# Integrated Energy System - Yarra City Council

## Heat Pump Technical Evaluation

## Richmond Recreation Centre


**Luke Hardy** Principal Consultant – SmartConsult
**Manuel Siegrist** Consultant – SmartConsult
**Derek Harbison** Consultant – SmartConsult
**Stefan Jensen** Director – Scantec

# 1. General Information

SmartConsult
Suite 201 – 36 Laver Drive
Robina, 4226 QLD
E: Lmhardy@smartconsult.com.au
E: derek@smartconsult.com.au
W: www.smartconsult.com.au
T: 1300 344 388
ABN 72 442 582 258

## 1.1 Project Partners

| Parties | Roles | People |
|---|---|---|
| Yarra City Council | Project Sponsor | Amna Abdalla |
| SmartConsult | Principal Consultant | Luke M Hardy |
| Scantec | Director | Stefan Jensen |

## 1.2 Acknowledgements

**Project concept and sponsorship**
Amna Abdalla – Yarra City Council

**System concept and design**
Stefan Jensen - Scantec Refrigeration Technologies
Luke Meredith Hardy - SmartConsult
Derek Harbison – SmartConsult

**Business analysis, modelling and report writing**
Manuel Siegrist – SmartConsult

**Heat pump energy analysis**
Rob Paul, Technical Sales Engineer - Johnson Controls International

**Heat pump maintenance data**
Graham Taylor, Service Manager – Scantec Refrigeration Technologies

**SCADA control system design**
David Hill - Scantec Refrigeration Technologies

## 1.3 Glossary

| Abbreviation or Acronym | Description |
|---|---|
| **COP** | Coefficient of Performance |
| **$CO_2$-e** | $CO_2$ equivalent |
| **GWP** | Global Warming Potential |
| **kWh** | Kilowatt hours of energy |
| **kW** | A thousand watts of electrical or thermal power |
| **LCA** | Low Charge Ammonia |
| **SEC** | Specific Energy Consumption- measured in kWh per cubic metre P.A. |
| **SCADA** | Supervisory control and data acquisition, a computer system for gathering and analysing real time data. |

## 1.4 Document History

| Revision | Description | Author | Checked | Approved | Date |
|---|---|---|---|---|---|
| A | Issued for Approval | LMH, SJ & DH | LMH | AA | 10/01/2020 |
| B | Issued for Approval | MS | DH, LMH | AA | 24/01/2020 |
| C | Issued for Approval | MS | DH, LMH | AA | 03/02/2020 |
| D | Issued for Approval | MS | DH, LMH | AA | 15/02/2020 |
| E | Issued for Approval | MS | DH, LMH | AA | 25/02/2020 |

# Table of Contents

# Table of Figures



# Index of Tables

## 2. Summary

This report provides the technical data to demonstrate that a Low Charge Ammonia (LCA) system using two Sabroe 108L heat pumps configured as **custom** HeatPACs with de-superheaters, can replace the existing gas and electrical A/C systems at the Richmond Recreation Centre. The LCA Heat pumps will be used to replace existing systems for the heating of the pools and heating and cooling of air in the wet and dry areas and the showers of the Richmond Recreation Centre. We have also provided an estimated operational cost comparison for both the old and the proposed new system.

### Key findings- using Low Charge Ammonia Heat Pumps

a) LCA heat pumps are viable for the Richmond Recreation Centre
b) Heat transfer rates using an LCA heat pump would be engineered to be equivalent to the current system using upgraded heat exchangers.
c) Cost for pool heating and pool air heating/cooling energy usage is reduced by **36.4%**
d) Gas heating is not required with an integrated energy system
e) Cooling the pool hall air in summer becomes possible
f) The Global Warming Potential of the refrigerant used in the new integrated energy system is **0**
g) Greenhouse Gas Emissions are reduced by 605 tonnes of $CO_2$-e
h) The SEC of the centre is currently **75.9** kWh/m$^3$/year
i) The revised SEC of the centre post installation will be **17.85** kWh/m$^3$/year
j) Projected lifespan of the LCA system is 30+ years

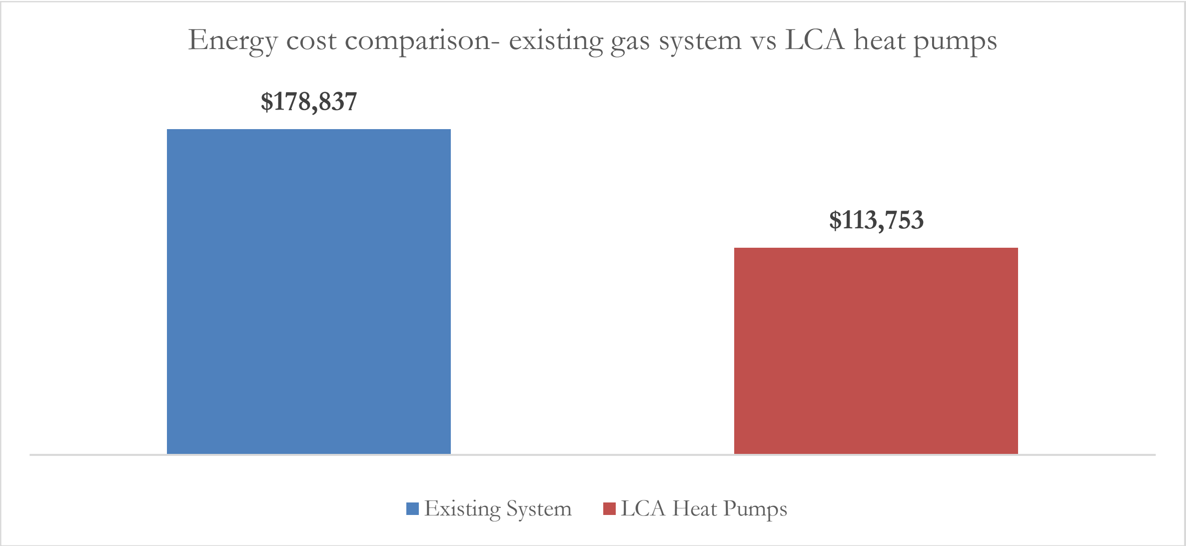



**Figure 1: Energy Cost Comparison - estimate**

The use of industrial Low Charge Ammonia heat pumps has not been considered and modelled for aquatic centres in Victoria before now. The aim of this report is to showcase that combining LCA heat pumps with other energy saving technologies can dramatically reduce the energy consumption costs of aquatic centres, utilise environmentally friendly refrigerants, and substantially reduce maintenance costs for councils.

Integrated Energy Systems can leverage large amounts of low-grade heat and heat recovery if the refrigeration engineers and building designers incorporate this technology into their designs during the planning stages. 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 to retrofit this aquatic centre.

In traditional gas systems, the supply output temperature from the gas boiler is 80°C which is much higher than an LCA heat pump water output temperature of 45°C. However, it is the amount of kW transferred that counts not the temperature differential. The LCA heat pumps, associated heat exchangers and pump flow rates would be re-engineered to have the same heat transfer (in kW) as the gas system to achieve target pool temperatures.
See **3.10** for a detailed description.

# 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 mid-2018 and the realisation that gas usage and choice of refrigerants were one of greatest contributor to council greenhouse emissions 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 is borne out by the proportion of energy costs that aquatic centres represent for councils in their budgets. By reducing energy costs in aquatic centres councils can go some way closer to running these centres at break-even or better budgets. With regular maintenance, an 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 demonstrated successfully in cold stores, food processing plants and other industries in Australia: this is not a new technology. It has been in use in Australia for about a century and is only now being considered for use in 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 renewable electricity, solar PV systems, PVT systems and thermal storage which can boost these savings further. This is only possible when these centres are using an efficient heating and cooling plant that is electrically powered.

## 3.1 The Project - Replacement of the Heating and Cooling Systems at the Richmond Recreation Centre

Yarra City Council is in the process of assessing the feasibility of high efficiency heat pumps to replace the existing heating and cooling systems at the Richmond Recreation Centre in Gleadell, St Richmond, Victoria. The council has committed to reducing their greenhouse gas emissions as a priority by means of sourcing 100% renewable energy and the phasing out of gas.

This technical evaluation study was a partnership effort between Yarra City Council, SmartConsult and Scantec Refrigeration as a proof of concept for the applicability of industrial scale heat pumps in aquatic centres.

## 3.2 Aims

This report aims to provide accurate modelling for the performance, reliability and costs of an Integrated Energy System. Specifically, this involves comparing the performance of LCA heat pumps compared with gas-based system that is currently installed. By sourcing accurate and independent information from a range of sources this report provides the council with a sound baseline they can work from to determine the viability of the installation of heat pumps.

## 3.3 Methodology

Basing our calculations on the data provided by Yarra City Council we have been able to model the heating and cooling and match this to the output of the LCA heat pump.

## 3.4 Project Deliverables

Analysis of data provided by Yarra City Council have allowed us to determine:

a) Establishing the thermal load profile for the centre and sizing the LCA integrated energy system for heating and cooling that can replace an existing gas and electrical A/C systems.
b) Maximum electricity demand in kW for the pool and pool enclosures heating and cooling requirements.
c) The annual $kWh^T$ consumption for the pool and pool enclosures heating and cooling.
d) High level cost estimate for pool and pool enclosures heating and cooling.
e) Projected lifespan of the system

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

- General Electricity
- General Lighting
- Pool Pumps (Filters and hot water circulation pumps) and ancillaries

## 3.5 Information Gathering

Data for this analysis has been provided by Yarra City Council, Scantec Refrigeration and Johnson Controls International. Further detailed information will be required for a detailed design specific to the site prior to implementation.

## 3.6 Current System

The current heating and cooling systems at Richmond Recreation Centre comprises of:

- 850 kW condensing main boiler
- 150 kW condensing secondary boiler
- 65 kW turbine cogeneration system
- 6 x gas hot water systems for domestic hot water
- 8 x packaged air conditioning units

## 3.7 Proposed System

Two Low-Charge Ammonia (LCA) heat pumps to simultaneously provide the space heating and cooling for the site, as well as hot water for the pools and DHW.

## 3.8 Pool and Pool Hall Requirements

Determine the heating and cooling loads from the data provided and model the performance of a Low Charge Ammonia heat pump system to calculate projected energy consumption.

## 3.9 Wet and Dry Area Air Conditioning

Summary investigation of the current pool heating and dry area A/C system and its conversion to using a hot and chilled water system to provide A/C services from the LCA heat Pumps.

## 3.10 Pool Heat Exchangers and Heat Transfer

Demonstrate that using the lower temperature of the water being produced by the LCA heat pumps compared to gas systems is not an issue.

The heat exchangers would be much larger in size than the existing heat exchangers to allow for sufficient heat transfer to the pool water. More details on this type of heat exchanger are available in Appendix D

**Considerations in designing and sizing heat exchangers**

In traditional gas systems, the difference between design pool water return (26ºC) and pool water supply (45ºC) temperatures is generally greater than when using an LCA heat pump. However, it is the amount of kW transferred that counts, not the temperature differential. The LCA heat pump and associated heat exchangers and pump flow rates would be re-engineered to have the same heat supply (in kW) as the gas system to achieve target pool temperatures.

If you increase the heat exchanger *logarithmic mean temperature difference* (LMTD) this would allow the heat exchanger to be smaller/cheaper, however, this decreases the heat pump COP and therefore its energy efficiency.

A supply temperature to the pool of 45°C (Scenario 1) is possible and would require the warm outlet temperature from the heat pump to be 49°C for a 4K approach[1] between heat pump and pool supply temperatures. If the supply temperature to the pool is, say, 33°C (Scenario 2), then the required warm outlet from the heat pump is 37°C for the same approach. This will deliver significantly better COP than 49°C.

[1] 4K approach refers to the temperature lift in the heat exchanger to achieve 45ºC input and 49ºC output, a technical term for heat exchangers.

The ***speed*** with which a volume of water is heated is a function of the amount of supplied heating (in kW) and flow rate. A pool water supply temperature of 45°C is no guarantee of rapid heating if the flow of water supplied at that temperature and therefore the heating effect entering the pool is relatively ***low***.

If the heat pump output in kW matches the heating output of the existing boiler(s), then the time required to heat the pool water from temperature A to temperature B will remain unchanged. If the heat exchanger between the pool water and the warm loop of the heat pump is designed accordingly, it is possible to operate both scenarios and anything in between. It would be necessary to design the heat exchanger for the worst-case kA, where kA is the element within:

The logarithmic mean temperature difference $\Delta T_m$ is given by the operating conditions required. The unit for kA is W/K and is represented by the product of surface area A in $m^2$ and the heat transmission k in $W/m^2K$ at the prevailing operating condition.

## 3.11 Domestic Hot Water Heating Requirements

Hot water for showers is provided from the desuperheaters available on the heat pumps. A desuperheater will provide water at up to 80 °C and this 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 total heat pump output. Any excess hot water produced can be fed back into the pool heating loop (45 °C).

## 3.12 The Richmond SEC efficiency metric

**Specific Energy Consumption (SEC)** is a widely used metric employed by designers and builders of cold stores. It is useful for aquatic centres as it allows for a meaningful measurement of the heating required in the pool (not measured specifically as the pool has a known heat loss rate) and the air heating requirement measure in volume. This metric captures the **overall** efficiency of the building envelope.

The current SEC was calculated to be **75.9** which is comparatively high due to the losses from the skylights in the roof over the pool and a lack of roofing insulation. Due to the heritage design of the building, this loss is difficult to overcome on this site. The SEC metric is discussed in more detail later in section 9 of this document.

**Table 1: Specific Energy Consumption (SEC)**

| Item | Pool Hall + Gym Volume $m^3$ | kWh Consumption | Specific Energy Consumption (SEC) in $kWh/m^3/p.a.$ |
|---|---|---|---|
| **Current SEC p.a.** | 37,360 | 2,835,443 | 75.9 |
| **New SEC Post LCA p.a.** | 37,360 | 666,771 | 17.8 |
| **Savings p.a.** | **-** | **2,168,672** | **76%** |

**Note -** The kWh Consumption refers to the energy use for space heating and cooling and pool heating that is comprised of both electricity consumption for the A/C as well as converted gas usage.

# 4. Sizing of the LCA Heat Pumps

The system was sized to meet the building's maximum heating and cooling demands with ambient air as the only heat source for the heat pumps. The whole of building heating and cooling loads and the pool heating load were plotted against the production from the heat pumps based on the ambient inlet temperature capped at 30°C. This is shown in the table and graph below.

The performance modelling graph demonstrated that the proposed system is well within its capabilities at each ambient temperature data point. While the graphs show daily summaries, the calculations are based on hourly data points over the full 365 days using weather data for the Richmond location.

Table 2 shows that the maximum usage of the heat pumps capacity is at 70% and is reached on a single point in September. The real maximum average usage of the heat pump capacity is in July and August which is 46%, with a yearly average of 32%.

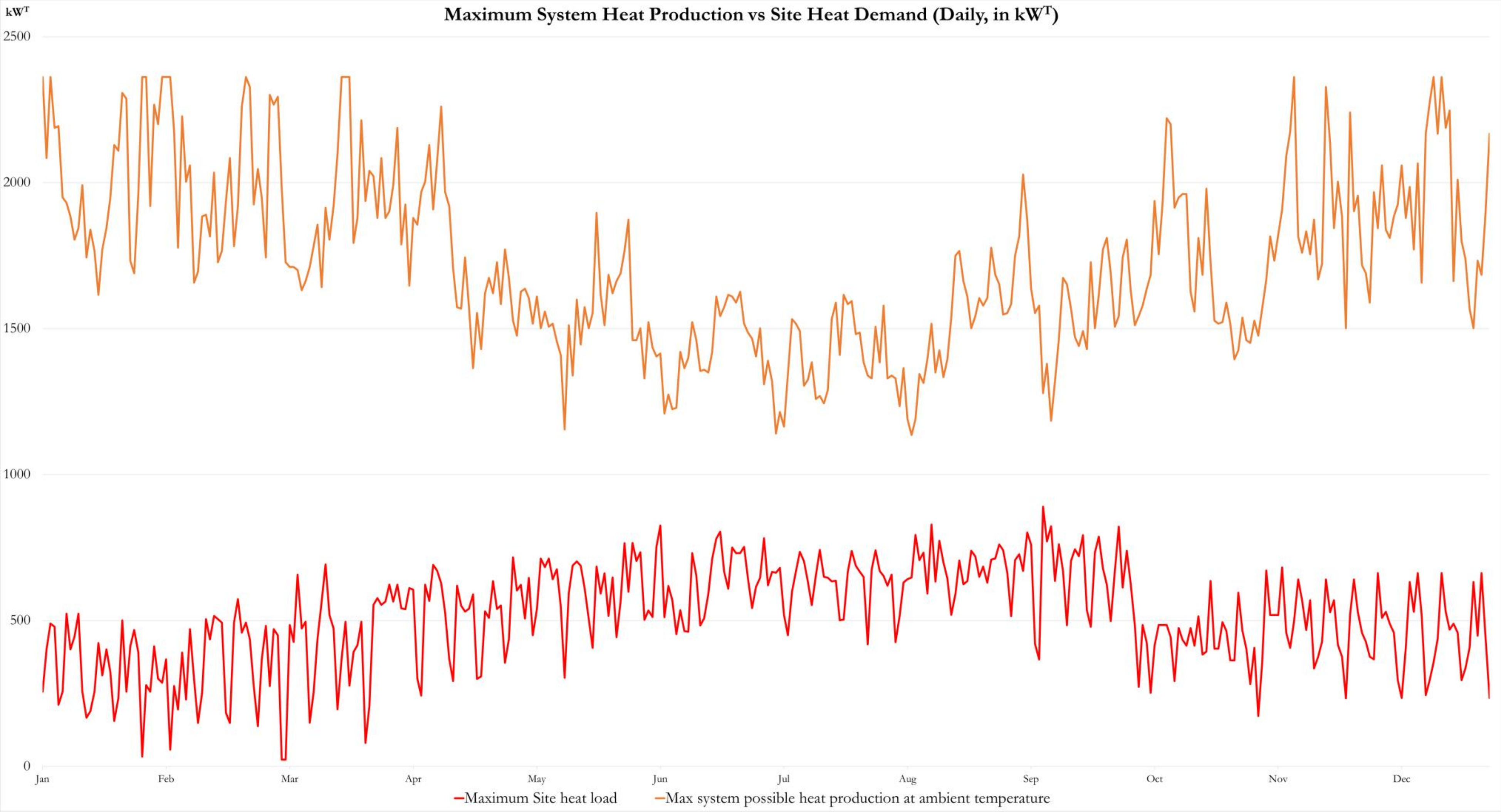
**Table 2: Peak and average usage of heatpump capacity across a year**

| Month | Peak Usage | Average Usage |
|---|---|---|
| January | 28% | 17% |
| February | 30% | 18% |
| March | 39% | 22% |
| April | 47% | 30% |
| May | 52% | 39% |
| June | 58% | 43% |
| July | 60% | 46% |
| August | 67% | 46% |
| September | 70% | 43% |
| October | 42% | 26% |
| November | 40% | 26% |
| December | 42% | 24% |
| **Peak / Ø** | **70%** | **32%** |

* Note this modelling is a worst-case scenario based on only air as a heat source.

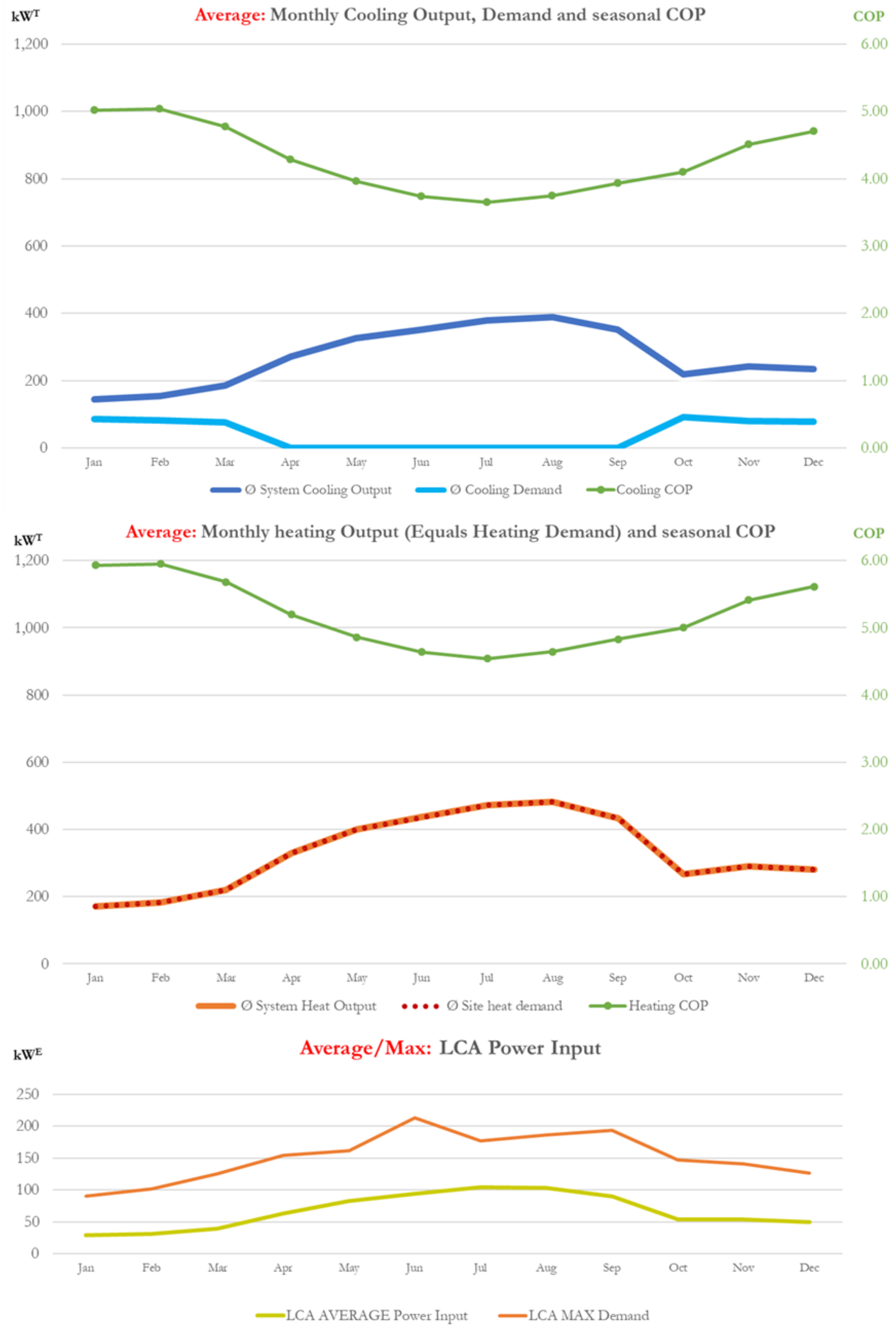
## 4.1 LCA Heat Pumps Performance Modelling Graph

**Figure 2: Max System Heat Production vs Heat Load for Richmond Recreation Centre**



## 4.2 System Inputs and Outputs

**Figure 3: Cooling and Heating Output/Demand, and LCA Power Input graphs**



# 5. Parameters used to formulate this report

To establish the heating and cooling loads for the site, sub-metered gas and electricity usage data was provided by council to establish a demand baseline. Multiple sets of data were provided of which the following were used to calculate the heating and cooling loads for the aquatic centre at 11 Gleadell St. Richmond. These were:

1. Gas usage profiles from gas sub-meters installed for the cogeneration system and the main boiler
2. Gas bills for the 2019 calendar year
3. Electricity consumption from sub-meters installed on the mechanical distribution boards on site.
4. Electricity production from the cogeneration system's sub-meter
5. Electricity interval data from the main meter.
6. Electricity bills for the 2019 calendar year

## 5.1 Existing energy usage – Gas and Electricity

### *Gas Data*

The gas data was provided in $m^3$ usage in hourly increments over a full year from both the cogeneration and main boiler sub-meters and were converted to GJ. A small portion of the gas usage for a secondary smaller boiler and ancillary hot water systems used for the spa and domestic hot water was missing, this was reconciled from the bills as seen in the table below.

The data was then adjusted/scaled to match the monthly usage from the bills using the same usage pattern as derived from the gas usage files and converted to $kWh^{T}$. The boilers data was multiplied by 0.9 being the efficiency of gas boiler (COP of 0.9) and the cogeneration data was multiplied by 0.5, being the efficiency of the system (COP of 0.5).

**Table 3: Normalised gas data**

| | | | | | COP: 0.9 | COP: 0.5 | |
|---|---|---|---|---|---|---|---|
| **Month** | **Total Bills GJ** | **Main boiler GJ** | **Cogen GJ** | **Secondary boiler GJ** | **All boilers (main & second) heating load kWh$^{T}$** | **Cogen heating load kWh$^{T}$** | **Total site heating load kWh$^{T}$** |
| Jan | 593 | 284 | 167 | 142 | 106,495 | 23,156 | 129,651 |
| Feb | 572 | 266 | 156 | 149 | 103,943 | 21,702 | 125,645 |
| Mar | 732 | 347 | 204 | 181 | 132,024 | 28,289 | 160,313 |
| Apr | 860 | 439 | 258 | 163 | 150,675 | 35,773 | 186,448 |
| May | 1,120 | 586 | 344 | 189 | 193,941 | 47,768 | 241,709 |
| Jun | 1,181 | 632 | 371 | 178 | 202,622 | 51,482 | 254,104 |
| Jul | 1,332 | 726 | 426 | 180 | 226,532 | 59,151 | 285,683 |
| Aug | 1,380 | 746 | 437 | 197 | 235,743 | 60,723 | 296,467 |
| Sep | 1,178 | 621 | 364 | 192 | 203,324 | 50,603 | 253,927 |
| Oct | 920 | 487 | 286 | 147 | 158,613 | 39,681 | 198,293 |
| Nov | 973 | 511 | 300 | 163 | 168,386 | 41,618 | 210,004 |
| Dec | 964 | 506 | 296 | 162 | 166,914 | 41,183 | 208,097 |
| **Totals** | **11,804** | **6,153** | **3,608** | **2,043** | **2,049,212** | **501,129** | **2,550,341** |

### *Electricity Data*

Electricity Usage data was extracted from the files as provided by Council.

1. The electricity heating load for the A/C was derived from the interval data from electricity sub-meters x 2.5 (Estimated COP of these units). The percentage for the dry areas and gym of the overall electricity usage from submeters showed that only 37% of the total site electricity consumption was used for A/C and for heating only for the months from April to October.
2. The 37% was an average of the total A/C usage from 2 relevant mechanical distribution boards as provided by the Council.

### *Existing thermal load summary*

| | Cogen Heating Load | Boilers Heating Load | Gas Heating Load | Electricity A/C Heating Load | Total Heating Load Gas + A/C | A/C Cooling load | Max Peak kW Heating Load Gas + A/C | Max Peak kW Cooling Load |
|---|---|---|---|---|---|---|---|---|
| Unit | $kWh^T$ | $kWh^T$ | $kWh^T$ | $kWh^T$ | $kWh^T$ | $kWh^T$ | $kW^T$ | $kW^T$ |
| Total | 501,129 | 2,049,212 | 2,550,341 | 352,643 | 2,902,984 | 360,111 | 890 | 191 |

### *Existing electricity and gas usage summary (excluding Solar)*

| | Grid Electricity Usage | Electricity Generation Cogen | Total Electricity Used | Electricity Monthly Peak Demand | Electricity usage for A/C Only (37%) | Gas Heating Load | Total energy for heating & cooling (Gas & A/C) |
|---|---|---|---|---|---|---|---|
| Unit | $kWh^E$ | $kWh^E$ | $kWh^E$ | $kW^E$ | kWh | kWh | kWh |
| Total | 643,095 | 127,449 | 770,544 | 176.77 | 285,101 | 2,550,341 | **2,835,443** |

## 5.2 Sabroe HeatPAC 108L heat pumps

The system was sized using 2 x HeatPAC 108L Sabroe Heat Pumps as a custom configuration. Table 5 shows the COP and shaft power for the Sabroe HeatPAC 108L as provided by Johnson Controls.

**Table 4: Sabroe HeatPAC 108L Output Specifications**

| Ambient Air | Shaft Electricity | Heat Pumps x 2 | Single Unit Duties, kW | | Nominal COP | | |
|---|---|---|---|---|---|---|---|
| **°C** | **kW** | **kW** | **Heating** | **Cooling** | **Hot** | **Cold** | **Total** |
| **0** | 111.4 | 222.8 | 405 | 316.7 | 3.64 | 2.84 | 6.48 |
| **5** | 123.1 | 246.2 | 494.6 | 392.6 | 4.02 | 3.19 | 7.21 |
| **10** | 134.6 | 269.2 | 614.9 | 498 | 4.57 | 3.7 | 8.27 |
| **15** | 140.2 | 280.4 | 740 | 613.2 | 5.28 | 4.37 | 9.65 |
| **20** | 147.7 | 295.4 | 872.3 | 734 | 5.91 | 4.97 | 10.88 |
| **25** | 151.6 | 303.2 | 1017 | 870.6 | 6.71 | 5.74 | 12.45 |
| **30** | 154 | 308 | 1181 | 1028.7 | 7.67 | 6.68 | 14.35 |

## 5.3 Ambient weather / temperature file

We used an hourly temperature file for the whole year, for the Richmond location for the Aquatic Centre at 11 Gleadell St. This was sourced from our Helioscope Solar program and is a 'TMY, Melbourne, RMY (epw)' file adjusted by the program for the Richmond location

## 5.4 Heat Pump Inlet Temperatures*

The heat pump inlet temperatures are critical to the performance of the heat pump. In Table 5 the number of hours for each degree have been summarized at the Richmond location. This shows that there are relatively few hours at low temperatures which affect the efficiency of the heat pump.

The COP of the Sabroe HeatPAC 108L varies according to the ambient temperatures as shown below.

**Table 5: Ambient Temperature – Number of hours and COP**

| °C | Count Hours | Seasonal COP Hot | °C (cont.) | Count Hours | Seasonal COP Hot |
|---|---|---|---|---|---|
| **0** | 0 | 3.64 | **16** | 438 | 5.41 |
| **1** | 3 | 3.68 | **17** | 433 | 5.54 |
| **2** | 7 | 3.74 | **18** | 365 | 5.68 |
| **3** | 51 | 3.82 | **19** | 335 | 5.81 |
| **4** | 123 | 3.92 | **20** | 305 | 5.95 |
| **5** | 198 | 4.02 | **21** | 271 | 6.09 |
| **6** | 292 | 4.13 | **22** | 234 | 6.24 |
| **7** | 472 | 4.25 | **23** | 186 | 6.39 |
| **8** | 489 | 4.38 | **24** | 143 | 6.54 |
| **9** | 545 | 4.50 | **25** | 96 | 6.71 |
| **10** | 530 | 4.63 | **26** | 92 | 6.88 |
| **11** | 608 | 4.76 | **27** | 79 | 7.07 |
| **12** | 621 | 4.89 | **28** | 54 | 7.26 |
| **13** | 555 | 5.02 | **29** | 33 | 7.46 |
| **14** | 575 | 5.15 | **30** | 98 | 7.67 |
| **15** | 529 | 5.28 | **Total Hours** | **8,760** | **-** |

*See further description in section 8.4 on how we intend to increase the inlet temperatures in the winter. For instance, if we increase the inlet temperatures by 4°C then the efficiency increases by around 5%.

## 5.5 Sundry Parameters

### *Pool & enclosure temperatures*

| Pool | Temperature |
|---|---|
| Pool 50m | 30°C |
| Toddler pool | 32°C |
| Spa | 37°C |

### *Pool enclosure and pool size summary*

| Pool Enclosures areas | $m^3$ |
|---|---|
| Pool Hall 50m + Toddler and Spa Volume | 34,203 |
| Dry Area Volume | 3,157 |
| **Total volume** | **37,360** |

### *Pool opening hours*

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

# 6. Results

## 6.1 Performance results

| Existing Thermal Load | | | | | | |
|---|---|---|---|---|---|---|
| **Month** | **Gas Heating Load** | **Electricity A/C Heating Load** | **Total Heating Load Gas + A/C** | **Electricity A/C Cooling Load** | **Max Peak kW Heating Load Gas + A/C** | **Max Peak kW Cooling Load** |
| **Unit** | $kWh^T$ | $kWh^T$ | $kWh^T$ | $kWh^T$ | $kW^T$ | $kW^T$ |
| **Jan** | 127,754 | 0 | 127,754 | 64,382 | 523 | 191 |
| **Feb** | 123,297 | 0 | 123,297 | 54,959 | 573 | 177 |
| **Mar** | 164,096 | 0 | 164,096 | 56,798 | 692 | 172 |
| **Apr** | 185,426 | 51,473 | 236,899 | 0 | 717 | 0 |
| **May** | 241,344 | 56,476 | 297,820 | 0 | 765 | 0 |
| **Jun** | 251,366 | 62,946 | 314,312 | 0 | 825 | 0 |
| **Jul** | 286,492 | 64,959 | 351,451 | 0 | 782 | 0 |
| **Aug** | 297,491 | 61,172 | 358,663 | 0 | 829 | 0 |
| **Sep** | 256,305 | 55,616 | 311,921 | 0 | 890 | 0 |
| **Oct** | 198,334 | 0 | 198,334 | 68,052 | 636 | 156 |
| **Nov** | 209,767 | 0 | 209,767 | 57,287 | 681 | 149 |
| **Dec** | 208,670 | 0 | 208,670 | 58,634 | 662 | 161 |
| **Total** | **2,550,341** | **352,643** | **2,902,984** | **360,111** | **Max: 890** | **Max: 191** |

| Existing Electricity & Gas Usage | | | | | | |
|---|---|---|---|---|---|---|
| **Month** | **Grid Electricity Usage** | **Electricity Generation Cogen** | **Total Electricity Used** | **Electricity used for A/C Only** | **Electricity kW Monthly Peak** | **Gas Consumption inc. Cogen** |
| **Unit** | $kWh^E$ | $kWh^E$ | $kWh^E$ | $kWh^E$ | $kW^E$ | GJ |
| **Jan** | 62,298 | 7,304 | 69,602 | 25,753 | 177 | 591 |
| **Feb** | 50,013 | 9,402 | 59,415 | 21,984 | 161 | 571 |
| **Mar** | 52,093 | 9,310 | 61,403 | 22,719 | 156 | 760 |
| **Apr** | 44,950 | 10,696 | 55,646 | 20,589 | 163 | 858 |
| **May** | 52,276 | 8,779 | 61,055 | 22,590 | 145 | 1,117 |
| **Jun** | 51,974 | 16,076 | 68,050 | 25,179 | 153 | 1,163 |
| **Jul** | 55,883 | 14,343 | 70,226 | 25,983 | 146 | 1,326 |
| **Aug** | 52,719 | 13,413 | 66,132 | 24,469 | 147 | 1,377 |
| **Sep** | 53,100 | 7,026 | 60,126 | 22,247 | 140 | 1,186 |
| **Oct** | 62,986 | 10,583 | 73,569 | 27,221 | 146 | 918 |
| **Nov** | 52,277 | 9,655 | 61,932 | 22,915 | 148 | 971 |
| **Dec** | 52,527 | 10,862 | 63,389 | 23,454 | 145 | 966 |
| **Total** | **643,095** | **127,449** | **770,544** | **285,101** | **Max: 177** | **11,804** |

| NEW Thermal Load | | | | | |
|---|---|---|---|---|---|
| **Month** | **Heat Pump - Heat Load** | **Total Cooling Availability** | **Average of Heating COP** | **Average of Cooling COP** | **Excess Cooling Available** |
| **Unit** | kWhT | kWhT | COP | COP | kWhT |
| **Jan** | 127,754 | 107,962 | 5.95 | 5.03 | 43,581 |
| **Feb** | 123,297 | 104,302 | 5.92 | 5.00 | 49,343 |
| **Mar** | 164,096 | 137,777 | 5.68 | 4.77 | 80,979 |
| **Apr** | 236,899 | 195,294 | 5.23 | 4.32 | 195,294 |
| **May** | 297,820 | 242,157 | 4.89 | 3.98 | 242,157 |
| **Jun** | 314,312 | 253,150 | 4.63 | 3.73 | 253,150 |
| **Jul** | 351,451 | 281,844 | 4.56 | 3.66 | 281,844 |
| **Aug** | 358,663 | 289,035 | 4.68 | 3.78 | 289,035 |
| **Sep** | 311,921 | 253,500 | 4.91 | 4.01 | 253,500 |
| **Oct** | 198,334 | 162,249 | 5.15 | 4.24 | 94,198 |
| **Nov** | 209,767 | 174,531 | 5.49 | 4.58 | 117,244 |
| **Dec** | 208,670 | 174,667 | 5.71 | 4.79 | 116,033 |
| **Total** | **2,902,984** | **2,376,468** | **Avg 5.23** | **Avg 4.32** | **2,016,358** |

The new thermal load matches the existing system load over a full year.

| NEW Electricity Usage | | | | |
|---|---|---|---|---|
| **Month** | **Total LCA Heat Pumps System Electricity Usage** | **Total LCA Heat Pumps System Peak Demand** | **Remaining Electricity Site Usage †** | **Total Electricity Site Usage** |
| **Unit** | kWhE | kWE | kWhE | kWhE |
| **Jan** | 24,744 | 104 | 40,434 | 65,178 |
| **Feb** | 23,798 | 116 | 31,771 | 55,569 |
| **Mar** | 33,176 | 144 | 34,589 | 67,765 |
| **Apr** | 52,378 | 177 | 30,825 | 83,203 |
| **May** | 70,377 | 186 | 38,646 | 109,023 |
| **Jun** | 77,829 | 245 | 36,553 | 114,382 |
| **Jul** | 88,851 | 204 | 41,288 | 130,139 |
| **Aug** | 88,672 | 214 | 39,820 | 128,492 |
| **Sep** | 74,183 | 223 | 40,451 | 114,634 |
| **Oct** | 45,559 | 169 | 42,928 | 88,487 |
| **Nov** | 44,504 | 163 | 36,358 | 80,862 |
| **Dec** | 42,700 | 146 | 35,785 | 78,485 |
| **Total** | **666,771** | **Max 245** | **449,449** | **1,116,220** |

†The remaining consumption above includes the electricity usage for pumps, lighting and ancillary equipment usage for the site.

## 6.2 Summary annual running costs for the pools and enclosures

### *A: Estimate of annual running costs using an LCA Heat Pumps System – no solar*

| Item | Levelized cost per kWh† | Total Est. Units | Total Cost |
|---|---|---|---|
| **Electricity Heat Pump** | $0.1706† | 666,771 kWh | **$113,753** |

† **Note:** This cost per kWh is an ***average cost,*** which **includes** the kVA charges. See **Appendix XXII** for a breakdown of the cost and assumptions. It also reflects the higher demand charges based on the ratchet tariff. In this case the maximum estimated demand per month is set at a conservative 500 kVA.

### *B: Estimate of annual running costs from the report using gas boilers and the existing A/C chiller*

| Item | $/Unit (GJ or kWh) | Total Est. Units | Total Cost |
|---|---|---|---|
| **Gas Cost** | $11.37 / GJ | 11,804 GJ | $134,212 |
| **Electricity Cost^** | $0.1565 / kWh^ | 285,101 kWh | $44,626 |
| | | | **$178,838** |

^**Note:** This cost per kWh is an ***average cost,*** which **includes** the kVA charges. See **Appendix XXI** for a breakdown of the cost and assumptions.

## 6.3 Maintenance comparison between existing system and LCA heat pumps

| Maintenance Costs | Actual p.a. Cost |
|---|---|
| Existing A/C Chillers + Cogen + Gas Boilers | $85,000 |
| Low-charge ammonia heat pump (estimate) | $20,000 |

## 6.4 Comparison of annual running costs incl. maintenance (no solar) p.a.*

| Item | Current System | Proposed System | Saving | Total Savings |
|---|---|---|---|---|
| Electricity + Gas | $178,838 | $113,753 | $65,085 | 36.39% |
| Maintenance | $85,000 | $20,000 | $65,000 | 76.47% |
| **TOTAL** | **$263,838** | **$133,753** | **$130,085** | **49.30%** |

*__Note:__ Energy tariffs used are standard large market tariffs, maintenance costs are standard costs for existing gas and A/C systems.

## 6.5 Greenhouse Gas Emission savings

| Item | Gas Type | Total t $CO_2$-e p.a. |
|---|---|---|
| Current System | Natural Gas & Refrigerant Leakage§ | 605 |
| Proposed LCA System | Ammonia | 0 |
| **Reduction in tonnes of $CO_2$-e** | | **605** |

§**Note:** Natural emits 0.05 tonnes of $CO_2$-e /Gj, while the average leakage of refrigerant is estimated at 15 tonnes of $CO_2$-e per annum.

# 7. Pool and Building AC Control and System Design Approach

## 7.1 Design

Scantec will design and specify the best system based on the specific environmental considerations. The design will employ the same design principles as those applied to any other medium to large scale industrial refrigeration plant design employing the same refrigerant. In addition, it will adhere to the relevant standard predominantly AS/NZS 5149 Refrigerating Systems and the Standards referred to the therein.

## 7.2 SCADA Building Pool Controls and LCA Systems

A SCADA control system with a customised display such as the one shown below will be developed for the Richmond Recreation Centre. This can also be integrated with the BMS, pool equipment, filters etc.


**Figure 4: Example SCADA Screen**

# 8. Differences between Traditional Systems and LCA Systems

LCA heat pumps have capacities up to **14MW** (Drammen Norway) or even larger and a large aquatic centre will 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** heat pumps 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 can be **replaced** by heating and cooling coils that connect into the system: a further saving in energy and maintenance costs detailed in Table 6.

In addition, this plant concept utilising secondary cooling/heating media on the cold and warm sides will totally eliminate the employment of HFC refrigerants, which are being phased down in Australia and across the world for environmental reasons (see section 11.3 - Why GWP is important).

**Table 6: Differences between existing design and integrated energy system components**

| Type | 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 |

## 8.1 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 than cooling required in an aquatic centre in Victoria for most of the year.

## 8.2 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 and space in the building has been allocated.

The energy usage within an aquatic centre is summarised in Figure 5. As a rule of thumb, the heat load for air in the wet exercise areas is usually around double the heat load for water in the pools.

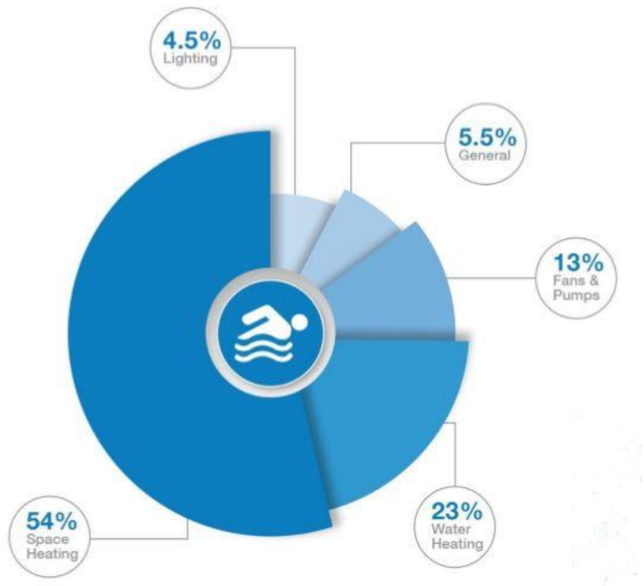



**Figure 5: Aquatic Centre energy 'Understanding swimming pool ventilation'**

The flows of energy in the system are summarised in Figure 6 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 from 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 ultimate goal.

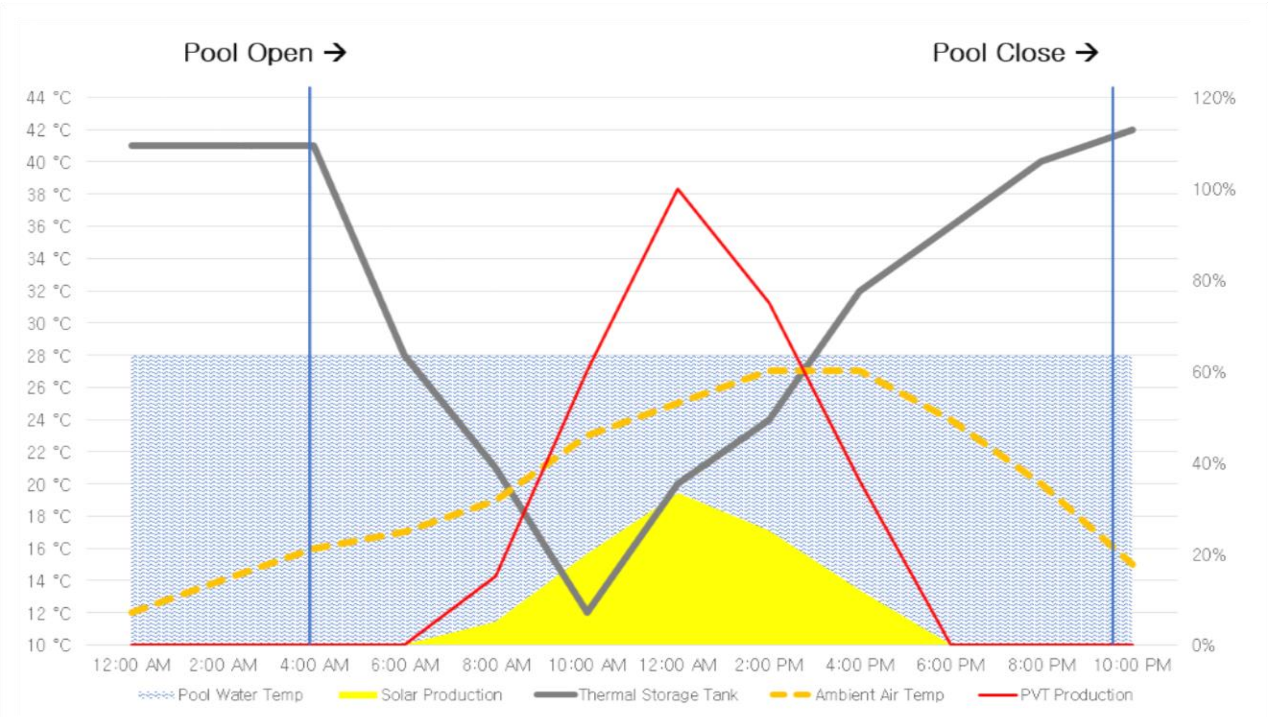



**Figure 6: Energy flows in an integrated energy system**

# 9. Using SEC as a centre wide efficiency metric

The use of a meaningful metric for measuring the efficiency of energy use in aquatic centres has not been agreed on by councils and the designers and builders of these centres to date. **Specific Energy Consumption** (SEC) is a widely used metric employed by designers and builders of cold stores that makes a lot of sense for use in aquatic centres as it allows for a meaningful measurement of the heating required in the pool (not measured specifically as the pool has a known heat loss rate) and the air heating requirement measured in volume. This metric captures the overall efficiency of the building.

SEC is measured in **$kWh/m^3*a$ (kWh per $m^3$ per annum)** and is particularly useful when it is applied to the wet exercise areas of an aquatic centre. In simple terms, the wet areas can be summarised as one-part pool water heating and two-parts pool air heating. The $m^3$ measurement captures that information and makes the SEC a meaningful and accurate measure of the highest energy demand area of the building structure. Knowing the SEC of a building is particularly useful for councils when they are making comparisons between the efficiencies of different centres they own.

The video below is an example of how this metric is used in comparing cold store efficiency between buildings with different sizes and upgraded refrigeration plant effectively:

https://www.youtube.com/watch?v=7Xsn-ui4liI&feature=youtu.be

# 10. APPENDIX

## A. Why commercial HFC & HFO based pool heat pumps are not efficient in a Victorian climate

### I. 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 between 2 to 4°C depending on the ambient temperature which also determines the COP. The lower the temperature, the lower the COP and the associated lift.

This explains why some commercial HFC & HFO heat pumps cannot provide enough heat for large pools in Victoria but will work in QLD: In Victoria they do not have sufficient 'lift' to heat a pool in the winter months and this results in pools not reaching their required target temperatures.

### II. How commercial HFC & HFO based pool heat pumps work

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

**Figure 8: Copeland Compressor**

**Figure 7: Heat Pump Compressors**

**Figure 10: Evoheat Commercial Heat Pump**

**Figure 9: Rheem Accent Commercial Heat Pump**

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. The 'packaging' of these components creates more maintenance issues for larger pool operators, as the additional plant requires more maintenance collectively. These compressors are designed to be replaced or exchanged should that be required during the life of the heat pump. They are sealed and not accessible internally except by specialized repairers.

**Figure 11: Multiple heat pump installations at Dreamworld Gold Coast Qld**

A 200kW heat pump using these compressors may have two or three compressors 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 and maintenance increases.

## III. Why a $CO_2$ heat pump will not work

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 (1) 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 HFO1234yf, 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 '**critical 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°C.

## IV. Why industrial 'Low Charge Ammonia' heat pumps will work in aquatic centres in Victoria

Low Charge Ammonia heat pumps of the 'water to water' type with a glycol circuit, which runs through an air cooler cooling ambient air or other heat source to increase the inlet temperatures. This makes the LCA Heat-Pumps much more flexible and allows the system components to be designed to work within the temperature range for the locality of the installed system.

The ambient air operating temperature and efficiency range for an LCA Heat-Pump is much wider than a traditional HFC and HFO based heat pump allowing for a greater lift in temperature. This means that the LCA Heat-Pumps can meet the required heating and cooling requirements for the Richmond Recreation Centre. The graph (See Figure 2) shows maximum heat output available from the heat pumps compared to the heat production as required throughout the year based on the actual heat requirements data for Richmond Recreation Centre.

The water entering the heat pump on the inlet side is 'lifted' in temperature by approximately 5°C. 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 DHW for showers and other air-conditioned areas.

This warm water loop is about **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 a speed controlled 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 heat absorbers 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 in these systems.

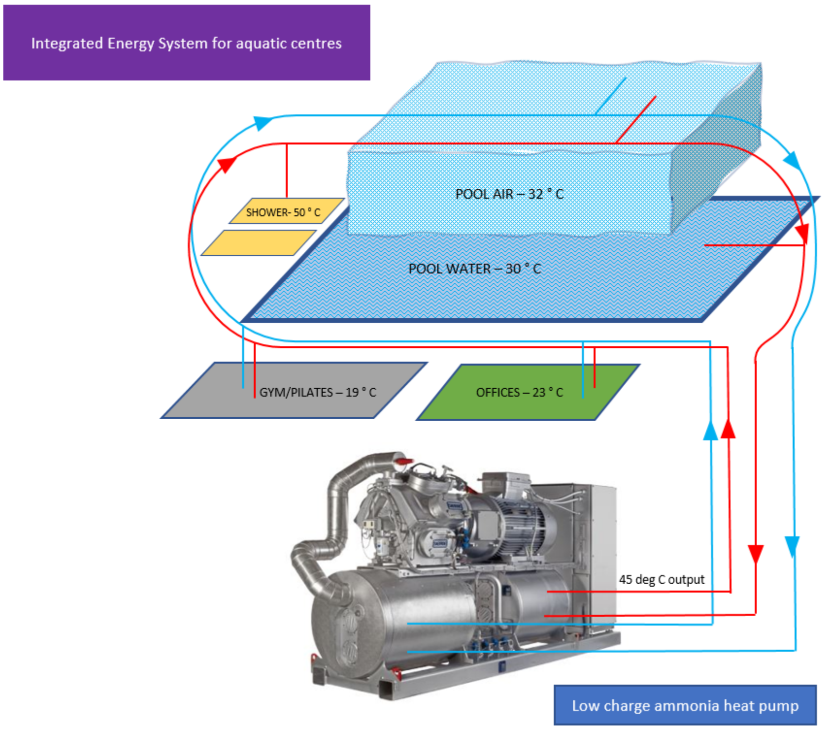



**Figure 12 Integrated System Overview**

LCA heat pumps provide a constant source of high-grade heat at around 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 for pool water.

To make the system even more efficient a thermal storage tank can be used that will reduce the running time of the unit in a day by buffering the demand for water from the various pools. 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.

# B. Background information on Heat Pumps

## V. 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 of a resistive electric heater (e.g. 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 to make the average efficiency even higher, both the cold and hot side of the heat pump can provide useful energy that can be stored for later use.

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 13 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. The COP 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 holding heat pumps in their optimal range can produce remarkable efficiencies.

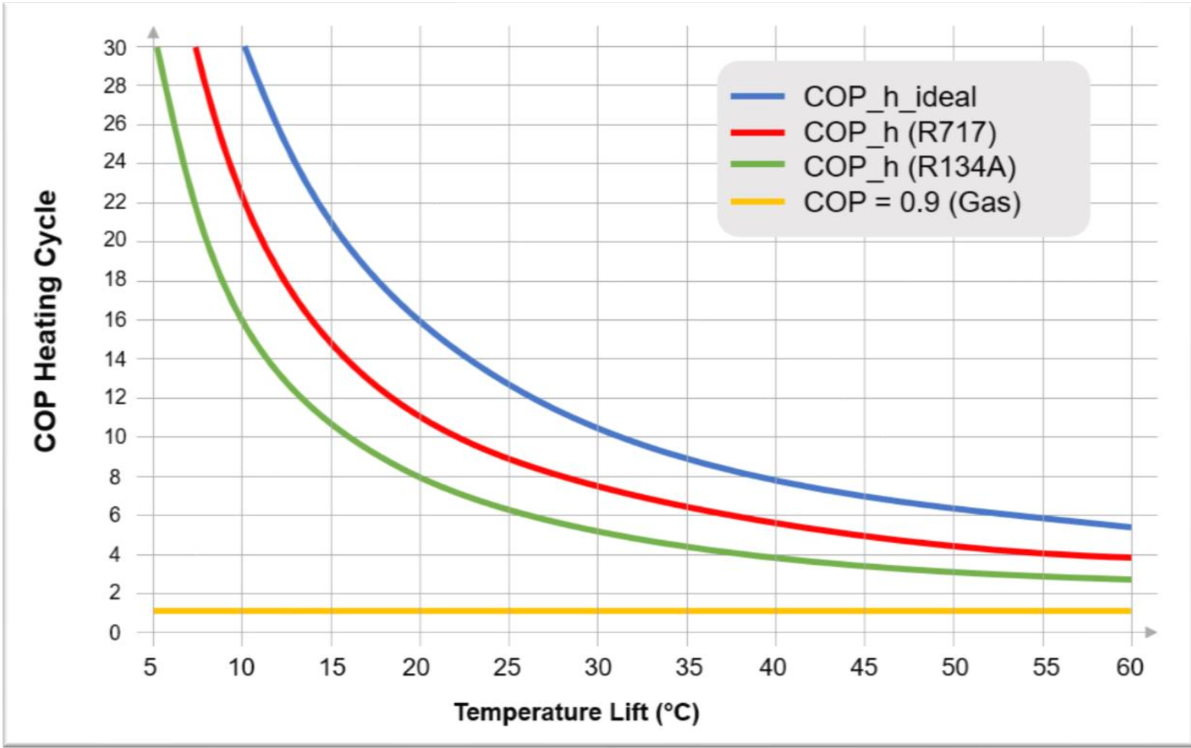



**Figure 13: The change of COP with inlet temperature**

# VI. Coefficient of Performance (COP) calculation

Table 7 shows an extract from the Load Tables and shows how we matched the relevant heating and cooling COP against the **ambient** inlet temperature for Richmond. The COP was then recalculated into 0.1°C increments and matched against the **actual** temperature for the site for each hour over one year.

The maximum ambient inlet temperature used by the system is set at 30°C. The maximum inlet temperature is controlled by the heat absorber which cools the inlet temperatures during the summer months.

The heat pump output for both hot and cold was then calculated and matched against the heating and cooling load for each hourly period. The resulting data was then plotted to see if the heat pump had the capacity to cover the load comfortably over the full year.

**Table 7: COP Matching Example**

| Year | Time | HP Heat Load | Richmond Vic Ambient | Ambient Inlet Temperature to 30C° MAX! | Heating COP | Heat Pump Electricity Consumption | Cooling COP |
|---|---|---|---|---|---|---|---|
| **2019** | Time | kW | °C | °C | **Match** | kW | **Match** |
| **1 - Jan 19** | 1:00 AM | 84.01 | 24.5383 | 24.5 | 6.6265 | 12.68 | 5.669 |
| **1 - Jan 19** | 2:00 AM | 84.01 | 24.3276 | 24.3 | 6.5937 | 12.74 | 5.641 |
| **1 - Jan 19** | 3:00 AM | 93.37 | 24.1702 | 24.2 | 6.5773 | 14.20 | 5.627 |
| **1 - Jan 19** | 4:00 AM | 93.37 | 24.0324 | 24.0 | 6.5449 | 14.27 | 5.599 |
| **1 - Jan 19** | 5:00 AM | 177.32 | 24.0029 | 24.0 | 6.5449 | 27.09 | 5.599 |
| **1 - Jan 19** | 6:00 AM | 158.60 | 24.7024 | 24.7 | 6.6597 | 23.81 | 5.697 |
| **1 - Jan 19** | 7:00 AM | 378.96 | 26.8779 | 26.9 | 7.0465 | 53.78 | 6.035 |
| **1 - Jan 19** | 8:00 AM | 341.12 | 29.027 | 29.0 | 7.4580 | 45.74 | 6.441 |
| **1 - Jan 19** | 9:00 AM | 293.75 | 31.1465 | 30.0 | 7.6700 | 38.30 | 6.680 |
| **1 - Jan 19** | 10:00 AM | 274.65 | 33.2941 | 30.0 | 7.6700 | 35.81 | 6.680 |

The inlet/ambient temperature will necessarily be increased in the winter from the heat recovered from the Pool Hall exhaust and possibly the backwash water. This improves the heat pump capacity and efficiency in the winter. The efficiency gains are shown in Table 3 as the inlet temperature rises. This was not taken into consideration in the calculations.

**Table 8: COP Efficiency Increase**

| Inlet Temp | | Output Duties, kW | | COP | | | |
|---|---|---|---|---|---|---|---|
| | **Model** | **Heating** | **Cooling** | **Hot** | **Cold** | **Total** | **Increase in Efficiency** |
| **0** | HeatPAC 108L | 405 | 316.7 | 3.64 | 2.84 | 6.48 | |
| **5** | | 494.6 | 392.6 | 4.02 | 3.19 | 7.21 | 18.12% |
| **10** | | 614.9 | 498 | 4.57 | 3.7 | 8.27 | 19.56% |
| **15** | | 740 | 613.2 | 5.28 | 4.37 | 9.65 | 16.91% |
| **20** | | 872.3 | 734 | 5.91 | 4.97 | 10.88 | 15.17% |
| **25** | | 1,017 | 870.6 | 6.71 | 5.74 | 12.45 | 14.23% |
| **30** | | 1,181 | 1,028.70 | 7.67 | 6.68 | 14.35 | 13.89% |

# VII. Gas types

Table 9 shows the different types of refrigerants as shown in Figure 13 (and others)

| Refrigerant | Type | GWP | Scheduled for phase down |
|---|---|---|---|
| **R410a** | HFC | 2,088 | Yes |
| **R407c** | HFC/HFO | 1,774 | Yes |
| **R404a** | HFC/HFO | 3,922 | Yes |
| **R134a** | HFC | 1,430 | Yes |
| **R143a** | HFC | 4,300 | Yes |
| **R22** | HFC | 1,810 | Yes (phased out) |
| **R32 (new)** | HFC | 675 | Yes |
| **R744 $CO_2$** | $CO_2$ | 1 | No |
| **R717 NH3** | Ammonia | 0 | No |

# VIII. 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 a large number of 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. 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 trans critical 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 supplied with electricity generated via 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 $CO_2$.

# C. LCA Heat Pump Sizing, Choice and Efficiency

## IX. Type of heat pump (ChillPAC vs HeatPAC)

It may sound counterintuitive but, in many instances, ChillPACs are a better option to heat a pool and the surrounding Pool Hall and ancillary areas. This is because ChillPACs feature oil separators integrated into the condenser and are therefore cheaper than the equivalent HeatPAC. A design constraint on the ChillPAC units **precludes** the use of a desuperheater which does not allow production of hot water for showers if that function is required. However, if DHW heating is required, a HeatPAC and desuperheater (which only can be fitted to Sabroe 108L configured as HeatPACs) would be the suitable option.

Scantec will design and specify the best system based on the specific environmental and performance criteria that is required for the site.

**Difference between a ChillPAC and a HeatPAC**

The difference is that ChillPACs have an oil separator built **into** the condenser. This makes it difficult, if not impossible to fit a shell-and-tube-type desuperheater in the discharge line. A HeatPAC has the oil separator fitted outside the condenser immediately upstream of it so to eliminates that problem.

**Use and purpose of the desuperheater**

A desuperheater is fitted immediately downstream of the compressor and upstream of the condenser. The desuperheater cools the superheated refrigerant leaving the compressor from the discharge gas temperature to a temperature approximately 5K above the refrigerant saturation temperature in the condenser. This cooling of the superheated refrigerant makes it possible to heat the coolant on the cold side of the desuperheater to temperatures that approach the compressor discharge gas temperature. Without a desuperheater, the superheated discharge gas simply enters the condenser where it is cooled until it reaches the condensing temperature at which point it starts to condense. Condensation takes place at a constant temperature. Note, that the water flow in the desuperheater is significantly lower than in the water-cooled condenser of the same system. Due the small size of the desuperheater, equating for approximately 6-8% of total heat pump output, it won't increase the condenser temperature of the heat which would reduce the COP. If the same water stream leaving the condenser would enter the desuperheater, the 'pinch point' in the condenser would prevent the coolant in the desuperheater from approaching the compressor discharge gas temperature.

## X. Inlet temperatures

Inlet temperatures to the Heat Pump are the single most critical factor in determining their efficiency. In this example we have used ambient air as the inlet temperature with a limit of 30°C controlled by the heat absorber. If we use recovered heat to increase the inlet temperature, then the efficiency only increases.

## XI. System Sizing

In the heat load evaluation program that SmartConsult has developed, we tested the sizing of the 2 x 108L and 2 x 112L heat pumps against the heat load over a full year from the data provided by the council. The results from this show that using the weather data as the inlet temperature for the heat pumps, the two Sabroe 108L heat pumps configured as HeatPACs and fitted with desuperheaters have enough capacity for the heating and cooling loads at the Richmond Recreation Centre.

The type and size of the LCA heat pump configuration depends on the following:

1. Site location
2. Thermal resistance of the building
3. Heat Load – Pool and Pool Hall and Ancillary structures
4. Heat Load - Spa
5. Cooling Load
6. Shower capacity required
7. Power supply to the site

The HeatPAC 108L LCA heat pumps has been calculated to have sufficient capacity for the heating and cooling loads at the Richmond Recreation Centre. The installation would require two heat pumps for a combined heat output of 1,744 kW @ 20°C ambient inlet temperature or 3,363 kW @ 30°C ambient inlet temperature. This is **not reliant** on the heat pumps having a low-grade heat source capable of delivering an inlet temperature of 4 to 6°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.

Table 10 shows the range of COPs, kW output and Electricity consumption at different heat pump inlet temperatures.

**Table 10: LCA heat pump performance at varying inlet temperatures**

| Inlet Temp | | Peak Electricity x 1 | Peak Electricity x 2 | Output Duties, kW | | COP | | |
|---|---|---|---|---|---|---|---|---|
| | Model | Shaft Electricity, kW | Heat Pumps x 2 | Heating | Cooling | Hot | Cold | Total |
| **0** | HeatPAC 108L | 111.4 | 222.8 | 405 | 316.7 | 3.64 | 2.84 | 6.48 |
| **5** | | 123.1 | 246.2 | 494.6 | 392.6 | 4.02 | 3.19 | 7.21 |
| **10** | | 134.6 | 269.2 | 614.9 | 498 | 4.57 | 3.7 | 8.27 |
| **15** | | 140.2 | 280.4 | 740 | 613.2 | 5.28 | 4.37 | 9.65 |
| **20** | | 147.7 | 295.4 | 872.3 | 734 | 5.91 | 4.97 | 10.88 |
| **25** | | 151.6 | 303.2 | 1,017 | 870.6 | 6.71 | 5.74 | 12.45 |
| **30** | | 154 | 308 | 1,181 | 1,028.7 | 7.67 | 6.68 | 14.35 |

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

Table 11 shows the lift on both the hot and cold sides in and out for the glycol loop from the heat pump.

**Table 11: 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 | 40 | 45 |
| **5** | 2 | -3 | 40 | 45 |
| **10** | 7 | 2 | 40 | 45 |
| **15** | 12 | 7 | 40 | 45 |
| **20** | 17 | 12 | 40 | 45 |
| **25** | 22 | 17 | 40 | 45 |
| **30** | 27 | 22 | 40 | 45 |

## XII. Heat exchangers

The lower temperature of the water being handled by the heat pumps (down from 80 ºC in a gas system) requires larger flat plate heat exchangers to be installed. These units are sized according to the formula:

Q = K * A * LMTD where the approach is 5-7 ºC.

These heat exchangers are usually much larger in size than the existing heat exchangers to allow for sufficient heat transfer to the pool water. More details on this type of heat exchanger is available in Appendix D.

To increase the efficiency of LCA heat pumps, a source of **low-grade heat** is invaluable. This has proven a difficult concept to grasp for centre owners who are accustomed to looking for heat sources for pools that are **at or above** the target temperature. Heat sources below these temperatures are often discarded as waste heat of no use in the centres.

## XIII. Heat recovery and low-grade heat sources

Low grade heat may be available from the shower wastewater, the exhaust air condensed from the pool hall, the backwash tanks: anywhere that heat is being transferred within the building. This heat can be usefully employed to feed the inlet of the heat pumps and increase their efficiency. In this way, the overall energy efficiency of the building is increased.

During opening hours, the pool hall has air being circulated continually with air being rejected from the hall and fresh air being added to the hall. The rejected air has a relatively high-water content and water can be recovered from it, and the heat that the air contains can also be recovered. This is achieved by cooling of this rejected air (using surplus cold from the heat pump) as the air is rejected from the building. This heat can be used to heat up the incoming fresh air or be fed back into the heat pumps at the cold side inlet to increase their efficiency. The water temperature of a buried water main is a minimum of 12°C in Melbourne in winter. This is a useful heat source at that time of the year and the refilling of backwash tanks provides an easily accessed source of heat for the centre. This also applies to top up water that the centre is consuming. A PVT system installed on the roof beneath the existing solar PV panels would also provide a very good source of low-grade heat during daylight hours as it can provide around **3 times** the thermal energy of the existing solar PV system's electrical energy.

## XIV. Thermal storage

This can be used to buffer the integrated energy system in peaks of winter and summer. If the centre is using and storing large amounts of water for backwashing this water can also provide a low-grade heat source for the centre. When combined with a PVT system, a thermal storage system can bridge the gap in the energy cycle of the centre when solar electricity 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 also be used to store cool water for the system.

**Figure 14: 30,000L water storage tanks at Leisure Link, Geelong**

## XV. Heat Ranges and Heat Exchangers

An Integrated Energy System operates **at lower temperatures** than the equivalent gas heating or Cogen system. Typically, gas systems produce output water that is around 85-90°C however most of the pool heating requirement is around 30°C.

LCA heat pumps are bespoke to suit the needs of the centre they are designed for. The LCA heat pumps produce water at around 43°C to supply pools that have target temperatures around 30 to 35°C. Less work has to be done to raise the inlet temperature of the water to the operating temperature thus allowing higher efficiencies.

The sizes of the heat exchangers used for gas and LCA heat pumps are different due to the different operating conditions. The heat exchangers will be larger as they require more surface area to effectively transfer heat to the water due to the lower temperature differences. This is an engineering calculation that will be determined during the detailed design phase of the project. An example of a suitable heat exchanger is described in Appendix D.

## XVI. Heat pump configurations

The installation would require 2 heat pumps to meet the combined heating and cooling required for the Richmond Recreation Centre.

**Figure 15: Sabroe HeatPAC 108**

The heat pump configuration uses ammonia as refrigerant and is designed for the best possible performance in a range of operating conditions using a small refrigerant charge and a limited footprint. The heat pumps would supply hot water for the pool at 43 °C and would also supply warm water for the air handling unit in the pool hall.

## XVII. Heat Absorber

The heat pump is configured with a heat absorber (air cooler) capable of controlling the inlet temperatures to the cold side of the heat pump during the summer months to prevent compressor overload.

The cold side inlet temperatures to the heat pump can be boosted from heat harvested from the backwash tank and/or the pool hall water and heat recovery unit during the winter and at other times where boosting cold side temperatures is advantageous to improve COP.

This creates a low-grade heat source capable of boosting the inlet temperature by +3 - 4 °C above ambient or higher to the cold side of the heat pump during winter.

Initial investigations regarding the available heat recovery from the exhaust air from the pool hall is shown below. This information was derived from the daily top-up water volumes.


**Figure 16: Example of a chilled air discharge evaporator**

**Table 12: Recoverable Water and Power from the Pool Hall Air Exhaust**

| Month | Total Top-Up P/Day | Litres P/Day Recovered | Recoverable kW Power (Heat per month) |
|---|---|---|---|
| Jan | 13,800 | 6,900 | 546 |
| Feb | 25,604 | 12,802 | 1,013 |
| Mar | 18,876 | 9,438 | 747 |
| Apr | 18,914 | 9,457 | 748 |
| May | 24,404 | 12,202 | 965 |
| Jun | 14,599 | 7,299 | 577 |
| Jul | 13,489 | 6,745 | 534 |
| Aug | 12,106 | 6,053 | 479 |
| Sep | 18,844 | 9,422 | 745 |
| Oct | 19,093 | 9,546 | 755 |
| Nov | 19,327 | 9,664 | 765 |
| Dec | 16,577 | 8,289 | 656 |
| **Totals** | **215,633** | **107,816** | **9,241** |
| **AVG.** | **17,969** | **8,985** | **711** |

It is assumed that half of the top-up water can be recovered with cooling coil(s) in the exhaust(s), then the average cooling capacity required is shown where 2500 kJ/kg is the approximate latent heat of water. This goes to the cold loop of the heat pump.

Heat pumps become 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 2 x 108L heat pumps at 0°C saturated suction temperature is **3.64** providing heating of 810 kW. This excludes auxiliary equipment and is based on compressor shaft power input of 222.8 kW. If the saturated suction temperature is raised to 6°C the 108L heat pump has a COP of **4.13** providing heating of 1008 kW. Both estimates are for a saturated condensing temperature of 43°C.

# XVIII. Example Servicing Costs and reliability of LCA heat pumps

A tailored maintenance plan and cost will be formulated for the Richmond Recreation Centre after the system has been designed. **Note**: the system proposed for the Richmond Recreation Centre is of a different configuration so the maintenance cost will be estimated more accurately once the design is settled.

An example of typical costs can be seen if we refer to the costs charged to Logan council for their Admin building. Graham Taylor, Service Manager at Scantec Refrigeration Technologies reports that the servicing of the 2 chillers at the Logan City Council installation is as follows-

*"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 valves 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 operating conditions of the compressor and then adjusts the service schedule accordingly."*

**Table 13: Summary of annual heat pump service costs**

| Service Item | Time interval | Annual cost |
|---|---|---|
| **Annual Service fee** | 12 months | $5178.62 |
| **Ammonia detection calibrations** | 12 months | $1061.20 |
| **Monthly service fee** | monthly | $959.91 |
| | **Total** | $11,519.82* |

*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.

# XIX. LCA Heat Pump Power Supply

It is noted on the SLD as provided by the client that there is a 400 Ampere breaker at the MSB indicating that the supply to the site is approximately 287 KVA @ 0.9 Power Factor.

The Heat Pumps Max demand will be approximately 260 kW, plus ~15% to include auxiliary equipment, resulting in ~295 kW.

This together with the pool pumps and other building supply requirements suggest that the MSB supply will need to be upgraded to at least 500 kVA or 700 Amps.

## XX. Power Factor Correction

It was noted during the analysis that an upgraded Power Factor Correction unit will provide additional savings on your electricity costs.

# D. Sondex Heat Exchanger (Example)

SONDEX®

## S7A - S14A - S20A

### Plate Heat Exchangers

**Recommended Applications:**
The S7A, S14A and S20A range of Sondex plate heat exchangers is specially designed for the HVAC area, the geothermal-, marine-, and heat recovery area as well as the food, industrial and chemical market.

**Design Principle:**
The Sondex type S7A, S14A and S20A plate range with lengths up to 1,0 m (3,8 ft) and a "long" thermal pattern will cover many duties up to 50 m³/h (220 gpm) in a single pass solution, meaning that all the connections are on the head side. This will ensure easy pipe- and service work, and by dismantling the exchanger for service, no pipes need to be removed.

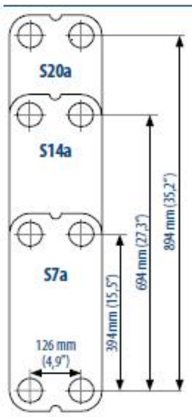
The heat transfer is obtained, when the warm medium transfers energy through the thin, strong flow plates between the channels and delivers it to the cold opposing medium without mixing the two media. Counter-current flow creates the optimal efficiency. The plate- and inlet design allows effective, easy CIP (Cleaning in Place) of all "flow" surfaces.

**Flow plates:**
The corrugated "herringbone" pattern ensures turbulent flow in the whole effective area. Furthermore, this pattern brings "metallic" contact between the plates, and together with "Sonder Lock" locking devices on the gaskets, the plate pack is easily assembled. The plate pack is held firm and safely between the fixed head and movable follower of the frame.

**Data Required for Correct Quotation:**
- Duty
- Type of media
- Pressure loss
- Flow rate
- Working pressure
- Thermodynamic properties
- Temperature
- Working Temperature

Above data determines the choice of heat exchanger.

S14A




For exact dimensions of the PHE please refer to the dimension drawing

**Technical Information**

**Frame:**
- Painted frame, colour RAL 5010 (available in other colours)
- Stainless steel frame, designed for the food and dairy industry.

Both frames comes with clamping bolts placed around the frame edge.

**Design Pressure:**
- Painted frames: 1.6/2.5 MPa. (232/362 PSI)
- Stainless steel frame: 1.6 MPa. (232 PSI)

**Intermediate Frames:**
Intermediate frames and corner blocks for IS and FS frames in stainless steel.

**Construction Standard:**
- EN13445 (PED 2014/68/EU)
- ASME sec VIII, Div. 1

**Connections:**
- DN50/2" flanges. Carbon steel, rubberlined or cladded with AISI 316.
- 2" pipe or threaded pipe in stainless steel or titanium
- 2"/DN50 dairy pipe or union.

According to all known standards.

**Plate Material:**
AISI 316, 254 SMO and titanium.
Also 2 x 0.4 mm "Sonder Safe" plates, for food and industry.
Other materials available on request.

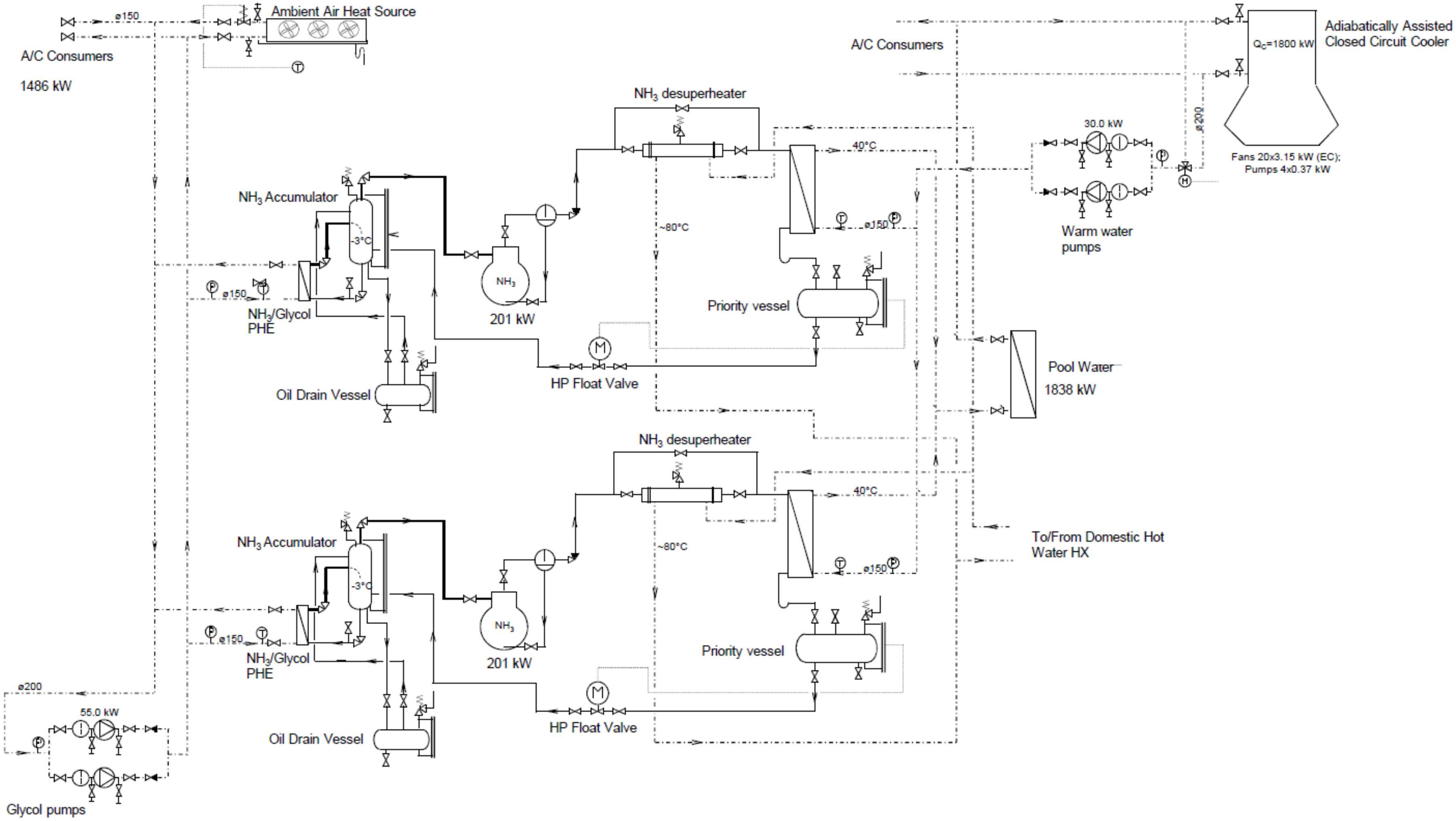
**Gaskets:**
The gasket is the unique non-glued "Sonder lock" gasket which locks the plates together with strong rubber buttons, so that the plates are strongly guided during the assembly of the plate heat exchanger.
Materials: NBR, EPDM and Viton.
Other materials available on request.

**Extra Equipment:**
- Safety cover in stainless steel
- Insulating jacket
- Assembling spanner
- Foundation feet
- Instrument flange
- Thermometer and manometer

Sondex A/S • Marsvej 5 • DK-6000 Kolding • Denmark • Tel. +45 76 306 100 • Fax +45 75 538 968 / Fax +45 75 505 019 • info@sondex.dk • www.sondex.net

# E. Concept Design (HeatPAC Sabroe 112L)

Please note the design on the following page used Sabroe 112L Heat pumps which are larger than the Sabroe 108L in this report, however the concept is the same.



# F. Energy Cost Breakdown

## XXI. Current Electricity Cost per kWh, including Demand

**Current Electricity Usage, Demand cost and cost per kWh**

| Metric | 42% | 58% | Sum | $ 0.1548 | $ 0.1071 | Sum | kVA | $ 8.1058 | Sum |
|---|---|---|---|---|---|---|---|---|---|
| **Month** | **kWh peak** | **kWh Off-peak** | **Total kWh** | **Cost kWh peak** | **Cost kWh Off-peak** | **Total kWh Cost** | **Max Demand** | **Demand kVA** | **Total estimated Cost** |
| Jan-19 | 24,114 | 33,595 | 57,710 | $3,733.37 | $3,597.60 | $7,330.97 | 195 | $1,580.63 | $8,911.60 |
| Feb-19 | 22,105 | 30,795 | 52,900 | $3,422.22 | $3,297.77 | $6,719.98 | 195 | $1,580.63 | $8,300.62 |
| Mar-19 | 22,526 | 31,382 | 53,908 | $3,487.43 | $3,360.61 | $6,848.04 | 195 | $1,580.63 | $8,428.67 |
| Apr-19 | 19,452 | 27,100 | 46,553 | $3,011.61 | $2,902.09 | $5,913.69 | 195 | $1,580.63 | $7,494.32 |
| May-19 | 20,472 | 28,521 | 48,994 | $3,169.51 | $3,054.25 | $6,223.77 | 195 | $1,580.63 | $7,804.40 |
| Jun-19 | 22,376 | 31,174 | 53,550 | $3,464.29 | $3,338.31 | $6,802.61 | 195 | $1,580.63 | $8,383.24 |
| Jul-19 | 22,439 | 31,261 | 53,700 | $3,473.99 | $3,347.66 | $6,821.65 | 195 | $1,580.63 | $8,402.28 |
| Aug-19 | 22,374 | 31,170 | 53,544 | $3,463.90 | $3,337.93 | $6,801.83 | 195 | $1,580.63 | $8,382.46 |
| Sep-19 | 21,917 | 30,534 | 52,451 | $3,393.18 | $3,269.79 | $6,662.97 | 195 | $1,580.63 | $8,243.60 |
| Oct-19 | 26,655 | 37,135 | 63,790 | $4,126.70 | $3,976.62 | $8,103.32 | 195 | $1,580.63 | $9,683.95 |
| Nov-19 | 22,491 | 31,334 | 53,826 | $3,482.10 | $3,355.47 | $6,837.57 | 195 | $1,580.63 | $8,418.20 |
| Dec-18 | 21,801 | 30,372 | 52,173 | $3,375.21 | $3,252.47 | $6,627.68 | 195 | $1,580.63 | $8,208.31 |
| **Total** | **268,723** | **374,375** | **643,098** | **$41,603.51** | **$40,090.56** | **$81,694.07** | **195** | **$18,967.57** | **$100,661.64** |

**Ø $ Per kWh Rate** **0.15653**

# XXII. NEW Electricity Cost per kWh, including Demand

**NEW Electricity Usage, Demand cost and cost per kWh**

| Metric | 42% | 58% | Sum | $ 0.1548 | $ 0.1071 | Sum | kVA | $ 8.1058 | Sum |
|---|---|---|---|---|---|---|---|---|---|
| **Month** | **kWh peak** | **kWh Off-peak** | **Total kWh** | **Cost kWh peak** | **Cost kWh Off-peak** | **Total kWh Cost** | **Max Demand** | **Demand kVA** | **Total estimated Cost** |
| Jan-19 | 27,235 | 37,943 | 65,178 | $4,216.53 | $4,063.19 | $8,279.72 | 500 | $4,052.90 | $12,332.62 |
| Feb-19 | 23,220 | 32,349 | 55,569 | $3,594.87 | $3,464.14 | $7,059.02 | 500 | $4,052.90 | $11,111.92 |
| Mar-19 | 28,316 | 39,449 | 67,765 | $4,383.90 | $4,224.47 | $8,608.37 | 500 | $4,052.90 | $12,661.27 |
| Apr-19 | 34,767 | 48,436 | 83,203 | $5,382.58 | $5,186.84 | $10,569.43 | 500 | $4,052.90 | $14,622.33 |
| May-19 | 45,556 | 63,467 | 109,023 | $7,052.98 | $6,796.49 | $13,849.47 | 500 | $4,052.90 | $17,902.37 |
| Jun-19 | 47,795 | 66,587 | 114,382 | $7,399.65 | $7,130.56 | $14,530.21 | 500 | $4,052.90 | $18,583.11 |
| Jul-19 | 54,379 | 75,759 | 130,139 | $8,418.98 | $8,112.82 | $16,531.80 | 500 | $4,052.90 | $20,584.70 |
| Aug-19 | 53,691 | 74,801 | 128,492 | $8,312.46 | $8,010.17 | $16,322.63 | 500 | $4,052.90 | $20,375.53 |
| Sep-19 | 47,901 | 66,734 | 114,634 | $7,415.96 | $7,146.27 | $14,562.22 | 500 | $4,052.90 | $18,615.12 |
| Oct-19 | 36,975 | 51,512 | 88,487 | $5,724.41 | $5,516.24 | $11,240.65 | 500 | $4,052.90 | $15,293.55 |
| Nov-19 | 33,789 | 47,073 | 80,862 | $5,231.15 | $5,040.92 | $10,272.07 | 500 | $4,052.90 | $14,324.97 |
| Dec-18 | 32,796 | 45,690 | 78,485 | $5,077.39 | $4,892.75 | $9,970.14 | 500 | $4,052.90 | $14,023.04 |
| **Total** | **466,420** | **649,800** | **1,116,220** | **$72,210.87** | **$69,584.85** | **$141,795.72** | **500** | $48,634.80 | $190,430.52 |

| | |
|---|---|
| **Ø $ Per kWh Rate** | **0.17060** |

# References

Duverge, J. (2019). Energy performance and water usage of aquatic centres.

Jensen, S. (2019). Real energy efficiency of DX $NH_3$ versus HFC.

Fryer J. (2019). Heat pumps in aquatic centres. (Report)

Pears, A. (2019). Heat Pumps: Application to Aquatic Centres. RMIT University

Sands, T. (2018). Understanding Swimming Pool Ventilation. (Presentation)