Integrated Energy System for St Albans Leisure Centre Keilor Downs

Brimbank Council

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Senior Sustainability - Officer Environment

Reference No: **Brimbank 1 Report**

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REFRIGERATION

1.1 *General Information*

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1.2 *Acknowledgements*

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Design peer review
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1.3 *Glossary*

Abbreviation or acronym	Description
COP	Coefficient of Performance
LCA	Low Charge Ammonia
SEC	Specific Energy Consumption- measured in kWh per cubic metre P.A
kWh	Kilowatt hours of energy
kW	A thousand watts of electrical or thermal power

1.4 *Table of Contents*

2. Executive Summary

This report covers the capital costs for total heating and cooling requirements for the Entire St Albans Aquatic Centre 'STALC' as opposed to the existing proposal, that only includes the pool and pool hall heating capital costs and building cooling loads but no capital or running costs. The STALC report does not go into how the rest of the building is heated or cooled and or the operational costs of electricity to run the whole centre. We have made the assumption that those areas are cooled/heated using a separate set of air conditioners.

We focus on the use of Low Charge Ammonia 'LCA' heat pumps for the heating of the pools and heating and cooling of air in the wet areas of the aquatic centre and the estimated operational costs only. It is these areas where the energy demand is highest: a more detailed study would need to be conducted to fully determine the operational costs for the whole building.

Key findings using Low Charge Ammonia Heat Pumps:

a) Electricity demand would be a maximum of 523 kW
b) Annual electrical energy consumption would be approximately 1,226,091 kWh
c) High level kWh cost estimate for pool enclosure and building heating would be $245,106
d) Cost of maintenance of plant and service regimes would be $ 11,519 P.A.
e) Projected lifespan of the LCA system is 30+ years

The use of industrial Low Charge Ammonia LCA heat pumps has not been considered for aquatic centres in Victoria before now, however, the Sydney Aquatic centre is heated/cooled using a conventional HFO heat pump. These heat pumps when combined with other energy saving technologies can dramatically reduce the energy consumption costs of these centres while also substantially reduce maintenance costs for councils.

Integrated Energy Systems can leverage large amounts of low-grade heat if the building designers incorporate this technology into their designs during planning. The aim of this report is to provide information for the council to better understand how these heat pumps function, the operational costs, and the best configuration within this aquatic centre.

2.1 *Heat and cooling load assumptions used to formulate this report*

Heating and cooling loads	$Q_{E\ Cooling}$ [kW]	$Q_{C\ Heating}$ [kW]	Data Source
Space heating, maximum, figure 4 (see appendix 1)	-	850	Report
Cooling load, maximum, figure 3 (see appendix 1)	550	-	Report
Pool, 50m, maintenance heat load	-	77.4	Report
Program pool, maintenance heat load	-	64.3	Report
LTS pool, maintenance heat load	-	23.8	Report
Leisure pool, maintenance heat load	-	36.9	Report
Booster heat load, approximate maximum	-	400.6	Scantec
Lower floor, 140 W/m², maximum design cooling load (no diversity)	407	-	Scantec
Upper floor, 140 W/m², maximum design cooling load (no diversity)	367	-	Scantec
Total Output in kW	1324	1453	

Comparison of Annual Running Costs Inc Maintenance (No Solar) P.A

Item	**Report as Provided Boiler + Chiller**	**This Report HP Only**	**Saving p.a.**
Electricity + Gas	$273,635	$245,106.40	$28,528.46
Maintenance	$30,000	$11,519	$18,481.00
Total p.a.	**$303,635**	**$256,625**	**$47,009**

2.2 *Report Summary Annual Running Costs for the Pools and Enclosures*

A: SmartConsult Estimate of annual running costs using LCA 2 x heat pumps – no solar

Item	Cost Per kW	Total Est. Units	Total Cost
50M + leisure + learn	$0.20	1,027,800	$205,559.98
Program Pool	$0.20	197,732	$39,546.42
Total		**1,225,532**	**$245,106.40**

B: Estimate of annual running costs from the STALC report using gas boilers and a single chiller

Item	$ Per MJ	Total Est. Units	Total Cost
Gas Cost	$0.013	19,413,389	$252,374.06
Electricity Cost	$0.200	106,304	$21,260.80
			$273,634.86

C: Adjusted annual running costs in item B. above using calculated actual heat and cooling loads for the chiller. The chiller usage for pool enclosures was considered insufficient given it represents only 60kW of cooling/heating load

Item	$ Per MJ	Total Est. Units	Total Cost
Gas Cost MJ	$0.013	19,413,389	$252,374.06
Electricity Cost kWh	$0.200	550,850	$110,169.90
			$362,543.96

Savings Calculations

Solutions Overview	Total Cost	Total Saving - LCA HP
Solution B (from the STALC report) Using Report Costs	$ 273,634.86	11.6%
Solution C (Our adjusted + Space heating estimates)	$ 349,135.06	47.9%
Difference between STALC Report and our Adjusted Costs	-$75,500.20	

Comparison of maintenance costs between the STALC report and our actual for LCA Heat Pumps

Maintenance Costs	STALC p.a. cost estimate	Actual Cost p.a.
Single Chiller plus Gas Boilers	$ 30,000	Unknown
Low-charge ammonia heat pump	$ 90,000	$11,519

The Maximum demand of the heat pumps in kW @ 30 deg C Inlet temperature:

			Duties, Kw		COP		
HP Inlet temp max	Max kW Each	Heat Pumps x 2 Max kW	Heating	Cooling	Hot	Cold	Total
30°C	227.9	455.8	1794.9	1568.7	7.88	6.88	14.76

Note: Max kW will be ~15% to include auxiliary equipment 523.25 kW.
Note: the inlet temperature of the heat pump is regulated to a maximum of 30°C
Detailed Monthly estimated data contained in the appendix below assumptions.

2.3 *Solar Production*

	Energy Purchased	Energy Exported	Net Purchases	Energy Charge
Summary	(kWh)	(kWh)	(kWh)	($)
Before Solar	1,225,532			$245,106.40
Post Solar	783,759	-187,732	596,026	$141,733.16
Solar Production	441,772	-187,732		$103,373.00

2.4 *Budget Capital Costs of LCA system*

The capital cost quoted are contained in Appendix 1 below and is for the complete heating and cooling requirements for the whole building including heating the pools using a Hydronic reticulated chilled and hot water system.

2.5 *Project Deliverables*

Analysis of data provided by Brimbank Council have allowed us to determine

a) Maximum electricity demand in kW for the pool and pool enclosures heating and cooling requirements.
b) Estimated annual kWh consumption for the pool and pool enclosures heating and cooling.
c) High level cost estimate for pool and pool enclosures heating and cooling.
d) Cost of maintenance of plant and service regimes
e) Projected lifespan of the system

It needs to be noted that the following is excluded from the analysis:

- General Power
- General Lighting
- Pool Pump and ancillaries
- Heating and cooling for dry exercise and office areas

2.6 *Information Gathering*

Data for this analysis has been provided by Brimbank Council, Scantec Refrigeration and Johnson Controls International.

Further detailed information will be required for an in-depth confirmation study of the whole building if this preliminary report is accepted.

2.7 *Requirements*

Determine heating and cooling loads from site plans and modelling software and compare these to Low Charge Ammonia heat pump performance to calculate projected energy consumption. Also calculate the maintenance and repair regimes for this system.

3. Introduction

"Aquatic centres are major community facilities that require large amounts of water and energy to operate. They are unlike any other type of building in terms of energy and water consumption, and can consume up to seven times more energy per floor area compared to an average commercial office building"

'Energy performance and water usage of aquatic centres' Jonathan Duverge- 2019

The rise in the price of gas for councils in Victoria and NSW in 2018 was a rude awakening to the realities of the cost of using fossil fuels for the heating of aquatic centres for councils. This has led to many councils looking further afield than their usual suppliers for more energy efficient and green solutions.

Aquatic centres have some of the largest energy consumption figures of any commercial building and this fact has now come home to roost for Councils. By reducing energy costs, councils can go some way closer to running their aquatic centres at break-even or better budgets with considered designs and planning further ahead than they have before. With regular maintenance Integrated Energy Systems will last the life of the building.

The incorporation of Integrated Energy Systems is a new approach to these centres that has been trialled successfully in cold stores and food processing plants in Australia: this is not new technology. It has been in use in Australia for over 40 years and is only now making its way into aquatic centres. By integrating the heating and cooling functions into one building wide system, large energy savings can be made, less equipment purchased and lower maintenance costs incurred.

By going 'off gas' these centres can also make full use of solar PV systems, PVT systems and thermal storage which boosts savings even more. This is only possible when these centres are using heating and cooling plant which is electrically powered. These allied systems allow aquatic centres to leverage their large roof spaces and the land surrounding them to maximum advantage over the life of the building.

3.1 *The Project- St Albans*

The Brimbank City Council are in the process of planning to replace the existing St. Albans Leisure Centre with an upgraded centre at 90 Taylors Road, Keilor Downs Victoria. The project aims to provide a large recreational facility which includes pools, management offices, a café, meeting and training rooms, Health Fitness and Wellbeing rooms, a 24hr gym and other spaces. The designers are aiming for a 6-star rated building for energy efficiency.

3.2 *Aims*

This report aims to provide accurate information about the performance, reliability and costs of an Integrated Energy System. Specifically, this involves comparing the performance of LCA heat pumps with the gas-based system that is currently included in designs. By sourcing accurate and independent information from a range of sources this report provides the council with a sounder baseline that they can work from.

3.3 *Methodology*

Basing our calculations on the data provided by Brimbank Council and the pool consultant we have been able to model the heating and cooling and match this to the output of the LCA heat pump. This is a relatively simple exercise in determining the heating and cooling loads for the wet areas and the dry areas of the centre.

The general power, general lighting and the pumps and ancillaries were not considered for this study.

An assumption for the dry exercise and administration areas energy usage was made based on 140 W/m^2, as per regular airconditioned areas in this climate.

3.4 *Domestic hot water heating*

Hot water for showers is provided from the water heated by desuperheaters available from the heat pumps. A desuperheater will provide water at up to 80 deg C and will be available whenever the heat pump is operating. This hot water is a product of the operation of the heat pumps and accounts for about 6-8% of the heat pump output.

3.5 *Pool heating requirements*

The thermal loads for the pools were provided to councils by the pool consultant and these used as the basis for the wet exercise areas. The air volume above the pools to be heated was stated by the council as 17,100m^3 for the main pool and ~2,859m^3 for the program pool.

3.6 *Energy estimation of plant*

The estimates for the LCA heat pump energy usage was modelled using proprietary software from Johnson Controls International and Scantec. This software allows thermal engineers to accurately predict heating and cooling performance in a range of conditions in a Victorian climate based on the heat pump output, the ambient temperature and the inlet temperature of the heat pump.

3.7 *Proposed Heating and cooling plant configuration*

With a Hydronic (reticulated chilled water) air conditioning system the centre can be heated and cooled from one **central** plant. This system also has the benefit of displacing other unitary plant that is either cooling or heating using their own internal energy systems. This reduction in replication in the system eliminates the use of HFC’s in unitary equipment, produces inherent efficiencies increases throughout the system as well as the added benefit of greatly reducing the maintenance budget for plant. For an overall system basic system design see figure 6.

3.8 *Heat pump configurations*

The 112L HeatPAC LCA heat pump has been calculated to have sufficient capacity for the heating and cooling loads at the St Albans aquatic centre. The installation would require two heat pumps for a combined heat output of 1794 kW. This is reliant on the heat pump having a low-grade heat source capable of delivering an inlet temperature of 6 deg C or higher to the cold side of the heat pump.

Heat pumps are more efficient as the temperature 'lift' between the warm and cold side reduces. For a constant temperature on the warm side, water to water heat pumps work more efficiently as the inlet temperature to the cold side rises. Thus, the higher the temperature of the low grade heat source is, the greater the heat pump efficiency (COP) will be.

The COP of the 112L heat pump at 0 deg C saturated suction temperature is 5.29 providing heating of 704 kW. This excludes auxiliary equipment and is based on compressor shaft power input. If the saturated suction temperature is raised to 6 degrees C the 112L heat pump has a COP of 6.25 providing heating of 886 kW. Both estimates are for a saturated condensing temperature of 43 deg C.

A PVT system installed on the roof beneath the Solar PV system would also provide a very good source of low-grade heat during daylight hours as it can provide around 2 times the thermal energy of a solar PV system's electrical energy.

4. Assumptions

Pool Opening Hours

Days	Monday - Thursday	Friday	Saturday	Sunday
Opening hours	6am – 10pm	6am – 9pm	8am – 5pm	8am – 5pm

Location and Weather data set used

The data used for the different models is as follows

PoolHeat – Melbourne hourly TTY file
Helioscope – Hourly Data for 90 Taylors Rd, Keilor Downs

Pool Enclosure and Pool Sizing Summary

Pool Enclosures Walls and Surface area's	**m^3**	**m^2**
Pool 50m + Leisure + Learn to Swim	17,001	5,311
Program Pool	2,302	920
Pool Volumes and Surface area's	**m^3**	**m^2**
Pool 50m + Leisure + Learn to Swim	2,859	1,810
Program Pool	360	270

The individual pool sizing data was taken from the statistics sheets as provided.

Pool & Enclosure Temperatures

Pool	Temperature
Pool 50m	30ºC
Leisure pool	32ºC
Learn to swim	32ºC
Program pool	34ºC

Cost of energy

Type	**Rate**
Electricity	.20 per kWh
Gas	.013 Per MJ

5. Performance Results

5.1 *Annual Estimated Energy Consumption Pools + Enclosure*

Month	Pool Heating	Additional Space heating	Total Usage
	kWh	kWh	kWh
Jan	52,697	34,332	87,029
Feb	41,276	23,838	65,114
Mar	52,548	36,625	89,173
Apr	52,005	39,067	91,072
May	60,786	53,555	114,341
Jun	61,145	61,371	122,515
Jul	65,779	66,451	132,230
Aug	63,209	58,170	121,378
Sep	58,653	52,279	110,932
Oct	59,723	48,055	107,779
Nov	53,401	40,291	93,692
Dec	53,462	36,814	90,276
Total	**674,683**	**550,850**	**1,225,532**

5.2 *Estimated Annual energy costs after Solar*

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Energy Charge ($)
Jan	33,123	34,999	-1,876	$3,824.59
Feb	27,971	32,228	-4,257	$3,016.03
Mar	44,128	22,312	21,816	$7,040.66
Apr	58,783	9,802	48,981	$10,972.48
May	90,377	957	89,420	$17,998.81
Jun	107,107	38	107,069	$21,418.30
Jul	114,983	101	114,881	$22,988.42
Aug	94,847	2,020	92,828	$18,807.89
Sep	74,035	8,724	65,311	$14,109.00
Oct	58,381	16,470	41,912	$10,358.70
Nov	43,348	26,540	16,808	$6,546.37
Dec	36,676	33,542	3,134	$4,651.91
Annual	**783,759**	**187,732**	**596,026**	**$141,733.16**

6. Low Charge Ammonia Heat Pump Performance Data

6.1 *Sizing of the system*

The 112L HeatPAC heat pump has been calculated to have sufficient capacity for the heating and cooling loads at the St Albans aquatic centre. The installation would require two of these heat pumps for a combined heating and cooling output of 3,363 kW @ 30 deg C inlet temperature. This is reliant on the heat pump having a low-grade heat source capable of delivering an inlet temperature of 6 deg C or better to the cold side of the heat pump.

The COP of the 112L heat pump at 0°C saturated suction temperature is 5.29 providing heating of 704 kW. This excludes auxiliary equipment and is based on compressor shaft power input. If the saturated suction temperature is raised to 6 degrees C the 112L heat pump has a COP of 6.25 providing heating of 886 kW. Both estimates are for a saturated condensing temperature of 43°C.

The table below shows the range of COP's, kW output and power consumption at different heat pump inlet temperatures.

Table 1 LCA heat pump performance at varying temperatures. Table 2 LCA heat pump performance at varying inlet temperatures

Inlet Temp		Peak Power x 1	Peak Power x 2	Output Duties, kW		COP		
	Model	Shaft Power, kW	Heat Pumps x 2	Heating	Cooling	Hot	Cold	Total
0	HeatPAC112L	164.5	329	604	472.9	3.67	2.87	6.54
5	HeatPAC112L	181.9	363.8	743.8	592.3	4.09	3.26	7.35
10	HeatPAC112L	199.6	399.2	923	749.8	4.63	3.76	8.39
15	HeatPAC112L	209.7	419.4	1108.9	918.9	5.29	4.38	9.67
20	HeatPAC112L	221.6	443.2	1306.3	1098.8	5.89	4.96	10.85
25	HeatPAC112L	224	448	1555.8	1338.3	6.95	5.97	12.92
30	HeatPAC112L	227.9	455.8	1794.9	1568.7	7.88	6.88	14.76

Note: the inlet temperature of the heat pump is regulated to a maximum of 30°C.

The table below shows the lift on both the hot and cold sides in and out for the glycol loop from the heat pump.

Table 3 LCA heat pump input and outputs as inlet temperature varies

	Cold Side, °C		Hot Side, °C	
Inlet Temp	In	Out	In	Out
0	-3	-8	35	40
5	2	-3	35	40
10	7	2	35	40
15	12	7	35	40
20	17	12	35	40
25	22	17	35	40
30	27	22	35	40

7. Differences between Commercial and Industrial Heat Pumps

7.1 *How commercial HFC & HFO pool heat pumps work*

Commercial pool heat pumps are usually designed as a stand-alone unit that allows the centre owner to increase their heating capacity for pool heating by simply adding more units. The largest capacity of these unit is usually around 200kW. Therefore, if you require 1000kW of heating you would install 5 of these heat pumps.

The design of these heat pumps is ‘packaged’ as the heat pump has a compressor, a condenser, an evaporator, and a heat exchanger all within the enclosure of the unit. This allows pool water to be directly heated to maintain the pool temperature. This packaging of these components creates more maintenance issues for larger pool operators, as the additional plant requires more maintenance collectively.

Let us break this down a bit more to better understand what is involved with these designs.

The compressors used in these heat pumps are usually reciprocating or scroll compressors, hermetically sealed and cannot be easily serviced. The compressors are of a similar type to those that are used in domestic refrigerators: just a larger design.

Figure 1 Copeland Compressor

Figure 2 Heat Pump compressors

Figure 3 Evoheat Commercial Heat Pump

Figure 4 Rheem Accent Commercial Heat Pump

Figure 5 Multiple heat pump installations at Dreamworld Gold Coast Qld

These compressors are designed to be replaced should that be required during the life of the heat pump as they are modular and can be accessed externally.

A 200kW heat pump using these compressors may have two or three machines within their casing (a total of up to **15 compressors** to achieve 1000kW output). It is understandable why the **maintenance** of these systems becomes a concern for centre owners as these systems age.

7.2 *Where does the heat come from?*

Commercial pool heat pumps are usually 'air to water' heat pumps. The heat pump draws air into the unit, the heat from the air is extracted and the cooled air is then rejected from the unit and discarded. The heat that is recovered from the air is then applied to water that is pumped through the units via a flat plate heat exchanger **within** the unit. The water that goes into the heat pump is usually 'lifted' in temperature by 2-4°C. This explains why some commercial heat pumps cannot provide enough heat for large pools in Victoria: they do not have sufficient 'lift' to heat a pool in the Winter months and this results in pools not reaching their target temperatures.

7.3 *How Industrial Low Charge Ammonia pool heat pumps work*

LCA heat pumps are one part of a much larger **system** and are designed to operate in excess of 30 years. They work to extract heat **from water** instead of air, and the heated water is then distributed to a pool or building as part of a water loop that may also be servicing the HVAC system, the HWS for showers and other air-conditioned areas. This warm water loop is about **40-45°C** which is far lower than the gas systems they replace (80°C). LCA heat pumps use a multi cylinder reciprocating compressor which is driven by an electric motor, that is separate to the compressor, via a drive shaft. A single LCA heat pump will fit through a standard doorway and is about 3-4 metres in length depending on the capacity of the unit.

The LCA heat pump works in conjunction with a heat absorber that may be metres away from the unit and if heat rejection is required in the system it may also combine with an external cooling tower or closed circuit fluid cooler. The heat exchanger for the pool is separate again from the unit and may be metres away in the plant room. The pool water never comes into contact with the heat pump.

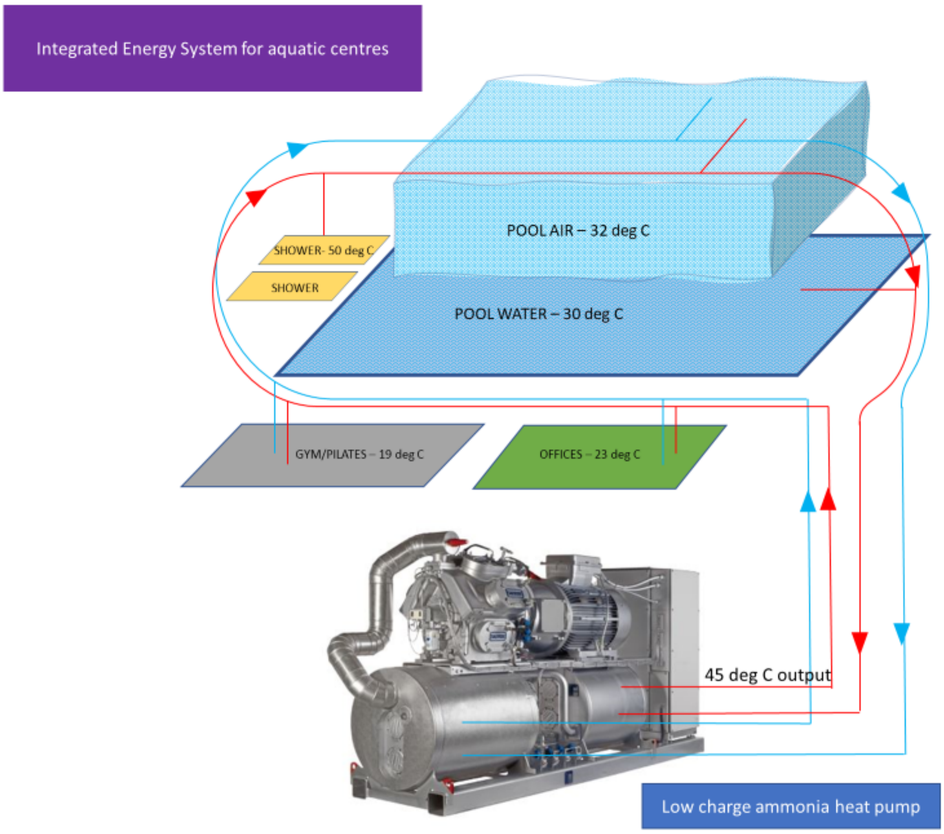


Figure 6: Integrated System Overview

LCA heat pumps provide a constant source of high-grade heat at around 40-45°C. It is possible to heat a few pools from the one heat pump by simply varying the flow of heated water through a heat exchanger for each pool as the heat pumps can easily provide 'lift' that is 10°C or more. To make the system even more efficient a thermal storage tank can be used that will reduce the running time of the unit by buffering the demand for water from the various pools throughout the day. This allows the heat pump to stay in an ideal operating range more of the time it is operating further increasing the efficiency of the unit.

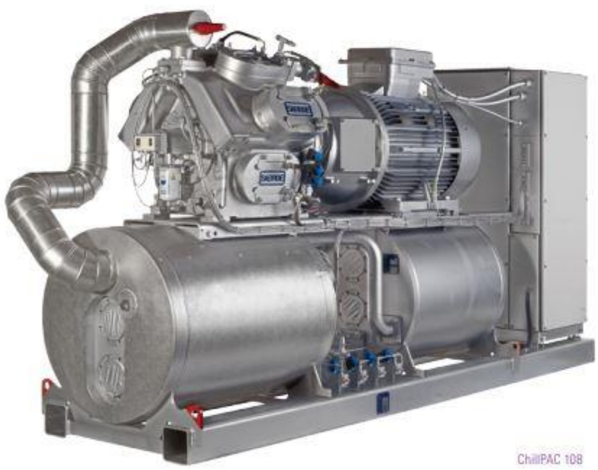


Figure 7: Sabroe Low Charge Ammonia Chiller

LCA heat pumps have capacities up to 2MW so a large aquatic centre might use two heat pumps to service the entire building (this allows for one to be serviced whilst the other heat pump continues operating). This greatly reduces maintenance costs as the centre has only two **central** compressors to service. The additional benefit from using an integrated energy system is that that the compressors would normally be installed for use in the HVAC air handling system for the pool hall and other air conditioned areas would be **replaced** by heating and cooling coils that connect into the system: a further saving in energy and maintenance costs detailed in Table 4. In addition, this plant concept utilizing secondary cooling/heating media on the cold and warm sides will eliminate the employment of HFC refrigerants, which are being phased down in Australia and across the world for environmental reasons.

Table 4: differences between existing design and integrated energy system components

	Existing gas/electric system	Integrated Energy System
Pool water	Gas boiler and/or CoGen	LCA heat pump
Pool air	HVAC unit -internal heat pump	LCA heat pump- coil and fan
Air Conditioning Gym	HVAC unit with heat pump	LCA heat pump- coil and fan
Air conditioning exercise spaces	HVAC unit with heat pump	LCA heat pump- coil and fan
Hot water for Showers	Gas HWS with storage	LCA heat pump water heated by desuperheaters(s) held in storage tanks

7.4 *Utilising the whole output from the heat pump - hot and cold*

As the heat pump is producing warm and cold water from the vapour compression cycle, the unit can be used to heat the pool water and pool enclosure air, while also air-conditioning office areas, dry exercise areas and the pool enclosure air in summer.

There is more heating required in an aquatic centre in Victoria than cooling for most of the year.

7.5 *Why not use a CO_2 heat pump?*

Industrial heat pumps are selected for use based on the temperature ranges they are operating in. CO_2 heat pumps are well suited to high temperature applications. The global warming potential (GWP) of CO_2 is relatively low (one) compared with synthetic HFC refrigerants such as R134a, which has a GWP 1300 times that of CO_2, or even the recently developed 'environmentally friendly' refrigerants such as HFO–1234yf, with a GWP of 4. By comparison, naturally produced methane has a GWP of 25. However, at the temperatures that are required for an aquatic centre, CO_2 heat pumps are constrained by the characteristic of the refrigerant they use. It just so happens that the 'transcritical point' of CO_2 is 31.1°C which is very close to the operating temperature of most pools. Exceeding the critical point will make condensation of the refrigerant impossible and make efficiency relatively poor. Operation of a CO_2 based heat pump with acceptable levels of energy efficiency and at reasonably high output temperatures of the medium to be heated is possible provided there is a large temperature change on the warm side. If the heated medium enters the CO_2 based heat pump at a temperature well below the critical point, then COPs are acceptable even at heated medium output temperatures of >80 degrees C.

7.6 *Understanding COP*

The efficiency of a heat pump is measured by its **Coefficient of Performance** (COP). A COP of 5 equates to 500% efficiency, providing 5 units of heat (or cooling) for each unit of electricity consumed – its running cost is a fifth that of a resistive electric heater (eg a fan heater). The best commercial building chillers claim remarkable seasonal (Integrated Part Load Value) COPs of 9.5 to 11 (e.g. http://www.smardt.com/AU-EN/prod_water_cooled.aspx). If you require both heating and cooling at the same time, or you can store warm water or cold water for later use, the efficiency can be even higher, as both the cold and hot side of the heat pump can provide useful energy.

The COP of a heat pump is not fixed: the COP ***varies*** with the temperature of the water or air that is supplying the heat pump. If you have spare heat or cold available, feeding this into the heat pump makes it even more efficient as there is less work to do: less 'lift' is required. In Figure 1 one can see that the COP of gas boilers does not vary with temperature, however, the COP of heat pumps will increase with the temperature supplying the cold side of the heat pump. These COPs can be very high as you get closer to the target temperature, and this needs to be considered carefully when designing systems around LCA heat pumps as keeping the heat pumps in their optimal range can produce remarkable efficiencies.

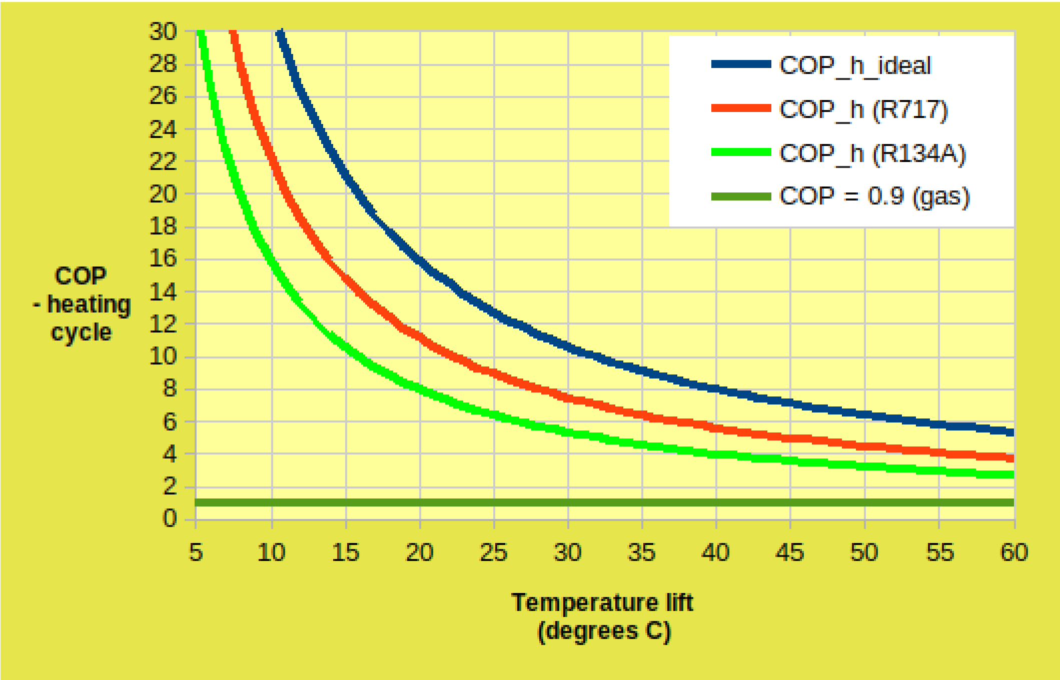


Figure 8: The change of CoP with inlet temperature

7.7 *Why GWP is so important*

The global RACHP (Refrigeration Air Conditioning and Heat Pump) industries are facing unprecedented change over the next two decades. In some jurisdictions these changes started taking place more than two decades ago driven by local environmental legislation. The global technology transition will accelerate over the coming five to ten years, but the industry must prepare now for continuing technology evolution beyond 2040.

This technology transition is driven by two major events that took place in October 2016. These are the Kigali Amendment to the Montreal Protocol and the Paris Climate Treaty, which has now been ratified by many developed economies (more than eighty) across the World. At least one nation (Norway) has responded by **banning fossil fuels** for space heating effective 2020.

The global hydrofluorocarbon (HFC) refrigerants phase-down that commenced in 2019 in accordance with the Kigali Amendment (in Australia it started January 2018), is much more than a refrigerant transition. The refrigerant transition must at the same time consider the Paris Climate Treaty targeting a maximum temperature anomaly of 2K by the year 2100 and carbon neutrality by 2050. In practice, this not only means minimisation of HFC use. It also means maximisation of energy efficiency at the same time.

Direct emissions from leak-tight HFC refrigerant based refrigeration plants represent approximately 10% of total emissions over the life of the plant [Velders et al - 2015]. The balance of 90% is caused by indirect emissions when these refrigeration systems are driven by electricity generated by means of combustion of fossil fuels. There are low global warming potential (GWP) synthetic refrigerant alternatives to HFC refrigerants. These are often referred to as 4th generation refrigerants and they generally belong to the hydrofluoroolefin (HFO) category or derivatives thereof. The environmental impacts of HFO refrigerants are underexplored.

In addition, HFO refrigerants offer no improvements in cycle efficiency compared with natural refrigerant alternatives [2]. The longevity of HFO refrigerants as long term, future proof working fluids is therefore questionable [Prof. Dr. Ing. Habil. Michael Kauffeld]. With very few exceptions, low GWP synthetic working fluids are flammable. This is a feature shared with natural refrigerants such as ammonia and hydrocarbons. The proliferation of flammable refrigerants will increase the focus on refrigerant inventories of individual systems. This development is already evident in many jurisdictions and industry sectors.

This is particularly the case in jurisdictions where refrigerant inventories beyond certain limits trigger costly compliance measures for refrigeration plant owners/users. The focus on minimisation of system refrigerant inventories causes a phenomenon often referred to as multiplexing. Multiplexing is when a relatively large number of small/smaller systems combined deliver sufficient cooling capacity to refrigerate or cool a large facility that could otherwise have been cooled or air conditioned by means of a central plant of identical capacity to the sum of the individual system capacities.

Examples of such multiplexed concepts are-
1) Several hundred split air conditioning systems servicing multi-storey apartment buildings
2) Large numbers of air-cooled roof top units servicing temperature controlled industrial facilities
3) several CO_2-based transcritical systems servicing a retail or distribution facility

If multiplexed systems cannot deliver equal to or better energy performances overall than equivalent central plant, they violate the intent of the Paris Climate Treaty unless these systems are powered by renewable energy sources eliminating indirect emissions.

In this context, centralized reticulated chilled water air conditioning plant employing minimal inventories of NH_3 refrigerant present themselves as potentially superior solutions both in terms of energy efficiency, but also in terms of safety, future proofing, industry knowledge and environmental acceptability. The operating NH_3 inventories in mid capacity range (500-1000 kW cooling capacity) water chillers range from 0.03 to 0.05 kg/kW. For larger capacity chillers, the specific NH_3 inventories are often even less.

Ammonia is self-alarming. The odour of ammonia is detectable by the human nose at concentrations from 3 to 5 ppm by volume in air. The ammonia concentration needs to be around 100 times higher than that concentration to present a risk to humans (IDLH or Immediate Danger to Life and Health value for NH_3 is 300 ppm). Ammonia belongs to flammability category 2L (same as R32 and HFO1234yf). Ammonia is in widespread use for applications other than refrigeration. Its refrigeration applications are covered by mature and well-developed technical/safety standards and it is often referred to as *the other hydrogen* being the only fuel other than pure hydrogen that combusts without emitting CO_2.

Table 5 GWP of refrigerants and their phasedown schedule

Refrigerant	Global Warming Potential value	Scheduled for phase down
R410a	2088	Yes
R407c	1774	Yes
R404a	3922	Yes
R134a	1430	Yes
R143a	4300	Yes
R22	1810	Yes (phased out)
R32 (new)	675how	Yes
R744 CO_2	1	No
R717 NH_3	0	No

7.8 *Looking for a 'low grade' heat source*

LCA heat pumps are more efficient if you have a 'low grade' heat source available to them. This reduces the 'lift' that they must achieve. In Europe these heat sources are usually lakes, rivers, the ocean or a sewer. In Australia it is a lot warmer than Europe so we can readily access heat from solar sources, water or the ground surrounding the pools. Low grade heat need only be greater than around 5°C to be useful and the higher the temperature of the heat source, the less energy you use to achieve target temperatures with the heat pump. It is these low-grade heat sources that are not considered at present for Australian aquatic centres and this is a missed opportunity.

7.9 *PVT (Photovoltaic Thermal) systems*

These are a simple way of harvesting low grade heat and providing electrical power at the same time from the same PV unit. These systems can operate whenever there is sunlight available or even when the ambient temperature is greater than the water temperature. The installation of solar PV systems needs to be carefully considered as Solar PV panels will work at ~15-20% efficiency whereas a PVT panel can achieve ~60% efficiency. The PVT panels also act to cool the PV cells, further increasing the electrical efficiency of the PV panels in warmer weather and are easily fitted beneath existing solar PV panels. Recent developments in PVT panel and manifold design, coupled together with minimal maintenance costs, make this an appealing option.

PVT systems operate ***almost*** in parallel with Solar PV systems, however they will continue to provide a small amount of heat once the sun has set due to the air around the system still being warm from the day's sun.

7.10 *Outdoor swimming pools*

If there is an outdoor pool adjacent to an indoor aquatic centre then this can also be utilised as a low-grade heat source. Outdoor pools can retain large amounts of heat during winter with pool covers on when hibernating and this heat can readily be used by an adjacent indoor pool using LCA water to water heat pumps: your outdoor pool is one great big solar collector if you set up it that way!

7.11 *Thermal storage*

This can be used to buffer the integrated energy system in peaks of Winter and Summer. When combined with a PVT system, a thermal storage system can bridge the gap in the energy cycle of the centre when solar power is not available and demand is high, as an integrated energy system can be boosted using low heat water to operate. Tanks can either be insulated polyethylene or high-density concrete and can be stored below ground to free up space around the building. Storing warm water is the **cheapest** form of energy storage available in Australia at present. In Summer months, this storage can be used to store cool water for the system.

Figure 9: 30,000L water storage tanks at LeisureLink Geelong

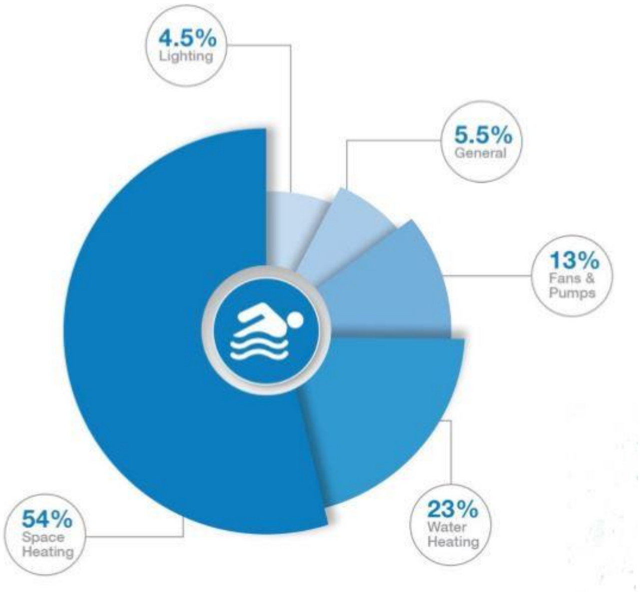
7.12 *It is a matter of balancing energy loads*

Until now energy in aquatic centres has been viewed in simple terms. If you need to heat the pool you use gas to heat the water. If you need to cool the air, you use a heat pump (HVAC compressor) to cool the air. But when we **integrate** the energy systems in the centre, a whole other range of opportunities are available to us for saving energy.

Once you reduce the cost of energy production in the centre to a very low level then the opportunity to store energy for use at peak electricity times becomes an option. However, this storage of energy needs to be carefully considered, as the amount of energy required in the whole centre is so large. The percentage of energy input vs storage should be carefully calculated as changing this ratio is very difficult once the centre has been constructed.

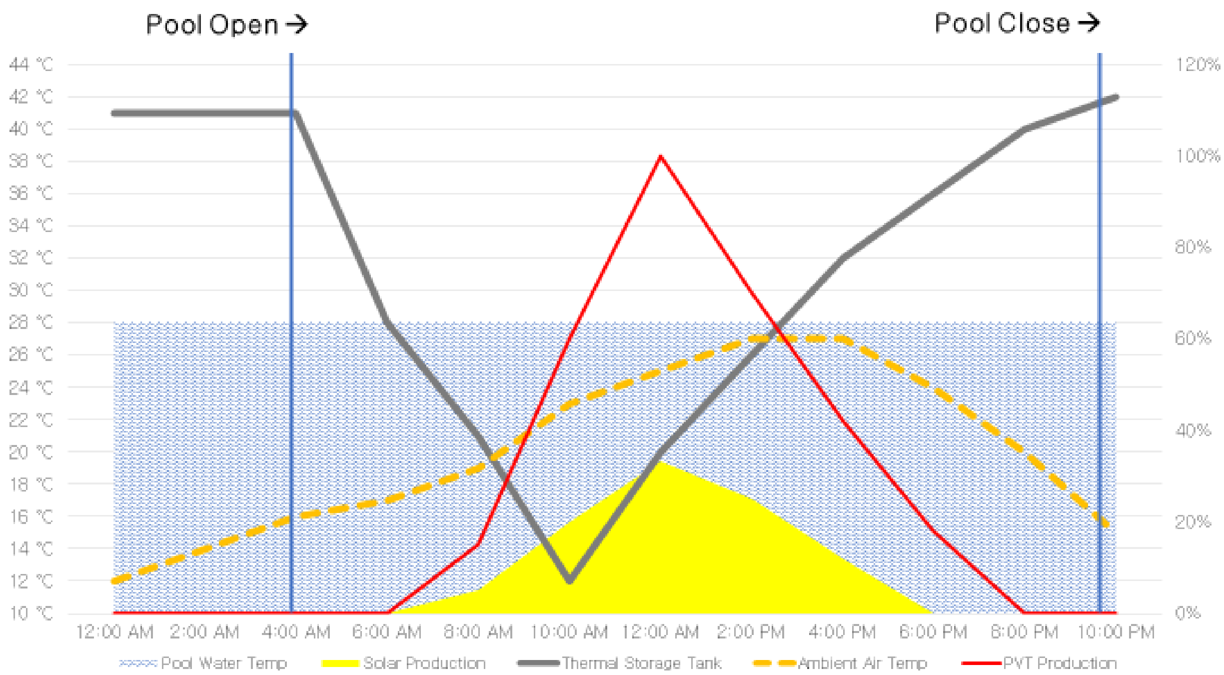
The energy usage within an aquatic centre is summarised in the figure below (Figure 10). As a rule of thumb, the heating load for air in the wet exercise areas is around double the heat load for water in the pools.

Figure 10 Aquatic Centre energy '*Understanding swimming pool ventilation'*



The flows of energy in the system are summarised in figure 11 and the diagram is quite complex, as the demands of the energy flow in the system ***are*** complex. A robust design of these systems and their BMS is essential to fully gain the most efficiency benefits of the system. An Integrated Energy System should be included in the design of these buildings from an early stage as many elements of the building design affect the efficiency of the system if the highest efficiencies are the goal.

Figure 11: Integrated Energy Systems and how they interact during a day



8. Energy performance and maintenance

8.1 *Servicing and Reliability of LCA heat pumps*

Graham Taylor, Service Manager at Scantec Refrigeration Technologies reports on the servicing of the 2 chillers at the Logan City Council:

‘*The two compressor packages that are installed at Logan City Council to date have been operating basically trouble free with some minor repairs on equipment in the field that is not associated with the packages. Over this period of 9 years we have not added any refrigerant to the systems and there have been no leaks This plant has a SCADA system installed that allows for remote access to address any issues that may occur and monitor the system if required during adverse weather conditions.*

This type of compressor has been installed in plants all over the world for well over 60 years and are still in operation today with improvements undertaken over the years. These older compressors are still in operation as they have been kept up to date with regular servicing. The availability of parts is not a problem as there has not been many changes to the parts design only making them more efficient and the newer parts are a direct replacement for the older parts.’

Looking at the Logan City Council chillers the basic operation costs are as follows:

- Annual servicing on each of the 2 compressors is $2,589.31 including GST (This is for replacement of oil and oil filters gaskets and checking compressor safeties)
- Carrying out this annual service on the compressors for 9 years and each year we have carried out inspections of the discharge and suction valve and springs in the heads of the compressors and to date, as the compressor packages have been operating well within their design conditions, the wear and tear on the compressor components is minimal.
- Next year these heat pumps would require a major service that would cost in the region of $7,000.00 + GST each.
- Annual ammonia detector calibrations- 2 x $530.60 including GST
- Monthly service $440.00 including GST on 2 of the systems.

The newer version of the Sabroe compressor UNISAB (Controller) has a built-in monitoring system that looks at the operation of the compressor monitoring the compressor during operation then adjusts the service schedule accordingly.

Table 6 Summary of annual heat pump service costs

Service Item	Time interval	Annual cost
Annual Service fee	12 months	$5,178
Ammonia detection calibrations	12 months	$1,061
Monthly service fee	monthly	$5,280
	Total	$11,519*

*Does not include water treatment

It should be noted that an Integrated Energy System does not utilise any other unitary HVAC equipment (such as HVAC and VRF packaged units) or hot water heating for showers. As such, there is no servicing required for this equipment in the building as it does not exist! This is a substantial saving in maintenance costs to owners over the life of the building.

8.2 *References*

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