Heat pumps: application to aquatic centres

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INTRODUCTION

This article is intended to be a general introduction to the potential for application of heat pumps in aquatic centres. Each application is different, and requires appropriate analysis, design, installation, operation and management.

OVERVIEW

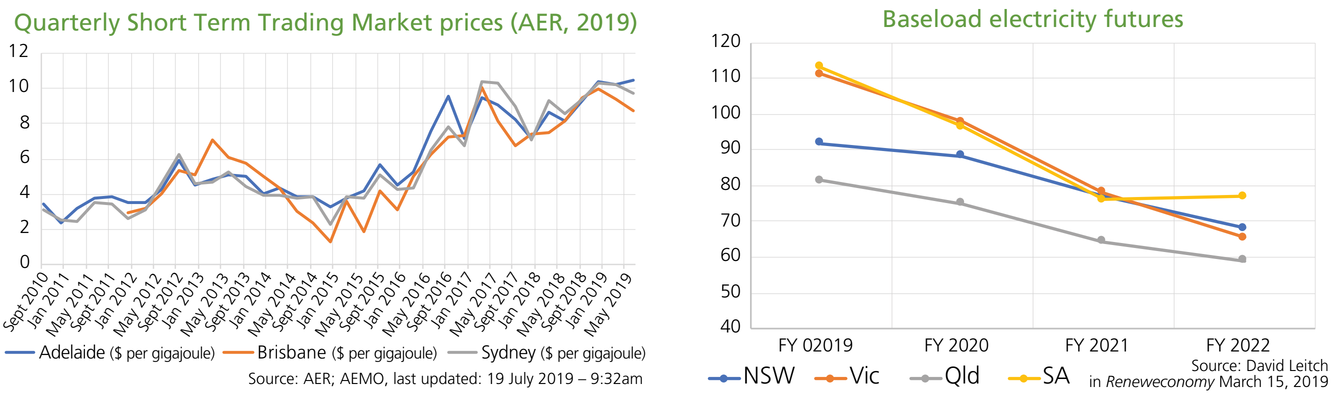
As gas and electricity prices increase and technologies evolve, heat pumps are gaining increasing recognition as an option for reducing energy costs and shifting away from fossil gas and electricity to renewable electricity. Heat pumps cut costs and emissions in two ways. First, they provide heat (and/or cooling) extremely efficiently. Second, they very effectively 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.

Recent trends in wholesale gas prices are shown in Figure 1. Looking ahead, it seems likely that present high gas prices will stabilise or continue to increase, and that price volatility will remain, due to our linkage to international liquefied natural gas markets. In contrast, Figure 1 shows "futures" prices for wholesale electricity: markets consider prices will decline. Potential future introduction of carbon pricing or incentives to cut emissions will also favour renewable electricity over gas. Many organisations face increasing pressure to cut emissions by shifting from fossil fuels to renewable energy. Some organisations incorporate a "shadow" carbon price when evaluating energy use of new equipment and facilities, as a form of risk management for long-lived assets like aquatic centres, factoring a carbon price into decisons makes sense.

Principles and examples of heat pump applications

A heat pump can provide heating or cooling, or both, depending on how it is installed. A refrigerator is a common example of a heat pump. Its refrigerant fluid extracts heat from inside the insulated cabinet, its compressor increases its temperature by compressing the gas (just like a bike pump heats up when compressing air), then this heat is released into the kitchen. If you are inside the cabinet, you experience cooling. If you are in the kitchen, you experience

Figure 1. Trends in wholesale gas and electricity prices.
Consumers pay higher than wholesale price to cover transmission, distribution and retailing costs and profits.



Wholesale gas prices used to be $2-6/gigajoule. They are now $8–10, and retail prices are much higher. They are not expected to decline, and are now linked to volatile global prices. Indeed, if proposed LNG import terminals are built, the price could be even higher. Gas is a fossil fuel, so many organisations are seeking to phase out its use as part of their climate response strategies.

Although wholesale electricity prices have risen steeply in recent years, expectations are that they will stabilise and decline as renewable energy costs decline and generation capacity increases. More sophisticated "firming" using energy storage, demand response, energy efficiency and new business models will also help. Behind-the-meter solar, and Power Purchase Agreements are increasingly being used by councils to reduce electricity costs and volatility.

heating. (For further explanation see www.eec.org.au/for-energy-users/technologies-2/heat-pumps).

The efficiency of a heat pump is measured by its Coefficient of Performance (CoP). A CoP of 5 means it is 500 per cent efficient, providing 5 units of heat (or cooling) for each unit of electricity consumed – so its running cost is a fifth that 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. 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. They actually 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 actually contains a lot of heat energy: the zero energy state of matter is at -273°C (the temperature of outer space). The laws of thermodynamics operate from that base temperature, so even icy cold air contains a lot of heat energy.

An example of a heat pump that condenses water vapour and captures heat from exhaust air is the heat pump clothes dryer shown in Figure 2.

For low-temperature applications such as pool heating, best-practice heat pumps (including recovery of heat from exhaust air) can use much less energy than gas heating. Even though electricity costs more per unit of energy than gas, well-designed heat pumps cost less to run because they are so much more efficient. The energy price trends discussed earlier will favour heat pumps.

Heat pump-based solutions for aquatic centres

Aquatic centres are very energy-intensive facilities. This need not be the case. In particular, the emergence of advanced heat pumps, combined with rooftop solar electricity generation and thermal storage offers the potential to dramatically reduce energy consumption and carbon emissions, and recover water from humid exhaust air.

These technologies can be combined with more thermally efficient buildings, evaporation control solutions and high-efficiency lighting, equipment and appliances. Smarter energy, water and activity monitoring, reporting and management systems also offer increasing potential to minimise waste of energy, water and money, as well as delivering much higher quality outcomes for centre users, and improving maintenance and reliability. These efficiency measures also reduce the capacity and capital cost of pool heating and space conditioning plant.

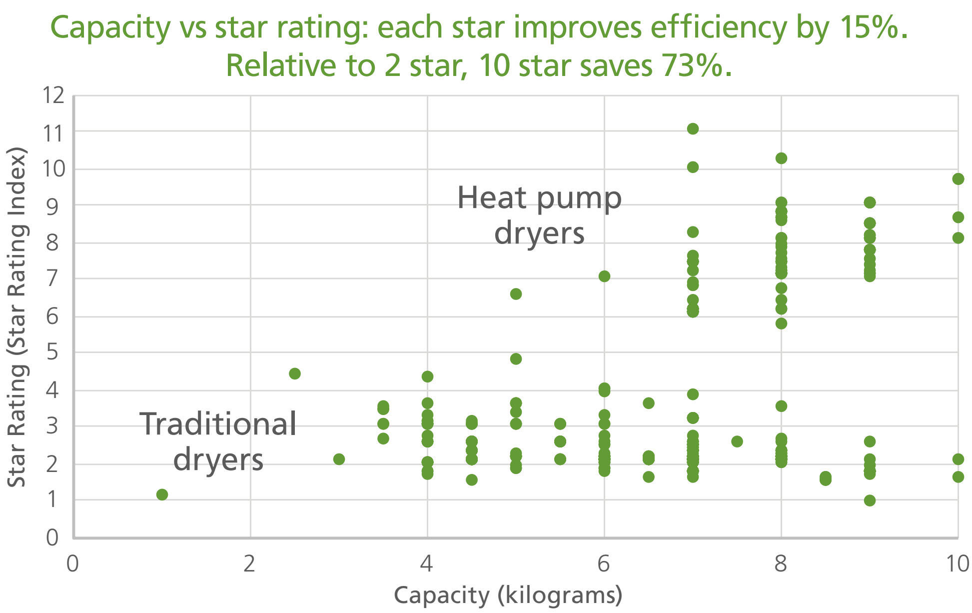
One review found that the energy consumption of swimming pool facilities is typically made up of 45 per cent for ventilation (including heating and cooling), 33 per cent for pool water heating, 10 per cent for heating and ventilation of the remainder of the building, 9 per cent electricity for power equipment and lighting, and 3 per cent for hot water services (Trianti-Stourna et al., 1998).

What this study did not point out is that a substantial proportion of the energy used for pool heating evaporates water. Much of this water vapour escapes from the facility in hot, humid exhaust air. The heat from the pool also raises the temperature of the pool hall, which reduces visible winter heating energy use but also increases the need for summer cooling.

Modern heat pumps, combined with other measures outlined, offer a potentially attractive lower operating

Figure 2. Data from the government energy rating website (www.energyrating.gov.au) comparing the star ratings of heat pump clothes dryers relative to traditional clothes dryers on the market.

6 to 11 star heat pump clothes dryers use much less electricity than a standard (e.g., 2 star) electric clothes dryer: they recover energy by condensing water vapour and recovering and "recycling" heat from the exhaust air



cost and low- or zero-carbon emission alternative to traditional gas heating for aquatic centres. They can deliver additional benefits, including recovery of useful water from humid exhaust air, reduced maintenance and longer plant life. Heat pumps are well-proven technology overseas, and are similar to the chillers used for cooling in many Australian buildings.

Figure 3 provides a simplified flow diagram that shows how a heat pump system can work at an aquatic centre. It utilises the "free" renewable heat in outdoor air and humid exhaust air from the facility. The compressors in the heat pump upgrade the temperature of the heat to a useful level for pool heating, space heating and domestic hot water.

For new aquatic centres, an all-electric solution using heat pumps, heat recovery and rooftop solar electricity can be a cost-effective alternative to mains gas at today's much increased prices. Its higher capital cost is offset over time – delivering a rate of return significantly higher than loan repayment costs or alternative investments. It is even more attractive relative to LPG.

For existing aquatic centres, a staged transition can be adopted. A heat pump can be designed to recover heat and condense water from the exhaust air, to supplement the existing gas system and reduce gas costs. When the gas system requires replacement, options can be evaluated.

Get the detail right

Careful heat pump system design is important to optimise performance and cost. Flexible performance over a wide range of conditions, ease of component replacement, and capacity to maintain pool operation while conducting maintenance or repairs are also factors to consider.

Importance of energy recovery from hot, humid exhaust air

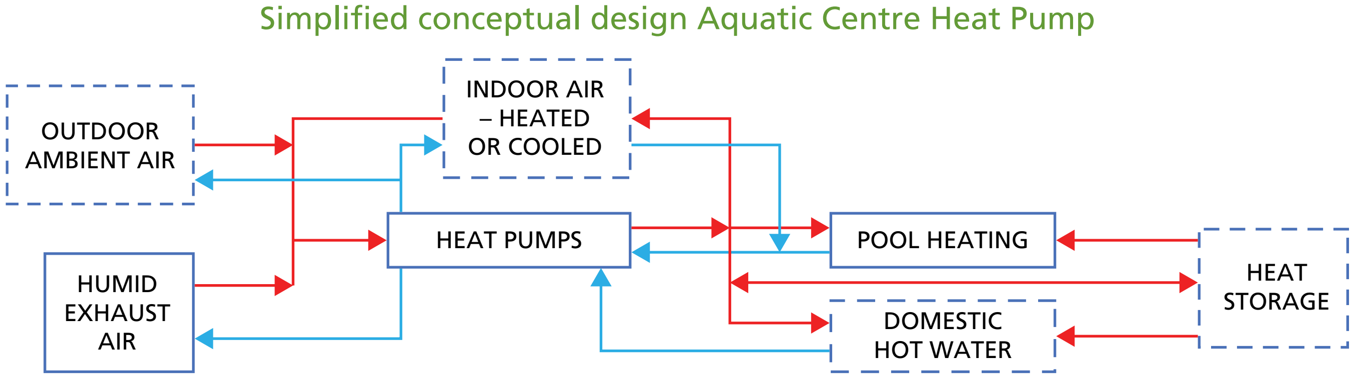
Aquatic centres have very high ventilation rates, often between four and 10 air-changes per hour: an amount of air equivalent to four to 10 times the volume of the building is exhausted and replaced by outdoor air every hour. Given the very large volume of a pool hall, a large amount of air, energy and water is dumped.

Recovery of water from humid exhaust air offers a key opportunity to recover energy, as shown in Figure 4. As an example, consider a pool hall of 10,000m³ volume with a ventilation rate of five air-changes per hour. The amount of heat energy potentially captured by a heat pump, if exhaust air at 35°C and 100 per cent humidity is cooled to 15°C, is around 3.6 gigajoules (GJ) per hour. Normally, this would simply be lost to the outdoors.

If this heat was supplied by a gas boiler system, at least 4.5GJ of gas (and possibly much more if the gas system is inefficient) would be consumed, equivalent to operating more than 50 typical home central heating units at full output. At $15/gigajoule, that would cost around $70/hour. About 700 litres/hour of water from the pool would have to be replaced.

Of course, a heat pump would use electricity to recover this energy for pool heating and other uses. It would also recover water to top up the pool. The amount of electricity required would depend on the design and management of the system, and the resulting efficiency. The electricity cost would also be influenced by the amount provided by rooftop solar and the price of purchased electricity. A well-designed and operated heat pump using competitively priced electricity seems likely to deliver significant operating energy and water cost savings while cutting carbon emissions. On a lifetime basis, it should be cheaper than a gas-fired system.

Figure 3. Schematic diagram of aquatic centre heat pump system. Dotted lines show elements potentially incorporated into all-electric system. Solid lines show basic elements that could supplement an existing gas system.

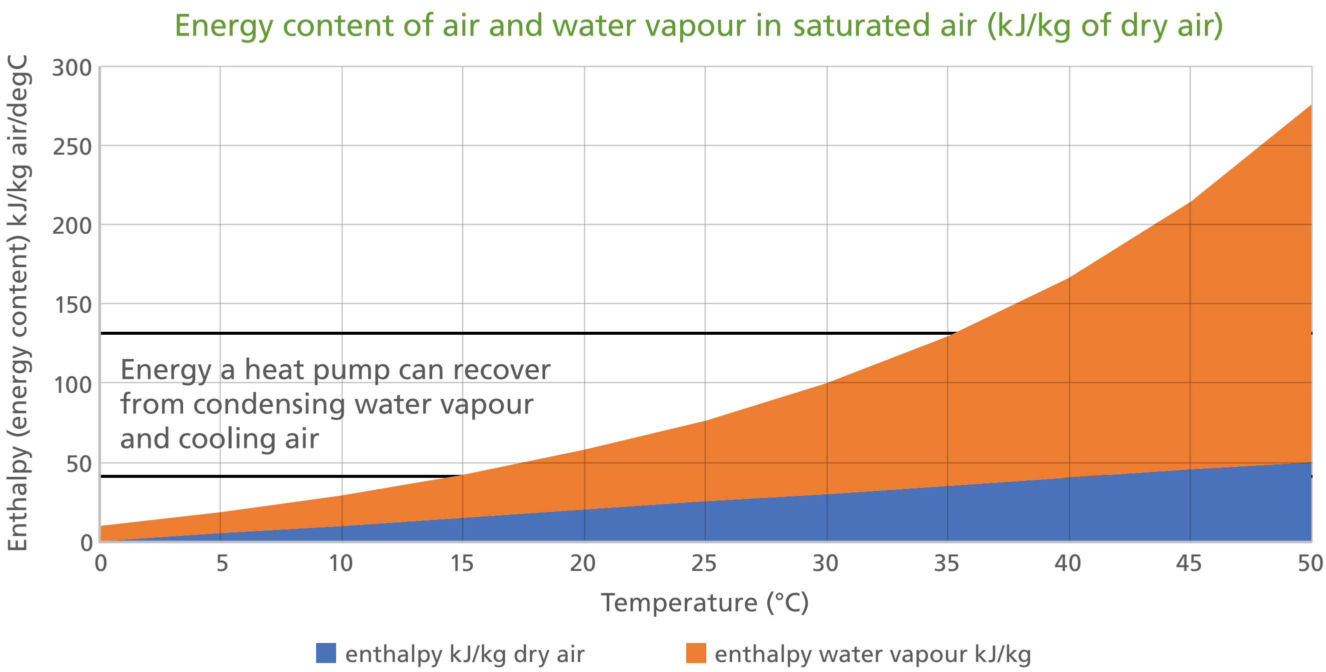


Operation:

Heat pump evaporator produces cold water and uses it (via heat exchangers) to extract low temperature heat from warm, humid building exhaust air (including latent heat from condensing water vapour) and/or ambient outdoor air and/or by cooling indoor air. This warmed water returns to the evaporator to be cooled again. [Condensed water from humid building exhaust air can be recovered for reuse in pool.]

Heat pump compressor 'concentrates' heat to higher temperatures at the condenser. This heats water which is supplied to pool, domestic hot water and/or (in space heating mode) indoor air. Cooler water from them returns to the condenser to be reheated. Heat storage can balance heat demand and supply.

Figure 4. Energy content of dry air (blue area) and water vapour (orange area) as temperature varies (note, to roughly convert from kilojoules/kg of air to kJ/cubic metre, divide by 1.2). If saturated (100 per cent humidity) air is cooled from 35°C to 15°C, 87 kilojoules per kilogram of dry air (73kJ/cubic metre) can potentially be recovered.



Other measures to cut aquatic centre energy waste

The more energy-efficient the aquatic centre building and equipment are, the lower the size of heat pump system required, and the lower is peak demand. Reducing energy waste also offers further potential energy and cost savings.

Opportunities are many, and they include:

- Minimising pressure drop across pool filters and in pipes, valves, etc., and using high-efficiency pumps with smart controls
- Efficient variable speed ventilation fans and optimised flow rates and ventilation rates
- Minimising evaporation from the pool surface using pool blankets, evaporation-reducing films, limiting air movement across the water surface, and managing pool temperature
- Efficient production, storage and use of hot water
- Efficient, carefully managed lighting, refrigerators, coffee machines and other miscellaneous equipment
- High building envelope thermal performance. Limiting heat flows through glazing by reducing area, shading and use of advanced glazing is critically important. Other measures include minimising uncontrolled air leakage and condensation, reduction of unwanted solar gain and minimising thermal bridging (where metal and concrete components allow heat to bypass insulation and condensation is also more likely to occur)
- Comprehensive building energy monitoring and data analytics to support optimisation of performance, management of peak energy demand and identification of emerging faults.

ABOUT THE AUTHOR

Alan Pears is an engineer and educator with a long history of work across all sectors of energy and climate response. Recently he has co-authored several documents that explore the potential of heat pumps across residential, commercial and industrial applications. Some are listed at the end of this document. However, he does not claim to be a specialist in technical design of heat pump systems.

Some useful publications to which the author has contributed

A2EP Transforming manufacturing guide https://a2ep.org.au/files/pdf/A2EP%20Transforming%20EP%20in%20Manufacturing%20Final.pdf. This includes a 20-page guide on Industry 4.0 and energy productivity, and a detailed review of industrial applications of heat pumps

Aust Alliance for Energy Productivity (contributor) Food Cold Chain Optimisation and heat pumps www.2xep.org.au/files/sectors/A2EP_Cold_Chain_Report_OEH_v2.pdf www.2xep.org.au/files/A2EP_HT_Heat_pump_report.pdf

Aust Alliance for Energy Productivity major report www.a2ep.org.au/files/Reports/2xEP_Innovation_Report_Phase_1_v2.pdf

Energy Efficiency Council Newsletter www.eec.org.au/for-energy-users/technologies-2/heat-pumps