Solar Cooling – a Review of Technology, and Feasibility Study for Ager Sectus Winery, Blenhein, New Zealand.

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Project Solar LTD
PERFORMANCE ANALYSIS OF RENEWABLE ENERGY SYSTEMS

Executive Summary

Solar cooling utilises incoming solar radiation to provide a useful cooling effect. There are several technologies that can be used, with each technology being application specific. The most common approach is the lithium bromide – water absorption chiller, where solar thermal collectors are used to drive a chemical reaction that produces chilled water down to 0ºC.

The Ager Sectus Winery, near Blenheim, is one of over 100 wineries that has committed to sustainable wine making practises. The majority of the energy needs at the winery is to provide cooling, with the waste heat recovered from the refrigeration plant. Outside of the harvest season, there is a relatively consistent demand for cooling, and it is proposed that a solar cooling system be trialled at the winery. It is expected that a cooling plant would integrate well into the winery.

The proven performance of such a plant is highly variable, with a number of both successful and underperforming systems installed throughout the world to date. However, recently several 35 kW system have been installed in both Europe and Asia, and have achieved the expected performance with COP's in the order or 0.6 – 0.7.

The estimated payback time, without additional funding, is likely to be 15-20 years. However, there are a number of uncertainties in this, and therefore worthy of further investigation.

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1. Introduction:

There is a growing trend for peak electricity demand to occur during the day in the height of summer in many countries. This demand is coming predominantly from the use of air-conditioning systems, both in the commercial and domestic sectors, and is resulting in summer-time peak loads on electricity grid networks matching or even exceeding winter-time peaks.

In April, 2009 Transpower announced that the increase in summer electricity demand was constraining its ability to take lines out of commission for service during the traditionally low demand summer period. This energy demand is considered additional demand that was not previously present.

There is a place, therefore, for technologies that provide cooling without increasing electricity consumption. Solar cooling is a promising technology that uses the energy from the sun to provide cooling. This approach has the advantage of being 'in phase' with the demand for cooling. Therefore, increased solar radiation during summer leads to an increased cooling requirement due to warmer temperatures. The system responds to the increased solar radiation by providing a greater cooling effect.

This is in contrast to the better known technology, solar water heating, where the hot water heating demand decreases during the summer months due to an increase in incoming cold water temperature. Typically, the systems also provide significant quantities of waste heat that is available for use.

This report considers the current state of solar cooling, and considers the appropriateness of the technology for integration into the heat / cooling system at Ager Sectus winery in Blenheim.

2. Solar Cooing Tchnologies:

2.1. Photovoltaic solar as source of electricity.

There are several approaches that can be taken to achieve solar cooling. The most obvious, but least economic, is to use photo-voltaic collectors to power conventional refrigeration systems. Photovoltaic collectors are 10-15% efficient, and cost \$2-3 / W_p installed. The cost of the collectors, whilst steadily reducing, is still uneconomic.

2.2. Heat engine

Heat engines, such as a Rankine engine, can also be used to power a vapour compressor, with overall system efficiencies of around 17-23%. The low efficiencies and additional difficulties associated with these mechanical systems means they are currently less economically viable when compared to sorbent technology (Florides, G. A. 2002).

2.3. Dessicant Cooling

Desiccant materials are an absorber specifically of water. For that reason they are a well suited absorbent for the use in air conditioning systems in buildings. This type of air conditioning differs from vapor compression systems because it does not rely on compressed refrigerants to produce cooling. Thus it does not require either a mechanical compressor or a chemical solution to provide pressure. Instead warm wet air passes across an area of a rotating desiccant wheel which removes the moisture. The condensed water is absorbed by the desiccant and condensation heat is given off. Then the dry hot air is regeneratively cooled by 'exhaust' air flowing back out of the building. Next the cooled dry air is evaporatively cooled, normally by passing through a wet panel, which causes some evaporation and thus air temperature loss. The air finally enters the building cold and slightly damp, due to the evaporation. In some cases this evaporative cooling stage is replaced by a cooling coil, which allows indirect evaporative cooling (IEC) to occur, which avoids the air becoming damp.

To complete the system the circulated air from the building is again evaporatively cooled and used to regeneratively cool the incoming air. Finally, it is heated by an external heat source, such as solar thermal energy, and passed through the desiccant wheel once again, such that the hot air removes the condensed water from an area of the desiccant, which can then continue to absorb new humid air from outside.

Desiccant systems have the advantage of requiring low temperature levels to operate successfully. They require relatively cheap flat panel solar collectors to operate as the heat input. The system, however, is bound thermodynamically to a minimum cooling level, meaning the technology is not appropriate for low level cooling. For the systems to work appropriately, the air flow must be reused in a regenerative process, limiting the potential for that exhaust heat or cold to be used in other processes.

2.4. Absorption Chiller Technology

The final method is to use solar thermal collectors to provide a cooling effect. This approach is the subject of much research at present, with Europe taking a strong lead in the development of such systems.

Whilst the use of heat to provide a cooling effect may seem counter-intuitive, absorption chillers are the most common approach for large-scale refrigeration systems. The modern reciprocating compressor, and its variants, has mostly displaced absorption chillers for small to medium chiller plants. An exception, is the recreational vehicle market where small propane powered fridges are widely used. However, absorption chillers are typically used for applications above 100 kW. Typically, either natural gas or coal is burnt to drive the process. With a solar cooling system, the system is modified to allow heat generated from solar collectors to instead drive the process.

There are two main systems used, depend on the cooling temperatures required. For cooling down to 0ºC, liquid water / lithium bromide (H_2O / LiBr) solution is used. For cooling below 0ºC, an ammonia / water (NH_3/H_20) system is used.

In most situations the LiBr- H20 solution is the preferred option, as it has a higher coefficient of performance (COP) and requires lower generator temperatures. However, because it cannot operate much below -5^{0}C, as the water refrigerant will freeze, low temperature cooling is more suited to the use of NH3-H2O.

In this case the system is more complicated as the water vapour must be kept out of the evaporator, by a rectifying column, or else it would freeze. Furthermore, because of the high generator temperatures required by the NH3-H2O system, flat plate solar collectors are not sufficient as the heat source and more expensive collectors must be used.

The absorption process works by the evaporation of the refrigerant (water) under very low pressures. The water vapour is absorbed into the liquid H_2O/ LiBr solution (thereby diluting it). A pump is then used to transfer the diluted H_2O/ LiBr solution to the 'generator'. Here, heat is applied to the solution. The water is evaporated back into the vapour phase, where it is then condensed (reducing the pressure via an expansion valve) and the process begins again. Figure 1 outlines the process.

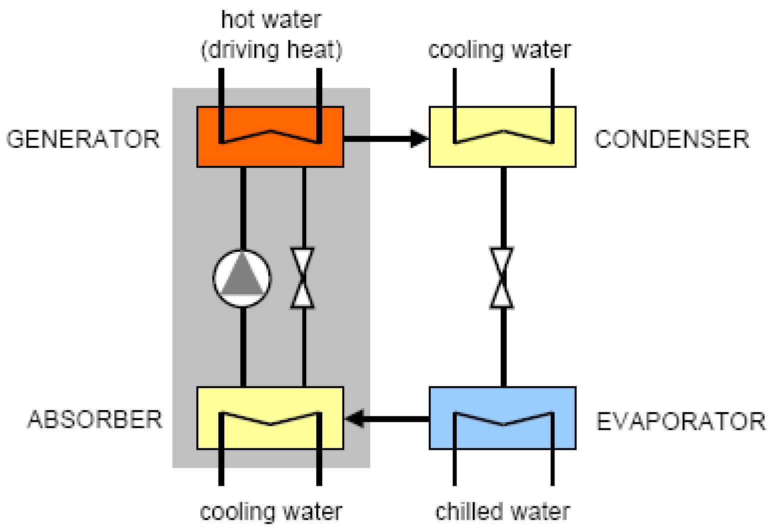

Fig 1. Process diagram of absorption chilling. Source: ESTIF Report (2006).

In addition to the chilled water, significant quantities of waste heat is generated by the process. The absorber is cooled to improve efficiency, and the condenser is cooled so the water vapour is condensed. The economics of an aborption chiller is improved if the is demand for the low grade heat produced.

2.5. Adsorption Chiller Technology

Adsorption systems work in much the same way as that of an absorption system, except the water is adsorped (collected) into a solid adsorber (eg silica gel) in a two chamber apparatus (Fig. 2). The water evaporates from the evaporator, and is absorbed onto the adsorber. Once the adsorber is saturated, the chamber is closed, and the adsorber is heated using the thermal heat source. This drives the water from the adsorber, and it is condensed back into the evaporator. Through the use of two chambers, the system can operate near-continuously.

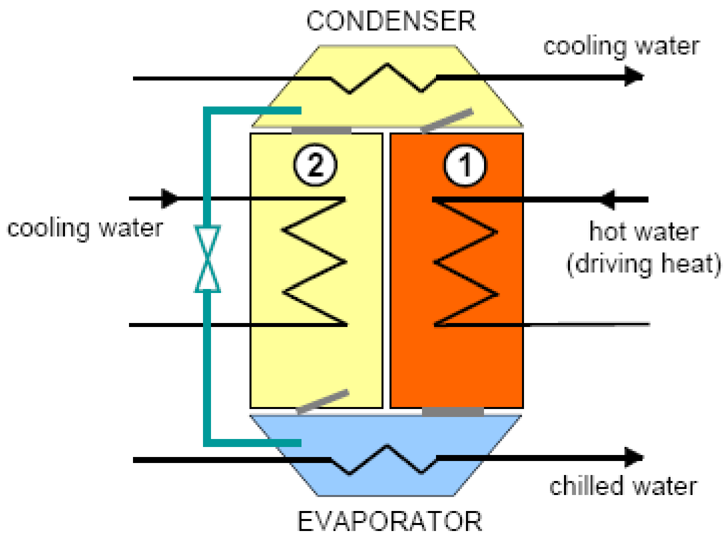

Fig 2. Process diagram of adsorption chilling. Source: ESTIF Report (2006).

The adsorption chillers have the advantage of comparatively simple construction, however they tend to be large and expensive.

3. Solar Thermal Technology:

The choice of solar collectors is critical for a successful solar cooling system. Flat panel collectors typically have low efficiencies at the required temperatures. Evacuated tube collectors have much higher efficiencies, but relatively low absorber areas. A new class of 'medium temperature' flat panel collectors is being developed for solar cooling applications. These collectors have additional insulation, and are double glazed, which improves efficiency at the required temperatures (AIT Test Report). These collectors are expected to be more cost effective than evacuated tube collectors for this application in suitable locations. It is unclear, however, if these collectors are commercially available at present.

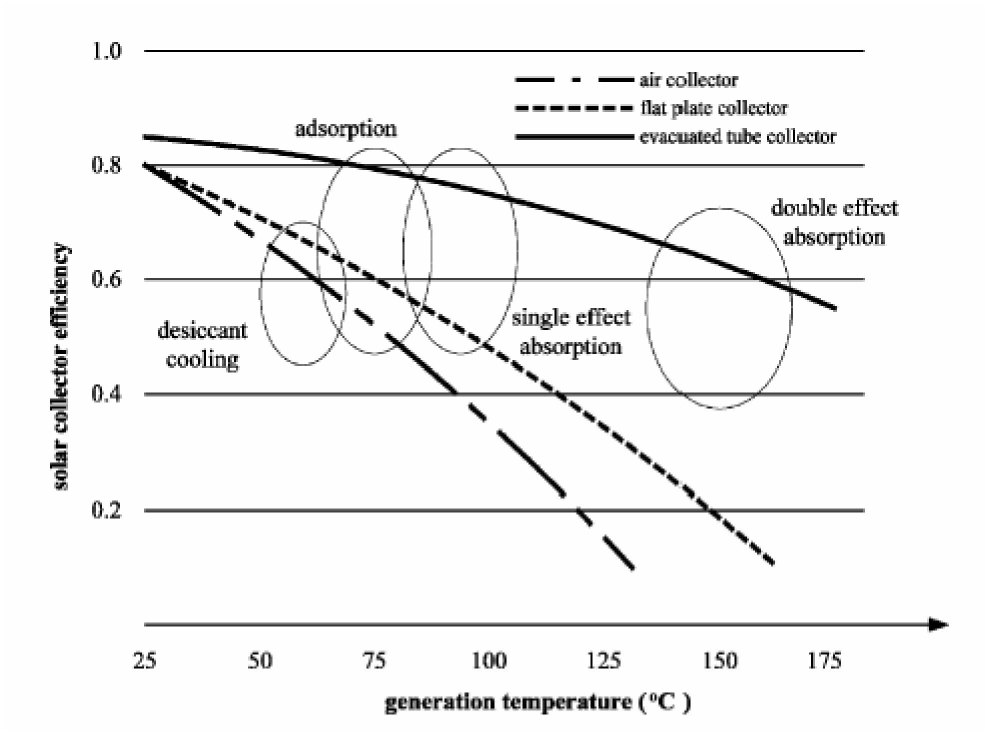

Fig. 3. Performance curves of solar thermal collectors technologies, and their suitability for solar cooling (Papadopoulos A.M. 2003).

The graph in Fig. 3. illustrates the performance difference between different types of solar collectors. Since the curves are based on absorber area, which for evacuated tubes is typically approximately half that of flat panels (for the same gross area, or cost), the actual performance is lower. Medium temperature collectors seek to bridge the gap between the two collector types.

Where water is heated above 90ºC, it can be stored in insulated tanks so cooling can be extended when there is insufficient solar energy available. Additional thermal heat-sources can also be used to supplement the solar energy resource.

4. Solar Energy Storage

For the solar system to function continuously some additional storage of heat or cold is necessary. This storage is needed when the solar radiation is insufficient to produce the thermal heat required, occurring on sunless days or at dusk, when the temperature is still high and cooling still necessary. Systems can incorporate a hot storage tank, cold storage tank or both, to ensure the systems continuous functioning. The tanks may also be able to supply additional functions, such as hot water or space heating and or cooling. The storage requirements will be heavily dependant on each particular situation and desired use.

A backup system will often also be required which runs off traditional energy supplies such as electricity or gas, to ensure cooling at times of low radiation. Traditional vapor-compression systems are used for cooling and oil, gas or pellet burners are used

for heating in this situation. Control systems are vital between the solar system and its backup to ensure maximum efficiency of the complete system.
(Isaksson, C. 2008)

<u>In Summary</u>

Advantages of Solar Cooling Systems

- Ab/Adsorption Refrigeration systems connected to storage tanks have the potential to use excess and or exhaust heat/cold in other processes such as hot water heating, or air conditioning.
- Can use solar energy, which is emission free.
- Off grid potential
- Make best use of the solar resource because solar radiation is in phase with loads.
- Ab/adsorption systems avoid the use of a mechanical compressor requiring electrical power. They also use less energy to compress the refrigerant vapor, which improves vapour-compression efficiency.

Drawbacks of Solar Cooling Systems

- Absorption and Adsorption systems have traditionally been designed for large scale cooling and only relatively recently have smaller scale systems been developed which can make use of thermal solar energy.
- Solar systems require low temperature generators which have lower relative efficiencies.
- In a similar way, increasing generator operating temperatures in solar systems, and thus increasing efficiency, requires the use of more expensive solar collectors, such as evacuated tube, and compound parabolic concentrating evacuated tube collectors.
- A cooling tower is required in most Ab/Adsorption systems, which increases costs.
- Storage tanks are needed for hot and cold storage, as are conventional backup systems for continuous use.
- Desiccant systems reach a natural thermodynamic cooling limit.

5. Application of solar cooling to Ager Sectus Winery, Marlborough.

5.1. Description of winery

The Ager Sectus Winery is a privately owned medium sized commercial winery located in the Awatere Valley, Blenheim. The region is characterised by warm dry summers and cool winters with frequent frosts. Blenheim, the closest main town to the winery, has New Zealand’s highest number of sunshine hours each year, with an average of 2500 hours recorded.

The Ager Sectus winery is a producing approximately 1 million litres of wine each year, with a mixture of red and white wines produced. The wines range in production requirements from the relatively short duration Savignon Blanc style, to wines matured in oak barrels. As a result, there is a near continuous demand within the winery for cooling, and heating as the different wine styles are produced.

Wine producers are becoming increasingly aware of the need for sustainable production of their product with over 100 Wineries, and several hundred Vineyards members of the organisation Sustainable Winegrowing New Zealand. The reduction of energy consumption, and the associated greenhouse gas emissions is an increasingly important aspect of the management and marketing of the winery.

5.2. Plant Operations at winery

The existing plant at the winery consists of a 350 kW ammonia refrigeration system with heat recovery via a glycol circuit. The glycol circuit comprises of both cold and hot glycol storage tanks, which is pumped around the fermentation room to cool or heat the fermenters, and maturation tanks as required. Heating is solely provided by waste heat recovery from the refrigeration system. Periodically, particularly during harvest time, there is insufficient heating provided by the refrigeration system to meet the needs of the winery. The glycol circuit also is used to control the air temperature in other parts of the winery, for example, the barrel storage room

Potable hot water is provided through waste heat recovery from the refrigeration plant, and is assisted by 45 kW of electric resistance heating. This water is mostly used for the cleaning of tanks and barrels.

The wine is normally held at approximately 12ºC post fermentation, and is then warmed to approximately 17ºC prior to leaving the winery. This is generally occurs throughout the year following the autumn harvest and fermentation period.

The plant consists of a number of tanks used to store the hot and cold glycol, and well as the hot potable water (Photo 1).

Photo 1. Storage tanks for cold (stainless steel) and warm glycol (plastic).

The winery is currently operating at near maximum capacity, and this capacity is limited by the lack of additional cooling capability.

5.3. Energy Consumption of Winery.

The Winery operation consists of both the winery, and the associated offices. The majority of the energy demand is from the winery. The Winery in the 12 months to December 2009 consumed 323 MWh of electricity. It is estimated that 80% of the energy demand was used for cooling at the winery, with pumps, lighting and the occasional use of resistance heating making up the rest.

The average price paid for the electricity during this period was 3-4 c/kWh during the day, and 2-3 c/kWh at night. However, during the 2008 year, the prices paid were 15-18 c/kWh (day) and 13-16 c/kWh (night). The difference between the two years relates to the differences in the spot price during years of high and low rainfall in the hydro storage lakes.

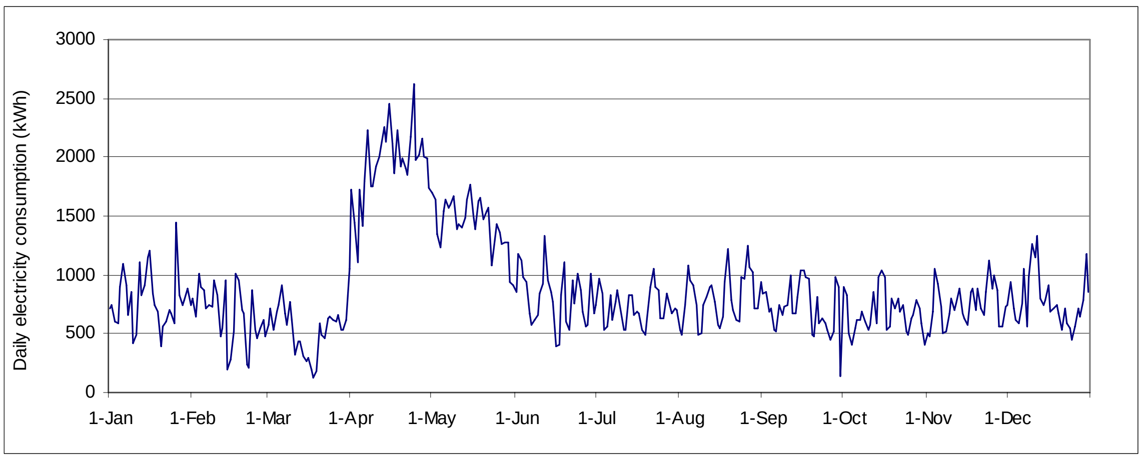

Fig. 4. Daily electricity consumption throughout the year. Dec 2008 – Nov 2009.

The peak electricity demand is during the grape harvest, which runs from April to late May, depending on the season. The grapes are pressed, and initially chilled to aid clarification before being transferred into the fermenters. The fermenters are heated to initiate fermentation, using heat recovery from the refrigeration. This accounts for a considerable portion of the annual energy requirements of the winery, as can be seen in Figure 4. During the rest of the year, the background energy consumption is mostly between 500 – 1000 kWh/day. There is little seasonal effect in energy demand outside of the harvest season. The lowest energy demand period is shortly before the start of harvest, when the plant is cleaned and prepared for harvest. The previous years production is in barrels or has been bottled by this stage leaving the tanks empty for the new season.

The average daily energy demand is shown is Fig 5. The peak energy demand for the winery occurs in the afternoons, with a smaller peak at night-time. The night-time peak is due to the use of off-peak electricity tariffs to operate the refrigeration system. This results in a low energy demand during the morning as the stored cold glycol from the previous night is used. Once this is used, the refrigeration plant will commence operation if required. Often, there will be sufficient cold glycol produced the previous night, so the refrigeration system is not required. As a result, the afternoon energy consumption is reduced compared to the actual cooling demand required.

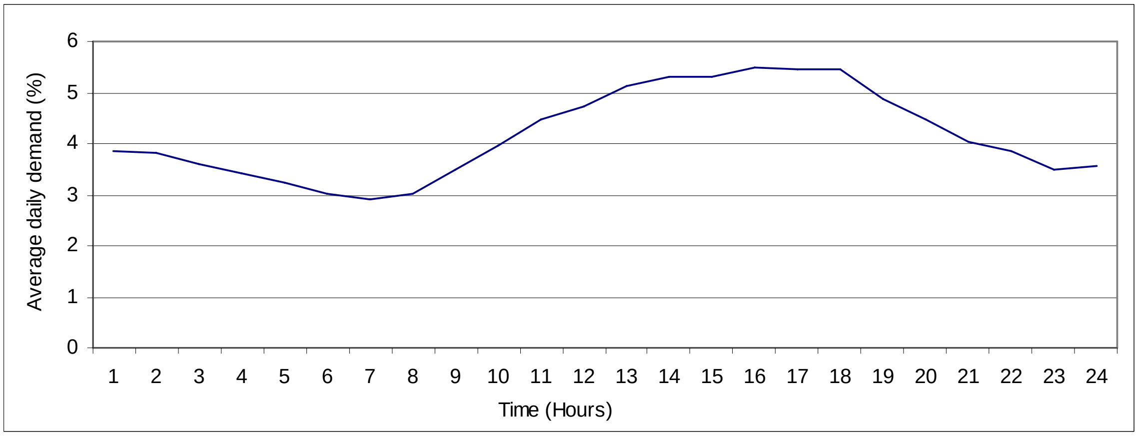

Fig. 5. Average daily electricity demand profile for winery.

6. Integration of Solar Cooling into the Winery Operations.

The integration of solar cooling technology appears to be well suited to this winery. There is a relatively consistent requirement for cooling throughout the year, with the exception of the harvest season, and also a demand for low grade heat. At present, both energy demands are met by the ammonia refrigeration system.

The most suitable solar cooling technology currently available is the lithium bromide-water absorption single effect system. The required temperatures are too low for the dessicant methods, and there is limited demand for the chiller to operate below 4ºC.

At present, the refrigeration system is primarily operated during the off-peak tariffs period occurring at night. This significantly reduces the cost of the electricity. The peak cooling demand, however, is during the afternoon. A well integrated solar cooling system would provide cooling during the daytime, with the peak production occurring around midday. This would extend the cooling provided by the ammonia system the previous night, substantially reducing the energy demand during the daytime. As a result, a greater proportion of the electricity purchased by the winery would be at the cheaper off-peak tariffs.

Solar cooling also provides significant quantities of low to medium grade heat, which needs to be removed for the cooling process to operate efficiently. Typically, this is removed via a cooling tower, however the winery would be able to use a significant proportion of this energy during the warming of wine prior to transportation for bottling.

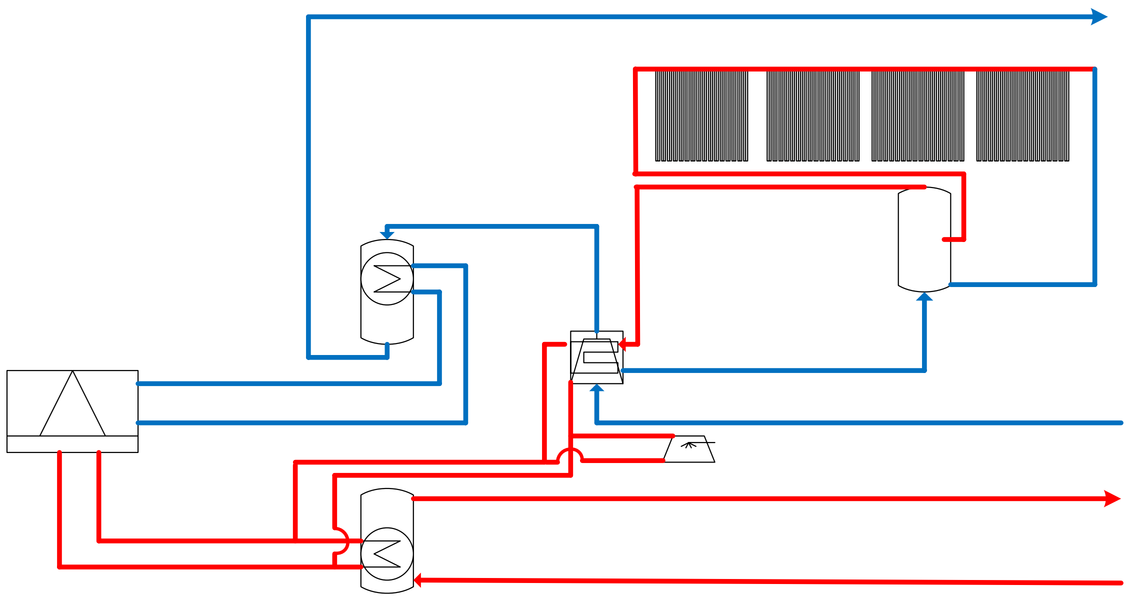

Fig 6. Integration of solar cooling system into the existing winery plant. Pumps, valves, controls and some pipework not shown.

It is proposed that the solar cooling plant be integrated on the cold glycol return line (Fig 6.). This would provide for the maximum performance from the cooling plant. Excess cooling potential would be used to cool the cold glycol storage tank (pipes not shorwn).

6.1. Analysis of cooling demand at Winery.

Detailed usage of the refrigeration plant is not available. However, it is assumed that 80% of the electricity demand is used for cooling, and the COP of the refrigeration plant is 2.5 (eg 1 kW of electricity consumption generates 2.5 kW of cooling). Therefore, the peak cooling demand is generally between 50 - 100 kW (Fig. 7.), outside of harvest time. A solar cooling plant would need to produce a higher peak cooling output, due to the restriction of sunshine hours available each day. This is offset by a reduction in storage losses compared to the system at present. Therefore, a solar cooling plant of 125 kW peak output is expected to be suitable for the winery cooling requirements. The waste heat produced, however, would be several times this amount, and is expected to be excessive compared to requirements.

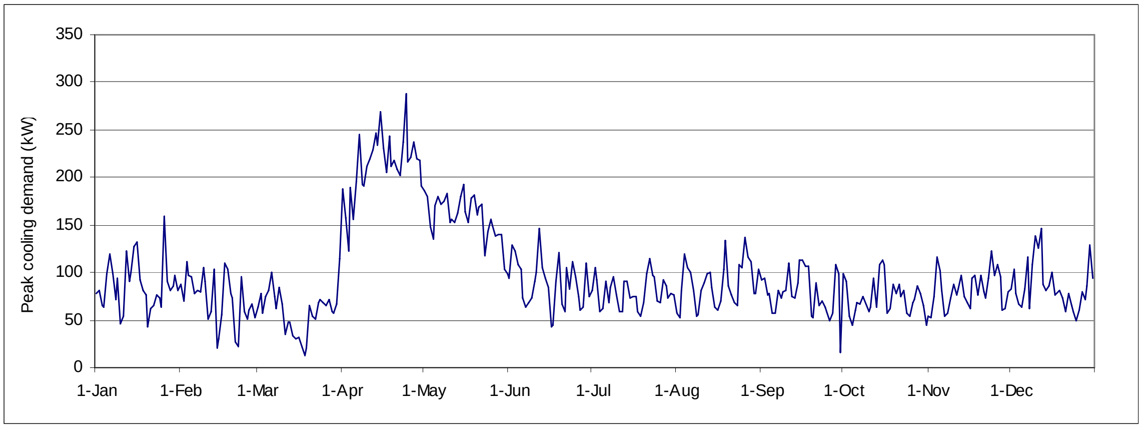

Fig. 7. Peak Daily cooling demand.

It is therefore recommended a smaller cooling system be considered, with a modular approach taken so that should further capacity be later required, the cooling system can be added to. This approach will maximise the utilisation of the solar cooling system, whilst avoiding the generation of excess waste heat. Two 35 kW cooling units are proposed for this report.

7. Economic assessment of a solar cooling system.

A 35 kW solar cooling system providing air-conditioning has been described in both Thailand and Germany with 72 m^2 (absorber area) of evacuated tube collectors (Pongtornkulpanich, 2008; Ali, 2008). A second 35 kW system in central Italy is described which uses 90 m^2 (absorber area) of compound parabolic concentrating evacuated tubes (Desideri, 2009).

These systems are summarised in Table 1.

	Thailand	Germany	Italy
Solar collectors, tanks, califonts	41,100		50,000
Cooling system	68,000		50,000
Control and monitoring	12,100		
Installation / commissioning	42,900		
Cooling tower / other			20,000
Total Cost	$NZ 164,100	Not provided	$NZ 120,000
Collector energy delivered (kWh/yr)	Not provided	Approx 10,000	78804
Energy Savings (cooling)	81% SF*	60% SF*	40,000 kWh (COP 0.5)

Table 1. Reported solar cooling systems. *SF- proportion of cooling needs met by the solar cooling system on an annual basis.

7.1. Proposed solar cooling system for Ager sectus winery.

A 35 kW solar cooling system in New Zealand would be expected to cost approximately $NZ 105,000 (Table 2). A system with 72m^2 of evacuated tube collectors, with 2000 L of storage has been modelled using TRNSYS thermal simulation software for the Nelson weather data files. The tank was maintained at 80ºC, with a daily load of 5000L at 80ºC (Fig 8.).

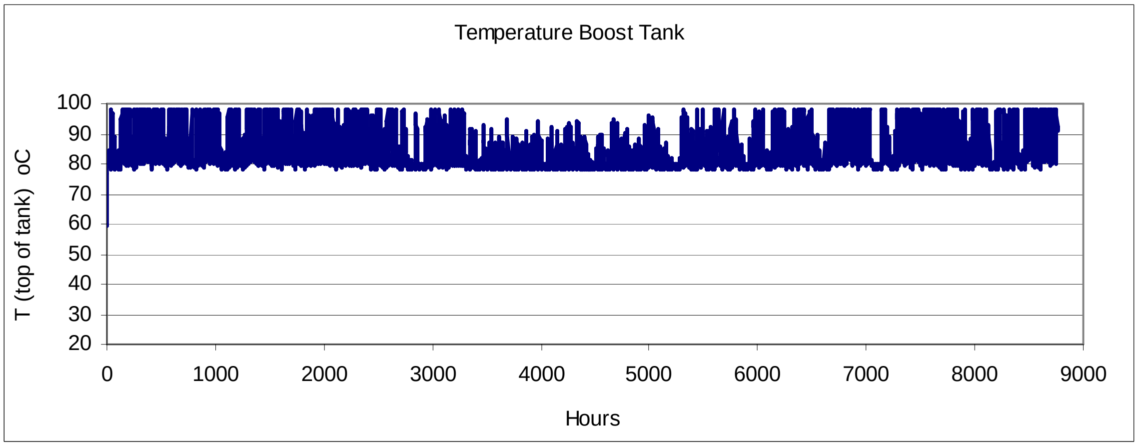

Fig. 8. Modelled thermal storage tank temperature (top of tank).

Such a system would be expected to achieve a COP of 0.6, where 60% of the cooling plant would generate cooling equivalent to 60% of the thermal energy generated by the collectors operating at greater than 80ºC. An estimated cooling potential of 40 MWh is likely from the system, which at an average cost of 15c/kWh, would result in a saving of approximately $6000 /year. The simple payback would be in the order of 18 years.

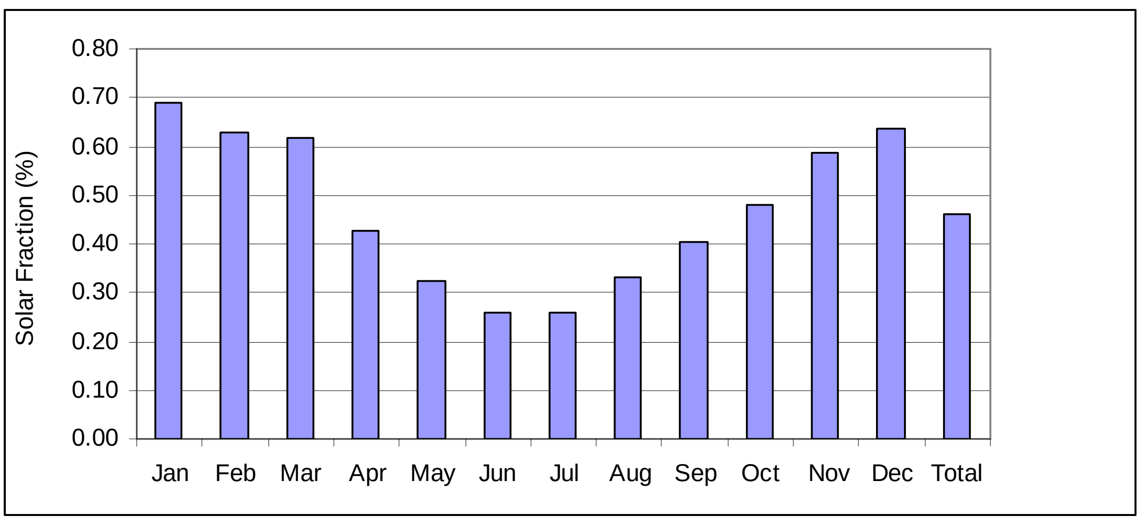

Fig. 9. Solar fraction of solar collectors as modelled. Nelson weather data.

The solar fraction of the collectors from the modelling is shown in Fig. 9. The system, when producing 3000 L of cooling fluid each day (COP = 0.6) is expected to have an annual solar fraction of 46%. Higher cooling demand will reduce the solar fraction achieved, but will increase the energy saved.

Solar collectors (30 x 30x58x1800)	30,000
Installation	15,000
Cooling plant	50,000
Tanks, connections	5,000
Control	5,000
Total cost	$105,000
Energy collected by collectors	66 MWh
Displaced cooling (COP = 0.6)	40 MWh
Energy savings (15c/kWh)	$6030/yr
Simple payback	17.5 years.

Table 2. Analysis of 35 kW solar chiller at Ager Sectus Winery.

Additional factors that would help reduce the payback period are:

- Unaccounted for hot water demand when cooling is not required.
- Government support for the system
- Increases in electricity prices in a carbon constrained era
- Decreased peak demand charges
- Increased capacity of the winery with additional cooling capacity available.

8. Conclusions

There are several variations of Solar cooling technology available on the market. Of these, solar thermal absorption cooling is the most common, and is increasingly used for air-conditioning applications throughout the world. Solar cooling has the advantage of being 'in phase' with the cooling demand. This is less of a consideration however for the Ager Sectus Winery, where there is minimal seasonal effect on cooling demand, outside of the harvest season.

The winery, however has a constant cooling demand of approximately 125 kW, which is presently met by a 350 kW ammonia refrigeration system. A lithium bromide – water absorption cooling system powered by an evacuated tube collector system would integrate well into the winery operations. The winery is located in one of the areas with the highest sunshine hours in New Zealand, and would be well positioned for a solar cooling pilot trial.

Solar cooling technology is still in the development phase, however a number of projects have now been successfully completed, particularly in Europe. The performance of the systems is still variable, however some systems are performing well with payback periods in the order of 15-20 years. A solar cooling pilot trial, with a single 35kW cooling system would be a worthwhile project, which if successful, is likely to be adopted by wineries throughout the Marlborough region.

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