Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

Technical Information Document

Ambient Source Heat Pumps for low carbon space and process heating up to 60ºC.

Technical Information Document 2019

New Zealand Government

Introduction

Heat pumps can provide most of the heating and cooling services required in buildings and low temperature processes. They can integrate two of the most cost-effective, sustainable energy options available: highly efficient heating from renewable sources, and efficient heat recovery systems. Heat pumps also offer excellent capacity and temperature control.

Heat pump installations can achieve efficiencies of over 300% (i.e. provide three units of heat for each unit of electricity) and utilise a diverse range of low-temperature heat sources such as outside air, exhaust air, ground or water sources. Despite electricity having higher unit costs compared to fossil fuels, the total operating costs of heat pumps can be much lower than other heating options such as gas, oil, coal or biofuel boilers.

Heat pump technologies are well established, with many off the shelf solutions with a range of capacities. Custom designed systems up to 3 MW are already in use. Heat pumps are easy to operate and relatively maintenance free, which makes them a good option for supplying heat to low-temperature processes. Because New Zealand's electricity supply is largely generated from renewable energy resources, heat pumps offer the highest efficiency and lowest CO_2 emission supply of process heat on the market.

High temperature heat pumps are also available. Refer to the High-temperature Heat Pumps Technical Information Sheet in this series.

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

General Operation

Compressing a liquid or gas raises its temperature while the opposite process (expanding) lowers its temperature. This is the core principal used in heat pump technology and refrigerators.

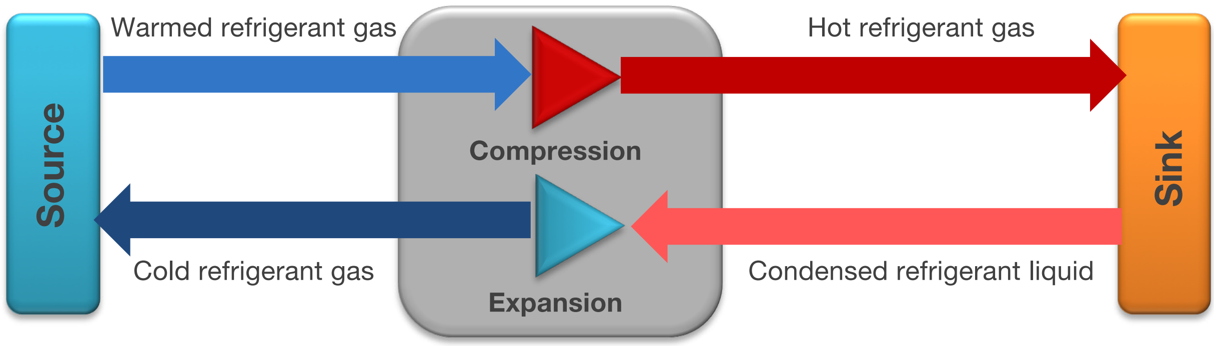

Figure 1. General heat pump operation

Using the compression/expansion cycle, heat pumps transport heat from one place (the source), to another, (the sink). For example, the outside unit of a domestic mini-split heat pump absorbs heat from outside air and transfers this to the inside of a building at a higher temperature. The temperature increase is achieved as the refrigerant gas is compressed. After transferring the heat via a heat exchanger to the air inside the building, the refrigerant's pressure is dropped (expanded) and cooled, and now ready to absorb more heat from outside.

Most air-heating heat pumps operate in both heating and cooling mode (reverse cycle inverter heat pumps). Heating and cooling performance of heat pumps is similar but not identical, so different terms are used. The efficiency of a heat pump for heating is called the Coefficient of Performance (COP) and the efficiency for cooling (air conditioner mode) is the Energy Efficiency Ratio (EER). Nearly all ambient source heat pumps can operate in heating or cooling mode with good capacity control from inverter power electronic controls.

When on a cooling cycle, heat pumps can also provide dehumidification; as the moist air is cooled, its moisture is condensed and collected as water. Heat pump dehumidifiers can provide an efficient alternative to heat for drying rooms or processes in manufacturing.

High efficiency from low temperature differences

The efficiency of a heat pump is defined by how much heat it delivers compared to the electrical energy it uses, for example 30 kWh of heating energy provided by a heat pump that uses 10 kWh of electricity has an efficiency of 300%, and a COP of 3.

These efficiency measures are not fixed. The closer the source and sink temperatures are, the more efficient the heat pump will be. BRANZ research has shown that the most common type, the split system[1] heat pump in New Zealand conditions can deliver heat for 5 to 7 cents per kWh[2] in residential homes. This is a third of the cost of using electricity directly to heat the home.

The ability of heat pumps to minimise energy used for space and water heating is an important and transformative component in energy efficiency improvements and renewable energy supply.

1 Systems where the evaporator and condenser are separate components
2 Heat pumps in New Zealand. BRANZ Study Report SR 329 (2015)
https://www.branz.co.nz/cms_show_download.php?id=31b486e20cf2d89b2337433553fad2588af75b88
http://heatpumpingtechnologies.org/publications/heat-pump-concepts-for-nearly-zero-energy-buildings-final-report-task-2-case-studies-on-building-system-technologies-for-nzeb/

Economics

Heat pumps play a key role in net zero energy buildings (nZEB). They are one of the lowest life-cycle cost energy systems. For zero (or low) energy buildings, based on test results for energy performance evaluation and the economic boundary conditions, heat pumps have been demonstrated to deliver energy-efficient, cost-effective system solutions.

Higher investment costs of heat pumps are usually offset by much lower operating costs. Heat pumps can be integrated with on-site generation (e.g. using solar PV) to deliver highly efficient hybrid energy systems for nZEB.

Main types of commercial and industrial heat pumps

Industrial heat pumps

Above outputs of 200 kW heat pumps are normally custom designed for specific applications. Typical industrial heat pump designs will be based around one or more central compressors, evaporators and condensers with water or brine piped to larger external condensers or evaporators. Heat pumps are commonly used in heat recovery applications, with refrigeration system condensers or waste heat used as heat sources. Heat pumps recycle heat from low-grade waste heat streams that will otherwise be exhausted into the environment. This allows otherwise lost energy to be recovered for reuse in processes or to preheat process water supply or combustion air. A typical commercial/industrial heat pump is shown in Figure 2.

Figure 2. A typical commercial/industrial heat pump

Sources: http://www.emersonclimate.com/en-US/products/compressors/industrial_compressors/industrial_heat_pumps/Pages/industrial_heat_pumps.aspx

Air source water heating heat pumps

Air source heat pumps used for water heating operate effectively in temperatures from -7ºC to 40ºC. Units of up to 300 kW can provide 45oC of hot water using R135a or 65ºC with R-410a refrigerant. (Note: if supplying potable water these systems may require a daily electric boost to over 60ºC to comply with the New Zealand Building Code).

Air source water heating heat pumps are cost-effective with a COP around 3.3 for potable water and up to 5.0 for swimming pools. They reduce hot water energy use costs by 70% - 80% compared to electric resistance heating methods. Systems can be constructed in modules with independent compressors and refrigeration circuits.

Hot-water-cylinder sized models can replace existing distributed electric or gas domestic hot water cylinders and can work together (ganged) to provide greater redundancy for larger applications such as swimming pools, motels or rest homes. Titanium heat exchangers are used for salt or chlorinated water heating.

Heat pump operation can be optimised by using smart controls, demand enabled response (DRED) and variable water or low-rate compressor drives with inverters and pumps. Designs can be customised to allow for multiple temperatures (e.g. floor heating and pool heating).

Figure 3. Modular 270l and packaged 80kW heat pump water heaters

Sources: https://www.bosch-climate.co.nz/products-bosch-hot-water/renewables/compress-3000/compress-3000.html

https://www.waterheating.co.nz/Products/Residential/Domestic+Hot+Water/7GD60-3/

Ground source heat pumps

A growing number of commercial facilities are adopting ground source heat pumps (GSHP). These use underground heat exchangers (essentially a long pipe loop that draws low-grade heat from the subsoil), or bore water from aquifers, to access constant ground temperature heat sources which in most New Zealand locations are around 12ºC.

These systems are particularly suited to colder climates and offset their higher installation costs with very low running costs. A ground source heat pump will typically raise water temperatures to 35°C at a COP of 4.

Installation of ground loop coils can comprise up to 50% of the cost of these heat pump systems, so any opportunity to bury the coil at low cost, such as under fill, or as part of foundation excavations, can provide significant savings.

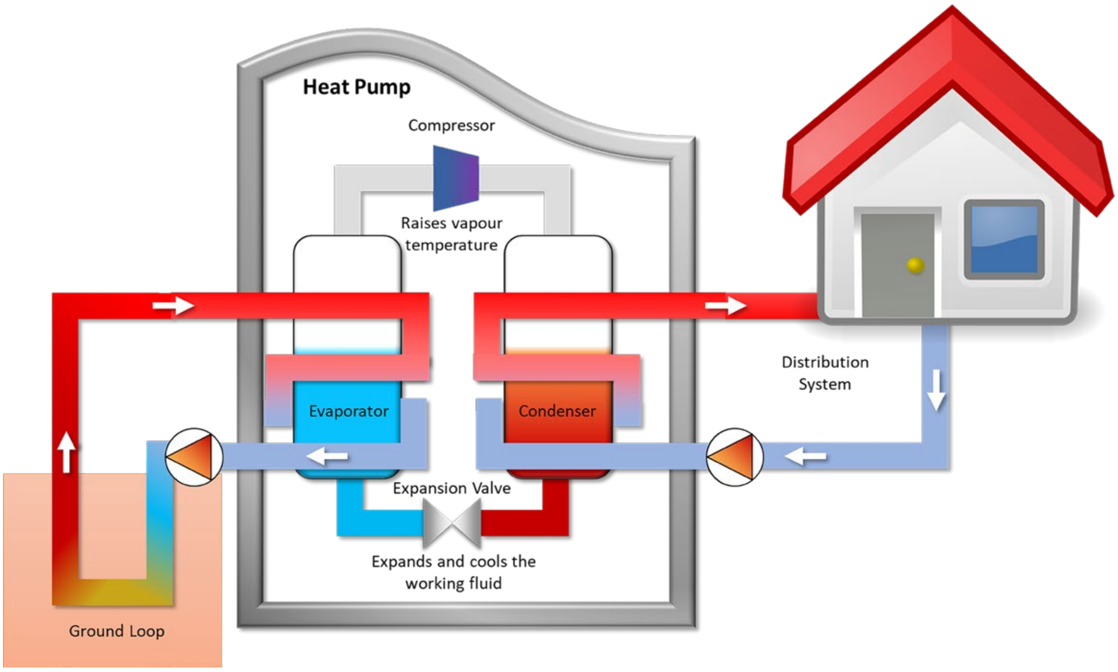

Figure 4. Ground source heat pump system

Source: http://nzgeothermal.org.nz/ghanz/geothermal-heat-pumps/

The rate at which ambient ground heat can flow through soil to the pipe (known as soil conductivity) is a key performance factor. Very dry, low conductivity ground material, such as pumice, will limit heat rates. Ground source heat pumps are generally subject to regional environment regulations particularly when they use ground water from aquifers.

Correct sizing of the ground loop is essential as longer pipe coils spread over larger areas will extract more heat but cost more to install.

Dehumidification with heat pumps

Heat pump dehumidifiers can extract water while they heat air. Heat pump dehumidifiers use about 1/10th of the energy of conventional dryers by continuously recycling and drying the air - condensing the moisture out of the system instead of discharging warm wet air. The energy requirements approach 0.19 kWh per kg of water vapour removed, and units generally have a COP of between 5.0 and 7.0 when they are used in moderate temperature applications. Heat pumps are ideal where drying rates and product quality are important but careful design is required for each application (such as for drying timber and food products). Key design factors for successful dehumidification include ensuring that the fan capacity and air flows enable effective air circulation in the drying space.

Packaged Air Source - Air heating heat pumps

Packaged air-source heat pumps consist of an outdoor unit (compressor), an outdoor heat exchanger (condenser) and an indoor heat exchanger (evaporator). These are the most efficient heat pumps and have low installation costs.

Air-to-air reverse cycle single-split systems are the most common and have a single source and single sink. Multi-split systems have two or more indoor units to a single outdoor source unit. Commercial systems will often use ducting to transport heat to different rooms as a cost-effective alternative to installing multiple indoor units. An example of a commercial heat pump - air conditioner is shown in Figure 5.

Figure 5. Packaged Air Source - Air Heating/Cooling Heat Pump
Source: http://www.refrigerationbasics.com/RBIII/heat_pumps2.htm

Benefits

Convenience and low cost
Compact and easily installed, smaller heat pumps can often use an existing electrical installation which reduces the capital cost.

Highly efficient and low carbon heating
High operating efficiencies with COPs between 3-5, combined with New Zealand's low carbon electricity generation, create a very low carbon way of generating heat with none of the heat losses of combustion processes.

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

Safe, high durability, low maintenance
Heat pumps contain proven components and built-in controls to self-regulate their operation. 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 low degradation rates.

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

Cooling and heating
Cooling, heating and dehumidification options are available for buildings and industrial processes.

Challenges

Heat source quality
Heat pumps require reliable heat sources for efficient operation. Higher efficiencies are achieved by locating the heat pump as close as possible to the heat source. Where source quality is variable or drops below 7°C, delivered heat quality will also vary. Ground source heat pumps can overcome this problem.

Potential capacity and network requirements
Larger heat pumps may require increases in electricity supply capacity. Units typically require 400v 3phase power supplies and associated switch gear. Costs of additional metering and cabling installation need to be considered.

Time of use energy pricing and peak demand charges mean that heat pumps may incur higher costs during peak energy use periods.

Cold weather performance and defrost
As outdoor temperatures decrease, the heat delivered by the heat pump will also reduce. At temperatures below 7°C, water vapour in the air will start to condense and freeze onto the outdoor evaporator coils and disrupt air flow. Most heat pumps have automatic defrost cycles. Manufacturers' specifications should be checked for low temperature operating environments.

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Heat pump supply in New Zealand.

Heat pumps have been used for small scale and commercial space heating applications in New Zealand but their full potential for process heat applications has not yet been realised. Because of this, at the time of writing, supplies were generally limited to small scale and commercial applications.

New Zealand Suppliers

Hot Water Heat Pumps Ltd. 09 838 9444
https://www.waterheating.co.nz

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

Daiken
https://www.daikin.co.nz

Hitachi
https://www.temperzone.co.nz

Fujitsu
http://www.fujitsugeneral.co.nz

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

Panasonic
https://www.panasonic.com/nz

Temperzone
https://www.temperzone.co.nz

Toshiba
http://www.toshibaheatpumps.com

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

Ground source heat pumps

Geothermal Heat Pump Association of NZ members:

Collins Plumbing
http://www.collinsplumbing.co.nz

Central Heating NZ Ltd.
http://www.centralheating.co.nz

ENGEO
http://www.engeo.co.nz/services/

Application Notes

Situations heat pumps are best suited for include:

- Processes where the difference between the source and sink temperatures is low and so allows for high thermodynamic efficiencies
- Low temperature heating and drying, where high rates of dry air flow are required
- Sites with a demand for both heating and cooling
- Sites where heat pump power supply needs can be met by existing electric capacity where heat loads are not coincident with electrical capacity peaks or demand costs
- Distributed heat loads where a number of smaller heat pumps can be optimized for different processes and avoid the need for a central hot water system

Common applications include:

Air-to-air heating

Commercial Building Heating and Cooling systems

Reverse-cycle heat pumps offer both cooling and heating at high efficiency with precise capacity controls, and are common in large and small commercial buildings. Dehumidification with heat pumps is also used in larger, high-quality internal environments that require full air conditioning and accurate zone control.

Air-to-water heating heat pumps

Water heating heat pumps are designed for four main types of end-use applications, each with different costs that can be reduced if multiple water heating processes are required (e.g. dual-purpose pool and underfloor heating applications).

1) **Underfloor heating:** Designed to heat the water circulating in a closed loop system, these heat pumps tend to have simple controls because floor slabs are generally large and slow to heat. Off-the-shelf systems are available at over 90 kW capacity in a single unit with a COP of around 3.5; larger capacities may be met with multiple units or custom designed larger units.

2) **Pool water heating:** Designed to handle chlorinated or salt water and provide water in the range of 24ºC to 30ºC. These tend to have simple controls as pools change temperature slowly relative to the heat pump capacity.

   Off-the-shelf pool water heating pumps are available in capacities up to 140 kW per unit with a COP of around 5. Larger pool heating requirements may be met using multiple units or custom-designed larger units.

   Heat pump water heaters for spa pools (36-40ºC) and therapy pools (30-36ºC) are also available.

3) **Domestic Hot Water:** Designed to heat clean, fresh water at up to 60ºC, these also tend to have simple controls due to the large volumes of water they heat.

   Off the shelf domestic hot water heating pumps are available at over 80 kW capacity in a single unit with a COP of around three. Larger hot water heating capacities may be met with multiple units or custom designed larger units.

4) **Potable Domestic Hot Water:** Drinking-quality hot water requires heat exchangers that are designed for food grade applications. These operate at up to 60ºC with fresh clean water and tend to have simple controls due to the large water volumes they are required to process. Off-the-shelf heat pumps are available at over 80kW capacity in a single unit with a COP of around three. Larger hot water heating capacities may be met with multiple units or custom designed larger units.

The New Zealand building code requires that all storage potable hot water systems must reach 60ºC at least once every day to minimise risk of moisture-borne infections. Some potable hot water systems will use an electric element to achieve this requirement; however, many heat pumps already reach the required temperature in their normal operation. Check with suppliers.

Figure 6 provides indicative budget prices of heat pumps for each of these applications.

A range of heat pumps is already available for these applications and buyers should check prices and operating parameters with suppliers.

Higher water temperature heat pumps are available.

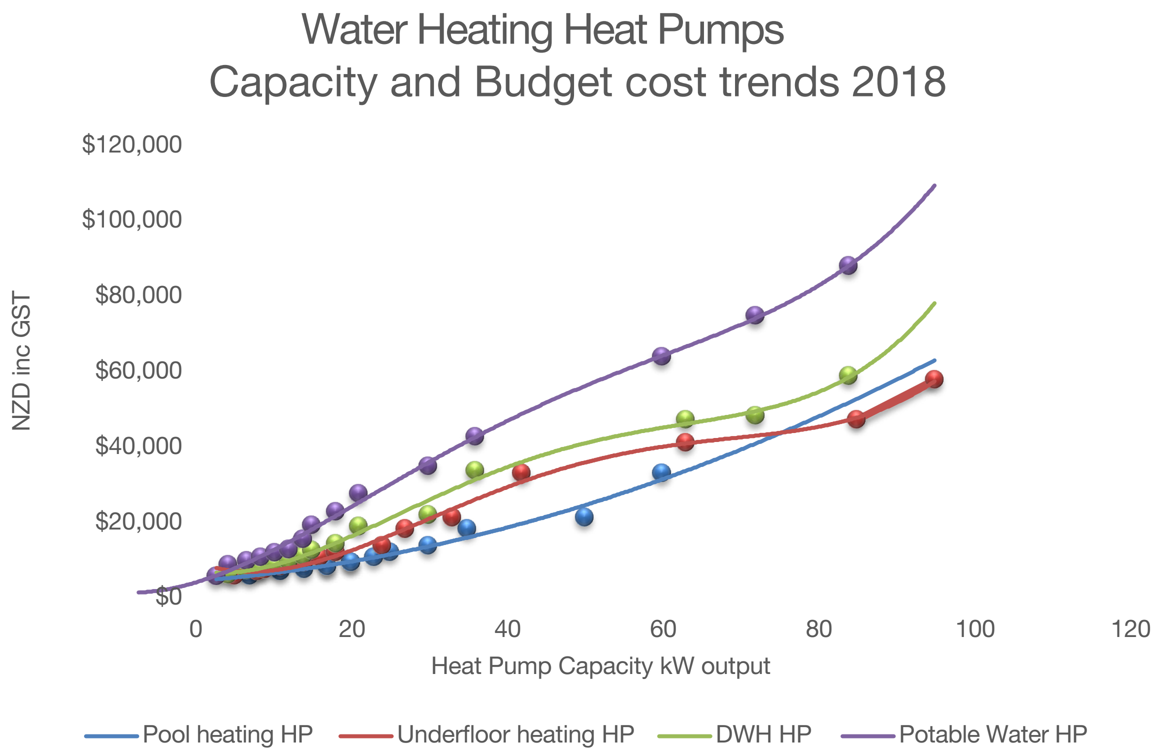

Figure 6. Water heating heat pump prices
Source: https://www.waterheating.co.nz

Water and ground source heat pumps

The rebuilding of Christchurch after the 2011 earthquake led to the installation of many ground source heat pumps. Heat pumps installed ranging in size from 0.5 to 3 MW to a total of 13 MW capacity with seven new systems commissioned in 2018 (see Table 1).

Project	Building size (m²)	Extraction depth (m)	Extraction rate (L/s)	Plant Size (MW)
Bus Exchange	9500	80	12	1.0
Art Centre	13000	130	80	1.6
ECan offices	8000	85	33	0.65
Justice Precinct	40000	150		3.0
The Terrace	4000	85	26	0.5
King Edward Barracks	30000	128	80	2.0
Town Hall	11000	80		1.2

Table 1. Commercial ground source heat pumps in Christchurch

Groundwater temperatures in Christchurch are stable between 12-13°C. A single well can yield over 100l/s to provide an ideal, low cost source for heating and cooling.

The estimated cost of wells (excluding distribution pipework, controls, pumps etc.) in Christchurch is around $135/kW of heating and $215/kW of cooling based on a domestic well yield of 50 l/s. The equivalent costs in London, for example, where over 35 similar schemes are installed are around $1,500/kW heating and $2,400/kW cooling respectively.

Most New Zealand settlements are located in natural harbours, or river estuaries and other locations that are ideal for ground source heat pumps.

Integrated heating and cooling

Heat pumps transport heat energy between sources and sinks and can operate in both directions using hybrid arrangements of compressors and evaporators.

One such example is the recent adaptation of the combined milk chiller and hot water heater for dairy sheds. Here, heat pumps have been designed to quickly chill milk and provide a reliable supply of domestic hot water for dairy shed cleaning.

Applications are often limited by site conditions rather than available technology. Experienced heat pump designers and suppliers should be consulted to determine the suitability of heat pumps for new applications.

Swimming pools - Humidity control

Heat pumps make efficient ventilation systems for swimming pools. Swimming pool halls require ventilation to manage the concentration of chloramines given off by the pool and provide fresh air for occupants.

The warm and high humidity exhaust air from pool ventilation systems makes a perfect heat source and a heat pump with a COP of 5 can extract latent as well as sensible heat from the exhaust stream.

Design of pool heating and ventilation is quite specialised and experience in successful swimming pool system design and implementation is important. Corrosion management is essential and heat pumps coils will be anodised or epoxy coated and will require the ability to regularly flush the coils with freshwater to further reduce corrosion.

Design for heat pump installations.

Installation design guidance

Efficiency in process heat systems requires properly designed and selected components, suitable integration with application processes and effective control strategies.

Step 1

Establish an accurate picture of end-use requirement for heat:

- what energy, air or water flow rates are needed for the process?
- what temperatures are required?
- how much energy is required?
- when, and for how long, is the energy required?

Step 2

Determine the operating load profile that will be on the heat pump.

- When does peak cooling and heating operation occur?
- What temperature extremes will the system face?

  Note that current summer and winter peak temperatures are much hotter and colder than they have been historically.
- How does this relate to the demand and capacity of the existing power supply and the energy and demand costs of your tariffs? Use the same degree of resolution as the electricity tariffs, such as ½ hourly data, if it is available.

Step 3

Identify and evaluate all opportunities to minimise heating and cooling inefficiencies and losses and the economics of alternatives.

- Explore options to spread heating loads. Identify if thermal storage would help.
- Explore whether smaller distributed heat pumps would be better than a central system.
- Explore options to recycle or reclaim heat.
- Explore options to change from steam to other direct or indirect process heat modes.

Step 5

Identify suitable heat pump options, establish capital, installation and project construction and transaction costs.

Impact on CO_2 emissions

Electric heat pumps will not directly produce any climate change gas emissions, but a proportion of the electricity used may have been generated from non-renewable sources that do produce GHG. In New Zealand, the proportion of non-renewable generation is low so the GHG impact from heat pump operation will be much lower than for gas or other fossil fuel 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 0.1

For every 100kWh of electricity used, 10kg of CO_2 is emitted

Gas

CO_2 = kWh consumed x 0.216

For every 100kWh of gas used, 21kg of CO_2 is emitted

For example, the potential electricity consumed by a 10 kW heat pump in use 8hrs a day, 6 days a week for 50 weeks a year is:

10 x 8 x 6 x 50 = 20,000 kWh

Generally, a heat pump will not need to 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 used will be:

20,000 x 0.7 = 14,000 kWh or 14 MWh

The CO_2 emitted by generators producing the electricity is estimated by multiplying the electricity used by 0.1. This shows that 1.4 t/CO_2 per year will be emitted.

The heat output to process from the heat pump will be the energy consumed (kWh) multiplied by the COP.

14,000 x 3 = 42,000 kWh or 42 MWh

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 kWh heat delivered to the process adjusted to reflect the efficiency of the gas system (e.g. 70%), then multiplied by 0.216.

42/0 .7 x 0.216 = 13 t/CO_2

So the gas option will lead to 9 times more climate change gas emissions.

In summary, electric heat pumps will generally use at least 66% less energy than an equivalent gas, oil or coal heating option and, because the electricity use for heat pumps emits at least 9 times less CO_2 than the equivalent fossil fuel options, electric heat pumps can reduce your CO_2 emissions significantly.

Case studies

Case study: Heat-pumps replace centralised boiler to provide hot water and heating

Replacing old diesel boilers is part of the Northland DHB strategy to reduce carbon emissions by 15% in 2025. Predicted annual energy and maintenance cost reductions of nearly $300,000 will rapidly repay the investment costs of over $700,000.

The heat pumps also provide individual sources of hot water and heating to separate buildings allowing the DHB to adjust to seasonal variations, manage buildings based on occupancy, and take account of the fact that only one ward is open day and night.

Dargaville hospital achieved annual energy cost reductions of $111,000 and $41,600 on maintenance costs; Kaitaia saved $89,000 on annual energy costs and $53,900 on maintenance costs. Diesel consumption reductions at both hospitals were 2,963,000 kWhs and include reduced losses from ageing steam reticulation pipes to the boiler. Total annual carbon dioxide emissions were reduced to 794 tonnes CO_2/year.

Source: https://www.eecabusiness.govt.nz/resources-and-tools/case-studies/northland-dhb-reduces-emissions-with-heat-pumps/

Case study: Ground source heat pumps at Christchurch International Airport

The largest ground source heat pump system in New Zealand is at Christchurch International Airport. The system, commissioned in 2011, has two 1.5 MW and one 600 kW ground source heat pump systems providing heating and cooling requirements.

The heat pumps replaced diesel and LPG boilers as part of a wider airport upgrade. When ambient temperature permits, water from artesian wells is used to cool the airport with no aid from the ground source heat pump (free cooling). Ground water from the onsite wells is passed through heat exchangers which increase or decrease the water's temperature to extract or inject heat energy as is required for cooling and heating services, and the water is discharged to a soak pit returning it to the ground.

Source: Rebuilding Christchurch – Using Ground Source Heat Pumps. IEA Heat Pump Conference2017,

https://www.researchgate.net/profile/Anya_Seward/publication/316919835_Rebuilding_Christchurch_-_Using_Ground_Source_Heat_Pumps/links/5a1c6db44585153731890660/Rebuilding-Christchurch-Using-Ground-Source-Heat-Pumps.pdf

Case study: Quick chilled milk and hot water from a single heat pump package

The Vari-COOL system is an on-farm milk chiller that snap chills milk to below 6ºC while using heat recovery to produce 48 litres / hr of domestic hot water at up to 70ºC for cleaning. The unit can chill multiple milk vats simultaneously and vary output to chilling load.

The integrated heat pumps achieve a COP of 3.6 with unique milk plate cooler design that integrates chilling and heating to minimize energy and water consumption.

This provides a snap milk chilling system that can cope with increased demand without the power bill going through the roof. With built in system and tank temperature monitoring and Wide Area Network (WAN) connectivity, the system is suitable for remote operation. The capital investment of around $15,000 more than conventional milk chilling equipment will be paid for over 18 months at a rate of $800 per month in savings on electricity costs.

Source: https://www.eecabusiness.govt.nz/resources-and-tools/case-studies/vari-cool-chilling-sysyem/

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