Commercial and industrial air source heat pump water heaters

Technical guidelines

AUSTRALIAN ALLIANCE FOR ENERGY PRODUCTIVITY

VICTORIA State Government | Environment, Land, Water and Planning

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Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

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1 EXECUTIVE SUMMARY

The Victorian Government has committed to net zero emissions by 2050. The state's interim target for 2021–2025 is to reduce the emissions by 28–33% below the 2005 levels. The interim target for 2026–2030 is to achieve a 45–50% reduction below 2005 levels.

Victoria has introduced a Gas Substitution Roadmap to help residents, businesses, and industries navigate the path to net zero emissions while providing greater choice and cutting energy bills. The Victorian Energy Upgrades (VEU) program is also available to accelerate the uptake of energy-efficient and low-carbon technologies across the state's various sectors.

One of the emerging key technologies supported by the VEU program is air source heat pump water heaters. In comparison to their counterpart technologies, such as gas boilers and electric resistive heaters, heat pump water heaters can reduce the energy consumption for heating applications by as much as 80%. However, such performance benefits are contingent upon good design and implementation of the technology that end users and engineers may not have experience with.

The information and recommendations in this document are based on extensive research and conversations with reputable heat pump solution providers in the country.

These guidelines provide steps to approaching heat pumps for water heating in commercial and industrial applications and various considerations that should be taken into account. The guidelines are also intended to help build the capacity of service providers and end users to successfully implement the technologies as part of the transition to a cleaner economy.

USING THESE GUIDELINES

A heat pump investment for a commercial or industrial application will range from $20k to over $1M. Understanding the differences between heat pumps and current technology will help save thousands of $ in investment and running costs and ensure the heat pump performs as needed.

	Recommended time to invest	What you'll get
What are heat pumps and how do they work?	1 hour	An understanding of the technology
Advantages and limitations of heat pumps	2 hours	Reduced operating costs Reduce risks
General design considerations & optimising the design	2 hours	Reduced risks Reduced capital and operating costs
Application-specific considerations & case studies: **- aquatic centres** **- dairy farms** **- multi-unit residential buildings**	2–50 hours	Reduced capital and operating costs Other non-energy benefits

KEY GUIDANCE FROM THIS DOCUMENT

UNDERSTAND YOUR NEEDS – AND REDUCE THEM WHERE POSSIBLE

- Understanding your energy consumption profile is critical to design a heat pump system for any application.
- Remember: heat pumps shouldn't be a one-for-one swap for boilers in terms of capacity.
- Energy efficiency is good value and should be improved first before sizing/designing.
- Revisit and decrease required temperatures where possible.
- To avoid oversizing your heat pump to meet peak demands, modify your energy use and then flatten remaining peaks using thermal storage systems.

CAREFULLY SELECT YOUR HEAT PUMP FOR YOUR APPLICATION AND TO MINIMISE LONG-TERM COSTS/ISSUES

- Select your heat pump on the basis of the required target water temperature.
- Choose a refrigerant with low global warming potential and which won't be phased out in the next decade to minimise environmental impacts and high system maintenance costs respectively.
- When seeking a heat pump, don't just look at cost; look also at quality, system lifetime, refrigerant type, system COP and warranty and support.
- Assess the COP of the whole system not just of the heat pump.
- The quality of heat pump system components should be scrutinised by consulting, reviewing datasheets and seeking reference from existing users, with those in the same climate zones and applications carrying more weight.
- The performance of the system should be modelled (and then monitored) to ensure the expected savings can be realised.
- Victorian Energy Upgrades incentives should be sought to reduce the capital cost.

DEALING WITH EXTREMELY COLD DAYS AND ICING ISSUES

- Understand the likely number of very cold days and the heat pump's capacity to meet demand on these days.
- As well as helping to meet target temperatures, auxiliary heaters can help meet heat demand on very cold days.
- The operation of resistive auxiliary heaters should be minimised and monitored to avoid high running costs and avoid lowering the system COP.
- Heat exchangers should be sized correctly to minimise the risk of icing.
- Control systems must detect the formation of frost early and initiate defrost cycles to prevent growth of ice.

2 GLOSSARY

Air source heat pump – Heat pumps that extract heat from air using an air-to-refrigerant heat exchanger.

Capacity factor – Measures the utilisation of the heat pump. It is calculated by the actual annual heat output from the heat pump divided by the total thermal output if the heat pump was to operate at its total rated heating capacity all the time.

CapEx – Capital upfront cost including equipment and installation costs.

CO_2-e - Carbon dioxide equivalent. The number of tonnes of CO_2 emissions with the same global warming potential as one tonne of another greenhouse gas.

Coefficient of performance (COP) – The indicator of a heat pump's efficiency, determined by dividing its thermal output by its electrical input.

Compressor – The core component of an electricity-driven heat pump that increases the pressure (and hence the temperature) of the refrigerant by compressing it.

Condenser – A heat pump's heat exchanger filled with high-pressure, high-temperature refrigerant in a heat pump. It transfers heat from the refrigerant to water and turns the gaseous refrigerant into liquid.

Evaporator – A heat pump's heat exchanger filled with a mixture of liquid and gaseous refrigerant at low pressure and low temperature. It absorbs heat from the air as its liquid refrigerant evaporates, changing from liquid to gas as it absorbs energy.

Expansion valve – A pressure-reducing device. The liquid refrigerant flowing through it loses pressure creating a high-pressure side behind the valve and a low-pressure region in front of it.

Heat sink – The target medium that heats up by the condensing refrigerant in the heat pump.

Heat source – The medium from which heat is extracted by the evaporating refrigerant in the heat pump.

ESC – Essential Services Commission.

Latent heat – The heat required for evaporating a liquid at a certain temperature.

LCOH – The levelised cost of generating heat over the lifetime of a plant.

OpEx – The cost of operation and maintenance, including variable and fixed costs.

Refrigerants – Special substances with typically low boiling temperatures. In liquid form and at low pressure, they absorb heat and evaporate. In gaseous form and at higher pressure, they reject their heat and condense.

Sensible heat – The amount of heat required for increasing the temperature of a medium.

Temperature lift – The difference between the heat sink temperature and the heat source temperature, which directly correlates with the heat pump's COP.

TRNSYS – Transient system simulation tool.

Water source heat pump – A heat pump that extracts heat from water using a water-to-refrigerant heat exchanger.

3 ABOUT THESE GUIDELINES

The VEU program provides incentives for consumers to make energy efficiency improvements to their homes or business premises. The objectives of the program are to reduce greenhouse gas (GHG) emissions, encourage the efficient use of electricity and gas, and encourage investment, employment, and technology development in those industries that supply energy and emissions saving products and services in Victoria. Detailed information about this program is available through the VEU website[1].

One of the emerging key technologies supported by the VEU program and the focus of these guidelines is efficient air source heat pumps for water heating applications.

The general guidelines and design considerations in the main section of this document are applicable to a range of commercial and industrial applications, including hotels, hospitals, aged care facilities and schools.

However, this document also provides guidance and design considerations specifically for the use of these heat pumps in the following sectors:

- multi-unit residential buildings
- aquatic centres
- agriculture (with a focus on dairy farms).

These sectors were selected because they have been identified to be prone to poor installation practices.

This document is expected to enable the end users and thermal system designers to avoid pitfalls of poor designs and low-quality components. Without considering the highlighted issues, switching to a heat pump water heating options may turn into a costly investment without tangible savings.

This document provides technical guidance to support best practice design and installation of commercial and industrial air source heat pump water heaters[2]. It outlines the relevant key information including the benefits of these heat pump systems, design considerations, potential issues and remedies.

THINGS TO NOTE IN THESE GUIDELINES:

- Only high-level aspects of heat pumps are included in this guide; reputable sources for further detailed information on any topics have been listed throughout this document.
- Beyond the Introduction, 'heat pump' in this document refers to air source heat pumps, unless otherwise stated.
- kW_e – refers to a kilowatt of electrical power
- kW_{th} – refers to a kilowatt of thermal power (either cooling or heating power)
- kWh_e – refers to a kilowatt-hour of electrical energy
- kWh_{th} – refers to a kilowatt-hour of thermal energy (either cooling or heating)

1. Department of Environment, Land, Water and Planning (DELWP), *Victorian Energy Upgrades program* [website], DELWP, 2022, accessed 27 July 2022.
2. Hot water usage in this document includes indirect space heating. Direct heat pump air heaters are excluded from the scope. This document covers only mechanical vapour compression heat pumps with air as their heat source, excluding ground-source and water-source heat pumps.

4 INTRODUCTION TO HEAT PUMPS

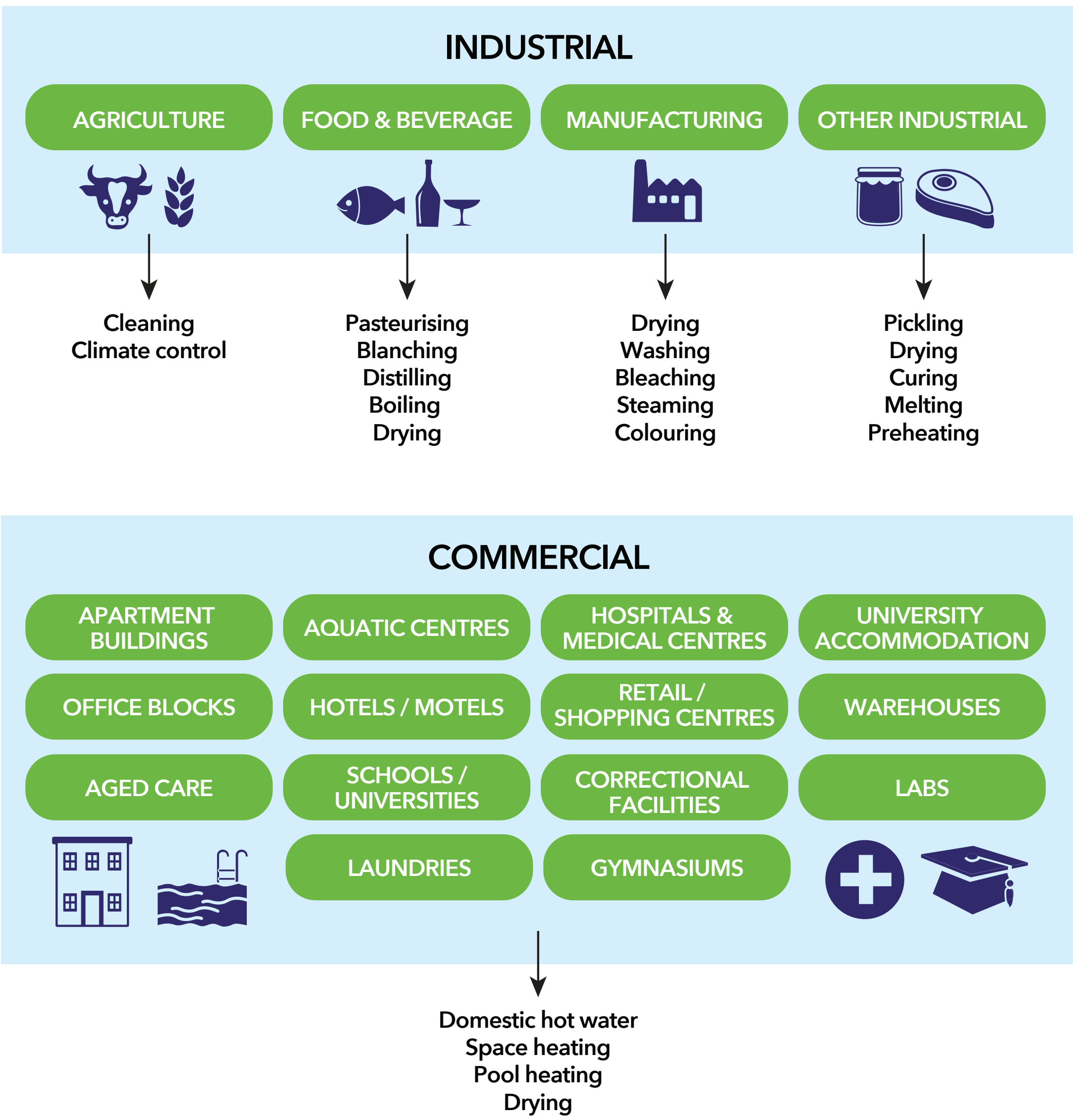
Heat pumps are electricity-driven devices that can deliver heat for a range of applications such as:

- domestic hot water, space heating and cooling in buildings
- process hot water, chilled water, product heating and product cooling in agriculture
- space heating, dehumidification, cooling, and pool heating in aquatic centres
- process air heating in agriculture and industry
- steam generation for industrial processes.

The majority of homes in Australia contain a heat pump – the humble refrigerator is a heat pump which extracts heat from the cold interior of the fridge and rejects it to the ambient air.

A heat pump hot water system extracts heat from the outdoor air (or other sources of warm or hot air) to heat water. In this instance, the air is the heat source, and water is the heat sink. Air source heat pumps are the dominant type of heat pumps found in Australia.

Potential applications for heat pumps in commercial and industrial applications



4.1 How heat pumps work

The thermal output of a heat pump is a combination of heat generated by the conversion of electricity and the additional heat that is extracted from the heat source, with the latter being two to five times greater in a well-designed heat pump system.

A heat pump generates cooling and heating simultaneously in two different locations. The heat pump extracts heat from a heat source and delivers it at a higher temperature to a heat sink using a vapour compression cycle. In the process, the heat source gets colder and the heat sink gets warmer/hotter.

If the cooling of the heat sink side is the product that is utilised by the application, the heat pump is considered a refrigerator or chiller. However, if the heat delivered to the heat sink is desired, the heat pump is considered a heater. Reverse cycle units can switch their sink and source sides to deliver heating or cooling, as in the case of a reverse cycle air conditioner.

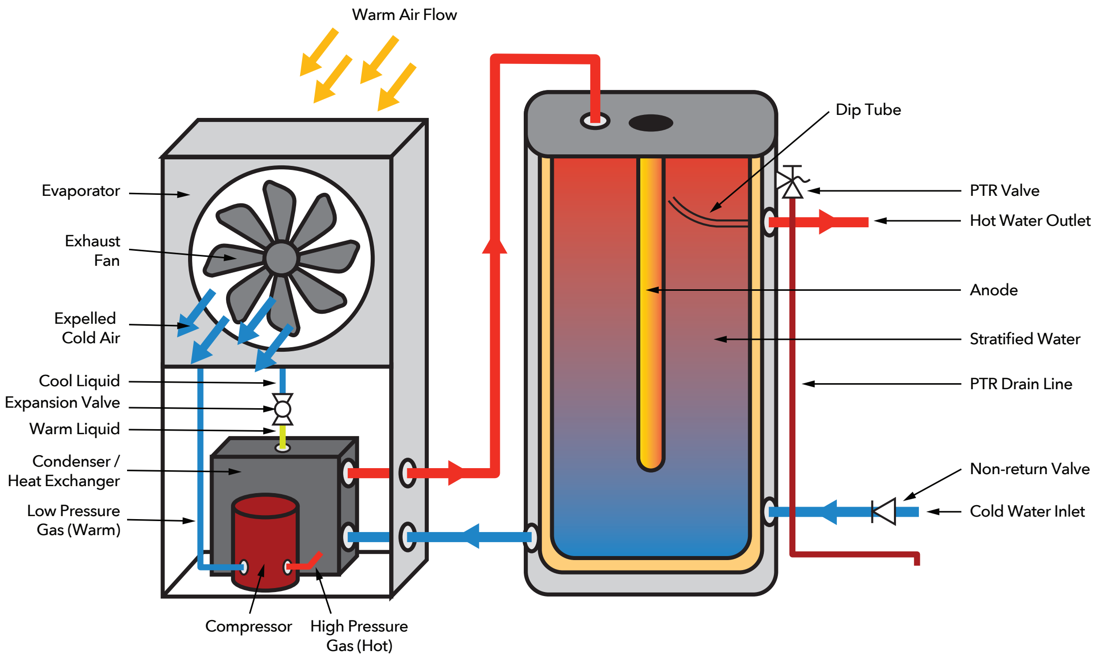


Figure 1: *An illustration of a heat pump coupled to a hot water thermal storage tank – refer to the Glossary on page 8 for a definition of each of the components.*

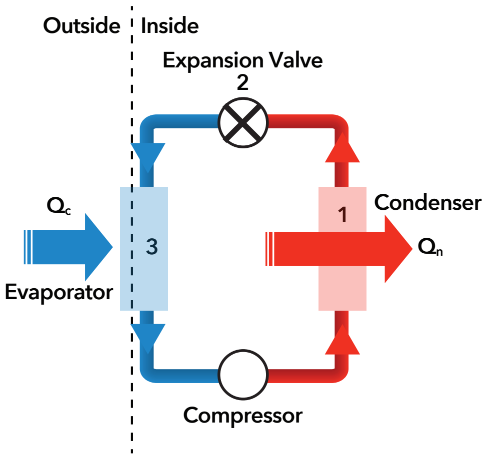


Figure 2: *General concept of a heat pump.*

In a heat pump, the compressor and the expansion valve create two distinct regions with high and low pressure in the refrigeration loop. As long as the compressor is operating, heat transfer from the heat source to the heat sink continues.

WHY IS THE TYPE OF HEAT PUMP REFRIGERANT IMPORTANT?

The ability of a heat pump to transfer heat from a cold medium to a hot medium is due to the particular properties of the refrigerant. Depending on the operating temperatures of the heat pump, different refrigerants with different boiling points may be used, and efficiencies can vary.

How is the efficiency of heat pumps measured?

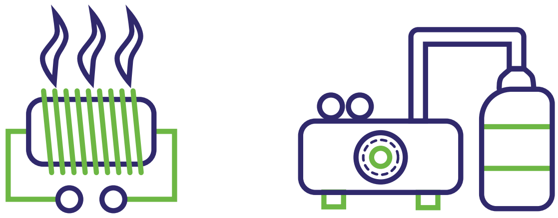
The parameter that indicates the efficiency of a heat pump is its coefficient of performance (COP). It is the ratio between the heat output power (usually in kW_{th}) and the electric input power (in kW_e).

$$COP = \frac{\text{Delivered heating power of HP } [kW_{th}]}{\text{Electric input power of heat pump } [kW_e]}$$

A higher COP shows that the heat pump delivers significantly more thermal energy compared to its electrical input energy. High COP is key to the utility of a heat pump as it drives the actual energy use.

COMPARING THE COP OF A HEAT PUMP TO A RESISTIVE HEATER

A resistive electric heater has a COP of 1.0, meaning that it produces 1 kW of heating for every kilowatt of electrical power that it consumes. Heat pumps can typically achieve a COP of three or more meaning that they can produce three or more units of thermal energy for every unit of electrical energy that they consume.



COP = 1.0 VS COP = 3.0+

4.2 General advantages of heat pumps

How is the efficiency of heat pumps measured?

Due to their COP being greater than one, heat pumps are capable of reducing primary energy use. The thermal output of a properly designed and installed heat pump can be three to six times higher than its electrical energy input. This feature is unique to heat pumps.

i Primary energy use refers to the amount of electricity or fuel consumption to serve the required thermal process. For example, with a 70% efficient gas boiler, 1.43 MJ of gas as primary energy is used to generate 1 MJ of heating for hot water generation.

Low cost to operate

With indicative gas prices between $12–24/GJ and electricity tariffs around A$0.25–0.35/$kWh_e$[3], the cost of operating a heat pump is always lower than resistive heating and, in many cases, even lower than gas-fired boilers. A simple comparison, based on these typical wholesale energy costs, is presented in the following table. Any rise in gas prices, the introduction of carbon prices, and a decline in electricity prices can all favour heat pump systems.

3. Australian Competition and Consumer Commission (ACCC), *Inquiry into the National Electricity Market* [website], ACCC, May 2022, accessed 22 July 2022.

***Table 1:** Comparing the operating cost of various heating technologies for equipment with 1MW nameplate[4]. Source: Australian Alliance for Energy Productivity.*

For equipment with a 1MW nameplate capacity

Fuel and cost	Equipment	COP	Cost to deliver 1 GJ of heat
Natural gas @ $12/GJ	Burner for heating air	0.95	$13.28
	Steam boiler	0.8	$15.65
	Steam system	0.65	$19.11
Natural gas @ $24/GJ	Burner for heating air	0.95	$25.90
	Steam boiler	0.8	$30.60
	Steam system	0.65	$37.50
Hydrogen @ $2/kg	Burner for heating air	0.95	$18.25
	Steam boiler	0.85	$20.30
	Steam system	0.7	$24.50
Electric resistive @ $120/MWh	Heating element	0.95	$33.33
Heat pump @ $120/MWh (for 70 °C hot water)	Air sourced	3	$12.92
	Water sourced	5	$8.48
	Water sourced, integrated with a waste heat source	6	$7.37

Lower CO_2-e emissions

Heat pumps are critical for decarbonising Australia's thermal systems, especially between now and 2030, as they have well-developed, highly competitive supply chains in Australia and do not need a large amount of research and development to become economical (in comparison to green hydrogen supply, for example).

With Australia's rapidly decarbonising electricity grid having an expected emissions factor of less than 0.3–0.45 t CO_2-e/MWh by 2030[5], the replacement of gas heaters with heat pumps for heating services will deliver major emission reductions. Replacement of electrical resistance heaters will also greatly reduce loads on the electricity grid, and the amount of renewable electricity production installed.

Heat pumps offer lower emissions due to their lower primary energy consumption. Exact emission savings will also depend on climate, choice of equipment, and the fuel used by the heat pump technology. A significant advantage of heat pumps is that they can utilise on-site renewable energy generation for even lower emissions. Learn more in Appendix C.

4. In comparison to natural gas boilers, hydrogen boilers achieve a higher efficiency thanks to the better performance of their economiser. For both technologies, steam leakage and heat losses from the steam reticulation lines leads to additional losses reducing the total system COP to 0.65–0.70.

5 Department of Industry, Science, Energy and Resources (DISER), *Australia's emissions projections 2020*, DISER, Australian Government, 2020, accessed 2 August 2022.

4.3 Benefits from electrification of heat

'Electrification of heat' refers to the replacement of combustion-based heating systems such as gas boilers with electric heating technologies such as heat pumps. For a comprehensive list of electrification technologies refer to the report published by the Australian Renewable Energy Agency[6]. Various benefits flow from electrification as outlined below.

Pathways for decarbonisation

Widespread electrification is a key strategy to reduce greenhouse gas emissions in a range of sectors[7,8]. Emissions from burning fuels for heat, steam, or pressure make up 20% of Australia's emission[9]. Deployment of heat pump technology can allow for efficient and practical electrification of heating, permitting fuel switching from other, more carbon intensive fuels. The benefit of heat pumps increases over time as the grid decarbonises with further deployment of wind and solar and utilisation of on-site renewable electricity generation and storage.

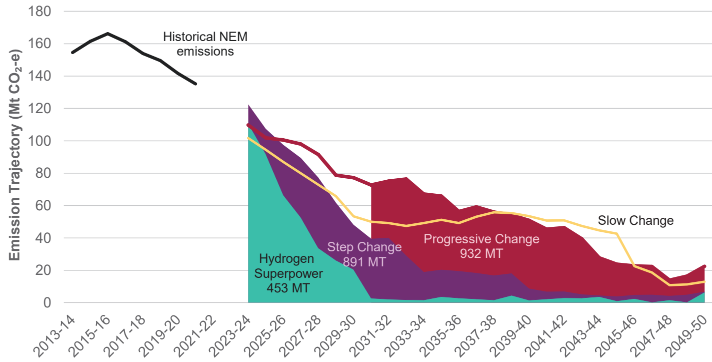


Figure 3: *NEM carbon budgets and he resulting emission trajectories. Source: AEMO 2022.*[10]

Economic utilisation of on-site solar photovoltaics (PV)

Synchronising heat pump operation with on-site solar PV generation can significantly lower its running costs and improve the economics of both the heat pump and the solar PV system. Effective pairing of heat pumps with on-site or grid-supplied renewable energy and use of thermal and/or electricity storage can fully decarbonise some heating processes.

Demand response

Owners of medium-to-large electrified heating processes have more potential to participate in and benefit from demand response. Demand response is the adjustment of the electrical demand in the network to limit network costs and match available generation. The participants in such services can be compensated for the demand response they provide.

Some commercial and industrial heat pump applications can operate flexibly, particularly when coupled with thermal storage. Such heat pump systems can ramp down and temporarily reduce their demand when the grid operator requires it. They can also help a site to manage demand within limited grid connection capacity. Larger scale business and industrial users that transition to heat pump technology will have the option of participating in these and other electricity market mechanisms to aid grid stability. The size of the demand response market is expected to grow as more wind and solar are deployed in the grid and energy market design evolves.

Safety

Electric heating technologies such as heat pumps offer safety benefits, including:

- Minimisation of fire hazards, since they do not need handling and storage of combustible or explosive fuels in confined spaces such as building plant rooms.
- Elimination of harmful gases and particulates in plant rooms, as electrified heaters do not rely on combustion for heat generation (although some heat pumps may use a flammable hydrocarbon as the refrigerant).

6. IT Power Australia, *Renewable Energy Options for Industrial Process Heat*, Australian Renewable Energy Agency (ARENA), 2019, accessed 10 July 2022.
7. Beyond Zero Emissions, *Zero carbon industry plan: electrifying industry*, Beyond Zero Emissions, 2018, accessed 8 July 2022.
8. Climateworks, *Decarbonisation futures: solutions, actions and benchmarks for a net zero emissions Australia*, Climateworks, 2020, pp 8-9, accessed 8 July 2022.
9. Department of Industry, Science, Energy and Resources (DISER), *Australia's emissions projections 2020*, DISER, 2020, p 24.
10. Australian Electricity Market Operator (AEMO), *2022 Integrated System Plan*, AEMO 2022, accessed 16 August 2022.

Low maintenance

Heat pumps are generally reliable devices with little need for maintenance. When correctly designed and installed, most of the required maintenance is limited to replacing filters and cleaning the condenser and evaporator coils to reduce fouling and maintain thermal performance and thermal capacity.

The large thermal applications covered in this document require industry-grade heat pumps. These heat pumps have more complexity but are also designed to operate under more intense conditions with minimal issues. They unusually have longer on-time capacities with little need for maintenance.

Equipment failure is not common in industry grade heat pumps. Refrigerant leakage is also rare with regular inspections likely to detect any possible leakage.

TIP: INCLUDE REMOTE MONITORING TO PICK UP LITTLE ISSUES BEFORE THEY BECOME BIG PROBLEMS

A properly instrumented heat pump with the ability to connect via data gateways can reduce the need for regular inspections. Such sensors that detect issues at their early stages can serve various purposes:

- ***Arrest the problem and prevent it from propagating***
  For example, a faulty expansion valve can cause damages to other components such as the compressor.
- ***Stop the increasing running cost immediately***
  Most component failures can lead to poor energy performance of the heat pump leading to higher running cost if they remain undetected.
- ***Minimise unserved thermal load***
  Poor performance of a heat pump leads to a drop in the delivered heat output.
- ***Minimise environmental impact***
  By monitoring for refrigerant leakage, the total amount of the refrigerant leaked to the ambient can be minimised, which is very important as most refrigerants have high global warming potential.

4.4 Challenges associated with heat pumps

Heat pumps are capable and versatile technologies. However, like any other technology, they also have certain limitations and disadvantages. Some of these limitations can be managed through careful equipment selection, design, installation and operation, while others are harder to overcome.

Limited output temperature

Heat pumps that supply heat above 100 °C are available but are not currently commonly used. Heat pumps that deliver heat above 160 °C are still in the early stages of development. While temperature considerations can limit heat pump use, ongoing research and development has continued to deliver improvements in product performance and efficiency for more diverse applications.

To boost the temperature of water from the heat pumps, auxiliary heaters such as resistive elements can be used.

FOR WAYS TO OVERCOME LIMITED OUTPUT TEMPERATURE CHALLENGES, SEE:

- Mapping the load profile
- Process temperature
- Auxiliary heaters

Upfront cost

Compared to gas boilers and resistive electric heaters, heat pumps have a significantly higher upfront cost if they are replacing 'like-for-like' equipment. Indicative equipment prices are shown in Table 7. Because the running costs of heat pumps are generally very competitive, reducing upfront costs – both in terms of capital costs and design and installation costs – is a critical pathway for driving the uptake of heat pumps.

The marginal cost of increasing heat pump size is much higher than gas boilers. Peak demand of the load should be captured by thermal storage to reduce the required heat pump capacity. Measures such as thermal storage, pre-heating inlet air and increasing heat exchanger size can be cheaper than increasing heat pump size.

SIZE HEAT PUMPS FOR AVERAGE DEMAND, NOT PEAKS

Heat pumps may be dismissed as an option due to their high capital cost (per kilowatt of delivered heat) when compared to a boiler rated for the same heating power. However, boilers are usually sized for the peak demand, whereas a heat pump should be sized for the average demand and utilise thermal storage (e.g., a hot water tank) to meet the peak loads.

FOR WAYS TO OVERCOME UPFRONT COST CHALLENGES, SEE:

- Cost and economics of air source heat pumps
- Tariff optimisation
- VEU program incentives

COP loss with large temperature uplift

The temperature difference between the heat source and the heat sink can significantly impact the COP and heat output capacity of a heat pump. The lower the temperature difference, the higher the heat pump COP. This can particularly affect the performance of air source heat pumps, as their heat source temperature (the ambient air) changes daily and seasonally.

This difference between the heat sink and the heat source is sometimes called the 'temperature uplift'. The temperature uplift will increase when the air temperature at the source drops and/or the target temperature at the sink side rises. The latter takes place, for example, as the required temperature of the hot water in heat pump water heaters rises. Inadequately sized or fouled heat exchangers and fan speeds can also lead to a larger temperature lift. shows the variation of a heat pump COP vs ambient air temperature.

In an air source heat pump water heater, if the evaporating temperature rises by 1 °C or the condensing temperature decreases by 1 °C, the COP of the system will increase by approximately 2.5% to 9%.

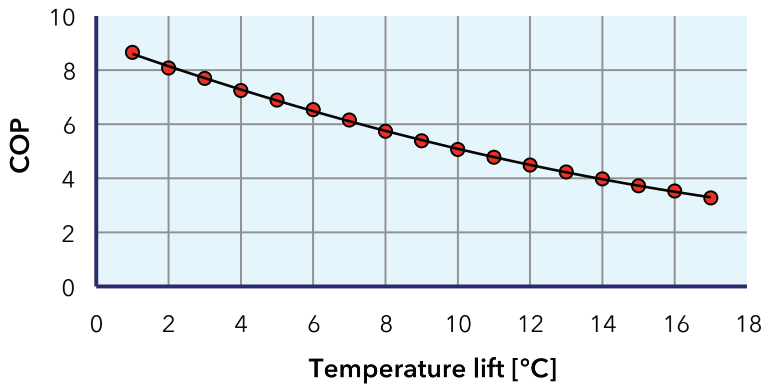


***Figure 4:** An example of change in the COP when the ambient air temperature drops; the temperature lift is the different between the heat pump target temperature (55 °C and 65 °C in this example) and the ambient temperature.*[11]

FOR WAYS TO OVERCOME LARGE TEMPERATURE UPLIFT, SEE:

- Integrating heat pumps with thermal storage and heat recovery
- Optimising for available air temperatures

11. Viessmann Group, Technical manual – Heat pumps, Viessmann Group, 2012, accessed 20 June 2022.

Space requirements

Heat pump equipment can be bulky and heavy, generally requiring three times more space than gas boilers for the same thermal power output.

For air source heat pumps, ideally the evaporator will be placed outdoors in a well-ventilated location (with the appropriate corrosion protection for the heat transfer coils). If the heat pump is located in a plant room, consideration should be given to ensure a large volume of airflow is accessible to the evaporator. Without this, the evaporator will lose its performance affecting the heat pump COP. Confined spaces lead to the formation of a local microclimate as the heat pump extracts heat from the air.

FOR WAYS TO OVERCOME SPACE CONSTRAINTS, SEE:
→ Location and space considerations

Evaporator icing

Air source heat pumps can 'ice up' at low ambient temperatures (generally below 5 °C). The moisture in the air usually condenses on the external surfaces of the condenser when the heat pump is operating. At low ambient air temperature (around 5 °C), the surface temperature of the condenser may be below zero, freezing the condensed moisture. This layer of ice gradually builds up on the condenser forming an undesirable thermal resistance that hampers the heat transfer between the ambient air and the refrigerant. Ice transfers heat very poorly, so icing should be either prevented or removed when it occurs.[12]

FOR WAYS TO PREVENT ICING, SEE:
→ Defrosting the heat pump

Noise

Heat pumps (particularly air source heat pumps) can be noisy, mainly due to their air source fans and main compressors. This can be an issue if the heat pump is located near people or other operations. The sound pressure level decreases by the square of the distance from the noise source and this is used to determine a suitable location for installing heat pumps. For guidelines on assessing and controlling noise level from heat pumps refer to Noise guideline: Assessing noise from residential equipment[13] from the EPA.

Sound power level is total sound power generated by the heat pump in all directions.

Sound pressure level is a measure of noise level reaching a certain location at a distance from the noise source, and is the noise level that reaches the ear.

12. Note that icing is of relatively limited concern in Australia, as the lowest winter temperatures experienced outside of the alpine zone are within the capabilities of currently available heat pump units sold in Australia.

13. EPA, *Noise guideline: Assessing noise from residential equipment*, EPA, 2021, accessed 20 July 2022.

5 INTEGRATING HEAT PUMPS WITH THERMAL STORAGE AND HEAT RECOVERY

5.1 About thermal storage systems

While heat pumps are already very efficient, integrating them with thermal storage and heat recovery can further improve their performance and economics. Thermal storage systems help match heat pump outputs to the load, provide solutions to temperature uplift and enable operators to take advantage of tariff and demand response arrangements for even greater operating cost benefits.

A thermal energy storage system (also called a thermal battery) absorbs heat, retains it for a period, and releases it upon the need for thermal energy. The simplest and most ubiquitous thermal storage system in the existing market is insulated hot water tanks. These tanks are practical products with commercially mature technology and relatively low cost compared to electrical storage. They are available in two different configurations:

Open loop – in which the tanks are connected to the mains water and should be rated for the mains pressure. With this configuration, the tank refills from the mains water while hot water is drawn from it.

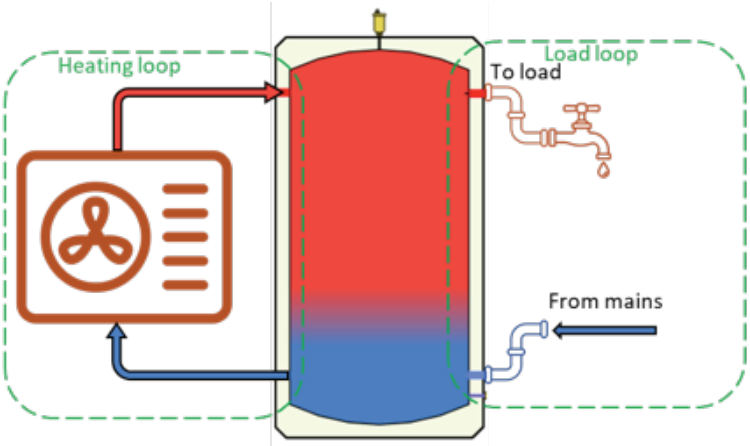


Figure 5: *Open loop configuration.*

Closed loop – in which these tanks are isolated from the mains water and contain water that circulates in the heating system. They operate at atmospheric or slightly higher pressure. In this configuration, water is circulating in a loop and is not consumed. Only heat is extracted from it via a heat exchanger.

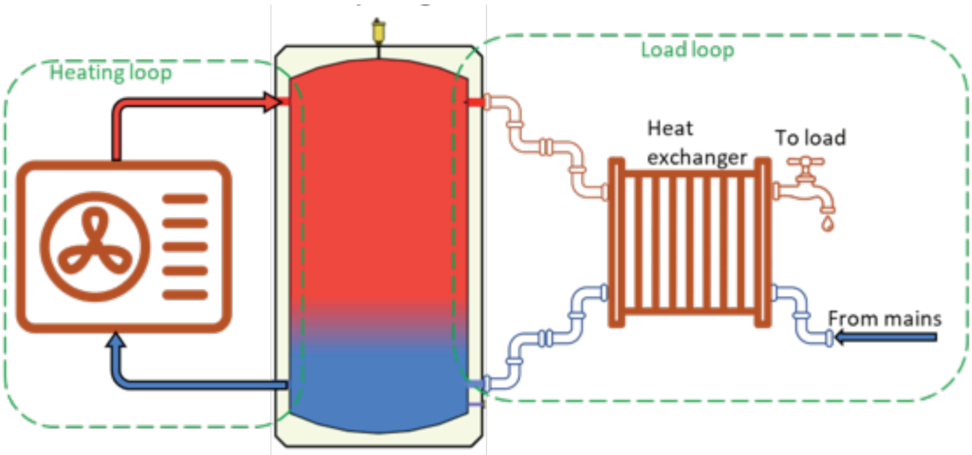
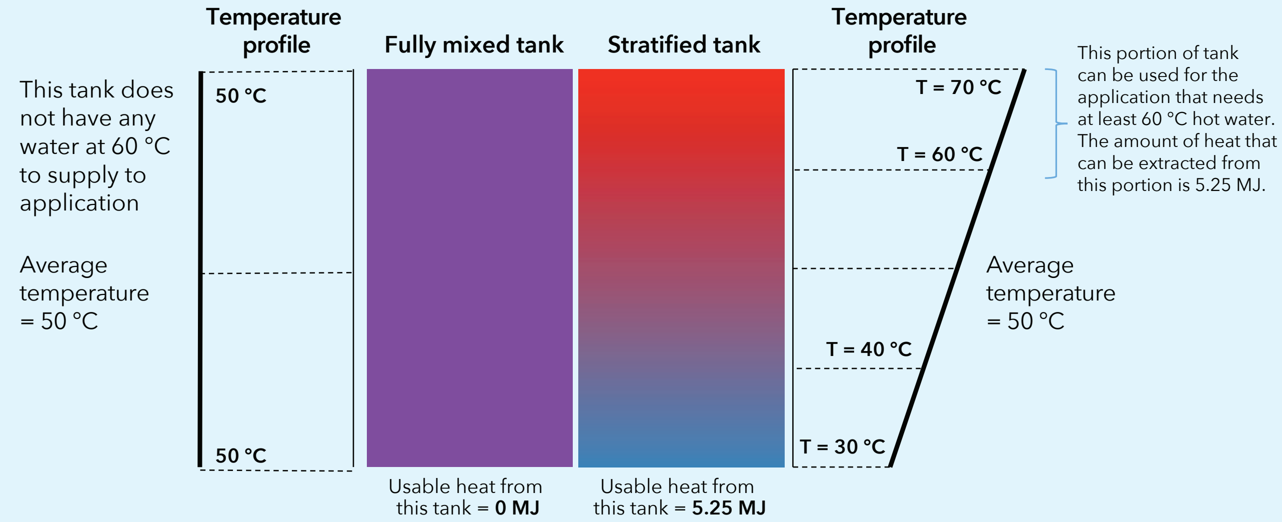


Figure 6: *Closed loop configuration.*

THE VALUE OF THERMAL STRATIFICATION IN THERMAL STORAGE TANKS

Efficient thermal storage systems maintain thermal stratification in the tank. In these tanks, hot water layers at the top of the tank are not mixed with the cold layers at the bottom. Hence, there is a temperature profile extending from the bottom of the tank to its top.

So how important is stratification? The below diagram illustrates just how important.



But both tanks have the same average temperature, and hence the same amount of energy, but only the stratified tank can supply useful energy

For most air source heat pump water heaters, including thermal storage is a necessity. Its main function is to match the intermittent heat load with the continuous output of a heat pump. However, the following issues can be addressed and additional advantages can be realised if suitable sizing and control of the heat pump and thermal storage is implemented.

Table 2: *The general benefits of coupling heat pumps with thermal storage.*

Issue	Benefit of thermal storage	Value
Intermittent operation of heat pumps affecting COP and operational lifetime.	***Smooth out*** heat pump operation so it runs at best efficiency point for an extended period.	• Reduced maintenance. • Increased COP.
Sizing a heat pump for peak demand - leading to an oversized heat pump, hence excessively higher CapEx and electric power demand.	***Shrink*** the heat pump capacity needed by reducing peak loads via storage to average out the peaks and troughs of the actual load profile.	• Save 10–30% on CapEx for the heat pump. • Potentially avoid costly electrical upgrade.
Increasing opportunities for heat users to exploit time-based electricity tariffs.	***Shift*** the heat pump operation to low or off-peak tariff times.	• Tariff-dependent - potential saving of 50% per kilowatt-hour.
Excess on-site solar PV generation exporting to the grid at less than the retail power price.	***Shift*** the heat pump operation to utilise more solar PV generation.	• Feed-in tariff-dependent - potential saving of 50% per kilowatt-hour.
Full emission-reducing benefits of heat pumps not realised.	***Enable*** heat pumps to produce heat when clean renewable generation is high and store for use at times of peak demand.	• Even lower emissions for thermal services provided.
Cold ambient air lowering the heat pump's COP.	***Shift*** the heat pump operation to periods with higher ambient temperature.	• 5 °C higher ambient can deliver >12.5% efficiency boost (even more if avoiding defrosting).
Maximum heat pump efficiency not utilised.	***Enable*** heat pumps to operate at optimum capacity.	• Greater efficiency from the heat pump.

5.2 Sizing thermal storage systems

It is important to size the thermal storage system together with the heat pump – they should not be sized independently – and as outlined below, consideration should be given about how the whole system will work: peak demands, seasonal variations, demand response opportunities and the need for an electric auxiliary heater.

STEP 1

- Conduct an energy audit and map the hourly load profile.

STEP 2

- Check the seasonal variation of the load profile and determine the base load profile for sizing.

STEP 3

- Size the storage to meet the peak demand while heat pump running at full load.
- Size the heat pump such that it can charge the storage in between the peak demand periods.

STEP 4

- Implement an electric auxiliary heater for rare extreme demand periods.
- Check if the heat pump + storage + auxiliary heater system can meet the demand throughout the year.

STEP 5

- Run a sensitivity analysis on the size of the storage and the heat pump to see if you can reduce the cost further.

Figure 5: *Design procedure for sizing a thermal storage tank for a heating application.*

Sizing the heat pump and thermal storage for lower running cost may not necessarily lead to lower emissions. Depending on the region, the share of renewables in the generation mix during the off-peak price periods may coincide with lower or higher emissions periods.

Currently in Victoria, off-peak is during the night when the share of fossil fuel generators in the generation mix is higher (see Figure 6), therefore a heat pump operating during these periods can cause more emissions. To overcome this issue, large heat pump operators can sign up for renewable power purchase agreements to lower their emissions.

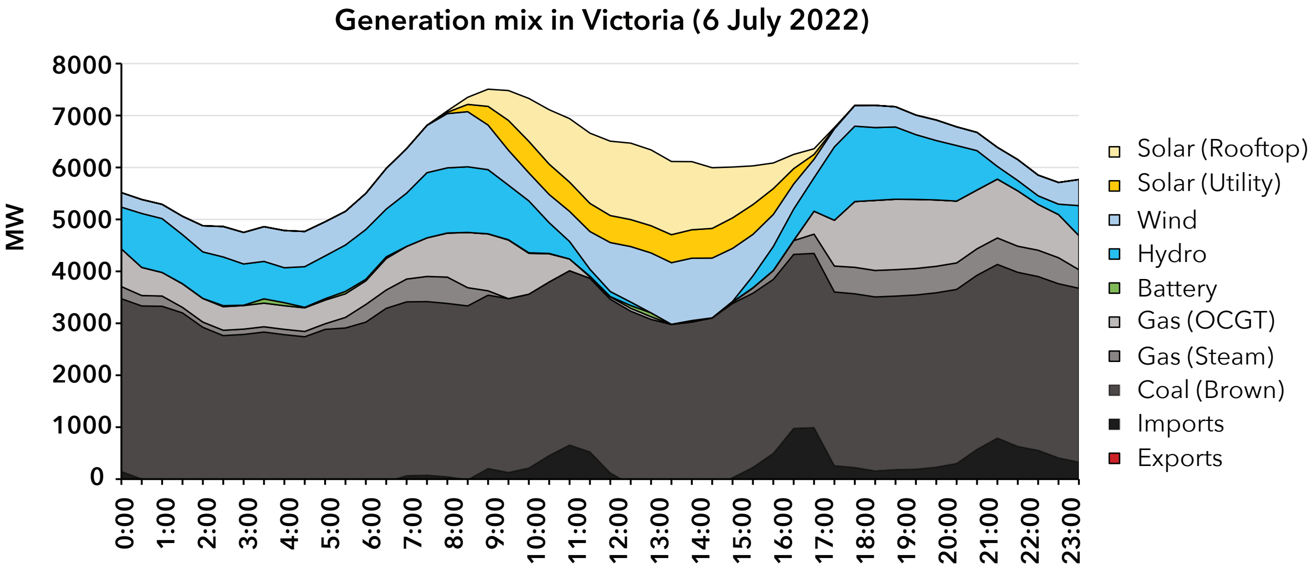


Figure 7: *Generation mix in Victoria (data acquired from OpenNEM)*[14]

From a running cost point of view, a thermal storage system enables the heat pump to operate during off-peak periods. However, three major aspects should be considered in this respect:

- **Costs associated with the size of the storage tank** – shifting heat pump operation usually needs larger storage capacity, hence larger tanks ➜ see Section 5.5 Cost of thermal storage systems
- **Heat loss from the storage** – total heat loss from the tank increases when the time difference between heat generation and consumption expands ➜ see Section 5.3: Heat loss from thermal storage systems
- **Lower COP** – during cold seasons, air temperature at night drops reducing the COP of the heat pump ➜ Section 4.4: COP loss with large temperature uplift

Note: current off-peak electricity tariffs are usually overnight (e.g., 10 pm to 7 am). However, with an electricity grid that utilises renewable technologies (such as solar PV and wind) this can be expected to change over time with off-peak electricity tariffs occurring during the middle of the day, as currently seen in the South Australian electricity market.

14. OpenNEM, *www.opennem.org.au*, OpenNEM, 2022, accessed 6 July 2022.

5.3 Heat loss from thermal storage systems

A well-insulated thermal storage system will lose as little as 0.5% of the stored energy per 24 hours. Heat loss from thermal storage will depend on:

Water temperature

The higher the water temperature, the higher the heat loss.

Thermal insulation

Better thermal insulation around the tank can reduce its heat loss significantly. The performance of the insulation layer is usually described with its R-value. Higher R-values lead to less thermal losses.

Proportions and design

The ratio of a tank's external surface area to its volume can alter the heat loss from the tank. For the same tank volume, increasing the surface area will lead to higher heat losses. 'Fat' tanks have less surface to volume ratios. However, maintaining stratification in them is more challenging. 'Slim' tanks can maintain stratification more effectively.

5.4 Standards related to thermal storage systems

There are two main standards that apply to thermal storage systems:

AS/NZS 4692.1: Electric water heaters - Energy consumption, performance and general requirements.

AS 3498: Safety and public health requirements for plumbing products - water heaters and hot water tanks

The temperature of the storage tank is a key factor from an efficiency point of view, and to comply with health and safety legislation for preventing legionella. High-temperature heat pumps can achieve stored hot water temperatures above 65 °C without supplementary heating. These heat pumps typically use refrigerants such as R290 (propane) or R134a. Lower temperature heat pumps will require support from an auxiliary heat source to reach the required temperature – this might be from another heat source, such as a fossil fuel boiler or a booster electric immersion heater.

For the full list of standards related to thermal storage systems, refer to Appendix G.

5.5 Cost of thermal storage systems

Thermal storage systems are typically made of stainless-steel cylinders with support structures, fittings, thermal insulation, covers, and immersion heaters. Research conducted in 2022 found that the cost of sourcing such storage tanks from reputable suppliers in Australia was around A$8,000-12,000/$m^3$ (excluding installation).

The unit cost of heat stored in a tank is a more precise indicator of a thermal battery cost. To do so, the amount of useful heat that can be stored in a tank is divided by the tank cost. The amount of useful heat in a tank is determined by the following parameters:

Maximum water temperature (T_{max}) – the maximum temperature to which the heat pump and the booster heat water.

Return water temperature (T_{return}) – the temperature of water that enters the heat pump. This temperature is application specific. For a domestic hot water tank, it is the mains temperature (e.g., 10 °C to 16 °C), but for space heating application, it is the return temperature from the space heating loop (e.g., 40 °C).

Tank volume – the mass of water in the tank.

The storage capacity can be estimated as the following:

$$\text{Capacity [kWh}_{th}] = \text{Storage Volume [m}^3] \times (\Delta T) \times 1.17$$

$$\Delta T = T_{max} - T_{return}$$

Unit cost of storage is calculated as the following:

$$\text{Unit cost of storage} = \text{Cost of storage tank [A\$]} \div \text{Capacity of the tank [kWh}_{th}]$$

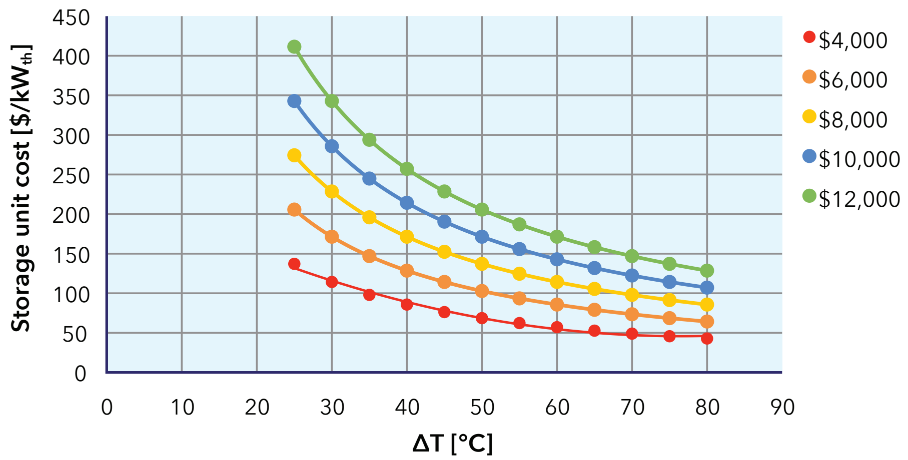


Figure 8: *Heat storage unit cost vs tank temperature difference for tank prices between $4,000 and $12,000.*

6 GENERAL DESIGN CONSIDERATIONS FOR AIR SOURCE HEAT PUMPS

Heat pumps are engineering solutions for specific conditions. They should be designed to suit the application, taking into consideration other key parameters such as load profile, the required temperature, ambient temperature, system up-time, etc. Incorrect design and heat pump usage will lead to poor performance and reduced operating life.

Heat pumps can be capital-intensive heating devices. However, they offer many benefits if designed, integrated and maintained correctly, including reduced operating costs which will justify the high capital expenditure.

HEAT PUMP SIZING

Heat pump implementation is not necessarily a one-to-one swap when it replaces an existing resistive or combustion heating system, especially when integrated with a thermal storage system.

The general procedure for sizing a heat pump system is as presented below.

STEP 1

- **Conduct an energy audit and map the hourly load profile.**

STEP 2

- **Check the seasonal variation of the load profile and determine the base load profile for sizing.**

STEP 3

- **Size the storage to meet the peak demand while heat pump running at full load.**
- **Size the heat pump such that it can charge the storage in between the peak demand periods.**

STEP 4

- **Implement an electric auxiliary heater for rare extreme demand periods.**
- **Check if the heat pump + storage + auxiliary heater system can meet the demand throughout the year.**

STEP 5

- **Run a sensitivity analysis on the size of the storage and the heat pump to see if you can reduce the cost further.**

6.1 Mapping the load profile

The starting step for upgrading to a heat pump system is to understand the heat requirements in the applications. The time-based heat usage in an application is called load profile. A load profile should ideally offer the following information:

- the total amount of heat that is required for the entire year
- load variation from hour to hour
- load variation from season to season
- the temperature of the required heat
- load under extreme conditions – often called the peak load.

Often this level of granularity is not available, so estimates using the hourly data from other indicators such as the total gas and electricity bills should be used. Extracting this information may need an energy audit for the application. More accurate knowledge of the load profile helps to size and operate the heat pump and the thermal storage unit more effectively and economically.

Once the load profile is obtained, the following steps should be taken:

- **Energy efficiency first**
  A kilowatt of heat from a heat pump is more expensive than many energy efficiency options, so consult with an energy efficiency expert on ways to reduce the heat load. Lower heat load will require a smaller and cheaper heat pump.
- **Reduce the required temperature**
  With some modification in the heating loop, the required temperature of the supply water may be reduced. Investigate such options to reduce the temperature. For lower water temperatures, more and cheaper heat pump options are available.
- **Reduce the peak load**
  Heat load profiles may contain peak loads that last short periods. Employ auxiliary heaters and thermal storage to help the heat pump respond to this peak load. A heat pump sized for the peak demand can be severely oversized most of the time and fail to deliver a good return on investment.

6.2 Process temperature

Most heat pumps in the market can produce heat at up to 55 °C to 65 °C. When the required application temperature increases, heat pump options dwindle. Ammonia and CO_2 heat pumps are the only commercial products that can supply heat at ~90 °C. However, they come with some limitations that will be discussed later. It is logical to rethink whether the process temperature can be reduced to suit common heat pumps that are cheaper.

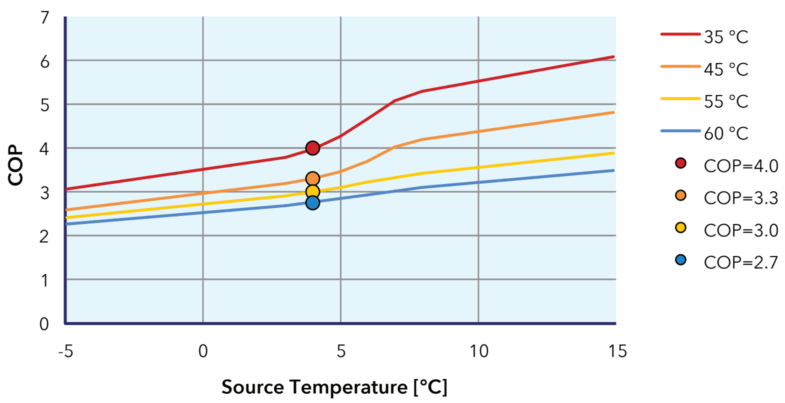


Figure 9: *The COP of a heat pump water heater as a function of source and water temperature; each line corresponds to different hot water outlet temperature (only for indicative purpose only).*[15]

15. Data extracted from: Viessmann Group, *Technical manual – Heat pumps*, Viessmann Group, 2012, accessed 20 June 2022.

The possible options for reducing the process temperature vary from application to application. In general, the following solutions can be conceived to reduce the required temperature:

- Increase the heat transfer rate from the heat emitters (e.g., radiator panel size in hydronic heating).
- Extend the operation duration of the heating system (e.g., start space heating earlier in the morning).
- Replace the nature of the load by modifying it (e.g., replacing cleaning chemicals with low-temperature ones).
- Increase the flowrate of the hot water going to the heat emitters (thereby increasing the heat transfer rate from the radiator panels).

6.3 Optimising for available air temperatures

As previously mentioned, minimising the difference in temperature between the heat source and the heat sink improves the COP. Significant savings can be achieved if the heat pump operation hours can be shifted to periods of the day when the air temperature is higher with the generated heat stored in a thermal battery for later use when the air temperature drops. This means that during cold hours, the heat pump can operate at part-load condition while the thermal storage tank covers the balance of demand.

In part-load conditions, the compressor efficiency decreases, but the evaporator performance improves. A typical combined effect is presented in Figure 10. Operating a heat pump in part load is equivalent to oversizing its evaporator. An oversized evaporator can partly compensate for the drop of air temperature.

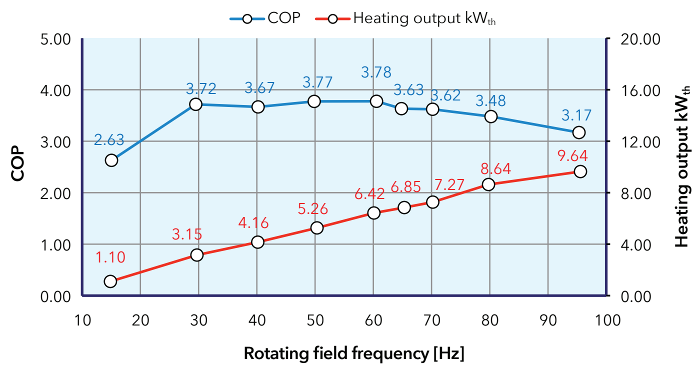


Figure 10: *Heat pump thermal output and COP as a function of its load; rotating field frequency is proportional to compressor speed (for indicative purpose only)*[16]

THINGS TO CONSIDER TO SHIFT THE HEAT PUMP OPERATION TO WARMER PERIODS:

- Size the thermal storage to balance heat generation during warm periods and the demand that occurs later in the day.
- The heat pump controller should be designed to allow for scheduling it to operate according to daily temperature profile.
- Lowering the running cost by limiting the heat pump operation to warm periods in each day should not lower the heat pump capacity factor to a level where the savings from higher ambient temperature are cancelled. Heat pumps are CapEx-intensive components and should be used at higher capacity factors for better system economics.

16. Data extracted from: Veissmann Group, *Technical manual – Heat pumps*, Veissmann Group, 2012, accessed 20 June 2022.

6.4 Refrigerants

Refrigerants are specific substances with generally low boiling point, low evaporation volume, and a high cooling capacity relative to their volume. Upon phase change from liquid to vapour, the density of a refrigerant should change as little as possible. This feature reduces the amount of energy that the compressor needs to consume to recompress the gaseous refrigerant.

Refrigerant loss reduces heat pump efficiency and capacity and can add to scope one greenhouse gas emissions. Refrigerant monitoring systems are increasingly important, and monitoring electricity use versus heat provided can allow real time COP and capacity to be tracked to identify the refrigerant loss as well as to optimise performance.

Driven by environmental and safety concerns, governments worldwide are moving towards the phase-out of traditional refrigerants such as hydrofluorocarbons (HFCs) in favour of alternative ones with lower global warming potential (GWP).

Toxicity, flammability and GWP are the main safety-related parameters of refrigerants. For the GWP of existing refrigerants, including the existing HFCs as well as HFC-blends and hydrocarbons, refer to Appendix A.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 34 provides a safety metrics for refrigerants based on their toxicity and flammability as illustrated in the following tables[17].

Table 3: *The safety risk criteria of refrigerants defined by ASHRAE 34.*

Increasing flammability ↑	Lower toxicity	Higher toxicity
Higher flammability	A3	B3
Lower flammability	A2	B2
Lower flammability	A2L	B2L
No flame propagation	A1	B1

Increasing toxicity →

Table 4: *The GWP and safety classification of most common refrigerants in the current market.*[17]

Refrigerant classification	GWP	Safety classification
HFC-410A	2088	A1
HFC-407C	1774	A1
HFC-134a	1430	A1
HFC-32	675	A2L
R513A	631	A1
R466A	733	A1
R454B	465	A2L
Hydrocarbons (e.g. Propane)	4	A3
CO_2	1	A1
HFO-1234	<1	A2L

For further information about the refrigerants listed in this table, refer to Climate Risk of Heat Pump report[18].

Natural refrigerants including ammonia, hydrocarbons (HCs), carbon dioxide are well proven options already used in the heat pump market.

LOOK AHEAD WHEN SELECTING YOUR REFRIGERANT

When selecting a heat pump, the long-term availability of its refrigerant should be considered. Many synthetic refrigerants may phase out in the coming decades. Maintaining a new heat pump until the end of its life can be costly or even impossible, should its refrigerant be phased in the next decade or two.

17. UNEP (UN Environment Program), *Update on New Refrigerants Designations and Safety Classifications - UNEP ASHRAE Factsheet 1*, UNEP, 2015, accessed 20 June 2022.

18. Data regenerated from: Expert Group, *Climate risk of heat pumps*, Energy Victoria - DELWP, 2022, accessed 24 June 2022.

6.5 Defrosting the heat pump

While heat pumps are designed with a defrost cycle to deal with icing, there can be impacts on performance, particularly if inappropriate equipment is selected. Poorly managed defrosting will reduce performance by more than 25%, while a heat pump will not deliver any heat at all in the worst-case scenario where the evaporator coils are fully iced-up. Evaporator sizing can reduce icing issues by reducing the temperature differential between the evaporator and air temperature.

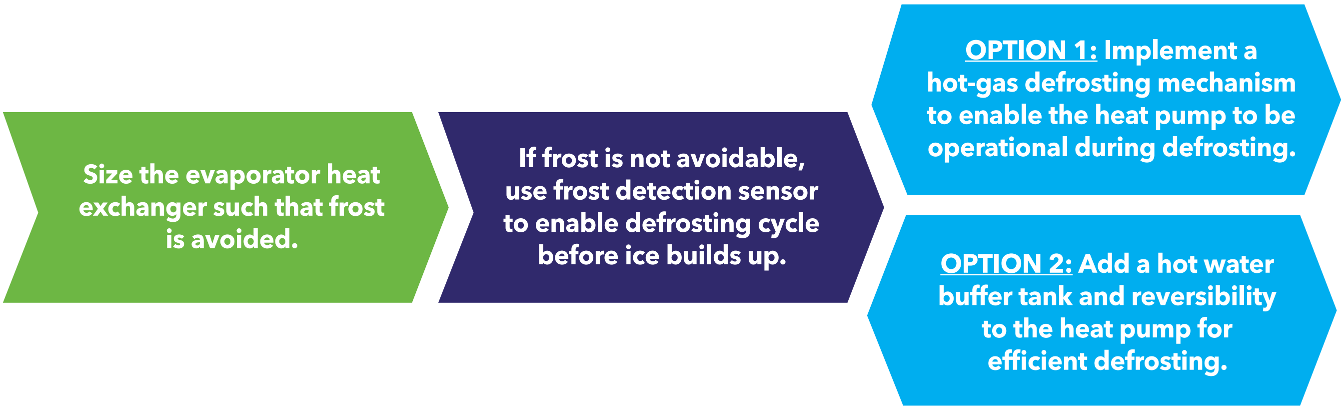


Figure 11: *Steps to mitigate icing issues on heat pumps.*

The best de-icing strategy is to detect ice on the coil via sensors and put the unit into defrost mode. This approach prevents the heat pump from operating under inefficient conditions and the further build-up of ice. As there is an increased focus on the reduction of energy consumption, performing a quick and efficient defrost is key to achieving overall energy consumption goals of the refrigeration system.

In reversible heat pump systems, defrosting is usually carried out by switching the heat pump into reverse cycle operation in which the evaporator becomes the condenser. Hot refrigerant is directed to the frozen heat exchanger to remove the ice. When operating in this mode, electricity continues to be used by the compressor and heat is removed from the new heat sink. Air source heat pumps are recommended to be installed with a buffer tank to prevent heat extraction from the hot water storage tank when operating in defrost mode. Typically, the defrosting cycle takes place between ambient temperatures of 0 °C to 10 °C.

Hot gas defrost is another efficient defrosting method. In most cases, it would be also the most cost-effective way when compared to other available methods (e.g., brine defrost). With this method, some hot gas from the compressor is diverted to the evaporator. The presence of hot gas increases the evaporator temperature slightly above the freeze condition and prevents further build-up of ice.

TO PREVENT ICING ISSUES:

- Maximise the use of waste heat to increase the heat source temperature.
- Use a thermal storage system to generate heat during warmer hours.
- Size the evaporator coil such that it minimises the intensity of heat extraction from air.
- Consider solar thermal collectors for a boost of air temperature at the evaporator coil.

6.6 Waste heat recovery

Waste heat has different definitions and characteristics across various thermal applications. In simple terms, it is any stream of heat (such as warm air leaving the condenser of an air-conditioning system) that is warmer/hotter than the ambient air and can be utilised for heating other media.

One of the features that should never be overlooked in a heat pump system is its ability to upgrade waste heat. Waste heat improves heat pump performance by improving its COP and helping it to avoid icing (See section 6.5).

THINGS TO CONSIDER WHEN UTILISING WASTE HEAT:

- **Waste heat temperature** should be within the operational range of the heat pump's evaporator.
- **Waste heat amount** should be significant enough to justify the extra heat exchanger
- Utilising waste heat should not introduce **corrosion risks** to the heat exchangers of a heat pump. Check this with the heat exchanger manufacturer. A special coating can be applied on the heat exchanger to avoid corrosion.
- If waste heat is available when there is no heat demand, the heat pumps should be coupled to a thermal storage system to upgrade and store the waste heat for a later use.

6.7 Auxiliary heaters

Auxiliary heaters are used in many heat pump systems when the:

- maximum required water temperature in an application remains beyond the reach of the heat pump system, even after utilising any opportunities to reduce it
- the output power of the heat pump power fails to meet a rare peak demand
- the output power of the heat pump fails to meet demand when the COP has dropped on cold winter days.

Using auxiliary heaters to meet the balance of demand in extreme conditions can be more economical than oversizing the heat pump. Otherwise, the extra capacity of the oversized heat pump will be used only for brief periods, increasing the CapEx of the system (it should be noted that heat pump CapEx is significantly higher than that for gas burners and resistive heaters).

Depending on the local price of gas and electricity, the resulting running cost can vary. Table 5 and Table 6 show how the cost of heating water at various gas and electricity prices can change when a gas burner or electric resistive heater is employed to boost the temperature of heat pump water heaters.

***Table 5:** Energy cost of heating 1000 L of water from 16 °C to 90 °C with a 60 °C heat pump and a gas boiler. Heat pump COP = 3.0, gas boiler efficiency = 90% (only for indicative purposes).*

Gas price ($/GJ)	Electricity Price ($/kWhe)												
	0.06	0.1	0.14	0.18	0.22	0.26	0.3	0.34	0.38	0.42	0.46	0.5	0.54
6	$2.11	$2.79	$3.48	$4.16	$4.84	$5.53	$6.21	$6.90	$7.58	$8.27	$8.95	$9.64	$10.32
8	$2.47	$3.15	$3.84	$4.52	$5.20	$5.89	$6.57	$7.26	$7.94	$8.63	$9.31	$10.00	$10.68
10	$2.83	$3.51	$4.20	$4.88	$5.56	$6.25	$6.93	$7.62	$8.30	$8.99	$9.67	$10.36	$11.04
12	$3.19	$3.87	$4.56	$5.24	$5.92	$6.61	$7.29	$7.98	$8.66	$9.35	$10.03	$10.72	$11.40
14	$3.55	$4.23	$4.92	$5.60	$6.28	$6.97	$7.65	$8.34	$9.02	$9.71	$10.39	$11.08	$11.76
16	$3.91	$4.59	$5.28	$5.96	$6.64	$7.33	$8.01	$8.70	$9.38	$10.07	$10.75	$11.44	$12.12
18	$4.27	$4.95	$5.64	$6.32	$7.00	$7.69	$8.37	$9.06	$9.74	$10.43	$11.11	$11.80	$12.48
20	$4.63	$5.31	$6.00	$6.68	$7.36	$8.05	$8.73	$9.42	$10.10	$10.79	$11.47	$12.16	$12.84
22	$4.99	$5.67	$6.36	$7.04	$7.72	$8.41	$9.09	$9.78	$10.46	$11.15	$11.83	$12.52	$13.20
24	$5.35	$6.03	$6.72	$7.40	$8.08	$8.77	$9.45	$10.14	$10.82	$11.51	$12.19	$12.88	$13.56
26	$5.71	$6.39	$7.08	$7.76	$8.44	$9.13	$9.81	$10.50	$11.18	$11.87	$12.55	$13.24	$13.92
28	$6.07	$6.75	$7.44	$8.12	$8.80	$9.49	$10.17	$10.86	$11.54	$12.23	$12.91	$13.60	$14.28
30	$6.43	$7.11	$7.80	$8.48	$9.16	$9.85	$10.53	$11.22	$11.90	$12.59	$13.27	$13.96	$14.64

***Table 6:** Energy cost of heating 1000 L of water from 16 °C to 90 °C with a 60 °C heat pump and a resistive heater. Heat pump COP = 3.0, resistive heater efficiency =100% (only for indicative purposes)*

Electricity Price ($/kWhe)												
0.06	0.1	0.14	0.18	0.22	0.26	0.3	0.34	0.38	0.42	0.46	0.5	0.54
$3.13	$5.21	$7.30	$9.38	$11.46	$13.55	$15.63	$17.72	$19.80	$21.89	$23.97	$26.06	$28.14

THINGS TO CONSIDER WHEN SIZING AN AUXILIARY HEATER TO MEET THE ANNUAL THERMAL LOAD:

- Calculate the hourly COP of the heat pump based on the outdoor temperature for a typical meteorological year for the site.
- Size the heat pump and the storage to deliver the 90% of the annual thermal demand
- Size the auxiliary electric heater to meet the remaining 10% of the load.
- Calculate the LCOH for this configuration (see Appendix B)

Microclimate effect

As described earlier, the COP of a heat pump for a certain output temperature depends on the heat source temperature. A heat pump poorly installed in a confined space, such as a plant room or a corner spot outside of the building, can limit the ability of a heat pump to access fresh ambient air. For air source heat pumps, the maximum heat source temperature that is available without any waste heat stream is the ambient temperature. As a result, the continuous extraction of heat from the air around the evaporator coil reduces the available air temperature creating a locally colder climate around the heat pump. This issue severely impacts the COP of the heat pump both because the actual heat source temperature has dropped below the ambient temperature, and also because of the potential icing of the heat pump.

Important: As presented in the tables above, heating with electric auxiliary heaters is costly. Hence, their operation should be reported by the heat pumps system and be monitored by the user. Auxiliary heater use should be kept within the designated range as determined during the design stage.

THINGS TO CONSIDER TO AVOID MICROCLIMATE EFFECTS WHEN INSTALLING HEAT PUMPS IN INTERNAL SPACES:

- Provide enough ventilation to the space.
- The required rate of ventilation is a function of heat pump power.
- The ventilation requirement can be calculated using psychrometric charts, similar to what is common in HVAC industry.
- In such a calculation, the required ventilation should be determined to compensate the heat extraction by the heat pump while preventing the air temperature from dropping more than 5 °C.
- Monitor the air temperature in the confined space to ensure enough ventilation over the lifetime of the heat pump.
- In the case of outdoor heat pump units, avoid directing the exhaust air from one heat pump to the inlet of the next one
- Regardless of installing the heat pump outside or inside, provide it with waste heat if possible.

6.8 Heat pump configurations

Correctly configured heat pumps can achieve a higher COP and deliver greater energy savings. As described in Section 4, heat pumps cool their heat source side and heat up their heat sink side. This concurrent generation of cooling and heating can be utilised to increase the energy performance and productivity of the heat pump system.

From basic thermodynamics, for a heat pump:

$$COP_{heating} \approx COP_{cooling} + 1$$

This means that a heat pump with a heating COP of 3.0, can simultaneously deliver 2 kWh_{th} of cooling energy and 3 kWh_{th} of heating energy for every kWh_{e} of electricity it consumes. Utilising this aspect of a heat pump is a form of waste heat recovery in which the cooling energy generated by a heat pump is used for cooling applications in the plant, with little extra capital investment in the heat pump system.

In the HVAC industry, this type of heat recovery is carried out by three- and four-pipe heat pump systems. In those systems, hot and cold refrigerant that are concurrently generated by the central heat pump system are directed to the indoor air-handling units that each can be operating in cooling or heating modes.

Depending on the ratio between the instantaneous cooling and heating demands, the main heat pump can be in cooling or heating modes controlling the amount of hot and cold refrigerant going into each air-handling units.

The same approach is applicable for heat pump water heaters. While heating up water, the cooling generated at the heat sink side of the heat pump can be utilised for other applications such as space cooling or chilled water generation. The schematic of refrigerant flow in a three-pipe heat pump system is presented in Figure 11.

Depending on the ratio between the instantaneous cooling and heating demands, the main heat pump can be in cooling or heating modes controlling the amount of hot and cold refrigerant going into each air-handling units.

The same approach is applicable for heat pump water heaters. While heating up water, the cooling generated at the heat sink side of the heat pump can be utilised for other applications such as space cooling or chilled water generation. The schematic of refrigerant flow in a three-pipe heat pump system is presented in Figure 12.

Depending on the amount of heating and cooling required, various outcomes can occur:

> **Balanced heating and cooling** – no heat will be wasted. All the cooling energy generated in the water heating side will be utilised for water cooling.
>
> **Heating mode** – when the required water heating power is higher than the cooling power, a smaller fraction of the refrigerant will be directed to the water-cooling side.
>
> **Cooling mode** – when the required cooling power is dominant, the cold refrigerant line carries more fluid to the chiller.

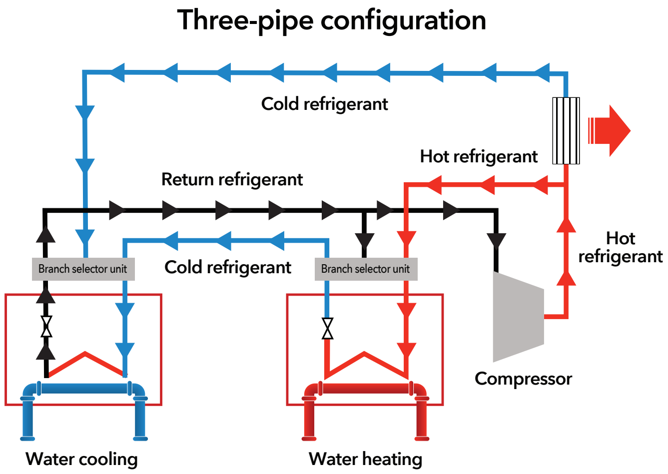


Figure 12: *A three-pipe refrigeration cycle.*

In the last two situations, some of the either cooling or heating power will remain unutilised. Hence, this kind of heat pump system is more beneficial when a relatively balanced and a similar amount of cooling and heating load exists simultaneously.

If the cooling and heating demands in an application occur at different times of the day, cold and hot thermal storage systems can be used to enable three- and four-pipe heat pumps to cogenerate heating and cooling.

> It should be noted that sometimes three- and four-pipe configurations are defined for the water loop. A schematic of a four-pipe heat pump is illustrated in Figure 12. Again, depending on the balance between the required heating and cooling load, the heat pump can absorb heat from or reject heat to the ambient. In a balanced mode, no heat exchange with the ambient will be required.
>
> Considering such heat pump systems can lead to a higher combined heat pump COP and lead to significant energy savings in a plant.

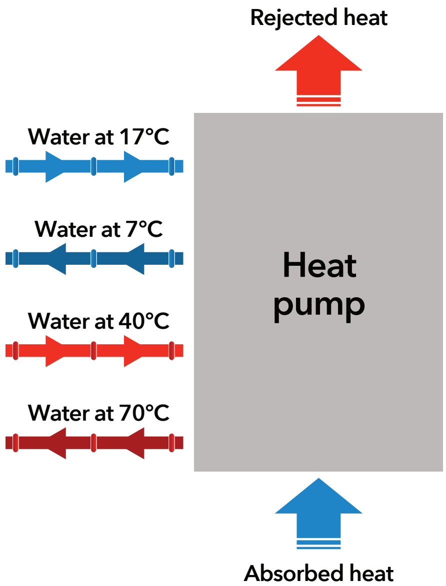


Figure 13: *A four-pipe heat pump.*

THINGS TO CONSIDER TO CHOOSE THE CORRECT HEAT PUMP CONFIGURATION:

- Review the energy use profile to identify whether there is a need for both heating and cooling
- Calculate the amount of heating and cooling – if the amount of required cooling is too low, cogeneration might not be economical. In these cases, separate smaller cooling systems can be added to the application without altering the main heat water heat pump configuration
- If there is a balancing cooling load, check if there is a time mismatch between heating and cooling
- In the case of a time mismatch, use a hot thermal storage tank to generate hot water when there is a need for cooling power (see Section 5) (hot storage tanks are more economical than cold storage tanks).

6.9 Heat pumps in manifold systems

'Manifold systems' refers to the piping configuration of multiple heat pumps to serve a thermal application. Such manifold configurations may be needed when the thermal load is beyond the reach of one heat pump. Hence, it is required to bundle multiple heat pumps and even storage tanks to meet the thermal demand. However, poor manifolding can occur, usually as the result of either series connections or unbalanced parallel connections.

Multiple heat pumps connected in series is usually an intentional design choice to compensate for a deficiency in performance of the heat pumps (likely an inability to get up to temperature). However, it is a poor choice. In such designs, the first heat pump in the will usually be generating lots of heat while the last one is operating under extreme conditions leading to wear and tear of its compressor. This leads to a shorter lifespan for the overloaded heat pumps.

Heat pump water heaters should be installed in parallel to each other. The principle of balanced flow (AS/NZS 3500.4: 2021 Plumbing and Drainage, Part 4 for Heated Water Services) should be applied across the entire system design. In such pipework design, the flow is spontaneously regulated between the heat units. For the correct pipework for manifold heat pumps systems, refer to the illustrations in Appendix H. Note that looping of pipe work to achieve a balanced parallel connection should always be on the cold water line to minimise heat losses.

Setting up heat pumps in series also increase difficulty during maintenance and repairs. In parallel systems, one heat pump can be turned off, isolated, and disconnected while the other heat pumps can continue functioning as normal, minimising disruption to the hot water service.

The rated flow rate of the tank connections should also be compared to the flow rate of the heat pump. If the heat pump is too powerful for the tank connections, you will need to manifold more tanks to split that flow across them.

Quality pipe insulation is critical. Particularly between heat pumps and tanks in split systems with significant distance between the tanks and heat pumps. A poor installation might have trouble bringing the tanks to the heat pump's set temperature causing the heat pump to operate 24/7.

6.10 Determining heat pump quality

A number of different factors help determine the quality of a heat pump, including:

Functionality
This refers to the capability of the unit to operate under various conditions of ambient operating temperature, water temperature range, part/full load operation, high performance in cold conditions, freeze protection, effective de-icing, resistance to local water quality. For more details, refer to Appendix F.

Build quality
Has the unit been manufactured from suitable/durable materials for the site/location it is being installed? For example, Australian sites are mostly located along the coastal line, and care should be taken to account for corrosion. Suitable materials and coil coatings may be required to protect the equipment against corrosion. For more details, refer to Appendix F.

Controls
The system should be relatively easy to understand and operate by the end user. It should be easily programmable to operate peak/off-peak and ideally be connected to a cloud server for monitoring and troubleshooting.

A quality heat pump unit should use efficient components such as:

- variable speed fans and pumps
- variable speed compressors
- pipe bending (instead of welding) to reduce brazed joints and to lower possible leak rates.

Good quality products should meet test requirements and comply with the relevant Australian standards. If a heat pump complies with standards, then the user can have some level of confidence that it is a well-designed product. However, meeting the standards does not necessarily mean that the heat pump will perform well in the user's specific application. The tests that are conducted on heat pumps to be certified covers a limited number of scenarios that might not cover all the nuances of a real-world installation and application.

THINGS TO CONSIDER TO VERIFY THE QUALITY OF A HEAT PUMP SYSTEM:

- Use components from reputable manufacturers at least for the key parts such as the compressor and the expansion valves.
- Request the components manufacturer data and get them checked through expert advice.
- Seek references from existing users preferably for the same system installed for similar applications in the same climate zone.
- Check the warranty policy and ensure that the components come with a market standard cover periods. For example, a compressor should last for around 40,000 to 50,000 hours.
- Ask for reports and certificates from the component supplier, such as datasheets covering the corrosion resistance of their products. If they do not have such reports, then their products have perhaps not been designed properly for that specific application and may not be fit for the purpose.

Refer to Appendix F for more comprehensive list of actions that can be taken to ensure the system is of high quality.

6.11 The impact of poor installation on performance

A heat pump with a good COP by itself does not guarantee an energy efficient performance. Thermal losses from the tank, heat losses from the pipe works, use of the auxiliary resistive heater and poor installation of the heat pump (such as in confined spaces) can adversely impact the COP of the entire system.

A heat pump water heater system usually includes additional components such as a thermal energy storage, extra pipe works, auxiliary heater, and a control system. When assessing the potential benefits of a heat pump design, one should carefully investigate the COP of the entire system, including these components, and not just the heat pump itself.

A lack of fundamental understanding of entire heat pump system and how each component interacts with the others is a key cause of poor installations. This is in addition to the conservative nature of sizing that affects a heat pump more than a typical chiller. Oversizing a heat pump tends to create more problems than oversizing a chiller, although both situations are sub-optimal for the equipment and the end user.

The following reasons can lead to poor performance of a heat pump system:

- **Wrong equipment sizing** – Oversizing leads to poor economics. Undersizing fails to meet the demand and can place equipment under increased loads reducing service life and efficiency.
- **Thermal loop capacity** – If the outlet temperature of the heat pump is lower than the existing system, then the thermal loop including the circulation pump and/or the heat delivery systems such as the radiator panels should be increased in size.
- **Controls** – While control is more prevalent in larger 4-pipe heat pumps, there are additional considerations in a heat pump installation that must be factored in. Interviews with suppliers have revealed that most failures in large plants are caused by control problems. Well-engineered control system is critically important for every heat pump application, but in large-scale systems, it is vital.
- **Inadequate output temperature** – If the output temperature of the heat pump does not match the load requirement, either the system becomes redundant, or significant amount of boosting is required to make it operational. At a certain level of electric resistive boosting, the heat pump may become uneconomical to operate.

THINGS TO CONSIDER TO VERIFY THE COP OF THE WHOLE SYSTEM:

Before installation:

- Collect the necessary information for performance modelling. This includes the specification of the heat pump, operating conditions, thermal storage, pipework's layout, and pumps.
- Engage an energy consultancy firm to develop a transient system simulation tool (TRNSYS) model to predict the energy performance of the designed system.
- The COP calculations should include the climate zone and operation schedule.

After installation:

- Use measurement and verification methods to quantify the actual COP.
- Use power meters to monitor the electricity consumption of the system.
- Use a flow meter to measure the flow rate of the water through the heating coil of the heat pump.
- Measure the inlet and outlet water temperate to and from the heat pump.
- Conduct an energy balance to quantify the COP using the below equation:

COP = water flow rate [kg/s] x (outlet T – inlet T) x 4.2 / input electric power [kW]

6.12 Location and space considerations

The importance of location to the performance of a heat pump system has been highlighted earlier, particularly with regard to ambient air temperature and microclimates. However, there are other location and space-related challenges with heat pumps.

Relative to gas boilers, heat pumps are bulkier, noisier and heavier particularly when they are coupled with thermal storage. They need to be tailored to the plant, taking the following aspects into consideration:

Specific floor area

In comparison to resistive and combustion-based water heaters, heat pumps usually take more floor space. As a rule of thumb, for the same delivered heating power, heat pumps require three times more space. This can be exacerbated when a larger thermal storage that is common for heat pumps is required. Consideration should be given to the available space when assessing the possibility of implementing a heat pump system. One possible solution to overcome the lack of space for heat pump installation is to split a large heat pump and thermal storage unit into smaller ones and install them in different locations.

Equipment weight

The location needs to be assessed to ensure that it can stand the weight of the heat pump and the thermal storage tanks.

Noise control

Noise generated by the heat pump should be quantified and prevented from reaching the occupied area in the building (see Section 4.4).

Access to the ambient air

Adequate ambient air supply to the space in which the heat pump is installed is required to avoid negative microclimate formation (see Section 6.8).

Proximity to a waste heat source

Heat pump can be installed next to a waste heat source (e.g. near an aftercooler for an air compressor) to be able to recover it when possible (see Section 6.6).

6.13 Cost and economics of air source heat pumps

The economic performance of a heat pump is determined by a combination of:

- heat pump equipment costs
- Site-specific condition costs, and
- operating criteria costs.

These factors will contribute to the total CapEx of the heat pump and the expected savings from the investment.

Heat pump equipment costs

The costs for air source heat pump equipment varies greatly according to the quality of the equipment provided. As discussed elsewhere, many factors affect the capital and operating cost of the heat pump equipment, including the control systems, corrosion protection, compressor type, compressor size, refrigerant, motor efficiency, heat exchanger types, service support from vendor, warranty, thermal storage volume and materials of construction. The overall installed cost of the heat pump also varies greatly according to site conditions. Typical equipment costs per kilowatt for heat pumps that deliver hot water between 65 °C and 75 °C are:

Table 7: *Indicative price of air-source heat pumps (equipment only) – prices are in A$/kW of heating power*

	<30 kW	30-100 kW	100-250 kW	>250 kW
HFC heat pumps	~1000	~700	~400	~350
HFO heat pumps	No data available.			
HC heat pumps	~2,000	~1,000		
CO_2 heat pumps	~3000-4000	~2,000	~1500	~1500
Ammonia heat pumps	Not available at this size.			1,000 (for 1 MW system)

Heat pump site-specific costs

Site specific factors affecting the heat pump economics are:

Total energy demand

This will have the largest impact on heat pump economics which is why energy efficiency must be considered first. The total heat demand (e.g., in kWh_{th}) will affect the CapEx and OpEx of the heat pump therefore minimising the total energy demand is the most important factor in improving heat pump economics. End-use services must be assessed for to reduce heat demand. For example, utilising more efficient products, such as low-flow shower heads, which reduce the amount of hot water needed.

Peak heat demand

Most heating demands will not be consistent throughout the day and will have peaks and troughs. If thermal storage is not employed and the heat pump is sized for the heat demand peaks, this will greatly increase the cost of the heat pump and reduce the financial returns. Reducing the peak demand – either by spreading out the demand over a large period or utilising thermal storage – is a vital step in heat pump design. Modelling of several combinations for different size thermal storage systems and heat pumps will be necessary to find the most optimal economics.

Gas price

When changing from using natural gas to an electrically driven heat pump, the assumed gas price will have a large impact on the business case. It may also be worthwhile to consider the impact a carbon price would have when estimating future gas prices. For example, a carbon price of $50/t CO_2-e will add $2.65/GJ to the cost of gas (using 0.053 t CO_2-e/GJ).

Electrical power availability

Upgrades to local distribution boards, main distribution boards or local substations can have a major impact on the heat pump economics. The impact of such upgrades can be alleviated by reducing total energy demand and employing thermal storage to smooth and reduce the peak electrical energy demand.

Timing of energy demand

If the heating demand is during peak electricity times and cannot be shifted and thermal storage cannot be employed, then the heat pump will operate using higher electricity tariffs. With firmed renewable electricity estimated to cost more than three times that of unfirmed renewable electricity, this will have a substantial impact on heat pump economics.

Space availability

The cost per square-metre of space will affect the heat pump economics and this will vary greatly between sites.

Distance between the heat pump and point of use

This will be a consideration particularly for sites that are converting from delivery of heat from a boiler via steam to delivery of heat from a heat pump via hot water. Large investment costs can be required for conversion of steam ring mains to hot water ring mains. Smaller heat pumps located closer to the point of use can reduce such costs.

Maintenance availability

Commercial and industrial grade heat pumps typically have a high availability of more than 98% when maintained correctly.

Other site-based considerations which may affect economics include noise constraints, building alteration approvals, building alteration costs, building ventilation requirements and the local environment (e.g., being close to salt spray from the ocean) necessitating higher grade materials for the evaporator coils and heat pump enclosure.

Heat pump costs from operating criteria

The economic factors relating to heat pump operating criteria are:

Electricity tariffs

The cost per kilowatt-hour for electricity will have a large impact on the heat pump economics, especially if the heat pump operates during peak time-of-use tariffs. Often this can be alleviated with operational timers, settings and thermal storage.

Capacity factor

The percentage of time that heat pump is operating at maximum capacity will affect the value extracted from the heat pump. The more often the heat pump is running at maximum capacity, the higher the rate of return.

COP

As discussed elsewhere this is closely linked to the heat lift required and can be optimised by reducing the demand temperature or increasing the ambient temperature by operating the heat pump during the day rather than at night.

CapEx

he CapEx of the heat pump is closely linked to the capacity of the heat pump typically listed in kilowatts (thermal) or recovery rate. A reduction in the required capacity can be achieved by implementing thermal storage.

You get what you pay for

The costs of heat pumps available can also vary greatly based on the quality of the offering. When considering product options, factor in the quality and support that may not be included in the cheaper equipment offerings and the future costs that may be incurred as a result down the line. Below are some examples of how grades of product offerings may differ in what they offer.

Table 8: *Different quality/performance levels for heat pump components.*

Heat pump attribute	Example of lower grade	Example of higher grade
Evaporator coils	No corrosion protection	Epoxy coated
Compressor type	Reciprocating	Screw
Compressor size	Smaller compressor	Larger compressor
Controls	Simple	Defrost, solar PV forecasting
Refrigerant	Higher GWP hydrofluorocarbon e.g., R410a	CO_2/ammonia/propane
Service	Long service waits	24-hour service
Warranty	Less than 12 months	More than two years

THINGS TO CONSIDER WHEN DETERMINING EXPECTED SAVINGS:

- **Total heating costs for the current system**
  Often the boiler efficiency is used to assess the current heating performance, however, this ignores the many hidden losses from a steam system, such as heat losses through pipes, condensate loss, boiler blowdown, standby losses, etc. Steam boiler efficiency is often simply calculated by considering the wasted heat leaving the flue, usually giving an efficiency of 75–85%. However, a steam system typically operates with an efficiency of less than 65% (i.e., a COP of 0.65) after considering all the hidden losses. Compared to a heat pump which will likely operate with a COP of 3.0, the reduction in energy used will be more than 4.5 times (3/0.65).
- **Levelised cost of heating (LCOH)**
  This is a good method to compare the true heating costs as it considers the operating and capital cost impact.
- **Non-energy benefits**
  Be sure to consider non-energy benefits such as the potential to increase production, higher product quality, water saved due to reduce boiler blowdown, reduce safety risks, etc. These can often provide a large boost to the business case for a heat pump.
- **Future electricity prices**[19]
  Using CSIRO's GenCost report , the expected cost of unfirmed, renewable electricity is expected to reduce greatly over the next 30 years.

19. Commonwealth Scientific and Industrial Research Organisation (CSIRO) *GenCost 2020-21 Final report*, CSIRO, 2021, accessed 24 July.

6.14 Tariff optimisation

If time-of-use electricity tariffs are available from the electricity provider, heat pumps can be scheduled to operate in particular periods to minimise energy costs. In the example presented in Figure 14, the heat pump operation is shifted outside of electricity peak price hours. With the price data mentioned in the caption of the figure, the cost of heat drops from $0.12/kWh$_{th}$ to $0.09/kWh$_{th}$ for each kilowatt-hour of heat from operation Schedule 1 to operation Schedule 2 (i.e., a 25% reduction). Tariff optimisation can be possible if suitable thermal storage is employed in the system (see Section 5).

Optimising for the least heat pump operation cost may not necessarily lead to lower emissions. However, it is expected that the off-peak hours will soon occur in the middle of the day when there is excess PV generation. This will mean that low-tariff periods will coincide with lower grid emission intensities periods.

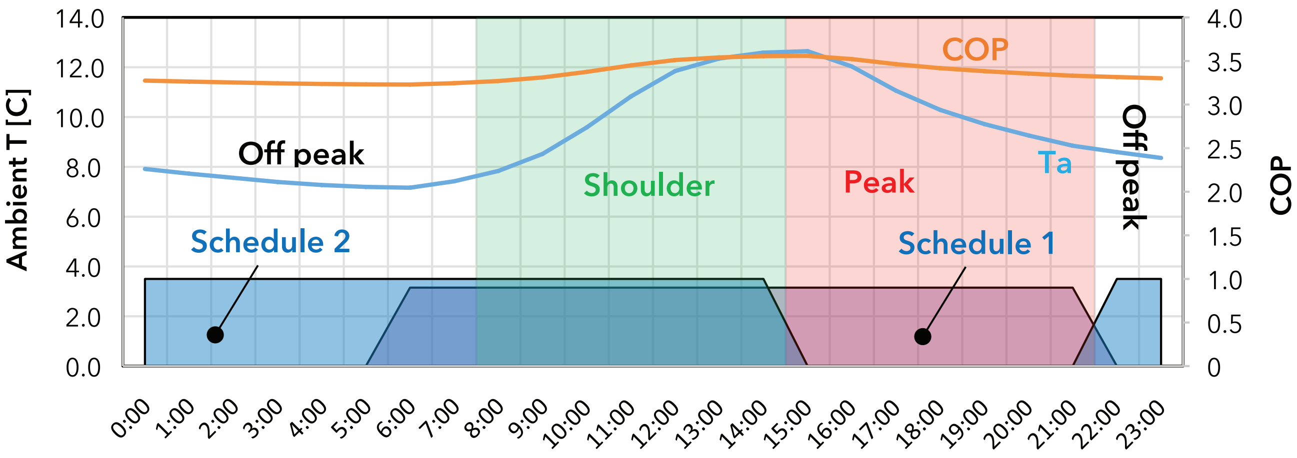


Figure 14: *Shifting heat pump operation schedule to optimise for electricity prices; electricity price = $0.50/kWh$_e$ (peak), $0.39/kWh$_e$ (shoulder), $0.24/kWh$_e$ (off-peak) – with operation Schedule 1, the heat pump operates from 05:00 (am) until 22:00 – with operation Schedule 2, the heat pump operates from 21:00 until 15:00 the next day.*

THINGS TO CONSIDER WHEN ADOPTING LOAD-SHIFTING

Cost of thermal storage
Price differences should be high enough to justify increasing the size of the storage. If the price difference is not high enough, it would be more cost-effective to run the heat pump for longer (even during the peak time) to achieve a higher capacity factor from it and lower the size of the storage tank.

Ambient air temperature
Currently off-peak prices are mainly at night-time. Operating the heat pump during cooler hours at night reduces its COP (see Section 6.3). The tariff price difference should be high enough to compensate the COP drop.

Heat losses from the thermal storage system
Heat loss from the storage should small enough to justify generating heat earlier and use it later in the day.

6.15 Victorian Energy Upgrades (VEU) program incentives

At the time of publishing this document, the Victorian Government has an active Victorian Energy Upgrade (VEU) program. This program is governed by the Victorian Energy Efficiency Target (VEET) Act 2007 with the primary objective to promote the reduction of greenhouse gas emissions. The VEET Act is accessible through the Victorian Legislation website[20].

DELWP has introduced a commercial and industrial heat pump water heater activity (Part 44) into the VEU program. The commencement date of this activity was 1 February 2022. The activity includes incentives for installing heat pump water heaters under three scenarios as described in Table 9.

Table 9: *Scenarios defined under activity 44 of VEU program (heat pump upgrade).*

Scenario	Description
44A	Decommissioning one or more gas-fired hot water boilers or gas-fired water heaters and installing an air source heat pump water heater.
44B	Decommissioning one or more electric resistance hot water boilers or electric resistance water heaters and installing an air source heat pump water heater.
44C	Installing an air source heat pump water heater.

The details of this activity have been provided as a guidance document by the Essential Services Commission (ESC)[21]. Those who are seeking accreditation or are accredited or are installer seeking to undertake installations for this activity under the program should refer to this guidance document for further details. The current document avoids duplicating the information contained in the above source, and only highlights the key facts.

To be eligible for the incentives under Part 44 of the VEU program, the upgrade must be undertaken in:

- a business or non-residential premise
- the common area of a multi-residential building.

Under this deemed activity, the number of VEECs that a heat pump upgrade can receive is calculated based the efficiency of the existing heating system (e.g., a resistive heater or gas boiler), expected lifetime of the new heat pump and the heat demand profile. A more comprehensive list of parameters determining the number of VEECs for a heat pump installation is provided in Section 2 of the ESC's guidance document.

Table 10: *The approximate VEEC incentives available for common heat pump upgrades at the time of preparing this document; Zone=4 (Vic), VEEC price = $63, Storage volume = 160–340 L (indicative values suggested by EnergyAE[22])*

	44A - Gas	44B - Electric heater	44C - New
Small 2–5 kW_{th}	$500	$2,000	$400
Medium 5–10 kW_{th}	$800	$4,000	$750
Large 10–20 kW_{th}	$2,000	$7,500	$1,500

20. Victorian Legislation, *Victorian Energy Efficiency Target Act 2007*, Victorian Legislation, 2021, accessed 24 July 2022.
21. ESC (Essential Services Commission), *Victorian Energy Upgrades program*, ESC, 2022, accessed 24 July 2022.
22. http://www.energyae.com/

In more complex heat pump installations where there is a desire for more accurate abatement values, the VEU measurement and verification (M&V) method can be used.

THINGS TO CONSIDER WHEN WANTING TO CREATE VEECs FOR A HEAT PUMP INSTALLATION:

- VEECs can only be created by accredited/approved providers. The end user needs to assign the rights to the emissions reduction to an accredited provider to complete the creation process of the VEECs. See the ESC website to find out who can be accredited.
- Ensure that the product you wish to install is an approved product on the VEU registry.
- Before carrying out the upgrade, collect the baseline information by investigating the existing heating system. The required information has been listed in Sections 5 and 6 of the ESC's guidance document.
- Complete the upgrade and collect the information for the creation of VEECs. The required information has been listed in Section 5 and 6 of the ESC's guidance document.

There are a number of steps for registering the product on the VEU registry, as illustrated below.

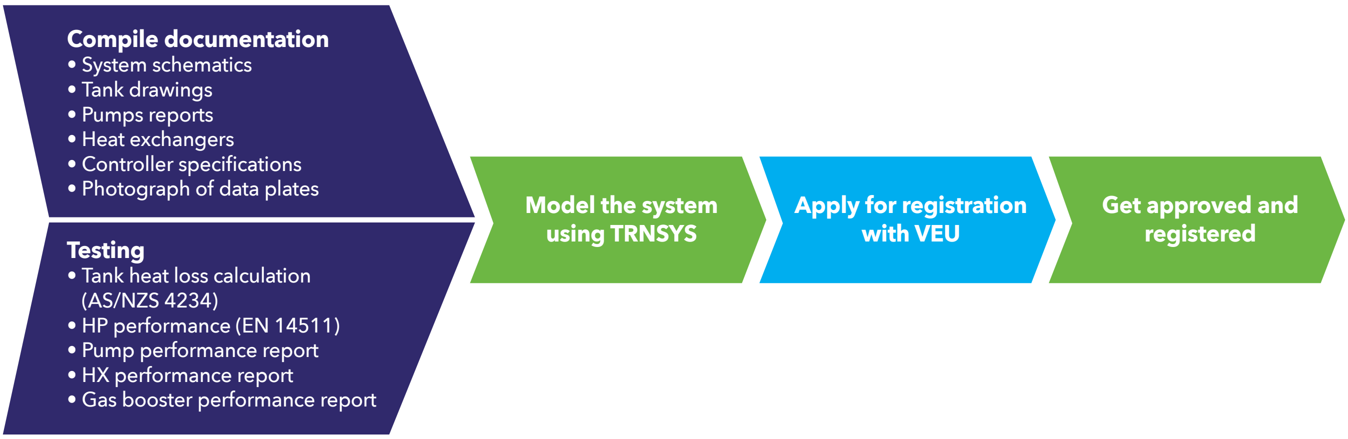


Figure 15: *The process for registering the product on VEU's registry (Courtesy EnergyAE[21])*

The process for claiming the VEECs for a heat pump upgrade is relatively straightforward, illustrated below.

Figure 16: *The process for claiming the VEECs for a heat pump upgrade (Courtesy EnergyAE[21]).*

Receiving VEECs for bespoke systems is sometimes more difficult. They may need more extensive TRNSYS modelling that can be costly. If the savings are expected to be high then the modelling cost can be justified, but if the saving is low, rough but conservative calculations can be carried out for the minimum number of VEECs that can created.

6.16 Sensitivity of heat pump system economics

As discussed, the main factors affecting the economics of a heat pump installation are heat demand, capacity factor, electricity price (and ratio to gas price), COP and capital expenditure (CapEx).

The relative impact of each is shown in Figure 16 using a base case for a 1 MW_{th} heat pump, with a capacity factor of 50%, CapEx of $700/$kW_{th}$, $130/MWh for electricity and COP of 3.0.

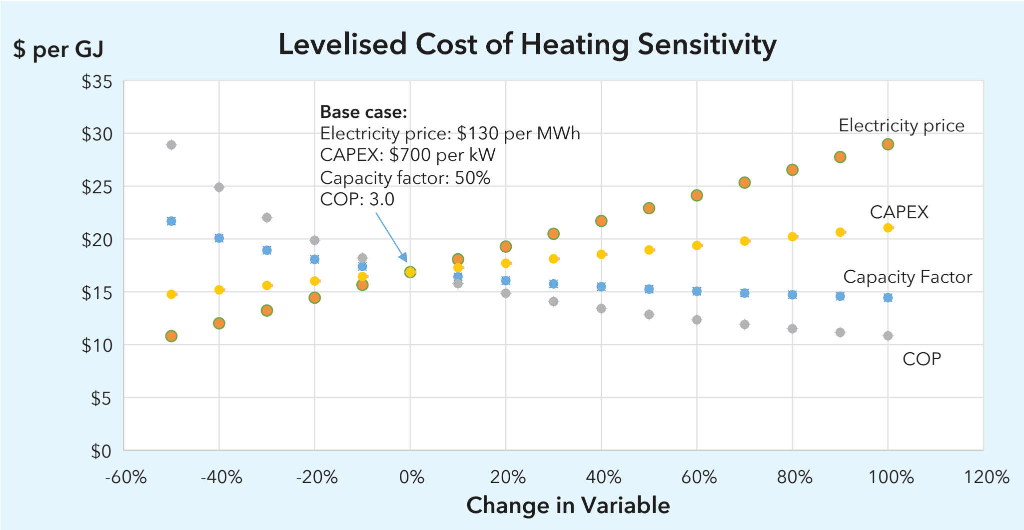


Figure 17: *Levelised cost of heating sensitivity.*

However, as mentioned earlier the most important factor is the heat demand. When considering the total annual levelised cost of heating, changes to the heating demand has the biggest impact as shown in Figure 18.

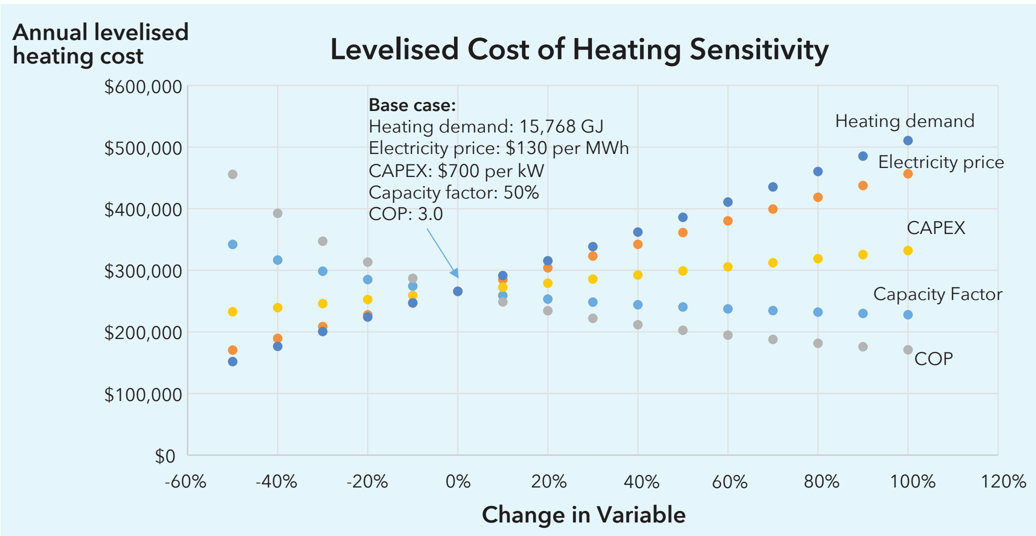


Figure 18: *Annual levelised cost of heating sensitivity.*

Note: The CapEx $/$kW_{th}$ adjusted for the 'Heating demand' curve as the size of the heat pump dictates the CapEx. Smaller heat pumps have higher costs per kilowatt-thermal.

Given this sensitivity, actions to improve heat pump economics could include:

- **Heating demand**
  Reduce heating demand through improving thermal building performance, reducing heat losses and recovering waste heat.
- **Electricity price**
  Procurement of best possible electricity contract or investing in on-site solar PV.
- **COP**
  Consider refrigerants which can deliver higher COP, such as ammonia, CO_2 and propane.
- **Capacity factor**
  Optimise the capacity factor through the inclusion of a thermal storage system.
- **CapEx**
  Optimise through the use of a thermal storage system and good engineering and procurement practices.

When upgrading for a heat pump water heater, the sensitivity of the system economics to the gas and electricity prices should be taken into account.

The cost of generating heat with gas boilers is driven mainly by their gas consumption, as they require little upfront cost for installation. Using a conversion efficiency of 78.8% as chosen by the VEU program, the cost of heat from gas can be calculate as the following:

Cost of heat from gas [$/GJ of heat] = gas price [$/GJ of gas] / 0.788

When the cost of heat generated by a heat pump over its useful lifetime considers the upfront cost and the running costs (i.e., electricity consumption), the levelised cost of heat is a better indicator of the economics of the system (see Appendix B).

Higher gas prices and lower electricity prices create a more suitable condition for a heat pump upgrade. Additionally, higher capacity factor also leads to better returns and lower levelised cost.

Capacity factor is defined as the number of uptime hours of the heat pump divided by the total hours in a year (i.e., 8,760 hours). The longer the heat pump operates, the higher the capacity factor.

An illustration of the impact of these factors is presented in the following figure.

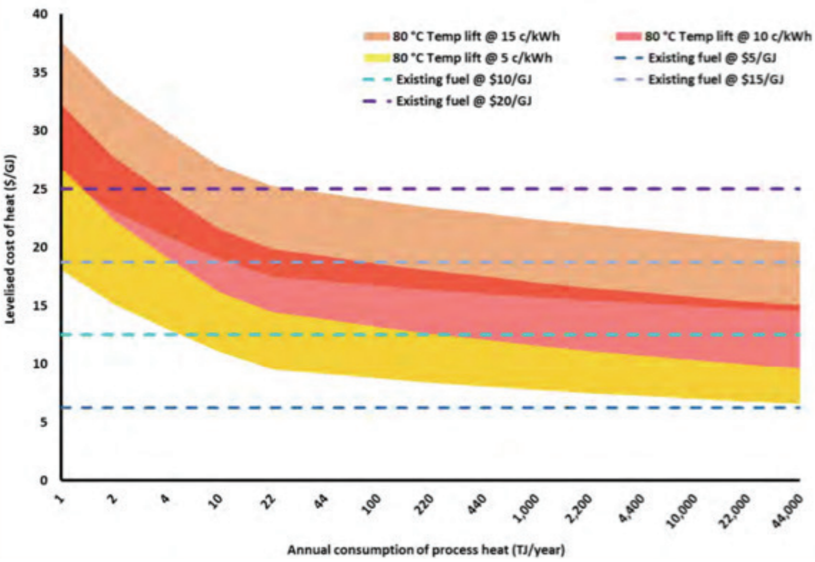


Figure 19: *Cost of heat from a heat pump vs cost of heat from a gas boiler for various annual heat demand, electricity prices and gas prices.*

6.17 Maintenance and monitoring of heat pumps

A typical heat pump will not offer much savings against a gas boiler in terms of maintenance. Maintenance costs can vary depending on the technology and refrigerants used. For example, CO_2 heat pumps require a different maintenance program due to higher pressures and different skill requirements.

Fixed costs are likely to be the maintenance program that includes monthly, quarterly or annual inspections. Often this will consist of oil replacements (for oil-based systems) and other consumables. In some systems, such services are sometimes performed on a need to do basis only and hence are a part of variable maintenance cost.

Variable costs include refrigerant refill (if leaks occur) and component replacement (compressor, controllers, valves, etc). These often depend on the product quality, controls, maintenance programs, and general diligence of those maintaining and operating the equipment.

7 APPLICATION FOCUS: USING AIR SOURCE HEAT PUMP WATER HEATERS IN AGRICULTURE (DAIRY FARMS)

An average dairy farm with no irrigation consumes approximately 48 kWh_e/kL of milk[24]. However, this intensity varies depending on the type of the farm, location and herd size. For example, dairy farms with an automated milking system generally have a higher energy intensity than dairy farms with a conventional milking system.

Switching to a heat pump with thermal storage in this sector offers the potential for lower energy costs. However, it also allows storage and utilisation of on-site renewable generation for use during high consumption periods (which usually do not align with solar generation periods). The steps and design considerations specifically for dairy farms are outlined in Figure 20.

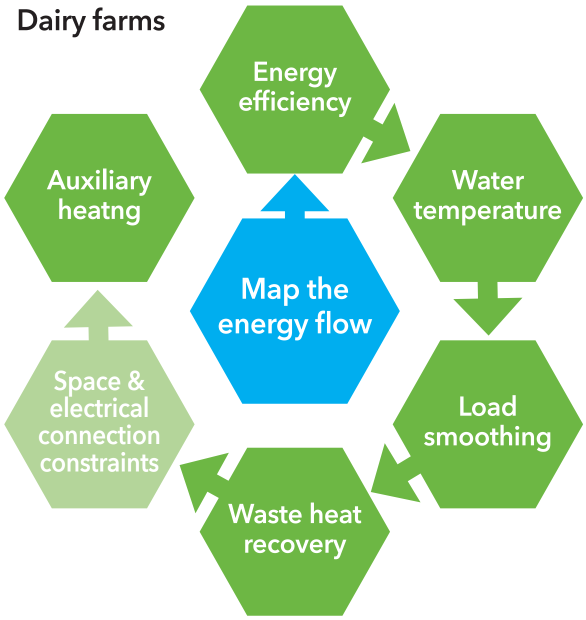


Figure 20: *Design considerations for a heat pump upgrade in a dairy application*

BEST PRACTICE DESIGN CONSIDERATIONS FOR DAIRY FARMS:

- Conduct an energy audit to map the daily and seasonal load profiles.
- Capture the peak heat demand with properly sized thermal storage to reduce the required heat pump rated power.
- Review hot water temperature in consultation with cleaning chemical suppliers to reduce the required temperature if possible.
- Recover waste heat from the primary milk chiller.
- Separate hot water storage tanks for general cleaning and bulk milk vat wash applications since they need different temperatures.
- Monitor hot water temperature at the outlet of the heat pump and the tank to avoid unnecessarily overheating it.

7.1 Energy flow in a dairy farm

The critical first step before any major capital investment is to analyse electricity consumption using metered interval data and equipment information to identify energy losses, rectify them and improve the site efficiency. A breakdown of energy consumption and a heat map can then be developed.

In dairy farms, cleaning milk harvesting (milking machine) and storage equipment with specially formulated chemicals and hot water is essential to ensure high levels of food safety and site hygiene. The hot water system for this purpose is a major component of the dairy farm's operations and energy use. To find out more about the details and required steps of mapping the energy flow in a dairy farm refer to Section 2 of Dairy Australia's Saving energy in dairy farms guide[23].

There are two types of hot water applications on dairy farms:

1. general purpose cleaning with water at a temperature of up to 90 °C, though lower temperatures are possible. This will depend on the cleaning program applied, and more specifically the detergents and sanitisers used.

2. vat cleaning with water at a temperature of up to 70 °C.

The traditional dairy hot water service is usually used for cleaning the milking machine and a mains pressure domestic hot water service is used for cleaning the bulk milk vat[24].

Resistive heaters (with a COP of 1.0) have been the dominant technology to produce hot water in the dairy farming sector. They have a low initial cost, need little maintenance, and have moderate running costs. These systems are sized to provide all of the daily hot water demand by running mainly at night-time and taking advantage of low electricity night-time tariffs (off-peak).

Milk cooling and water heating are the main contributors to the total energy use in a dairy farm. Figure 21 shows the indicative values for each application.

Dairy farms usually have two daily peak loads, which occur during the morning and afternoon milking periods. Based on the size and operation of the farm, the afternoon peak can be similar to or smaller than the morning peak (see Figure 22).

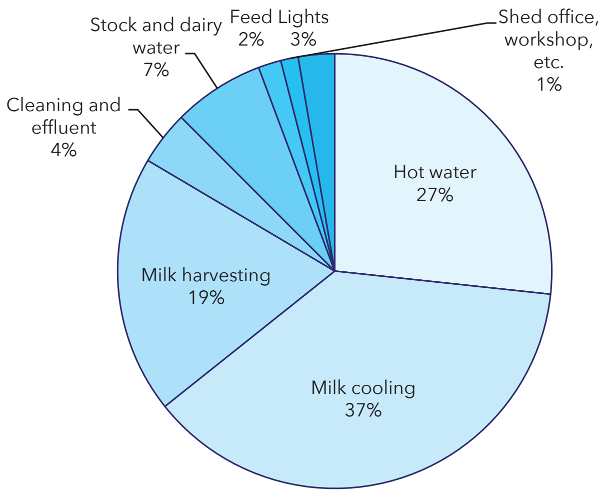


Figure 21: *Breakdown of average energy use in a dairy farm (data provided by pitt&sherry[25]).*

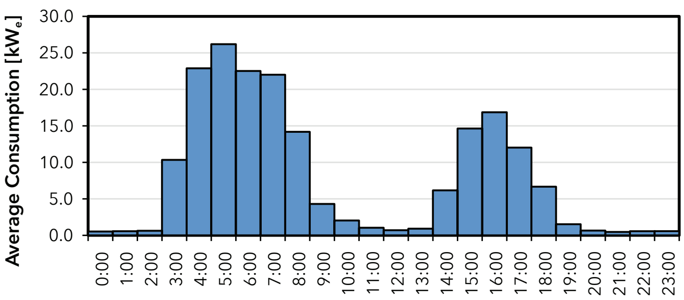


Figure 22: *An example of hourly load profile in a dairy farm (data provided by pitt&sherry.[25])*

23. Dairy Australia, *Saving energy on dairy farms*, Dairy Australia, 2018

24. Water for bulk milk vat cleaning should not be hotter than 70 °C, as specified by vat manufacturers, to prevent potential damage to the evaporative plates inside the vat.

25. https://www.pittsh.com.au/

Energy flow in a dairy farm

This energy consumption profile of a dairy farm varies throughout the year, depending on the calving season. During calving (in spring and autumn), milk production falls off, and so does the energy usage. The seasonal profile for a typical dairy farm is shown in Figure 23. In summer, refrigeration energy consumption is higher, while in winter heating requirements become the dominant end use of energy in winter.

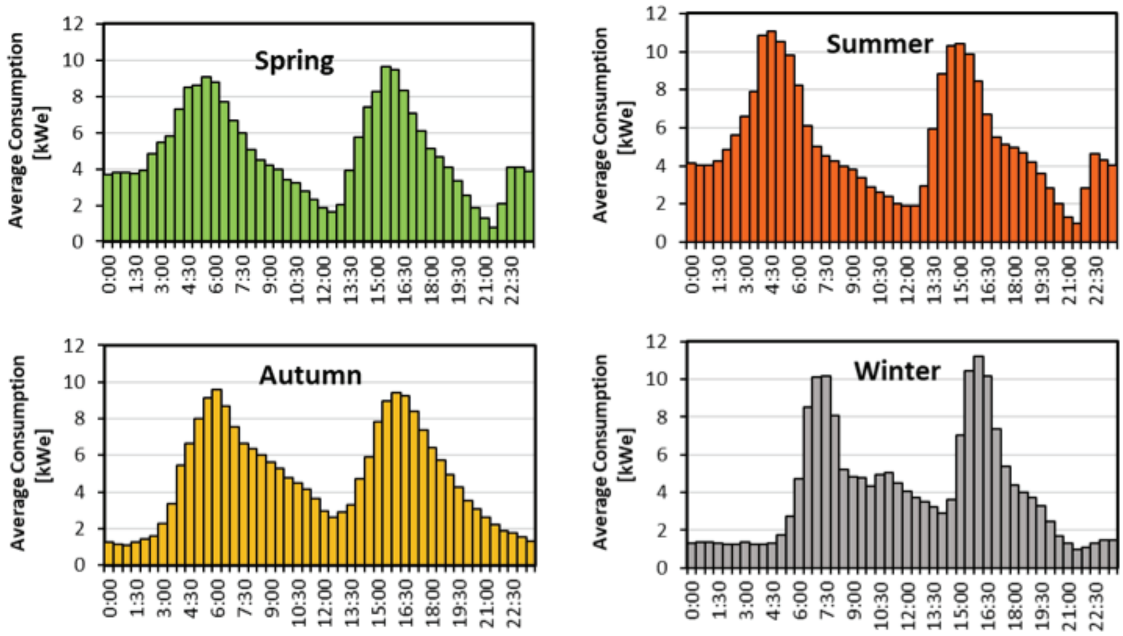


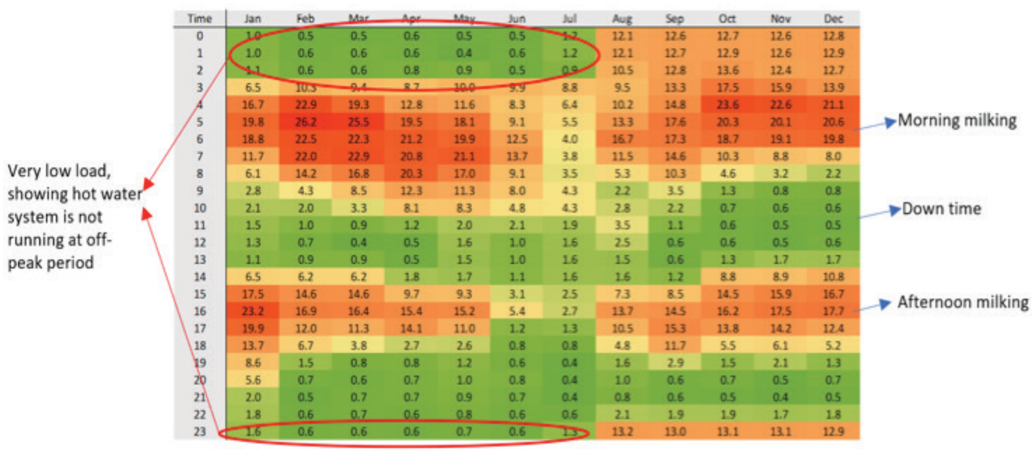
Figure 23: *Average daily profile in a typical dairy farm in different seasons (data provided by pitt&sherry.[25])*

At the time of preparing this document, the majority of dairy farms were using traditional hot water systems with resistive electrical elements. Interviews with industry indicated that a large number of improvement opportunities existed in the sector that could reduce energy consumption, especially by improving the energy efficiency of hot water generation.

Excessive energy use on dairy farms can occur due to a lack of awareness of alternative technologies (such as heat pumps), system failure, low capacity of storage tanks, operator mistakes and lack of understanding the electricity tariffs.

A heat map of energy use can be a useful tool to identify the potential issues. It shows the average energy consumption (in kilowatt-hours for each hour, or kilowatts) for each month throughout the year. Daily heat maps for a dairy farm should have three clearly defined features:

1. two daily peaks corresponding to milking periods
2. downtime between milking intervals, when only equipment such as water pumps and office equipment should be operating (e.g., water pumps and office equipment)
3. an off-peak load where the hot water systems turn on (11 pm-7 am).



Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	1.0	0.5	0.5	0.6	0.5	0.5	1.2	12.1	12.6	12.7	12.6	12.8
1	1.0	0.6	0.6	0.6	0.4	0.6	1.2	12.1	12.7	12.9	12.6	12.9
2	1.1	0.6	0.6	0.8	0.9	0.5	0.9	10.5	12.8	13.6	12.4	12.7
3	6.5	10.3	9.4	8.7	10.0	9.9	8.8	9.5	13.3	17.5	15.9	13.9
4	16.7	22.9	19.3	12.8	11.6	8.3	6.4	10.2	14.8	23.6	22.6	21.1
5	19.8	26.2	25.5	19.5	18.1	9.1	5.5	13.3	17.6	20.3	20.1	20.6
6	18.8	22.5	22.3	21.2	19.9	12.5	4.0	16.7	17.3	18.7	19.1	19.8
7	11.7	22.0	22.9	20.8	21.1	13.7	3.8	11.5	14.6	10.3	8.8	8.0
8	6.1	14.2	16.8	20.3	17.0	9.1	3.5	5.3	10.3	4.6	3.2	2.2
9	2.8	4.3	8.5	12.3	11.3	8.0	4.3	2.2	3.5	1.3	0.8	0.8
10	2.1	2.0	3.3	8.1	8.3	4.8	4.3	2.8	2.2	0.7	0.6	0.6
11	1.5	1.0	0.9	1.2	2.0	2.1	1.9	3.5	1.1	0.6	0.5	0.5
12	1.3	0.7	0.4	0.5	1.6	1.0	1.6	2.5	0.6	0.6	0.5	0.6
13	1.1	0.9	0.9	0.5	1.5	1.0	1.6	1.5	0.6	1.3	1.7	1.7
14	6.5	6.2	6.2	1.8	1.7	1.1	1.6	1.6	1.2	8.8	8.9	10.8
15	17.5	14.6	14.6	9.7	9.3	3.1	2.5	7.3	8.5	14.5	15.9	16.7
16	23.2	16.9	16.4	15.4	15.2	5.4	2.7	13.7	14.5	16.2	17.5	17.7
17	19.9	12.0	11.3	14.1	11.0	1.2	1.3	10.5	15.3	13.8	14.2	12.4
18	13.7	6.7	3.8	2.7	2.6	0.8	0.8	4.8	11.7	5.5	6.1	5.2
19	8.6	1.5	0.8	0.8	1.2	0.6	0.4	1.6	2.9	1.5	2.1	1.3
20	5.6	0.7	0.6	0.7	1.0	0.8	0.4	1.0	0.6	0.7	0.5	0.7
21	2.0	0.5	0.7	0.7	0.9	0.7	0.4	0.8	0.6	0.5	0.4	0.5
22	1.8	0.6	0.7	0.6	0.8	0.6	0.6	2.1	1.9	1.9	1.7	1.8
23	1.6	0.6	0.6	0.6	0.7	0.6	1.3	13.2	13.0	13.1	13.1	12.9

Figure 24: *The heat map of energy consumption in a dairy farm.*

7.2 Energy efficiency to reduce demand

As advised in the general considerations in Section 6, taking steps to improve general energy efficiency of the operations will improve the economics of heat pumps for dairy farms (and reduce energy consumption costs/in the process). Two main methods are:

1. **Reducing the thermal load**
   Increase thermal insulation of the tanks and the pipes carrying hot water from the tank to the point of use.

2. **Reduce the required temperature**
   Thermal insulation of the tank and pipes helps to reduce the temperature of water that needs to be stored. More importantly, consult with a cleaning chemical provider and consider the possibility of using other products that require lower temperatures.

For a more descriptive and detailed options for improving energy efficiency in dairy farms refer to the guidance document published by Dairy Australia[26].

7.3 Heat pump options for dairy farms

The non-uniform hot water usage on dairy farms necessitates the inclusion of a thermal storage system, regardless of the heating technology. Some gas boilers with high heating capacity can operate instantaneously without storage, but heat pumps and resistive heaters will not be able to meet the required thermal demand cost-effectively without storage.

For the high-temperature cleaning application (i.e., at 80 °C), the stored water should have a temperature close to 90 °C to account for heat losses from the tank and the hot water delivery pipes. Hot water at 90 °C is beyond the reach of most heat pumps currently on the market.

Option 1: CO_2 heat pumps

CO_2 heat pumps can generate hot water in two modes: low-temperature at 60 °C to 65 °C, and high-temperature at 90 °C. They are most efficient when they heat up water in one pass from a low temperature below 30 °C (the temperature of mains water) to 65 °C or 90 °C. The COP of these heat pumps can reach a high value of four to five if such a condition is met.

CO_2 heat pumps can be considered for providing both the low temperature and high-temperature applications if the hot water tank in the farm is completely drained in every washing cycle and no hot water is left in the tank. However, complexities arise when the tank is not fully used in each cleaning cycle, and a substantial amount of hot water is left in it until the next cleaning cycle.

When hot water is left in the tank, after a few hours, the temperature of the hot water will drop due to thermal losses, and the CO_2 heat pump will be unable to raise its temperature to above 90 °C again. As a result, the warm water with a significant amount of unusable heat may have to be dumped and fresh water to be heated again with the heat pump. Depending on the amount of hot water that is discarded after each cycle, the economics of a CO_2 heat pump for this application can be weakened.

One solution to overcome this problem is to transfer the remaining hot water from the high-temperature tank to the low-temperature tank if the water temperature is still above 65 °C.

26. Dairy Australia, *Saving energy on dairy farms*, Dairy Australia, 2018. Accessed 20 July 2022.

Option 2: Heat pump with booster

An alternative option is to use a medium temperature heat pump, such as a propane heat pump, to heat up water to around 60 °C to 70 °C to meet the demand for the low temperature application, and then heat this warm water to above 90 °C with the use of a gas boiler or an electric resistive heater. In this option, the running cost will depend on the local cost electricity and gas. Example figures have been presented in Table 11.

HEAT PUMP SELECTION AND PROCUREMENT

Several heat pumps installed in 2021-2022 using CO_2 as a refrigerant have not met performance expectations with cases where:

a. The COP for the heat pump is well below specified in the quote
b. The hot water temperature is not achieving what was specified in the quote
c. Only part of the water in the tank is heated to the required temperature.

Whilst CO_2 heat pumps offer promise, the technology may not yet be fully proven so the purchaser should approach such an investment with caution.

Performance guarantees should be documented to describe the minimum performance standard for typical operating conditions with damages for not achieving 30% of contract value, for example:

For winter
COP >3.0 for 1,500 L of water all at >82 °C, during ambient temperatures of 5 °C to 10 °C and inlet water temperature between 12 °C and 15 °C, with heating completed in less than eight hours.

For summer
COP >3.5 for 1,500 L of water all at >82 °C, during ambient temperatures of 20 °C to 30 °C and inlet water temperature between 15 °C and 20 °C, with heating completed in less than six hours).

Retention of final 30% of contract payment should be included in the terms and conditions to be released once performance guarantee is achieved or full refund and re-instatement of previous equipment at buyer's option.

7.4 Heat pump and thermal storage sizing for dairy farms

As with other applications, the heat pump for a dairy farm should be sized in conjunction with the thermal storage volume. Depending on the climate zone in which the heat pump is to operate, various considerations should be taken into account:

1. Thermal storage capacity should be sized to maximise the capacity factor of the heat pump.
2. The heat pump should be able to recover the heat in the storage tank in between the peaks – this includes the downtime in between the milking periods and over the night.
3. The heat pump storage combination should be able to provide the required heat during the coldest days. To achieve this, optimise the size of the auxiliary heater by considering waste heat recovery options and the average length of the cold periods.

For the evening demand on a dairy farm, the heat pump can generate and store the required hot water during the daytime when the ambient temperature is relatively high. By doing so, the heat pump can benefit from a higher COP and possibly lower electricity prices that are likely to shift to the middle of the day as more solar PV is added to the generation mix. On-site solar PV generation can also be utilised.

Generation of heat for the morning demand is less energy efficient as the heat pump will be operating overnight to store heat for the early hours of the day. During cold nights of the year, this night-time operation will penalise the COP of the heat pump and can even cause icing.

7.5 Heat recovery options in dairy applications

Utilising waste heat has a significant impact on the economics of the heat pump systems, including those used on dairy farms. It improves the COP of the heat pump and therefore the financial viability of the project. There are two main waste heat sources that can be utilised in systems on dairy farms.

Waste heat recovery from the chiller condenser
Milk cooling accounts for a third of the energy consumption in a dairy farm. The heat rejected by the chiller at its heat sink side can be directed to the heat source side of the heat pump water heater. With this method, the heat pump can recover most of the rejected heat from the refrigeration system. Given this recovered heat can be more than the heat required for hot water generation, the heat pump should be sized based on the required heat for hot water generation. A detailed assessment should be carried out to look at the existing refrigeration system, its operational condition and COP to calculate amount of rejected heat and properly size the heat pump.

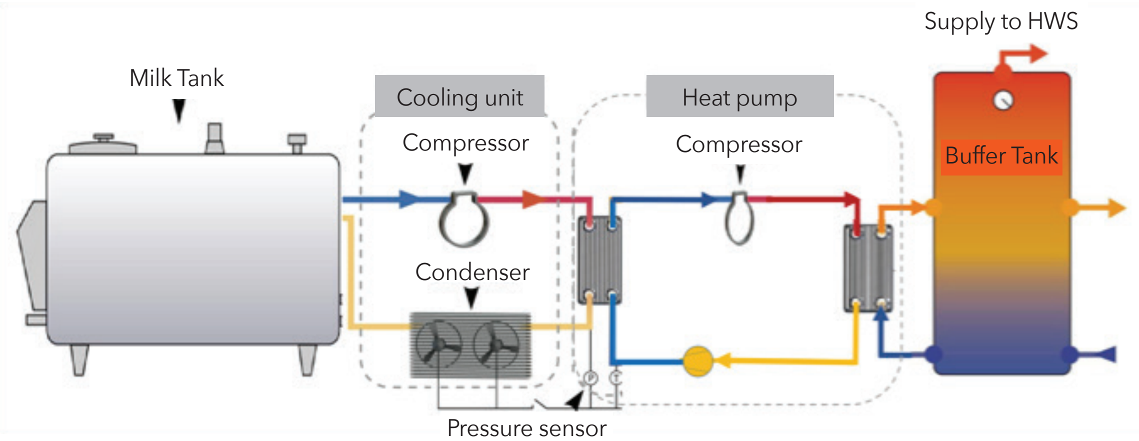


Figure 25: *Schematic of heat pump heat recovery on refrigeration system.*

Waste heat recovery from the chiller compressor
Additionally, by adding a pit stop for the hot refrigerant of the chiller and passing it through a heat exchanger in the water tank, the water can be pre-heated to between 40 °C and 65 °C. This preheated water can be heated further with the heat pump water heater to the desired temperature. This kind of waste heat recovery typically allows to capture up to 33% of the thermal heat rejected by the condenser, while reducing the temperature lift that the hot water systems are required to provide.

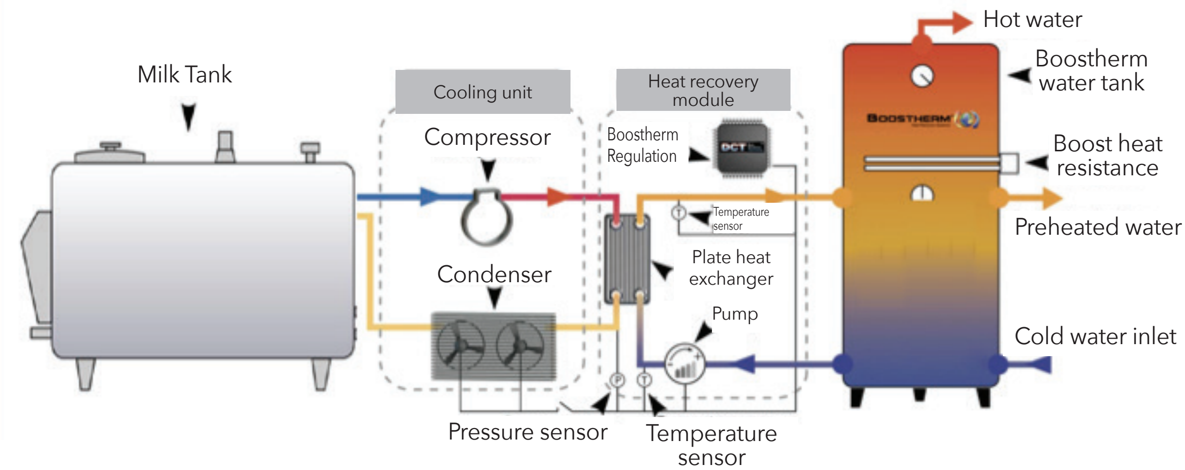


Figure 26: *Schematic of a desuperheater on the refrigeration system.*

7.6 Utilising on-site solar PV generation

Solar generation periods do not directly align with the periods of high energy demand on a dairy farm. Solar energy is generated in the middle of the day while dairy farms typically need heat in the morning and late in the afternoon. Thermal energy storage and electrical batteries are suitable options for dairy farms to maximise on-site utilisation of their solar PV output and make best use of this relatively low-cost energy (see Section 5 for more information about thermal energy storage).

When feed-in tariffs are lower than the off-peak electricity rate, the excess solar PV generation can be directed to the thermal storage to be stored as heat. This can be done via two heating options:

- running the main heat pump
- generating heat with the resistive heater in the tank.

The first option requires enough excess solar PV power to minimise the grid consumption for running the heat pump. The second option can be used at lower excess solar PV power but at the expense of lower COP (i.e., COP of 1.0).

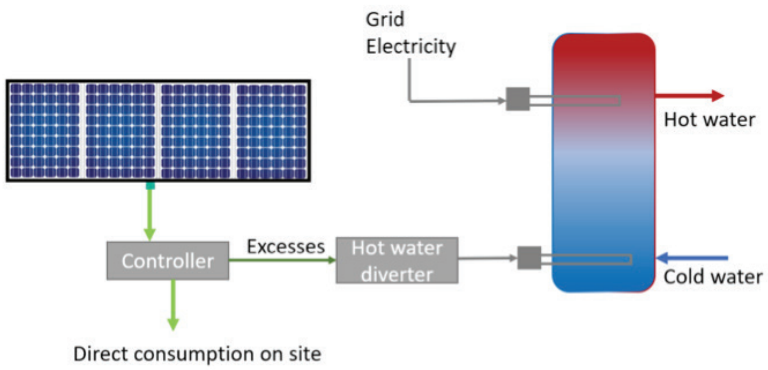


Figure 27: *Schematic of solar system with hot water diverter.*

7.7 Electrical connection capacity

For plants already relying on electric resistive heaters to generate hot water, switching to heat pump is not expected to raise any issues with the capacity of the electrical connection. This is the case because in this situation the heat pump will likely reduce the electric demand,not increase it.

In the case of switching from gas to heat pumps, depending on the size of the farm, the capacity of the electrical connections should be revisited.

To minimise the need for higher connection capacity, consider:

- larger storage tanks to allow a smaller heat pump to operate for longer
- reduce the heat demand (see Section 6.1).

7.8 Economics of heat pumps on dairy farms

The relative energy/emission savings is dependent on the baseline existing system. With most farms located in rural and regional areas (where there is little to no access to mains gas) LPG and electricity tend to be used for on-farm processes and heating.

The potential for on-site renewable electricity generation, coupled with storage and heat pump, can offer an attractive business case in this sector, particularly because the LPG and resistive heating options are the most expensive in most cases.

Table 11: *Cost of heat generation in a dairy farm – comparison of different technologies*

	8 Unit	9 Gas heater	10 Electric heater	11 Heat pump
Water tank size	L/day	1000	1000	1000
Energy cost (gas)	$/MJ	0.02	-	-
Energy cost (electricity)	$/kWh$_e$	-	0.15*	0.15*
Energy input	kW (MJ/hr)	3(10.7)	3	3
COP	-	0.8	0.9	3.7
Transferred energy to water	kW$_{th}$	2.4	2.7	11.1
Hour of operation	Hours	34.3	30.5	7.4
Energy consumption (gas)	MJ	367.5		
Energy consumption (electricity)	kWh$_e$		91.4	22.2
Energy cost	**$/day**	**7.35**	**13.7**	**3.3**

**Off-peak rate*

7.9 CASE STUDY: Ellinbank Dairy Research Farm, Victoria

Owner: Agriculture Victoria, Department of Jobs, Precincts and Regions (DJPR)

Designer: DJPR developed all the design requirements that the system needed to meet.

Supplier: CO_2 heat pump was supplied by Automatic Heating

Installers: The system was installed by a local plumber and electricians that were familiar with Ellinbank Farm.

Summary

Ellinbank Dairy Research Farm is a 'dairy farm' located in Ellinbank, Victoria. It is Australia's leading dairy innovation facility, fast-tracking innovative technology solutions in a research environment and showcasing them to the dairy industry.

The Ellinbank energy demonstration site will showcase energy efficiency and on-farm renewable energy options suited to different types of working farms. These will be demonstrated through on-farm integration at the Research Farm. Farmers will be able to inspect equipment at Ellinbank through on-site visits, open days and tours. Information will also be made available on-line so farmers can 'attend' the farm virtually though video tours and participation in education and information sessions.

Hot water is required to sterilise piping and equipment after milking. The hot water is required to be above 80 °C to ensure the system works correctly. A new glycol chiller system and CO_2 heat pump system, a heat recovery system and variable speed drives have been installed as part of dairy shed energy efficiency upgrades.

The farm also has horizontal and vertical wind turbines, pumped hydro, solar PV system with battery storage and electric all-terrain vehicles.

This SmartFarm has an ambitious target of being the world's first carbon neutral dairy farm by:

- reducing methane emissions
- generating electricity through a range of alternate options including solar, wind and bio-digestion
- improving fertiliser and manure management practices.

The 231 hectare, 500-cow farm is Australia's leading dairy innovation facility, fast-tracking innovative technologies in a research environment and showing them in a way that is accessible to the dairy industry.

Agriculture Victoria will provide updates as each demonstration becomes available, on the Energy Smart Farming website.

OVERVIEW OF ELLINBANK SMART FARM:

- Provides research ready resources
- Operates on a commercial level
- 217 ha (175 ha perennial pasture)
- 50 ha support area (leased)
- 450 spring calving milking cows/heifers
- 3.1 million L/year milk produced (~7500 L milk/cow/year)
- Pasture-based system (60% total diet)
- Water supply is treated rainwater

Original system details

The dairy farm's existing hot water system equipment was more than 20 years old.

- 2 x 1250 L electrical hot water tanks, each rated at 24 kW_e
- Supplied by pre-heated LPG gas system and heat recovery system
- Hot water delivery: 2500 L
- Recovery rate: 800 L/hour - roughly twice that of a heat pump

New system details

The electrical supply to the system is supported by the farm's 100 kWp solar PV system and operates with no additional heating or gas heating system. The new hot water system features:

- CO_2 heat pump
- 26 kW_{th} (heat capacity), 8 kW_e electrical power
- 2 x 1,500 L tanks
- CO_2 refrigerant
- Heat recovery was removed from system and diverted elsewhere
- Tank 1 stores water at 60 °C
- Tank 2 stores water at 83 °C
- Recovery rate: 400 L/hour
- Online monitoring for temperatures of Tank 1 and Tank 2
- Online monitoring of electrical power consumption
- Online monitoring of water flow

The COP of the heat pump system installed has an estimated **savings of approximately a third** of the previous power requirements. The COP fluctuates between 3.0 and 3.5 across the seasons.

Issue and solutions

To maintain operation of the dairy shed during installation, a temporary backup system was established to supply hot water. An existing hot water tank was retrofitted and connected the existing gas hot water system.

When the heat pump system was initially installed it was not able to operate at the stipulated 80 °C to 85 °C supply temperature in large volumes for dairy hygiene twice a day for morning and evening milking periods.

A lot of tweaking of the installed system was required to get the heat pump to operate to expectation, including:

- Diverting the heat recovery (52 °C water) away from Tank 2 and use it for the vat wash system
- Installing a solenoid and timer for transferring water from Tank 2 to Tank 1
- Installing a backup electrical element (auto to manual) and backup manual N/C bypass valve
- Installing an additional outlet for the requirement of warm water supply (60 °C) in between the morning and afternoon milkings (low volume) and moved outlet from Tank 2 to Tank 1.

Key learnings

- Understand your system capacity hot water volume and temperature requirements.
- Understand electrical consumptions of your existing system.
- Get the supplier of CO_2 heat pump system and installer (plumber) together early to discuss the system and project.
- Look at a backup system or maintain the existing system until new system is installed.
- Monitor system parameters (temperatures, volume, electrical consumption) – preferably online, or in manual log.
- Ensure you have a maintenance plan for the system (minimum required maintenance, six-monthly checks).
- Ensure temperature sensors are installed in ideal position and are reading correctly.
- Consider the physical footprint of the system and maintain recommended clearances for CO_2 heat pumps.
- Understand the estimated electrical consumption of the new system in advance.

8 APPLICATION FOCUS: USING AIR SOURCE HEAT PUMP WATER HEATERS IN AQUATIC CENTRES

Aquatic centres are large and complex heat users and usually include all of the following facilities and services:

- main competition pool at 26 °C
- learning-to-swim pool at 32 °C
- spa at 35 °C
- change room showers at 40 °C
- space heating
- dehumidification
- space cooling.

Most aquatic centres rely on central gas boilers and separate chillers to generate heating and cooling required for these applications. If designed and integrated properly, heat pumps can be a more suitable option to meet all of these needs because:

- The temperature requirements are all within the range of commercially available heat pumps
- Heat pumps can cogenerate water heating and space cooling
- They can offer superior waste heat recovery from various sources in the centre including the moist exhaust air, the heat rejected by the space air conditioner, and the wastewater from showers and filter cleaning (in the case of using a water-sourced heat pump).

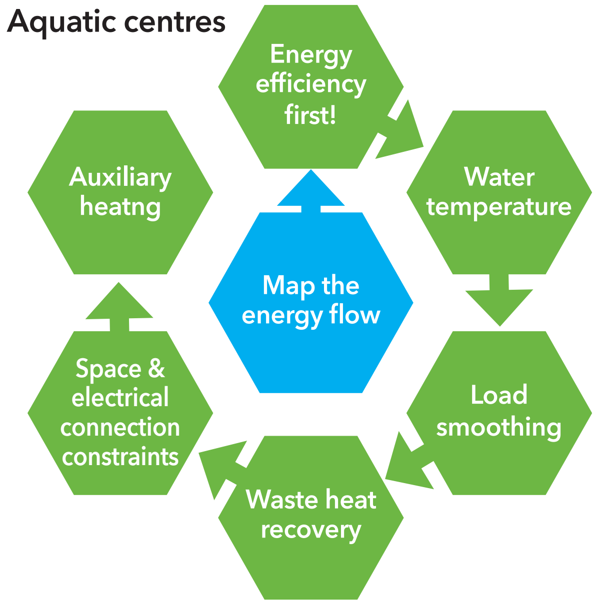


Figure 28: *Design considerations for a heat pump upgrade in aquatic centres.*

BEST PRACTICE DESIGN CONSIDERATIONS FOR AQUATIC CENTRES:

- Utilise waste heat recovery to minimise icing and improve COP in extremely cold conditions.
- While a suitable application for heat pumps to reduce energy consumption and emissions, aquatic centres require careful design and product selection owing to the complexity of various heating, cooling and dehumidification needs.
- Aquatic centres are industry-grade facilities, they should be treated as such and not be equipped with domestic-grade products.
- Aquatic centres usually offer enormous opportunity for energy efficiency before sizing the heat pump due to their energy intensive nature in large spaces maintained at high temperatures, requiring multiple heating applications, presence of significant amount of waste heat in the form of hot air, hot sewerage water and moisture in the exhaust air.
- Replacing gas and resistive heaters with heat pumps often does not involve a one-to-one swap. The nominal heat requirement can often be significantly reduced if some simple efficiency features are adopted before switching to a heat pump system.

8.1 Energy flow in an aquatic centre

Although energy efficiency approaches are not within the scope of this report, a heat pump system designer cannot separate the key aspects of energy management in aquatic centres from a practical heat pump solution. The energy flows for a site needs to be considered before the switch to a heat pump is made, with the main flows identified below.

Chemical control

The air space up to a metre above the pool surface contains chemicals, concentrations of which should be controlled via adequate ventilation. Australian Standards mandate a significant (10–15 L per second) air change requirement compared to the European standards[27,28]. Although this higher ventilation requirement may provide a healthier pool environment, it comes at the cost of higher heat demand and therefore energy consumption.

Swimming pools sometimes have very high ceilings with a large amount of air above the pool. The location of the exhaust for this purpose should be at a correct height to ensure that the air next to the surface of the pool is being replaced. If the exhaust is too high, then the ventilation system is just losing heat by venting the hot air at higher heights without removing the chemicals. Usually, one duct is needed for supply and the second one close to the ground to extract air and remove chemicals.

Australian Standards do not prevent stopping air chemical control when the pool is not in use. One solution to reduce energy use is to reduce the ventilation rate when the pool is not occupied. During these periods, the moisture condensation in the facility is the only parameter that needs to be controlled by the ventilation system. Reducing pool ceiling height in new centres can also reduce the heating load significantly as less volume of air is required to be displaced for ventilation.

Energy efficiency questions to answer before designing a heat pump system for an aquatic centre:

- Does the centre operate only in summer or throughout the year?
- Are there indoor and outdoor pools?
- What is the most significant energy consumer?
- Is warm humid air vented and lost?
- The temperature and thermal content of the vented air?
- What is the temperature profile of water and space across the centre?
- Is cooling also required at the centre?

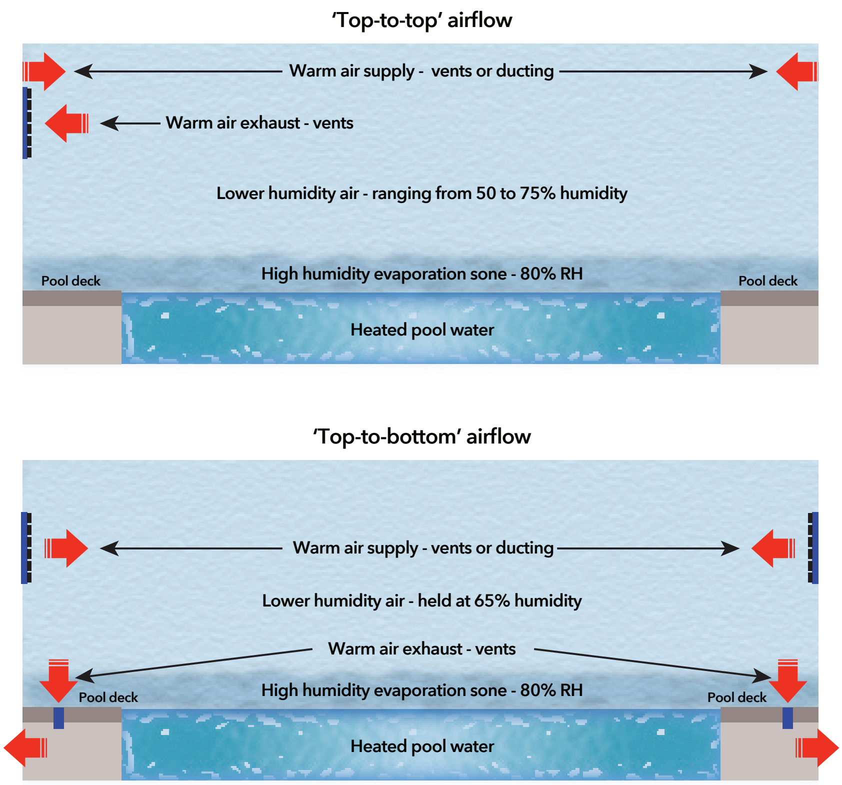


Figure 29: *Changing ventilation from 'top-to-top' to 'top-to-bottom' reduces the heat load while extracting the chemical heavy air above the water (Source: Negawatt Projects).*[29]

27. Aquatic and Recreation Victoria, *Benchmarking Energy and the Indoor Environmental Quality of Aquatic Centres in Victoria*, Aquatic and Recreation Victoria, 2016, accessed 8 July 2022.

28. Standards Australia, *The use of mechanical ventilation and air-conditioning in buildings: Part 2 mechanical ventilation for acceptable indoor air quality*, Standards Australia,1991, accessed 8 July 2022.

29. https://negawattprojects.com.au/

Heat recovery

Without heat recovery in the ventilation pathway, a significant amount of thermal energy is wasted. The vented air to control chemicals contains both sensible heat and latent heat. Sensible heat refers to the amount of energy that has been used to heat up the moist air from ambient outside temperature (e.g., 5 °C in winter) to the designated temperature inside the centre (e.g., 20 °C to 24 °C). Latent heat is the amount of heat that the water content in this moist air has absorbed to turn from liquid to vapour. An efficient heat recovery system should be able to extract both thermal contents.

Heat loss

Properly designed swimming pools are usually thermally insulated at the walls and bottom of the pool. Heat loss due to conduction from the pool body is relatively low. The major heat loss mechanism is via surface evaporation and convection. The air inside the pool facility also loses significant heat through the walls, windows and roof. Thermal insulation of the walls and roof with low emissivity double or even triple glazing can significantly reduce the heat loss from the building and lead to a smaller heat pump capacity, as well as reduce building fabric condensation problems.

Internal arrangement of facilities

When planning new or renovated aquatic centre facilities, good practice is to lay out the internal arrangement of the centre and aim for minimal temperature differences between the adjacent facilities. For example, an air-conditioned gym should not be located next to the spa or the swimming pool – the temperature and humidity difference between the air above the heated water and the air inside the gym leads to heat and moisture transfer between them, increasing the cooling load of the gym and the heating load of the pool area.

It is recommended to arrange the facilities from low temperature to high temperature with gradual changes. Of course, this cannot be possible in existing facilities. An option for existing centres with a poor layout is to thermally isolate areas from each other with curtains or shields.

8.2 Seasonal effects

As mentioned in Section 6.3, low ambient temperature can reduce the heat pump COP and may cause icing on the outdoor coil. In the case of aquatic centres, the drop in the thermal power output of a heat pump has little impact on the swimming pool itself, as its temperature does not change rapidly, due to its high thermal mass. However, the air temperature in the indoor facilities can drop.

Energy recovery from the exhaust air is important to tackle this, especially in cold weather, as it improves the COP, increases output capacity and avoids icing up.

Low-temperature thermal storage coupled to low-cost solar thermal collectors can be used to boost the heat pump when the ambient temperature is low. The warm water from the collector can be collected in a storage tank and then fed to the cold side of a heat pump (heat source) when it is generating heat in cold conditions.

8.3 Suitable heat pumps for aquatic centres

Due to the industrial nature of thermal applications in aquatic centres, ammonia heat pumps can be considered a suitable option. They can cogenerate heating and cooling, have a lifetime of up to 50 years and an up-time of 99.7%. They can provide a COP of 6 in winter and cogenerate cooling at an additional COP of 5. For the value of cogeneration refer to Section 6.10.

8.4 Waste heat recovery

Three distinct waste heat recovery methods are commonly suggested for aquatic centres:

- Cross-flow heat exchange between the warm exhaust air and the cold point of the supply air. In this method, the two streams of the air come to a single spot at a cross-flow heat exchanger.
- Run-around coil, in which the supply and exhaust air streams exchange heat with one another indirectly through piping filled with a heat transfer fluid.
- Thermal wheels, in which a sector of a spinning wheel exposed to the exhaust air absorbs heat from it and, after spinning for a certain angle, transfers the captured heat to the supply air.

Although the above methods have shown some success, they do not recover much of the latent heat of the exhaust air. This is where heat pumps offer a unique and effective capability. They can condense the moisture in the exhaust air extracting both the sensible and latent heat from it and uplifting it to heat up water and air.

Corrosion of the heat exchangers in the waste heat recovery system should be accounted for. The use of paint, anticorrosive tubes, and specially designed powder coatings can practically overcome this problem.

In aquatic centres, a critical advantage of waste heat recovery is 'desensitising' the heat pump operation to the ambient air temperature on extremely cold days. When the exhaust air from the centre is directed to the heat source coil of the heat pump, the effective temperature on the coil increases reducing the risk of icing. The heat pump can switch to defrost mode less frequently and provide high up-time[30]. For realising this purpose, using an effective control system is critical.

The controller should ensure that the heat from the exhaust is diverted to the evaporator, and when there is not enough heat, ambient air is added to the mix. An optimal mixture of ambient air and exhaust air should be controlled properly for the best outcome. Ambient air should only be used when the heat in the exhaust air is not adequate to maintain a temperature higher than ambient conditions.

8.5 Sizing the heating/cooling power

Once the energy efficiency measures have been taken to reduce the thermal load of the centre, the heating and cooling loads can be estimated from the operation profile of the existing heating and cooling systems. To size the heat pump at this stage:

- Measure the heat load profile from the existing heating system (audit it)
- Measure the heat rejected by the central chiller (if there is any)
- Quantify the waste heat available to be utilised by the heat pump
- Estimate the COP of the heat pump after including the waste heat and in accordance with the climate zone
- Size the storage and heat pump together aiming for the least cost of heat, including the capital cost and running cost
- Size the auxiliary power for the extremely cold days considering the reduced COP of the heat pump.

30. Uptime is total time that a heat pump runs annually.

8.6 Electrical connection capacity

When switching from gas boilers to heat pumps in aquatic centres, the electrical connection capacity is likely to be a major consideration. This is because the heat pump capacity for such an application may be well in megawatt range. Also, other electrical device such as pool pumps, lighting, air handling units and air conditioners in the building can consume a major part of the existing connection capacity.

Often, an electrical upgrade is required to enable the installation of heat pump water heaters in aquatic centres. The cost of electrical connection upgrade and demand charges should be incorporated in the CapEx analysis. The required connection upgrade can be minimised by using energy efficiency measures as described above to reduce the rated capacity of the heat pump and therefore the required electrical connection capacity. Minimising the peak demand with the use of thermal storage, on-site solar PV and optimised heat pump operation will also assist.

8.7 Rooftop solar PV

Due to their high energy demand and well alignment with daytime operation, aquatic centres offer significant opportunities for utilising on-site solar PV generation. Given heat pumps in this application are expected to have a high capacity factor in this application, rooftop solar PV generation in most cases can be directly used by the aquatic centre with little need for thermal storage.

If a large rooftop solar PV system generates peak PV output in excess of the instantaneous power demand of the centre, the excess energy should be utilised in the following ways and order:

- If the heat pump has spare capacity (i.e. it is running at part-load), the excess power from the solar PV generation can be directed to power the heat pump with the excess generated heat stored in the thermal storage or the water pool itself.
- If the heat pump is operating in full load, the excess solar PV generation can be captured by resistive heaters in the storage tank and stored for later use.

8.8 Auditing and VEECs

The heating systems installed for aquatic centres are far more complex than many other applications. Different approaches can be taken for quantifying their performance and the VEECs that could be created:

- In the case of a simple installation in which a heat pump offsets a portion or the entire gas or resistive heater, the energy savings can be calculated using deemed methods explained in Section 6.1.
- In the case of a more complex installation in which the heat pump provides various end products such pool heating, hot water, space heating, and space cooling with complex operation schedules and thermal storage, the VEU program measurement and verification method may be more cost-effective and accurate. With this approach, flow meters, power meters, and temperature sensors are installed on the heating system to accurately measure its energy use and generation to calculate the potential VEECs.

8.9 Thermal energy storage

The pool itself can act as a thermal energy storage device, depending on the flexibility of the occupants and their activities. For example, to maximise the use of on-site solar PV generation, the pool could be heated to a higher temperature during the day, say an extra 1 °C, which may allow the heat pump to be turned off during peak electricity times (e.g., 4 pm to 8 pm).

Another thermal storage option for this application is using hot water tanks, which can be used in two configurations:

1. **Before the heat pump at a low temperature** – warm water generated by solar collectors or waste heat recovery can be stored in the tank and then used as the heat source of the heat pump during operation.
2. **After the heat pump at a high temperature** – when the heat pump has excess capacity (for example, during a warm day) it can generate hot water at its maximum operating temperature and store it in the tank. The stored water can be used directly for an application in the facility when the heat pump needs backup or can be turned off during peak electrical tariffs.

8.10 Standards related to this application

The following standards and documents are related to this application:

- *AS1668.2–1991: The use of mechanical ventilation and air-conditioning in buildings: Part 2 mechanical ventilation for acceptable indoor air quality,* Standards Australia, 1991.
- *Pool Operators' Handbook*, Department of Human Services Victoria, 2000.
- *Benchmarking Energy and the Indoor Environmental Quality of Aquatic Centres in Victoria*, Aquatic and Recreation Victoria, 2016.

8.11 CASE STUDY: Galston Aquatic & Leisure Centre, Galston, NSW

Client/owner: Hornsby Shire Council

Consultant/designer/installer: Air Change Group

Summary

Galston Aquatic & Leisure Centre is located in the Hills district of Sydney, within the local government area of Hornsby. The centre features a 25 m eight-lane indoor pool and fully equipped gymnasium. It offers swimming lessons, squad training and aqua aerobics.

In 2014 Hornsby Shire Council sought expressions of interest to provide a de-humidifier for the pool hall that would provide ventilation and heating and be subject to an Energy Performance Contract (EPC). The EPC was focused on improving air quality, improved system management processes and reducing heating, ventilation and maintenance costs over the long term.

Previous system

The existing pool HVAC and water heating system at Galston comprised of a direct exchange air handling unit with a typical pool water heat pump using outside air as the heat source for pool water heating, supplemented by a bottled gas water heater. This was a costly method and neither of the air heating or water heating systems performed their design function. The lack of any outside air ventilation or air temperature control contributed greatly to the pool's list of challenges. This led to poor indoor air quality and indoor condensation with subsequent building fabric degradation and poor amenity for the pool patrons.

New system

In May 2015 Air Change supplied and installed a PoolPac Plus system to address the focus of the EPC. Fresh air ventilation to dilute the moisture laden internal air has seen significant air quality improvement for pool occupants, as well as the reduction of condensation and corrosion on pool surfaces.

The PoolPac Plus combines two traditionally separate functions – pool water heating and indoor pool air handling. This combined functionality optimises DX heat pump efficiency and produces large energy savings for indoor pool facilities without compromising occupant comfort or building integrity.

Project costs

The combination of air and water heating in a single unit provides economies of scale and production costs are minimised. This makes the system comparable in capital costs to a conventional installation with separate air and water heating.

Benefits

Significant savings were achieved during installation and from the resultant energy savings. "Over the past six months of monitoring, the system clearly meets the requirements of the Council. There is evidential improvement of air quality in the pool hall and a significant reduction in energy use and costs." Since being commissioned in May 2015 gas and electricity usage has been recorded at the aquatic centre.

From May to December 2015 the total energy cost has been $51,341 compared with $72,323 for the same length of time in 2012/2013. This includes the initial commissioning period during May and June where savings were not optimised. The system is on track to provide an estimated 30% saving in its first year of running.

OTHER BENEFITS:

1. Provides energy efficient heating for the pool, both air and water
2. Eliminates condensation and corrosion issues
3. Improves indoor air quality within the pool environment.

8.12 CASE STUDY: Kardinia Aquatic Centre, Geelong, Victoria

Client/owner: City of Greater Geelong

Designer: Bridgeford Group

Project overview/scope

In order to progressively remove its reliance on natural gas operations, an engineering-based concept study for the electrification of pool heating at the City of Greater Geelong's Kardinia Aquatic Centre was conducted by the Bridgeford Group. This study analysed existing system operations and developed options for system upgrades, from hybrid to fully electrified, with a focus on energy efficiency as well as analysis of infrastructure limitations.

The centre includes FINA, Olympic, diving, toddler, waterslide and learner pools. The site has high gas consumption, however, the electricity supply is zero-emissions via VECO. The existing heating system was not coping following a move to year-round operation, the pools operated at different temperatures and pool covers were only used on some pools.

Existing system:

- 1 x 800 kW_{th} boiler (at end of life)
- 1 x 800 kW_{th} boiler (only five years old)
- Electrical constraints (transformer and supply)

Proposed system

A model of annual pool heat loss and energy consumption was developed and benchmarked that considered evaporation rates, conduction, radiation and convective losses. This enabled production of an annual operating profile to set a baseline for the new required gas and water consumption, prior to considering various electrification options.

A key part of the analysis for defining suitable options was the understanding that although peak capacity of the system might be required on particular warm and dry days, or windy and cool days (when evaporation rates were highest), these time periods represented less than 2% of the annual operational load. Sizing heat pump systems for this peak would not be an efficient use of project funding, as for the majority of the year, the heating requirement was much lower. As a result, Bridgeford Group defined options for electrification that would provide a 90% emissions reduction, half of the peak capacity and near half of the cost of a fully electrified system.

This strategy and outcome enables the City of Greater Geelong to reduce emissions by a similar factor at another recreation centre, maximising emissions reduction for the cost.

Load assessment:

Rather than focusing on 100% electrification (which would necessitate a transformer and feed upgrade) partial electrification was considered.

A calibrated pool simulation model was developed to determine optimum heat pump sizing. The model included:

- Directional wind speed
- Sources of heat gain/loss including evaporation, conduction, radiation
- Ability to convert from seasonal to year round
- Calibration to actual energy consumption
- Local weather data (temperature and relative humidity).

Key outputs were:

- Alignment between current equipment sizing and model
- Alignment of baseline energy data
- Pool load driven by evaporation – wind speed or ambient temperature + humidity
- Under 400 kW required for 45% of the year
- Under 1 MW required for 80% of the time.

Based on this analysis, the recommendation was for a smaller hybrid heat-pump system (with option for provisioning infrastructure for future electrification if needed).

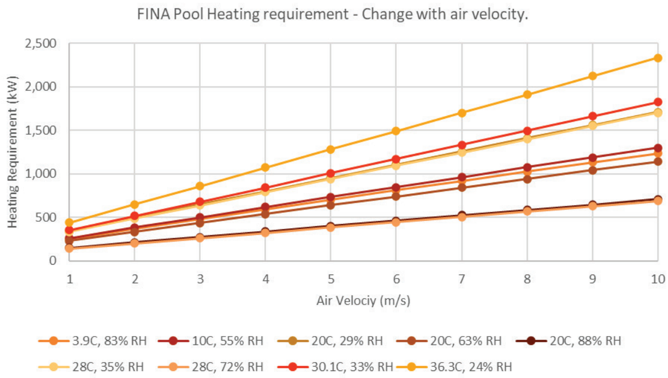


Figure 30: *Modelling of the pool heating requirements for the FINA pool at Kardinia Aquatic Centre*

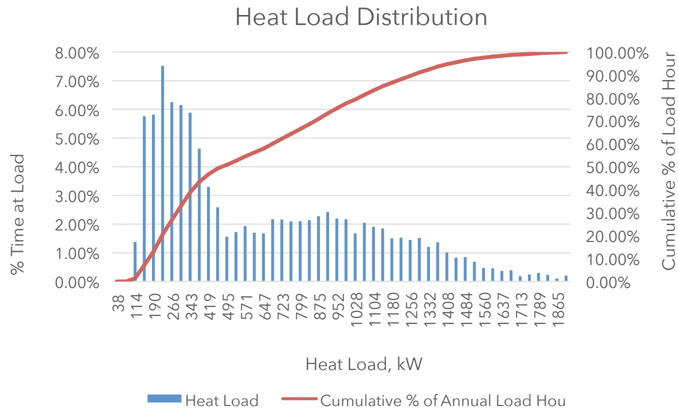


Figure 31: *Modelling of the heat load distribution at Kardinia Aquatic Centre.*

Item	Current : (100% Gas Fired)	Option 1: Boiler upgrade only	Option 2: 400kW heat pump	Option 3: 800kW Heat pump	Option 4: Fully electrified system
Total Investment Cost ex. GST		$ 219,000	$ 496,200	$ 721,200	$ 1,558,300
Marginal uplift on Option 1			$ 277,200	$502,200	$1,339,300
Marginal savings vs. Option 1			$ 57,234	$ 95,414	$ 86,390
Emissions tCO2 p.a.	1,229	965	441	119	-
Emissions Reduction to BAU	-	22%	64%	90%	100%
Remaining Emission offsets	$68,149	$53,499	$24,442	$6,581	$ -
Net Operating Costs p.a.	$420,873	$321,422	$235,130	$179,090	$181,533
Marginal SPB			3.21	3.53	9.57

Figure 32: *A comparison of system options for Kardinia Aquatic Centre.*

Focusing on operation-led design and sizing for partial electrification enabled:

1. Ability to design for ~90% emission reduction for 50% CapEx – lowest cost of carbon reduction and best marginal pay back.
2. Remaining budget can be used for another electrification project, potentially providing up to x1.8 emissions reduction of single aquatic centre.
3. Focus on 'marginal uplift/savings' compared to BAU asset replacement, which assists in payback.

Installation date

Full design is now in progress for implementation.

Project costs:

$500,000–$750,000

Benefits

Expected reduction of gas-based emissions by 90% (1000 t CO_2-e/year), while the remaining 10% of the emissions will be offset via renewable energy sources (generation of electricity via solar).

Lessons learnt

Include cost of carbon for the status quo in the business case and design within constraints of:

- End of life
- Electrical infrastructure
- Pool operation and load
- Pools act as thermal storage system for heat pumps
- Addition of or regular use of blankets drastically reduced energy consumption
- Wind-breaks can be effective in reducing plant size and operational cost

9 APPLICATION FOCUS: USING AIR SOURCE HEAT PUMP WATER HEATERS IN MULTI-UNIT RESIDENTIAL BUILDINGS

In multi-unit residential buildings, heat pumps are mostly used for sanitary hot water production. However, it is also possible to implement them for hydronic heating applications if the building does not have a central HVAC system.

Supplying heat to such buildings requires industry-grade heat pumps which offer high up-time and low maintenance while operating for extended periods. For this reason, it is recommended that the heat pump be industry-grade for this application, as opposed to those used in residential applications.

For space heating, heat pumps will reach their peak efficiency at low water temperatures and are most effectively installed in conjunction with low-temperature heat distribution systems (typically underfloor heating or fan convectors). In the case of using conventional radiators, they should be suitably oversized to allow effective operation at lower water flow temperatures. Radiator manufacturers provide tables to calculate the radiator output across a range of water flow temperatures. In the case of underfloor heating, designers should ensure that the underfloor pipe matrix is designed with low-temperature operation in mind (ideally 35 °C to 40 °C). This is essentially a matter of pipe spacing.

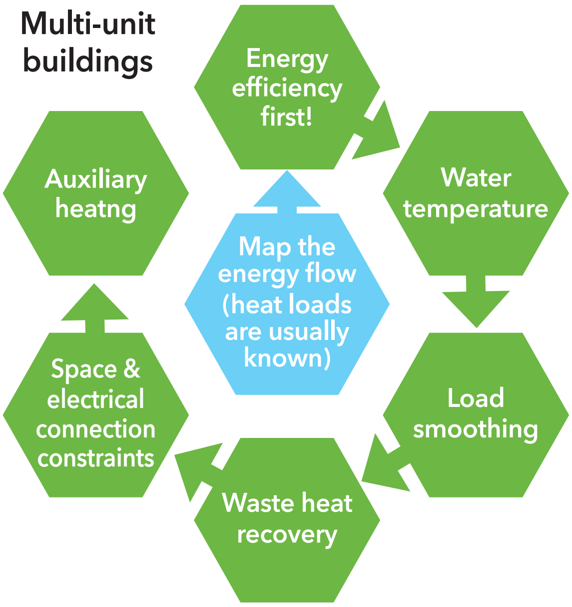


Figure 33: *The design considerations of a heat pump water heater system for multi-unit residential buildings.*

BEST PRACTICE DESIGN CONSIDERATIONS FOR HEAT PUMPS IN MULTI-UNIT RESIDENTIAL BUILDINGS

- Ensure sufficient temperatures are being supplied by the heat pump and any auxiliary heaters are only occasionally used for a very minor part of the heat supply.
- Retrofitting a heat pump to an existing building requires careful assessment of spacing requirements for the heat pump and thermal storage: if installed on the roof, piping work may need to be redirected from a previous site in the basement.
- Map the energy flows in the building to understand the heat demand and factor in climate conditions.
- Replacing existing electric and gas boilers at end-of-life with a heat pump system provides favourable economic conditions.

9.1 Energy flows in multi-unit residential buildings

Energy flow in a building should be mapped to quantify the following:

- the hourly heat demand of the building separately for the hot water and space heating applications
- the supply temperature of hot water required for each application
- the return temperature from the heat emitters[31]
- the return temperature from the circulation loop.

To quantify these parameters an energy audit may be required.

9.2 Heat pump sizing approach

All heat pump sizing and installation work and control in multi-unit residential buildings must adhere to relevant Australian Standards and the National Construction code (which includes the Plumbing Code of Australia).

Design procedures for incorporating heat pumps in new buildings

For **space heating** applications the following should considered:

- The heating load should be determined for a particular winter design ambient temperature.
- Select the type of heat emitter from options such as panel radiators, underfloor heating, fan coil, etc. The emitter determines the required supply water temperature. Underfloor heating and fan coils can operate at water temperatures of 35 °C, but radiators will need water at least 55 °C.
- The type of the heat emitter also determines the return water temperature.
- The heat pump is selected according to the required heating power and supply and return temperature.
- A thermal storage system should be sized such that it maximises the on-time (capacity factor) of the heat pump. A heat pump plus thermal storage system generally achieves its best economic outcome when the most expensive component (i.e., the heat pump) is utilised as much as possible.
- The heat pump and storage tank should be sized to meet the peak demand with minimal reliance on the electric booster.

31. Heat emitters refer to radiator panels, underfloor heating loops, and fan coils

For **domestic hot water** applications the following should considered:

- The heating load of the hot water system should be determined for a particular winter design ambient temperature. This can be done via auditing.
- The heat loss from the recirculation loop should be determined and reduced by extra thermal insulation if possible. This is particularly important as AS/NZS 3500.4 requires hot water to leave the plant room at no less than 60 °C and return at no less than 55 °C.
- The recirculation water can be extracted from the storage tank but returning it to the same tank may diminish its stratification. Consider supplying the recirculation water with a separate loop.
- The recirculation water can be heated by a smaller heat pump or an electric boiler. Cost comparison of these two options helps to decide the one with the lowest LCOH for recirculation.
- To reduce the peak demand, consider restricting the hot water flow rate when multiple hot water features turn on at the same time.
- The heat pump and storage tank should be sized to meet the peak demand with minimal reliance on the electric booster.

Design procedures for retrofitting heat pumps in building that previously had a gas or electric boiler

For **space heating** applications the following should considered:

- The correct actual flow and return water temperatures needs to be determined for each heat emitter (most likely to be a radiator) at design conditions.
- If the flow temperature required is less than 65 °C for all emitters, no additional measures are needed for the refit.
- If the flow temperature is higher than 65 °C in some of the emitters, those emitters must be replaced by larger surface heat exchangers.
- If the flow temperature is greater than 65 °C for all emitters and it is not possible or not desired to carry out the replacement, a high-temperature heat pump will need to be used.
- The thermal storage should be sized similar to the criteria mentioned above for a new build. However, in existing buildings, space can limit the size of the hot tank so a lower capacity factor from the heat pump can be achieved.

For **domestic hot water** applications in existing buildings, the design procedure mostly follows the same steps were listed for the new buildings, with the following modifications:

- The existing recirculation loop may need to be separated from the main heater.
- The heat loss from the recirculation loop may need to be reduced with further thermal insulation
- The heat loss from the how water pipes may also need to be reduced by further insulation.

9.3 Impact of climate zone

The requirement for thermal energy services varies by climate zone in residential buildings, with warmer climates have less need for space heating. The market demand for various thermal energy services across Australia's climate zones (coupled with the market penetration of heat pumps in delivering these services) suggests several areas in which heat pumps could play an important role:

- space heating in all property types, especially climate zones 4-8
- pool heating, especially in climate zones 4-8
- domestic hot water in all property types in all climate zones.

9.4 Retrofitting gas and electric boilers

Buildings in which the existing heating asset is close to the end of its operating life offers better economics for switching to a heat pump because the existing asset has been fully depreciated, and replacement is necessary.

Gas and electric boilers have a lifetime of 10–15 years in residential buildings. It can be assumed that many existing assets in this sector will be nearing the end of their lifetime over the next decade, presenting a good opportunity to switch to a heat pump system. Missing the retrofit opportunity to switch to heat pumps in these buildings when they have depreciated their existing heating assets can lock the owners/managers into gas-sourced heating or low efficiency resistive boilers for at least another decade.

Several considerations need to be addressed to ensure that the heat pump will deliver the expected service as some barriers can hinder retrofit projects.

Issues to consider when an existing gas boiler plant is replaced with heat pump in a multi-unit residential building:

- Gas and electric boilers have a lifetime is 10–15 years.
- Replacing these systems close to the end of their lifecycle improves the business case for heat pumps and makes better sense financially.
- The heat pump system should be designed to deliver the required temperature for heating coils (in space heating applications) and the required sanitary water temperature of 60 °C to 65 °C.
- Consider whether the heat pump needs to have the same capacity as the boiler.
- Investigate whether the electricity connection needs to be upgraded?
- Consider whether the heat pump can meet the peak heating demand in cold season.
- Is an auxiliary heater required?
- Is legionella a concern?

9.5 Space and electrical constraints

Floorspace has a significant monetary value in multi-unit residential buildings and a heat pump system takes roughly three times more floor area compared to a gas boiler with the same thermal power output. These systems may also require additional space for thermal storage tanks that smooth demand and reduce heat pumps' size and capital cost. The thermal storage size is the main driving factor in the required floorspace.

In many cases, the roof area of a multi-unit residential building is the most feasible place to install the new retrofit heat pump. However, the piping network will need to be modified if the old central heating plant is located in the basement. The piping should be minimally modified to allow the supply of hot water to be delivered to the unit from the rooftop area.

Read more about responding to location and spacing constraints in Section 6.12.

Switching a gas-based hot water and/or space heating system to a heat pump can significantly increase the electrical demand of the building. The following steps should be considered to reduce the complexities and costs associated with this issue:

- Improve energy efficiency to reduce the required rated capacity of the heat pump and hence the required electrical connection capacity
- Utilise thermal storage and on-site solar PV generation to reduce the maximum electrical demand
- Utilise smart control features to shift the operation of the heat pump system outside of the period when other appliances and electrical devices in the building are running.

9.6 Microclimate effects

The general definition of a microclimate was introduced in Section 6.8. The microclimate effect for heat pumps in multi-unit residential buildings is a result of two main factors:

- installing the heat pump in a confined space with not enough air exchange
- poor arrangement of heat pump arrays when they are installed next to each other.

In the main example of the latter case, the air flowing through the evaporator of one heat pump is sucked into the evaporator of the next one. In this case, the air from the first evaporator has already lost its temperature, increasing the temperature lift of the second heat pump. The evaporator coils of a heat pump should be oriented to blow the 'used' air away from the array.

Read more about microclimate considerations in Section 6.8.

9.7 Adjusting the water temperature

For the sanitary water applications, typical flow temperature form the plant room is 60 °C to 65 °C, which is well within the reach of existing common heat pump water heaters. As mentioned the return temperature from the recirculation loop is mandated to be above 55 °C (as per AS/NZS 3500.4). Hence, there is no need to adjust these temperatures as they can be met by existing heat pumps efficiently.

The issue of heat recovery of the building return flow by the heat pump is a difficult one because of the legal requirement of such a low temperature lift of 5 °C (55 °C to 60 °C). As much as it is desired for the heat pump system to do this, there are very good reasons why it is better to have an auxiliary bypass-booster doing that instead and leaving the heat pump system to deal entirely with the actual hot water load.

For space heating applications in buildings with gas boilers, the pipes, radiators, and fan coil units are usually sized for the supply of a particular temperature of (e.g., 80 °C). With most current generation heat pump technologies producing hot water below 70 °C, the designer may need to think outside the box.

Firstly, heat losses from the building can be reduced by energy efficiency measures, including draught-proofing, upgrading windows, insulation and even installing insulating panels behind the radiators or installing small fans that increase heat transfer from the radiators.

Another solution is to increase the size of the pump and the radiators in the units to match the lower temperature of the supply water from the heat pump. Heat losses from pipework can also be reduced by upgrading insulation.

Unlike a heat pump with a COP of 3.0 or more, an electric heater has a COP of 1.0. Most of the final heat should be produced by the heat pump component and very little should be left to be produced by the electric heater. The heating ratio between the heat pump and the element is determined by the return, supply and heat pump outlet temperature. If this approach is taken, there is a case for varying the maximum temperature with weather conditions, running it lower, except when the weather is extremely cold. Most of the time, the temperature provided by the heat pump would provide sufficient heat for the building.

The COP of the entire heating system, including the heat pump, thermal storage, and control strategies, needs to be investigated in advance.

Demand charges can be overlooked when the system is being designed due to lack of expertise. It needs to be considered from the very beginning.

9.8 Recirculation water

Unlike domestic homes, large buildings have a recirculation pipeline that carries hot water from the central plant room to each unit and returns it to the plant room. Hot water lines in each unit branch off from this recirculation line. This line ensures that hot water is immediately available at the tap when it is turned on. In the absence of such a recirculation line, when the tap is turned on in large buildings it will take a long time to receive hot water at the tap. The return temperature from this line to the plant room is less than the supply temperature, but still high. CO_2 heat pumps are very inefficient in reheating such a warm stream of water.

Even when using other refrigerants, handling the return recirculation water in the storage tank requires careful design. It needs to be either boosted in temperature to the maximum temperature before letting it in the tank, or carefully let it enter the tank at a certain height to not disturb the tank stratification.

One solution to avoid complexities associated with the return water from the recirculation system is to use a separate gas or electric boiler. The heating power from this auxiliary heater should be only enough to compensate for the heat losses from the pipes. For the cost impacts of using these auxiliary heaters refer to Section 6.7.

Increasing the thickness of the pipe insulation from 25 mm to 40 mm delivers immediate returns. It leads to lower energy consumption, lower running costs, lower pump flow rate, smaller pipes, less velocity and smaller pumps. Reducing the heating set point temperature of water heater by 1 °C can also save 2% of energy.

9.9 Waste heat recovery

The heat pump system may capture the heat rejected by air conditioning systems at its outdoor condenser and feed it to the hot water. However, the applicability of this method is limited to cooling-dominated seasons during which hot water and space cooling are required simultaneously.

9.10 Auxiliary heater

For sanitary water application the use of auxiliary heater is mainly for the recirculation loop. This case was outlined in the previous section (see Sections 9.7 and 9.8). The reality is that recirculation top-up with heat pumps is very hard to manage because such low temperature lift (of 5 °C, with hot water output required always at above 60 °C) will have very hot tanks requiring this boost, no matter where the recirculation water comes into them. Such low lift can result in significant heat pump short-cycling and/or not being able to meet the output temperature of 60 °C for when demand occurs. Hence, one practical solution to the heating requirement of the recirculation loop is to supply it with an electric auxiliary heater.

For space heating application in residential buildings, a heat pump system can lead to poor performance if the outlet temperature of the heat pump does not reach a certain level. Most existing hydronic heating systems have been designed to operate with a supply temperature of 80 °C and a return water temperature of ~60 °C.

If the outlet temperature of the heat pump is not high enough, the performance of the space heating system can be adversely impacted. Three possible solutions to this are:

1. **Use a heat pump technology capable of supplying above 80 °C water to the radiators**
   Currently, supercritical CO_2 heat pumps are the only commercial systems capable of reaching this temperature, but this solution has not been proven reliable yet as the performance of these heat pumps strongly depends on the return water temperature. Using standard radiators with a return temperature of say 50 °C, the COP of these heat pumps will deteriorate, rendering their performance unacceptable. To enable these heat pumps to be functional for space heating applications, the air-handling unit inside the room should be capable of extracting heat from the working water to a level that the return temperature drops to below 30–35 °C. This requirement might be possible with specially engineered fan-coil units.

2. A more common heat pump such, as R410A, can heat the working water to 65 °C to 70 °C, and then an electric or gas booster raises its temperature to 80 °C before supplying it to the radiators. This option comes with a risk of diminishing the cost-effectiveness of the whole system, especially if the return temperature is above 50 °C. With such a high return temperature, only two-thirds of heating needs are provided by a 70 °C heat pump, and the booster supplies the remaining third. In the case of using a resistive booster, the running cost will be less favourable.

3. Use a conventional 65 °C to 70 °C heat pump and increase the size of the radiators to ensure the heating power they deliver matches the heating power they delivered using 80 °C water. This approach is recommended by reputable suppliers and seems to be the most energy- and cost-efficient option.

An auxiliary heater might be required to reduce the risk of legionella growing in the stored water. This means that, regardless of the end-use temperature of the water, the water inside tanks needs to be heated enough to drastically reduce or eliminate the risk of legionella growth according to Australian Standards (traditionally, this has been daily heating to 60 °C). This extra heating may be required from a resistive heater if the heat pump is not able to reach the required temperature.

Heat pump systems for multi-unit residential buildings can be designed for occasional extremely cold conditions at the expense of higher capital cost o the heat pump system. This approach leads to system oversize and poor economics. An auxiliary electric heating element can be used to meet these rare demands to prevent oversizing of the heat pump. However, the choice of this heater and its proper control is critical to avoid what should be the supplementary backup element generating most of the heat, which leads to very poor economics.

The operation of the heating element in the heat pump system should be reported by the systems and monitored by the user. Its total use should not go beyond the design point, otherwise, the system has been either poorly designed and/or operated.

9.11 Thermal energy storage

Heat pumps for multi-unit residential buildings usually need thermal energy storage. The hot water peak power demand is generally beyond the power output of a heat pump. A heat pump can be oversized to provide very high thermal outputs, but this approach comes with a significant capital cost, physical system size, a low utilisation rate of the heat pump and poor economics.

Heat pumps have a significant lag when they are starting up, with this not acceptable for domestic hot water applications. Additionally, frequent on-off operation of a heat pump leads to poor COP and shorter equipment lifetime, so the implementation of thermal storage is usually a necessity for these applications.

If appropriately sized and controlled, thermal storage offers the opportunity to also capture excess solar PV generation during the day in the form of hot water generated by the heat pump for later use in the evening or over the night.

Thermal storage should be sized according to the following:

- Duration of the peak demand periods
- Size of the peak demands
- Recovery from the heat pump (while heat is being extracted from the storage, the heat pump may operate to recover it)
- Whether redundancy in the building is allowed (can some loads be deactivated during the peak demand?)
- Winter performance for heat pump recovery
- Simultaneous demand being controlled by reducing hot water velocity at each fixture
- Consideration of the balance between system capacity and storage (i.e., cost vs space/weight).

9.12 Standards related to this application

The following document and standards are related to the application of heat pump water heaters in buildings.

AS/NZS2712:2007	The main standard document
AS/NZS 4020	All materials in contact with drinking water should comply with this standard.
AS/NZS4692.1	Stainless-steel tanks in the grade of 316L
AS/NZS4692.1	For the strength of the containers
AS/NZS60335.2.21	For the strength of the containers
AS/NZS3498:2009	For legionellae bacteria control
AS/NZS2712:2007	Regarding cross contamination of drinking water with refrigerant
AS/NZS 60335.1	Electrical safety
AS/NZS60335.2.40	Electrical safety
AS/NZS 4692.1	Thermal insulation
AS/NZS5125	Thermal performance testing
EN14511	Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling
EN14825	Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - testing and rating at part load conditions and calculation of seasonal performance

9.13 CASE STUDY: 101 Collins Street, Melbourne, Victoria

Client/owner: 101 Collins Street Management

Contractor: A.G. Coombs Advisory

Designer and installer: Energy Smart Water (ESW) and Thermal Energy Solutions (TES)

Supplier: Enermax

Project summary

A prominent fifty-storey office skyscraper in Melbourne's central business district required the replacement of one of its existing gas hot water plants. The plant in question supplied domestic hot water to 23 levels. This project involved the conversion of domestic hot water generation from the original building calorifiers (which were connected to the buildings natural gas-fired heating hot water plant) to a system featuring highly efficient commercial heat pumps, thermal storage calorifier tanks and solar PV collectors to provide off-grid direct current (DC) electrical energy production as the primary form of heat generation.

Separating the domestic hot water system from the central heating hot water plant enables the gas fired heating hot water plant to be able to shut down during summer periods to further reduce gas consumption, pumping energy consumption, plant operating costs and associated plant maintenance.

A.G. Coombs Advisory was commissioned to prepare a design-and-construct tender package and provide technical and installation administration services for a retrofit solution for conversion of the high-rise DHW plant. Thermal Energy Solutions provided technical input to the tender concept and were subsequently successful in being awarded the project.

This project was recognised at the 2022 National Energy Efficiency Awards with the Integrated Clean Energy Award. This award recognises projects that have demonstrated excellence in integrating high levels of energy productivity and renewable energy considering aspects of performance, leadership and innovation.

System requirements

- Reliable and uninterrupted hot water delivery over 23 levels
- Use electric heat pumps to efficiently heat water without gas
- Use solar PV system to maintain water temperature (when solar is available)
- Be separated from the existing heating hot water plant
- Inclusion of a business management system (BMS) interface to the heat pumps and solar PV
- Meet minimum first-hour hot water demand of 1060 L to supply 132 handwash basins, 22 service sinks and pipework heat loss.

The original system

The original domestic hot water plant (pictured to the right) comprised of an ageing 7000 L calorifier heated by the building's heating hot water plant which operated at 70% efficiency. By separating the domestic hot water plant from the heating hot water system, the heating hot water system can be completely shut down during the summer months.

The new system

The new Enermax system is designed to reduce the building's carbon footprint and energy expenses while ensuring the reliable delivery of hygienic hot water. Further, the plant boasts a smaller footprint and improved durability. It was essential to our clients that the system replacement be conducted at low cost and with minimal disruption to the buildings hot water supply.

A high efficiency heat pump solution reliably delivers primary domestic hot water requirements. In addition to an existing solar PV system connected to the building's electrical supply, an 8 kW solar PV system was installed to provide energy for supplementary heating for the 4 x 500 L storage tanks via electric immersion heating elements.

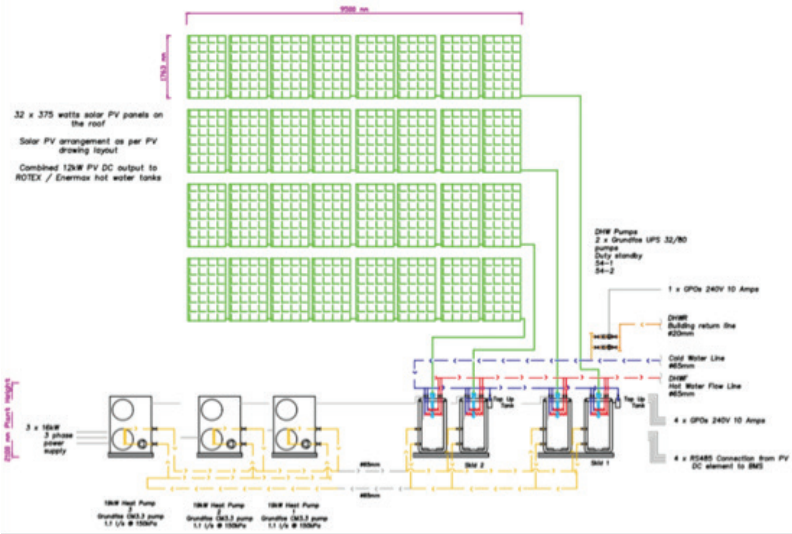
The system is designed to integrate fully into the building's existing systems and was delivered to site as a 'plug-and-play' package ready to be assembled and commissioned.

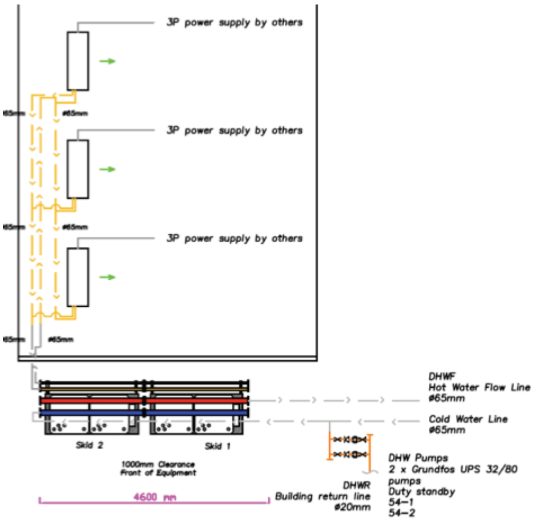
New system components

The ENERMAX solution consisted of

- 4 x Enermax 500 L SMARTcube Tanks
  - Heat exchanger tank
  - Dual stainless-steel coils providing DHW
  - Highly insulated thermal storage tank (1.4 kWh_{th}/day heat loss)
- 3 x Enermax 19 kW commercial heat pumps
  - External
  - COP = 3.58
- 4 x my-PV 2 kW SC20 immersion elements
  - Powered by DC energy from dedicated PV panels without the need of inverters
  - The heat pumps and solar PV elements are interfaced with the BMS to monitor and measure the system's operation and performance.

- 2000 L of thermal storage
- 57 kW of heat pump capacity
- 8 kWp of solar PV via DC element





System performance

Energy

During a 25-day test period following final commissioning, the solar PV system had generated 3.78 GJ (1050 kWh) of solar energy. The heat pumps had delivered an estimated thermal output of 17.01 GJ (4725 kWh_{th}) for a total thermal output of 20.79 GJ (5775 kWh_{th}) while only consuming 5.67 GJ (1575 kWh).

The previous plant, with convention natural gas-fired heating hot water boilers operating at 70% thermal efficiency, would consume approximately 29.7 GJ of gas to meet the same hot water demand.

During this period the new plant reduced energy consumption by 80.91% at the plant level, with a similar reduction in associated greenhouse gas emissions.

The heat pump systems offered significantly improved energy efficiency, providing up to 358% of the energy consumed, compared to 80% for most gas systems. The solar PV heating further reduced energy consumption.

This innovative project in a high-profile existing building showcases a scalable and practical technology solution using available technology to degasify to remove Scope 1 emissions in existing buildings while improving energy efficiency.

Service delivery

Consistently delivering up to 1257 L at 65 °C in the first hour with a recovery rate of 893 L/hour.

Footprint

The total footprint is less than the original system. Heat pumps are in a previously unused outdoor area with only the tanks located in the plantroom.

Hygiene

The Enermax SMARTcube allows for hygienic hot water delivery. Water intended for consumption is never stored in the tank, as it flows through the tank's stainless-steel coils it draws heat from the surrounding hot water. This avoids the build-up of sediment and residue.

Installation

The modular system was prefabricated then disassembled and brought on site without the need for external cranes or lifts. It was reassembled on site with minimal disruption to the building's domestic hot water supply.

Durability

Piping between the tanks and heat pumps is unpressurised, which reduces wear and tear for improved durability and less ongoing maintenance. The solar PV boosting reduces heat pump operation, further improving durability.

Summary

- This Enermax solution led to a significant reduction in energy consumption.
- Heat pump hot water systems improve energy efficiency three-fold.
- Heating from dedicated solar PV can further significantly reduce energy consumption on days with high solar gain.
- Heat pumps and solar heating elements provide valuable and actionable data to facility managers through BMS integration.
- Heated water is reliably and consistently delivered over 23 levels from a single system.
- Installation occurred with minimal disruption to water supply with a reduced plant room footprint.
- The unique Enermax system design delivers improved long-term durability and lower maintenance costs.

The heat pump units.

The highly insulated thermal storage tank reduces energy waste from heat loss.

9.14 CASE STUDY: Matterhorn Lodge, Perisher Valley, NSW

Client/owner: Matterhorn Lodge

Designer/supplier: Mitsubishi Heavy Industries Air-Conditioners Australia (MHIAA)

Installer: Jindabyne Refrigeration

Project summary

The Matterhorn Lodge is located in the alpine region of Australia in Perisher Valley, where ambient temperatures can reach –20 °C. The 32-room ski lodge is open for winter ski season (long weekend June to long weekend October). Under the contract of sale (prior to the 2016 ski season) the current owners of the lodge had to do a number of upgrades. This included the replacement of diesel boiler that supported the hot water and hydronic heating system. This boiler was more than 50 years old and while there was no data available due to the change in ownership, it was soon clear it was extremely inefficient.

The owners of the lodge were looking for a safe and cost-effective solution to replace the existing diesel boiler and supply hot water to their guests. The lodge is located in the Kosciuszko National Park, so the owners were also looking to invest in reducing the facility's long-term environmental impact.

Due to time limits prior to the start of the ski season it was determined it would be best to complete the upgrade in two phases: phase 1 involved installing a heat pump for the pre-heating of the water and then converting the diesel boiler to a gas boiler. Stage 2 involved replacing the LPG boiler.

Jindabyne Refrigeration installed the MHIAA Q-ton CO_2 air-to-water heat pump for pre-heating of the water for both the domestic hot water and hydronic heating system. This was the first installation of such a system in the alpine region of Australia. The diesel boiler was replaced with an LPG boiler to be used for final water heating. The existing 2 x 560 L tanks were retained and an additional 1000 L water storage tank was installed.

The Q-ton was plumbed into the existing system with the idea that there was a redundancy between the unit and the LPG boiler. It received water at an inlet temperature of 2 °C could heat about 1000 L of water in two hours in ambient conditions of –5°C.

The plan was to replace the gas boiler and install four or five additional Q-ton at the end of 2017 after the ski season. However, there were issues with moving ahead with this plan:

- Concern that the additional Q-tons would be an over-design to eliminate risk of demand shortfalls
- Space was an issue – the old boiler had not been removed as it was not straight forward and there were time constraints. National Parks would not rent out any additional space for the lodge to use.
- Noise – the obvious installation location was between the lodge and a neighbour, who was concerned about this.
- The CapEx for installing four or five more Q-tons was high when the owners had just performed extensive upgrades the lodge facilities at the time.

As a result of the issues above, the Lodge went for a gas solution. The Q-ton was switched to providing the domestic hot water only and a new gas boiler was installed for hydronic heating system.

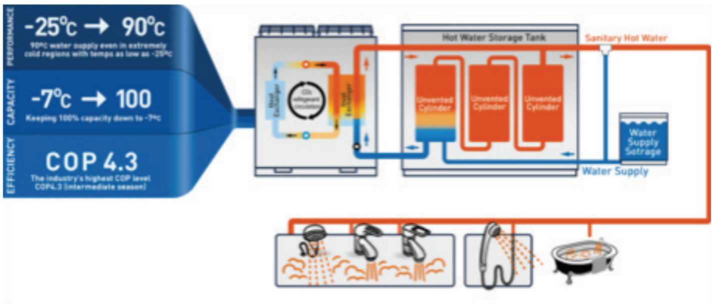
The owners' intention was for the old boiler to be removed and an additional redundancy installed. This stage third has not progressed at this time.

The heat pump solution

The Q-ton is an air source heat pump water heater that utilises CO_2 as a natural refrigerant to deliver a reliable and highly efficient hot water solution in even the coldest environments. The Q-ton heat pump draws air through an evaporator that contains CO_2 refrigerant, which absorbs the heat in the air. The two-stage compressor puts the refrigerant under high pressure in order to raise its temperature, while an on-board heat exchanger uses heat from the refrigerant to generate hot water, which is then stored in tanks for sanitary use.

Q-ton, which has WaterMark certification, runs like a boiler and can generate hot water from 60 °C to 90 °C, even in –25 °C ambient temperatures, without requiring an electric immersion heater backup. It can therefore be used in a variety of applications, such as hotels, restaurants, apartment blocks, fitness centres, hospitals, universities, commercial laundries and aged care facilities.

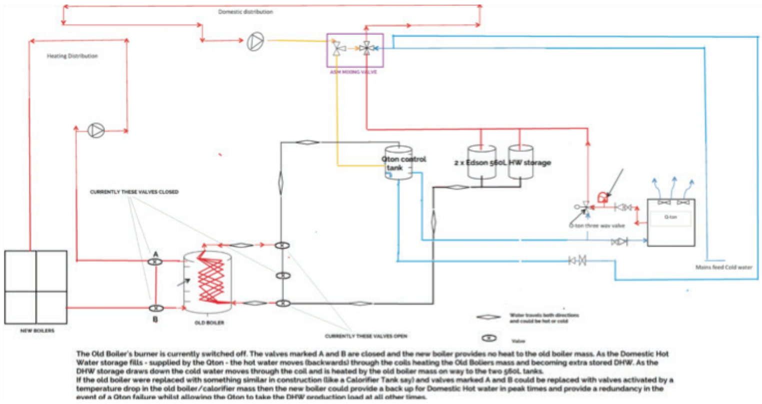
To produce 90 °C hot water at –7 °C ambient temperature, the Q-ton consumes 64% less energy than an electric water heater, according to MHIAA.



The Q-ton works on the principle of storing water in stainless storage cylinders in varying configurations and then distributing this into the reticulation pipework. The design of Q-ton enables the production of hot water based around a 24-hour profile and can also be configured around off-peak tariff or solar feed-in power periods.

Performance

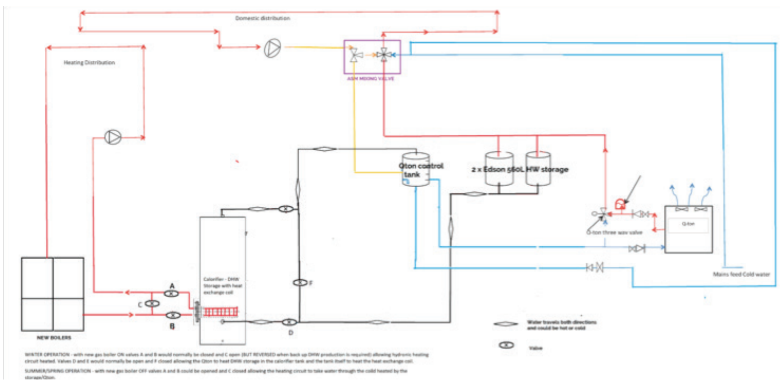
Though Matterhorn Lodge Perisher is a great example of an end-user company that is forward-thinking and environmentally responsible, the number one reason it chose to go with the Q-ton was the cost savings that it delivers. MHIAA predicts that by using the Q-ton, Matterhorn Lodge will cut 50% of its energy costs versus a traditional gas boiler.



Information sources:

Accelerate Europe Winter 2017 Article "Lofty potential for CO2 heat pumps in Australia"by By Devin Yoshimoto & Jan Dusek Page 64

Accelerate Australia & NZ Spring 2017 Article "Lofty potential for CO2 heat pumps in Australia" by By Devin Yoshimoto & Jan Dusek Page 62



9.15 CASE STUDY: 222 Exhibition Street, Melbourne, Victoria

Client/owner: 222 Exhibition Street Management

Contractor: Knight Frank

Designer and installer: Energy Smart Water (ESW) and Thermal Energy Solutions (TES)

Project summary

A Melbourne CBD office tower required replacement of the water heating plant to service office amenities on 30 levels. The new system needed to ensure reliable supply of hygienic hot water, deliver energy usage reduction, improved plant durability and free up plant room space. It was essential that the system replacement be conducted at lowest possible cost and with minimal disruption to hot water supply.

System requirements

- Reliable, uninterrupted hot water delivery over 30 levels, including as basins and sinks for each level.
- Must be capable of delivering more than 1200 L warm water at 51 °C within a peak usage hour.
- Priority to be put on increasing energy efficiency, decreasing footprint and decreasing maintenance requirements.

Original system

Existing natural gas (atmospheric gas burner with electric resistive boost) comprising:

- 2 x 200 L gas water storage tanks
- 3 x 400 L stainless steel electric storage tanks

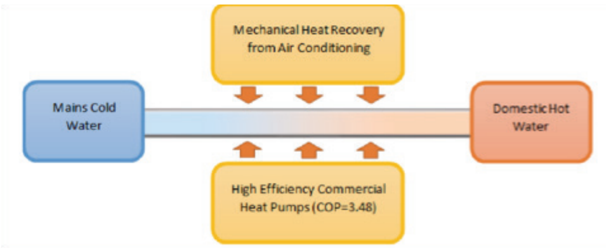
The plant was failing to meet energy efficiency targets, with maintenance costs higher than desired and operational issues.

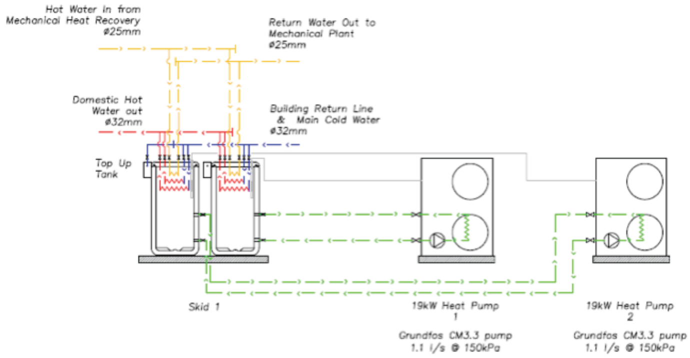
System solution

- 2 x ENERMAX SMARTcube unpressurised 500 L tanks comprising triple stainless-steel coils for hygienic hot water and high flow rate capability.
- 2 x ENERMAX high-temperature 19 kW commercial heat pumps with COP of 3.48

The system is BMS-compatible, so it can be integrated with the building's BMS to measure and monitor operation, energy consumption and efficiency.

The system makes use of mechanical waste heat recovery. By fitting one of the coils from the SMARTcube tanks to the air conditioning system, excess heat produced by the air conditioning plant is reclaimed by the hot water plant. The system can be linked in future to solar thermal and/or solar PV panels as an additional energy source to further reduce energy consumption and carbon footprint.





System performance[32]

Energy reduction
Significantly reduced energy usage, as system thermal efficiency is improved from previous 80% (original system) to 348% through the heat pump's superior COP. The energy reduction is further increased with the use of mechanical waste heat recovery.

Cost reduction
The running and maintenance costs are significantly reduced, with savings projected to exceed installation costs after 2.7 years of operation.

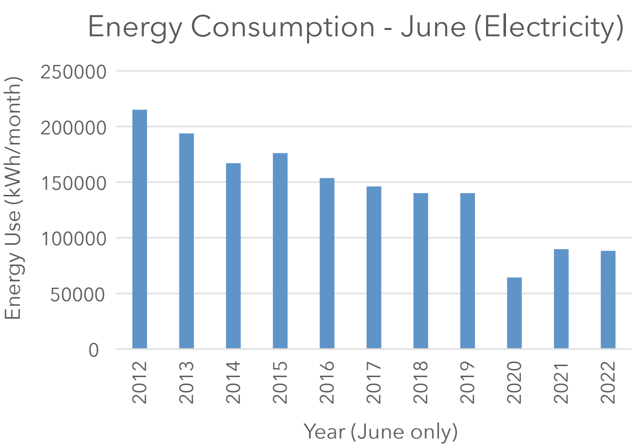
Energy consumption in June 2022 compared to consumption in pre-COVID years:

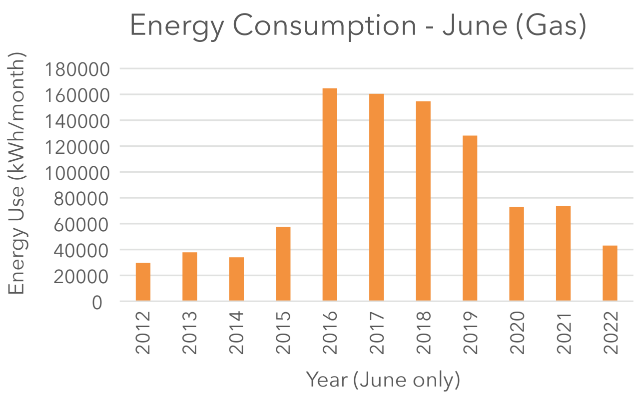
- 55% reduction in gas consumption
- 47% reduction in electricity consumption
- 49% reduction in total energy consumption
- Equivalent gas requirement for old system: 29.7 GJ (8250 kWh)

Service delivery
Consistently delivering up to 1200 L at 65 °C over all 30 levels.

Footprint
Total footprint is less than the original system.

Hygiene
The ENERMAX SMARTcube design passes water being heated for consumption through dedicated 316 stainless-steel coils, separated from heat exchange water in the tank.





32. Data supplied by the building manager.

Installation changeover
The modular system was built then disassembled and brought on site without the need for external cranes or lifts. It was then reassembled in-situ with minimal disruption to the building's domestic hot water supply.

Durability
The primary loop within the ENERMAX system is unpressurised, reducing wear for improved durability and less ongoing maintenance.

Summary
This solution provides significantly improved energy efficiency without the need for additional boosting and the ability to monitor performance and efficiency through the BMS. Combined with lower maintenance and greater efficiency, it is projected to save 88% of the annual expenses of the pre-existing plant. Heated water is reliably and consistently delivered over 30 levels from a single system. Installed with minimal disruption to water supply when retrofitted in position and space-saving is maximised. The solution delivers improved long-term durability and lower maintenance costs

Challenges

- System monitoring and data collection
- Quantifying performance is difficult without measurement and verification
- Heat pump positioning relative to ENERMAX tanks
- Equipment footprint
- Site access (being a tall building)
- Justifying higher CapEx of heat pumps compared to traditional plants.

Lessons learnt

- If possible, implement measurement and verification as part of project
- Plan for monitoring and data collection during the design process to remove reliance on getting data from BMS
- Consider including flow meters and other instrumentation to measure thermal output of the plant
- Maintain communication with building managers as part of feedback loop to improve on system design and operation.

10 APPENDICES

Appendix A List of current refrigerants[33]

Table 12: *HFC refrigerants and their Global Warming Potential (GWP) according to IPCC's Fourth Assessment Report.*

Code	Substance name	Chemical name	Chemical formula	GWP
R-125	HFC-125	Pentafluoroethane	CHF_2CF_3	**3,500**
R-134A	HFC-134a	Tetrafluoroethane	CH_2FCF_3	**1,430**
R-143A	HFC-143a	Trifluoroethane	CF_3CH_3	**4,470**
R-152A	HFC-152a	Difluoroethane	CH_3CHF_2	**124**
R-227EA	HFC-227EA	Heptafluoropropane	CF_3CHFCF_3	**3,220**
R-23	HFC-23	Trifluoromethane / Fluoroform	CHF_3	**14,800**
R-236CB	HFC-236CB		$CH_2FCF_2CF_3$	**1,340**
R-236EA	HFC-236EA		CHF_2CHFCF_3	**1,370**
R-236FA	HFC-236FA	Hexafluoropropane	$CF_3CH_2CF_3$	**9,810**
R-245CA	HFC-245CA		$CH_2FCF_2CHF_2$	**693**
R-245FA	HFC-245FA	Pentafluoropropane	$CHF_2CH_2CF_3$	**1,030**
R-32	HFC-32	Difluoromethane	CH_2F_2	**675**
R-365MFC	HFC-365MFC	Pentafluorobutane	$CF_3CH_2CF_2CH_3$	**794**
R-41	HFC-41	Fluoromethane (or Methyl fluoride)	CH_3F	**92**
R-43-10MEE	HFC-43-10MEE	Decafluoropentane	$CF_3CHFCHFCF_2CF_3$	**1,640**

Table 13: *HFC blend refrigerants and their Global Warming Potential (GWP) according to IPCC's Fourth Assessment Report.*

Code	Blend name	GWP	Code	Blend name	GWP	Code	Blend name	GWP
R-404A	HFC-404A	3,922	R-424A	HFC-424A	2,440	R-449C	HFC-449C	1,250
R-407A	HFC-407A	2,107	R-425A	HFC-425A	1,505	R-450A	HFC-450A	601
R-407B	HFC-407B	2,804	R-426A	HFC-426A	1,508	R-451A	HFC-451A	146
R-407C	HFC-407C	1,774	R-427A	HFC-427A	2,138	R-451B	HFC-451B	160
R-407D	HFC-407D	1,627	R-428A	HFC-428A	3,607	R-452A	HFC-452A	2,139
R-407E	HFC-407E	1,552	R-429A	HFC-429A	13	R-452B	HFC-452B	697
R-407F	HFC-407F	1,825	R-430A	HFC-430A	94	R-452C	HFC-452C	2,219
R-407G	HFC-407G	1,463	R-431A	HFC-431A	36	R-453A	HFC-453A	1,765
R-410A	HFC-410A	2,088	R-434A	HFC-434A	3,245	R-454A	HFC-454A	236
R-410B	HFC-410B	2,229	R-435A	HFC-435A	26	R-454B	HFC-454B	465
R-413A	HFC-413A	2,053	R-437A	HFC-437A	1,805	R-454C	HFC-454C	145
R-417A	HFC-417A	2,346	R-438A	HFC-438A	2,264	R-455A	HFC-455A	145
R-417B	HFC-417B	3,027	R-439A	HFC-439A	1,983	R-456A	HFC-456A	684

33. Department of Climate Change, Energy, the Environment and Water (DCCEEW), *Global warming potential values of hydrofluorocarbon refrigerants*, DCCEEW, 2022, accessed 4 August 2022.

Code	Blend name	GWP	Code	Blend name	GWP	Code	Blend name	GWP
R-417A	HFC-417A	2,346	R-438A	HFC-438A	2,264	R-455A	HFC-455A	145
R-417B	HFC-417B	3,027	R-439A	HFC-439A	1,983	R-456A	HFC-456A	684
R-419A	HFC-419A	2,967	R-442A	HFC-442A	1,888	R-458A	HFC-458A	1,650
R-419B	HFC-419B	2,384	R-444A	HFC-444A	87	R-500	HFC-500	8,077
R-421A	HFC-421A	2,631	R-444B	HFC-444B	293	R-503	HFC-503	14,560
R-421B	HFC-421B	3,190	R-445A	HFC-445A	129	R-507A	HFC-507A	3,985
R-422A	HFC-422A	3,143	R-446A	HFC-446A	459	R-508A	HFC-508A	13,214
R-422B	HFC-422B	2,526	R-447A	HFC-447A	582	R-508B	HFC-508B	13,396
R-422C	HFC-422C	3,085	R-447B	HFC-447B	739	R-512A	HFC-512A	189
R-422D	HFC-422D	2,729	R-448A	HFC-448A	1,386	R-513A	HFC-513A	629
R-422E	HFC-422E	2,592	R-449A	HFC-449A	1,396	R-513B	HFC-513B	593
R-423A	HFC-423A	2,280	R-449B	HFC-449B	1,411	R-515A	HFC-515A	386
R-417A	HFC-417A	2,346	R-438A	HFC-438A	2,264	R-455A	HFC-455A	145

Table 14: *A list of hydrocarbon and other natural refrigerants that all have a global warming potential of less than 5 according to data provided by DCCEEW.*[33]

Code	Name	Chemical name	Chemical formula
R-1270	HC-1270	Propene / Propylene	C_3H_6
R-12A	HC-12A	(Hydrocarbon blend)	
R-170	HC-170	Ethane	C_2H_6
R-22A	HC-22A	(Hydrocarbon blend)	
R-290	HC-290	Propane	C_3H_8
R-502A	HC-502A	(Hydrocarbon blend)	
R-600	HC-600	Butane	C_4H_{10}
R-600A	HC-600a	Isobutane	C_4H_{10}
R-601A	HC-601a	Isopentane	$((CH_3)_2$ CH--CH_2 --$CH_3)$
R-717	HC-717	Ammonia	NH_3
R-744	HC-744	Carbon Dioxide	CO_2

Appendix B Levelised cost of heat

Levelised cost of heat (LCOH) refers to the unit cost of heat that a heating system delivers over its useful lifetime. It accounts for the CapEx and running cost of the heating system.

A simple formula to calculate the LCOH is as the following[34]:

$$\frac{\text{(Overnight capital cost [in A\$] x capital recovery factor + fixed O\&M cost [in A\$ per year] + annual fuel cost [in A\$ per year] + annual variable O\&M cost [in A\$ per year])}}{\text{(Total annual heat generation [kWh}_{th}\text{ per year])}}$$

Capital recovery factor = i(1 + i)n / {[(1 + i)^{n}]-1}

i: discount rate

n: number lifetime years

34. National Renewable Energy Laboratory (NREL), *Simple Levelized Cost of Energy (LCOE) Calculator Documentation*, NREL, 2022, accessed 27 July 2022.

Appendix C Lower CO_2-e emissions

Typically, lower emissions are a natural outcome of reducing primary energy consumption. The exact emissions saving will also depend on climate, choice of equipment, and the fuel used by the technology the heat pump is compared to. For example, an efficient heat pump used in Melbourne to heat a room can use just 21% of the electricity that a resistive electric heater would use to heat the same space, reducing emissions by up to 79%[35]. It would use up to 90% less energy than a gas heater.

Heat pumps are critical to decarbonise Australia's energy system, especially between now and 2030. The Australian electricity grids rely on large fossil fuel generators, which are expected to remain part of the mix of electricity generation for some time to come, though their share of generation is declining. Replacing outdated technologies like electric resistive heaters and gas heaters with heat pumps for services such as air heating and hot water generates an immediate and significant emissions reduction by using less grid electricity or fossil gas for the same service.

The ability of heat pumps to further reduce the emission intensity in heating applications is contingent upon the relative emission intensity of the electricity used to power heat pumps compared to the emission intensity of other fuels. Since June 2008, the emission intensity of the National Electricity Market has reduced by 20%[36] since it peaked in 2008. As the share of renewable energy in the generation mix increases, the average emissions intensity of grid electricity falls. As a result, the emissions savings that can be achieved by switching fossil fuel-based heating to heat pumps will grow further.

According to the Australian Energy Market Operator's 2020 Integrated System Plan, the emissions intensity of the National Electricity Market is projected to fall considerably by the middle of the 2030s[37]. Recent updates show faster decline rates and deeper reductions.

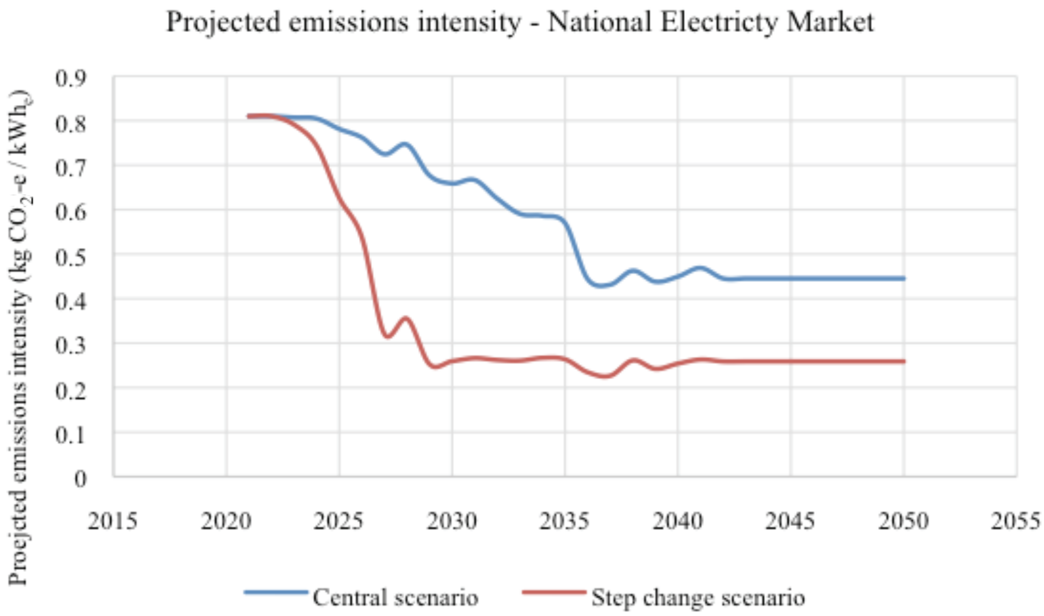


Figure 34: *Projected greenhouse gas emissions intensity in the National Electricity Market. Source: The Heat Pump Energy and Emissions Savings Model, based on AEMO ISP 2020.*

35. Based on Sustainability Victoria, *Calculate heating running costs* [website page], Sustainability Victoria, 2022, accessed 30 July 2022.
36. The Australia Institute, *National Energy Emissions Audit Report*, The Australia Institute, 2020, accessed 2 August 2022.
37. DISER, *Australia's emissions projections 2020*, DISER, 2020, accessed 2 August 2022.

Appendix D Current costs of air source heat pump water heaters

The price of some air source heat pump water heaters in the Australian market.[38,39]

Supplier	Model	Refrigerant	Compressor	Thermal output power [kW_{th}]	Unit price
Mitsubishi Heavy Industries	Qton	R744	Reciprocating	30	$25,000 (2019 price)
Automatic Heating	Revere CHP15HF-PKG	R744	Twin scroll	15	$20,000 (2022 price)
Mayekawa	Unimo AW	R744	Reciprocating	72	$48,100 (2019 price)
Automatic Heating	Revere CHP26H4-PKG	R744	Twin scroll	26	$30,000 (2022 price)
Automatic Heating	Revere CHP80Y2-PKG	R744	Twin scroll	78	$65,000 (2022 price)
Mayekawa	Unimo AWW	R744	Reciprocating	82	$74,900 (2019 price)

38. ITP Australia, Renewable Energy Options for Industrial Process Heat, published by the Australian Renewable Energy Agency, 2019, accessed 30 July 2022.

39. Email from Terry Plaisted, Automatic Heating, 7 November 2022.

Appendix E Procurement

Below is a non-exhaustive list of criteria to assess a heat pump supplier. Each purchaser must do their own due diligence and adjust the criteria and weighting as they see appropriate for their own conditions.

Supplier Selection Criteria	Example	Assessment scores (scale: 0 to 100)			
		Sub-criteria score	Supplier 1	Supplier 2	Supplier 3
Cost (15%)	Price	15%			
Time (10%)	Capability to meet required delivery time for equipment and installation	10%			
Quality & performance (45%)	Has the HP been certified for the VEU program?	5%			
	Positive feedback from existing users of the product	5%			
	Detailed quality and performance score - see next table	30%			
	Detailed Energy Savings Analysis Report and Performance Guarantee	5%			
Service (10%)	Pre and Post Sales Costumer Support	5%			
	Service capability - local, 24/7, size of service team?	5%			
Terms and conditions (20%)	General terms and conditions (purchaser T&C's - best, Australian Standards T&C's - good, Vendor's T&C's - worst)	4%			
	Retention of final payment (ideally >10%) until reaching performance guarantee or end of warranty period?	4%			
	Liquidated damages for late delivery to site	4%			
	Warranty - clear obligation to rectify faults, onsite in a timely manner	4%			
	Performance guarantee - clear damages and obligations if not meeting specifications (eg COP at given conditions)	4%			
Total selection criteria (weight)		100%			

Further comments

- The sub-criteria weighing is subject to adjustment depending on the conditions of the purchaser.
- For a heat pump package, pricing usually includes most components.
- Price is a subjective matter, especially when the quality of the heat pump needs to be taken into account.
- A relatively cheap system may comprise one or more heat pumps, tanks, some form of controllers, pumps, but may still be lacking quality compared to other more expensive ones with seemingly the same equipment.
- Time can be critical in some situations. It can outweigh other factors when no delays is acceptable.
- Reports of testing to AS/NZS 5125 and EN 14511 can help to acquire some performance assessment.
- An expected annual operational report would be more informative where product is considered in the application and relevant climate zone.
- Some form of written guarantee needs to be provided, with clear terms and conditions of what this means.

Appendix F Quality and performance assessment

Detailed Quality and performance assessment	Sub-criteria		Assessment scores (scale: 0 to 100)		
		Sub-criteria score	Supplier 1	Supplier 2	Supplier 3
Standard features across most heat pumps	Vendor demonstrates a clear understanding of requirements				
	Meeting Australia standards and test reports				
	Manufacturer of compressor				
	Manufacturer of tank				
	Manufacturer of heat pump system				
	Performance track record (references)				
	COP across expected ambient and hot water temperature				
	Max hot water temperature				
	Operating temperature limits				
	Noise level (less than 45 good, <55 OK, >55 may not be OK				
	Compressor lifetime				
	Control systems and smart features				
	Energy usage data reporting and accessibility				
	Control system connectivity (e.g. Ethernet etc.)				
	Storage tank daily heat loss (%)				
	Storage tank materials / corrosion protection				
	Evaporator coils corrosion protection				
	Condenser heat exchanger materials				
	Defrost method				
	Booster element required?				
	Booster element alarm indication?				
	Refrigerant type (high or low GWP?)				
	Warranty period				
Site specific issues	Is the system suitable for the conditions of the environment? (in terms of corrosion)				
	Is the system suitable for poor water quality (e.g. bore water)				
	Is the system able to link with on-site solar PV?				
	+ other site specific considerations				
Other features as mentioned by vendors	Feature 1, e.g. smart defrost functions				
	Feature 2, e.g. smart energy management				
	Feature 3				
	Feature 4				
Overall quality and performance score					

Further comments

- For products that have components in contact with potable water, it would be necessary to be compliant to AS4020, for safety reasons. For non-potable applications this is irrelevant.
- For heat pumps where the heat exchanger is in contact with potable water, some evidence is required to show that a leak will not result in water contamination. This can be assured by following the requirements for heat exchangers in AS/NZS 2712, regarding design and construction for solar water heaters and heat pumps. Note: heat pumps that already comply with CER requirements for STCs and VEECs and ESCs, already have compliance assured in this aspect.
- A COP for a test will not mean a COP for the application in which the product is used. That requires verification of some sort. So here a performance report providing expected energy consumption and savings vs conventional equipment can be compared with the verification afterward.
- For noise levels, the data from the manufacturer should be compared to identify the comparative noise level.
- Noise scoring is application-specific. For example, a system for commercial and industrial use with a sound power level of 65 dB(A) may be perfectly fine. Therefore, a lower figure from another system would add no value to the purchaser, but could cost more. So, if noise level is not a serious issue, this item can be removed.
- For domestic use, noise level is more important, but for commercial and industrial it is less important.
- The control system should be well detailed on what it can do and this will probably include any smart and advanced features.
- Actual performance data that can be logged with added smart system manipulation should be scored higher.
- Details on the heat exchanger protection type should be requested from the supplier
- It is important to not just ask for booster element, but why it is required and how it is used.
- Warranty period should be detailed for all components involved in the system and upfront about whether it involves product replacement and/or repair, if it includes labour and if there are pro-rata type of applied conditions as there are for some commercial tanks.

Appendix G Australian standards related to heat pump water heaters

AS 3498:2020 Safety and public health requirements for plumbing products – water heaters and hot water tanks

AS/NZS 4692.1 Electric water heaters - Energy consumption, performance and general requirements.

AS/NZS 5125.1 Heat pump water heaters - Performance assessment Air source heat pump water heaters

Air-Conditioning, Heating, & Refrigeration Institute Standard 1230 Performance Rating of Variable Refrigerant Flow (VRF) Multi-Split Air-Conditioning and Heat Pump Equipment.

AS/NZS 3823.1.1:2012 Performance of electrical appliances – air conditioners and heat pumps – Part 1.1: Non-ducted air conditioners and heat pumps – Testing and rating for performance (ISO 5151:2010, MOD).

AS/NZS 3823.1.2:2012 Performance of electrical appliances – air conditioners and heat pumps – Part 1.2: Ducted air conditioners and air-to-air heat pumps— Testing and rating for performance (ISO 13253:2011, MOD).

AS/NZS 3823.1.3:2005 Performance of electrical appliances – air conditioners and heat pumps. Part 1.3: Water-source heat pumps—Water-to-air and brine-to-air heat pumps—Testing and rating of performance (ISO 13256-1, Ed. 01 (1998) MOD).

AS/NZS 3823.1.4:2012 Performance of electrical appliances – Air conditioners and heat pumps. Part 1.4: Multiple split-system air conditioners and air-to-air heat pumps–Testing and rating for performance (ISO 15042:2011, MOD).

AS/NZS 3823.1.5:2015 Performance of electrical appliances – Air conditioners and heat pumps. Part 1.5: Non-ducted portable air-cooled air conditioners and air-to-air heat pumps having a single exhaust duct – Testing and rating for performance.

AS/NZS 3823.2:2013 Performance of electrical appliances – air conditioners and heat pumps. Part 2: Energy labelling and minimum energy performance standards (MEPS) requirements.

AS/NZS 3823.4.1:2014 Performance of electrical appliances – Air conditioners and heat pumps. Part 4.1: Air-cooled air conditioners and air-to-air heat pumps– Testing and calculating methods for seasonal performance factors – Cooling seasonal performance factor (ISO 16358-1:2013, (MOD)).

AS/NZS 3823.4.2:2014 Performance of electrical appliances – Air conditioners and heat pumps. Part 4.2: Air-cooled air conditioners and air-to-air heat pumps– Testing and calculating methods for seasonal performance factors – Heating seasonal performance factor (ISO 16358-2:2013, (MOD)).

European Standard 12102:2013 Air conditioners, liquid chilling packages, heat pumps and dehumidifiers with electrically driven compressors for space heating and cooling. Measurement of airborne noise. Determination of the sound power level.

European Standard 12102-1:2017 Air conditioners, liquid chilling packages, heat pumps, process chillers and dehumidifiers with electrically driven compressors - Determination of the sound power level - Part 1: Air conditioners, liquid chilling packages, heat pumps for space heating and cooling, dehumidifiers and process chillers.

European Standard 14511:2018 Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors.

ISO 5151:2017 Non-ducted air conditioners and heat pumps - Testing and rating for performance.

ISO 13253:2017 Ducted air conditioners and air-to-air heat pumps - Testing and rating for performance.

ISO 15042:2017 Multiple split-system airconditioners and air-to-air heat pumps - Testing and rating for performance.

ISO 5149-1:2014 - Refrigerating systems and heat pumps — Safety and environmental requirements — Part 1: Definitions, classification and selection criteria. Amendment 1 (2015): Correction of QLAV, QLMV. Amendment 2 (2021): Update of Annex A and the refrigerant tables

ISO 5149-2:2014 AMD 1(2020) - Refrigerating systems and heat pumps — Safety and environmental requirements — Part 2: Design, construction, testing, marking and documentation

ISO 5149-3:2014/AMD 1 (2021) - Refrigerating systems and heat pumps – Safety and environmental requirements – Part 3: Installation site. Amendment 1 (2021): Update of the requirements for machinery rooms and emergency mechanical ventilation

ISO 5149-4:2014 - Refrigerating systems and heat pumps – Safety and environmental requirements – Part 4: Operation, maintenance, repair and recovery. NOTE: ISO/FDIS 5149-4 Underdevelopment

ISO 5151:2017/AMD 1(2020) - Non-ducted air conditioners and heat pumps – Testing and rating for performance – Amendment 1

ISO 13253:2017/AMD 1(2020) Ducted air-conditioners and air-to-air heat pumps – Testing and rating for performance – Amendment 1

ISO 13261-1:1998 - Sound power rating of air-conditioning and air-source heat pump equipment – Part 1: Non-ducted outdoor equipment

ISO 13261-2:1998 - Sound power rating of air-conditioning and air-source heat pump equipment – Part 2: Non-ducted indoor equipment

ISO 13612-1:2014 - Heating and cooling systems in buildings – Method for calculation of the system performance and system design for heat pump systems – Part 1: Design and dimensioning

ISO 13612-2:2014 - Heating and cooling systems in buildings – Method for calculation of the system performance and system design for heat pump systems – Part 2: Energy calculation

ISO 13971:2012 - Refrigeration systems and heat pumps – Flexible pipe elements, vibration isolators, expansion joints and non-metallic tubes – Requirements and classification

ISO 14903:2017/DAMD 1 - Refrigerating systems and heat pumps – Qualification of tightness of components and joints – Amendment 1

ISO 15042:2017/AMD 1(2020) - Multiple split-system air conditioners and air-to-air heat pumps – Testing and rating for performance – Amendment 1

ISO 16358-1:2013/AMD 1:2019 - Air-cooled air conditioners and air-to-air heat pumps – Testing and calculating methods for seasonal performance factors – Part 1: Cooling seasonal performance factor – Amendment 1

ISO 16358-1:2013/COR 1:2013 - Air-cooled air conditioners and air-to-air heat pumps – Testing and calculating methods for seasonal performance factors – Part 1: Cooling seasonal performance factor – Technical Corrigendum 1

ISO 16358-2:2013/COR 1:2013 - Air-cooled air conditioners and air-to-air heat pumps – Testing and calculating methods for seasonal performance factors – Part 2: Heating seasonal performance factor – Technical Corrigendum 1

ISO 16358-3:2013 - Air-cooled air conditioners and air-to-air heat pumps – Testing and calculating methods for seasonal performance factors – Part 3: Annual performance factor

ISO/TS 16491:2012 - Guidelines for the evaluation of uncertainty of measurement in air conditioner and heat pump cooling and heating capacity tests

ISO 16494:2014 - Heat recovery ventilators and energy recovery ventilators – Method of test for performance

ISO 18326:2018/AMD 1 (2021) - Non-ducted portable air-cooled air conditioners and air-to-air heat pumps having a single exhaust duct – Testing and rating for performance – Amendment 1

ISO 19967-1:2019 - Heat pump water heaters – Testing and rating for performance – Part 1: Heat pump water heater for hot water supply

ISO 19967-2:2019 - Heat pump water heaters – Testing and rating for performance – Part 2: Heat pump water heaters for space heating

ISO 21922:2021/AWI AMD 1 - Refrigerating systems and heat pumps – Valves – Requirements, testing and marking – Amendment 1 NOTE: Underdevelopment

ISO 21978:2021 - Heat pump water heater – Testing and rating at part load conditions and calculation of seasonal coefficient of performance for space heating

ISO/FDIS 22712 - Refrigerating systems and heat pumps – Competence of personnel NOTE: Underdevelopment

ISO/DIS 24664 - Refrigerating systems and heat pumps – Pressure relief devices and their associated piping – Methods for calculation NOTE: Underdevelopment

AHRI 210/240-2023 (2020): Performance Rating of Unitary Air-conditioning & Air-source Heat Pump Equipment

AHRI 211/241-0B/1B (SI/2021): Performance Rating of Unitary Air-conditioning & Air-source Heat Pump Equipment

AHRI 270 (2015): Sound Rating of Outdoor Unitary Equipment (with Addendum 1)

AHRI 275 (2018): Application of Outdoor Unitary Equipment A-weighted Sound Power Ratings

AHRI 310/380 (2017): Packaged Terminal Air-conditioners and Heat Pumps (CSA-C744-17)

AHRI 340/360 (I-P/2022): Performance Rating of Commercial and Industrial Unitary Air-conditioning and Heat Pump Equipment

AHRI 350 (2015): Sound Performance Rating of Non-ducted Indoor Air-conditioning and Heat Pump Equipment (Reaffirmed May 2021)

AHRI 370 (2015): Sound Performance Rating of Large Air-cooled Outdoor Refrigerating and Air-Conditioning Equipment (with Addendum 1)

AHRI 390 (I-P/2021): Performance Rating of Single Package Vertical Air-conditioners and Heat Pumps

AHRI 490 (I-P/2011): Remote Mechanical-Draft Evaporative Refrigerant Condensers

AHRI 491 (SI/2011): Remote Mechanical-Draft Evaporative Refrigerant Condensers

AHRI 545 (2017): Performance Rating of Modulating Positive Displacement Refrigerant Compressors

AHRI 550/590 (I-P/2020): Performance Rating of Water-chilling and Heat Pump Water-heating Packages Using the Vapor Compression Cycle (with Addendum 1)

AHRI 551/591 (SI/2020): Performance Rating of Water-chilling and Heat Pump Water-heating Packages Using the Vapor Compression Cycle (with Addendum 1)

AHRI 575 (2017): Method of Measuring Machinery Sound Within an Equipment Space

AHRI 870 (I-P/2016): Performance Rating of Direct Geoexchange Heat Pumps

AHRI 871 (SI/2016): Performance Rating of Direct Geoexchange Heat Pumps

AHRI 1160 (I-P/2014): Performance Rating of Heat Pump Pool Heaters (with Addendum 1)

AHRI 1161 (SI/2014): Performance Rating of Heat Pump Pool Heaters

AHRI 1230 I-P (2021): Performance Rating of Variable Refrigerant Flow (VRF) Multi-Split Air-Conditioning and Heat Pump Equipment

AHRI 1300 (I-P/2013): Performance Rating of Commercial Heat Pump Water Heaters

AHRI 1301 (SI/2013): Performance Rating of Commercial Heat Pump Water Heaters

Appendix H Manifolding - balanced flow principle

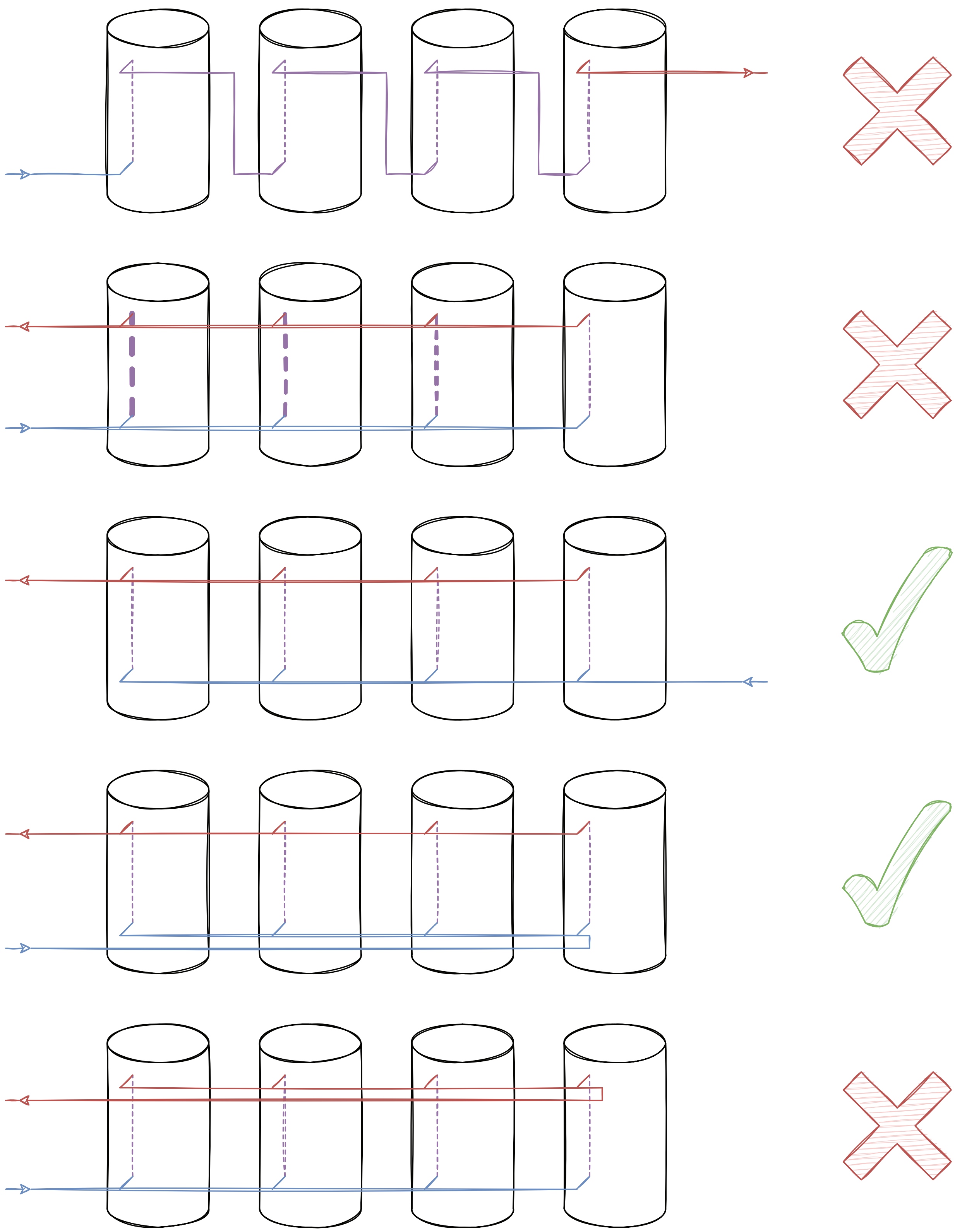


Diagram courtesy of Energy Smart Water.

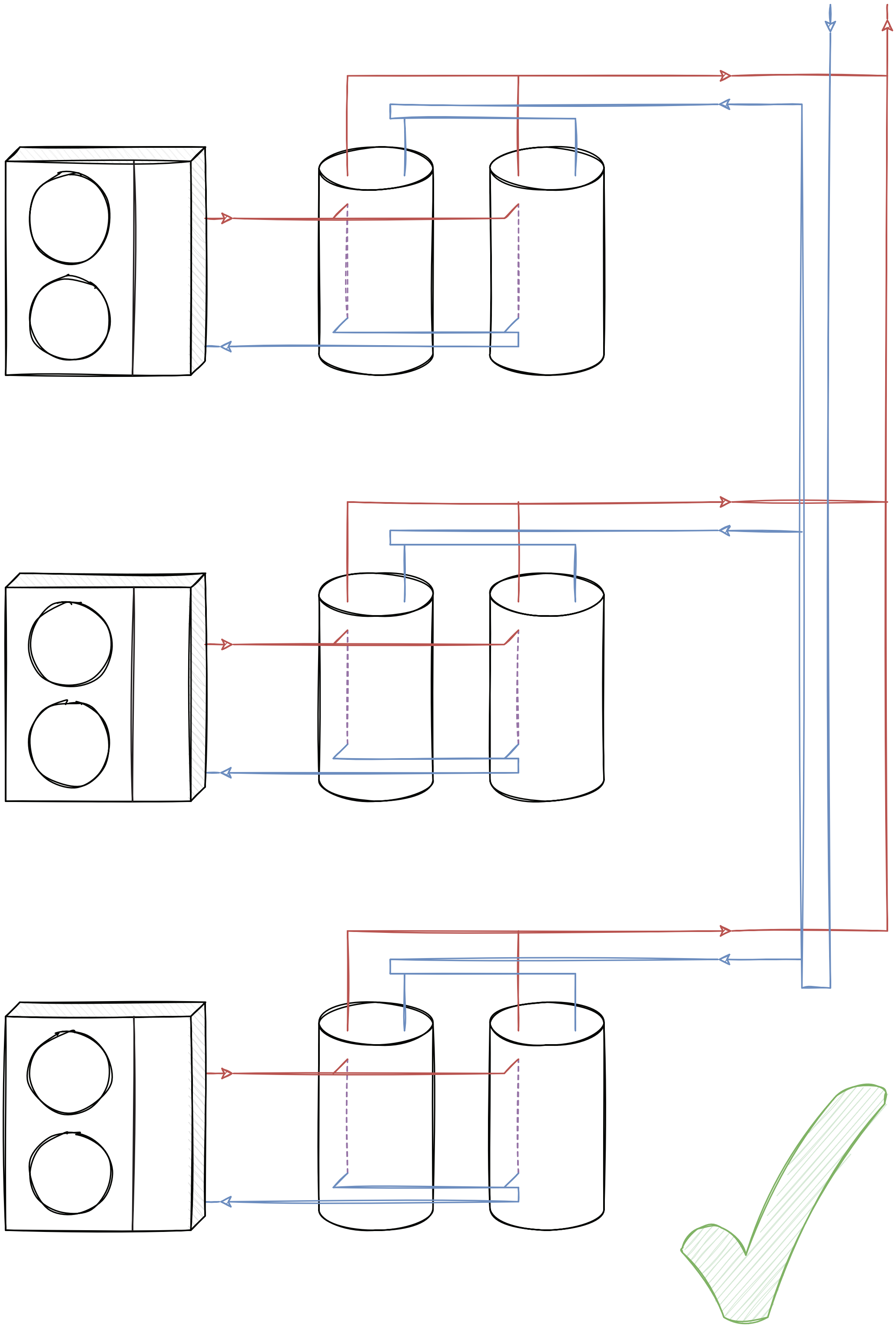


Diagram courtesy of Energy Smart Water.

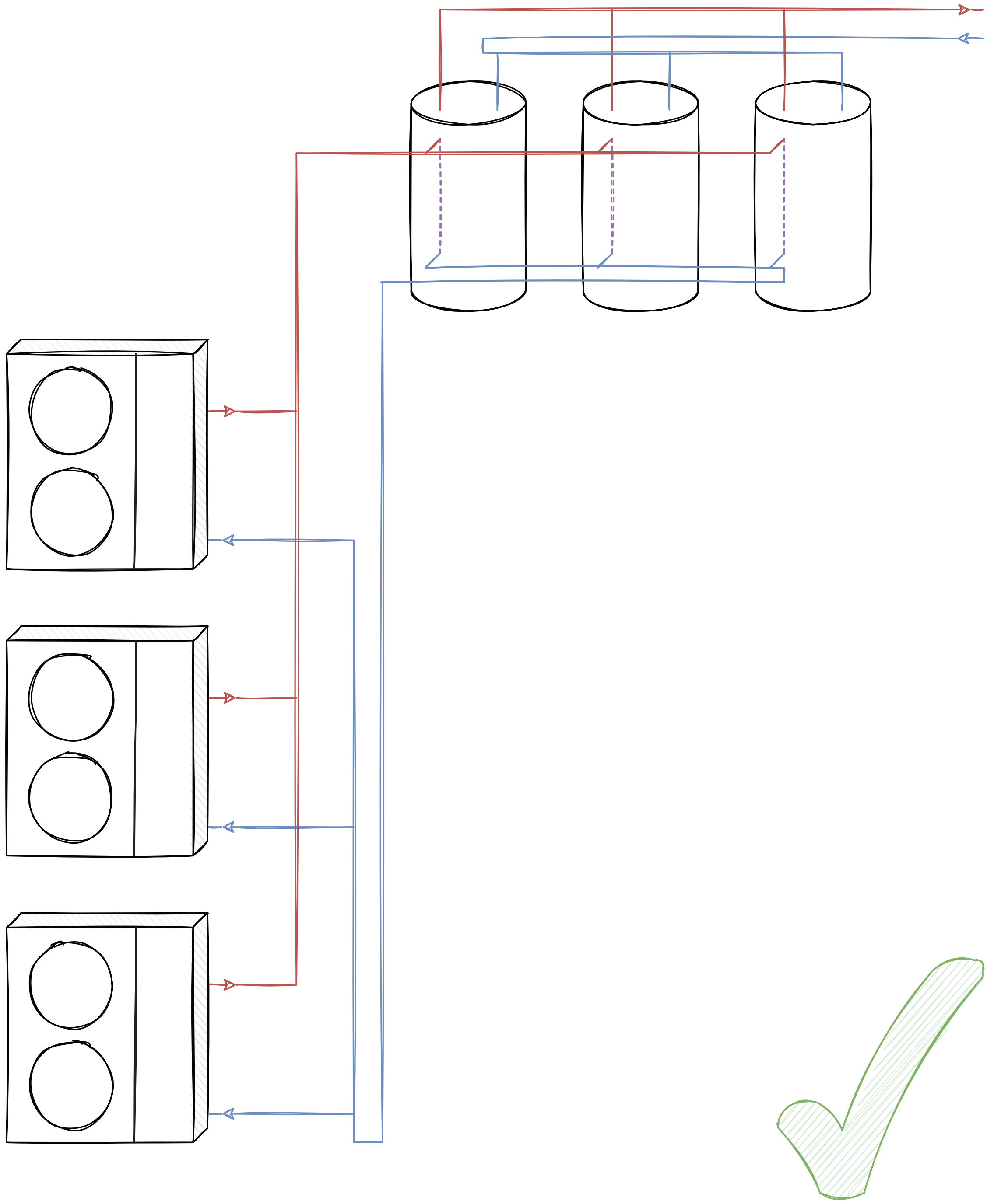


Diagram courtesy of Energy Smart Water.

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