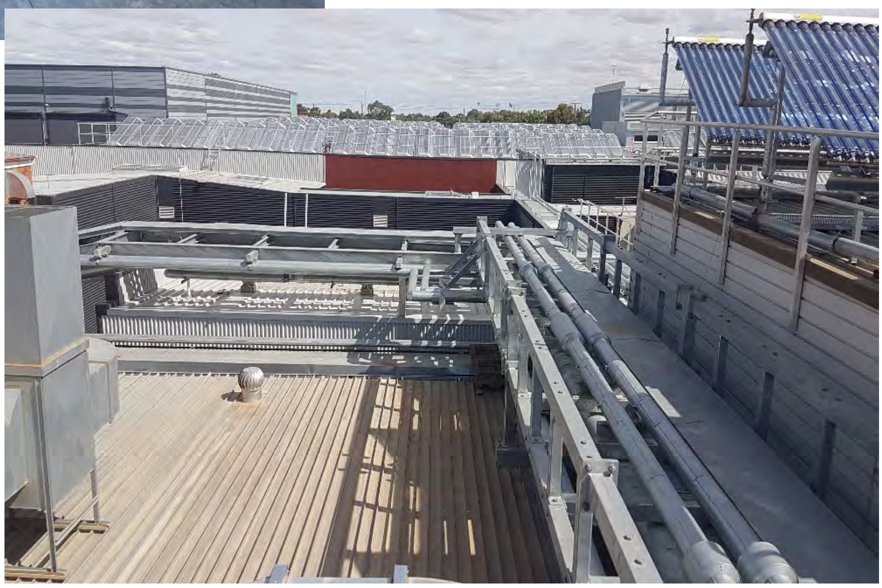
Echuca Regional Health

Rooftop Concentrated Solar Thermal for Hospital Heating/Cooling Demonstration Project - Case Study



Rooftop Concentrated Solar Thermal for Hospital Heating/Cooling Demonstration Project - Case Study

August 2021

Issue Date: refer Revision box below

Uncontrolled when printed/PDF

Author : Matt Martin (Balance Energy)

Reviewed by : Mark Hooper (Echuca Regional Health)

Contacts : matt.martin@balanceenergy.com.au; mhooper@erh.org.au

ARENA acknowledgement and disclaimer:

This Project received funding from ARENA as part of ARENA's Advancing Renewables Program.

The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Rev	Date	Comment
A	28th April 2020	Initial issue – with Milestone Report#2 • For review
B	20th July 2021	Preliminary final case study – issued with Final Milestone Report • Draft for initial review and comment
0	31st August 2021	Revised to include minor edits

Foreward

This Case Study is the primary Knowledge Sharing deliverable for ARENA Agreement 2019/ARP028, 'Rooftop Concentrated Solar Thermal for Hospital Heating/Cooling Demonstration Project'.

The document is authored by consulting firm Balance Energy Pty Ltd, the Approved Subcontractor engaged for Project Management and as Knowledge Sharing Agent in Agreement 2019/ARP028.

Echuca Regional Health ('ERH') is the owner and operator of rooftop solar thermal ('ST') fields installed at Echuca Hospital and the Recipient of funding per Agreement 2019/ARP028.

The Project received funding from ARENA as part of ARENA's Advancing Renewables Program.

Summary

Echuca Regional Health ('ERH') operates two rooftop solar thermal ('ST') fields supplying energy for space cooling and some heating services. The use of solar thermal energy provides the site with operational flexibility to reduce marginal costs for hospital energy use.

Solar thermal equipment was installed at Echuca hospital in three project stages, with two different ST collector technologies. The Greenland evacuated tube field was installed in 2010-11 and the Chromasun axis-tracking Microconcentrator ('MCT') solar field installed in 2015-16 during major redevelopment of the hospital. The collector technologies are reflective of innovations and market offerings over this period. The larger Chromasun field has suffered significant performance, operability and reliability problems. A third stage project was initiated in 2018-19 to improve extraction and use of ST from this field. This project was successfully installed and commissioned during ongoing hospital operation.

This Case Study addresses conclusions, recommendations and lessons learned from the third stage project, which was supported by ARENA Agreement 2019/ARP028. The findings are intrinsically linked to the previous two stages of ST development at the hospital, particularly for the Chromasun field.

Summary findings are presented for consideration by two primary groups ('1' and '2' below), as follows:

1. For key stakeholders of the Echuca hospital ST development:
    1. Further improvements could increase solar thermal use by another 100-200%, or 1-2 TJ/yr. Opportunities include:
        - automation and controls for the ST fields, ST users and the integration loop
        - proving operation of the nominally more efficient Thermax absorption chiller
    2. Reliable Chromasun field performance is needed to fully exploit remaining ST opportunities. Skilled ERH personnel will need time allocated to achieve adequate field reliability.
    3. In the absence of vendor support, ERH has developed considerable skills and expertise to recently improve operation of the Chromasun ST field.
    4. By design, the Chromasun field is reliant upon thousands of moving parts, which are potential failure modes, and complex software controls, which require diagnostic expertise.

2. For Proponents, or prospective investors in, similar ST developments:
    1. Design ST for high solar fraction, by:
        - specifying ST equipment with high reliability and high availability
        - selecting proven ST collectors with limited moving parts
        - reducing manual operation through automation where possible
    2. Develop solar thermal concepts for buildings on a bespoke basis, accounting for factors such as: available roof space; backup power generation and essential service requirements; local climate; capital replacement costs (including existing equipment); the Coefficients of Performance and efficiencies of proposed equipment packages; a viable solar fraction; manning levels for operation and maintenance and opportunity costs associated with changes to electricity and gas markets.

Contents

1 Introduction

The Echuca hospital extracts renewable energy from rooftop solar thermal ('ST') collectors to partially supply its heating and cooling requirements.

Two different ST collector technologies were installed, in 2010-11 and 2015-16. Each solar collector field circulates hot water through separate circuits to power separate absorption chillers for space cooling. Each circuit can also heat hospital heating streams, for air-conditioning, domestic hot water and boiler feedwater.

Development of the Echuca ST systems has occurred in stages. Accordingly, ST collector technologies are commensurate with technologies available at the stage of development. The stages of development are outlined in Table 1.1 below and Figure 1.1 overleaf.

The first solar field installed uses evacuated tube collectors. The second field consists of micro concentrator ('MCT') single-axis tracking collectors. The two ST technologies have performed vastly differently in terms of their design capacity and expected reliability. In particular, the MCT field has underperformed.

In 2019, a third stage project was initiated to balance flows from the MCT field and to exchange heat between the two solar fields. The scope of this third stage uses standard building services equipment. Its objective is to extract more solar energy from the MCT field and to distribute more solar thermal energy for beneficial use.

2010 - 2011	**Stage 1 Installation -** Solar Field #1 (evacuated tube collectors) and 500kW 'Broad' Absorption Chiller
April 2011 to May 2017	**Stage 1 Operation -** hospital heating / cooling energy partly supplied by Solar Field #1
2015-2016	**Stage 2 Project*** -CST expansion - Solar Field #2 (tracking collectors) and 1.5MW 'Thermax' Chiller (*****ARENA Project ref Contract No. 2015/ERP037, '*Case Study and Implementation of Solar Field Chilling & Heating Opportunities in a Hospital Environment*')
Summer '16/'17	**Stage 2 Project Commissioned** Commissioning of Solar Field #2 (tracking collectors) and 1500kW 'Thermax' Chiller
Summer '16/'17 to Apr 2020	**Stage 2 Operation and assessment-** Echuca hospital heating / cooling energy partly supplied by Solar Fields #1 or #2
Oct 2019	**Start Stage 3 Project*** -Capacity Improvement and Flow Balancing (*****ARENA Project, '*Rooftop Concentrated Solar Thermal for Hospital Heating/Cooling Demonstration Project 2019/ARP028*')
April 2020	**Stage 3 Project Commissioned** Additional heat from Solar Field #2, integrated with Solar Field #1
April 2020 to May 2021	**Stage 3 - extended period of operation**

Table 1.1 : Stages of Development – Echuca Hospital Rooftop ST Heating/Cooling

This Case Study is issued in conjunction with the Final Milestone Report for the third stage project. It is a knowledge sharing deliverable in accordance with Funding Agreement 2019/ARP028.

It is not clear that similar Case studies were prepared for the first and second stages of the ST development. However, the conclusions, recommendations and learnings from this third stage project are linked to those of the previous stages of ST development and this Case Study addresses several issues related to the previous ST projects.

Where constrained by the scope of this study or the availability of data, the Case study provides qualitative observations and coarse quantitative estimates.

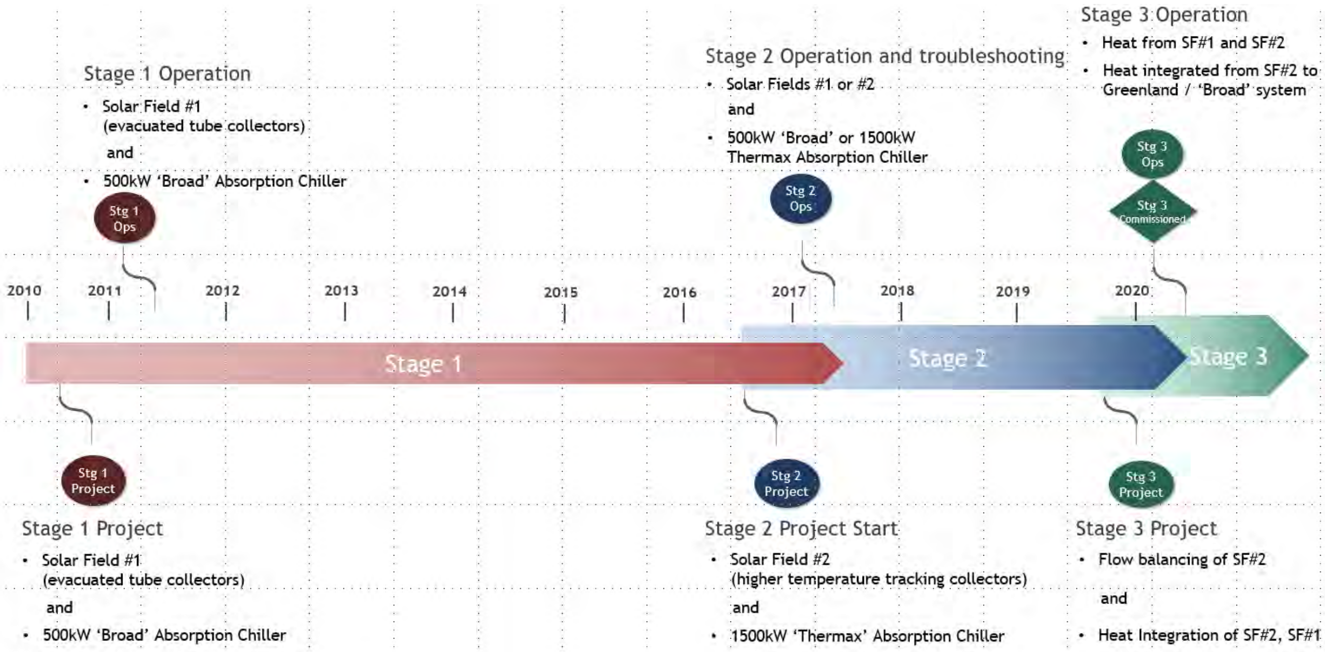


Figure 2.1: Timeline – Echuca Rooftop ST Heating/Cooling

2 Context

The Australian built environment is a major consumer of energy. In 2015, about one-quarter of national greenhouse emissions were accounted for by buildings (Campey et al, 2017). As space conditioning demands about 40% of built environment energy use (Sheldon et al, 2018), about 10% of Australia's emissions are the result of space heating and cooling of buildings.

Under the 2016 Paris Climate Accord, Australia committed to reducing its 2005 greenhouse emission levels of 26-28% by 2030 and recognised that global emissions need to be net zero by 2050. Replacing energy sources for building space conditioning with emission-free renewable energy may provide a significant contribution to emission reduction targets.

In addition to space conditioning, hospitals require energy for utilities such as sterilisation. Hospitals are unique in the built environment sector and have characteristics which may make them attractive candidates for renewable energy supply (Sheldon et al, 2018). These include:

- very high hot water (including steam) demand, compared with other buildings
- continuous demand for space heating as well as space cooling

and

- complex existing energy systems with high replacement capital costs over hospital life.

Australia has over 1,300 hospitals which use natural gas for about 50% of their energy supply (Sheldon et al, 2018). If an emission free renewable technology were proven to adequately replace existing non-renewable hospital energy sources, widespread application would provide a sizeable reduction in national emissions.

3 Description of Echuca Solar Thermal equipment

3.1 General

This section of the Case Study describes the equipment and technology used to extract and use solar thermal ('ST') energy at Echuca hospital.

Like most hospitals, Echuca hospital's building services were previously powered by mains electricity and natural gas. Renewable ST energy is now integrated with electricity and gas to operate standard building services equipment. The ST heat is generated by collector fields:

- Solar Field #1 – 'Greenland' evacuated tubes installed in 2010-2011
- Solar Field#2 – 'Chromasun' Microconcentrator ('MCT') modules installed in 2015-2016

The fields supply heat to a heating medium (hot water) which in turn energises various building services equipment to produce utilities – chilled water, heating hot water, domestic hot water and steam (boiler feedwater).

A key feature of ST application is the design for space cooling, which incorporates absorption chillers. Rather than using electricity to compress a refrigerant like conventional chillers, absorption chilling makes use of thermal heat to drive a thermodynamic absorption process. The process was discovered over a century ago, although its main use evolved to applications with limited access to electricity. Absorption chilling was new to the hospital when installed with Solar Field #1 and for the purposes of this Case Study, a brief description is included in section 3.2 below.

The hot water circuits from each ST field are designed to operate at different temperatures and pressures, to integrate with absorprtion chiller design requirements. Each circuit also exchanges heat with various hospital heating utilities as outlined in section 3.3.

3.2 New technologies

Solar thermal Collector technologies

The two solar fields are representative of development in ST collector technology across the period of their implementation from 2010-11 to 2015-16, noting that both technologies had been commercially offered for some time prior to installation at the hospital. For example, Chromasun MCT modules were marketed in 2012 (Parkinson, 2012), well prior to installation at ERH.

Since the first stage solar thermal project, evacuated tube supplier Greenland Systems has introduced several higher performance evacuated tube models. ERH recently replaced some of the initial 'Black' series tubes with higher performing 'Green' tubes. The overall capacity and annual energy capability impact of these improvements has not been assessed for this Case Study but is estimated to have resulted in a marginal increase above the original thermal design capacity of 275kW (Table 3.1).

Year(s) implemented	2010-11	Subsequent improvements[1]
Supplier	Greenland Systems	Greenland Systems[1]
Collection technology	Evacuated tube modules • Greenland Black series	Evacuated tube modules: • Greenland Black series and some: • Greenland Green[1] series
No. of tubes	144	tbc[1]
Design Capacity	275 kW th	tbc[1]
Design conditions (nominal)	2 barg, 90°C	2 barg, 95°C[1]

1. Full details of improved evacuated tube technology and impact on overall field capacity and capability require confirmation.

Table 3.1: Solar Field#1 – 'Greenland' SF - summary

Figure 3.1: Photo of newer 'Green' series tube module adjacent to 'Black' series module at ERH (April 2021)

Subsequent improvements have not been implemented for the MCT field modules. Chromasun has ceased trading and ERH has had little to no vendor support. The hospital has solved problems with the Chromasun field largely on its own accord. Ongoing operational and reliability problems with the MCT modules have restricted the ability of the hospital to fully test and understand field capacity and annual capability. The third stage 'Flow Balancing and Capacity Enhancement' project was initiated to extract and use additional solar thermal energy from this solar field.

Year(s) implemented	2015-6
Supplier	Chromasun
Collection technology	Fresnel Micro-concentrator Single-axis tracking
Number of Solar Field Controllers (SFCs)	6
Number of Strings per SFC	4
Number of MCTs per String	8, 10, 12 or 15
Total No. of MCTs	about 288[1]
Design Capacity	690 kW th
Design conditions (nominal)	12 barg, 170°C

1. Exact number of MCTs in operation requires confirmation

Table 3.2: Solar Field#2 – 'Chromasun SF' - summary

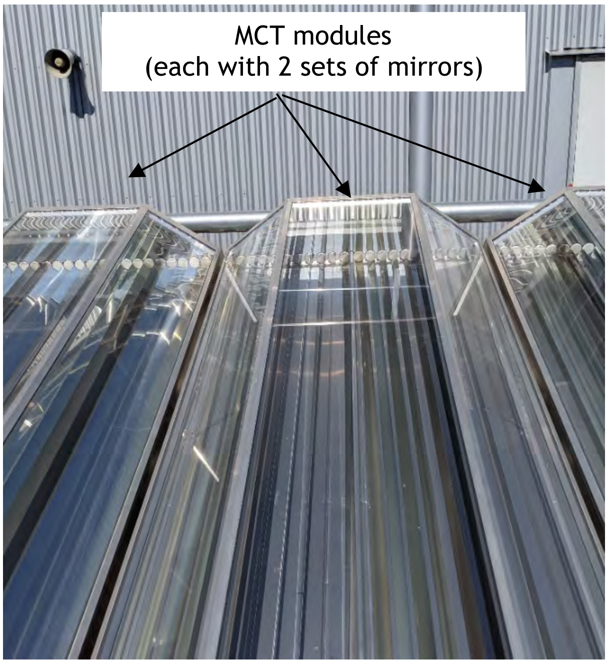


Figure 3.2: Photo of 3 off rooftop Chromasun MCT modules at ERH (April 2021)

Absorption Chillers

Absorption chilling was new to the hospital when introduced. Two absorption chiller vendor packages were installed, one in each of the first two stages of solar thermal development. Each Chiller is sized for its respective solar field, with the larger Chiller coupled to the Chromasun field.

Hot fluid from each solar field is directed to each Chiller package. It boils refrigerant from a formulated dilute solution such as Lithium-Bromide (the refrigerant and solution are package specific). The refrigerant is subsequently condensed by site cooling water then vaporised under vacuum conditions due to the affinity of the refrigerant for absorption by concentrated solution. At Echuca hospital, this absorption chilling process cools site chilled water to 6°C and operates in conjunction with electric driven chillers.

Solar Field	SF#1 (Greenland)	SF#2 (Chromasun)
Absorption Chiller	'Broad' Chiller	'Thermax' Chiller
Chiller Type	Single effect	Double effect
Design Chilled Water Capacity	500 kW	1500 kW Total 900 kW solar only
Design heat input (nominal)	625 kW hot water at 2 barg, 95°C	hot water at 12 barg, 170°C
Coefficient of Performance (COP)[1]	0.8	1.3
Notesr	Steam heat supplements solar thermal as required to achieve cooling load	Solar thermal and natural gas fired

1. These are understood to be the 'design COPs'. COPs vary with Chiller load.

Table 3.3: ERH Absorption Chillers

3.3 Integrated heating and cooling utilities design

Block schematic Figure 3.3 (overleaf) shows integration of the solar thermal fields with the Echuca hospital heating and cooling systems. Equipment modifications associated with the third stage solar thermal project are highlighted in 'clouds'. As indicated, the Flow Balancing and Capacity Enhancement Project has installed:

- valves to balance flows and improve temperatures from the Chromasun field;

  and

- heat integration equipment to permit transfer of ST energy from heating medium to another.

Aside from the collector fields and absorption chillers, other notable features of the Echuca ST design for hospital heating and cooling include:

- Thermal Storage.

  Two 200kL Chilled Water storage tanks at 6°C provide a buffer which acts as a 'cold battery' for operation of the hospital space cooling system.

  Electric chillers operate at night-time during off-peak conditions to charge the cold battery. In addition, when instantaneous hospital cooling loads are lower than the available solar thermal capacity for cooling, the 'cold battery' can be charged by ST and absorption chilling. This offers 'free' energy, by reducing subsequent use of some electricity and/or gas.

  The 'cold battery' provides for operational flexibility which increases the beneficial use of ST. Associated energy savings are not quantified as part of this Case Study.

  In addition to 'cold storage', Greenland ST fluid is connected to two 5kL hot water storage tanks, allowing 'hot battery' charge when surplus solar thermal heat is available.

- Building Management System (BMS)

  The BMS software used to operate and monitor hospital building services provides process control and performance analysis for ST operations.

  For example, specific instrumentation such as Direct Normal Irradiance ('DNI') measurement is provided to the BMS to assist operation of the solar collector fields.

Notes regarding Flow Balancing and Capacity Enhancement Project modifications:

1. 7 off adjustable balancing valves installed on outlet of Chromasun MCT modules
2. Heat integration equipment includes pumps, instrumentation, control loops, data logging not shown on this schematic.

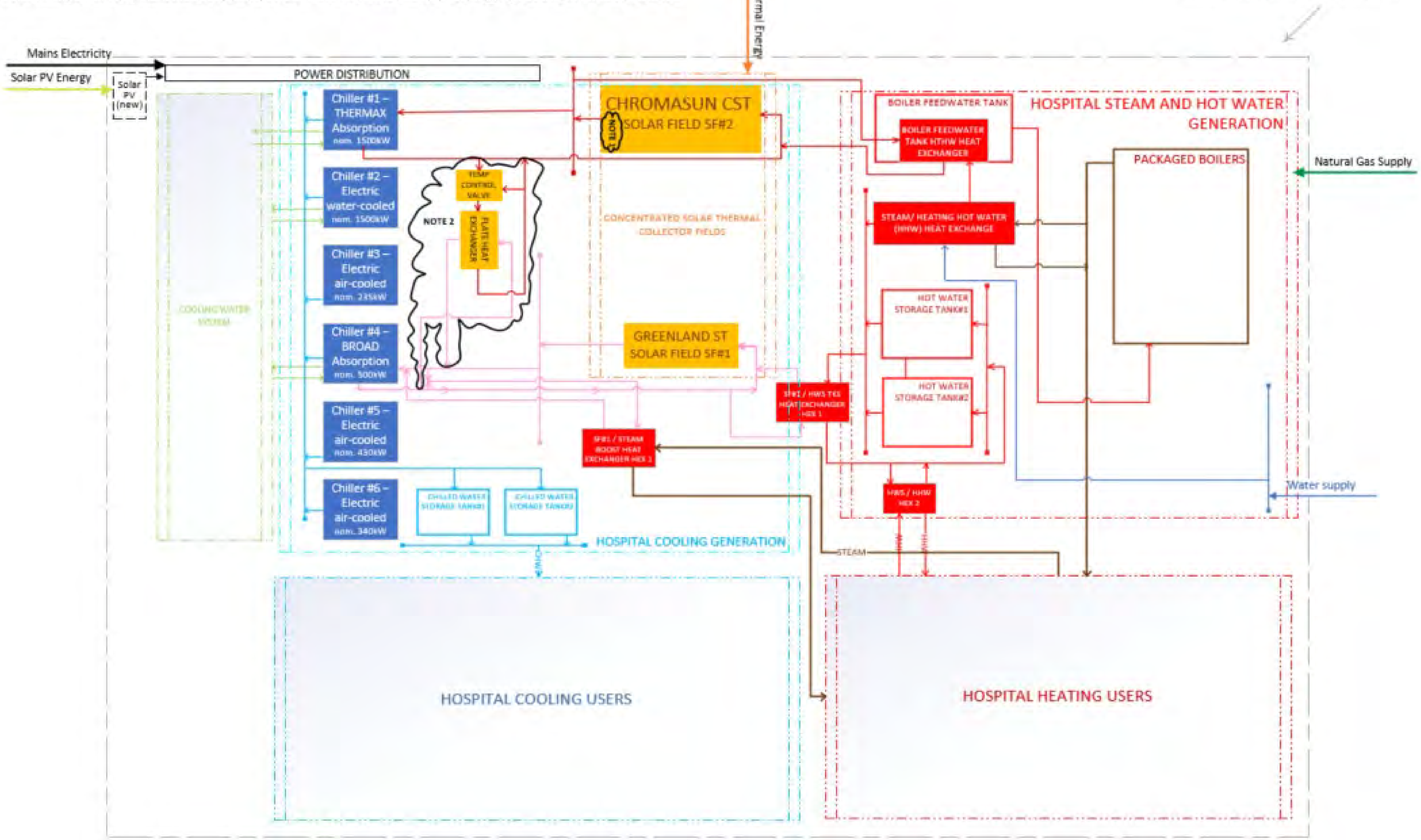


Figure 3.3: Schematic of ERH building Heating and Cooling utility systevhms showing solar thermal fields and scope of Flow Balancing / Capacity Enhancement

4 ST Performance

4.1 Third stage ST project

The performance of the third stage project is quantitatively evaluated in 'Supporting Report for Final Milestone - Capacity Enhancement and Flow Balancing of Rooftop CST'. The evaluation is limited by available data, which includes about 140 days of operation and does not comprise an annual cycle. To date, project modifications have operated and been tested with heat transferred from the Chromasun field to the Greenland/Broad system. The available data indicates that, in this configuration, at least 125kW can be transferred. Actual capacity in this configuration may be 200kW or more. Additional evaluation is needed to confirm this performance at high ambient temperatures.

The current annual energy gain is lower than possible because the integration loop operates for only about 40-50% of available solar hours. Table 4.1 summarises available operating data from the supporting Final Milestone report. It shows that the integration loop is only operated on about 75% of days when adequate solar is available, and for only about 60% of available solar hours in a day.

% of days loop in operation[1]	% of days with avg DNI>200[1,2]	% days operated when solar available	Average hours per day heat integration[1,3]	% of available day hours (nom. 0900-1700)	% of operation when solar available
54%	70-80%	70%-80%	4.7	59%	40-50%

1. This table is based on available operating data for the integration loop and DNI from period 15/10/20 -6/5/21. Ref - Table 5.3 of Final Milestone Report.
2. DNI is Direct Normal Irradiance measured at Echuca hospital; 'avg DNI' = the average of 5 minute spot DNI readings over period 1200-1600.
2. Average hours of operation and average energy from the integration loop on the days that it operated.

Table 4.1: Operating data indicates that heat integration operated only about 40% of available hours

Although not available for a full year, there is sufficient data to estimate the annual energy capability of the third stage project. Currently, with the heat integration occurring for about 40% of available solar hours, an estimated 200 GJ/yr is delivered from the Chromasun field to the Greenland circuit. If the integration loop is operated for maximum available solar, thermal energy gain can increase to 500 GJ/yr.

Operation of Echuca ST is currently manual. A collaborative project with CSIRO, ERH and Conserve IT plans to use predictive control to optimise energy use at the hospital. This project could be extended to automate operation of the integration loop and assist to achieve annual energy gain of 500 GJ/yr.

Delivery of improved solar thermal energy use is contingent upon reliable performance of the Chromasun field. This will require ERH to dedicate its skilled resources to maintain operation of the hardware and software of the Chromasun field.

The third stage project has not tested operation of the heat integration loop in a configuration which transfers heat from the Greenland system to the Chromasun/Thermax fluid. This remains an outstanding opportunity which could further increase the energy gain from the project, ie – in excess of 500 GJ/yr. This opportunity is contingent upon proving operation of the Thermax chiller with higher solar thermal energy input, as well as reliable Chromasun performance. It is discussed further in section 4.2 below.

4.2 Previous project stages

The scope of this Case Study does not include quantitative evaluation of previous ST project stages. Performance of the two solar fields is, however, critical to the performance of the third stage capacity enhancement project. Accordingly, this Case Study reviews performance of the two ST fields using selected operating data and qualitative observations. These findings contribute to conclusions and lessons learned included in this Case study. Operating performance is compared with design for each solar field and their respective absorption chillers, as follows.

1. Greenland Solar field and Broad Chiller

As outlined in Table 3.1, the Greenland ST field was initially installed with 275kW thermal capacity. In 2018, ERH considered full replacement of the initial 'Black series' evacuated tubes with a higher performing 'GLX100-16HT-LP' model offered by Greenland Systems (Witts, 2018). During the site visit conducted for the third stage project in April 2021, it was noted that at least one 'Black series' tube module has been replaced by higher performing a 'Green series' tube module (not the GLX100-16HT-LP model). This represents replacement of at least 16 tubes with higher performance tubes. ERH has advised of plans to replace more 'Black' tubes with higher performance Greenland tubes. The performance impact of installing 16 off new 'Green series' tubes is not quantitatively determined as part of this study. It is noted, however, that:

- Thermal output from this field is now designed for in excess of 275kW
- Data from the 'Supporting Report for the Final Milestone - Capacity Enhancement and Flow Balancing of Rooftop CST' indicates that current Greenland field performance can sustain heat transfer of 300kW for at least 1 hour
- Greenland ST operation is typically reliable, with high overall uptime
- Greenland Systems offers new generation tubes with even higher performance than the 'Green series' tubes recently installed on site.

As outlined in Table 3.3, the Broad absorption Chiller is single-effect, designed for thermal fluid input of 625kW, to achieve 500kW of cooling with Coefficient of Performance at design of 0.8. Gas is consumed (for steam) to supplement any shortfall in thermal fluid temperature.

At present, ERH operates the Broad Chiller as the primary chiller for use of renewable energy. The operational philosophy for the new heat integration loop is to extract as much heat as possible from the Chromasun system, transfer it to the Greenland ST fluid and direct the combined heat to the Broad Chiller. Table 4.2 indicates that solar thermal heat could now provide 70-80% of the energy requirements of the Broad Chiller, delivering 300-400 kW of chilling. Steam heat supplements any shortfall of solar heat.

Greenland Solar Field Thermal input – design	275^{+} kW th
Observed capacity	approx.. 300 kW th
Observed Chromasun heat via integration loop	125 kW – 200 kW th
Observed capacity Greenland ST + integration loop	430 - 500 kW th
Broad Chiller thermal capacity – design input	625 kW th
% Broad Chiller capacity provided by ST	70 - 80%
Broad COP at Design	0.8
Approx. cooling delivered by ST	340 – 400 kW th c

Table 4.2: Broad absorption Chiller capacity using Solar Thermal heat (Greenland ST & integration loop)

2. Chromasun field and Thermax absorption chiller

The Chromasun field was installed with 690kW thermal capacity, however its achievable thermal output is not well understood. The collectors have not operated frequently since first being commissioned. Problems with collector field reliability, operability and performance have reduced usage. Data provided by CSIRO show that the Chromasun field was only operated in the hotter months from February 2017 to February 2019 and in only about 9 months out of 24 overall. Frequency of operation during the hotter months was less than 100% and it is estimated that the field operated on only about 30% of all days in this 2 year period.

During a site visit in April 2021, ERH Executive Project Manager Mark Hooper demonstrated some of the problems which can prevent or reduce performance of the Chromasun field. These are detailed in Lessons Learned, 'section 5.2 – Technology Lessons'. Operation of the Chromasun field improved following troubleshooting of hardware and software components around this time. Mark Hooper advised that operational knowledge of the Chromasun field was still being obtained and that in some respects ERH was 'still commissioning' the Chromasun field.

While thermal output from the Chromasun field is not able to be quantified, the following observations are noted:

- thermal heat produced by the Chromasun field exceeds any heat transferred across the integration loop. Hence, the Chromasun field must have produced at least the 125-200 kW (Table 4.2) measured for the integration loop during October 2020 to May 2021.

- the solar collection efficiency of the Fresnel type collectors differs from the evacuated tube collectors, with different relationships to angle of sun and DNI. These relationships are not investigated for this Case Study, however ERH advised that Greenland field performance is less dependent on clear skies than the Chromasun Fresnel collectors and that temperature from the Chromasun field can drop considerably under cloudy conditions. Hence, achievable hours of operation of the Chromasun field may be considerably lower than for Greenland. Further tests are recommended to review this.

As outlined in Table 3.3, thermal fluid from the Chromasun field is designed to provide 690kW of thermal heat to the Thermax Chiller. A gas burner provides the remaining energy required to deliver its capacity of 1500kW of cooling. The nominal Coefficient of Performance of the Thermax Chiller is 1.3, therefore the gas burner design is for about 460 kW of additional heat.

Thermax performance was particularly impacted by lower output temperatures than design from the Chromasun field in the first years after commissioning. At present, the Thermax Chiller is not operated. It is serviced regularly and managed as a standby unit. The current service vendor, Air Solutions, has provided support for many years and advised that various modifications to the initial package have sought to improve the Thermax cooling performance.

The Thermax Chiller performance is not quantified as part of this Case Study, however the following qualitative observations are noted:

- difficulties with Chromasun field performance have led to poor chilling performance, operational difficulties and loss of confidence in operation of the Thermax. This would appear to explain why the Thermax Chiller is not operated frequently, and why base solar thermal cooling operation utilises the Broad Chiller.

- the Coefficient of Performance of the Thermax Chiller, quoted at 1.3, is over 60% higher than the Broad Chiller. It is not clear how this COP varies with part load, or if the COP of 1.3 is at full or part load. If proven to operate with higher COP, the Thermax will deliver up to 60% more cooling than the Broad for the same input energy. The Thermax would also deliver more space cooling using ST, prior to consuming supplementary gas or power.

- consumption of gas in the Thermax burner (COP of around 1.3), should be more efficient than gas consumed to consume steam for Broad Chiller operation (COP of 0.8). This will depend on actual behaviour of the Chillers' COPs with part load.

- the new heat integration loop could be directed to transfer heat from the Greenland thermal fluid circuit to the Chromasun circuit. This configuration was inferred in the 'Powering Forward' report prepared for ERH (Witts, 2018) which conceived the third stage project. It has not been tested due to concerns that the Greenland-Broad system may strip heat from the higher temperature Chromasun-Thermax system. However, if the Broad Chiller is not in service, the Greenland-Broad circuit should build temperature and transfer heat to the Thermax return line, thereby increasing the energy delivered to the Chromasun-Thermax circuit. This heat transfer may be significant (around 200 kW capacity) and provide incremental energy to improve Thermax operations.

- With heat integration from the Greenland to Chromasun circuit and recent improved performance from the Chromasun field, there is an opportunity to investigate whether Thermax Chiller operation can deliver up to 60% more beneficial consumption of ST. The best way to check this would be to conduct dedicated tests for the Thermax.

This opportunity - to increase the efficiency of ST use at the hospital, by proving operation of the Chromasun/Thermax system – is summarised in section 6 of this Case Study and supported by additional reference material in Attachment 3 which suggests that the Thermax Chiller has a higher COP than the Broad even at part load conditions. Like the opportunity to extract and use more ST by automating operations, this opportunity is heavily dependent upon improved uptime and performance of the Chromasun field.

4.3 Costs of Energy

ERH has calculated hospital energy costs since 2017 (refer Attachment 2). Contracted annual prices for electricity and gas are used to calculate the marginal cost of energy for each of the hospital energy sources – gas, electricity and solar thermal. Other spreadsheet inputs include the Coefficients of Performance (COPs) for chillers and the efficiencies of heating equipment. An excerpt of the 2019 spreadsheet is included in Figure 4.2 overleaf.

The scope of this Case Study does not include to corroborate these energy cost calculations. However, the following observations regarding Echuca hospital's energy costs are noted:

	Rates from 1 Jun 19			Dec-18				
	Gas	10.45	$/Gj	9.39				
	TS Delivery	0.6065		0.5867				
	VEET	0.15817		0.154		% Change from 2018		
	AEMO	0.08709		0.0846		Gas	Elec	
	$/GJ	**$ 11.30**		**$ 10.22**		110.63562	88.0654	
		peak	off peak	peak	off peak		Loss Factor	
	energy	12.08052	7.79312	10.8506	6.9997			1.11335
	network	4.19	2.22	4.19	2.22			
	AEMO ANC	0.058161	0.05816	0.0533	0.0533			1.0912
	AEMO Market	0.040156	0.04016	0.0368	0.0368			1.0912
	LRET	0.994738	0.99474	0.9116	0.9116			1.0912
	Sret	0.889219	0.88922	0.8149	0.8149			1.0912
	Veet	0.402107	0.40211	0.3685	0.3685			1.0912
	c/KWh	**18.6549**	**12.3975**					
	$/MWh	186.549	123.975					
	$/GJ	**51.81916**	**34.4375**	diff bw P & OP		1.5047309		
	Delivered Energy Cost $/GJ				**COP**	**COP Night**		
		Peak	**Off**	**Gas**				
Thermax	Absorption Gas/Solar			$ 8.69	1.3			
Chromasun Solar		30%		$ 6.09				
Broad	Absorption Gas/Solar			$ 16.05	0.8			
Solar		30%		$ 11.24				
		50%		$ 8.03				
		80%		$ 3.21				
Elec RTAD CGAH		7.959932	5.28994		6.51			
Elec 23XRV		7.402737	3.13068		7	11		
		weekend	4.91964		7			
Tank Charge Cost			6.08343					
Tank Dischage Cost			$ 18.65				pumping energy	
	WEEKENDS ARE OFF PEAK ****Opportunity							
	Sun Down peak times run electric ** Opportunity**							
	DHW gas fired HWS		$/Gj	$ 15.07	75	% efficiency		
	Steam production		$/Gj	$ 12.84	88	% efficiency	plus trap loss etc	

Figure 4.2: Excerpt from ERH Energy Costs Calculation for 2019

- ERH electricity costs are based on time of use tariffs and incorporate a peak demand charge on a rolling 12 month basis. Multiple energy sources permit to ERH to direct its energy consumption from the lowest cost source to take advantage of lower marginal cost.

- Solar thermal has a relatively minor marginal cost and is the lowest cost energy when available, ie - during daylight hours. Marginal ST operating costs are for operating and maintaining the solar fields and solar thermal circuit pumps, instruments, etc.

- At night, electricity is lowest cost for space cooling because the combination of high CoPs from water-cooled electric chillers and off-peak power tariffs drive marginal the cost below that of gas. During daytime, gas is lower cost for cooling than electricity.

- High power consumption can occur when electric chillers are used during evenings on hot days, or during hot nights. ERH's peak and demand charges have recently changed to apply over from 7am to 7pm, previously they applied from 7am – 11pm. This change permits ERH to lower its marginal cost for electric chiller use. In addition, the peak demand tariff can be reduced if solar thermal use is extended into evening hours.

5 Lessons Learned

Lessons associated with the third stage Echuca solar thermal project are inferred in various sections of this Case Study and the 'Supporting Report for the Final Milestone - Capacity Enhancement and Flow Balancing of Rooftop CST'. This section of the Case Study serves to compile the lessons learned and provide further background details.

Many learnings from the third stage Echuca solar thermal project are related to lessons from previous stages of ST development at Echuca. Accordingly, this section details lessons from installation of the Greenland and Chromasun fields including their respective thermal fluid circuits and absorption chillers.

Learnings from Echuca ST may prove useful to stakeholders in various industries and professions, and the following Lessons Learned are presented with these potential stakeholders in mind :

- designers, developers or project managers of future building projects;
- proponents and suppliers of solar thermal equipment and other renewable energy equipment in building applications;
- government entities and relevant industry associations such as for refrigeration, HVAC and hospital engineering;
- existing building operations, including Echuca hospital itself

There are numerous learnings and many are inter-related. For ease of presentation, the following key learnings are categorised into 'Design', 'Technology' and 'Project Management'.

5.1 'Design' Lessons Learned

Learning D1 – Design ST systems and specify ST equipment for high reliability / availability

Solar thermal systems require high uptime to maximise beneficial energy use. Accordingly, all system equipment – solar thermal collector fields*, absorption chillers, heaters and fluid distribution equipment – should be designed and specified to achieve high system reliability and availability.
(* - also refer 'Technology' Learning 'T1' regarding design features to minimise downtime.)

Implications for stakeholders

- Building services designers will be familiar with the reliability and availability of standard equipment including boilers, burners, pumps and heating and chiller packages. Designers should scrutinise the reliability of newer technologies in a solar thermal system, particularly the solar collection technology, for potential failure modes. At Echuca hospital, the multiple components, moving parts and complex software associated with the Chromasun solar collector field have contributed to low uptime in the first 4 years of operation. Collector reliability is likely to be a significant factor in overall ST system uptime, however outages for periodic equipment service and reactive replacement of parts for all ST equipment should also be considered.

- Building owners and project developers should consider solar thermal system reliability and availability when estimating the benefits of ST and building energy costs. Lost opportunity associated with solar thermal downtime will detract significantly from project economics.

Background

The third stage Echuca solar thermal project was conceived to address shortcomings associated with the Chromasun solar collector field, particularly its lower-than-expected solar energy extraction. Fluid temperatures achieved from the Chromasun field were significantly less than design. In 2018, it was reported that, for the previous 12 months, temperatures were limited to about 115°C, compared with design of 170°C.

The third stage project has improved temperature performance from the Chromasun field by balancing the outlet flows. In addition, it has permitted more beneficial use of the Chromasun heat by integrating heat with the Greenland solar fluid/Broad Chiller circuit. This heat integration is of particular benefit if the Chromasun field does not achieve a high outlet temperature. In the past, low temperature thermal heat directed to the Thermax Chiller has detracted from its cooling efficiency, leading to reduced use of Chromasun heat.

While the third stage project has improved Chromasun field temperature performance, the beneficial use of Chromasun energy will remain heavily dependent upon the reliability of the Chromasun field. If the entire field is down due to problems with software, or if certain hardware components like MCTs or strings are not operational due to damaged motors or failed circuit boards, the energy benefit of the third stage project is reduced. These potential failure modes are further discussed in Learning T1.

Key 'Design' Learning D2 - Design ST building systems to require minimal manual intervention

The Echuca ST system is currently reliant upon manual operation to maximise extraction and beneficial use of solar thermal energy. Automation of solar thermal equipment has the potential to significantly increase the amount of solar thermal extracted and used by ERH and is as an opportunity presented by this Case Study. More generally, the design of solar thermal systems should consider 'smart' technology to maximise beneficial solar use and to minimise manual operation and intervention.

Implications for stakeholders

- For ERH, well-designed automation could significantly increase solar thermal extraction and use.

  As presented in Table 5.1 below, automation, optimisation and proof of operation of both solar fields, both absorption chillers and the heat integration loop may increase current beneficial solar thermal by about 100% to 200% or 1 to 2 TJ/yr from current.

- For policy makers, future implementation of 'smart' automated building operation has the potential to improve the commercial readiness of solar thermal technology.

- Building services designers should design solar thermal equipment operation to be automated, requiring minimal manual intervention by the building owner / operator. Package specifications should include requirements for instrumentation and control which integrates with building operations management systems. Bespoke functional descriptions may be required for large scale and specialised buildings.

- Solar thermal equipment packagers (including solar thermal energy consumption packages such as absorption chillers) will benefit from including reliable 'smart' instrumentation and controls, with flexibility for customisation in specific building applications.

- Technologists, innovators and researchers should consider 'smart' requirements including interfaces for building services automation into the design of new technologies.

- Building owners and project developers should manage building developments to ensure limited manual operation requirements and familiarise with design requirements for 'smart' technology offerings where solar thermal equipment is proposed.

Background

Building-owner funded solar projects should maximise both the capture and self-consumption of solar energy. Relying upon manual activation of solar extraction and solar energy consumption equipment leads to renewable energy 'losses' and dilution of project economics. Renewable energy at virtually zero marginal cost must otherwise be externally procured from gas or electricity providers.

At Echuca hospital, solar thermal extraction and use is largely manually instigated and monitored. As an example, utilisation of the recently installed solar field heat integration loop is only about 40% of available solar hours (as measured for the Final Milestone of the

Capacity Improvement & Flow Balancing of Rooftop CST Heating/Cooling system Project). In addition, more generally, solar extraction and use from each of the solar collector fields (particularly the Chromasun field) has not been optimised. Further opportunities exist to improve both Chromasun extraction and solar use by the Thermax Chiller. Automation of all hospital solar thermal equipment has the potential to significantly increase beneficial solar use.

A collaborative project is in train with CSIRO and Conserve IT to implement artificial intelligence generated predictive control at the hospital. This Case Study has not investigated the status nor detailed scope of the AI-MPC project. However, it is apparent that this project may be well-positioned to implement wide ranging automated control of the hospital's solar thermal equipment, including the recently installed heat integration loop and any future improvements proven for the Chromasun field and Thermax Chiller.

Although this Case Study has not quantified all current solar extraction and use at the hospital, and therefore cannot claim high accuracy in its predictions of total solar thermal capacity, it offers estimates of the additional solar thermal energy obtainable from remaining opportunities, including automation. These estimates are coarse, based on a limited review of recent operational data, but offer an insight into the potential of fully functioning 'smart' solar thermal building. Current beneficial solar thermal energy use is estimated at 1.3 TJ/yr. It is restricted by the Broad Chiller CoP of 0.8. If all future opportunities listed in section 6 are successfully implemented, the solar thermal capacity at the site is estimated at 3 TJ/yr.

As mentioned, this estimate is coarse and is deliberately presented to 1 significant figure at 3 TJ/yr. Representing a 100-200% improvement on current solar thermal benefit, it is nevertheless a reasonable estimation basis to consider actioning remaining opportunities.

	Current estimate TJ/yr	Opportunities	Potential improvement % / TJ/yr	ST Capability TJ/yr
ST Extraction				
ST Extraction - Greenland	1.4 [1]	• automation & AI-MPC	20%[2]	1.7
ST Extraction – Chromasun	0.3[3]	• continued Chromasun performance & reliability improvements • automation & AI-MPC	0.3 – 1	1.3
ST Extraction – TOTAL	1.7[2]		1.3	3
ST transfer benefit –integration loop	0.2	• prove Greenland to Chromasun circuit transfer • automation & AI-MPC	0.3	0.5 (Broad in use) Thermax in use - test required -
ST Use				
ST use – Greenland-Broad circuit	1.1[4]	• automation & AI-MPC	-1.1 (use Thermax) to +0.6 (retain use of Broad)	0 (Thermax in use) 1 – 2 (Broad in use)
ST use –Chromasun-Thermax circuit	neglig-	• prove Thermax operation, higher CoP • automation & AI-MPC	1 - 3	0 (Broad in use) 1 – 3 (Thermax in use; tests required)
ST beneficial use – TOTAL	1.3[5]		3	3

1. Energy delivery as advised by ERH in 2018 2. Coarse estimate of 20% improvement in extraction from Greenland if AI-MPC optimises field operations; 3. Current Chromasun extraction estimate based on the 200 GJ/yr estimate of heat transferred by integration loop at current low frequency of operation; 4. Estimate based on nominal COP of 0.8 at extraction est. of 1.4 TJ/yr; 5. Includes 200 GJ/yr from Chromasun field transferred by integration loop; 6. Beneficial use of energy through Thermax could theoretically be 1.3 times 3 TJ/yr (total energy extracted) if all ST energy directed to Thermax operating with CoP of 1.3. Overall beneficial energy estimate is ~20% less due to inability to operate Thermax at COP of 1.3 across its entire load profile. Tests are required to firm up the 3 TJ/yr beneficial use estimate.

Table 5.1: Coarse estimates of annual solar thermal energy capability at ERH

5.2 'Technology' Lessons Learned

Key Learning T1 – ST technology benefits from less moving parts and lower complexity

Solar thermal systems require high uptime to maximise beneficial energy use. Echuca hospital is a demonstration of two solar collector technologies. The first collector field uses evacuated tube modules. It has few moving parts and minimal complexity. The other collector field design is reliant upon complex software and thousands of moving parts to optimise solar thermal extraction. Component failures and system complexity have contributed to low uptime for this field. While improvements have recently increased field performance, the Echuca experience is instructive for technology selection of future solar thermal projects.

Implications for stakeholders

- Technologists and researchers will be familiar with this learning, nevertheless it is noted that the impacts of failure of any system component (not simply the solar collection technology) require consideration, eg – does component failure remove solar thermal extraction or use from an entire module or field ? The same issues apply to operational complexity - how simple will a technology be for the building owner to operate ? Can it be a 'set and forget' system ? What level of vendor support is required ?

- Building services designers will seek proven energy supply and consumption equipment in an increasingly carbon-constrained world. Many building projects will encounter bespoke design bases with multiple drivers for lowering their lifetime energy supply costs and total energy consumed. Selection of solar thermal building services equipment should consider multiple design criteria to optimise energy costs and consumption:

    - imported power source; and/or local rooftop PV (capex, operating costs)
    - emergency or critical power supply load and cost (capex)
    - energy storage requirements (capex, operating costs)
    - gas supply availability (capex, operating costs)
    - available rooftop area for solar thermal or solar PV
    - equipment COPs
    - overall operational complexity, reliability, availability and system redundancy
    - solar thermal technology which promotes ease of operation and high availability.
      Evacuated tube technology will promote lower complexity and less moving parts than technologies reliant upon axis tracking.

- Building owners and project developers should provide clear direction to designers regarding what is to be optimised – lifetime energy costs or overall energy consumed ? These objectives may result in different building designs. In any case, building owners should work with designers to understand the reliability, availability and complexity of solar thermal technologies.

Background

The Chromasun solar field installed at Echuca comprises single-axis tracking MCT technology with thousands of mirrors and motorised parts. Complex software is required to operate the field. ERH has operated the field with virtually no vendor support, however solar extraction has been limited by troubleshooting of moving parts, deciphering software and diminished confidence in operation. In addition, ERH staff can not be expected to dedicate significant time to operation of hospital energy systems.

The third stage solar thermal project at Echuca was conceived to extract and use more solar thermal energy from the Chromasun field. Operation of the Chromasun field has improved following the implementation of project scope (balancing valves) as well as concentrated efforts by skilled ERH personnel to troubleshoot the collector field. ERH Executive Project Manager Mark Hooper demonstrated the complexities of the Chromasun field while troubleshooting during April 2021; including :

- Moving parts and electronics

  Figure 5.1 is a photo of two motors at one end of an MCT module. These are located at each end of each MCT. They orient the mirrors according to available sun. The control board receives information such as DNI from solar field controller software for 'single-axis' tracking. Communication systems between the MCTs in the field, the controllers and system software are integral to system operation.

  ERH has advised of multiple previous hardware failures within the system, including failed circuit boards, bowed mirrors or mirrors with lost tension, and erroneous temperature instrument (RTD) connections. Component failures have had cascading effects on field performance (uptime and outlet temperature) and have required significant time investment to rectify. During the April 2021 site visit, a communications problem with controller 'SFC5' resulted in multiple MCTs not tracking. In addition, a full 'String' of about inoperable 10 MCTs had to be enabled by through software override of the tracking status of one set of MCT mirrors. Prior to the change, the SFC2 software program appeared to disable all MCTs when there was an error in tracking any mirror.

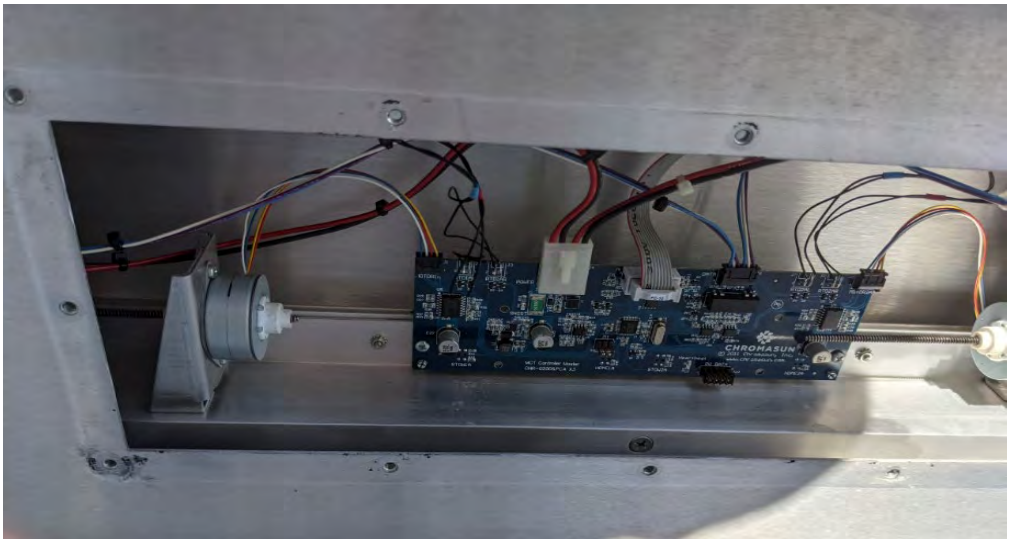


Figure 5.1: MCT motors and Chromasun control board

- Software and controls

The software which operates the Chromasun collector field controls each of the approx. 288 MCTs. A screen for 'string A' of one of the six Solar Field Controllers (SFCs), consisting of 15 MCTs, is shown in Figure 5.2 below. Each of the two sets of MCT mirrors is tracked. In this example, all mirrors were tracking in the ‘Middle’ operating position.

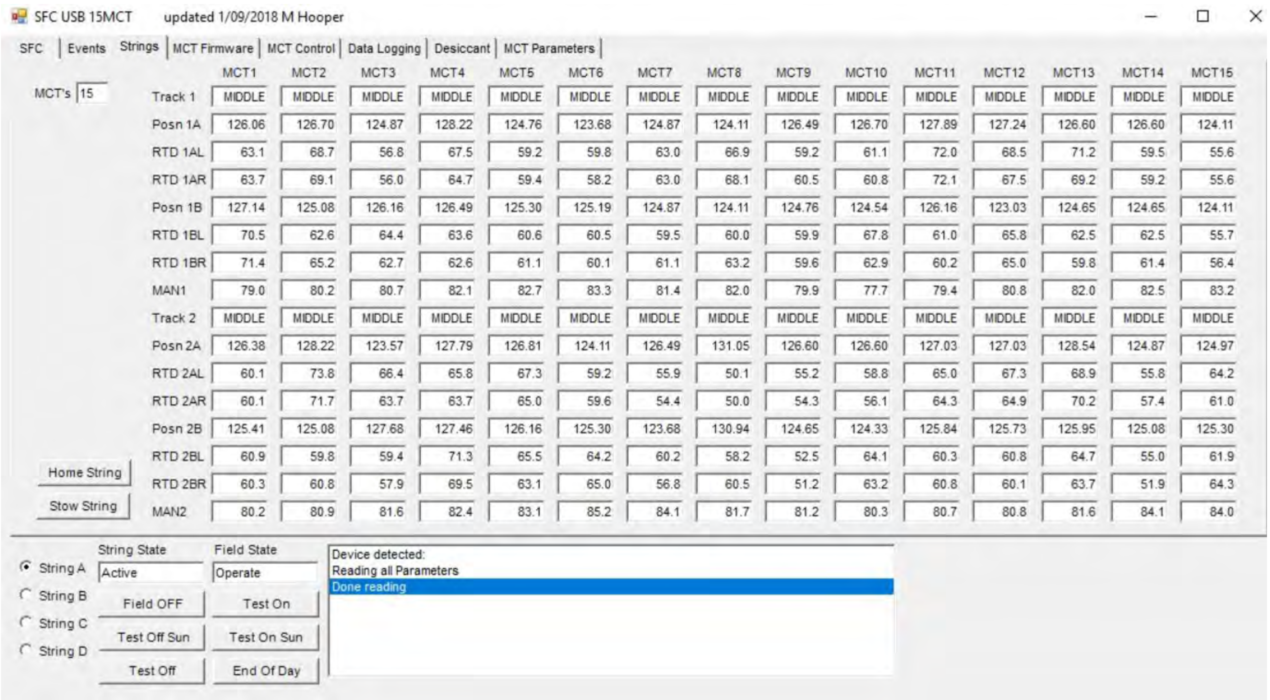


Figure 5.2: Example Solar Field Controller screen for a String with 15 MCTs

Each SFC sets parameters to optimise tracking of the sun based on site DNI. Multiple tracking descriptors are used to indicate the status of MCT mirrors. These include ‘FIND_FW’, ‘WAIT_(for)_SUN’ and ‘ERROR’ as per Figure 5.3.

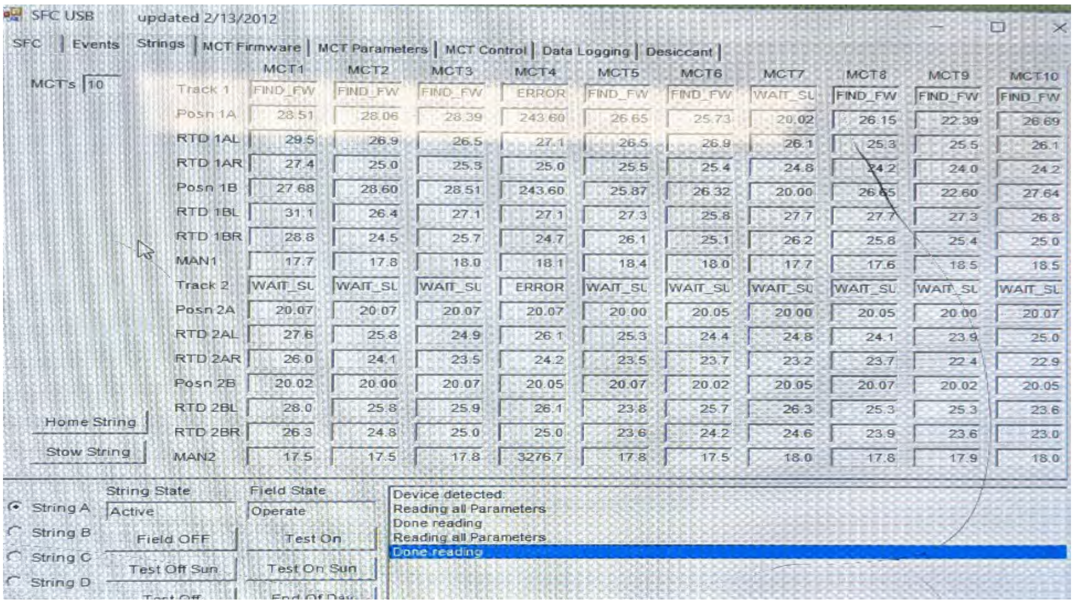
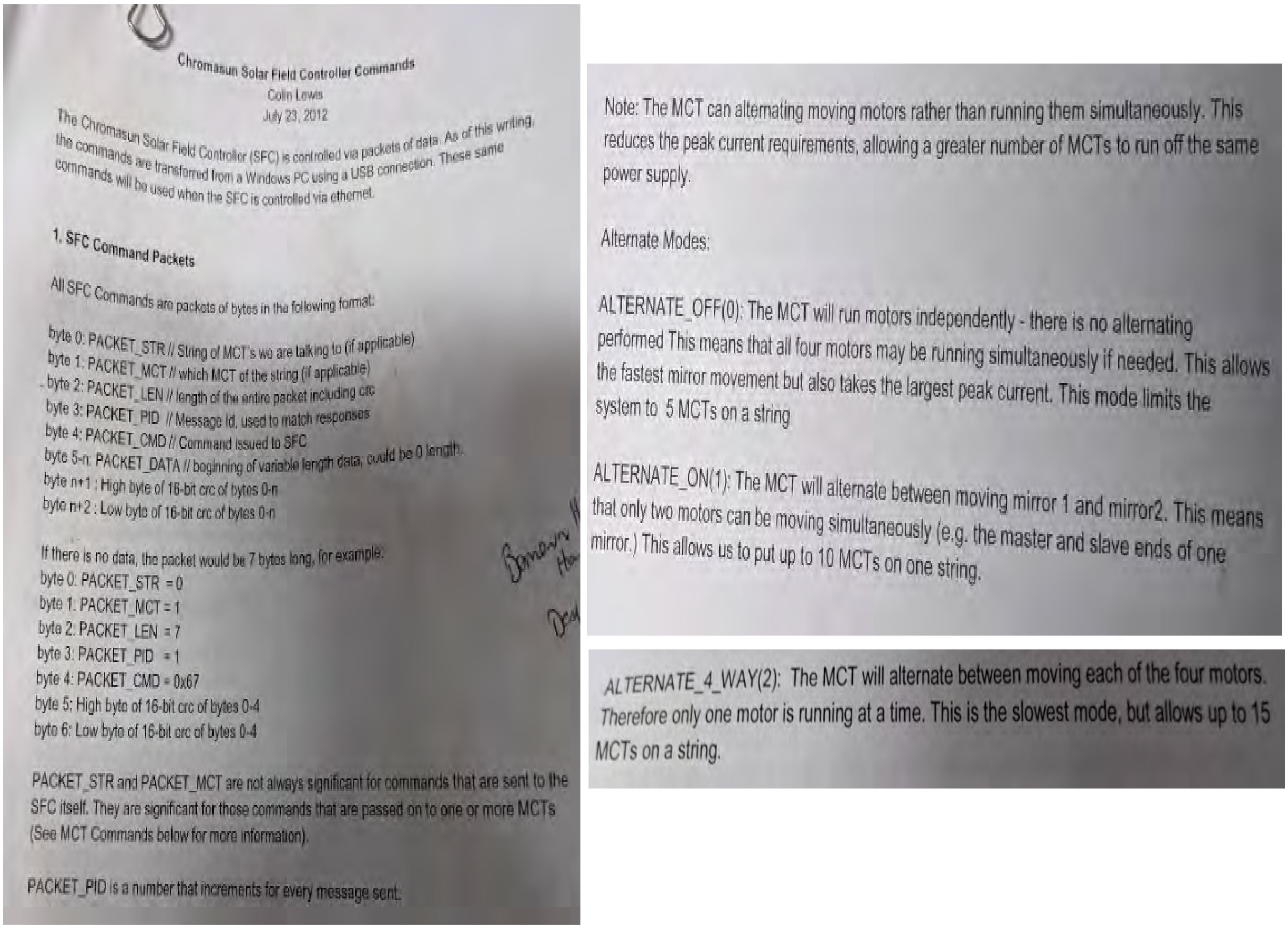


Figure 5.3: Example Solar Field Controller with 10 MCTs showing various tracking status

During the April 2021 site visit, ERH Executive Project Manager Mark Hooper demonstrated impacts of MCTs tracking ‘in error’. An apparent ‘voltage drop’ problem on String C for SFC2 prevented 9 MCTs from contributing fluid temperature. The problem was rectified by modifying software settings. In the software, an 'Alternate Mode' was activated to allow only 1 of 4 MCT motors to operate at once, thereby reducing current draw and voltage sag. The previous default setting had allowed multiple motors to operate. There was insufficient power to activate mirror tracking. Rectification of this problem led to each of the 9 MCTs tracking properly ('HOME' then 'SUN status) and a significant increase in the outlet temperature to 135°C.

Figure 5.4 provides excerpts of software command instructions provided by Chromasun. This illustrates the type of information which ERH has had to interpret to improve Chromasun field performance. ERH has developed in-house Chromasun knowledge and operating skills with little or no vendor support.

Following recent time investment in troubleshooting activities, the operation of multiple Chromasun strings - representing dozens of MCTs – was re-established. Recent troubleshooting is illustrative of the complex relationship between the Chromasun software and hardware. It also demonstrates entrained knowledge developed at ERH and additional opportunity associated with reliable operation of the Chromasun field.



Chromasun Solar Field Controller Commands

Colin Lewis

July 23, 2012

The Chromasun Solar Field Controller (SFC) is controlled via packets of data. As of this writing, the commands are transformed from a Windows PC using a USB connection. These same commands will be used when the SFC is controlled via ethernet.

1. SFC Command Packets

All SFC Commands are packets of bytes in the following format:

byte 0: PACKET_STR // String of MCT's we are talking to (if applicable)
byte 1: PACKET_MCT // which MCT of the string (if applicable)
byte 2: PACKET_LEN // length of the entire packet including crc
byte 3: PACKET_PID // Message Id, used to match responses
byte 4: PACKET_CMD // Command issued to SFC
byte 5-n: PACKET_DATA // beginning of variable length data, could be 0 length.
byte n+1 : High byte of 16-bit crc of bytes 0-n
byte n+2 : Low byte of 16-bit crc of bytes 0-n

If there is no data, the packet would be 7 bytes long, for example:
byte 0: PACKET_STR = 0
byte 1: PACKET_MCT = 1
byte 2: PACKET_LEN = 7
byte 3: PACKET_PID = 1
byte 4: PACKET_CMD = 0x67
byte 5: High byte of 16-bit crc of bytes 0-4
byte 6: Low byte of 16-bit crc of bytes 0-4

PACKET_STR and PACKET_MCT are not always significant for commands that are sent to the SFC itself. They are significant for those commands that are passed on to one or more MCTs (See MCT Commands below for more information).

PACKET_PID is a number that increments for every message sent.

Note: The MCT can alternating moving motors rather than running them simultaneously. This reduces the peak current requirements, allowing a greater number of MCTs to run off the same power supply.

Alternate Modes:

ALTERNATE_OFF(0): The MCT will run motors independently - there is no alternating performed This means that all four motors may be running simultaneously if needed. This allows the fastest mirror movement but also takes the largest peak current. This mode limits the system to 5 MCTs on a string

ALTERNATE_ON(1): The MCT will alternate between moving mirror 1 and mirror2. This means that only two motors can be moving simultaneously (e.g. the master and slave ends of one mirror.) This allows us to put up to 10 MCTs on one string.

ALTERNATE_4_WAY(2): The MCT will alternate between moving each of the four motors. Therefore only one motor is running at a time. This is the slowest mode, but allows up to 15 MCTs on a string.

Figure 5.4: Excerpts from Chromasun Field Controller Commands

Key Learning T2 – Use Commercial Readiness Index to support application of ST equipment

The Echuca hospital installed a solar collector field which, although commercially available, may not have scored highly for Commercial Readiness Index (CRI). The single-axis tracking MCT collector field has experienced reliability, operability and performance problems which, in retrospect, could have been highlighted prior by prior review of CRI.

Implications for stakeholders

- With increasing pressure to minimise the carbon footprint of built infrastructure, building services designers can utilise Commercial Readiness Indices for the renewable energy sector (Sheldon, 2018) to consider suitability of solar thermal equipment and aid the selection of building service packages.
- Building owners and project developers will also benefit from understanding CRIs of recommended packaged equipment.
- Technologists, innovators and researchers, who are likely to already be familiar with Commercial Readiness Index and Technology Readiness Level ratings, should consider CRI criteria to guide progress and application of new technologies.

Background

Technology Readiness Level (TRL) is an internationally accepted measure developed by NASA in the 1970s to support development of new technologies. Commercial Readiness Index (CRI) builds on TRL by considering the status of, and barriers to, commercial maturity of new renewable energy technologies. CRI levels begin with proof of technology and rise with increasing investor acceptance.

The CRI was developed by ARENA and permits self assessment. It has significant parallels with aspects of 'Front End Loading' Index or assessment for major projects in the resources industry, which is an established tool for investment decisions and project decision making.

This Case Study has not investigated whether a TRL or CRI evaluation was undertaken for the single axis tracking MCT solar collectors. It is also not asserting that use of a CRI would have resulted in different solar thermal equipment selection or indeed a more effective renewable energy outcome for Echuca hospital. Solar thermal deployment at Echuca hospital is a successful demonstration of ST technology integrated with standard building services equipment and has led to considerable gas, electricity and energy cost savings.

The Promoting Use of Solar Cooling and Heating industry roadmap (Sheldon, 2018) was published after the 2015-2016 installation of ERH's single-axis tracking MCT solar collectors and double-effect absorption chiller. The roadmap includes evaluation of CRI levels for available solar heating and cooling technologies (excerpt below in Figure 5.5) which may be useful for selection of renewable equipment in future built environment projects.

Table 3. Solar heating and cooling technology options[9]

	RESIDENTIAL	LARGE-SCALE BUILT ENVIRONMENT
Solar water heating with thermal collectors	Technically mature, CRI6	Technically mature, CRI3
Solar water heating with PV systems and PV-assisted heat pumps	Components technically mature, optimal integration with household loads required, CRI3	Components technically mature, optimal design required for chosen application, no known commercial scale-ups
Solar air heating	Technically mature, CRI6	Technically mature, no known commercial scale-ups
Solar thermal cooling: single effect absorption and adsorption systems (flat plate, evacuated tube collectors)	Technically mature, CRI2	Components technically mature, optimal design required for chosen application, CRI2
Solar thermal cooling: Double effect and triple effect chillers (concentrating and non-concentrating collectors)	No known technology development at smaller scale	TRL7, CRI2
Solar desiccant cooling	TRL7, CRI2	Components technically mature, optimal design required for chosen application, CRI2
Solar PV cooling (partly grid connected, off grid)	Many components technically mature, optimal design required for meeting end user objectives, lack of available data on commercial systems	
Solar combi-systems (multiple uses of heat)	TRL7, CRI2	Components technically mature, optimal design required for chosen application, CRI2

9 Technically mature – refer footnote # 2; TRL7 –technology demonstration carried out, system under development; CRI2 – small-scale commercial trials; CRI3 – commercial scale-up after small-scale commercial installations; CRI6 – bankable asset

Figure 5.5: PUSCH report evaluation of solar heating and cooling equipment options including CRIs, as at 2018.

5.3 'Project Management' Lessons Learned

Key Learning PM1 – Develop robust project performance targets

Clear project objectives and well understood performance targets support effective decision making and successful projects. The third stage Echuca solar thermal project will not achieve its incremental ST energy target of 1.4 TJ/yr. A robust and traceable calculation of annual energy gain would have established a realistic target and improved understanding of the project risks and benefits. Resource industry practice 'P10/P50/P90' may be useful for energy saving targets.

Implications for stakeholders

- Technologists, researchers, innovators and project proponents benefit from a detailed understanding of solar energy capacity, solar equipment failure points, solar availability and equipment solar annual energy capability.
- Policy makers benefit from improved understanding of technology, commercial and project risks.

Background

As outlined in 'Supporting Report for the Final Milestone - Capacity Enhancement and Flow Balancing of Rooftop CST', the third stage ST project will not achieve its annual energy target from Agreement 2019/ARP028, to," increase ST extraction and utilisation in the order of an additional 125kW capacity, producing an estimated 380MWh per year compared to current operations.". The capacity target of 125 kW is achieved however current performance will deliver 0.2 TJ/yr compared with target 1.4 TJ/yr (380 MWh/yr).

A review of the basis for the targets included in Agreement 2019/ARP028 reveals that:

- a clear calculation basis for the targets could not be found
- the 380 MWh estimate appeared to be based on 'double the current annual energy collected of 380 MWh' as included in Advancing Renewables Program Application MM062 v1. However, further review indicated that the 380 MWh estimate for current performance may have been based on Greenland field design data, rather than actual historical operating data.
- ERH's Mark Hooper considers that the 380 MWh annual target may have been intended to be a cumulative target following the project, as opposed to the annual incremental energy delivered by the project.

A documented and clear basis for quantitative project objectives is sound practice, commonly employed in resources industry projects. For technology-based projects, or projects intended for demonstration where significant uncertainties apply, a range of quantitative outcomes would provide better guidance. Probabilistic outcomes such as 'P10/P50/P90' could be proposed in a similar manner to resource industry practice, to provide estimates for 'best/most likely/lowest' energy gains. For example, the most likely or 'P50' energy saving for a project may be 2 TJ/yr. Depending upon operational performance, the same project may have about 10% probability or 'P10' of delivering 4 TJ/yr savings and about 90% probability or 'P90' of saving at least 1 TJ/yr.

Key Learning PM2 – Allocate time for robust review processes including key project stakeholders

Small projects often seek to limit costs from activities like engineering and drafting. However, well-established practices for large industrial capital projects can drive more effective outcomes for all projects, irrespective of size. Well-regarded practices include project reviews and design reviews, which incorporate the perspectives of key stakeholders such as owners, equipment vendors, operators and designers.

Implications for stakeholders

- Building services designers, owner's engineers and project managers should be careful when 'cutting' design and project review activities (including checking) from scope.
- Policy makers may wish to request that design and project reviews are undertaken, to include representation of technologists and key project stakeholders as outlined above.

Background

The third stage solar thermal project at Echuca hospital intentionally used a 'lean design' approach to limit engineering and drafting hours and costs. However, this may have contributed to gaps in knowledge between parties, an unrealised opportunity to use more solar thermal energy and re-work of some engineering and procurement activities. Other stages of the solar thermal development at Echuca would also appear to have taken a 'leaner' approach to design and scoping, leading to re-work or diminished outcomes.

Examples of diminished outcomes which in hindsight could have employed more rigour and considered the perspectives of designers, vendors or project managers include:

Diminished outcome	Problem	Preventative actions
Rework / potential project delay	Transfer pump procured for heat integration was too large. Identification of equipment - thermal relief valve, 3-way control valve - was late in design. These requirements were identified in a review meeting with ERH and knowledge sharing agent.	• designer QA review • Project and/or design review with owner/PM, designer, vendor
Unrealistic project expectations.	The forecast of annual energy gain was significantly over-estimated and stated in Agreement 2019/ARP028 as a 380 MWh or 1.4 TJ/yr target. This was found to be unachievable during project performance evaluation.	• review of project performance outcomes with owner/PM, designer, prior to commencement of project execution,
Rework / diminished energy output from Stage 2 CST project.	Hydraulic imbalance in the pipework from Chromasun modules led to a significant reduction in available thermal energy for beneficial use. Value management had removed scope which may have provided for hydraulic balancing of flows.	• designer QA / review • designer hydraulic modelling • Project and/or design review with owner/PM, designer, vendor
Re-work / diminished energy output from Stage 2 CST project	Stage 2 project did not design for integration of heat between the two solar thermal fields. Subsequently installed in Stage 3 project.	• Project and/or design review with PM, designer, vendor

Table 5.2: Observed diminished outcomes from stages of ERH Solar thermal development

6 Opportunities

This section of the Case Study compiles and summarises opportunities to further improve solar thermal performance at Echuca hospital. The opportunities are detailed in various other sections of this Case Study and referenced in the 'Supporting Report for the Final Milestone - Capacity Enhancement and Flow Balancing of Rooftop CST'. The remaining opportunities are therefore not repeated in detail in this section but referenced to background descriptions provided in other sections of the Case Study and abovementioned report, in Table 6.1, for:

- Opportunity OP1 – Automate Solar thermal operations
- Opportunity OP2 – Prove (and establish) Chromasun-Thermax operation

Note that potential energy gains listed in Table 6.1 are coarsely estimated, as explained in section 5.1 (learning D2). The estimated gains are not additive, and the OP2 gain requires the benefit of automation delivered by OP1.

Opportunity	Potential energy gain TJ/yr[1]	Reference details	Next activities
OP1 – Automate Solar Thermal operations	0.3[1] - 1[2]	• Case Study: - section 4.1 - section 5.1, learning D2	• Implement AI-MPC project • Automate heat integration loop • Establish Chromasun field reliability and performance
OP2 – Prove Chromasun-Thermax operation	1 – 2[1]	• Case Study: - section 4.2 - Attachment 3 • 'Supporting Report[1]' - sections 5.3, 6.3	• Plan testing of: - heat integration loop in Greenland-to-Chromasun mode - Thermax with higher ST temperature input and at higher Chiller loading • Assess performance of Thermax • Review operating benefit of Thermax, consider automation • Establish Chromasun reliability and performance

1. Automating operation of Broad Chiller, Chromasun field and heat integration loop estimated to gain 0.3 TJ/yr;
2. Automation of other ST equipment including Greenland field and Thermax Chiller coarsely estimated to increase benefits up to 1 TJ/yr.

Table 6.1: Summary and reference details for remaining ST opportunities at ERH

Figure 1.1: Echuca Regional Hospital CST Rooftop Solar Heating/Cooling system - view from above

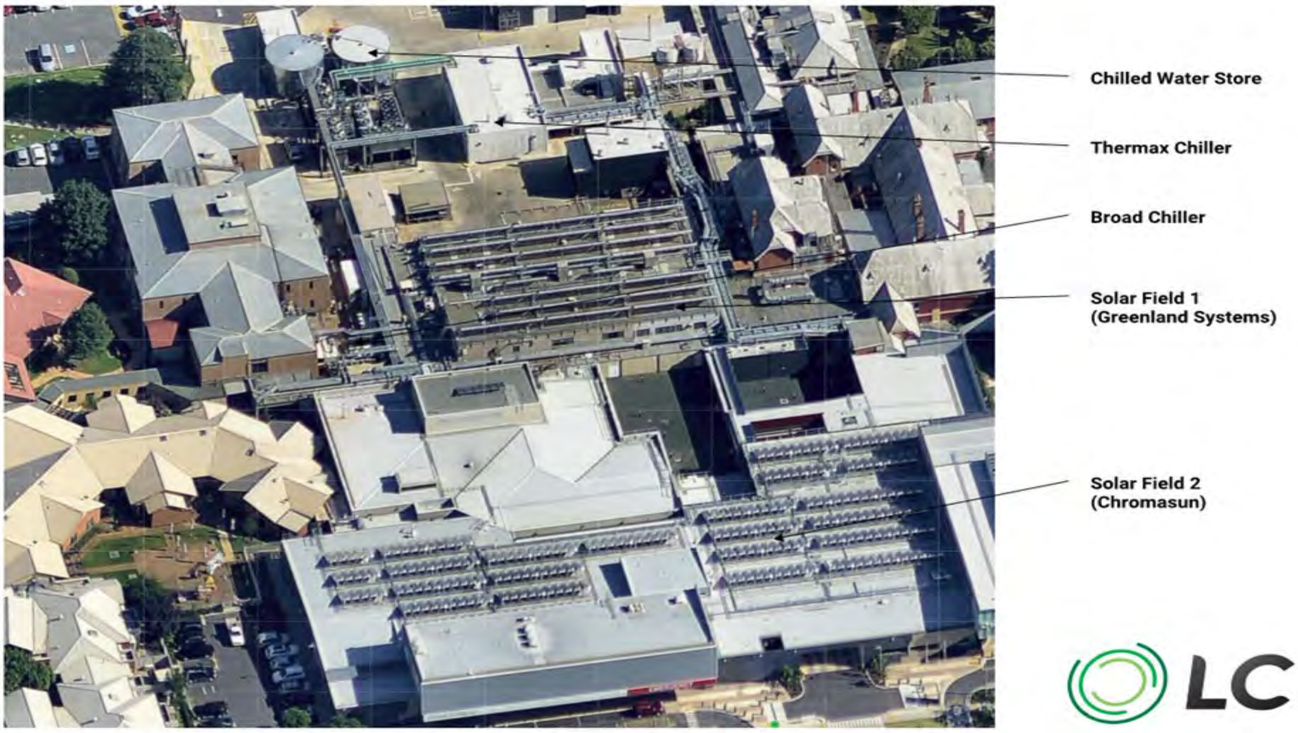
References

Sheldon, M., Sethuvenkatraman, S., Goldsworthy, M. 2018, *Promoting the Use of Solar Heating and Cooling in Australian Buildings – An Industry Roadmap*

Parkinson, G. 2012, *Made in Australia – Bringing local solar technology home, Renew Economy 19 April 2012*, retrieved from https://reneweconomy.com.au/made-in-australia-bringing-local-solar-technology-home-60261/ 9 March 2021

Witts, S., Hooper, M. 2018, *Solar Integration & Optimisation, Powering Forward – Echuca Regional Health – Revision C, Lehr Consultants International and ERH*

Attachment 1 – Various photographs



Topograhical view of Echuca hospital rooftop

Greenland and Chromasun solar field collector modules

Attachment 2 – Hospital Energy Cost Calculation Sheet (illustrative)

	2021			Jan-19				
	Gas	10.15	$/Gj	10.45				
	TS Delivery	0.658		0.6065				
	VEET	0.21		0.15817		% Change from 2018		
	AEMO	0.08887		0.08709		Gas	Elec	
	$/GJ	**$ 11.11**		**$ 11.30**		98.2755783	101.0611	
		peak	off peak	peak	off peak		Loss Factor	
	energy	12.202476	7.871793	10.8506	6.9997			1.12459
	network	3.85	2.11	3.85	2.11			
	AEMO ANC	0.025139	0.025139	0.023	0.023			1.093
	AEMO Market	0.0402224	0.040222	0.0368	0.0368			1.093
	LREC	0.9930998	0.9931	0.9086	0.9086			1.093
	SREC	1.2576058	1.257606	1.1506	1.1506			1.093
	Veec	0.4843083	0.484308	0.4431	0.4431			1.093
	c/KWh	**18.852852**	**12.78217**					
						Demand chg	$ 112	per kVA pa
	$/MWh	188.52852	127.8217			pf	0.93	$ 120
	$/GJ	**52.369032**	**35.50602**	diff bw P & OP		1.4749338		
	Delivered Energy Cost $/GJ				**COP**	**COP Night**		
		Peak	**Off**	**Gas**				
Thermax	Absortion Gas/Solar			$ 8.54	1.3			
Chromasun Solar		30%		$ 5.98				
Broad	Absortion Gas/Solar			$ 15.78	0.8			
Solar		30%		$ 11.04				
		50%		$ 7.89				
		80%		$ 3.16				
Elec RTAD CGAH	~~Heat Pumps~~	8.0443982	5.454074		6.51			
Elec 23XRV	~~Heat Pumps~~	7.4812903	3.22782		7	11		
	~~Heat Pumps~~	weekend	5.072289		7			
Tank Charge Cost			6.272185					
Tank Dischage Cost			$ 18.85				pumping energy	
	WEEKENDS ARE OFF PEAK ****Opportunity							
	Sun Down peak times run electric ** Opportunity**							
	DHW gas fired HWS		$/Gj	$ 14.81	75	% efficiency		
	Steam production		$/Gj	$ 12.62	88	% efficiency	plus trap loss etc	

HEAT EXCHANGER	150Kw x 5hrs	750	kwHr	>COP7	107.1428571	20.19948381	5049.870952	
		0.75	MWhr	demand	21	$ 2,580.65	$ 2,580.65	$ 7,630.52
		2.7	GJ		150	$ 18,064.52		
		$ 29.99	GAS	>COP 0.8	$ 37.49		$ 9,371.42	
Loddon DHW								
specific heat of water	4.18	J/mL/C	Joules to raise 1 mL of water 1C					
specific heat for 1 L	4180	J/L/C	Joules to raise 1 L of water 1 C					
DHW capacity	275	L						
Usage / day	2		17 beds*10min*6		1020	SHW		
usage / year	200750	L				Dishwash		
Avg town water temp	16	C				handwash		
Final HW Temp	70	C						
Temperature rise	54	C						
annual energy required	45.31329	GJ						
				Capital cost	Life	20Ycost (fixed price gas)	20y Capital	20Y total
annual cost	$ 1,342.10	Gas DHW		$5,600	10Y	$ 26,842.07	$11,200	$ 38,042.07
	$ 1,143.84	Steam		$14,000	30Y	$ 22,876.76	$14,000	$ 36,876.76
	$200	Solar		$28,000	30Y	$4,000	$28,000	$32,000

- but what is the electrical cost of delivering a GJ/via the absorbers?

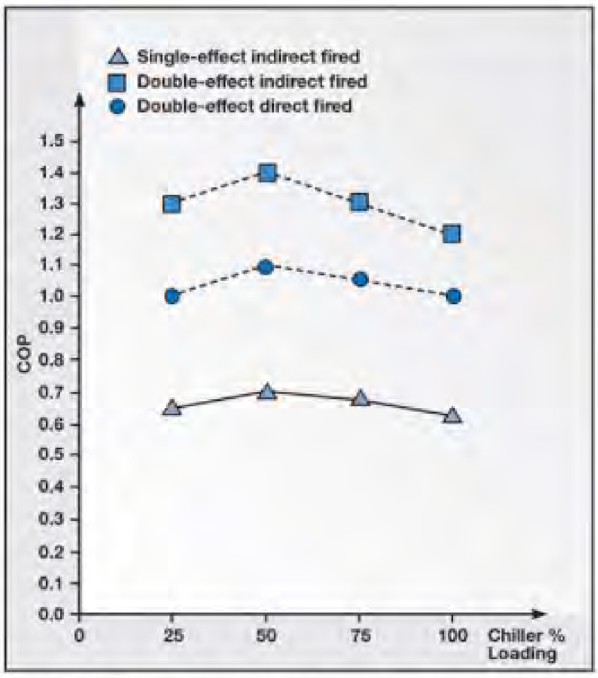
-assuming cooling tower and pumping energy are similar for CGAH and Thermax

					40	55
						165
					6600	9075
Theatres / Services/ ED / IMG /Loddon DHW						
specific heat of water	4.18	J/mL/C	Joules to raise 1 mL of water 1C			
specific heat for 1 L	4180	J/L/C	Joules to raise 1 L of water 1 C			
DHW capacity	275	L	4000	L/day		
Usage / day	15		14.54545			
usage / year	1505625	L				
Avg town water temp	16	C				
Final HW Temp	70	C				
Temperature rise	54	C				

2021 gas & elec | 2019 gas & elec | 2018 gas & elec | 2017 gas & elec | AHU filter costings | Sheet3

Attachment 3 - Supporting information for improving Thermax operation

from: https://www.esmagazine.com/articles/82307-basics-for-absorption-chillers



GRAPH 1. Chiller part-load energy usage.

Chiller Operating Performance

As with motor-driven vapor compression chillers, absorption chillers do not operate at the standard operating conditions noted above. Though there are many variables that can be evaluated; for this article, absorption chiller COP vs. part -load percentage and chilled water leaving temperature vs. chiller capacity shall be evaluated. Note that the graphs are illustrative only. It is important that you use the particular chiller performance data for the equipment you are evaluating.

Effect of part-load operation on chiller efficiency. Looking at Graph 1, all three types of absorption chillers are most efficient at 50% part load with the single-effect indirect-fired chiller having a 9.4% increase in efficiency; the double-effect direct-fired chiller having a 10% increase in efficiency; and the double-effect indirect-fired chiller having a 16.7% increase in efficiency. At part loads below 50%, the chiller efficiencies are lower as the chiller part load is lower.

Hi Matt,

Thanks for that.

Please see the actual Thermax circuit diagram.

All of the solution flow travels through the HW-HTG (hot water high temp generator)

So we would need to see well above 150 degrees under full load requirements.
If the chiller was running at part load, this temperature would be able to drop slightly.

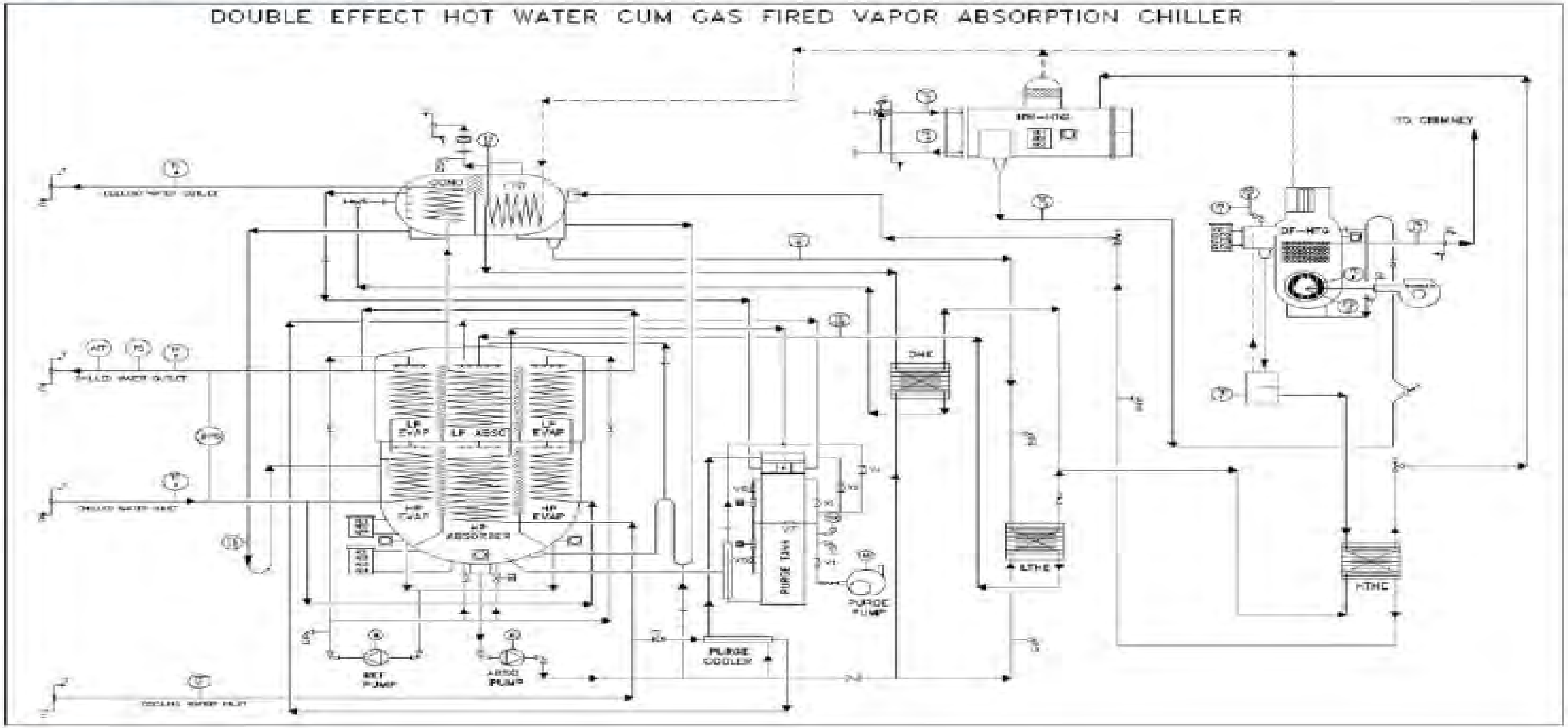


Fig.1 Cooling mode

A.6 Cycle of Operation

Regards,
Matthew Watkins
Technical Support Manager

airsolutions