Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

Technical Information Document

High-temperature Heat Pumps for low carbon process heating.

Technical Information Document 2019

New Zealand Government

Introduction

High-temperature heat pumps supply temperatures higher than 60ºC. Commercially available heat pumps can reach temperatures up to 100ºC by using alternative refrigerants and compressors to those used in low-temperature heat pumps. High-temperature heat pumps are usually custom designed for particular applications using equipment from established large OEM[1] refrigeration equipment suppliers, whereas low temperature heat pumps are typically generic, off the shelf products.

High-temperature heat pumps often utilise waste heat or low-grade heat resources as heat sources. This achieves efficiencies by using higher source temperatures than ambient heat pumps. They are often integrated with industrial refrigeration systems where they can use condenser heat as a heat source.

Despite over 100 years of development globally, high-temperature heat pumps are currently underutilised in New Zealand. This is likely to change in the future as there are significant CO_2 reduction opportunities from using heat pumps in process heat intensive industries. The first few installations in New Zealand (see case studies) have proven cost-effective, with reliable performance and increased productivity benefits.

The efficiencies of high-temperature heat pumps generate returns on investment through reduced energy use and other operating costs. Even when electricity costs are higher than coal, oil, gas or biofuel options, investing in high-temperature heat pumps can still be commercially viable. Heat pumps are relatively simple with well-established technical performance. They are relatively small, safe to operate, and easy to use. Further efficiency gains, reduced operating costs and system responsiveness can be achieved by installing precise temperature controls.

The ratio of the delivered heating energy divided by the electrical energy required to run the heat pump provides the energy efficiency value of the heat pump. For example, if a heat pump uses 10 kWh to produce 30 kWh of heat, the efficiency is 300% which gives a coefficient of performance COP of 3.

With New Zealand's highly renewable electricity supply, electric heat pump technologies can offer a cost-effective, low carbon heat source for process heat applications. Heat pumps can, cost effectively, displace fossil-based heating. With the cost of photovoltaic electricity and batteries falling rapidly, some businesses may soon substantially power their heat pumps from their own PV systems.

Low temperature (<60ºC) heat pumps are also available and are covered in a separate Technical Information Sheet available in this series.

1 An original equipment manufacturer (OEM) is a company that produces parts and equipment that may be marketed by another manufacturer

Strata ENERGY CONSULTING

Efficient Energy International
Markets • Policies • Results

EECA commissioned Strata Energy Consulting and Efficient Energy International
to produce this document which is one of a series on electrical heating.

Technical Features

High-temperature (>60ºC) heat pumps

Heat pumps move available heat energy from one place (the source) to another (the sink), typically by compressing and expanding refrigerant gases[2] to transport the heat energy. High temperature heat pumps operate higher than 60°C by using specialised refrigerants, compressors and thermodynamic system designs.

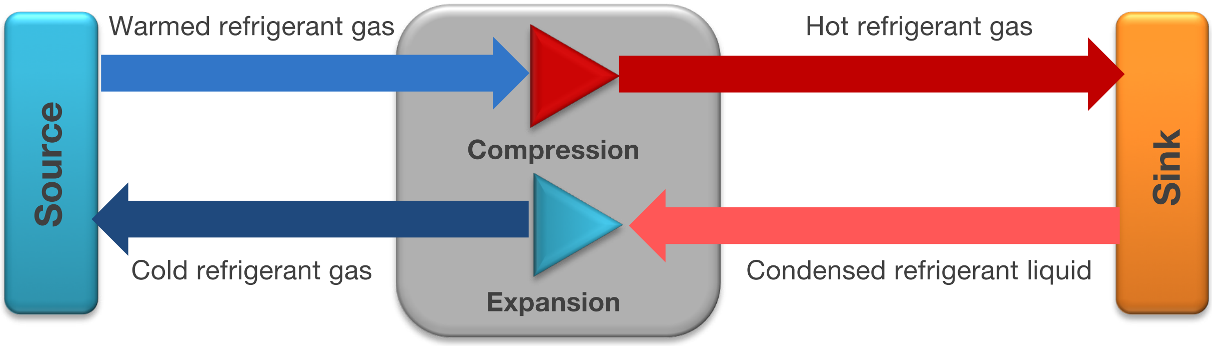


Figure 1. General heat pump operation

Vapour compression heat pump cycles for higher temperatures.

Achieving higher temperatures typically requires more complex systems using different refrigerants that can be compressed and evaporated at the higher temperatures.

Ammonia (R717) is widely used in large scale industrial heat pumps. It is a non-greenhouse gas forming refrigerant with high efficiency. However it can be dangerous and while its strong odour enables easy leak detection, it is flammable, can damage lungs and eyes, and cause asphyxiation at low concentrations. It is essential that effective safety systems are used with this refrigerant.

Butane (R600) and iso-butane (R600a) are used in refrigeration installations and can operate at lower pressures than many other refrigerants. R600 and R600a installations have safety requirements that limit their application as they are both flammable and carry an explosion risk.

Carbon Dioxide (R744) is one of the oldest, natural refrigerants; it is used in combination with ammonia to improve heat pump system efficiency. CO_2 has a trans-critical temperature of 31°C and is limited to applications suited to variable evaporation temperatures.

Water (R718) can be used in heat pumps at higher temperatures where the pressures required by other refrigerants becomes too high for efficient compression. Advances in compressor design may make water an increasingly economic refrigerant option for high-temperature heat pumps supplying heat to large scale, high-temperature drying processes.

Refrigerant	Code	Temperature limit (Celsius)	Flammable	Toxic
Ammonia	R717	~ 80	Yes	Yes
Butane	R600	~ 80	Yes	-
Iso-butane	R600a	~ 80	Yes	-
Water	R718	> 100	-	-
CO_2	R744	~ 100	-	-

2 There are also systems based on absorption/de-absorption processes, but these are not covered by this application note.

2. Multistage Heat Pumps

Cascade vapour-compression heat pump systems

Cascade vapour-compression heat pumps are two-stage heat pumps that cascade to create a higher temperature lift. A heat exchanger acts as the condenser/evaporator between stages. Each stage may use different refrigerants and compressors to maximise its efficiency and attainable temperature.

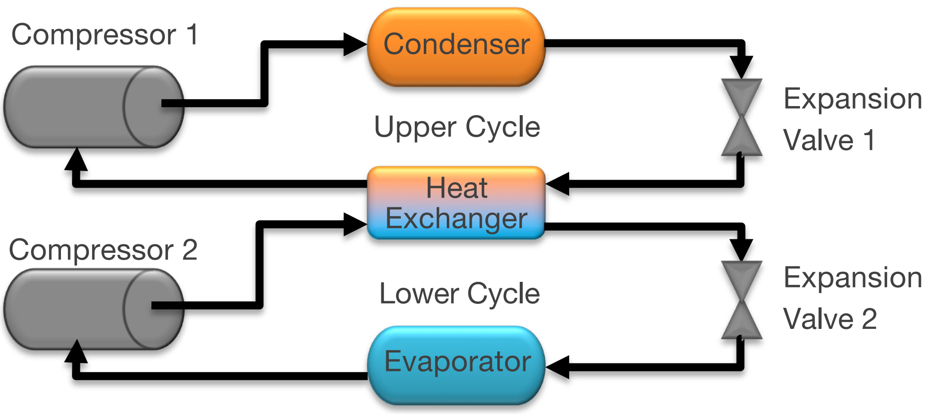


Figure 2. Cascade vapour-compression heat pump

Multi-stage vapour-compression heat pumps systems

These systems replace the heat exchanger with a flash vessel. Both stages must use the same refrigerant because the flash vessel separates its vapour into the upper cycle and its liquid into the lower cycle.

The multi-stage cycle heat pump offers some higher cycle efficiencies than the cascade cycle, but it cannot optimise each cycle stage with a different refrigerant.

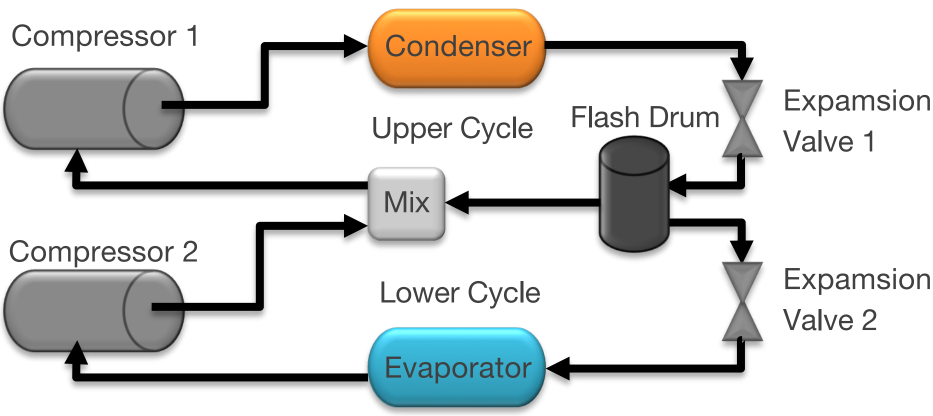
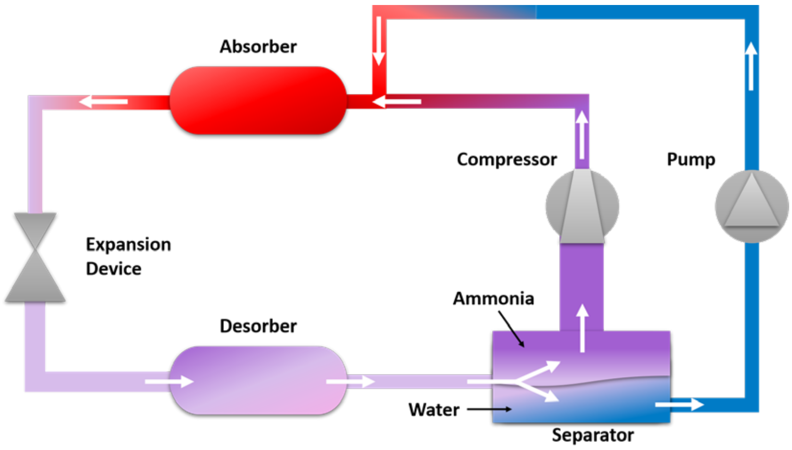


Figure 3. Multi-stage vapour compression heat pump

3. Hybrid Heat Pumps

Hybrid heat pumps achieve high temperatures by integrating an absorption heat pump and a generic vapour compression heat pump into a hybrid unit. The hybrid heat pump transfers heat at variable temperatures by changing the composition of two fluids, usually ammonia and water, as they flow through an efficient absorption and desorption cycle.

A hybrid heat pump consists of the following main components:



Desorber:
Waste heat is extracted from the outside environment into the refrigerant mixture.

Separator:
The separator separates water and ammonia.

Pump:
The pump increases the water pressure.

Compressor:
Ammonia is compressed to a high pressure inside the compressor.

Absorber:
Useful heat is released towards the environment.

Expansion element:
The pressure of the mixture is lowered.

Figure 4. Hybrid heat pump

A difference in temperature between the refrigerant liquid and vapour (*known as the temperature glide*) decreases the heat pump's required compression ratio, which results in a more efficient process with a higher COP.

Efficiency can be further optimised by increasing the range of the temperature glide, increasing the sizes of the absorber and desorber, and applying precise temperature adjustments as they are needed.

Trans-critical CO_2 heat pumps

Trans-critical heat pumps can heat water to 95ºC, heating at COPs of up to 5.0 (depending on the source temperature). At certain temperatures, the liquid and gas phases of fluids like refrigerants can't be distinguished from each other. At this point, the refrigerant is in a supercritical state. The boundary between the critical (liquid and gas are distinguishable) and supercritical state (gas and liquid are indistinguishable) is known as the trans-critical state. Trans-critical heat pumps absorb and release heat across the boundary.

CO_2 is trans-critical above 31°C and is the most widely used trans-critical refrigerant.

In a CO_2 heat pump:

- heat is absorbed in the evaporator below the critical pressure of 7.1 MPa (1030 Psi), and
- heat is released within the gas cooler (condenser) above the critical pressure.

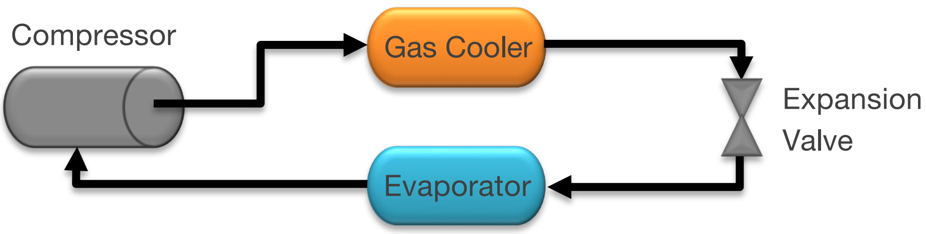


Figure 5. Trans-critical CO2 heat pump

A supercritical fluid's properties are between that of a gas and a liquid. It can expand like a gas, but its density is higher, like a liquid. This allows a high heat exchange rate between the supercritical fluid allowing the heat exchangers to efficiently raise cold water to temperatures close to 100°C. Unlike other refrigerants, the heat is released over a temperature range as the trans-critical gas is cooled.

The elements in a trans-critical heat pump cycle are like a standard heat pump operating cycle but with some differences:

1. CO_2 compression to trans-critical pressure
2. Gas cooling in trans-critical area, to heat process water
3. Expansion to low pressure
4. Evaporation by cooling down the waste water flow
5. Superheating in evaporator

The COP of a heat pump is usually calculated using the evaporation and condensation temperatures. The efficiency of a CO_2 trans-critical heat pump can be higher than conventional heat pumps. Trans-critical heat pumps work with high refrigerant pressures of more than 100 bar. However, trans-critical heat pumps have no condensation temperature, so an average temperature is calculated using the temperature at the inlet of the gas cooler and the temperature at the outlet of the gas cooler.

To make trans-critical heat pumps an efficient solution, the temperature of the fluid being heated must be low enough; typical cold-water supply temperatures are ideal. If the CO_2 is not cooled sufficiently by the incoming fluid then the process will not be efficient. In this situation, an ammonia heat pump is a better solution.

Benefits

Highly efficient and low carbon emissions

High operating efficiencies of 300% to 500% combined with New Zealand's low carbon electricity generation enable a very low-carbon way of generating heat with none of the losses of combustion processes.

Convenience and cost

Compact, easily installed, and avoiding boiler house costs; heat pumps can often use existing power supplies when retrofitted.

Highly-responsive

Staged compressors and variable speed drives offer rapid load response and good turndown control.

Safe, high durability

Heat pumps are reliable; they contain proven components and built-in controls to self-regulate their operation.

Safer with lower maintenance

Unlike combustion boilers, no part of the heat pump is ever at a temperature significantly higher than the output temperature, making them safer to operate with lower component degradation rates.

Future proofing - industry integration

Future power grids will require more rapid responses to changes in demand; heat pumps can offer cost-effective demand response capabilities.

Cooling and heating

Both cooling and heating options are available to processes.

Challenges

Heat source quality

Heat pumps require reliable heat sources for efficient operation. The closer the heat source is to the output temperature, the higher the efficiency.

Electricity supply requirements

Heat pumps typically operate with 400 Volt three-phase power supplies and switchgear, so metering and cabling costs need to be considered. Larger heat pumps may require an increases to a site's electricity supply capacity.

Network charges

Capacity, time of use and peak demand charges may mean that heat pumps incur significant costs during certain periods. It may make sense to use heat pumps alongside non-electric water heaters, or with thermal storage for use during peak-electricity demand periods and to increase system resilience.

Complexity

High-temperature heat pump systems can be technically complex and may be expensive to design and install.

High-temperature heat pump supply in New Zealand

High-temperature heat pumps have only been used in a limited number of applications in New Zealand and have yet to expand into process heat applications. They have, however, proven the scope to produce high temperatures for a range of common process heat and hot water applications.

New Zealand Suppliers

Active Refrigeration
https://www.activerefrigeration.co.nz

Air Conditioning Services Ltd
http://www.airconcentre.co.nz

Carrier
http://www.ahi-carrier.co.nz

Cooke Industries
https://www.cookeindustries.co.nz

McAlpine Hussmann Ltd.
http://mcalpinehussmann.co.nz

Mitsubishi
http://www.mitsubishi-electric.co.nz

Trane
https://www.trane.com/commercial/asia-pacific/nz/en.html

Further reading

Jutsen, J., Pears, A., Hutton, L. (2017). High-temperature heat pumps for the Australian for industry: Opportunities assessment. Sydney: Australian Alliance for Energy Productivity. Australian Alliance for Energy Productivity 2017.

https://www.airah.org.au/Content_Files/Industryresearch/19-09-17_A2EP_HT_Heat_pump_report.pdf

The website www.industrialheatpumps.nl published by De Kleijn Energy Consultants & Engineers of The Netherlands, is a source of clear technical information.

Application Notes

Applications

Applications for electric high-temperature heat pumps include supplying hot water for domestic, commercial and industrial situations, and industrial process heating requirements up to 90°C. Examples of where high-temperature heat pumps can be used are:

Farming

- Dairy – washing down milking plants and vats
- Viticulture industry – washing down vats
- Commercial applications where hot water is required for high temperature wash down or sanitisation of plants and equipment
- Replacement of existing small fossil fuel hot water boilers

Food Processing

The ability to produce high-temperature hot water at a variable output makes high-temperature heat pumps ideal for food processing operations.

The process heat supply requirements in food, dairy and meat processing plants can vary significantly depending upon the type of process, type of product, time of day and whether batch or continuous processing is required.

Often steam is used to achieve pasteurisation temperatures, and with product chilling after heat exchange achieved using refrigerated water. Heat pumps can replace both the heating and cooling stages, simultaneously heating and cooling with high efficiency although they usually require some thermal storage to align the heating and chilling phases around the heat exchangers.

High-temperature heat pump components are typically available in stainless steel construction to meet potable water supply and food processing plant construction standards.

Process plant cleaning and hygiene

Hot water at high temperatures of 65-90°C is used for cleaning and sterilising process plant. Cleaning in place (CIP) systems can use up to seven wash cycles to maintain hygiene. Heat pumps designed to meet CIP temperatures, with storage, are well suited to this cyclical duty. Waste heat from refrigeration condenses at 25-30°C is an ideal source for heat pump water heaters achieving temperatures of up to 80°C at COPs of 4 or higher.

Process drying

Many drying processes simply heat fresh air, pass it over the wet product, and exhaust the moist air in an open loop process. This can waste up to 80% of the heat supplied. In contrast heat pump dryers can recover up to 90% of the latent and sensible heat in the exhaust stream and use it to heat fresh air and dry recirculated air.

https://heatpumpingtechnologies.org/publications/industrial-drying-processes-with-heat-pumps/

Application economics

The economics of high-temperature heat pumps depends heavily on how the heat pump is applied in the particular process. The designer should have experience and understanding of the process heat demand and explore options to identify the most reliable and economic heat pump configuration. Consideration needs to be given to source and sink reliability over project life, whether thermal storage will improve operation and minimise stop-start cycling, heat-exchanger fouling and cleaning costs, and process quality impacts. Detailed project calculations should be undertaken on several options to identify the best life-cycle investment option.

The most economic applications tend to be those that upgrade heat from exhaust or waste streams. Importantly, heat pumps can utilise the latent heat energy in humid exhaust air from dryers, or pools and use the heat from refrigeration condensers and chillers. They can also provide simultaneous heating and cooling.

Heat pump solutions often recover capital investment within six years (15% per annum internal rate of return) from direct energy cost reductions. Where further multiple benefits from productivity improvements (greater product volumes, quality or profitability) occur: avoidance of boiler and steam system operating and maintenance costs, or where the heat pump provides simultaneous cooling and heating, the capital can be recovered in less than three years.

Reduction in GHG emissions from industrial processes and reduced ETS costs provide additional benefits and reduce investment payback periods.

Estimating potential for CO_2 emissions reduction

Electric heat pumps do not directly produce any CO_2 emissions, but a proportion of the electricity they use may be generated from non-renewable sources that do produce CO_2. In New Zealand, the proportion of non-renewable generation is low and the climate change impact from using a heat pump will be much lower than fossil-fuelled heating options.

To estimate how much CO_2 emissions will reduce by using electric heat pumps use the following rule of thumb comparison:

Electricity

CO_2 = kWh consumed x 0.10 kg/kWh[3]

For every 1,000 kWh of electricity used 100 kg of CO_2 is emitted

Natural gas

CO_2 = kWh consumed x 0.15 kg/kWh

For every 1,000 kWh of gas used 150 kg of CO_2 is emitted

For example, the potential electricity consumed by a 300kW high temperature heat pump, with a COP of 3, operating 16 hours a day, 7 days a week for 50 weeks (5,600 hours) a year is:

300 kW x 5,600 h / 3.0 = 560,000 kWh

Generally, a heat pump will not operate at full output continuously and will automatically control its output to deliver the required heat. In this example, we will use a 70% load factor which means that the electricity usage will be:

560,000 kWh x 70% = 392,000 kWh

Multiplying this by the emission factor gives the calculated CO_2 emissions:

392,000 kWh x 0.10 kg/kWh = 39 t CO_2

For comparison with a gas heating option, the CO_2 emitted by burning the gas to meet the equivalent process heat demand is calculated by multiplying the MWh heat delivered to the process adjusted to reflect the efficiency of the gas system (e.g. 80%), then multiplied by 0.216.

1,176,000 kWh / 80% x 0.15 kg/kWh= 221 t CO_2

So the gas option leads to five times higher GHG emissions than using a high-temperature heat pump.

In summary, electric high-temperature heat pumps generally use at least 66% less energy than an equivalent fossil-fuelled heating option and, because the electricity used by heat pumps has an emission factor less than half that of a fossil-fuelled option, electric heat pumps can significantly reduce CO_2 emissions.

3 The emissions factor for electricity in New Zealand varies, the average for 2016 was 90 g/kWh

Design for high temperature heat pump installations.

Installation design

Efficiency in process heat systems requires properly designed and selected components, suitable integration of these components into the system and effective control strategies for each component and for the entire system.

Step 1

Establish an accurate picture of end-use demand for heat, (not just boiler fuel input or steam output). Assess the required temperature and duration of heat demands.

Step 2

Determine the load profile that will be presented to the heat pump and from this identify the electrical demand capacity and energy costs (using the expected electricity tariffs). The same degree of resolution as the electricity tariffs should be used i.e. ½ hourly if necessary.

Step 3

Identify and evaluate all opportunities to minimise heat system inefficiencies and losses and the economics of alternatives to heat production.

- Identify the best heating medium for the product and process. Assess if high-temperature heat pumps or other efficient methods (e.g. RF, or IR heating) are better suited to the process requirements
- Assess options to spread heating loads, for example if thermal storage could help meet process peak loads
- Assess whether smaller distributed systems would work better than a centralised heat system
- Assess options to source heat from refrigeration systems, chillers, ovens, dryers, etc. It is important to understand the quality of the source (the temperature, heat rate and variability) and the correlation of availability with the heat demand and if storage is required to align them.

For more complex processes, particularly where heating and cooling occur, a process integration approach is warranted. This minimises external heat and cooling inputs and identifies effective opportunities for heat pumping.

Step 4

Identify suitable heat pump options with an experienced supplier to determine if a high-temperature heat pump is commercially viable. Establish the capital, installation and transaction costs, ensuring that the operations and maintenance costs are identified. High-temperature heat pumps operate with high pressures and tend to have higher maintenance requirements than lower temperature heat pumps. Planned maintenance is likely to include bi-annual checks, with 30,000 hour $25,000 overhaul cycles for small packaged, high-temperature heat pumps being typical. Remote real time monitoring and planned maintenance schedules are normal, and minimise long run operations and maintenance costs.

Step 5

Identify if heat pumps can be installed to operate in parallel with existing heat sources. This may minimise overall costs, improve system resilience, and allow reductions in electricity peak load costs by operating the existing boilers. However this approach may retain some of the operations and maintenance costs of the existing system.

Integrating industrial heat pumps into processes

Increasingly, the methods for integrating heat pumps into processes are shifting from estimation and calculation to modelling. The integration of a heat pump into a process based on pinch analysis can include:

- An add-on model to existing pinch analysis programmes
- Simultaneous optimisation of hot and cold utilities and heat pumps
- Approximation of the heat exchanger network as in the standard pinch analysis
- Selecting the hot and cold streams to which the heat pump could be connected.

Case studies

Case study: Refrigeration system waste heat provides domestic hot water

Christchurch-based company Active Refrigeration designed and installed a new ammonia-based heat pump to simultaneously create cooling and high-temperature heating at Ashburton Meat Processors. Capturing and adding energy to heat that was normally rejected from the cooling system led to higher performance efficiencies.

The plant is achieving annual energy savings of over $200,000 which has freed up capital for maintenance and upgrades. The plant ensures the facility's viability and stability as an employer and has been able to increase output with confidence.

The new system will have paid for itself within three years with reduced energy, operating and maintenance costs.

Changing from Light Fuel Oil (LFO) to a mixture of electricity and LPG for heat services has reduced the plant's annual carbon footprint by 42% (690 tonnes). This reduces its exposure to future carbon emission pricing and provides positive branding opportunities. Furthermore, Ashburton Meat Processors' new plant has been able to confidently take on increased capacity, strengthening the business and providing more stable employment.

https://www.activerefrigeration.co.nz

Case study: Efficient supermarket hot water heater

Air Conditioning Services supply three high-temperature heat pump models that can deliver water at up to 80°C, operating in an ambient temperature range of 0°C to 43°C. Higher ambient temperature increase the efficiencies.

The heat pumps utilise refrigerant R134 in an Enhanced Vapour Injection (EVI) compressor which increases the enthalpy difference (amount of heat content released in the system at constant pressure) rather than increasing the mass flow, giving an increased COP.

In 2014, the Paraparaumu PAK'n SAVE supermarket needed to replace its gas fired hot water system. The hot water was required for the sanitary wash down of the supermarket's butchery department so it was critical that the water temperature was hot enough to meet strict hygiene requirements. A 13.2 kW high temperature heat pump was installed in 2014 and has met constant demand at a lower operating cost than the pre-existing gas system.

http://www.airconcentre.co.nz/high-temperature-heat-pumps.html

Case study: High need for efficient hot water

Heller's and Active Refrigeration partnered to use waste heat to produce hot water - which food processors like Heller's require a lot of for hygiene and plant cleaning.

The existing system to produce hot water was expensive to run and capacity limits meant it was often running short by the end of the cleaning shift. Increasing hot water capacity was important and getting it more efficiently was even better.

The heat pump offers long-term benefits as the plant grows because as hot water throughput increases so do the returns on the investment in the heat pump.

The plant has a coefficient of performance of 8.3 meaning that, for every kilowatt of electricity used, 8.3 kilowatts of heat energy is supplied at 65°C from a cold water source at 13°C.

The majority of the site's hot water is now generated using the heat pump, resulting in an 84% reduction in hot water costs worth $148,000 a year, and 91% reduction in GHG emissions.

Heller's continuous improvement programme is reinvesting the money saved into further maintenance and upgrades elsewhere in the plant.

https://www.activerefrigeration.co.nz

Case study: Japanese CO_2 water heaters

Japan leads the world in the application and deployment of CO_2 water heating and CO_2 heat pumps have now reached a market share of 98% of all new residential heaters in Japan. Popularly known as 'EcoCute' heat pumps, five million CO_2 heat pumps were in operation 2014, with a market worth 56.5 billion yen.

One of the products, the Sanden Eco Plus CO_2 Heat Pump Water Heater is available in Australia. The Sanden heat pump system consumes 900 Watts of electricity to supply 5 kW of heat (COP = 5) - only 20% of the energy used by a traditional electric system. Sanden Eco has up to 50% faster heat recovery than other currently available hot water heat pumps. In ambient 20ºC air it takes approximately four hours to heat 315 litres of water from 17ºC to 65ºC. The Sanden Eco Plus system uses an inverter-type compressor, DC fan motor and pump. The design minimises energy consumption, maximises water-heating capacity, and allows for faster recovery, resulting in significantly lower operating costs than electric-resistance storage water.

http://www.newgensolar.com.au/heat-pump-hot-water/sanden-eco-heat-pump-hot-water-system.html

Case study: High-temperature timber drying heat pump

An industrial-scale, high-temperature heat pump-assisted dryer prototype 354 m^3 forced-air wood dryer with steam heating coils and two high-temperature heat pumps has been studied in Canada. Softwood species (pine, spruce and fir) are generally dried at relatively high temperatures of up to 115°C, so high-temperature heat pumps, coupled with convective dryers, are required. An oil-fired boiler supplies steam for wood preheating and supplemental (back-up) heating during the subsequent drying steps. The dryer's central fans force the circulation of the indoor drying air and periodically change their rotation sense to dry uniformly and improve the overall process and the wood's final quality.

Each heat pump includes a 65 kW compressor, an evaporator, a variable speed blower and electronic controls located in an adjacent mechanical room. Both remote condensers are installed inside the drying chamber. The industrial-scale prototype demonstrates that, compared with traditional heat-and-vent dryers, the high-temperature heat pump-assisted dryers offer very interesting benefits for drying resinous timber. Its actual energy consumption is between 27.3% and 56.7%, lower than the energy consumed during the conventional (steam) drying cycles, whereas the average reduction in specific energy costs, compared to the average costs of the Canadian conventional wood drying industry (2009), is approximately 35%.

Source: IEA Heat Pump Implementing Agreement Annex 35 Part 1
https://heatpumpingtechnologies.org/publications/

Case study: Combined heating and cooling heat pumps in food and beverage

Chocolate manufacturing requires both cooling and heating. An analysis of a site's measured heating and cooling load profiles showed that a heat pump would have to produce 1.25 MW of high grade heat. The heat source is the cooling process where glycol is chilled from to 0°C. The ammonia heat pump condenser operates at -5°C and the heat pump lifts it to 61°C in one stage, heating water from 10°C to 60°C.

The selected heat pumps provide 914 kW of refrigeration capacity with an absorbed power rating of 346 kW and the combined heating and cooling COP is 6.25. For a temperature lift of 17oC in discharge pressure, the increase in absorbed power was 108 kW, boosting the COP an impressive 11.57.

The project initially focused on providing 90°C hot water using a heat pump. However, as only 10% of the water was required at 90°C and this could be more economically provided by a small gas boiler the designers developed the heat pump to supply 60°C hot water.

The integrated heat pump system reduces heating costs by an estimated NZD 280,000 per year and GHG emissions by 120,000 kg. Despite the new refrigeration plant providing both heating and cooling, it consumes NZD 230,000 less electricity annually than the previous cooling-only plant and total water consumption has decreased from 52,000 m^3/day to 34,000 m^3/day.

Source: IEA Heat Pump Implementing Agreement Annex 35 Part 1.
https://heatpumpingtechnologies.org/publications/

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