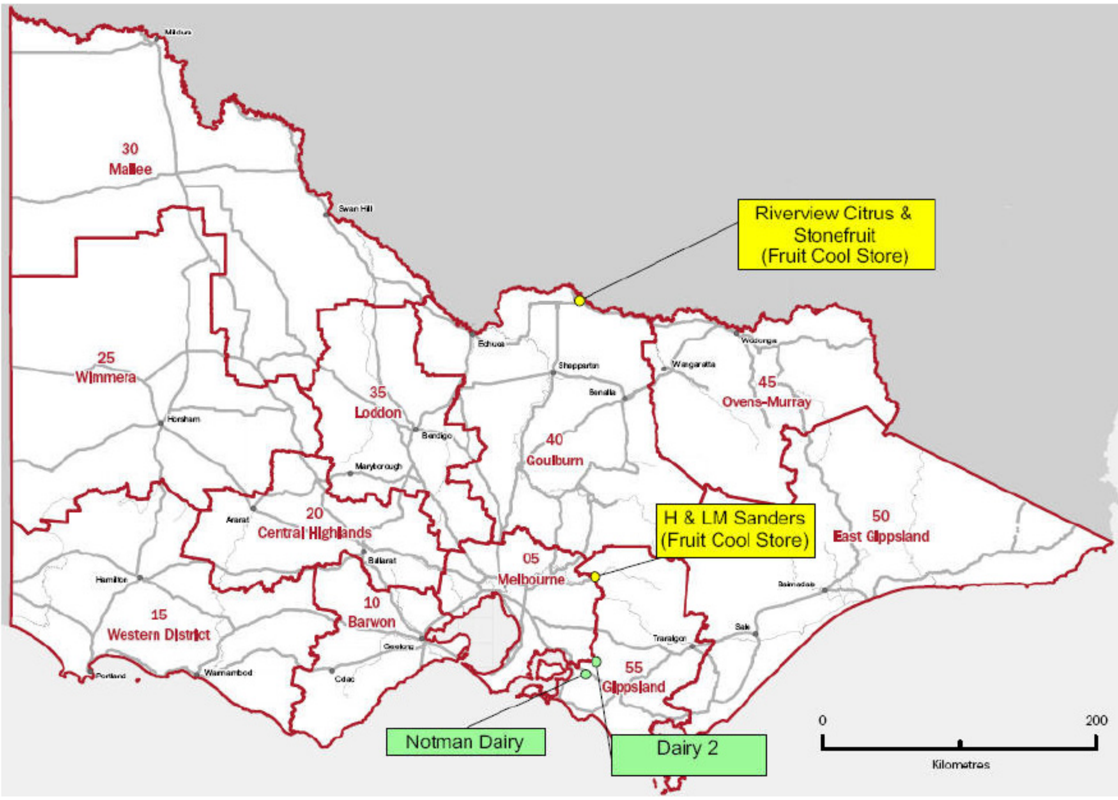


Figure 1. Map of Victoria with overview of sites. Picture sourced from [1].

More details on each site can be found in the report by Genesis [1].

2.2 Methodology and results

Electricity and hot water consumption has been recorded for the four sites in various time intervals. Data was recorded in half hour intervals, daily and sometimes monthly only. Heating and cooling loads have been calculated based on annual average COP's of the refrigeration systems used.

TRNSYS simulation software has been used to model the cooling loads of the cold stores in hourly time steps. Weather data has been sourced from the METEONORM database [2] and the Bureau of Meteorology [3]. Weather stations used in TRNSYS are given in Table 2.

Table 2. Weather data used in TRNSYS simulations

Name of site	Weather data from station	Climate zone	Distance weather station to site
Dairy 2	Latrobe Valley Airport	4	64km
Notman	Latrobe Valley Airport	4	93km
Riverview	Kyabram	3	94km
Three Bridges	Melbourne	4	75km

The cold stores have been modelled as zones based on the building data given in the Genesis report [1]. A fan coil refrigeration system has been assumed with a set temperature of 0.1 degC in the cold store. Lights, fork lift movements and fruit loading/unloading patterns have been integrated in the simulation as given in [1]. Fruit loading/unloading data was provided monthly so had to be extrapolated to the hourly intervals used in the simulations.

The specific heat capacity of fruit bins has been assumed to 3.5 kJ/kg/K and the temperature difference has been assumed to 30K (eg cooling down from 30degC ambient temperature to 0 degC in the coolroom).

Dairy farms have not been modelled as a building/zone but rather as hourly schedules of milk cooling and hot water loads. The hourly schedules were based on recorded data and assumptions for milking and hot water usage times, Table 3.

Table 3. Milking and hot water usage pattern –dairy farms

Time	Milk cooling	Hot Water usage
Morning	6am – 8am	9am - 11am
Afternoon	3pm – 5pm	6pm – 8pm

All simulations were performed over the course of a year at an interval of one hour.

2.2.1 Dairy 2 dairy farm

Measured electricity data provided for Dairy 2 included half hour measurements of electricity consumption for hot water and refrigeration in the year 2006. There was however data missing from June 17th to July 15th 2006. This data has been estimated using extrapolated values from June and July 2006.

The main hot water system consists of two 1250 L electric resistance tanks and the vat hot water tank is 450L electric resistance. Condenser heat from vat refrigeration is rejected into the vat hot water tank. Pre-cooling of milk is done with a plate heat exchanger using tank water that has been cooled during night time with a cooling tower. Refrigeration consists of an air-cooled glycol chiller for milk line cooling and a water-cooled chiller for vat cooling. The annual average COP has been assumed 1.7 for the air-cooled and 2.1 for the water-cooled chiller as described in [1]. Hot water and cooling loads have then been calculated and are shown as follows. The results for measured and simulated data are given in Figure 2 and Figure 3.

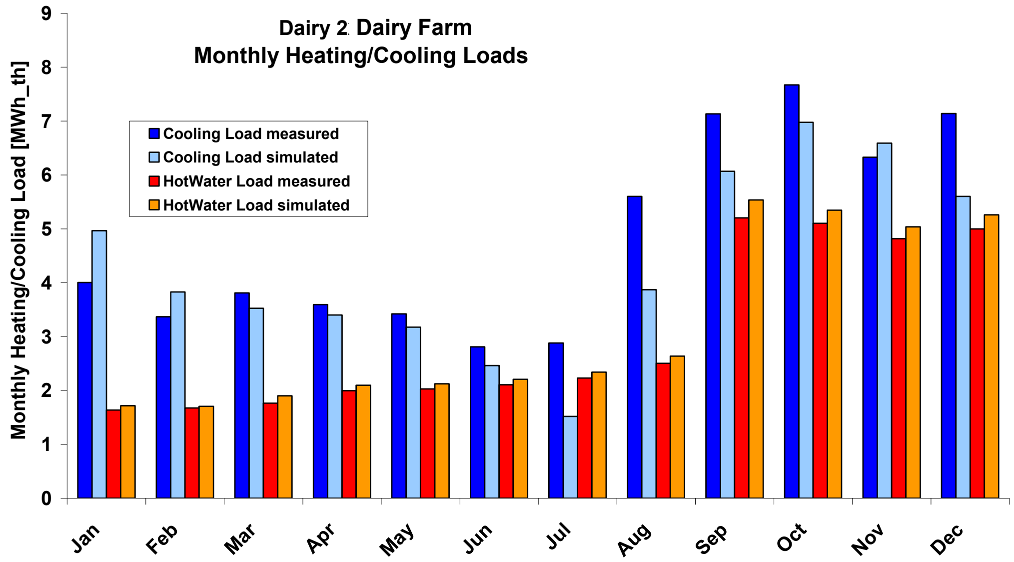


Figure 2. Monthly cooling and heating loads – Dairy 2 dairy farm

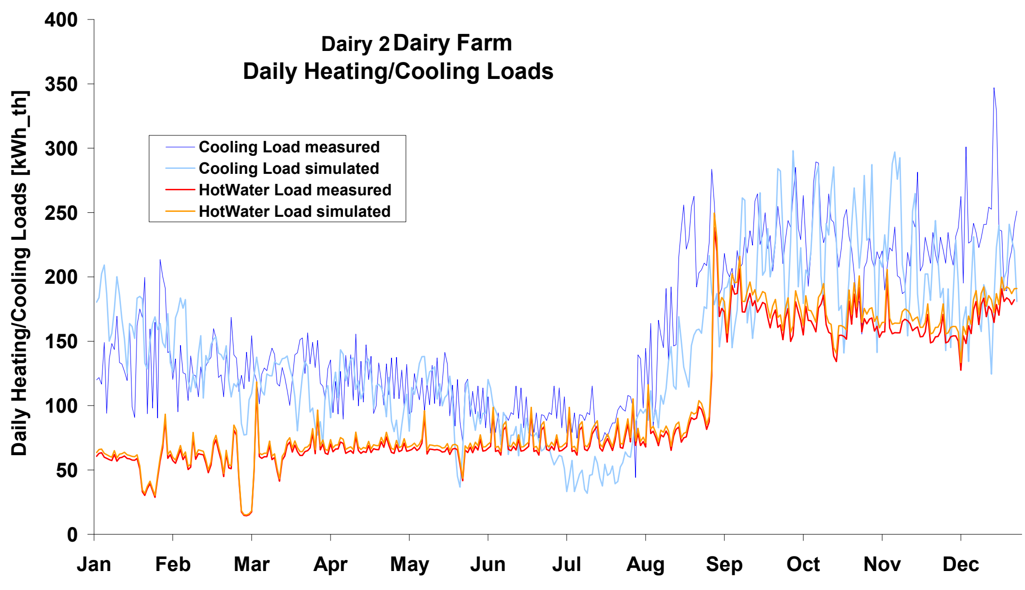


Figure 3. Daily cooling and heating loads – Dairy 2 dairy farm

Total annual figures for Dairy 2 are summarised in Table 4.

Table 4. Annual heating and cooling load – Dairy 2 dairy

Dairy 2	Unit	Milk cooling	Hot Water usage
Measured	MWh_th/a	58	36
Simulated	MWh_th/a	52	38

2.2.2 Notman dairy farm

Measured electricity data provided for Notman included half hour and daily measurements of electricity consumption for refrigeration and hot water system in the years 2003-2005. These values have been averaged and used for the calculations.

The main hot water system is a 1200 L electric resistance tank and the vat hot water tank is 200L electric resistance with off-peak storage. Pre-cooling of milk is done with a plate heat exchanger using dam water. Refrigeration consists of an air-cooled glycol chiller for milk line and vat cooling. The annual average COP has been assumed 1.7 for the air-cooled chiller [1]. Hot water and cooling loads have then been calculated and are shown as follows.

Hourly values for milk production and hot water haven been extrapolated from daily average values given. The results for measured and simulated data are shown in Figure 4 and Figure 5. Total annual figures for Notman are summarised in Table 5.

Table 5. Annual heating and cooling load – Notman dairy

Notman	Unit	Milk cooling	Hot Water usage
Measured	MWh_th/a	56	51
Simulated	MWh_th/a	62	46

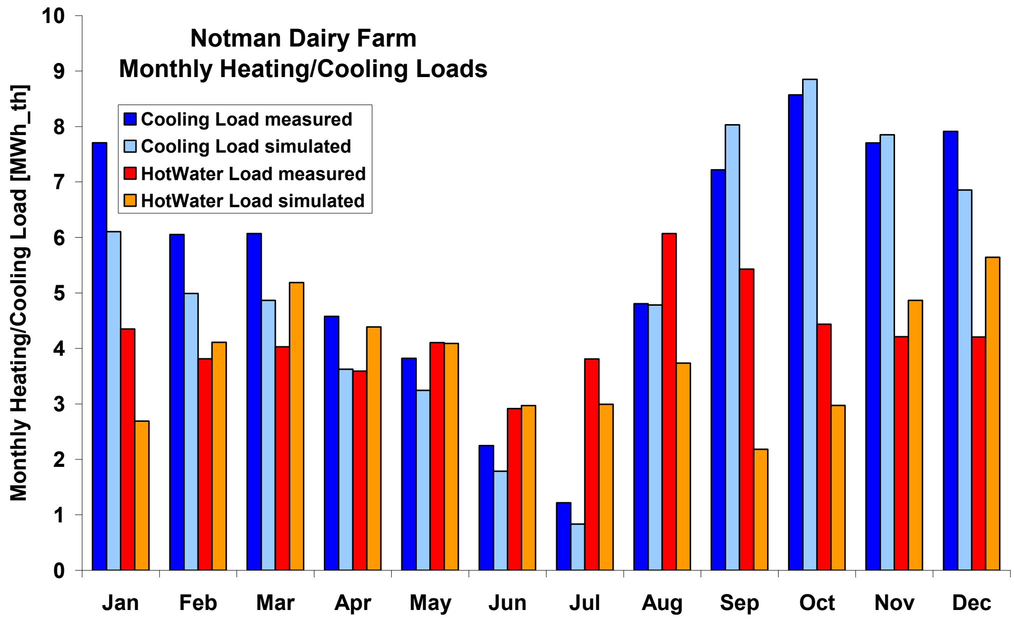


Figure 4. Monthly cooling and heating loads – Notman dairy farm

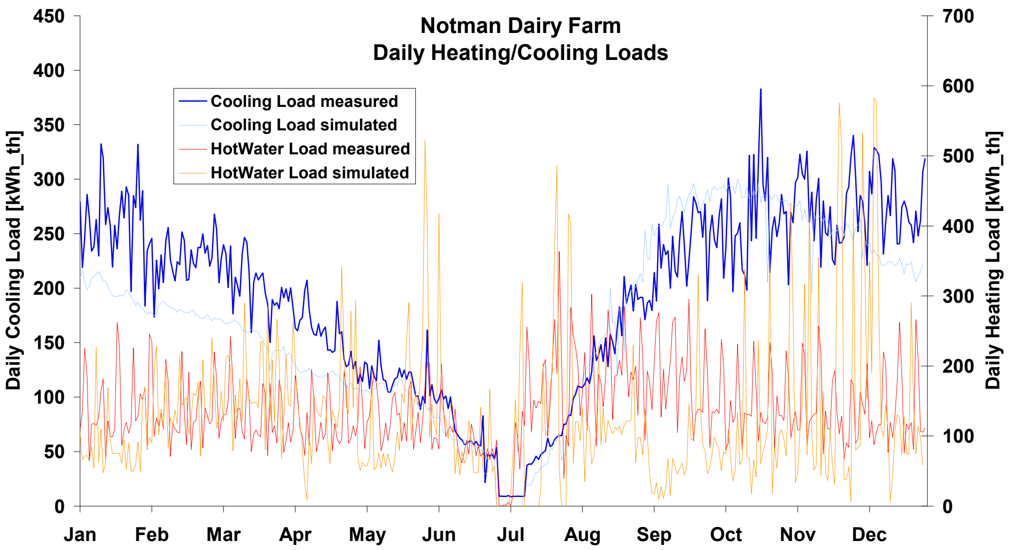


Figure 5. Daily heating and cooling loads – Notman dairy farm

Please note that the heating load is displayed on the right y-axis in Figure 5.

2.2.3 Riverview cold store

Data provided for Riverview included daily values of electricity consumption as well as half hour values of power consumption for the whole site in 2007-2009. Unfortunately there was no individual metering data of the refrigeration system available. It was therefore estimated from a summer and a winter day load profile that 85% of the total annual electricity consumption was used for refrigeration of the cold stores. Further, the annual average COP of the existing refrigeration units has been assumed to 1.9 during the warmer months (Nov to Mar) and 2.1 during the colder months (Apr to Oct).

The Riverview cold store is in use for most of the year with the exception of May. The three cold rooms have been modelled as a single zone since they have the same loading/unloading patterns throughout the year. The assumptions for heat and moisture gains in the cold room are given in Table 6. The fruit loading pattern is shown in Table 7 [1]. Each bin holds 400 kg of fruit.

Table 6. Assumptions for sensible and latent heat load gains in simulation – Riverview coldstore

Sensible heat load	Value	Schedule
Person	Light seated work	2 mins every 15 mins during workhours
Electric fork lift	500 W_{el}	2 mins every 15 mins during workhours
Lights	4.8 kW_{el}	06:30-18:30 on workdays
Ambient air	10% air change when door open	2 mins every 15 mins during workhours
Fan coil unit fan	2kW_{el}	30% of the time
Latent heat load	**Assumption**	
Person	Light seated work	2 mins every 15 mins during workhours
Ambient air	10% air change when door open	2 mins every 15 mins during workhours
Fruit respiration	4 kg water/bin	According to loading pattern

Table 7. Fruit loading and unloading pattern – Riverview coldstore

		Stonefruit		Apples/pears		Citrus		Total	
Month		Bins In	Bins Out	Bins In	Bins Out	Bins In	Bins Out	Bins In	Bins Out
Capacity (bins)	1700								
January		1000	1000	0	0	1000	1000	2000	2000
February		1000	1000	500	0	0	0	1500	1000
March		1000	1000	0	0	0	0	1000	1000
April		500	500	0	0	0	0	500	500
May		0	0	0	0	0	0	0	0
June		0	0	0	250	0	0	0	250
July		0	0	0	250	200	200	200	450
August		0	0	0	0	200	200	200	200
September		0	0	0	0	200	200	200	200
October		0	0	0	0	200	200	200	200
November		0	0	0	0	1000	1000	1000	1000
December		500	500	0	0	1200	1200	1700	1700

Cooling loads have then been calculated/simulated and are shown as follows.

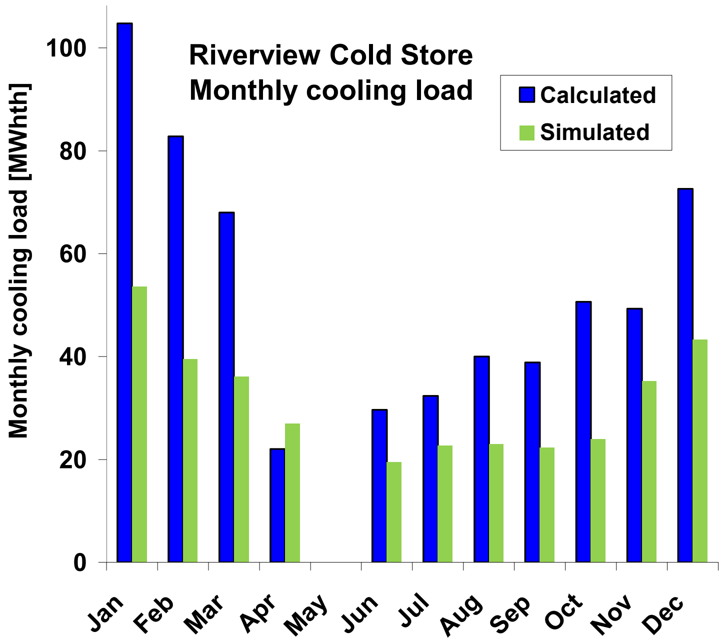


Figure 6. Monthly cooling load – Riverview cold store

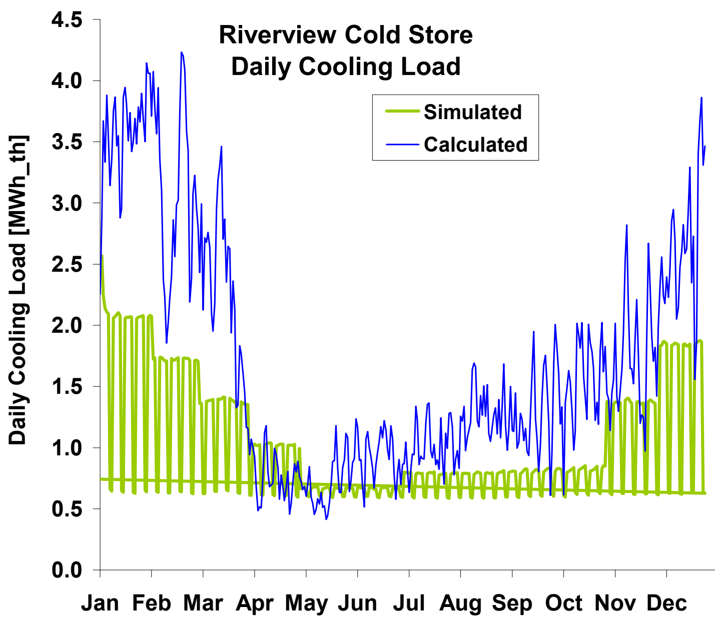


Figure 7. Daily cooling load – Riverview cold store

Table 8. Annual cooling load – Riverview cold store

Riverview	Unit	Refrigeration
Measured	MWh_th/a	591
Simulated	MWh_th/a	368

2.2.4 Three Bridges cold store

Data provided for Three Bridges only included monthly values of electricity consumption for the whole site in 2007-2009. Unfortunately there was no hourly metering data of the refrigeration system available. It was therefore not possible to determine the electricity consumption used for refrigeration of the cold stores. An estimate has been made that 85% of the total electricity consumption is used for refrigeration. Again, the annual average COP of the refrigeration units has been assumed to 1.9 during the warmer months (Nov to Mar) and 2.1 during the colder months (Apr to Oct).

The Three Bridges site is in use all of the year however with different numbers of cold stores in operation. Each cold store has been modelled as an individual zone with its respective usage pattern. The assumptions for heat and moisture gains in the cold room are given in Table 9. The cold store usage and fruit loading pattern is shown in Table 10 [1]. Each bin holds 340 kg of fruit.

Table 9. Assumptions for sensible and latent heat load gains in simulation – Three Bridges cold store

Sensible heat load	Value	Schedule
Person	Light seated work	1hr during workweek
Electric fork lift	500 W_{el}	1hr during workweek
Lights	80 W_{el} per coldstore	1hr during workweek
Ambient air	10% air change when door open	1hr during workweek
Fan coil unit fan	0.5 kW_{el} per coldstore	30% of the time
Latent heat load	**Assumption**	
Person	Light seated work	1hr during workweek
Ambient air	10% air change when door open	1hr during workweek
Fruit respiration	3.6 kg water/bin	According to loading pattern

Table 10. Fruit loading and unloading pattern – Three Bridges coldstore

Month	Start of Month	Bins In	Bins Out	Net Change	End of Month		Average bins per Cool Store	Indicative Usage						
	All				All		All	In use	Load factor	CS 1	CS 2	CS 3	CS 4	CS 5
Capacity (bins)	3360				3360		3360			700	630	630	700	700
January	0	0	0	+0	0		0	1	0.2	in use	not in use	not in use	not in use	not in use
February	0	1200	430	+770	770		257	3	0.6	in use	not in use	not in use	not in use	not in use
March	770	800	430	+370	1140		326	3.5	0.7	in use	not in use	part	part	in use
April	1140	1400	430	+970	2110		469	4.5	0.9	in use	part	in use	in use	in use
May	2110	900	430	+470	2580		516	5	1.0	in use	in use	in use	in use	in use
June	2580	0	430	-430	2150		430	5	1.0	in use	in use	in use	in use	in use
July	2150	0	430	-430	1720		344	5	1.0	in use	in use	in use	in use	in use
August	1720	0	430	-430	1290		258	5	1.0	in use	in use	in use	in use	in use
September	1290	0	430	-430	860		191	4.5	0.9	in use	part	in use	in use	in use
October	860	0	430	-430	430		123	3.5	0.7	in use	not in use	part	in use	in use
November	430	0	430	-430	0		0	2.5	0.5	in use	not in use	not in use	part	in use
December	0	0	0	+0	0		0	1.5	0.3	in use	not in use	not in use	not in use	part

(blue)	= in use for whole month
(pink)	= not in use for whole month
(orange)	= not in use for part of month

Cooling loads have then been calculated and are shown as follows.

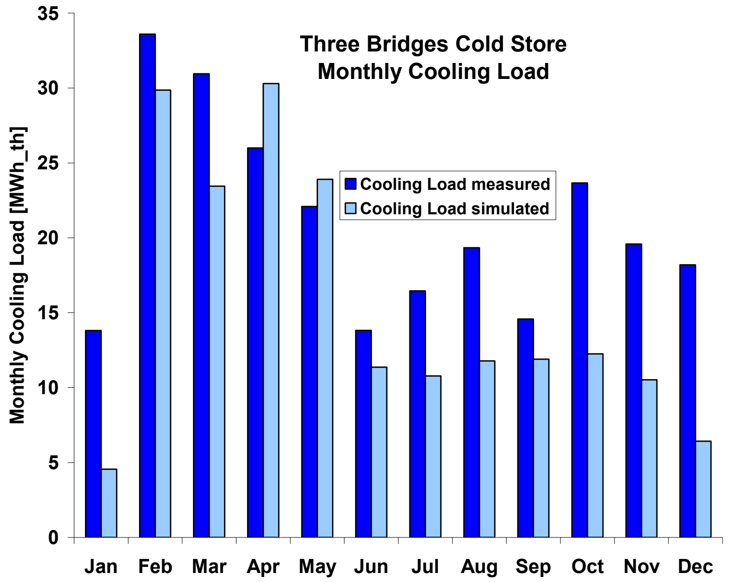


Figure 8. Monthly cooling load – Three Bridges cold store

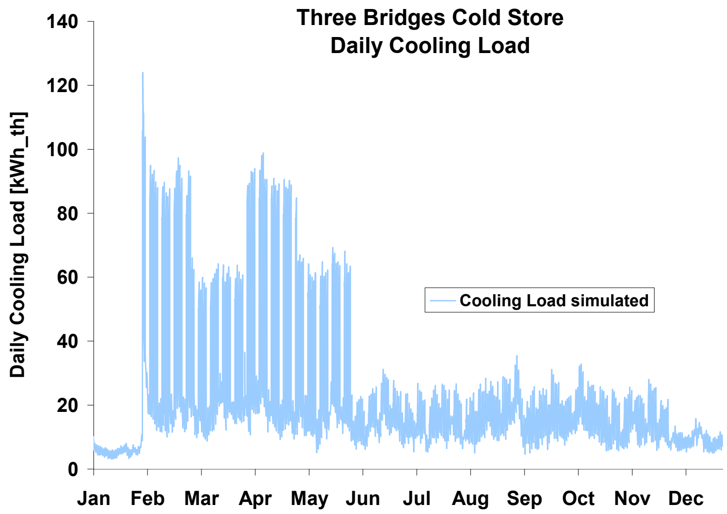


Figure 9. Daily cooling load – Three Bridges cold store

Table 11. Annual cooling load – Three Bridges cold store

Three Bridges	Unit	Refrigeration
Measured	MWh_th/a	252
Simulated	MWh_th/a	187

2.2.5 Chapter summary

The cooling and hot water loads of two different dairy farms and two different cold stores have been analysed. The loads have been estimated in two different ways:

a) calculated from measured electricity data, and
b) simulated using TRNSYS software.

The annual cooling and hot water loads are summarised in Table 12.

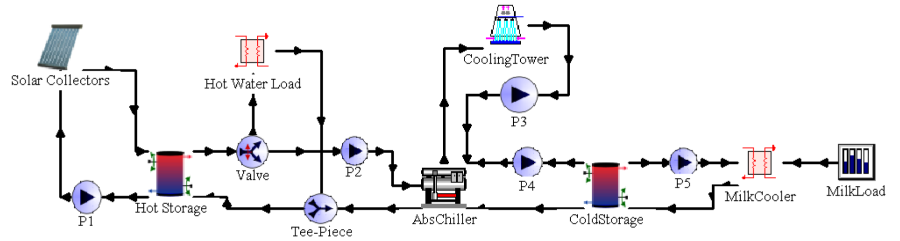
Table 12. Annual cooling and hot water load data for all sites

	Dairy 2	Notman	Riverview	Three Bridges
Application refrigeration	Milk line and vat cooling	Vat cooling	Fruit storage	Fruit storage
Application Hot Water	Milk line and vat cleaning	Milk line and vat cleaning	-	-
Electricity consumption for cooling [MWh_{el}]	32	34	301	127
Electricity consumption for hot water [MWh_{el}]	36	51	-	-
Calculated Cooling load [MWh_{th}]	58	56	591	252
Simulated Cooling load [MWh_{th}]	52	62	368	187
Calculated Hot water load [MWh_{th}]	36	51	-	-
Simulated Hot water load [MWh_{th}]	38	46	-	

3 SOLAR COOLING SYSTEM MODELLING

TRNSYS simulation software has been used to model the system design in hourly time steps.
Table 13 shows the hydraulic flow schemes of the TRNSYS model. For both options, hot water is heated in the solar collectors and stored in a hot-side storage tank. Hot water is directly taken from the tank for line and vat cleaning in the dairy farms. The cold stores do not make use of hot water directly. The absorption chiller is driven with hot water from the tank. An evaporation-type open cooling tower is used for the rejection of waste heat from the chiller. In the dairy farms, the pre-cooled milk is further chilled via a plate heat exchanger. In the cold stores, the chilled water is used in fan coils inside the stores.
The hydraulic system configurations as assumed in the simulation are shown in Table 13 for both dairy farms and cold stores. Backup cooling and hot water heating equipment is not shown. The solar collectors in the simulations have been assumed with a true north orientation.

Table 13. Hydraulic configurations for TRNSYS simulations

<table>
<tr><td>Dairy farms</td><td>
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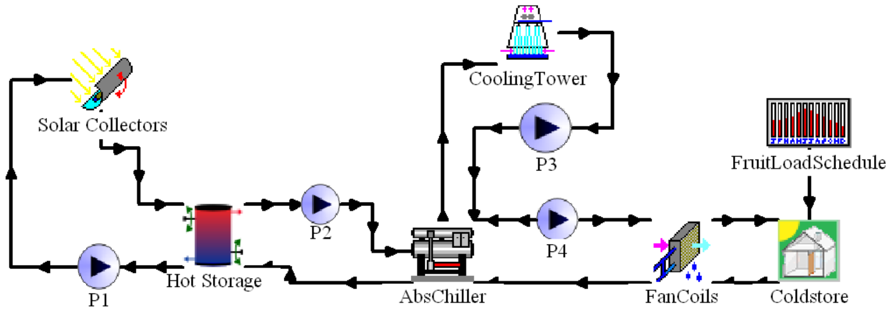
<tr><td>Cold stores</td><td>
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3.1 Methodology and control

The solar pump P1 is controlled via a two-way controller (not shown in Table 13) and uses radiation data to switch pump P1 on and off. The hot water pump P2, cooling water pump P3 and chilled water pump P4 are controlled via the top temperature of the hot storage tank. If this temperature exceeds the start-up temperature of the absorption chiller then all these pumps are switched on. If the top temperature of the storage tank falls below the start-up temperature of the absorption chiller then pumps P2, P3 and P4 are switched off. The absorption chiller also operates only if the ON-condition for P2, P3 and P4 is satisfied. Pump P5 in the dairy farm application runs only if cooling is needed for milk cooling. Likewise, hot water is only drawn from the hot storage tank when needed for cleaning purposes. A backup electrical chiller has not been modelled as an individual component since its contribution to the total cooling load provided can be calculated as the difference between solar cooling provided and cooling load needed.

Table 14 shows the constant parameters assumed in all simulations.

Table 14. Constant values used in TRNSYS simulations.

Constant values			Dairy Farms	Cold Stores
General	Simulation time	h	8760	8760
	Simulation time step	h	1	1
Solar thermal collectors	Type	-	Evacuated tube	Parabolic trough
	Conversion efficiency η_0 (aperture)	-	0.73	0.65
	a1 (aperture)	$W/K/m^2$	1.04	4.2
	a2 (aperture)	$W/K^{2/}m^2$	0.0086	0.01
	Collector slope	deg	30	tracking
	Orientation	-	North	East-West
Storage tank	Tank heat loss coefficient	$kJ/h/m^2/K$	1.5	1.5
Absorption chiller	Working pair	-	LiBr/water	NH_3/water
	Nominal COP (100% load)	-	0.7	0.6
	Nominal hot water temperature (100% load)	degC	95	160
	Start-up temperature	degC	75	100
	Chilled water temperature setpoint	degC	4	0.1
Thermal properties	Water heat capacity	kJ/kg/K	4.19	4.19
	Water density	kg/m^3	1000	1000

3.2 Design approaches

Four different design approaches were asked for by Sustainability Victoria. These include

- Peak load

– Summer average load
– Annual average load
– Minimal size with conventional backup

The peak load design approach assumes that the solar cooling system is designed to provide the maximum cooling power needed throughout year, usually needed on the hottest day of the year. A peak load system will therefore be oversized for most of the year as the cooling loads are usually smaller than the peak load.

The average summer load design uses an average capacity determined from data provided for the summer months of December, January and February. This system will still be oversized for most of the rest of the year, however undersized for peak days.

The average annual load design uses the average annual capacity determined from one year's data. It will be undersized for summer and peak days, however still cover most of the base load throughout the year.

The minimal size approach is choosing a small economic solar cooling system that is supported by a backup conventional system. This solar cooling system will be undersized for most of the year and cover part of the base load.

Peak, average summer and average annual cooling capacity have been calculated from measured data. The minimal size approach loads were chosen to match available small absorption chillers. They were not calculated from existing data. All cooling capacities for the four sites are given in Table 15.

Table 15. Peak, average summer, average annual and minimal size cooling power of cold stores and dairy farms

	PEAK LOAD	AVERAGE SUMMER	ANNUAL AVERAGE	MINIMAL SIZE
Site	**Cooling Power [kW]**	**Cooling Power [kW]**	**Cooling Power [kW]**	**Cooling Power [kW]**
Dairy 2	58	28	26	18
Notman	64	42	32	18
Riverview	176	150	84	50
Three Bridges	55	32	29	15

The modelling results and analyses for the different sites are given in the following chapters.

3.3 *Dairy 2 dairy farm*

3.3.1 Savings and investment cost

The energy performance as well as auxiliary energy and water consumption for Dairy 2 are given in Table 16. These results are for the solar cooling system only – the backup heater is not included. This was done to show the potential of a stand-alone solar cooling system. The backup heater is however included in the lifetime cost analysis in the next chapter.

Table 16. Energy and water consumption - Dairy 2

ENERGY	Unit	Peak Load	Average Summer	Annual Average	Minimal size
Metered electricity consumption[1]	MWhel/a	67	67	67	67
Calculated cooling load[2]	MWhth/a	58.4	58.4	58.4	58.4
Calculated hot water load[2]	MWhth/a	38.3	38.3	38.3	38.3
Simulated cooling load provided	MWhth/a	41.2	30.1	30.1	20
Simulated hot water load provided	MWhth/a	20.2	11	11	4.6
Coverage cooling load	%	80	59	59	38
Coverage heating load	%	76	65	65	56
Auxiliary energy consumption	MWhel/a	27	8.4	8.4	5.1
Auxiliary water consumption	kL	146	113	113	78

1: Total electricity consumption for cooling and hot water per year.

2: From measured data

It can be seen that the peak load design results in the highest fraction of solar cooling (80%) and hot water heating (53%). Electricity and CO2 savings of 61% compared to the existing conventional system can be achieved with this design. All other designs with smaller chillers and collector fields result in lower savings.

The system cost and main component sizes can be found in Table 17.

Table 17. Investment cost summary - Dairy 2

DAIRY 2 SOLAR COOLING SYSTEM	Unit	PEAK LOAD	SUMMER AVERAGE	ANNUAL AVERAGE	MINIMAL SIZE
Chiller capacity installed	kWth	58	28	26	18
Collector field size	m2	180	90	90	50
Total equipment cost	AU$	225,970	114,360	114,360	87,600
Total installation cost	AU$	32,655	15,415	15,415	9,765
Total system Cost	**AU$**	**258,625**	**129,775**	**129,775**	**97,365**
Specific system cost	AU$/kWth	4,459	4,635	4,635	5,409

3.3.2 Economic analysis

The cost for the solar cooling system and operation cost has to be compared against the total cost of conventional AC operation. The economic comparison is made as follows:

a) Baseline: New installation of conventional system
b) Solar cooling: New installation of solar cooling system sized for four different operation modes

For the base line calculations (a) the total cooling capacity of the chiller is assumed to be of the same capacity as installed on site eg sized for peak operation.

The solar cooling system (b) has been sized differently as explained in chapter 3.2. All lifetime costs are net present value (NPV) at 6% discount rate. An electricity price of AU$ 0.20/kWhel has been assumed for the first year with an annual increase of 2% over the lifetime calculations. CO_2 emissions have been calculated at 1.22 kgCO2/kWhel for Victoria.

Table 18. Lifetime cost analysis conventional system - Dairy 2

Dairy 2 Conventional System	Unit	Total
Total electricity consumption/year	MWhel/a	68
Total maintenance cost/year	$/a	$ 1,000
Total O&M cost/year 1	$/a	$ 14,541
Total CO2 emission/year	t/a	82.6
Discount rate	%	6%
Unit lifetime	years	8
Equipment cost per 60 kW chiller	AU$	$ 50,000
Balance of plant	AU$	$ 10,000
Total equipment cost for conventional unit	AU$	$ 60,000
Total electricity consumption/lifetime	MWhel	542
Total CO2 emission/20 yrs	t	1652
Projected total cost for 20 years	AU$	$ 327,520

Note: The equipment cost for the conventional chiller in Table 18 does not include the cooling tower – it is included in the balance of plant cost. Balance of plant cost also includes piping, ducting, controls, refrigerant and electrical work. A CPI increase of 2.5 per annum has been assumed. Installation cost is assumed as 10% of total equipment cost.

The lifetime cost for 20 years is given in Table 19. This data includes an electrical backup heater.

Table 19. Lifetime cost analysis solar cooling system - Dairy 2

Dairy 2 SOLAR COOLING SYSTEM	Unit	PEAK LOAD	SUMMER AVERAGE	ANNUAL AVERAGE	MINIMAL SIZE
Total electricity consumption/year	MWhel/a	27.0	8.4	8.4	5.1
Total maintenance cost/year	$/a	$ 1,000	$ 1,000	$ 1,000	$ 1,000
Total O&M cost/year 1	$/a	$ 6,396	$ 2,686	$ 2,686	$ 2,023
Total CO2 emission/year	t/a	32.9	10.3	10.3	6.2
Unit lifetime	years	20	20	20	20
Total system cost	AU$	$ 258,625	$ 129,775	$ 129,775	$ 97,365
Discount rate	%	6%	6%	6%	6%
Total electricity consumption SCS/20 yrs	MWhel	539.6	168.6	168.6	102.3
Total electricity consumption backup/20 yrs	MWhel	504	931	931	1344
Total CO2 emission/20 yrs	t	1273.4	1342.0	1342.0	1764.8
Total cost/20 yrs	AU$	$ 388,759	$ 274,316	$ 274,316	$ 287,606

It can be seen that summer average, annual average and minimal size designs attract lower lifetime costs than the conventional system. Peak load, summer average and annual average have lower GHG emissions, while the minimal size design has higher GHG emissions than the conventional alternative. This is due to the high share of backup heat provided by the electric heater in this configuration. The reduction compared to the conventional system is shown in the following table.

Table 20. Reduction of solar cooling system cost and GHG emission compared to conv. system-Dairy 2

Dairy 2	**Peak Load**	**Summer Average**	**Annual Average**	**Minimal Size**
Total energy consumption/20 yrs	-23%	-19%	-19%	+7%
Total GHG emission/20 yrs	-23%	-19%	-19%	+7%
Total lifetime cost/20 yrs	+19%	-16%	-16%	-12%

3.4 Notman dairy farm

3.4.1 Savings and investment cost

The energy performance as well as auxiliary energy and water consumption for Notman are given in Table 21.. These results are for the solar cooling system only – the backup heater is not included. This was done to show the potential of a stand-alone solar cooling system. The backup heater is however included in the lifetime cost analysis in the next chapter.

Table 21. Energy and water consumption - Notman

ENERGY	Unit	Peak Load	Average Summer	Annual Average	Minimal size
Metered electricity consumption[1]	MWhel/a	85	85	85	85
Calculated cooling load[2]	MWhth/a	62	62	62	62
Calculated hot water load[2]	MWhth/a	46	46	46	46
Simulated cooling load provided	MWhth/a	50	42	35	20
Simulated hot water load provided	MWhth/a	28	18	15	7
Coverage cooling load	%	80	67	57	33
Coverage heating load	%	80	59	66	57
Auxiliary energy consumption	MWhel/a	36	18	15	6
Auxiliary water consumption	kL	193	155	130	72

1: Total electricity consumption for cooling and hot water per year.

2: From measured data

It can be seen that the peak load design results in the highest fraction of solar cooling (80%) and hot water heating (60%). Electricity and CO2 savings of 70% compared to the existing conventional system can be achieved with this design. All other designs with smaller chillers and collector fields result in lower savings.

The system cost and main component sizes can be found in Table 22.

Table 22. Investment cost summary - Notman

NOTMAN SOLAR COOLING SYSTEM	Unit	PEAK LOAD	SUMMER AVERAGE	ANNUAL AVERAGE	MINIMAL SIZE
Chiller capacity installed	kWth	64	42	32	18
Collector field size	m2	180	120	100	50
Total equipment cost	AU$	234,470	148,610	131,990	87,600
Total installation cost	AU$	33,405	20,227	17,701	9,765
Total System Cost	**AU$**	**267,875**	**168,837**	**149,691**	**97,365**
Specific system cost	AU$/kWth	4,186	4,020	4,678	5,409

3.4.2 Economic analysis

The cost for the solar cooling system and operation cost has to be compared against the total cost of conventional AC operation. The economic comparison is made as follows:

a) Baseline: New installation of conventional system
b) Solar cooling: New installation of solar cooling system sized for four different operation modes

For the base line calculations (a) the total cooling capacity of the chiller is assumed to be of the same capacity as installed on site eg sized for peak operation.

The solar cooling system (b) has been sized differently as explained in chapter 3.2. All lifetime costs are net present value (NPV) at 6% discount rate. An electricity price of AU$ 0.20/kWhel has been assumed for the first year with an annual increase of 2% over the lifetime calculations. CO_2 emissions have been calculated at 1.22 kgCO2/kWhel for Victoria.

Table 23. Lifetime cost analysis conventional system - Notman

Notman Conventional System	Unit	Total
Total electricity consumption/year	MWhel/a	85
Total maintenance cost/year	$/a	$ 1,000
Total O&M cost/year 1	$/a	$ 18,000
Total CO2 emission/year	t/a	103.7
Discount rate	%	6%
Unit lifetime	years	8
Equipment cost per 60 kW chiller	AU$	$ 50,000
Balance of plant	AU$	$ 10,000
Total equipment cost for conventional unit	AU$	$ 60,000
Total electricity consumption/lifetime	MWhel	680
Total CO2 emission/20 yrs	t	2075
Projected total cost for 20 years	AU$	$ 371,307

Note: The system cost for the conventional chiller in Table 23 does not include the cooling tower – it is included in the balance of plant cost. Balance of plant cost also includes piping, ducting, controls, refrigerant and electrical work. A CPI increase of 2.5 per annum has been assumed. Installation cost is assumed as 10% of total equipment cost.

The lifetime cost for 20 years is given in Table 24. This data includes an electrical backup heater.

Table 24. Lifetime cost analysis solar cooling system - Notman

Notman SOLAR COOLING SYSTEM	Unit	PEAK LOAD	SUMMER AVERAGE	ANNUAL AVERAGE	MINIMAL SIZE
Total electricity consumption/year	MWhel/a	36.4	18.1	15.1	5.7
Total maintenance cost/year	$/a	$ 1,000	$ 1,000	$ 1,000	$ 1,000
Total O&M cost/year	$/a	$ 8,270	$ 4,623	$ 4,029	$ 2,141
Total CO2 emission/year	t/a	44.3	22.1	18.5	7.0
Unit lifetime	years	20	20	20	20
Total system cost	AU$	$ 267,875	$ 168,837	$ 149,691	$ 97,365
Discount rate	%	6%	6%	6%	6%
Total electricity consumption SCS/20 yrs	MWhel	727.0	362.3	302.9	114.1
Total electricity consumption backup/20 yrs	MWhel	524	946	1035	1511
Total CO2 emission/20 yrs	t	1526.3	1596.4	1632.0	1982.1
Total cost/20 yrs	AU$	$ 423,720	$ 337,561	$ 340,788	$ 310,158

The reduction compared to the conventional system is shown in the following table.

Table 25. Reduction of solar cooling system cost and GHG emission compared to conv. system-Notman

Notman	**Peak Load**	**Summer Average**	**Annual Average**	**Minimal Size**
Total energy consumption/20 yrs	-26%	-23%	-21%	-4%
Total GHG emission/20 yrs	-26%	-23%	-21%	-4%
Total lifetime cost/20 yrs	+14%	-9%	-8%	-16%

3.5 Riverview cold store

3.5.1 Savings and investment cost

The energy performance as well as auxiliary energy and water consumption for Riverview are given in Table 26. These results are for the solar cooling system only – the backup cooling system is not included. This was done to show the potential of a stand-alone solar cooling system. The backup cooling system is however included in the lifetime cost analysis in the next chapter.

Table 26. Energy and water consumption - Riverview

ENERGY	Unit	Peak Load	Average Summer	Annual Average	Minimal size
Metered electricity consumption[1]	MWhel/a	301	301	301	301
Calculated cooling load[2]	MWhth/a	591	591	591	591
Simulated cooling load provided	MWhth/a	175	148	88	62
Coverage cooling load	%	30	25	15	10
Auxiliary energy consumption	MWhel/a	84	61	19	17
Auxiliary water consumption	kL	666	566	335	228

1: Total electricity consumption for cooling per year.

2: From measured data

The system cost and main component sizes can be found in Table 27.

Table 27. Investment cost summary - Riverview

Riverview SOLAR COOLING SYSTEM	Unit	PEAK LOAD	SUMMER AVERAGE	ANNUAL AVERAGE	MINIMAL SIZE
Chiller capacity installed	kWth	176	150	84	50
Collector field size	m2	600	500	280	180
Total equipment cost	AU$	700,950	599,800	357,960	283,840
Total installation cost	AU$	147,520	122,470	71,234	49,670
Total system Cost	**AU$**	**848,470**	**722,270**	**447,194**	**333,510**
Specific system cost	AU$/kWth	4,714	4,815	5,324	6,670

3.5.2 Economic analysis

The cost for the solar cooling system and operation cost has to be compared against the total cost of conventional AC operation. The economic comparison is made as follows:

a) Baseline: New installation of conventional system
b) Solar cooling: New installation of solar cooling system sized for four different operation modes

For the base line calculations (a) the total cooling capacity of the chiller is assumed to be of the same capacity as installed on site eg sized for peak operation.

The solar cooling system (b) has been sized differently as explained in chapter 3.2. All lifetime costs are net present value (NPV) at 6% discount rate. An electricity price of AU$ 0.20/kWhel has been assumed for the first year with an annual increase of 2% over the lifetime calculations. CO_2 emissions have been calculated at 1.22 kgCO2/kWhel for Victoria.

Table 28. Lifetime cost analysis conventional system - Riverview

Riverview Conventional System	Unit	Total
Total electricity consumption/year	MWhel/a	301
Total maintenance cost/year	$/a	$ 1,000
Total O&M cost/year 1	$/a	$ 61,200
Total CO2 emission/year	t/a	367.2
Discount rate	%	6%
Unit lifetime	years	8
Equipment cost per 180 kW chiller	AU$	$ 75,000
Balance of plant	AU$	$ 20,000
Total equipment cost for conventional unit	AU$	$ 95,000
Total electricity consumption/lifetime	MWhel	2408
Total O&M cost/lifetime	AU$	$ 404,864
Total CO2 emission/20 yrs	t	7345
Projected total cost for 20 years	AU$	$ 1,001,801

Note: The investment cost for the conventional chiller in Table 28 does not include the cooling tower – it is included in the balance of plant cost. Balance of plant cost also includes piping, ducting, controls, refrigerant and electrical work. A CPI increase of 2.5 per annum has been assumed. Installation cost is assumed as 10% of total equipment cost.

A backup chiller of the same type as the conventional system is assumed in the following analysis of the solar cooling system.

Table 29. Lifetime cost analysis solar cooling system - Riverview

Riverview SOLAR COOLING SYSTEM	Unit	PEAK LOAD	SUMMER AVERAGE	ANNUAL AVERAGE	MINIMAL SIZE
Total electricity consumption/year	MWhel/a	83.5	60.9	19.3	17.0
Total maintenance cost/year	$/a	$ 1,000	$ 1,000	$ 1,000	$ 1,000
Total O&M cost/year	$/a	$ 17,698	$ 13,174	$ 24,579	$ 4,393
Total CO2 emission/year	t/a	101.9	74.3	23.6	20.7
Unit lifetime	years	20	20	20	20
Total system cost	AU$	$ 848,470	$ 722,270	$ 447,194	$ 333,510
Discount rate	%	6%	6%	6%	6%
Total electricity consumption SCS/20 yrs	MWhel	1669.8	1217.4	386.5	339.3
Total electricity consumption backup/20yrs	MWhel	4214	4515	5117	5418
Total CO2 emission/20 yrs	t	7178.2	6993.6	6714.3	7023.9
Total cost/20 yrs	AU$	$ 1,557,836	$ 1,419,623	$ 1, 131,146	$ 1,056,011

No design results in lower lifetime cost than the conventional system, however all designs result in lower GHG emissions than the conventional system.

3.6 *Three Bridges cold store*

3.6.1 Savings and investment cost

The energy performance as well as auxiliary energy and water consumption for Riverview are given in Table 30. These results are for the solar cooling system only – the backup cooling system is not included. This was done to show the potential of a stand-alone solar cooling system. The backup cooling system is however included in the lifetime cost analysis in the next chapter.

Table 30. Energy and water consumption – Three Bridges

ENERGY	Unit	Peak Load	Average Summer	Annual Average	Minimal size
Metered electricity consumption[1]	MWhel/a	127	127	127	127
Calculated cooling load[2]	MWhth/a	252	252	252	252
Simulated cooling load provided	MWhth/a	72	41	41	20
Coverage cooling load	%	29	16	16	8
Auxiliary energy consumption	MWhel/a	31	10	10	6
Auxiliary water consumption	kL	336	219	219	137

1: Total electricity consumption for cooling per year.

2: From measured data

The system cost and main component sizes can be found in Table 31.

Table 31. Investment cost summary – Three Bridges

Three Bridges SOLAR COOLING SYSTEM	Unit	PEAK LOAD	SUMMER AVERAGE	ANNUAL AVERAGE	MINIMAL SIZE
Chiller capacity installed	kWth	55	32	29	15
Collector field size	m2	180	100	100	50
Total equipment cost	AU$	317,840	210,190	201,190	112,160
Total installation cost	AU$	49,670	29,560	29,560	14,903
Total system Cost	**AU$**	**367,510**	**230,750**	**230,750**	**127,063**
Specific system cost	AU$/kWth	6,682	7,692	7,692	8,471

3.6.2 Economic analysis

The cost for the solar cooling system and operation cost has to be compared against the total cost of conventional AC operation. The economic comparison is made as follows:

a) Baseline: New installation of conventional system
b) Solar cooling: New installation of solar cooling system sized for four different operation modes

For the base line calculations (a) the total cooling capacity of the chiller is assumed to be of the same capacity as installed on site eg sized for peak operation.

The solar cooling system (b) has been sized differently as explained in chapter 3.2. All lifetime costs are net present value (NPV) at 6% discount rate. An electricity price of AU$ 0.20/kWhel has been assumed for the first year with an annual increase of 2% over the lifetime calculations. CO_2 emissions have been calculated at 1.22 kgCO2/kWhel for Victoria.

Table 32. Lifetime cost analysis conventional system – Three Bridges

Three Bridges Conventional System	Unit	Total	
Total electricity consumption/year	MWhel/a	127	
Total maintenance cost/year	$/a	$	1,000
Total O&M cost/year 1	$/a	$	26,432
Total CO2 emission/year	t/a	155.1	
Discount rate	%	6%	
Unit lifetime	years	8	
Equipment cost per 56 kW chiller	AU$	$	50,000
Balance of plant	AU$	$	10,000
Total equipment cost for conventional unit	AU$	$	60,000
Total electricity consumption/lifetime	MWhel	1017	
Total O&M cost/lifetime	AU$	$	174,622
Total CO2 emission/20 yrs	t	3103	
Projected total cost for 20 years *	AU$	$	478,030

Note: The system cost for the conventional chiller in Table 32 does not include the cooling tower – it is included in the balance of plant cost. Balance of plant cost also includes piping, ducting, controls, refrigerant and electrical work. A CPI increase of 2.5 per annum has been assumed. Installation cost is assumed as 10% of total equipment cost.

A backup chiller of the same type as the conventional system is assumed in the following analysis of the solar cooling system.

Table 33. Lifetime cost analysis solar cooling system – Three Bridges

Three Bridges SOLAR COOLING SYSTEM	Unit	PEAK LOAD	SUMMER AVERAGE	ANNUAL AVERAGE	MINIMAL SIZE
Total electricity consumption/year	MWhel/a	30.8	10.3	10.3	6.0
Total maintenance cost/year	$/a	$ 1,000	$ 1,000	$ 1,000	$ 1,000
Total O&M cost/year	$/a	$ 7,162	$ 3,060	$ 3,060	$ 2,205
Total CO2 emission/year	t/a	37.6	12.6	12.6	7.3
Unit lifetime	years	20	20	20	20
Total system cost	AU$	$ 367,510	$ 230,750	$ 230,750	$ 127,063
Discount rate	%	6%	6%	6%	6%
Total electricity consumption SCS/20 yrs	MWhel	616.2	206.0	206.0	120.5
Total electricity consumption backup/20 yrs	MWhel	1806	2136	2136	2340
Total CO2 emission/20 yrs	t	2954.7	2857.5	2857.5	3001.4
Total cost/20 yrs	AU$	$ 665,913	$ 526,811	$ 526,811	$ 443,921

Only the minimal size design results in 7% lower cost than the conventional system, while all systems result in lower GHG emissions.

3.7 Chapter summary

Four different solar cooling system configurations have been modelled for each of the four sites:

- Peak load
- Summer average load
- Annual average load
- Minimal size with conventional backup

For each configuration, the energy and GHG savings have been calculated as well as the lifetime cost compared to the existing conventional (peak load) system. Table 34 shows the summarised comparison of the best configuration of each site.

Table 34. Energy savings and lifetime cost for all sites (best configuration) compared to existing system

Best Configuration Solar Cooling	Dairy 2	Notman	Riverview	Three Bridges
Solar cooling fraction of total cooling load	80%	80%	30%	29%
Solar cooling fraction of total hot water load	65%	57%	-	-
Total energy consumption/20 yrs	-19%	-23%	-4%	-3%
Total GHG emission/20 yrs	-19%	-23%	-4%	-3%
Total lifetime cost/20 yrs	-16%	-9%	+5%	-7%
Design	Summer Avg	Summer Avg	Minimal Size	Minimal Size

From Table 34 it is obvious that the dairy farms have the better suitability for solar cooling. This is mainly due to their load profile which is not 24/7 operation like in the cold stores but daytime operation only. For a better analysis, the dairy farms have therefore been summarised in more detail as follows, again compared to the conventional system.

Table 35. Summary of Dairy 2 results.

Dairy 2	Peak Load	Summer Average	Annual Average	Minimal Size
Solar cooling fraction of total cooling load	80%	59%	59%	38%
Solar cooling fraction of total hot water load	76%	65%	65%	56%
Total energy consumption/20 yrs	-23%	-19%	-19%	+7%
Total GHG emission/20 yrs	-23%	-19%	-19%	+7%
Total lifetime cost/20 yrs	+19%	-16%	-16%	-12%

Table 36. Summary of Notman results.

Notman	Peak Load	Summer Average	Annual Average	Minimal Size
Solar cooling fraction of total cooling load	80%	67%	57%	33%
Solar cooling fraction of total hot water load	80%	59%	66%	57%
Total energy consumption/20 yrs	-26%	-23%	-21%	-4%
Total GHG emission/20 yrs	-26%	-23%	-21%	-4%
Total lifetime cost/20 yrs	+14%	-9%	-8%	-16%

4 CONCLUSIONS

This work provides a study of different solar cooling system configurations applied to four different sites, namely two dairy farms and two cold stores in Victoria. Four options have been analysed per site, a peak load configuration based on maximum cooling capacity, a summer average load configuration based on the average capacity during summer months, an annual average load configuration based on the annual average capacity and finally a minimal size configuration where the smallest commercially available absorption chiller was chosen.

In the first part of the study the cooling and hot water loads (dairy farms only) have been analysed. Firstly, the loads have been calculated using metered electricity data for each site and annual average coefficients of performance (COP) for the installed refrigeration systems. Secondly, the cooling and hot water loads have been modelled using a commercial software package. For the dairy farms the milking and cleaning schedules of have been implemented in the software. The cold stores have been modelled as individual buildings using construction data provided. Annual load simulations in hourly time intervals have then been carried out for each site using appropriate weather data. The results show very good agreement between calculated and simulated data for the dairy farms with a variation of ± 10%. The results for the cold stores match within an average of 32%.

The second part of the study investigates the energy and GHG savings of the different solar cooling system configurations for each site. Time-dependent annual performance modelling has been carried out for each configuration to examine energy and water consumption as well as CO_2 emissions. Further, an economic analysis has been carried out with regard to investment and lifetime cost for each configuration, comparing to the existing conventional system. The summarised results are shown in the following table.

Solar Cooling	Dairy 2	Notman	Riverview	Three Bridges
Solar cooling fraction of total cooling load	80%	80%	30%	29%
Solar cooling fraction of total hot water load	65%	57%	-	-
Total energy consumption/20 yrs	-19%	-23%	-4%	-3%
Total GHG emission/20 yrs	-19%	-23%	-4%	-3%
Total lifetime cost/20 yrs	-16%	-9%	+5%	-7%
Design	Summer Avg	Summer Avg	Minimal Size	Minimal Size

It can be seen that solar cooling can contribute up to 80% of the total cooling load and 57-65% of the hot water load for the dairy farms (Dairy 2 and Notman). Lifetime cost can be reduced between 9-16% compared to the existing conventional system. Greenhouse gas emissions can be reduced up to 23% in the dairy farms using solar cooling.

The contribution of a solar cooling system in the cold stores is much lower than in the dairy farms, mainly because cold stores require 24hr operation of their refrigeration systems, while dairy farms only operate during the day. Solar contributions of 30% can be achieved towards the cooling loads of the two cold stores (Riverview and Three Bridges), resulting in energy and GHG savings of 3-4%. The cost decrease compared to the existing system is between +5 and -7 % in the best configurations, respectively.

It can be concluded that for the configurations investigated in this study the application in dairy farms looks more promising than in cold stores. Significant reductions in lifetime cost, energy consumption and GHG emissions are possible in the dairy farms.

5 REFERENCES

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6 APPENDIX

6.1 Additional simulation results using exchanged climate zones

An additional investigation was to perform the same simulations as described in chapter 3 but for exchanged climate zones. Using the same sites, TRNSYS has been used to simulate the solar cooling systems with the following climate zones, Table 37.

Table 37. Exchanged weather data used in additional TRNSYS simulations

Name of site	Weather data from station	Climate zone
Dairy 2	Kyabram	3
Notman	Kyabram	3
Riverview	Melbourne	4
Three Bridges	Kyabram	3

This has been done to investigate the influence of different climate zones on the solar cooling system performance. The two climate zones 3 and 4 are slightly different. Climate zone 3 is located in the north of Victoria, near the NSW border. It has a total horizontal solar radiation of 1667 kWh/m2/a. Climate zone 4 is located around Melbourne and has a total horizontal solar radiation of 1533 kWh/m2/a. Climate zone 4 also has slightly lower ambient temperatures on average. Therefore, cooling loads should be higher in climate zone 3 due to the higher ambient temperatures. Solar coverage should also be higher in climate zone 3 due to the higher solar radiation.

The following tables show the simulation results for exchanged climate zones.

6.1.1 Dairy 2 dairy farm

Table 38. Energy and water consumption - Dairy 2 - with exchanged climate zone

ENERGY	Unit	Peak Load	Average Summer	Annual Average	Minimal size
Metered electricity consumption[1]	MWhel/a	67	67	67	67
Calculated cooling load[2]	MWhth/a	58.4	58.4	58.4	58.4
Calculated hot water load[2]	MWhth/a	38.3	38.3	38.3	38.3
Simulated cooling load provided	MWhth/a	44.2	33.7	33.7	22.4
Simulated hot water load provided	MWhth/a	25.9	14.5	14.5	5.5
Coverage cooling load	%	84	64	64	43
Coverage heating load	%	84	69	69	57
Auxiliary energy consumption	MWhel/a	30	9.7	9.7	5.8
Auxiliary water consumption	kL	176	148	148	99

1: Total electricity consumption for cooling and hot water per year as measured in original location.

2: From measured data in original location.

6.1.2 Notman dairy farm

Table 39. Energy and water consumption - Notman - with exchanged climate zone

ENERGY	Unit	Peak Load	Average Summer	Annual Average	Minimal size
Metered electricity consumption[1]	MWhel/a	85	85	85	85
Calculated cooling load[2]	MWhth/a	62	62	62	62
Calculated hot water load[2]	MWhth/a	46	46	46	46
Simulated cooling load provided	MWhth/a	53.6	45.6	39.6	22.7
Simulated hot water load provided	MWhth/a	34	22.4	18.4	8.2
Coverage cooling load	%	86	73	64	37
Coverage heating load	%	87	74	70	59
Auxiliary energy consumption	MWhel/a	42.7	20.8	17.3	6.3
Auxiliary water consumption	kL	245	197	169	105

1: Total electricity consumption for cooling and hot water per year as measured in original location.

2: From measured data in original location.

6.1.3 Riverview cold store

Table 40. Energy and water consumption - Riverview - with exchanged climate zone

ENERGY	Unit	Peak Load	Average Summer	Annual Average	Minimal size
Metered electricity consumption[1]	MWhel/a	301	301	301	301
Calculated cooling load needed[2]	MWhth/a	591	591	591	591
Simulated cooling load needed[3]	MWhth/a	346	346	346	346
Simulated cooling load provided[3]	MWhth/a	163	137	78	54
Coverage cooling load	%	28	23	13	9
Auxiliary energy consumption	MWhel/a	66.8	49.2	16.5	14.8
Auxiliary water consumption	kL	546	467	270	185

1: Total electricity consumption for cooling per year.

2: From measured data

3: From simulation

6.1.4 Three Bridges cold store

Table 41. Energy and water consumption – Three Bridges - with exchanged climate zone

ENERGY	Unit	Peak Load	Average Summer	Annual Average	Minimal size
Metered electricity consumption[1]	MWhel/a	127	127	127	127
Calculated cooling load needed[2]	MWhth/a	252	252	252	252
Simulated cooling load needed[3]	MWhth/a	229	229	229	229
Simulated cooling load provided[3]	MWhth/a	87	46.5	46.5	24.6
Coverage cooling load	%	35	18	18	10
Auxiliary energy consumption	MWhel/a	35.9	9.0	9.0	6.8
Auxiliary water consumption	kL	437	262	262	198

1: Total electricity consumption for cooling per year.

2: From measured data

3: From simulation

6.1.5 Chapter summary

The comparison of the results for original and exchanged climate zones is given in Table 42 and Table 43. (PL: peak load, AS: average summer, AA: average annual, MS: minimal size)

Table 42. Comparison of results for different climate zones – dairy farms

SITE		Dairy 2				Notman			
	Unit	PL	AS	AA	MS	PL	AS	AA	MS
Original climate zone: Calculated cooling load needed	MWhth/a	58	58	58	58	62	62	62	62
Original climate zone: Simulated cooling load provided	MWhth/a	41.2	30.1	30.1	20	50	42	35	20
Original climate zone: Coverage cooling load	%	80	59	59	38	80	67	57	33
Original climate zone: Calculated hot water load needed	MWhth/a	38	38	38	38	46	46	46	46
Original climate zone: Simulated hot water load provided	MWhth/a	20.2	11	11	4.6	28	18	15	7
Original climate zone: Coverage hot water load	%	76	65	65	56	80	59	66	57
Exchanged climate zone: Calculated cooling load needed	MWhth/a	58	58	58	58	62	62	62	62
Exchanged climate zone: Simulated cooling load provided	MWhth/a	44.2	33.7	33.7	22.4	53.6	45.6	39.6	22.7
Exchanged climate zone: Coverage cooling load	%	84	64	64	43	86	73	64	37
Exchanged climate zone: Calculated hot water load needed	MWhth/a	38	38	38	38	46	46	46	46
Exchanged climate zone: Simulated hot water load provided	MWhth/a	25.9	14.5	14.5	5.5	34	22.4	18.4	8.2
Exchanged climate zone: Coverage hot water load	%	84	69	69	57	87	74	70	59
Original to exchanged climate zone: Difference in coverage cooling load	% abs	+4	+5	+5	+5	+6	+6	+7	+4
Original to exchanged climate zone: Difference in coverage hot water load	% abs	+8	+4	+4	+1	+7	+15	+4	+2

Table 43. Comparison of results for different climate zones – cold stores

SITE		Riverview				Three Bridges			
	Unit	PL	AS	AA	MS	PL	AS	AA	MS
Original climate zone: Simulated cooling load needed	MWhth/a	368	368	368	368	187	187	187	187
Original climate zone: Simulated cooling load provided	MWhth/a	175	148	88	62	72	41	41	20
Original climate zone: Coverage cooling load	%	30	25	15	10	29	16	16	8
Exchanged climate zone: Simulated cooling load needed	MWhth/a	346	346	346	346	229	229	229	229
Exchanged climate zone: Simulated cooling load provided	MWhth/a	163	137	78	54	87	46.5	46.5	24.6
Exchanged climate zone: Coverage cooling load	%	28	23	13	9	35	18	18	10
Original to exchanged climate zone: Difference in cooling load provided	MWhth/a	-12	-11	-10	-8	+15	+5.5	+5.5	+4.6
Original to exchanged climate zone: Difference in coverage	% abs	-2	-2	-2	-1	+6	+2	+2	+2

It can be seen that the results are as expected. Moving a site from colder and less sunny climate zone 4 to warmer and more sunny climate zone 3 (Dairy 2, Notman, Three Bridges) results in better performance of the solar cooling system. Increases of up to 7% in cooling and up to 15% in hot water load coverage can be achieved for the dairy farms, while an increase of up to 6% can be achieved for Three Bridges cold store. Moving a site from warmer and sunny climate zone 3 to colder and less sunny climate zone 4 (Riverview) results in decreased solar cooling system performance. A decrease in performance of 2% can be observed for Riverview cold store.