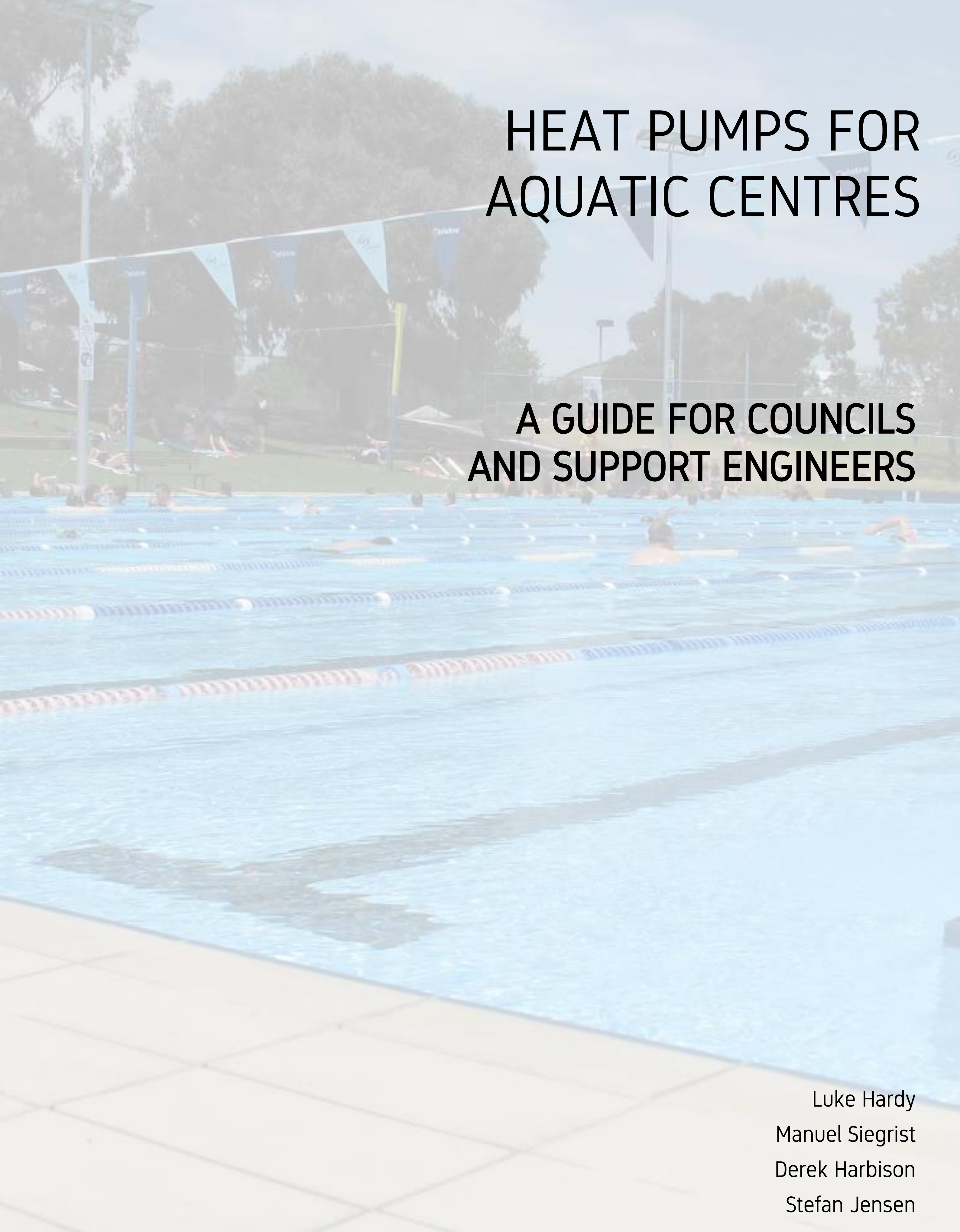

HEAT PUMPS FOR AQUATIC CENTRES

A GUIDE FOR COUNCILS AND SUPPORT ENGINEERS

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1. General Information

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1.3 Glossary

Abbreviation or Acronym	Description
Air to water heat pump	A heat pump with an air inlet and a warm water outlet
AHU	Air Handling Unit
Chilled water system	A cooling system that uses chilled water to deliver cold to outlets
Cooling Coil	Allows cold to be transferred to air or water from a cooling loop
COP	A measure of efficiency
Condenser	A device or unit used to condense a gaseous substance into a liquid state through cooling
Compressor	It works as a heat pump to control the circulation of the refrigerant, and it adds pressure to the refrigerant, heating it up
Evaporator	The opposite of the condenser: here refrigerant liquid is converted to gas, absorbing heat from the air in the compartment
Fan-Coil Unit	A fan coil unit (also known as a Vertical Fan Coil Unit) is a simple device consisting of a heating and/or cooling heat exchanger or 'coil' and fan. It is part of an HVAC system found in residential, commercial, and industrial buildings
GWP	Global Warming Potential
Heat Absorber	Used to gather heat for the inlet of the heat pump
HVAC	Heating, Ventilation and Air Conditioning System
Low grade heat	Heat source below the temperature of the heat pump target temperature
Heating Coil	Allows heat to be transferred to air or water from a heat loop
Inlet Temperature	The temperature of the water entering a heat pump
LCA	Low Charge Ammonia
Outlet Temperature	The temperature of the water leaving a heat pump
Relative Humidity	The amount of water vapour present in air expressed as a percentage of the amount needed for saturation at the same temperature.
Vapour Compression Cycle	The vapor-compression cycle is a process used to extract heat from a box or a room that underlies most refrigeration and air conditioning techniques
Water to water heat pump	A heat pump with a water inlet and a warm water outlet

Technology	Description
Gas Boilers	Heating provided by gas boilers
Low Charge Ammonia Heat Pump	Ammonia R717 is used as a refrigerant with a GWP of 0
HFC Heat Pump	Hydrofluorocarbons (HFC) R32 gas is used as a refrigerant with a GWP of 675
CO_2 Heat Pump	CO_2 is used as a refrigerant with a GWP of 1

1.4 Document History

Revision	Description	Author	Checked	Approved	Date
A	Draft	DH		LMH	24/05/20
B	Draft	DH		LMH	25/06/20
C	Final 1.0	DH/LMH/MS	MS	LMH	28/07/20

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2. Aquatic Centre Energy Systems – General Information

2.1 Existing Aquatic Centres

The ability to reliably predict the energy requirements of a building during the planning phase is a basic prerequisite for achieving high energy efficiency in the building. It enables the optimization of individual components as well as a holistic building concept. Due to many interactions and regulations, the energy flows in an indoor pool are very complex and can be difficult to determine. The design philosophy of aquatic centres in the past has been focused on heating water for aquatic centres and the supply of air to the wet exercise areas was given little thought. As such these centres would have excessive energy usage and the heat that was being produced for the wet exercise areas was easily lost from the building through thermally inefficient building envelopes.

To counter this, larger heating systems have been installed using more gas to heat inefficient building envelopes. Gas heating is a very inefficient way of producing heat compared to other systems available when the total energy being consumed is measured accurately. The historically low cost of gas per kWh has masked this fact until recent gas price rises prompted councils to revisit aquatic centre energy usage. The most effective strategy for increasing the efficiency of these buildings is to **retain the heat** in the building as effectively as possible. The retrofitting of double-glazed panels to the existing windows at aquatic centres has proven the value of these upgrades as an effective way to reduce heat loss and save costs and an important first step in the increase of energy efficiency of these centres.

Existing aquatic centre designs suffer from:

1) excessively high energy usage utilising gas heating systems
2) air quality issues
3) corrosion and maintenance issues
4) condensation on glazing in the pool hall
5) limited ability to control the pool environment (heating, cooling, and humidity)
6) high maintenance costs

Jonathan Duverge completed a comprehensive study of aquatic centres in Victoria in January 2019, "Energy performance and water usage of aquatic centres" and this is well worth reading as a primer on this topic.

2.2 High Efficiency Aquatic Centres: what are the goals?

There has been extensive study conducted by the Passivhaus Institute in Germany to determine the optimum design for high efficiency aquatic centres. These centres were first designed in Lünen and Bamberg in 2009 and the findings in these studies is well worth considering prior to any upgrade work on Australian aquatic centres.

High efficiency aquatic centres have these characteristics:

- building envelope is fully sealed for air leaks with no thermal bridging
- location of different activity areas in the building is carefully considered to prevent excessive temperature changes between areas
- high efficiency heat pumps allow full integration of energy systems
- all wet area windows are double/triple glazed - this eliminates condensation and reduces the need for the heating of glass with specific air flows
- there are no skylights in any areas
- there are multiple humidity sensors in all of the exercise wet areas and showers to assist in maintaining the target humidity required throughout these spaces very accurately
- the optimal humidity of the air in the wet areas is 64%
- ventilation has a 'top-down' air flow with air supplied close to the ceiling and air extracted close to the level of the pool water
- the rate of air flow in the Air Handling Units is less than half that of an existing Australian aquatic centre
- there are two groups of HVAC systems- one for the wet exercise areas and one for the dry exercise areas of the building and heat is recovered from these units continually
- if sized correctly, Solar PV has the ability to balance the energy flow close to a net zero balance in a warmer climate than Europe
- thermal storage is an integral part of the energy system design and is sized to suit the centre demand and allow for load shifting of heat
- water reclaim and sufficient water storage is essential

The three main elements that need to be addressed can be summarised as:

- heating of the pool water
- heating (and cooling in summer) of the air in the pool area via the HVAC system
- thermal insulation and air sealing of the building envelope

In the temperate climate of Melbourne, it should be possible to achieve higher efficiencies than those of the European aquatic centres recently designed as:

- the average outside ambient temperature is higher in Melbourne than in Europe
- heat pumps used are working more efficiently as they can run closer to their optimal range
- there is more solar PV energy available for the centre each day as the solar days are longer
- there is more land surrounding the centre as Melbourne is less dense than most European cities

The higher efficiency of these centres produces some unexpected changes. By fully recovering heat from the HVAC system and more accurate control over the evaporation from the pools in the wet areas the balance of energy in the building changes dramatically from existing centres. The very good thermal insulation of Passivhaus (pools) allows this limit to be shifted to higher moisture contents due to the higher internal surface temperatures of the external components. The evaporation rate of the pool water decreases with increasing indoor air humidity. This in turn has a big impact on the required air change, which in turn significantly influences the amount of ventilation heat loss.'

'The greatest energy losses then arise from the transmission and cooling of the pool water and the hall air due to evaporation. The reduction in transmission heat losses can be almost halved by consistently implementing the Passivhaus standard. In addition to this reduction, the highly thermally insulated casing is also of particular importance for a second reason. It is only due to the high internal surface temperatures that it is possible to set higher indoor air humidity levels without causing damage to the building envelope through moisture.'

'The largest single item is the energy requirement for the evaporation of pool water. This makes it clear where the particular challenge of saving energy lies.'

- *Lünen Metrics report 2018*

Energy loss from a swimming pool is closely linked to evaporation. When water evaporates, the latent heat of evaporation is effectively absorbed by the process, resulting in heat loss from the body of water and the surrounding air. To help minimise evaporation the pool hall should be maintained at a relative humidity of ~64%. At this level of humidity, evaporation from the pool surface will still take place, and needs to be offset by dehumidification using a mechanical system. By using a passive heat transfer process using heating and cooling coils, significant savings in the cost of running AHUs are possible as there are no 'mechanical' system utilising heat pumps required to achieve this heat transfer. This has a flow on effect to the rest of the system when it is integrated which results in substantially less energy being required for the whole centre.

Increasing the relative humidity set point by just 5% can result in a 30% reduction in peak air flow required for dehumidification. Once you factor in the reduced fan and heating energy associated with this adjustment, as well as the reduced heat loss to the evaporation process, it becomes obvious that this element is an essential consideration of any high efficiency centre design.

By taking the stated energy savings for the building envelope and ventilation in the pool hall, and adding the increase using a high efficiency heat pump, the decrease in energy consumption that can be achieved with an integrated system becomes obvious.

The new Passivhaus aquatic centre being built in Exeter in the UK has accurately forecast the energy usage of their new centre and provides a good example of the degree of precision that is possible in the energy usage estimates:

- space heating demand for the pool hall of <40kWh.m^{-2} per year
- heating demand for all other areas of <20kWh.m^{-2} per year
- gym cooling demand <22kWh.m^{-2} per year
- pool water heating demand <73kWh.m^{-2} per year
- DHW heating demand <56kWh.m^{-2} per year
- total electricity demand (ventilation, lighting, appliances, pool water treatment and circulation <120kWh.m^{-2} per year
- total primary energy demand for Passivhaus accreditation, including space heating, hot water, cooling, ventilation, and electrical loads, including lighting, is 375kWh.m^{-2} per year.

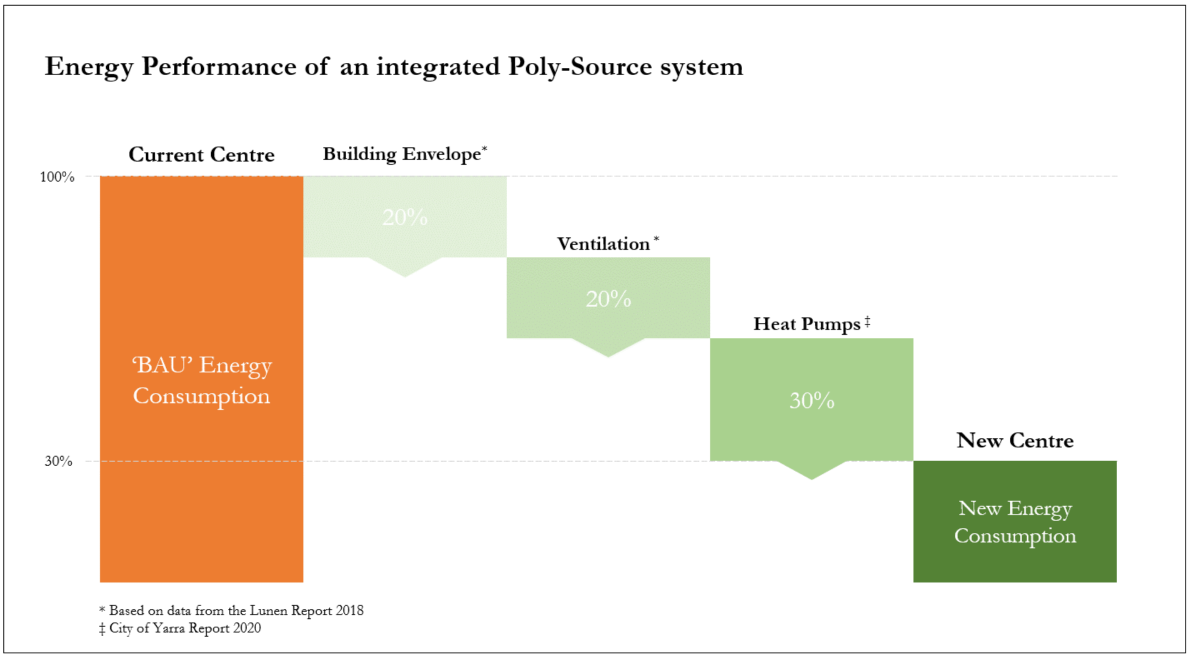

Figure 1: Energy performance of an integrated Poly-source system compared to existing gas systems.

2.3 Measuring Energy Usage: An important first step

Councils who are interested in improving the energy efficiency of their aquatic centres are well served by accurate data for the energy usage of their existing operations. Relying solely on the energy bills provided by their energy supplied is insufficient to draw meaningful conclusions. Once more detailed data is fully understood the best path forward can be determined with more confidence and allow councils to set performance benchmarks that centre builders must exceed and guarantee.

2.4 Considerations in changing from a gas to an electrical system

There is no magic bullet in changing over from a gas system to an electrical system as the existing buildings were designed to accommodate a gas system. This presents issues with the size of piping, size of heat exchangers and the siting of new plant. Further to this there are broader issues that need to be taken into account:

- The lifespan of the building and how many more years the building is forecast to be in operation
- The location of the building in relation to other buildings, outdoor pools, water courses and clearances around the building structure
- The electrical supply to the building and any constraints the electricity DNSP has in place for usage and billing
- The capacity for solar PV system installation and limits on export
- Location of plant rooms in relation to the pools and the HVAC system: are there multiple plant rooms?
- The capacity for thermal storage tank installation

2.5 Changing from Gas to Heat Pumps: A temperature issue

A significant stumbling block for the conversion of these centres to heat pumps is the temperature of the water output from the gas systems these centres currently use. The typical output of a gas boiler is ~80^{0}C which is substantially higher than the average pool temperature of around 30^{0}C. Existing pipework and heat exchangers in the plantroom are designed for this operating range which must be considered in any heating upgrade.

In contrast to this, some heat pumps can supply water closer to the temperature of the pool water (~45^{0}C). This represents a substantial saving as the temperature of the water that is used to heat the pool water must be 'lifted' less. However, the use of these heat pumps also requires heat exchangers to be increased in size and the pipework enlarged to allow more water to flow around the system to deliver the equivalent amount of heat required. The choice of which heat pumps to use is not arbitrary: different heat pumps use different refrigerants that suit a range of temperatures better than others.

3. Integrated Poly-Source Energy Systems

3.1 A matter of balancing energy loads

Until recently 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 an air conditioner to cool the air – This is depicted under Figure 2 below.

Gas Boilers (BAU)

Operating temperature range	-5 to 80°C
Winter boost required?	No
COP of gas boiler	0.9
GWP of HP refrigerant	N/A
A/C Refrigerant	R410A
HVAC heat recovery	75%
Solar system size limited	Yes
Thermal storage applicable	No
Heat recovery applicable	No
Pool warm water supply	80°C

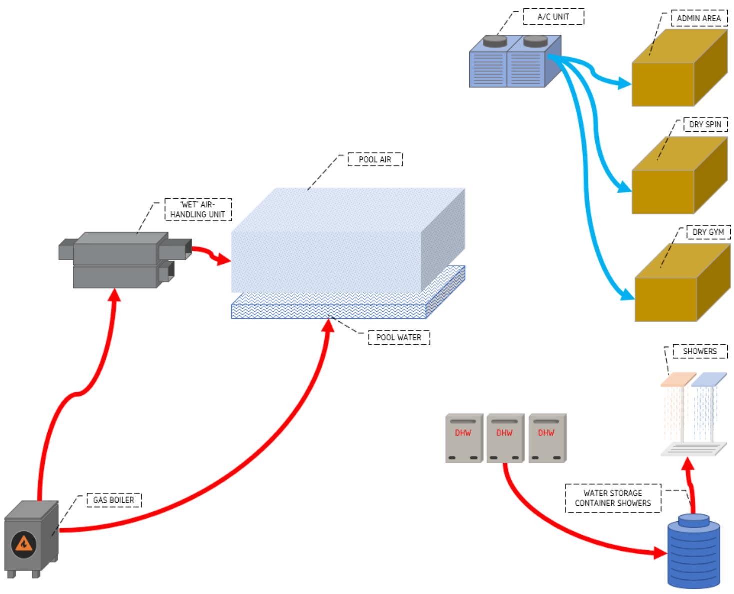

Figure 2: A gas-based pool energy system

However, when we **integrate** the energy systems in the centre, a range of new opportunities become available to us for saving energy as heat in the system can be recovered more easily and this heat can be reused or stored for later use. This also allows for the use of larger solar PV systems in these centres than is currently possible.

Once the cost of energy production in the centre is reduced 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 and storage takes up valuable space. The percentage of energy input versus storage should be calculated as changing this ratio is very difficult once the centre has been constructed and space in the building for plant has been allocated and installed.

3.2 Utilising the whole output from a 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, air-conditioning office areas, dry exercise areas and the pool enclosure air in summer and DHW supply. There is also the opportunity to use the **cold** produced to assist with heat recovery and humidity control. There is usually more heating than cooling required in an aquatic centre in Victoria for most of the year.

There are substantial savings available when the HVAC system increases in efficiency as the HVAC system in the wet areas of the pool in an existing aquatic centre accounts for **over 50%** of the heat being consumed. A more efficient HVAC system results in these gains that add up to substantially higher efficiency:

- Increased heat recovery
- Increased water recovery
- Increased chemical removal
- Less cycles per hour
- Less fresh air required per cycle
- More accurate control over temperature
- More accurate control over humidity

4. Heat Pumps

4.1 Overview

As gas and electricity prices increase and technologies evolve, heat pumps are gaining increasing attention as an option for reducing energy costs and moving away from fossil sourced gas and electricity to renewable electricity. A heat pump is an electrical device that extracts heat from one place and **transfers** it to another. The heat pump is not a new technology: they have been used around the world for over 150 years. Refrigerators and air conditioners are both common examples of this technology.

In general, all water to water heat pumps do the same thing in a similar way but using a different gas inside. For the application of pool water and pool hall heating at an aquatic centre, LCA and HFC units can effectively do the same thing. However, the CO2 units currently available in Australia are designed for heating water, which is not recirculated and instead used for showers, cleaning etc. These units are not as flexible and cannot be used in a system designed to run at the temperatures most suitable for other heat pumps in this application.

A very good primer on heat pumps in aquatic centres has been prepared by Alan Pears AM from RMIT. It is available **here:** https://www.smartconsult.com.au/wp-content/uploads/2020/05/AP-Airah-article-aquatic-centres.pdf

Heat pumps cut costs and emissions in two ways:

- Provide heat (and/or cooling) extremely efficiently
- Recover and upgrade the temperature of waste heat for reuse, including the enormous amount of energy released by condensing water vapour to water: a resource available in hot, humid exhaust air from aquatic centres and shower/backwash wastewater

From the energy **output** side, the operation characteristics of a heat pump are different to conventional systems (such as electric/gas/oil boilers or electric heaters). With conventional systems, 1kW of input energy provides less than 1kW of output energy or heat. With a heat pump system, every 1kW of input energy is converted into an average of 2 to 6 times of output energy or heat by absorbing heat from outdoor air or water. Also a heat pump, as its name suggests, 'pumps up' heat from a low-temperature source (outdoor air for example), and transfers it at a higher temperature in a building, making it far more efficient than conventional boilers and a natural choice for low-cost heating and hot water. In an aquatic centre, the cold (low side) of the heat pump can be used effectively to recover heat from different parts of the centre. This ability to recover heat substantially increases the overall efficiency of these systems.

4.2 How a heat pump works

Heat pumps transfer heat by circulating a substance called a refrigerant (there are many types of refrigerants) through a cycle of evaporation and condensation. A compressor pumps the refrigerant between two heat exchanger coils. In one coil, the refrigerant is evaporated at low pressure and absorbs heat from its surroundings. The refrigerant is then compressed en-route to the other coil, where it condenses at high pressure. At this point, it releases the heat it absorbed earlier in the cycle.

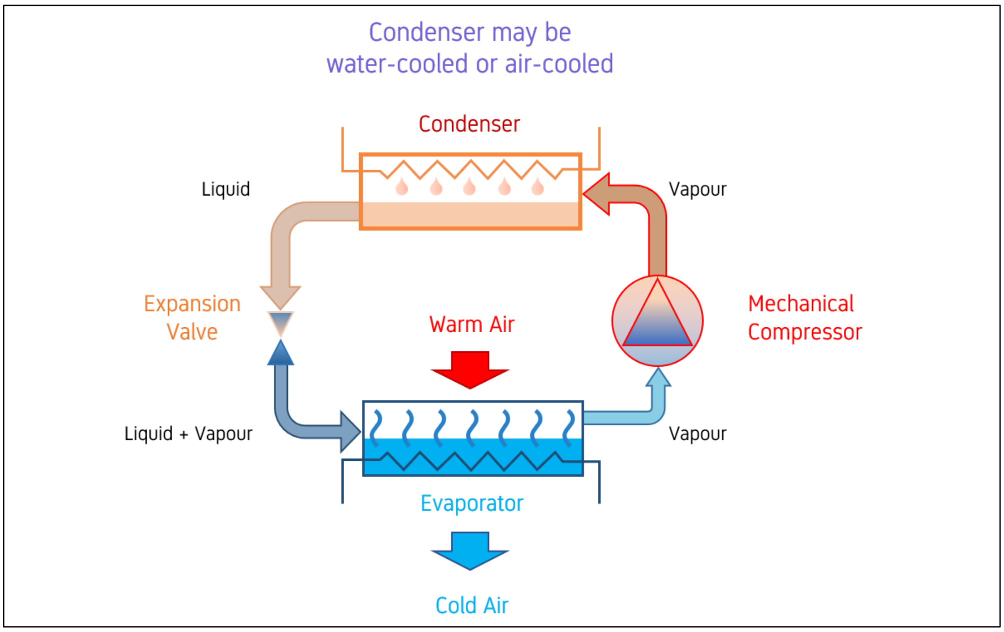

Figure 3 - The Vapour Compression Cycle

It should be noted that the **choice of refrigerant** is critical to the efficient operation of the heat pump. Refrigerants have varying performance characteristics at different temperatures and this needs to be considered carefully for energy systems utilising heat pumps. The temperature of the warm water loop using high efficiency heat pumps will be around 45^{0}C. This is far lower than existing aquatic centres using gas systems which supply hot water at around 80^{0}C: a substantial energy saving.

Heat Recovery:

- Effective use of waste heat
- Heating and cooling simultaneous operation

Heat recovery systems can provide an ideal solution when considering the system from an exhaust energy point of view. This is because air conditioning and hot water are used throughout the year and with a heat recovery system, exhausted heat from the indoor unit is diverted to be reused for a different purpose. For example, the waste heat from cooling operation is reused for heating or hot water supply and wasted heat from the heating operation or hot water supply is reused for cooling operation or cold-water supply. The more frequently heating and cooling simultaneous operation is carried out, the higher the energy saving effect becomes.

4.3 How we measure heat pump efficiency: COP

The Coefficient of Performance (COP) of a heat pump is a ratio of useful heating or cooling provided to work required: a higher COP equates to lower operating costs.

The COP usually exceeds 1 because instead of just converting work to heat (which, if 100% efficient, would be a COP of 1), it pumps **additional** heat from a heat source to where the heat is required. For complete systems, COP calculations should include energy consumption of all power consuming auxiliaries. COP is highly dependent on operating conditions, especially absolute temperature and relative temperature between sink and system.

A COP of 6 means it is 600% efficient, providing 6 units of heat (or cooling) for every 1 unit of electricity consumed: its running cost is a sixth that of a resistive electric heater (e.g., a fan heater). The best commercial building chillers claim remarkable seasonal (integrated part-load value) combined COPs of 9.5 to 11 (hot and cold). If you require both heating and cooling at the same time, or you can store one of them for later use, the efficiency can be even higher, as both the cold **and** hot side of the heat pump can provide useful energy.

This seeming overturning of the laws of thermodynamics occurs because heat pumps do not generate heat like a traditional electric heating element. Heat pumps **extract heat** from the environment via their evaporator, raise its temperature using mechanical motion provided by an electric motor to compress the refrigerant, then release heat from the condenser. Importantly, what we consider to be 'cold' air, water or other materials contains a lot of heat energy and heat pumps can work well below 0^{0}C and still be viable if they are well designed. It is a matter of careful consideration of:

- The type of heat pump selected
- The refrigerant that is used
- The heat source temperature (low grade heat)
- The heat output
- Heat recovery opportunities

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 2 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 heat pumps as keeping the heat pumps in their optimal range can produce remarkable efficiencies.

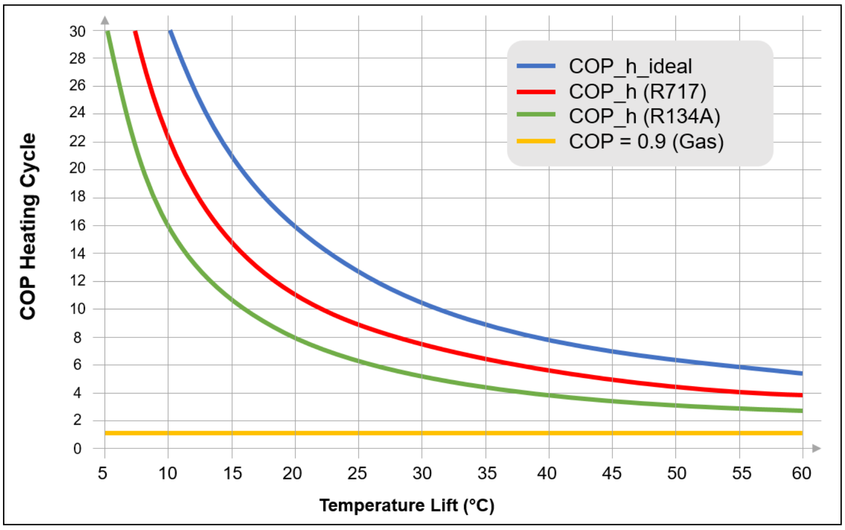

Figure 4 - The change of COP with inlet temperature

4.4 Global Warming Potential- GWP

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.

4.5 Surface to Volume ratio- why it influences heat pump design (greatly)

Packaged commercial heat pumps have not been used successfully in aquatic centres in Southern Australia as they have proved to provide insufficient heating at lower temperatures experienced in winter months. This is largely due to the **surface area to volume ratio** of these heat pumps which becomes less than satisfactory as the units get larger. This affects the size of the evaporators which are the critical component that needs to be larger. This principle is discussed in detail in this article.

Figure 6 - A series of air to water heat pumps

Figure 5 - A typical commercial compressor unit

The compressors in these heat pumps are relatively small in comparison to the casing of the heat pump and are not designed to be serviced regularly. If you require more heat, you need to install more heat pumps as the heat pumps are limited by the size of their casings.

4.6 Air Sourced Heat Pumps

Figure 7 - Air Sourced Heat Pump

Air Sourced heat pumps use **ambient air** as their low-grade heat source to absorb heat from and heat up water.

1) air is entering the unit via an evaporator mounted on the casing of the unit
2) heat is extracted from this air
3) warm water leaves the unit to heat the pool (usually at less than 40^0C)
4) cold air is rejected as waste air by a fan located on the unit

Air source heat pumps have been trialled before at some aquatic centres in Australia without much success in southern Australia. Using an air source heat pump with CO_2 as the refrigerant does not eliminate the problems with this type of design. The main problem with air source heat pumps occurs during winter as the heating load is at a maximum and the capacity of the heat pump is at minimum. The rated capacity of each heat pump is based on dry coils and fins. In winter when the ambient temperature is below ~12^0C, ice forms on the absorbers and this reduces the capacity of the units.

The efficiency of an air to water heat pump is constrained by its ability to absorb heat from the ambient air. As the ambient air temperature drops to maintain the warm water output (~ 40^0C) more air is required to flow through the evaporator or have a larger evaporator as there is less heat available in each cubic metre of air. You can only force so much air through a coil before it develops frost at colder temperatures and the option of increasing the evaporator size becomes a zero-sum equation: to make the evaporator larger the casing housing the heat pump must be substantially larger. You would then need to construct a casing a multiple in size of the original unit!

This explains why commercial air to water heat pumps from most supplier catalogues are only available to about 200kW capacity: the **surface area to volume ratio** of these units constrains their size. Once you get above 200kW of heating required your only option is to install an additional unit with the same performance limitations.

The Defrosting Conundrum

These heat pumps have to stop heating to **defrost**, further reducing the heating available while the unit is offline. It is also possible (likely) that most, if not all the units will require defrost at the same time, further compounding the problem. The efficiency of the heat pump is substantially affected by the temperature of the heating water it is producing, with the unit generally being inefficient at making warm pool water in colder climates, with very low COPs.

This can be very confusing to understand as many equipment specification brochures for these heat pumps will detail reasonable COP figures at these temperatures. What is not detailed so clearly is how much **time** the heat pump is **defrosting** during each hour as when this is occurring the heat pump is not producing heat and is also consuming energy to defrost.

To better explain this let us use a hypothetical commercial air to water heat pump with a similar model optimised to reduce defrosting times, with an outlet temp of **55^0C**

Cold water inlet temp	0^0C	5^0C	10^0C	15^0C	20^0C	25^0C
Standard HP COP	1.89	2.15	2.39	2.58	2.78	2.98
Optimised HP COP	2.78	2.98	3.20	3.40	3.70	3.90

Table 1 - Air to water heat pump performance

The standard air to water HP will be defrosting for an excessive time in winter months. A specialised heat pump can achieve higher COPs in these temperatures and does not spend as long in defrost mode however their performance is still affected by the defrosting of each heat pump during each hour in colder weather. This needs to be carefully considered. A water to water heat pump with a separate heat absorber is not constrained in this way, as the heat pump can continue to operate whilst the heat absorber is defrosting. The design of systems using these heat pumps needs to take into account this 'pause' in the output of the heat pumps as over the length of a day, this adds up to a substantial loss of heating capacity when compared systems using water to water heat pumps.

4.7 **Commercial Water to Water heat pumps**

Water to water heat pumps have a supply of water to them to provide **low grade heat** which is different to air to water heat pumps which are supplied by ambient air. This can be a little confusing, as the heat source for a water to water heat pump **may be air** (via heat absorbers) or water external (and possibly distant) to the heat pump. However, the heat being supplied directly into the heat pump (the water pipes that protrude from the units) is via water.

The simplest way to explain this is to look at two **commercial** heat pumps from the same manufacturer with the same target output temperatures of 40^0C.

Figure 8 - Air to Water heat pump

Figure 9 - Water to Water heat pump

A commercial **air to water** heat pump:

- Has exhaust fans on the top or side of the unit to reject cold air
- Has an evaporator on the sides of the unit to accept ambient air
- Has one set of outlet pipes on the side of the unit for cold water supply and return warm water
- Uses ambient air as the heat source

A commercial **water to water** heat pump has no air exhaust fans or evaporator built into the unit. Those functions are all **external** to the unit and are connected via cold and warm water pipes.

1) Low grade heat is entering the unit via a water supply
2) Heat is extracted from this water
3) Warm water leaves the unit to heat the pool (at 45^0C)
4) Cold water is available for use in dehumidification and cooling for air conditioning via the cold water leaving the unit (note the **two sets** of inlet/outlet pipes)

The heat pumps in Figure 7 and Figure 8 are using the same refrigerants and the same compressors: the difference is their heat sources and how they are dealing with the cold that is produced from the vapour compression cycle. The amount of heat available to the water to water heat pump can be increased by increasing the size of the heat absorber. This unit is separate to the heat pump and make be located some distance away.

Heat absorbers in colder temperatures will '**sequentially defrost**' as part of their normal operation. The system needs to be designed for the coldest days and the capacity of the heat absorber designed so that even with one coil being defrosted continually, there is still sufficient heat available to supply the heat pumps.

4.8 Industrial Water to Water heat pumps

Low Charge Ammonia (LCA) - Water to Water heat pump

LCA **industrial** water to water heat pumps use a small amount (charge) of ammonia as a refrigerant to achieve very high COPs. An LCA heat pump is fully serviceable and has a projected lifespan more than 30 years. These heat pumps are slowly gaining acceptance as alternatives to commercial heat pumps as they have the highest COPs of any heat pumps available. This figure is even higher if the **combined** output of warm and cold water is utilised. More importantly as the heating and cooling from the heat pump can be readily used, they allow any heat reclaimed in the centre to be used to further boost the efficiency of the heat pump.

Figure 10 - Industrial Water to Water heat pump

Poly-Source Water to Water heat pump- LCA	
Operating temperature range	-5 to 45ºC
Winter boost required?	No
COP of heat pump (combined)	9
GWP of HP refrigerant	0
A/C Refrigerant	R717
HVAC heat recovery	~100%
Solar system size limited	No
Thermal storage applicable	Yes
Heat recovery applicable	Yes
Pool warm water supply	45ºC

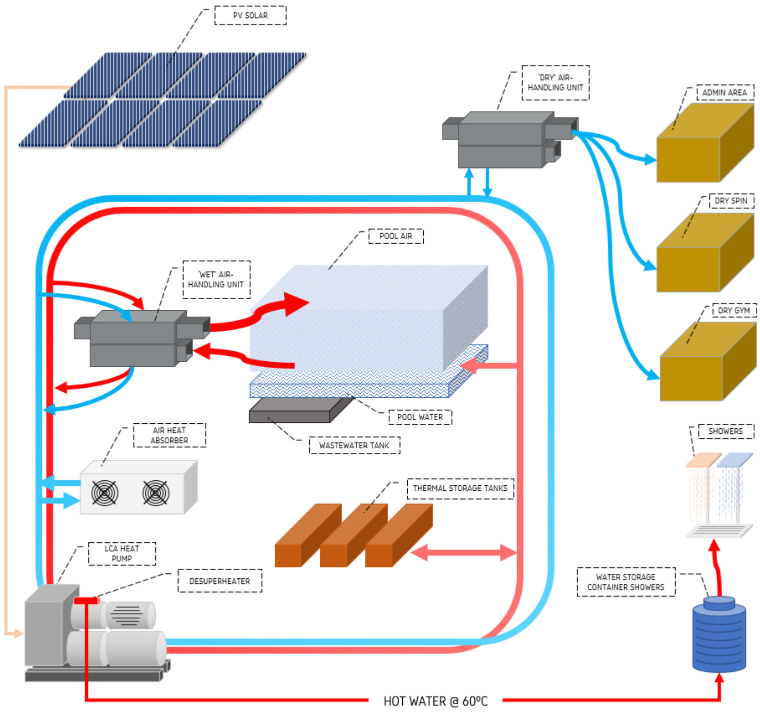

Figure 11 - A Low Charge Ammonia Poly Sourced Integrated heating and Cooling System

Figure 12 - An air to water heat absorber that is used with water to water heat pumps separate to the heat pump

HFC - Water to Water heat pump

HFC heat pumps are called 'chillers' however they are still functioning as a heat pump. The key difference between an HFC chiller and an LCA heat pump is the refrigerant used. HFC heat pumps use HFC refrigerants to operate and will have a lower COP than an ammonia heat pump due to the characteristics of the refrigerant. HFC refrigerants are now gradually being phased out. Councils should be wary of installing these heat pumps as they will become unviable in the near future if Australia abides by the phaseout commitments that have been committed to internationally, as other countries are already well progressed with this phasedown: at some point, Australia is going to need to catch up.

Poly-Source Water to Water heat pump HFC	
Operating temperature range	-5 to 45ºC
Winter boost required?	No
COP of gas boiler	0.9
GWP of HP refrigerant	N/A
A/C Refrigerant	R410A
HVAC heat recovery	75%
Solar system size limited	Yes
Thermal storage applicable	No
Heat recovery applicable	No
Pool warm water supply	80ºC

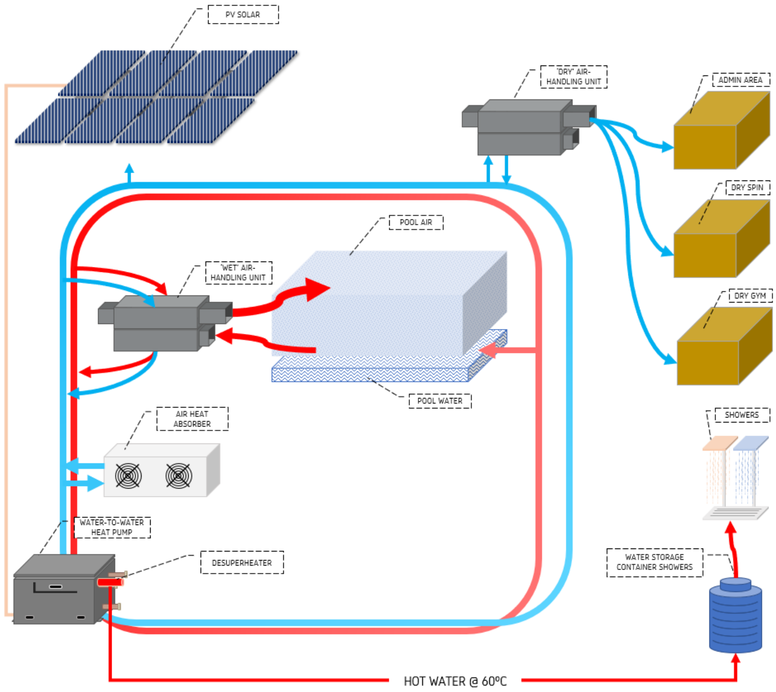

Figure 13 - A HFC Poly Sourced Integrated Heating and Cooling System

CO_2 - Water to water heat pumps

In Australia there are currently 3 main companies selling CO_2 heat pumps of a commercial size (not domestic): Mayekawa, Mitsubishi and Automatic Heating. Automatic Heating uses the Mayekawa unit so technically there are only 2 units, both imported from Japan. The Mitsubishi unit is only available as air source and is smaller in size, so we will concentrate mainly on the Mayekawa Unimo. It is possible that somewhere a CO_2 heat pump is produced for recirculating hot water and certainly one can be custom built, however the operating efficiency is too low to make it viable as you will see later.

These heat pumps use CO_2 (a natural refrigerant) instead of chemical refrigerants such as HCFC/HFC typically used in other heat pump systems. CO_2 has a GWP of 1 and is a fire retardant. However, the gas has a transcritical point of 31.1 deg C which results in the performance of the heat pump being dismal. This temperature is almost the same temperature of most pools in aquatic centres and results in the COP of heat pumps working at or near this temperature being very low compared to other heat pumps.

Poly-Source Water to Water heat pump - CO_2	
Operating temperature range	-5 to 45ºC
Winter boost required?	Yes
COP of heat pump	2
GWP of HP refrigerant	1
A/C Refrigerant	N/A
HVAC heat recovery	100%
Solar system size limited	No
Thermal storage applicable	Yes
Heat recovery applicable	Yes
Pool warm water supply	45ºC

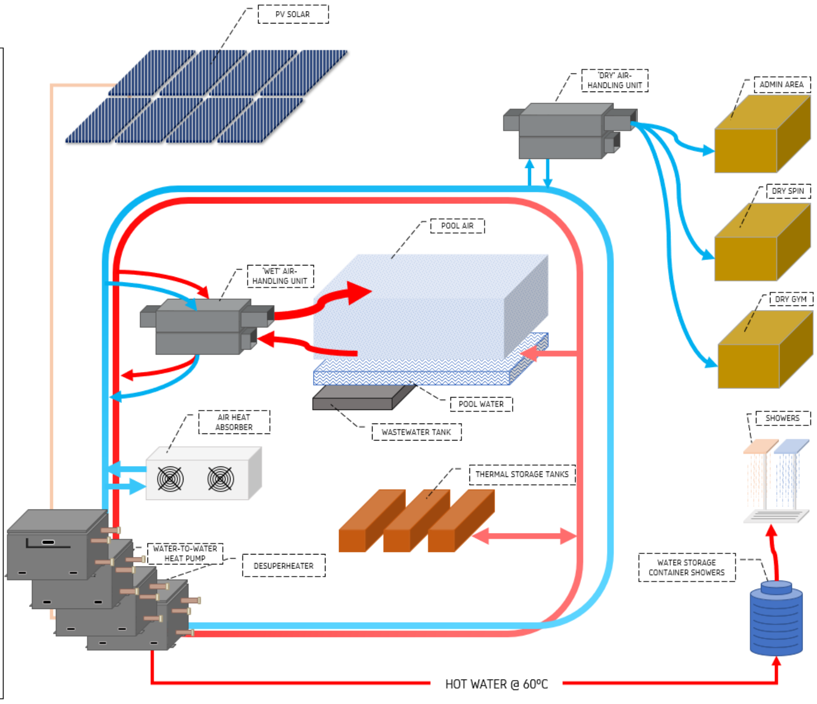

Figure 14 - A CO_2 Poly Sourced Integrated heating and Cooling System

An additional hot water tank is required when utilizing CO_2 heat pumps. This hot water tank can be maintained at any temperature but the higher the temperature, the lower the efficiency and capacity of the heat pump. 45ºC is the operating temperature of the other heat pumps used in our design and is an ideal temperature for the efficiency of the system.

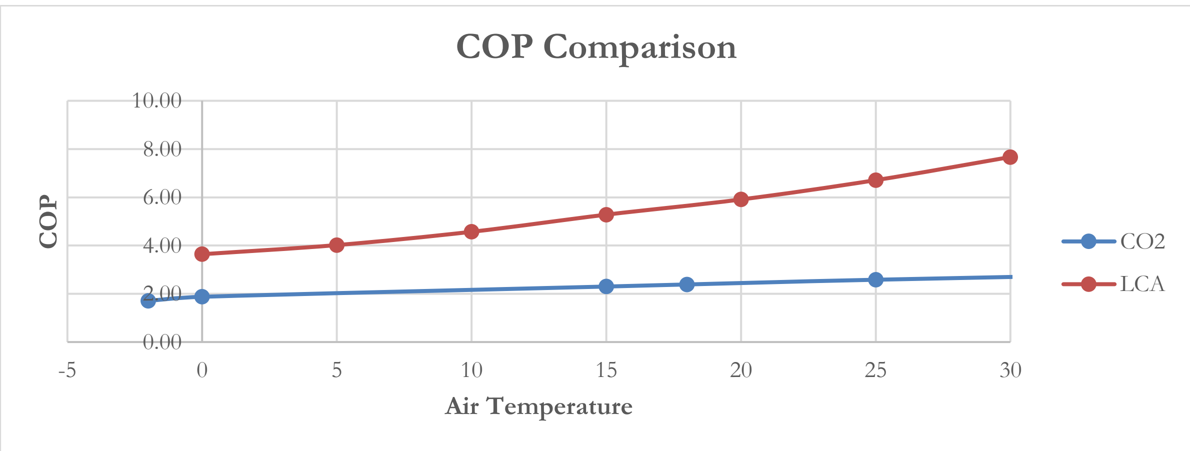

Figure 15 - LCA vs CO_2 heat pump COP at 45ºC output

Ammonia is considered the most efficient refrigerant. With all things equal, the ammonia system will have the highest COP. In some recent reports, consultants have suggested that all heat pumps have the same COP, however this is not correct. To operate at the temperatures required to heat aquatic centres, a CO_2 system will need to operate at pressures and temperatures that are well beyond its critical temperature. The result of operating trans-critical is a poor COP. The graph above shows the two water sourced options. Over ~50^0 C the COP for the ammonia-based heat pump is more than double the CO_2 option.

Mayekawa Unimo

The Mayekawa Unimo comes in one size. It can produce water at either 65^0C or 90^0C. It is designed for production and storage of hot water. For swimming pool heating 65^0C would be enough, however the unit will only operate to heat to 65^0 C until the return water reaches somewhere between 30^0C and 38^0C. When the return water temperature rises above the 30 to 38^0C point, the unit automatically converts to producing 90^0C water.

This is a problem for operation in an Aquatic Centre. Spas for example may operate at or above 38^0C and heating water must return at a higher temperature than this. As a result, to use these units, the supply water temperature must be 90^0C. This unit can be delivered as water or air source. They come complete with a waterproof housing and do not require the construction of a plant room.

Propane - Water to Water heat pumps

Currently, there are five natural refrigerants: air, water, ammonia, CO_2, and hydrocarbons. The 'hydrocarbons' are usually propane or butane. As you may suspect, there is an issue of these refrigerants' flammability (A3) and there are restrictions on the size of these heat pumps to limit the charge that could potentially escape from these units due to significant safety concerns. Most heat pumps will usually leak refrigerant to some degree during operation.

R290 (C_3H_8) heat pumps offer a similar or larger operational envelope compared to HFCs. Propane heat pumps can operate from the coldest climate (climate zone 8) to the hottest (climate zone 1). Currently, hot water can be supplied at a maximum of 62^0C (with potentially higher temperatures in the next generation of units). At present, available ranges exceed the 200kW capacity.

Due to its high flammability, European manufacturers have adopted the following safety devices to further reduce possible accidents:

- Compressors are fully enclosed. The compressors enclosure is equipped with extractor fans (complying with ATEX regulations)
- Leak detections are set at 5% of LEL
- Vibration absorbers are part of the refrigerant circuits
- In case of refrigerant leak inside the compressor box, the power supply is disconnected, and the extraction fan runs at full speed to wash the compressor box of refrigerant
- All the components inside the compressor's box are ATEX certified.

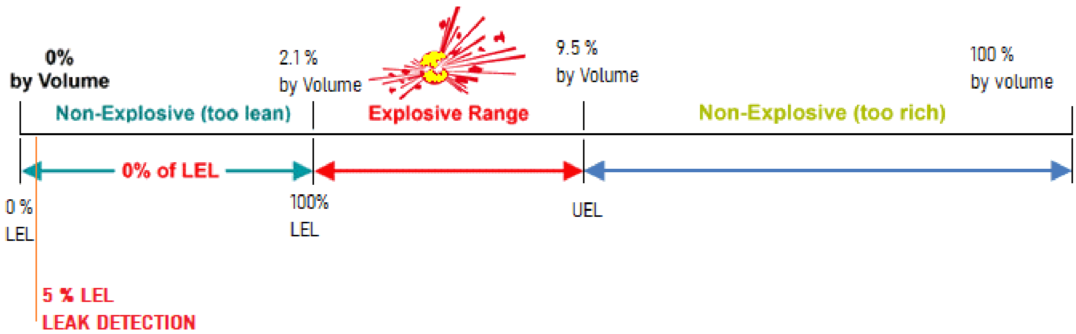

Figure 16 – Flammability of refrigerants (Eurothermal, 2020)

Recently, a paper ('Thermodynamic Study on Blends of Hydrocarbons and Carbon Dioxide as Zeotropic Refrigerants') was published which discusses the use of a Propane/CO_2 refrigerant mix which has proved to be effective in reducing the flammability of the refrigerant while maintaining reasonable COP performance. This mixture of refrigerants is a trade-off between a lower COP and reduced flammability and makes the case that this should be investigated further.

4.9 A rule-of-thumb guide to heat pumps for aquatic centres

Heating plant	COP Hot	COP Cold	Combined COP	Hot water output	Cold water output	Heat recovery possible	Lifespan in years
Gas boilers	0.9	N/A	0.9	Yes	No	No	Up to 20
HFC Air to water heat pump (optimised)	3	N/A	3	Yes	No	No	Up to 15
HFC water to water heat pump	4	3	7	Yes	Yes	Yes	Up to 15
LCA water to water heat pump	5	4	9	Yes	Yes	Yes	30+

Table 2 - Rule of Thumb Guide to Heat Pumps working at 10°C ambient air temperature

5. Low-Grade Heat Sources

5.1 Geothermal Systems: How they work

Geothermal systems are another type of energy system for aquatic centres. There are a variety of applications of 'geothermal' and the adopted approach will depend on local ground conditions.

Direct-use geothermal utilises geothermal heat directly from a (usually) deep aquifer. In Victoria, this approach already exists in limited areas around Mornington Peninsula and Warrnambool. Heat pumps are typically not required with this approach as the available temperatures enable a direct heat exchange process.

The more widely available approach that does not require specialist geology, utilises solar energy stored within the top approximately 100m of the ground as a heat source, a heat sink and for thermal storage. In aquatic centres, the thermal storage capability of this approach is of interest due to their mixed and seasonal heating and cooling requirements.

Across Victoria, the typical ground temperature is approximately 18C and as such a ground source heat pump (GSHP), a variation of a water to water heat pump, is required. Presently geothermal systems usually utilise commercial water to water heat pumps. However, they would also be able to utilise LCA heat pumps as an option if an optimal system was the goal.

5.2 Geothermal Systems: System Components

The two main components of a geothermal system are the ground loop or ground heat exchanger (GHX) and the Ground Source Heat Pump (or geothermal heat pump), which is typically located within the building or plant room. The ground loop provides the passive component of the system, whereas the Ground Source Heat Pump provides the mechanical component.

5.3 Ground Source Heat Pump

The first component of the geothermal system is the Ground Source Heat Pump (or geothermal heat pump). It is the Ground Source Heat Pump which receives the water returning from the GHX and transfers it to either hot/cold air via ducts (water to air) or as hot/cold water for hydronic heating, chilled beams, pools, spas etc (water to water). It achieves this through conventional (water source) heat pump technology. The main difference is that a GSHP can operate on a conventional condenser water loop, whereas a conventional water source heat pump may not be able to operate off a GHX or will require some design modifications. This is due to the lower temperature ranges present in a GHX. The GSHP is typically controlled by a thermostat and can be connected to a Building Management System (BMS).

5.4 Ground Heat Exchanger

The GHX can be classified as open or closed and in some instances can be coupled to conventional heat sources or heat sinks as a hybrid system. Closed ground loops are constructed of Polyethylene (PE) pipe in a vertical (borehole) or horizontal (trench) configuration and water is used as the heat transfer fluid. The heat transfer fluid may also include small percentages less than 30% of additives for water treatment or anti-freeze in colder regions.

The loop fluid is simply circulated through the ground loop and returned to the GSHP. In accordance with the Zero Law of Thermodynamics, the loop fluid and the ground will endeavour to reach a thermal equilibrium. During its passage through the ground, the loop fluid is equilibrating with the stable ground temperatures either by extracting heat from the ground (winter) or rejecting heat to the ground (summer). The extent of this equilibration is determined by the residence time in the ground, the temperature differential between the loop fluid and the ground and other ground properties such as thermal conductivity and thermal diffusivity. Open loops utilise ground or surface water directly, pass it through a heat exchanger and then return the water to either its origin or a secondary application such as irrigation, industrial water etc. Open loop sources are varied and include groundwater, rivers, oceans, dams, and treated effluent.

5.5 **Outdoor Swimming Pools as a low-grade heat source**

This may not have occurred to you before, but an outdoor pool that is not in use contains large amounts of useful low-grade heat for a heat pump. Let us do some basic numbers around an outdoor 50m pool:

- temp in pool in winter is ~10^{0}C
- contains around 1,500,000L of water
- will usually have water supply and return pipes in the existing plant room for summer use
- the heat pump would require a supply of ~25,000L per hour
- if pool covers are fitted, the pool will retain additional heat from the sun during daylight hours

It would not be feasible to solely use the pool as a heat source, however as a winter boost to an air sourced heat absorber used by a high efficiency water to water heat pump the pool would have sufficient capacity to be viable. To further boost the value of the pool the fitting of a pool cover would retain more heat during daylight hours.

6. 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.

7. Standards that apply or must be applied to the electrification technologies

Listed below are the standards that apply to the electrification technologies as detailed in this report and the four individual reports for each centre.

- HVAC Standards
- AS/NZS 5149 Refrigeration Systems
- AS 1668 Parts 1-3: The use of ventilation and air conditioning in buildings by Standards Australia
- AS/NZS 3666 Parts 1-3 Air-handling and water systems of buildings: microbial control by Standards Australia
- AS 2913 Evaporative air conditioning equipment by Standards Australia
- The National Construction Code
- the National Construction Code sets out requirements for building works in Australia.
- Volume 1 Part J5: Air-conditioning and ventilation systems
- https://libguides.bhtafe.edu.au/refrigeration/codes

7.1 Building Standards

In building the LCA plantroom Australian Standard AS/NZ 5149 needs to be taken into consideration in regarding the following:

1) Externally located emergency stop
2) Location of ventilation and relief valve exhaust
3) Leak detection
4) Alarm system
5) Bunding
6) Signage
7) Hearing protection

7.2 Specific Standards that apply to Low Charge Ammonia Systems

Standard that apply to Ammonia Refrigeration and heating system are much more rigorous than normal fluorocarbon refrigerants HVAC systems and has been like this for many years. The designers and installers have to be qualified to both install and sign off on these systems.

Standards Australia has recently released five new Standards relating to refrigeration systems and refrigerant designation which has superseded the equivalent existing standards AS/NZS 1677.1 Refrigerating systems.

Part 1: Refrigerant classification and AS/NZS 1677.2 Refrigerating systems,

Part 2: Safety requirements for fixed applications which have been in use since 1998.

The new standards are based on standards already published by the International Organization for Standardization (ISO) and will be adopted with minor modifications in an Appendix ZZ.

The publication of the ISO standards in 2014 has been driven by the gradual reduction of fluorocarbon refrigerants which in turn has accelerated the introduction of new and alternative refrigerants and blends. The adoption of the ISO standards in Australia and New Zealand will bring local refrigeration practice in-line with international practice.

The new standards include

1. AS/NZS ISO 817:2016 Refrigerants – Designation and safety classification

   This has superseded AS 1677 Part 1 and introduce two new refrigerant safety classifications including A2L (non-toxic, lower flammability) and B2L (toxic, lower flammability) in addition to the existing five classifications A1, A2, A3, B1 and B2. The new 'lower flammability' classification will include the A2L refrigerants R32 and R1234 and the B2L refrigerant R717.

* Refrigerant Classification per ISO 817:2014 and ANSI/ASHRAE Standard 34-2013. A2L and B2L are lower flammability refrigerants with a maximum burning velocity of 10 cm/s.

2. AS/NZS 5149 Refrigerating systems and heat pumps – Safety and environmental requirements, Part 1 to 4[1].

   This has superseded AS 1677 Part 2 and "specifies the requirements for the safety of persons and property, provides guidance for the protection of the environment, and establishes procedures for the operation, maintenance, and repair of refrigerating systems and the recovery of refrigerants".

   The new standards relate to a wide range of installations from low charge systems to very large industrial refrigeration systems. The AS/NZS 5149 series, when introduced, will apply to:

   1) New refrigerating systems, extensions or modifications to already existing systems, and for used systems being transferred to and operated on another site.
   2) Fixed or mobile systems (excepting vehicle air conditioning systems) of all sizes including heat pumps.
   3) Secondary cooling or heating systems.
   4) Conversion of a system to another refrigerant.
   5) The location of the refrigeration systems.
   6) Replaced parts and added components if they are not identical in function and in capacity.

AS/NZS 60335-1:2011 covers the requirements for electrical appliances used for household and commercial purposes. Industrial Refrigeration, Refrigeration Standards, Standards Australia

8. Identify any risks and/or opportunities including health and safety implications, legal implications.

The designers specify the best system based on the specific environmental considerations. The heating and cooling design will employ the same design principles as those applied to any other medium to large scale industrial refrigeration plant design employing synthetic or natural working fluids such as ammonia, R32 or CO_2 refrigerants. In addition, it will adhere to the relevant standard predominantly AS/NZS 5149 Refrigerating Systems and the Standards referred to the therein. In this context it is noteworthy that all HFC refrigerants are currently subject to phase-down in Australia and globally.

8.1 **Ammonia – R717**

The compliance requirements with respect to standards for development approval, design, construction, and maintenance for Ammonia plants are significantly stricter than for refrigeration plant employing refrigerants of the A1 classification (non-toxic and non-flammable). In Victoria the code of practice applicable for ammonia plant is available via the following link https://www.airah.org.au/Content_Files/TechnicalPublications/VCP-Ammonia-Refrigeration-2011.pdf

Under Australian work health and safety laws, workplaces with ammonia-based refrigeration systems must have a documented emergency plan in place. The Australian government provides an online Occupier's Guide to Emergency Planning assisting users in preparing and implementing an emergency plan for ammonia-based refrigeration systems. Emergency planning guidance for all hazardous industries is also provided online in Emergency Planning: A Guideline for Hazardous Industry.

In addition, a Workplace Health and Safety Queensland (WHSQ) Safety tool for ammonia refrigeration safety (which included an audit checklist and supporting reference material) is currently being updated. The tool will raise awareness of the hazards and risk control measures and provides additional educational and training material about ammonia safety in the industrial refrigeration industry. The Australian technical standard of reference for ammonia-based refrigeration systems is AS/NZS 5149:2016, which refers to the international standard ISO 5149.

Local councils may also have their own rules. That is the case for Brisbane City Council. An ammonia charge >0.1 ton requires an impact assessable development approval process that can take anything up to nine months.

In this context, centralized reticulated chilled water air conditioning plant employ minimal inventories of NH_3 refrigerant. The operating NH_3 inventories in the mid capacity range (500-1000 kW cooling capacity) water chillers range from 0.03 to 0.05 kg/kW. For larger unit 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 (the 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.

8.2 **HFC – R32**

Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Under the GHS classification, any gas that is ignitable at a concentration of 13% or less, or has a flammable range of at least 12 percentage points, is classified as a Category 2.1 gas and is required to carry the hazard statement "Extremely Flammable Gas". R32 has a flammable range of around 15 points so it meets the definition of the GHS for a Category 2.1 gas.

R32 is classified as an Extremely Flammable Gas and under ISO 817 lists the burning velocity of R32 at 6.7 cm/s (0.24 km/h). R32 also belongs the HFC category of refrigerants. It is therefore currently subject to phase-down in Australia and across the world.

As such R32 is a controlled substance and therefore remains under the jurisdiction of the national ARCtick licence. From a regulation standpoint, individuals handling R32 must possess either a Certificate II in split system installation or the full Certificate III trade together with a current refrigerant handling licence.

8.3 **CO_2 – R744**

The Australian technical standard of reference for CO_2-based refrigeration systems is AS/NZS 5149:2016, which refers to the international standard ISO 5149.

R744 systems operate at extremely high pressures. Even when the system is turned off, the static pressure of R744 can be very high if the temperatures surrounding the system are relatively high. In these cases, special measures (expansion tanks, separately powered pressure limiting condensing units and/or automatically operated bleed systems) are required.

R744 can displace oxygen if released in excessive amounts (it is heavier than air and can congregate), and therefore precautions must be taken to prevent its release and breathing in of high levels of CO_2. Do not handle this refrigerant in confined spaces. All precautions must be taken to prevent its release. Symptoms from overexposure to CO_2 range from drowsiness to asphyxiation, and in extreme cases, death. But the right training, equipment and attitude will allow safe use of R744.

R744 systems must also be charged and degassed in a specific manner to avoid the formation of dry ice inside the refrigerant pipework. Frost burns can occur if contact is made with liquid or solid CO_2. Appropriate Personal Protective Equipment (PPE) must be used. Refer to the relevant material safety data sheets and ensure system specific safety procedures are followed.

For example, R744 systems can operate at up to 170 bar (2466 psi) and trapped liquid CO_2 in hoses can cause pressure explosions if exposure to higher temperatures causes-liquid expansion giving rise to extreme hydraulic pressures. If dry ice can form within a system or in pressure relief valves, it can block parts of the system for long periods of time until it has evaporated.

9. Risk, Opportunities and Social Implications of Electrification

Social implications for electrification

Consider & address any social implications for electrification (such as potential power outages or potential benefits of solar & battery storage to maintain service during outages).

Risk

The risk of failure for these systems to work is very low as the technology is very established and has been in operation in the refrigeration industry for over 50 years. This also insulates the users of this equipment from future price shocks due to the phase out of hydrofluorocarbon refrigerants.

The level of professional qualifications and regulation is much greater than both the Gas and or Hydrofluorocarbon Based Air-Conditioners that are installed today. The designs and equipment are made and supported by some of the largest companies in the world, including GEA & Johnston Controls, which supply many of the existing hydrofluorocarbon chillers in the market today.

Potential Power Outages

During power outage's even today with gas, the Aquatic Centre would need to close during opening hours as the pumps and heating would be non-operational without electricity.

It would be possible to add DC batteries like Solarwatt batteries to the power mix with the existing inverters which could be charged using solar, to run the centre during outages and peak usage, however the minimum size would be 400-500 kW of batteries to be able run the centre for say 30 minutes. To run the centre a peak discharge usage of 200kW would need to be covered to run this centre.

This may not be cost effective in the short term however the main benefit would be to allow for the centre and its systems to be gracefully shutdown and the public ushered from the centre.

1) Benefits
   a) Clean and Green
   b) Max Solar
   c) Min run time for outages with batteries ~1 hour
2) Risks
   a) Outages

Heat and Cooling Reclaim Opportunity

In designing a new integrated heating and cooling system for an aquatic centre, or other building heat and cooling reclaim, and reuse is a major contributor to reducing the OPEX costs of these centres. If utilized, the heat recovered will not change the size of the LCA units themselves but can change the capacity required for the heat absorbers. By absorbing reclaimed heat into the system, less heat is required from the environment. It is assumed that if the pool hall is going to be heated by the LCA system, a heat recovery coil will also be installed in the air handling unit to recover heat from the exhaust air. This should be a standard inclusion in any design put forward to the council.

Typical methods to achieve this are:

1) Heat and cooling reclaim and reuse from the AHU
2) Water reclaim from the AHU (At least 50% of the evaporation from the pool can be reclaimed.)
3) Pool Waste and shower waste Heat Reclaim - health and safety (Dirty Tank)
4) Rainwater heat reclaim
5) Using a non-used 50 m pool as a heat store in the winter allowing for heat reclaim.

The reclaimed heating and cooling are re-tasked by the control system to be used in the most efficient manner. This could be as follows:

1) Heat and cooling reclaim redirected to the evaporators and or heat absorbers to uplift or cool the heat pump inlet temperatures.
2) Reuse in the building

Typically, this can reduce the OPEX running costs significantly, improving the social implications. The risk of not reclaiming energy is very low as this is a standard professional discipline when designing these systems. Each centre's improved efficiency will vary depending on the availability of heat or cooling sources. The actual calculated savings can only be determined once the engineering has been completed.

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