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Heat Pump ad Natural Gas Comparison Study

CA Group Services

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AUTHORSHIP OF THIS REPORT

This report was produced by the CA Group Services Pty. Ltd. (CA Group) for the Zero Carbon Tatura (ZCT) on Heat Pump and Natural Gas Comparison Study.

CA Group is a leading refrigeration company that promotes the use of natural refrigerants and an energy-efficient and low carbon emissions economy.

Introduction

A heat pump is a mechanical device that transfers heat from one compartment of the environment to another, usually against a temperature gradient (i.e., from cool to hot). Energy input is necessary for this, which can be mechanical, electrical, or thermal energy. Electrical energy powers a compressor in most modern heat pumps, which drives a refrigerant fluid compression–expansion cycle between two heat exchangers: a cold evaporator and a warm condenser. The thermal output divided by the main energy (electrical) input is the heat pump's efficiency or the coefficient of performance (COP). As the temperature differential between the cold heat source and the warm heat sink grows, the COP drops. A COP of 3 - 5 is the typical performance of heat pumps. Heat pumps are useful for extracting heat from low-temperature sources such as the air, surface waters, or the earth. Heat Pumps have the potential to save money while also reducing CO_2 emissions. The COP of the heat pump can be higher than 5 when heating and cooling are used at the same time.

There is growing interest in increasing the use of natural refrigerants, driven by international agreements such as the Montreal and Kyoto protocols (UNEP 1999 and United Nations 1998), as well as a desire for sustainable growth. Natural refrigerants are a group of refrigerants that have the potential to improve the energy efficiency of refrigeration systems. CA Group supports the use of natural refrigerants such as ammonia, carbon dioxide, hydrocarbons, air, and water in refrigeration and heat pump systems because of its alignment with sustainability goals.

Natural gas is still the predominant fuel for providing heat and hot water in Australia. According to the Australian Bureau of Statistics, over half of Australians still rely on gas as a source of energy.

Heat pump technology

In simple terms, a Heat Pump is a heat engine operating in reverse. It reverses the natural heat flow process (where heat transfers from warmer places to colder spaces) by absorbing energy from a cold environment and releasing it as heat at a higher temperature. The process requires an external energy source such as electricity. This electrical input could come from a renewable source, which provides a carbon-free movement of heat.

A heat pump has four main components: an evaporator, a compressor, a condenser, and an expansion device. It essentially operates as a refrigerator. A mechanical heat pump, which is the most widely used in industrial settings, operates on the principle of compression and expansion of a working fluid, or ‘refrigerant’, which passes through all these components.

The evaporator is the heat exchanger between the low-temperature heat source and the refrigerant. In terms of heat source, ambient air, seawater and cleaned effluent water account for most future district heating projects. The refrigerant enters the evaporator as a low-pressure liquid and the outside air/waste heat source evaporates the refrigerant.

The refrigerant leaves the evaporator as a low-pressure gas, which then enters the compressor, where it is compressed. The compression process turns the cool, low-pressure gas from the evaporator into a hot, high-pressure gas. This gas enters the condenser, which is another heat exchanger that serves to deliver this heat to the consumer at a higher temperature level. Electric energy is required to drive the compressor and this energy is added to the heat that is available in the condenser. That is heat will be generated during the gas compression in the compressor, so COP of the heat pump is usually higher than the chiller for the same circumstances.

Heat Pump versus Gas-Fired Hot Water Heater

The capital cost of a heat pump is higher than an oil or gas fired hot water heater. However, payback times can be shorter, and it is therefore necessary to make a full economic analysis before deciding between the two. Further, it is worth noting that various funding and government incentives are available, which make for an attractive business case.

The EU Strategy for Energy System Integration focuses on the direct electrification of energy demand. A report by the Australian Energy Market Operator (AEMO) mentioned that Australia could exit coal-fired power entirely by 2043. It, therefore, recommends the phasing out of fossil fuels and the use of technologies such as heat pumps, for example, in buildings and industry.

There are increasing costs of emission quotas and possible future carbon taxation on fuels. The average carbon price has been increasing significantly in recent years. This rise is likely to continue. By installing heat pumps, it is possible to avoid or mitigate these costs by being able to use low-carbon or renewable sources.

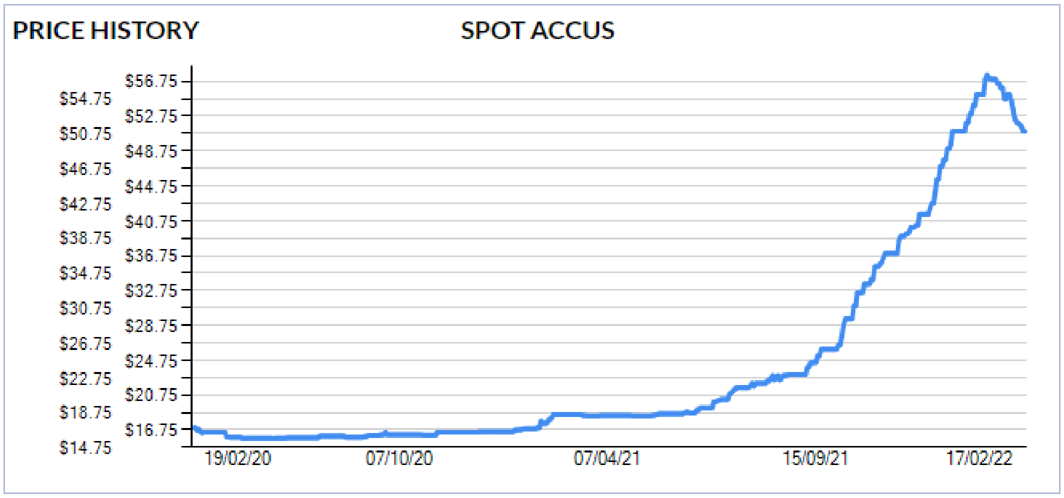
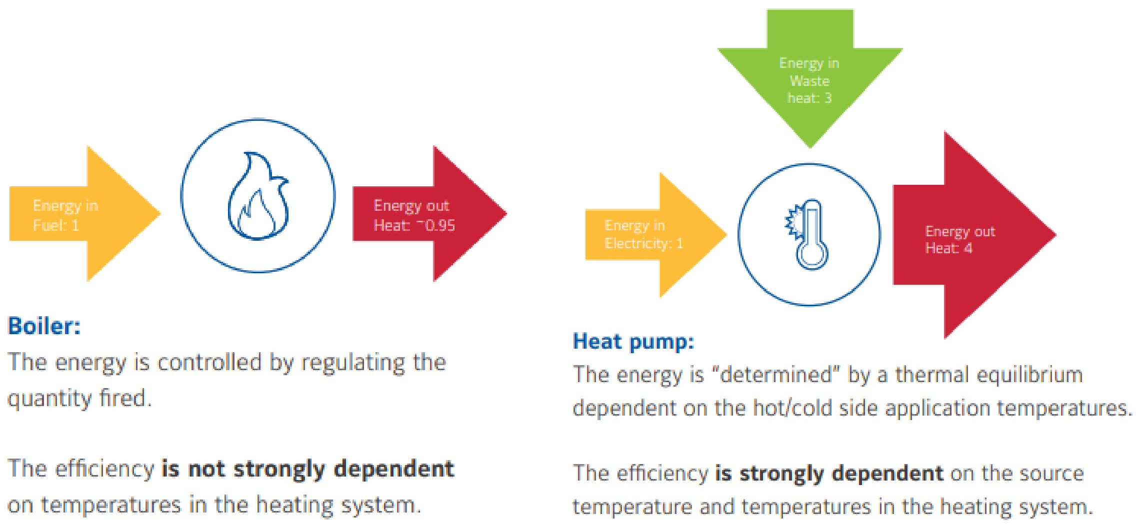


Fig 1. Australian Carbon Credit Units Price

Unlike a hot water heater, where the energy is controlled by the amount of fuel fired, a heat pump's energy is determined by a thermal equilibrium based on the hot/cold side temperatures. When the temperature at the cold side (heat source) is lower, physics dictates there are fewer molecules inside the refrigerant vapor, meaning that the amount of heat it can pump is less. This thermodynamic equilibrium determines the performance and therefore suitability of a heat pump for a particular application.



The heater efficiency is not closely dependent on temperatures in the heating system, in a heat pump efficiency is closely tied to the heat source temperature and required temperature for the application. This makes it difficult to compare the two technologies. However, in general, ambient temperatures in Australia are higher than in many other parts of the world and it is more efficient to use heat pumps in this type of climate.

Reliability of Supply of Heat

1) Natural Gas Hot Water Heater

   Natural gas is used for more than 50% of heating in Australia which suggests that these systems provide a level of reliability similar to electrical systems. Natural gas pipes are buried underground to prevent them from the environment and other factors above ground that could cause an outage. These gas pipes are also connected directly to the end-users, ensuring that there is constant access to a source of energy.

   On average, a conventional gas hot water heater can last for 15 to 20 years provided that it is well maintained and serviced annually.

2) Heat Pump

   Heat pump water heaters are relatively complex compared to gas water heaters. There is a variety of designs, energy efficiencies, and performances in available heat pump water heaters. They are designed to run all year long and use electricity as the main power source. As heat pumps and refrigerators use the same theory and similar process, heat pumps are as reliable as a refrigerator if it is well maintained.

In general, heat pumps have a lifespan of at least 20 years.

Capacity of Heat Pumps

In recent years, there has been a demand for residential and commercial heating projects at different scales. Heat pumps have become more popular to reduce emissions in the supply of low temperature (<100 °C) heat. There is a range of heat pumps using natural refrigerants with different capacities, from 3.5 kW up to 1000 kW. Mostly, propane (R290) is used in the small (3.5-15kW) capacity units, and CO_2 (R744) in small to medium (40-250kW) capacity units, while ammonia (R717) in large (250+kW) capacity (i.e. industrial) units.

Fig. Residential propane refrigerant Heat Pump Hot water heater unit

Fig. Commercial Carbon Dioxide Heat Pumps

Capital Cost

Since heat pump performance vary depending on the ambient temperature, hot water input and output temperature, it is difficult to provide general capital costs and economic analyses, but the following provides some guidance on order of magnitude expenses. Generally, the capital cost of a domestic heat pump system is about 2 to 3 times than a domestic natural gas hot water heater, including installation. For example, the residential heat pumps can cost between $3000 to around $5000 while the gas heaters are $1000 to $1800. However, there are some rebate programs available from the federal government for example the Small-scale Technology Certificates (STCs) and the Victorian Energy Efficiency Certificates (VEECs). Currently, each STCs credit is $37.5 and the VEECs credit is $42. For installing a residential heat pump, 17-27 credits can be obtained from STCs and 6-13 credits from VEECs depending on the unit size. As the result, around $900 to $1550 is saved which much reduces the capital cost of the heat pump.

For commercial and light industrial applications, 30 kW CO_2 refrigerant heat pump hot water services with a COP of 3-4 can be found for around $25,000. These are a good substitute for natural gas water heaters since their operating costs are 40 to 60 percent lower. The energy rebate program for this type of application is considered case by case as further investigation on the amount of energy saving is needed.

Table 1 Capital Costs

	Residential	Light Commercial	Medium Commercial	Large Commercial/ Industrial
Example	House, Units	Bakery, Launderette, Cafe	Hotel, Community Centre	Food processing factory, Manufacturing
Estimated Annual Heat Demand (kWh)	5,000	65,000	200,000	600,000
Indicative Capital Cost of Gas Heater (AUD)	$1500	$5,000-$12,000	$100,000-$150,000	$300,000-$400,000
Indicative Capital Cost of Heat Pump before incentive (AUD)	$4000	$15,000-$50,000	$200,000-$400,000	600,00-$1,000,000

Australia has higher electricity to gas price ratio than other countries. The estimated payback period is around 4 years, with a lot of variability and room for improvement in the future with cost reductions due to increased sales volumes. If energy efficiency certificate schemes (e.g. VEECs) are applied, the capital cost can be reduced and it can attract more customers to heat pump use.

Operational Cost

According to statistics from Global Petrol Prices, the average electricity price for users in Australia is 26.20c/kWh and the average natural gas equivalent usage price is 10.50c/kWh. The operational cost can be calculated by using these rates.

1) Natural Gas Hot Water Heater

   Heating costs of using natural gas hot water heater can be calculated using the following formula

   Heating costs = heat demand/efficiency x gas price

   *Normally, the efficiency of natural gas water heater is around 85-92%, so **90%** is used for this calculation.

   *Heat demand depends on the application of the heater.

   Heating costs = heat demand (kWh) /0.90 x 10.50 (c/kWh)

2) Heat Pump

Heating

Heating costs of using heat pump can be calculated using the following formula

Heating costs = heat demand/COP x electricity price

*Normally, the COP of heat pump is around 3-5, so **4** is used here for simpler calculation.

*Heat demand depends on the application of the heat pump.

Heating costs = heat demand (kWh) /4 x 26.20 (c/kWh)

Since the heat demand should be the same when comparing the performance of heat pump and natural gas water heater, the heating cost can be compared directly by their ratio.

Heating costs (Heater) / Heating costs (Heat Pump) = 1/0.90 x 10.5 / (1/4 x 26.2)

Heating costs (Heater) / Heating costs (Heat Pump) = 1.78

Heating costs (Heat Pump) = Heating costs (Heater) x 0.56

The above analysis shows that using heat pump can save up to 44% on the heating bills compared to a natural gas water heater.

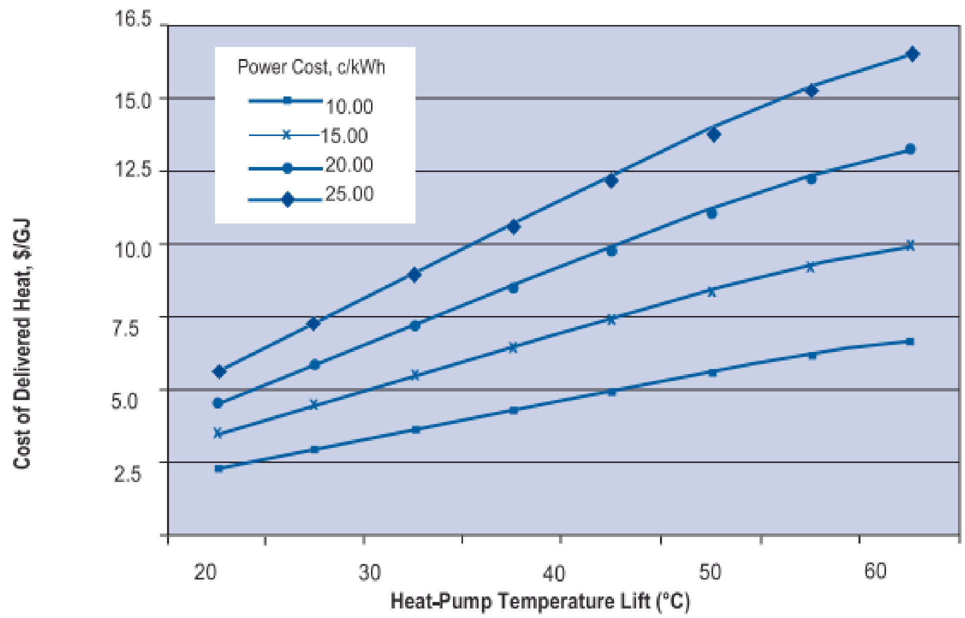


Chart basis: – Heat-pump evaporator temperature = 55°C
– Efficiency of heat-pump cycle is 65% of thermodynamic maximum
– Information is intended only to present trends, and will not apply to all cases.

Fig 1. Cost of delivered heat based on temperature lift

Assumed same maintenance interval and servicing cost for the gas water heater and heat pump, the operating costs can be compared for different industries by using the equations above.

Table 2 Operating Costs

	Residential	**Light Commercial**	**Medium Commercial**	**Large Commercial/ Industrial**
Example	House, Units	Bakery, Launderette, Cafe	Hotel, Community Centre	Factory, Commercial Building
Estimated Annual Heat Demand (kWh)	5,000	65,000	200,000	600,000
Cost of using Gas Heater (AUD)	$583	$7,583	$23,300	$70,000
Cost of using Heat Pump (AUD)	$327	$4,257	$13,100	$39,300
Annual Saving (AUD) for Heat Pump	$256	$3,326	$10,200	$30,700

Heating and Cooling

For medium or large commercial and industrial uses, heat pump can be used to produce heating and cooling at the same time. The COP of cooling and heating should be added up, so further saving can be obtained. However, heating and cooling demand need to be relatively stable in order to achieve this performance.

Heating and cooling costs of using heat pump can be calculated using the following formula

Heating and cooling costs = (heat demand+ cooling demand)/COP x electricity price

*Normally, the COP of heat pump is around 4-6, so **5** is used here for simpler calculation.

*Heating demand and cooling demand depends on the application of the heat pump.

Heating and cooling costs = (heat demand+ cooling demand) (kWh)/5 x 26.20 (c/kWh)

Table 3 Heat Pump compared Gas Heater and Chiller for heating and cooling

	Medium Commercial	**Large Commercial/ Industrial**
Example	Hotel, Community Centre	Factory, Commercial Building
Estimated Annual Heat Demand (kWh)	200,000	600,000
Estimated Annual Cooling Demand (kWh)	160,000	480,000
Cost of using Gas Heater on heating (AUD)	$23,300	$70,000
Cost of using Chiller on cooling (AUD)*	$13,900	$41,900
Cost of using Heat Pump on heating and cooling (AUD)	$18,860	$56,590
Annual Saving (AUD) using Heat Pump	$18,340	$55,310

* Estimated COP of 3 is used here for chiller.

The heat pump can also reduce the capital cost of the project as the cost of chiller can be saved. The heat pump's running costs will be substantially lower if the solar panels are added to the system.

Carbon Emissions

Carbon footprint is also another important criterion for choosing heat pump or gas fired water heater.

Table 4

	Efficiency	**Energy Consumption (based on 1kW heat demand)**	**CO2 Emission**	**Carbon Footprint**
Gas heater	0.9	1kWh/0.9 = 1.11	185g CO2/kWh from gas heater	1.11 x 185 =205 g CO2
Heat Pump	4	1kWh/4 =0.25	~650g CO2/kWh from power plant *	0.25 x 650 =162.5g CO2

* From Australian Carbon intensity statistics in 2020, emissions were 650g CO2/kwh and it is estimated emissions will be reduced to 580g in 2030, 310g in 2040 and 100g in 2050 as renewable energy generation increases, which means the carbon emissions of using heat pump will decrease through the years.

The heat pump's running costs and CO2 emissions will be substantially lower if the solar panels are added to the system.

According to the calculation, for every 1kWh of heat demand, heat pumps can save about 40g of CO2 emission (in Victoria) which is a 20% reduction. If this is applied to the previous table on energy saving, the following result can be obtained as detailed in Table 5.

Table 5

	Residential	**Light Commercial**	**Medium Commercial**	**Large Commercial/ Industrial**
Example	House, Units	Bakery, Launderette, Cafe	Hotel, Community Centre	Factory, Commercial Building
Estimated Annual Heat Demand (kWh)	5,000	65,000	200,000	600,000
Cost of using Gas Heater (AUD)	$583	$7,583	$23,333	$70,000
Cost of using Heat Pump (AUD)	$327	$4,257	$13,100	$39,300
Annual Saving (AUD) using Heat Pump	$256	$3,326	$10,233	$30,700
Annual Carbon Saving (kg CO2)	**212**	**2,762**	**8,500**	**25,500**

The above CO2 reduction would again increase if solar PV were used.

Barriers to the adoption of Heat Pump

There are several key barriers to the adoption of heat pump in Australia. These include defining how to go to market, identifying markets, affording equipment cost, and identifying customers.

1) **Lack of consumer/ supply chain awareness**

Consumers are unfamiliar with heat pump technology and rely on the supply chain to inform them of options. Meanwhile, the supply chain is also unfamiliar with heat pump technology resulting in low usage of heat pumps across Australia. Education throughout the supply chain on business cases, manufacturers offering installation training and hosting technology workshops can help increase the awareness of heat pumps to the public.

2) **Higher up-front cost**

The relatively high up-front cost discourages consumers to install heat pumps, so gas and electric water heaters still occupy most of the market in Australia. Supporting trade workforce development could lead to more efficient installations and decreased installation fees. The government providing more incentives on heat pumps could also encourage consumers to use a more energy efficient option on heating.

3) **High temperature applications**

In some cases, high temperature water (>85 degree C) or steam are required for certain applications. However, the technology of high temperature heat pumps is still developing. The costs of those heat pumps are relatively high so additional investment would need to cover the full capital cost of heat pumps for this application. The return on investment becomes longer and affects the customers' decision on choosing a more environmentally friendly type of equipment.

4) **Lack of government restriction and promotion**

Heat pump adoption has been impeded by a lack of restriction and marketing, as well as a confusing and often changing environmental policy at the Commonwealth level. There are fossil fuel heating restrictions in Europe, for example, France has banned using gas boilers in new buildings from 2022. Based on strong and continuous long-term support for the development and tech transfer of heat pumps in Europe, Japan, and South Korea; this technology has become widely used in industry.

5) **Lack of equipment technicians**

There are 28600 skilled technicians who have done a certificate III refrigeration course, but there may be only around 500 who can work competently on those natural refrigerants heat pumps or refrigeration systems. This number reduces significantly when it is moving to large commercial and industrial systems.

Conclusions

Generally, using heat pump is more economical and environmental-friendly (lower carbon emission) than the gas heater in Australia. A detailed case by case study should be adopted when it is for commercial and industrial uses. The growing movement of countries towards net-zero carbon emissions by 2050 will accelerate the replacement of gas fired hot water heaters with heat pumps. Gas hot water heaters depend on a non-renewable resource that continues to cause significant environmental damage. Heat pumps run on electricity, which can come from a local renewable energy source, or the grid (which is also becoming increasingly renewable). With increasing will to reduce emissions and save on total-cost-of-ownership, heat pumps will become more attractive for wider use in residential, commercial, and industrial applications.

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