Improving Winery Refrigeration Efficiency
Winery B
Case study report 2

- Storage temperatures
- Night-time cooling

Funded by:

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Abstract

Trials were performed on the use of different wine storage temperatures and the use of night-time cooling in order to shift peak electricity use to cheaper off-peak electricity use.

Two storage temperature trials with a Chardonnay wine and a Semillon-Chardonnay wine found no significant sensory difference between wine that had been stored at an average temperature of 10°C as opposed to 5°C for a period of two-three months. The effect of storage temperature on quality may vary for other wines, and a simple equation to quickly estimate order of magnitude savings from storage (when using tanks with 75 mm thick polystyrene insulation) at warmer temperatures is provided so individual wineries can balance electricity savings against their own assessed risks of warmer storage temperatures to product quality:

$$\text{Maintenance saving (\$/kL/week)} = 0.006 \times \left(\frac{1}{\mathrm{L}} + \frac{4}{\mathrm{D}}\right) \times \left(\mathrm{T_{High}}\text{-}\mathrm{T_{Low}}\right)$$

Where T_{Low} and T_{High} are the alternate storage temperatures under consideration (e.g. 5°C and 10°C), and L and D are the tank height and diameter, respectively in m.

Night-time cooling trials were performed for a tank-farm consisting of twenty-four 10 kL tanks serviced by a custom ammonia refrigeration plant and brine reticulation system. Modifications were made to control systems to allow different day and night tank temperature set-points. This strategy worked effectively with refrigeration plant power monitoring demonstrating the shift of refrigeration plant operation from short repeated cycles throughout the day to operation predominantly at night for a sustained period.

The shifting of peak to off-peak electricity use by this or similar means is an opportunity for wineries to save on electricity costs. Often energy saving opportunities in wineries have to be balanced against a risk to quality (e.g. storing wine at warmer temperatures), which can be difficult to quantify. In comparison, night-time cooling has minimal quality risks when correctly implemented, as wine is still being stored at essentially the same temperatures – just using cheaper electricity for refrigeration. Additionally, refrigeration plants should operate more efficiently in lower ambient temperatures (if compressor discharge pressure is allowed to float appropriately), and operation for a sustained period instead of short repeated cycles would be expected to reduce wear on equipment. Options for different wineries will depend on their existing control system. As a conservative means of estimating potential savings it is recommended that the differential between the unit price of peak and off-peak electricity combined with the quantity of electricity that is likely to be shifted from the peak to the off-peak tariff be used. Where new control systems are being installed, a control system that accommodates the increased use of off-peak as opposed to peak electricity should be selected as a matter of course.

Contents

1. Introduction

Refrigeration can account for 50%-70% of winery electricity consumption. Improving the efficiency of winery refrigeration is therefore of considerable interest. The Grape and Wine Research and Development Corporation (GWRDC) funded a project by Commercial Services at The Australian Wine Research Institute (AWRI) to help the Australian wine industry improve refrigeration efficiency and decrease electricity usage and/or costs.

As part of this project, a reference guide was produced and is available for download from the GWRDC (www.gwrdc.com.au) and AWRI (www.awri.com.au) websites. This short guide provides background on the operation of winery refrigeration systems and lists improvement opportunities.

Case studies were performed at two wineries (Winery A and Winery B) during 2011 in order to investigate some improvement opportunities/topics in more detail. These case studies have been written up in three technical reports (this document and two others) and are available for download from the aforementioned websites.

This report describes the work at Winery B related to bulk wine storage. Storage temperatures and the use of night-time cooling were investigated.

2. Materials and methods

2.1 Winery and cooling system

Winery B is a large winery (>20,000 tonnes) with five refrigeration plants (all employing ammonia as refrigerant), which provide direct expansion cooling of some tanks/devices as well as cold brine for reticulation around the winery to cool other tanks.

2.2 Storage temperature trial

Two storage temperature trials were performed outside in two 58 kL (nominal) stainless steel tanks insulated with 75 mm thick Isolite Class SL expanded polystyrene. The first trial involved storing Chardonnay wine for approximately two months with a tank temperature set-point of 5°C or 15°C. The second trial involved storing Semillon-Chardonnay wine for a period of approximately four months with a tank temperature set-point of 5°C or 15°C. The hysteresis ('deadband') setting was 0.5°C (i.e. if the set-point was 5°C, the tank brine jacket valve would open when the wine temperature had warmed to 5.5°C and then would close when the wine temperature had been reduced to 5°C). The tank agitator status was set to Auto, such that the agitator was on whenever brine was flowing through the tank cooling jacket and was off when the brine was not flowing.

The experimental arrangement employed for each tank and the approximate tank dimensions are illustrated in Figure 2.1. For each tank, brine flow rate (F_{Brine}) was measured using a ¾" turbine flow meter (G2S07I09LMA; GPI, USA) and brine temperatures into ($T_{Brine,in}$) and out of ($T_{Brine,out}$) the cooling jacket were measured using 12-bit temperature sensors (S-TMB; Onset, USA) inserted in custom-built in-line thermowells. Juice/wine temperature was measured using a sensor inserted in a new thermowell installed next to the tank door (T_{Low}) and also by a sensor directly in the juice/wine much higher in the tank (T_{High}). These sensors were interfaced with a data logger capable of communicating via the GSM cellular network (Hobo U30/GSM; Onset) logging at one minute intervals. A pulse access module (GPI) and pulse input adapter (Onset) were required to interface each flow meter with the data logger. In addition to this AWRI data logger, temperatures recorded by the winery's own temperature probe (T_{Mid}) were logged at five minute intervals together with the set-point temperature and the tank agitator status using the winery Citect SCADA system. However, the availability of this data was inconsistent as a consequence of intermittent system issues. The experimental arrangement was identical to that used in 2011 vintage fermentation trials performed at Winery B. Additional photos illustrating the experimental arrangement are included in that case study report.

The cooling imparted on the wine by the brine flowing through the tank jacket over the course of the storage trial was calculated from the logged brine flow rate (F_{Brine}) and brine temperature rise ($T_{Brine,out} – T_{Brine,\ in}$) during each minute of the storage time, assuming the brine properties presented in Table 2.1. Average daily ambient temperature data during the trial were calculated by taking the average of the minimum and maximum temperatures from the closest (~10 km away) weather station (Bureau of Meteorology 2012).

Wine chemical analyses were performed by the winery's laboratory during the trial using standard techniques. Duo-trio difference sensory testing was performed once during each storage trial at the winery. In both cases, the 5°C wine was used as the reference.

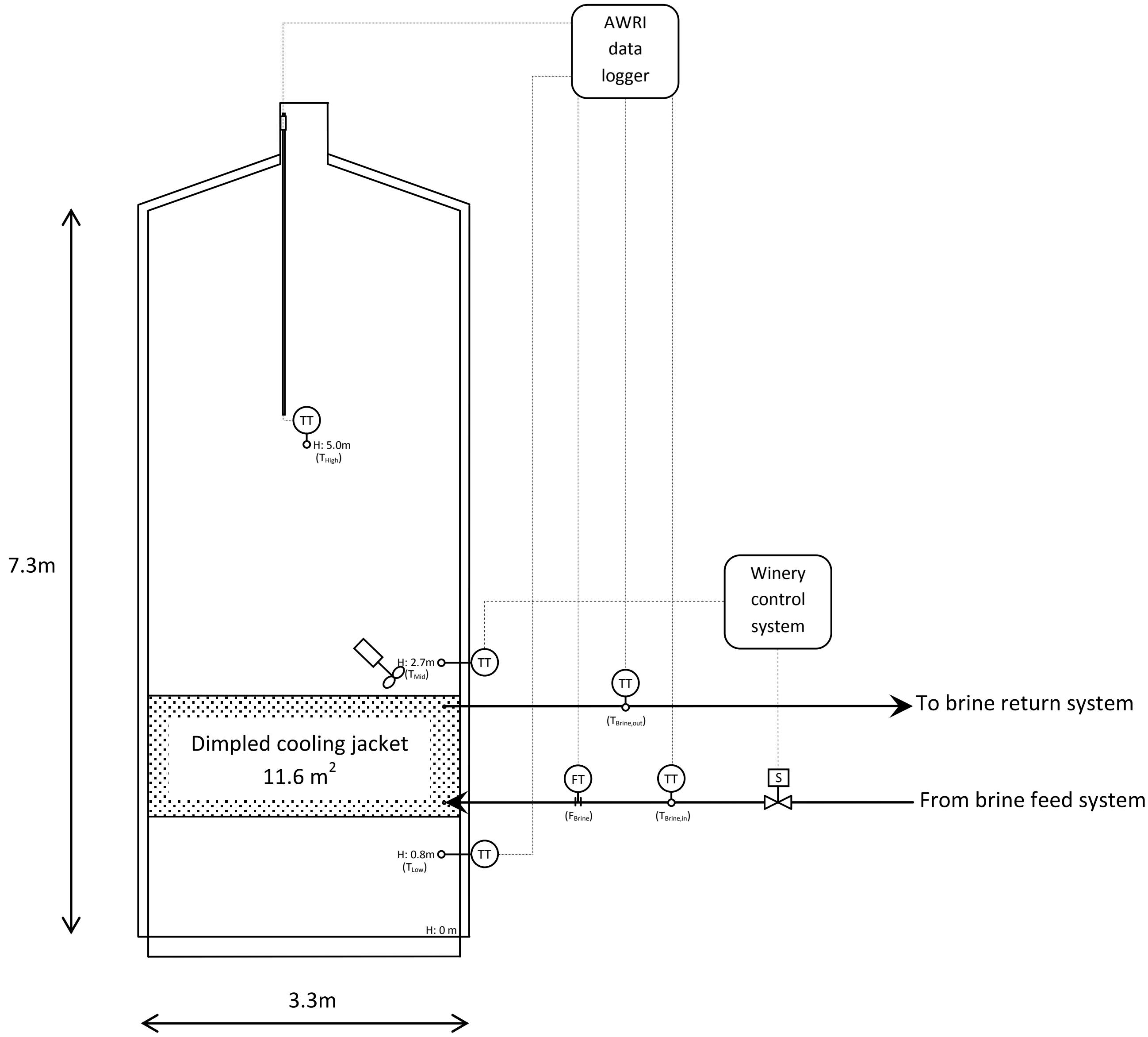

Figure 2.1: Approximate tank dimensions and control/data logging arrangement for one of the two 58 kL tanks (tank fittings, brine line ball valves and strainers not shown)

Table 2.1: Properties of brine and wine

Property	Brine[a]	Wine[b]
Density (kg/m^3):	985	978
Specific heat capacity (kJ/kg/°C):	3.6	4.3

[a]Brine properties from Alcool LF data spreadsheet obtained by email from Wendy Do at Sucrogen Bioethanol in November 2010. A brine freezing point of -15°C was assumed, which corresponds with an Alcool LF concentration of 34% v/v.
[b]Wine properties from Rankine (2004), assuming a wine temperature of 10°C.

2.3 Night-time cooling trial

The night-time cooling trial was performed in a tank farm comprising twenty-four 10 kL wine tanks serviced by a custom ammonia refrigeration plant and a brine reticulation system. The wine tanks had dimpled cooling jackets and were insulated in a similar manner to the 58 kL tanks discussed previously but were located in a shed. The general tank-farm/brine distribution arrangement is shown in Figure 2.2. Key components of the refrigeration plant and the wine tank design are shown in Figures 2.3 and 2.4, respectively.

The tank farm temperature control system consisted of a Programmable Logic Controller (PLC) interfaced with a PanelView screen. This was also partially interfaced with a Citect SCADA system. Prior to the trial, the control system only allowed for a single temperature set-point for each tank. Modifications were made to the system to facilitate this trial and allow the setting of dual set-points: a 'day' set-point and a 'night' set-point. The ability to set the time when the 'day' and 'night' started was also added. The Citect SCADA system was programmed to log the actual temperature, set-point temperature and agitator status for each of the 24 tanks in the farm at 20 minute intervals.

Electricity use by the refrigeration plant (including the brine tank to refrigeration plant pump) was monitored using a power logger (PowerMonic PM30Plus-E; Gridsense, Australia, Figure 2.5) at 30 second intervals. 0-100 A current clamps were used on each phase. The pump distributing brine to the tank farm was on a separate electrical circuit and was monitored using three 0-20 A current clamps (Magnelab, USA, Figure 2.6). Voltage and power factor were not measured for this pump so average values obtained from the main power logger were employed to calculate power use. These current clamps were interfaced with a data logger (Hobo U30/NRC; Onset) using a Flexsmart TRMS module (Onset) and data were logged at 30 second intervals. Ambient temperature during the trial was monitored using a temperature sensor interfaced with the same data logger.

The trial procedure was to alternate between periods using single tank set-point temperatures and periods using different day and night set-point temperatures (i.e. dual set-points). Night was set as being between 2:00 am and 6:00 am, with day being the remaining hours. The tank farm was in regular production use and for this trial it was not possible to dictate when wine entered or exited. Between 11 and 13 of the 24 tanks contained wine being subject to temperature control at different times during the trial. The protocol when switching from the single-set point mode to the dual set-point mode was to make the night set-point 0.5°C lower than the single set-point (which the winemaker had set) and the day set-point 0.5°C higher than the single set-point for each wine tank. For example, if a set-point of 5°C was used when in the normal single set-point mode, a night set-point of 4.5°C and a day set-point of 5.5°C would be used. In all cases, the hysteresis setting was 0.5°C.

The refrigeration plant itself had a separate control system. The refrigeration plant brine set-point was -8°C with a hysteresis setting of 2°C (i.e. the refrigeration plant would start running when the brine tank temperature had warmed to -6°C and stop running when the brine tank had been cooled to -8°C).

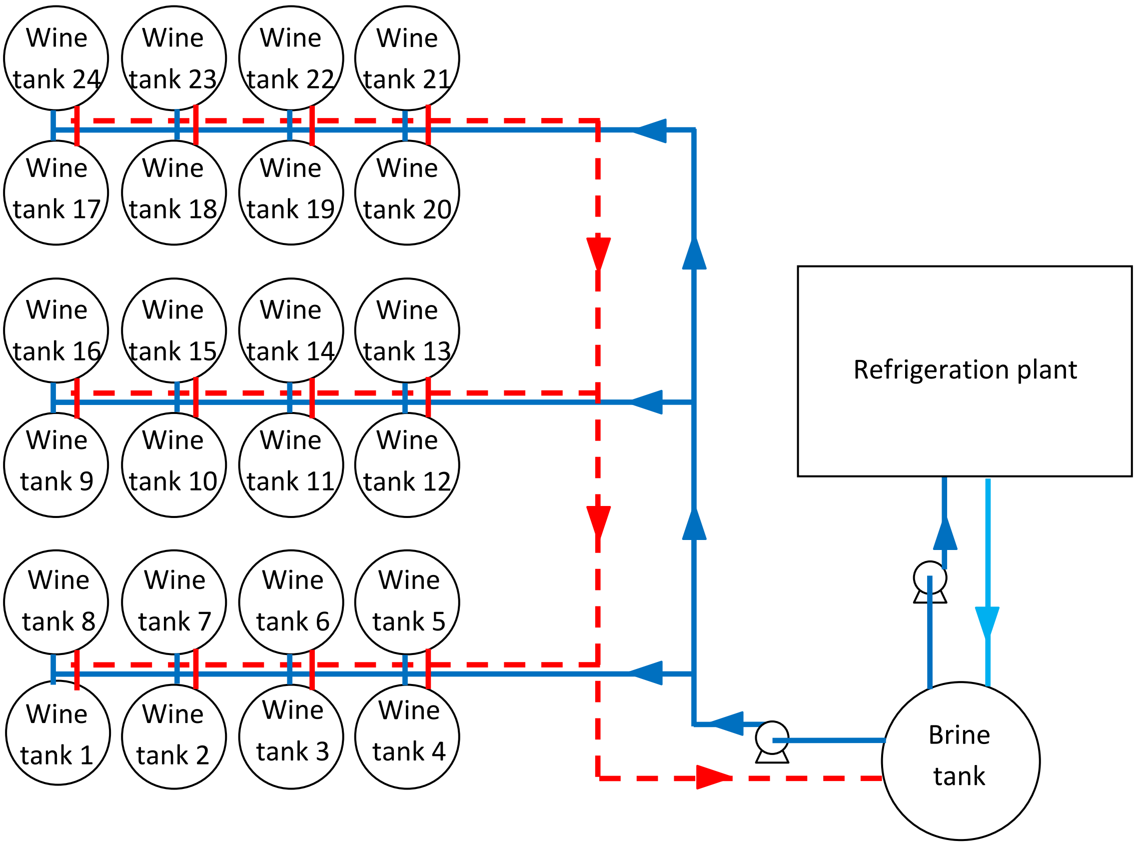

Figure 2.2: Simplified tank farm arrangement showing brine distribution to cooling jackets on 10 kL wine tanks

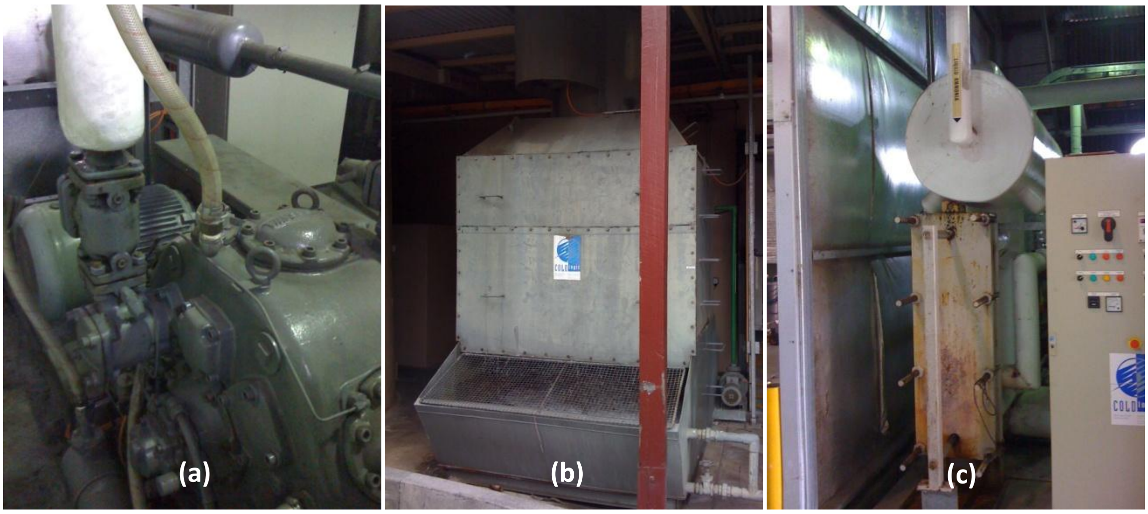

Figure 2.3: Key refrigeration plant components: (a) Compressor, (b) Condenser, and (c) Evaporator

Figure 2.4: 10 kL wine tanks: (a) front, and (b) rear

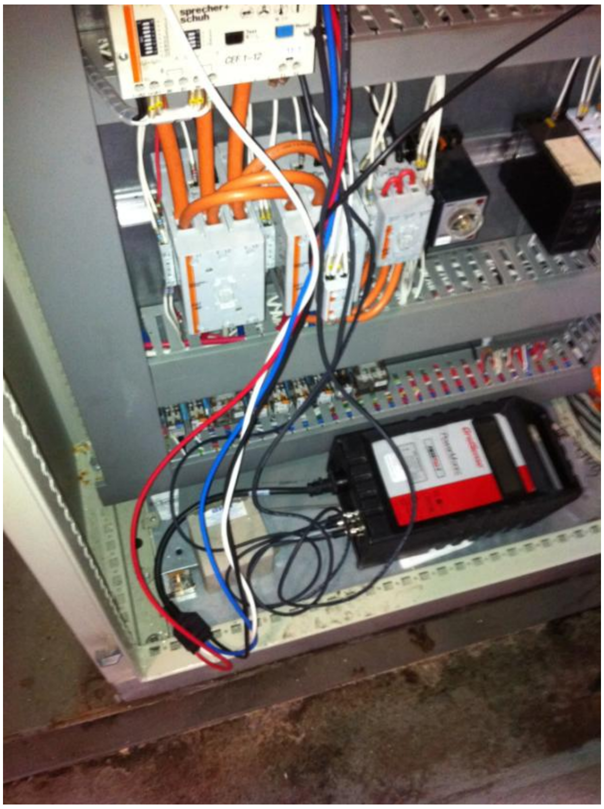

Figure 2.5: Power logger connected to refrigeration plant power supply

Figure 2.6: Current clamps connected to brine distribution pump power supply

3. Results and discussion

3.1 Storage temperatures

The brine flow rate through each tank jacket, wine set-point and actual temperature, and daily average ambient temperature are shown in Figures 3.1 and 3.2 for the Chardonnay trial and Figures 3.3 and 3.4 for the Semillon-Chardonnay trial. Please note that the gaps in wine set-point and actual temperature data were related to winery data logging system issues. The winery control systems themselves were still working correctly during these times. Chemical and sensory data are reported in Tables 3.1 and 3.2.

In each trial, the wine had been previously stored in a larger common tank before being divided between the two 58 kL tanks. In the Chardonnay trial, the wine was at approximately 10°C when it was pumped into the two 58 kL tanks. The set-point in one of the tanks was 5°C, therefore brine flowed initially for a period to pull the wine temperature down to set-point. Cooling was then intermittently required to maintain the wine temperature at 5°C. For the tank with a set-point of 15°C, no cooling was required throughout the Chardonnay trial as the relatively low ambient temperature (averaging approximately 10°C) meant that the wine never warmed to the set-point temperature. Similar general patterns were seen for the Semillon-Chardonnay trial. However, as the ambient temperatures were higher, the 15°C set-point wine eventually warmed and did require cooling. In Figure 3.3, it is also clear that the period between brine jacket operations decreased as the ambient temperature increased.

As an indication of costs associated with cooling, the cost of pulling down the temperature of the Chardonnay from 9.7°C to 5°C was $0.37/kL (assuming an electricity cost of $0.15/kWh and a COP_{+brine} of 2). The average maintenance cost over the rest of that trial was $0.07/kL/week. In the Semillon-Chardonnay trial, the maintenance costs were significantly higher for the same wine temperature as a consequence of warmer ambient temperatures, e.g. they averaged $0.22/kL/week for maintenance at 5°C over the period between 3/11/2011 and 20/12/2011. The influence of the wine-average ambient temperature differential on cost is presented in Figure 3.5 based on data for five different maintenance periods during the trials. The overall heat transfer coefficient over these periods, calculated from the brine exchange energy, ranged from 0.65 to 0.85 $W/m^2/°C$, with an average of 0.76 $W/m^2/°C$. This was higher than the 0.47 W/m2/°C expected from theory (see Appendix A for calculation). This may indicate a problem with the insulation on these specific tanks or might be related to the applicability of data from the weather station located 10 km away and to the averaging of the minimum and maximum temperatures to derive the average ambient temperature.

No significant difference between the two temperature treatments was observed during sensory analysis in either trial (Tables 3.1 and 3.2). However, it should be noted that the average wine temperature over the storage period was actually 5°C vs 10°C in both instances as opposed to 5°C vs 15°C, since the wine was initially at less than 15°C. These results are only for two wines and the effect of storing wine at different temperatures on quality is not going to be decided by this trial alone, particularly given the different existing industry opinions on this matter. However, it is possible to make some quick order of magnitude estimates of the potential savings possible from storing wine at warmer temperatures, such that individual winemakers can make decisions on whether the savings outweigh the risks for their specific product. Using the theoretical overall heat transfer coefficient of 0.47 W/m^2/°C, and the previously stated assumptions of COP and electricity cost, the electricity saving from storing wine in (75 mm polystyrene insulated) tanks at a temperature of T_{High} instead of T_{Low} can be estimated using (see Appendix B for derivation):

$$\text{Maintenance saving (\$/kL/week)} = 0.006 \times \left(\frac{1}{L}+\frac{4}{D}\right) \times \left(T_{High} - T_{Low}\right) \qquad \text{Eq. 1}$$

If we look at a winery that typically stores wine in tanks that are 10 m tall and 7 m in diameter, the saving from using a storage temperature of 10°C instead of 5°C would be $0.02/kL/week. If that winery held stocks of 30,000 kL subject to this regime throughout the year, the annual saving would be approximately $31,000 (if this calculation was performed using the experimentally determined overall heat transfer coefficient of 0.76 W/m^2/°C the saving would be $51,000). Whether this saving justified the risk of storing at the warmer temperature is something that would be a decision for that winery. Any saving is beneficial and if there is no risk it is an easy decision, but this example considered a fairly large volume of wine, and a large change in storage temperature (10°C - 5°C = 5°C) and the savings were not huge. This was based on a well insulated tank. The results will be different for an uninsulated tank, where heat gains may result in savings several times this, and heat transfer associated with condensation on the outside of tanks may become important.

In addition to the maintenance temperature saving, the cost of pulling down the temperature of a large volume of wine can be considerable as was observed in this trial. Employing the same assumptions on electricity price and system performance described previously, the cost of the electricity used to pull wine down from $T_{Initial}$ to T_{Final} (°C) can be estimated using (see Appendix C for derivation):

$$\text{Pull-down cost (\$/kL)} = 0.09 \times (T_{Initial} - T_{Final}) \qquad \text{Eq. 2}$$

This is somewhat different to the maintenance saving in that this might not be completely wasted. If the wine is subsequently going to be stored at a warmer temperature, the extra 'cold' can offset some of the refrigeration requirement to maintain the wine at that warmer temperature. The 'cold' may also be recovered by product-product heat exchange. The lifetime temperature profile of the wine really needs to be considered to understand cost. If wine had been stored at 5°C and then it was warmed up prior to bottling to 15°C, without any heat recovery, then from Eq. 2, $0.90/kL has been spent (excluding the cost of energy used to provide warming).

In the current trial, when a set-point of 15°C was used, the wine was often at a much lower temperature since the wine was at a lower temperature when it was pumped into the tank. In this case, the use of the set-point temperature alone to describe the wine temperature would be misleading. It is speculated that wine might often be stored cooler than winery staff think is being stored at because of situations such as this.

Dimpled cooling jackets with a surface area of 11.6 m^2 were installed on the tanks used in these trials. These were calculated to have an overall heat transfer coefficient of approximately 400

$W/m^2/°C$ during cooling. In this trial, the tank agitators were set to auto such that they ran whenever the brine was flowing. In arrangements without this vigorous mixing it is expected that the cooling jacket heat transfer coefficient would be significantly lower. In this winery and many others it is atypical to agitate during storage. Agitation was a necessity in these tanks to prevent brine-induced stratification as a consequence of the placement of the only cooling jacket at the bottom of the tank (see Winery B case study report 1 for further details). The use of agitation during brine flow is something that should be considered by wineries given the likely much higher heat transfer coefficients. The overall savings in energy may be relatively small (slightly reduced heat gains/brine pumping from reduced brine recirculation) but the faster cooling speed can have benefits including completing a pull-down in tank temperature in periods of cheaper electricity (i.e. night-time cooling).

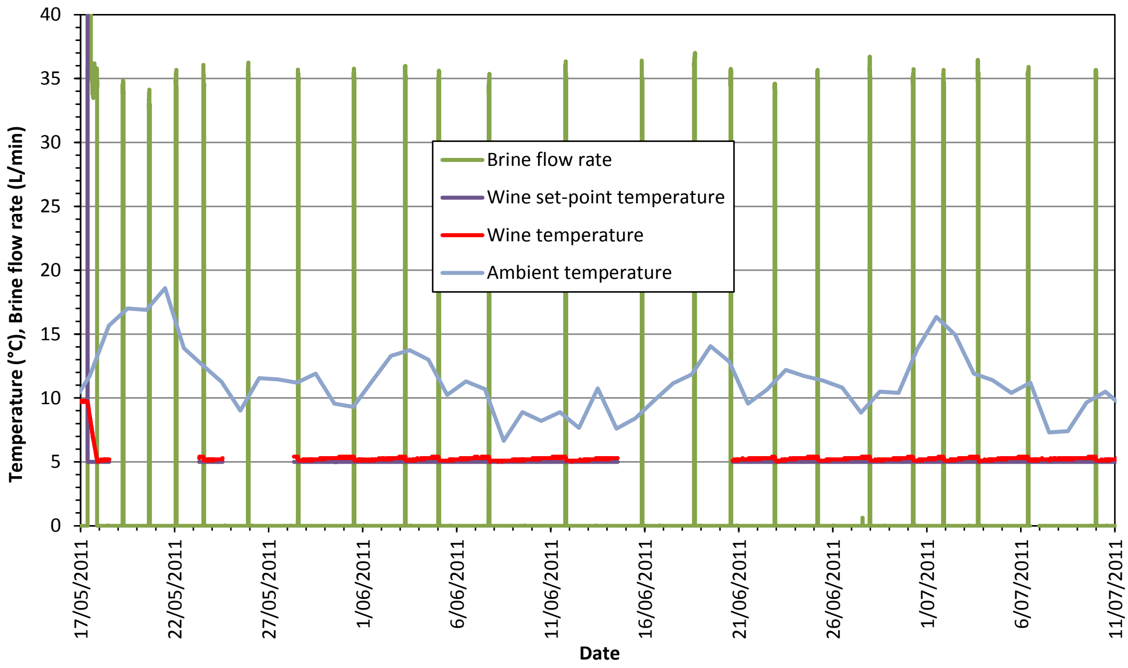

Figure 3.1: Chardonnay, 5°C set-point

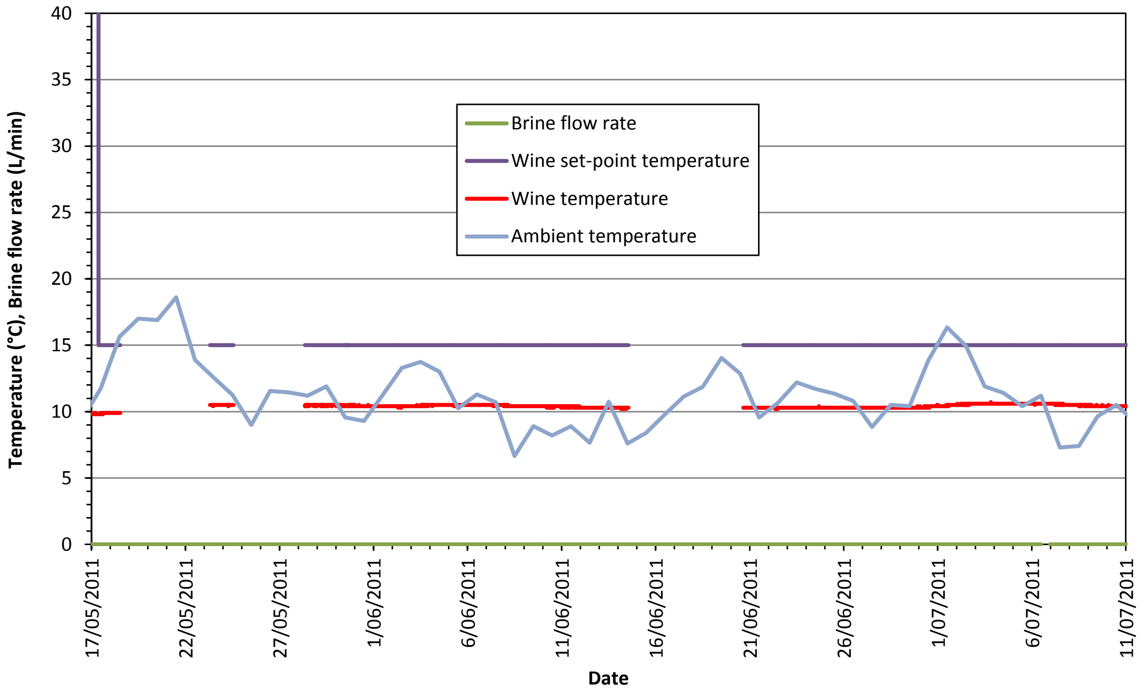

Figure 3.2: Chardonnay, 15°C set-point

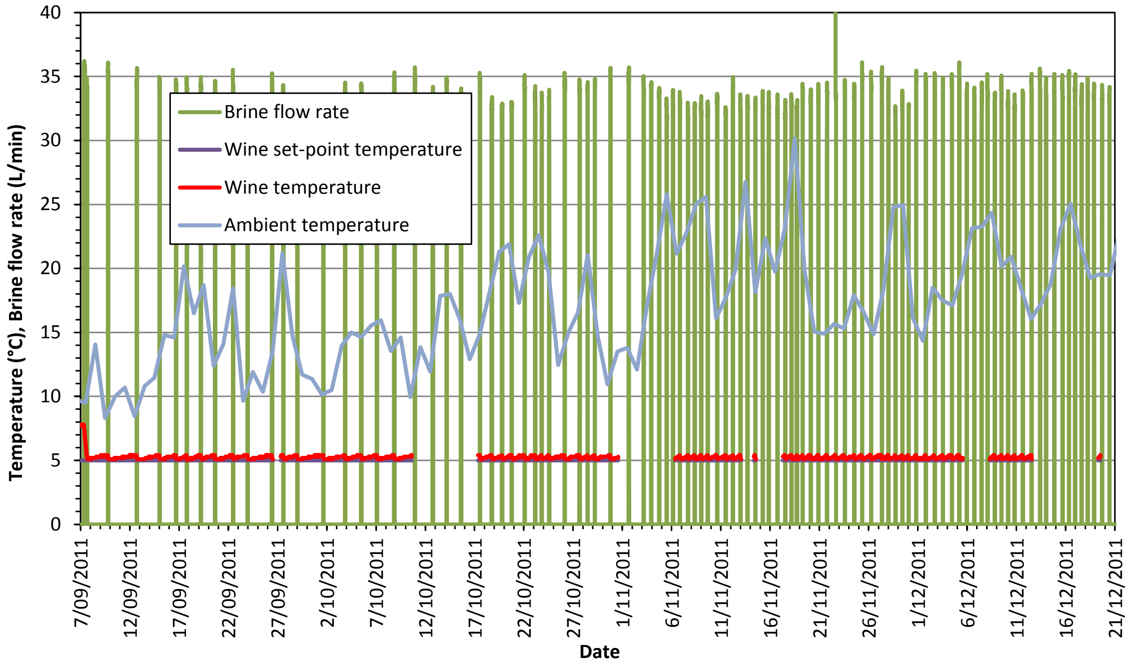

Figure 3.3: Semillon-Chardonnay, 5°C set-point

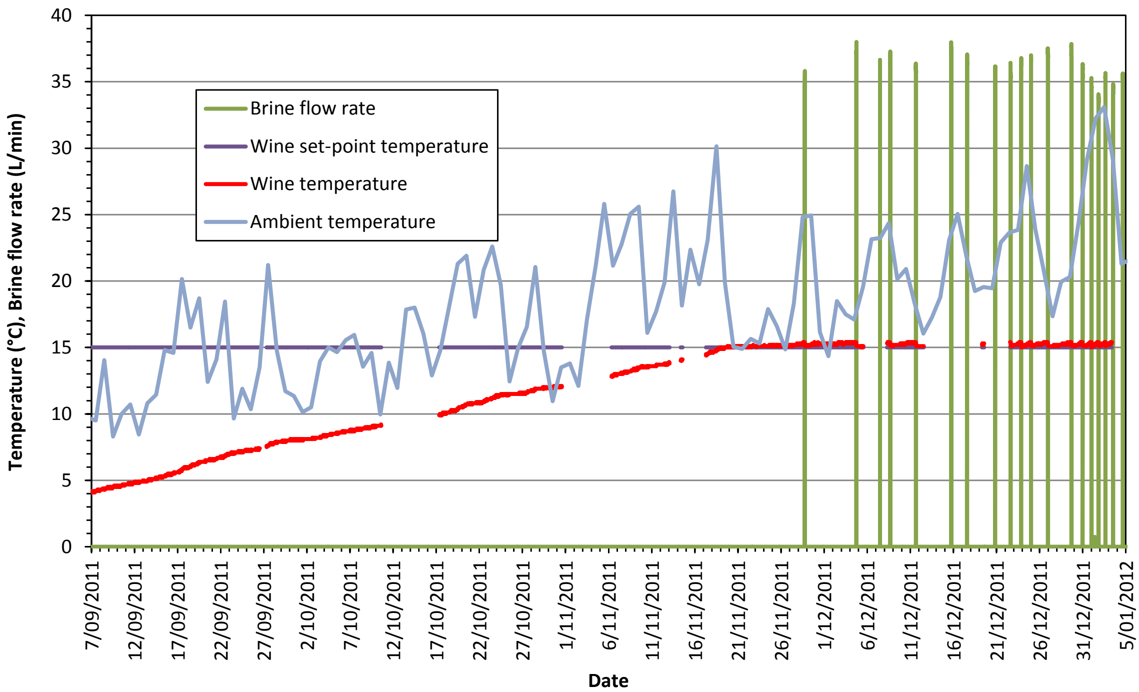

Figure 3.4: Semillon-Chardonnay, 15°C set-point

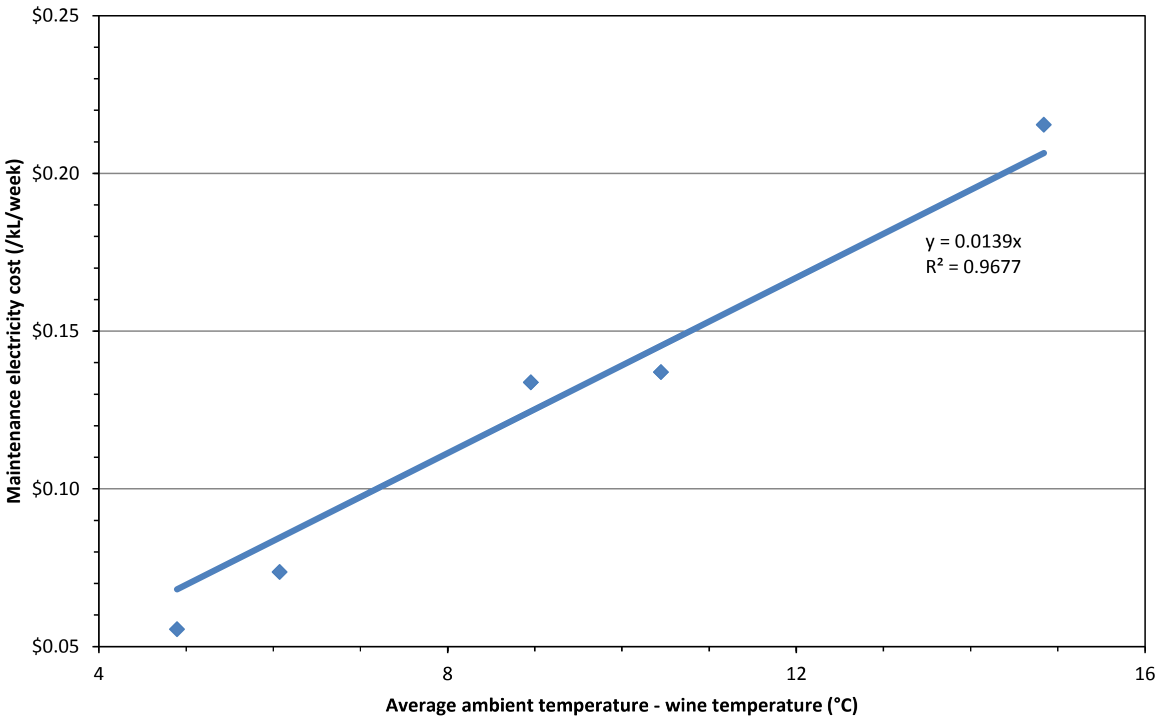

Figure 3.5: Relationship between temperature differential and electricity requirements during trials

Table 3.1: Chemical and sensory analysis for Chardonnay wine

Storage period (days)	Set-point Temp. (°C)	Average Temp. (°C)	Alcohol (%v/v)	TA (g/L)	pH	Ascorbic acid (mg/L)	Free SO_2 (mg/L)	Total SO_2 (mg/L)	DO (mg/L)	CO_2 (g/L)	OD_{280} (au/cm)	OD_{320} (au/cm)	OD_{420} (au/cm)	Duo-trio sensory
43	5	5.2	13.1	6.1	3.24	58	35	126	0.04	1.74	n.d.	2.547	0.086	n.m.
	15	10.4	13.1	6.1	3.23	57	35	128	0.03	1.73	n.d.	2.543	0.089	
65	5	5.3	13.1	n.m.	3.27	71	38	112	0.055	1.81	7.95	2.712	0.093	no significant. difference p = 0.55[a]
	15	10.4	13.1	n.m.	3.27	74	38	121	0.03	1.82	8.41	2.75	0.094	

[a]31 sensory panellists in duplicate, standard glasses used.

Table 3.2: Chemical and sensory analysis for Semillon-Chardonnay wine

Storage period (days)	Set-point Temp. (°C)	Average Temp. (°C)	Alcohol (%v/v)	TA (g/L)	pH	Ascorbic acid (mg/L)	Free SO_2 (mg/L)	Total SO_2 (mg/L)	DO (mg/L)	CO_2 (g/L)	OD_{280} (au/cm)	OD_{320} (au/cm)	OD_{420} (au/cm)	Duo-trio sensory
1	5	5.1	11.05	6.4	3.26	70	28	121	0.046	2.3	7.64	2.7	0.069	n.m.
	15	4.3	11.08	6.4	3.25	71	25	112	0.032	2.31	7.56	2.7	0.073	
28	5	5.2	11	6.6	3.29	59	23	110	0.095	2.34	7.56	2.76	0.065	n.m.
	15	6.5	11	6.6	3.29	65	24	109	0.093	2.29	7.57	2.71	0.065	
56	5	5.2	11	6.2	3.19	68	28	108	0.025	2.31	7.66	2.71	0.076	n.m.
	15	8.2	11	6.2	3.18	66	28	109	0.015	2.33	7.72	2.73	0.08	
91	5	5.2	11.1	6.4	3.29	67	32	114	0.001	2.27	7.58	2.64	0.041	No significant difference p = 0.81[a]
	15	10.5	11.1	6.4	3.29	77	35	116	0.005	2.27	7.92	2.7	0.07	
119	5	5.2	10.9	6.4	3.29	67	30	119	0.018	2.25	7.58	2.76	0.064	n.m.
	15	11.3	10.8	6.4	3.28	69	35	116	0.012	2.31	8.14	2.84	0.075	

[a]30 sensory panellists, black glasses used.

3.2 Night-time cooling

The power usage by the refrigeration plant and the brine reticulation pump together with ambient temperature are shown in Figure 3.6 for periods where a single set-point or dual set-points were in use. Plots showing the tank set-point temperature and actual temperature for parts of these periods for tanks employing single set-point temperatures of 2, 5 and 12°C are shown in Figures 3.7, 3.8 and 3.9, respectively.

Figure 3.6 displays a clear difference in the operation of the refrigeration plant between the dual and single tank set-point modes. With the dual set-point mode, the refrigeration plant ran for a sustained period starting at 2:00 am, and remaied off for much of the day-time, while with the single set-point mode, the refrigeration plant ran regularly for short periods through both the day and night. In the dual set-point mode, this particular refrigeration system should run more efficiently as the compressor discharge pressure should float down with lower ambient temperatures as the condenser will be able to more easily cool refrigerant (whether this will be realised on other systems will be dependent on whether compressor discharge pressure is allowed to float with temperature – often it is not). Running the refrigeration plant for a sustained period and reducing the on/off switching would also be likely to reduce the wear on the compressor. The largest readily quantifiable benefit of the increased night-time operation would be shifting peak electricity use to cheaper off-peak electricity use.

In Figures 3.7-3.9, in the dual set-point mode with lower storage temperatures (2°C or 5°C), on warm days cooling was sometimes required during the day, while with warmer storage temperature (12°C) cooling was never required during the day even on the warmest day. With larger but similarly insulated tanks, cooling would likely often not be required during the day even for lower storage temperatures.

During the current trial, winery staff were made aware of the trial, and two dot-point instructions were placed next to the control screen on the settings to use. However, on one occasion, the same temperature set-point was used for both the day and night set-points for one tank. This suggests that in widespread winery adoption of control strategies taking advantage of off-peak cooling a simplified user input strategy may be required, particularly in large wineries with many personnel who have access. The user input arrangement could involve only a single set-point being entered, with appropriate working set-points and hysteresis settings then being implemented in the background at different times as appropriate.

Pulling-down wine temperature significantly for cold stabilisation in-tank is something that must be accommodated in any night-time cooling control strategy as this involves a significant load. The simple dual set-point strategy adopted can accommodate this to an extent. For example, if it were 1:00 pm and a winemaker wanted to pull-down the tank temperature from 10°C to -4°C, then they could set the night set-point to -4°C and the day set-point as 10°C, so the cooling only starts at night. However, to accommodate cooling of this nature, the definition of night-time used in this trial (2:00 am - 6:00 am) might need to be expanded to include the entire period of cheap off-peak electricity (9:00 pm - 7:00 am at this winery) otherwise it might take several night-times to get the wine down to the cold stabilisation temperature.

In order to assess possible savings if this night-time cooling strategy was adopted across the entire winery, the current winery electricity use profile (excluding the packaging facility, which was on a separate meter) was inspected for June 2010 – May 2011. Maximum monthly usage occurred in January to March. Given that winery refrigeration capacity may be stretched during this vintage period, it was conservatively assumed that no shifting of peak electricity to off-peak electricity in this period would be possible. In the April-December period, approximately 55% of electricity was currently consumed during off-peak periods. It was assumed that 60% of total winery electricity was related to refrigeration and that, like overall electricity use, 55% of refrigeration-related electricity use was consumed off-peak. It was estimated that the winery might realistically be able to increase the off-peak refrigeration fraction to 80% using a strategy similar to that outlined in this report. This would involve shifting approximately 580,000 kWh annually from peak to off-peak or a saving of $38,000 annually based on their peak/off-peak electricity price differential of $0.065/kWh. This is a conservative value as it does not include savings related to any refrigeration efficiency improvements. A cost was sought from the current winery refrigeration control supplier to implement this control scheme across the winery. Given that this winery is quite complex and has numerous refrigeration-related control systems of varying ages, they would only provide a budget price of $580/tank (excluding any required PLC upgrades) in the first instance. Given approximately 300 tanks at the winery under temperature control, this equated to a cost of $174,000 and to a payback period of 4.6 years. A more detailed quotation could be prepared by the supplier if the winery desired, but it would take some time to prepare. It is hoped that it could ultimately be done for much more cheaply than this. The programming for this 24-tank trial cost only $2,160 ($90/tank), however this did not completely integrate with the Citect SCADA control system. At this winery, it may only prove economic to perform control changes on specific tank farms/refrigeration systems. At other wineries without the unusually complex mixtures of different outdated systems found at the trial winery, the changes would likely be performed much more economically.

An alternative option to programming a custom solution is to purchase a largely off-the-shelf system such as VinWizard. This software has various modules available to utilise off-peak power and can be retro-fitted over the top of existing PLC hardware if required. A system of this style may prove a more cost-effective option in some wineries, particularly given that it may facilitate other energy saving and capacity increasing improvements such as automatically setting the brine temperature at the highest temperature possible based on the lowest temperature wine tank on the brine loop. A winery that is installing a new control system should ensure that it includes functionality to take advantage of cheaper off-peak electricity as a matter of course.

While the cost of control system modification will vary according to the state of existing systems, with correct implementation the risks to wine quality are minimal, since wine is still being stored at essentially the same temperature. This makes it an attractive improvement option.

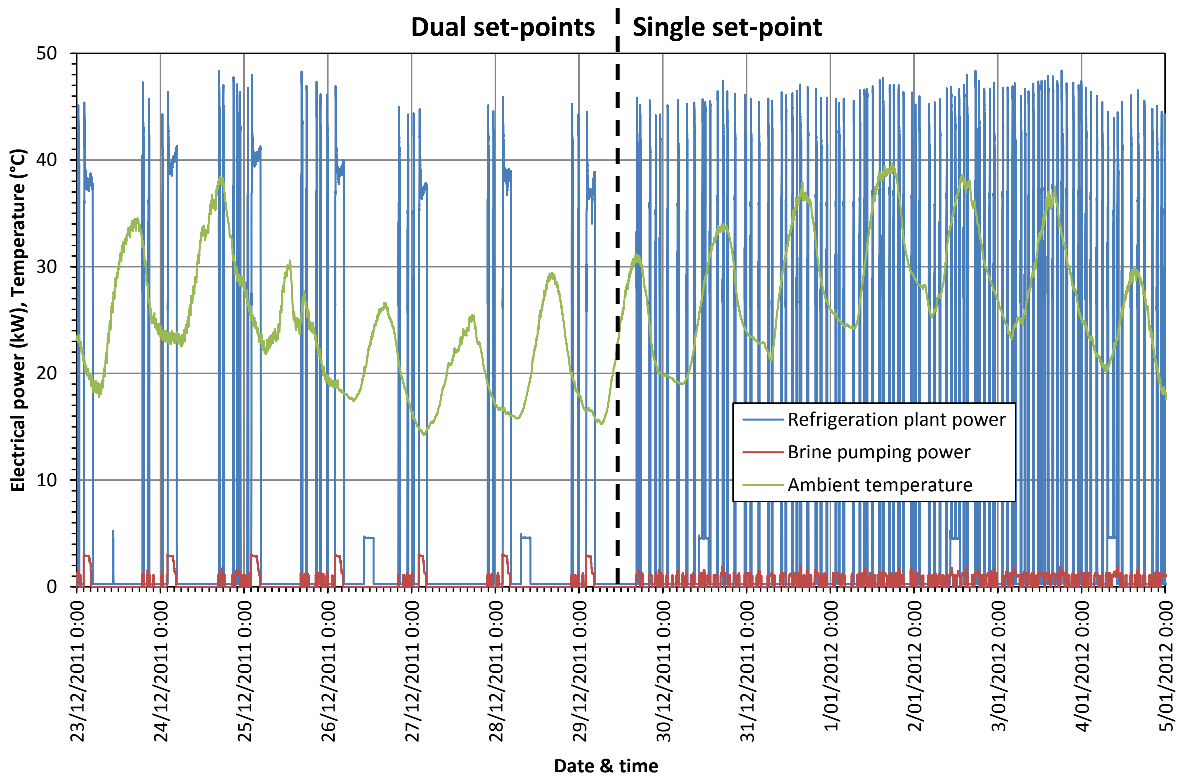

Figure 3.6: Difference in refrigeration plant operation when employing dual or single set-point temperatures

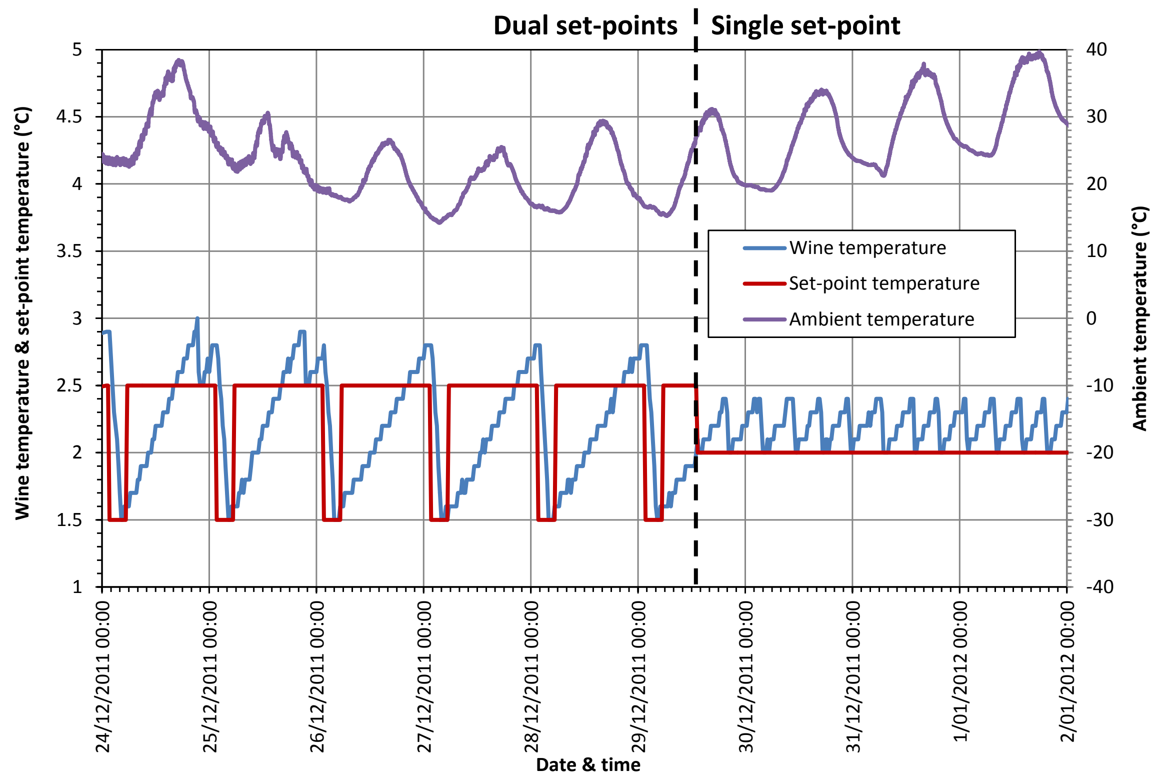

Figure 3.7: 2°C single set-point, agitator auto (i.e. on when brine is running)

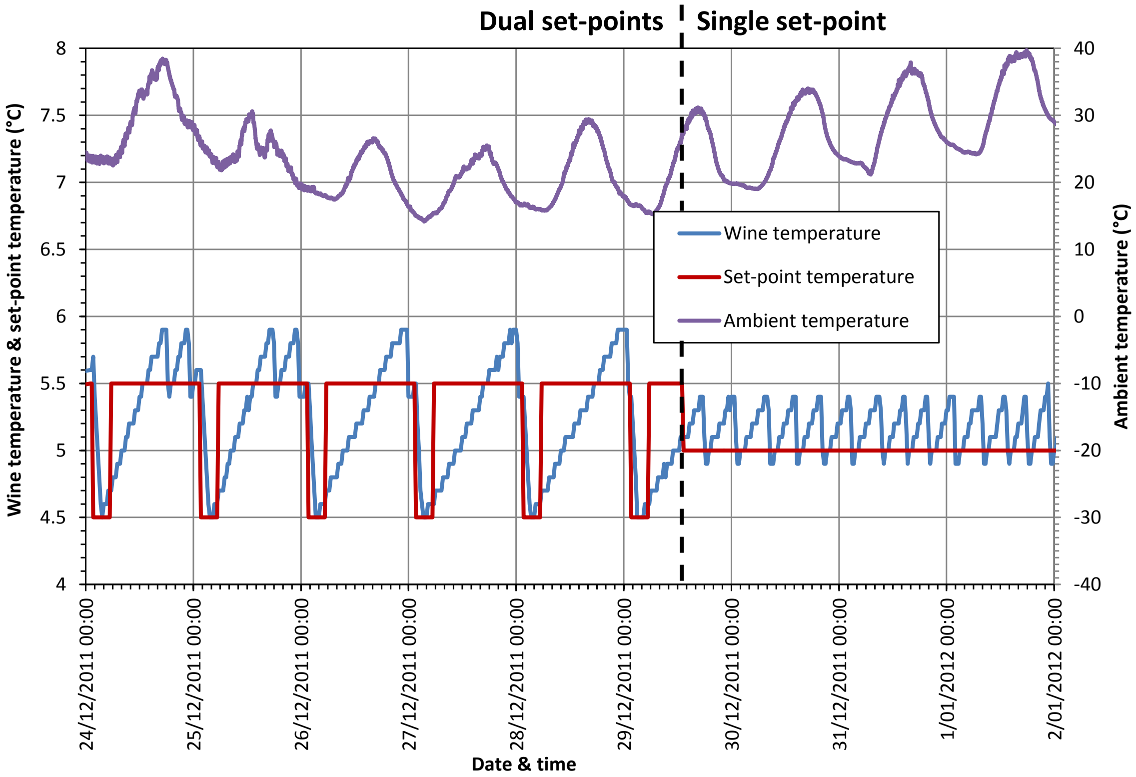

Figure 3.8: 5°C single set-point, agitator off

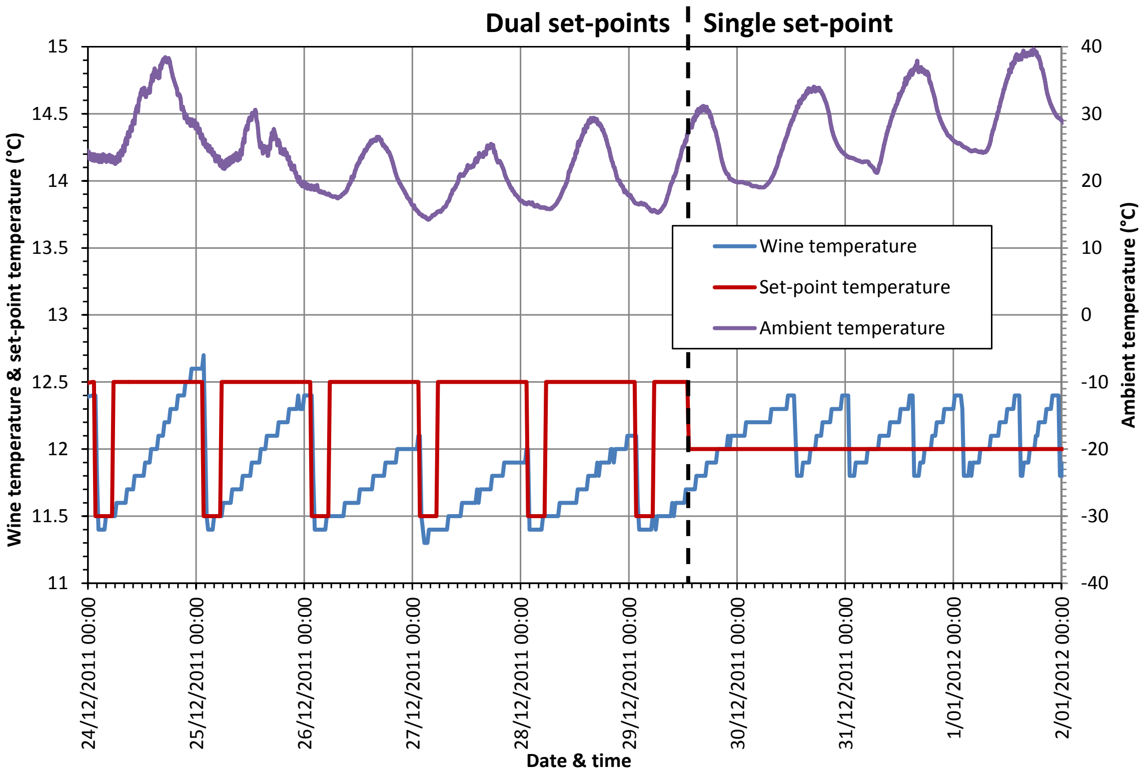

Figure 3.9: 12°C single set-point, agitator off

4. Conclusions and recommendations

1. No significant sensory difference was found for either a Chardonnay or a Semillon-Chardonnay wine stored at 10°C as opposed to 5°C for two-three months. The effect of storage temperature on quality will vary for different wines.

    a. *The following simple equation should be used by wineries to quickly estimate order of magnitude electricity savings from storage (when using tanks with 75 mm thick polystyrene insulation) at warmer temperatures. The winery should then balance potential electricity savings against their own assessed risk to product quality:*

    $$\textit{Maintenance saving (\$/kL/week)} = 0.006 \times \left(\frac{1}{L} + \frac{4}{D}\right) \times \left(T_{High} - T_{Low}\right)$$

    Where T_{Low} and T_{High} are the alternate storage temperatures under consideration (e.g. 5°C and 10°C), and L and D are the tank height and diameter, respectively in m.

2. Night-time cooling trials using different day and night tank temperature set-points demonstrated the shift of refrigeration plant operation from short repeated cycles throughout the day to operation predominantly at night for a sustained period. The shifting of peak to cheaper off-peak electricity use is a good opportunity for wineries to save on electricity costs with minimal risk to wine quality.

    a. *Wineries should look to shift their electricity use to off-peak tariffs. Options for different wineries will depend on their existing control system. As a conservative means of estimating potential savings, it is recommended that the differential between the unit price of peak and off-peak electricity combined with the quantity of electricity that is likely to be shifted from the peak to the off-peak tariff be used. Where new control systems are being installed, a control system that accommodates the increased use of off-peak as opposed to peak electricity should be selected as a matter of course.*

    b. *Wineries should consider alterations to refrigeration plant control systems that allow the refrigeration plant discharge pressure to float appropriately with differing ambient temperatures so that improved efficiencies in refrigeration plant performance during night-time cooling can also be realised.*

5. Acknowledgements

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7. Glossary

Brine:	The fluid that is cooled by a refrigeration plant and then circulated around the winery to cool vessels and other operations. Brine consists of water with freezing-point suppressants together with corrosion inhibitors and colorants.
COP:	The coefficient of performance (COP) describes the efficiency of a refrigeration plant. It is the ratio of the cooling power to the electrical power input, principally that to drive the compressor. The overall efficiency of the winery cooling system will also be influenced by brine reticulation system heat gains and pumping electricity requirements.
Compressor:	This device compresses refrigerant and is the main user of electricity in a refrigeration plant.
Condenser:	The heat exchanger used to condense refrigerant after it has passed through the compressor.
Evaporator:	The heat exchanger in which the brine is cooled by the refrigerant (as the refrigerant evaporates).
Freezing-point suppressant:	An additive that lowers the temperature at which brine will freeze.
Hysteresis:	A setting in an on-off control system that prevents rapid switching as a parameter (e.g. temperature) drifts around the set-point. For example; with a temperature set-point of 5°C and a hysteresis setting of 0.5°C; cooling will switch on when the measured temperature reaches 5.5°C and switch off when it reaches 5°C. Hysteresis is often referred to as dead-band.
PLC:	A Programmable Logic Controller (PLC) is a highly reliable special-purpose computer used in industrial monitoring and control applications.
Refrigerant:	The working fluid in a refrigeration plant.
SCADA:	Supervisory Control And Data Acquisition (SCADA) generally refers to a centralised system for controlling and monitoring an industrial site.
Set-point:	The desired setting.

Specific heat capacity: The amount of energy required to raise the temperature of a unit mass of a substance by a given amount.

Stratification: Layering; related to less dense warmer liquid layering on top of more dense colder liquid in this instance.

Thermowell: A thin closed-ended tube that extends into a vessel (or into other equipment) into which a probe can be inserted to measure temperature without direct contact with the vessel contents.

For further background, the reader is directed to the 'Improving Winery Refrigeration Efficiency' reference guide produced as part of this project. This can be downloaded from the AWRI (www.awri.com.au) and GWRDC (www.gwrdc.com.au) websites.

Appendix A: Theoretical overall heat transfer coefficient

Wine temperature (T_i) = 5°C
Air temperature (T_e) = 15°C

Assume that tank wall is at wine temperature.

Tank wall and insulation construction (thickness, Δx, and thermal conductivity, k):

Stainless steel: Δx_1 =0.0016 m, k_1 = 16.3 W/m/°C (Azom 2012)
Isolite Class SL: Δx_2 =0.075 m, k_2 = 0.0386 W/m/°C (RMAX 2012)
Aluminium sheathing: Δx_3 =0.00055 m, k_3 = 171 W/m/°C (Matweb 2012)

Surface heat transfer coefficient (f): 5.7 W/m^2/°C (CSR 2012)

This approximation of surface heat transfer coefficient combines both convection and radiation at the external surface of the cladding.

The overall heat transfer coefficient (U) is thus:

$$\frac{1}{\frac{\Delta x_1}{k_1}+\frac{\Delta x_2}{k_2}+\frac{\Delta x_3}{k_3}+\frac{1}{f}} = 0.47 \text{ W/m}^2/°\text{C}$$

Appendix B: Derivation of maintenance saving

Theoretical overall heat transfer coefficient (U) = 0.47 $W/m^2/°C$ (see Appendix A)
Tank surface area = $\pi D^2/4 + \pi DL$ m^2
Tank volume = $L\pi D^2/4$ m^3
(where tank is approximated as a cylinder for simplicity, and D and L are tank diameter and height, respectively in m).
Average ambient temperature (T_e)

Unit electricity cost = \$0.15/kWh = \$4.17 × 10^{-8} /J
COP_{+brine} = 2 (A modified COP for estimation purposes that incorporates brine reticulation loop heat gains and pumping requirements)

The difference in heat gain per kL (m^3) from using a wine storage temperature of T_{High} instead of T_{Low} (°C) is:

$$\frac{0.47 \times \left(\frac{\pi D^2}{4} + \pi DL\right) \times \left((T_e - T_{Low}) - (T_e - T_{High})\right)}{\left(\frac{\mathrm{L\pi D^2}}{4}\right)} = \frac{0.47 \times \left(\frac{\pi D^2}{4} + \pi DL\right) \times \left(T_{High} - T_{Low}\right)}{\left(\frac{\mathrm{L\pi D^2}}{4}\right)}$$

$$= 0.47 \times \left(\frac{1}{L} + \frac{4}{D}\right) \times \left(T_{High} - T_{Low}\right) \quad J/s$$

The saving in electricity cost per kL per week (604,800 seconds), is:

$$0.47 \times \left(\frac{1}{L} + \frac{4}{D}\right) \times \left(T_{High} - T_{Low}\right) \times \frac{\$4.17 \times 10^{-8} \times 604{,}800}{2}$$

$$= \$0.006 \times \left(\frac{1}{L} + \frac{4}{D}\right) \times \left(T_{High} - T_{Low}\right)$$

Note: If for whatever reason, $T_{High} > T_e$, this equation will exaggerate the potential savings as refrigeration will not be required when wine is at temperatures above the average ambient temperature.

Appendix C: Derivation of pull-down cost

Wine specific heat capacity = 978 kg/m^3 (Rankine 2004)
Wine density = 4,300 J/kg/°C (Rankine 2004)

Unit electricity cost = \$0.15/kWh = \$4.17 × 10^{-8} /J
COP_{+brine} = 2 (A modified COP for estimation purposes that incorporates brine reticulation loop heat gains and pumping requirements)

The heat removal required to pull-down the wine temperature from $T_{Initial}$ to T_{Final} (°C) per kL (m^3) is:

$$978 \times 4{,}300 \times (T_{Initial} - T_{Final}) \quad J$$

The electricity cost to achieve this heat removal is:

$$\frac{978 \times 4{,}300 \times (T_{Initial} - T_{Final}) \times \$4.17 \times 10^{-8}}{2} = \$0.09 \times (T_{Initial} - T_{Final})$$