ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAMME

International Renewable Energy Agency

Heat Pumps

Technology Brief

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The International Renewable Energy Agency (IRENA) is an intergovernmental organization dedicated to renewable energy. In accordance with its Statute, IRENA's objective is to "promote the widespread and increased adoption, and the sustainable use of all forms of renewable energy". This concerns all forms of energy produced from renewable sources in a sustainable manner and includes bioenergy, geothermal energy, hydropower, ocean, solar and wind energy.

As of December 2012, the membership of IRENA comprises some 160 States and the European Union (EU), out of which 104 States and the EU have ratified the Statute.

About IEA-ETSAP

The Energy Technology Systems Analysis Programme (ETSAP) is an Implementing Agreement of the International Energy Agency (IEA), first established in 1976. It functions as a consortium of member country teams and invited teams that actively cooperate to establish, maintain, and expand a consistent multi-country energy/economy/environment/engineering (4E) analytical capability.

Its backbone consists of individual national teams in nearly 70 countries, and a common, comparable and combinable methodology, mainly based on the MARKAL / TIMES family of models, permitting the compilation of long term energy scenarios and in-depth national, multi-country, and global energy and environmental analyses.

ETSAP promotes and supports the application of technical economic tools at the global, regional, national and local levels. It aims at preparing sustainable strategies for economic development, energy security, climate change mitigation and environment.

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Insights for Policy Makers

Based on thermodynamic refrigeration cycles, heat pumps use a process fluid and electricity to extract thermal energy from a low-temperature source and provide heat to a higher temperature sink (and refrigeration of the heat source). Heat sources (in heating applications) or sinks (in cooling applications) include outdoor/indoor air, river/lake/sea water, ground heat and waste heat. Common applications for heat pumps are air-conditioning, refrigeration and space heating in both residential and commercial buildings. Other applications include hot water supply in commercial buildings, cold storage warehouses and process heat and steam for industrial applications.

Heat pumps are very energy efficient devices. They can provide three to six units of useful thermal energy for each unit of energy consumed. In comparison, traditional combustion-based heating systems only provide less than one unit of thermal energy for each unit of energy consumed. An important performance indicator for heat pumps is the co-efficient of performance (COP), which is the ratio of the energy output to the energy input. The smaller the temperature difference between the heat source and the sink, the higher the COP. Today's best heat pumps can offer COP values between six and seven and high reliability under a wide range of operating conditions. In particular, significant advances have been achieved for air-source heat pumps (ASHPs), which are mostly used for air conditioning. Some ASHP models can provide indoor space heating even with outdoor air temperatures as low as -25°C, while keeping COP values greater than one. These technical advances have significantly enlarged the range of applications. With capacities between 1kW and 10 MW, current heat pumps can provide heating and cooling to single houses or to entire districts . In industrial applications, they can be used at temperatures from below -100°C to above 100°C. Although efficiency has been improved by a factor of 2.5 over the past decades, an additional increase of 20-50% is expected between now and 2030.

The economics and market penetration of heat pumps have significantly improved. However, their contribution to space and water heating is still relatively modest except for some OECD countries. Space heating/cooling and hot water supply account for roughly half of the global energy consumption in buildings, with a fast-growing demand in emerging economies, most of this demand being met by the combustion of fossil fuels. Therefore, the highly efficient heat pumps have a key role to play in reducing CO_2 emissions in the residential, commercial and industrial sectors. Furthermore, because heat pumps mostly use the renewable sources of heat and sinks (apart from the electricity used to run the process), they can be regarded as renewable technologies that contribute significantly to the penetration of renewable energy.

Heat pumps are considered as a renewable energy technology in the European Union (EU), where they are expected to account for between 5% and 20% of the EU's renewable energy target for 2020. Several other countries (e.g. the United States, the United Kingdom, Australia and Japan) grant tax reductions, subsidies or other benefits to facilitate the use of heat pumps. In many other countries however, heat pumps are not considered as renewable technologies and receive no incentives or subsidies. In addition, because significant differences exist in national standards and regulations to measure heat pump performance, their contribution to the penetration of renewable energy is not well captured in today's energy statistics. To support heat pump deployment, national standards should be harmonised, consumers should be fully informed of the efficiency of heat pumps, and the investment costs of heat pumps (compared to traditional combustion devices) should be reduced. Therefore, continued support to R&D and policy measures are essential to improve competitiveness and market penetration of heat pumps, thus exploiting their large potential to supply efficient and clean energy services.

Highlights

- **Process and Technology Status –** Heat pumps are devices to move heat from *low-temperature sources* to *high-temperature heat sinks.* They are widely used to supply heating and cooling for residential, commercial and industrial applications, such as space heating and cooling, water heating, freezing and refrigeration, within a wide range of temperatures. The newest heat pumps can generate air and steam at temperatures of up to 165°C. A heat pump consists basically of a compressor, an expansion valve, two heat exchangers (evaporator and condenser) and a proper refrigerant (process fluid). Heat pumps can move heat from the low- to the high-temperature sink with as much as several times the energy consumed to run the process. As a heat source, heat pumps can use outdoor air, underground heat, water (e.g. sea-water, river water) and all kinds of waste heat (e.g. industrial heat, heat from sewage treatment). Heat pumps for heating and cooling were first commercialised in the second half of the 20th century, but applications in cold climates were limited to ground-source heat pumps because of the low temperatures of outdoor air. Today's air-source heat pumps are able to supply heat even with outside air temperatures of -25°C. The market share of heat pumps for both heating and cooling applications is growing rapidly due to improved performance in terms of energy efficiency and CO_2 emissions.

- **Performance and Costs –** The heat pump's efficiency has increased substantially over the past years as a result of technical improvements and the use of inverters and control systems. Recently, the seasonal performance factor or SPF (i.e. the ratio of heat delivered to the energy consumed over the season) of the most efficient, commercial heat pumps has reached the level of 6-7, although SPF varies considerably with the heat pump technology, heat source and operating conditions. *Ground-source heat pumps* (GSHPs) can serve as effective systems for space cooling (summer) and heating (winter), as in most regions the ground temperature remains stable throughout the year (i.e. between 10-15°C). However, *air-source heat pumps* (ASHPs) are often the technology of choice for air-conditioning. The use of ASHPs is very cost-effective in regions where both space heating and cooling are required throughout the year. Most advanced devices can reach co-efficients of performance or COP(i.e. the ratio of thermal energy provided to the energy consumed) of higher than six. *Variable refrigerant flow* (VRF) ASHPs for space heating and cooling of medium-scale buildings can offer a COP above five in mild climates and above three with outside air temperatures of -10°C. Large-scale ASHPs for large buildings or industrial processes can reach a COP above six. Among ASHPs for water heating, the so-called "Eco Cute", using CO_2 as a refrigerant, can reach a COP of 5.1 (i.e. about four in terms of average annual performance factors). Large devices, such as *centrifugal chillers,* offer high performance for air-conditioning large buildings and industrial cooling (i.e. COP up to seven). Under certain operating conditions, centrifugal chillers with inverters, now being commercially sold, can reach a COP of up to 20. As far as cost is concerned, ASHPs are relatively inexpensive because neither underground nor water equipment is needed compared with GSHPs or water-source heat pumps. Especially room air-conditioners and VRF-ASHPs are becoming popular because of their low prices and easy installation. GSHPs are eco-friendly but expensive due to the need to bury heat exchangers underground and drill wells for heat sourcing. However, their running costs are lower.

- **Potential and Barriers –** Currently, space heating and cooling, together with hot-water supply, are estimated to account for roughly half of global energy consumption in buildings. Most of this energy demand is met by combustion of fossil fuels with their related CO2 emissions. Air-conditioning and cooling demand is growing, particularly in emerging economies. Heat pumps can reduce energy consumption and CO2 emissions, as well as improve energy security. If combined with thermal storage, heat pumps can also reduce the demand for peak power. It has been estimated that widespread use of heat pumps for space heating/cooling and water heating in the commercial sectors could reduce CO2 emissions by 1.25 billion tonnes by 2050. The thermal energy captured by heat pumps from the air, water or ground sources should be considered as renewable energy. In the European Union, the *EU Directive on Promotion of Renewable Energy,* passed by the European Parliament in 2009, clearly states that aero-thermal, hydrothermal and geothermal sources used by heat pumps are to be classified as renewable energy and introduces policy measures to promote the use of heat pumps. The contribution of heat pumps to the EU target of reaching 20% of renewable energy share by 2020 is estimated at about 4.9%, compared to a contribution of 2.9% for photovoltaic energy. Major barriers to the widespread use of heat pumps include the insufficient recognition of benefits and the high investment costs. Defining international standards for heat pump efficiency, as well as labeling and providing incentives (e.g. subsidies, grants) for heat pump use, could help overcome these barriers. The use of heat pumps would be greatly encouraged if the thermal energy they captured were recognised worldwide as a renewable energy source. As for performance and costs, current R&D activities are expected to increase efficiency by 40-60% for heating services and by 30-50% for cooling services, and to reduce costs by 30-40% and 5-20%, respectively, by 2050. _

Process and Technology Status

Heat pumps are widely used to supply heat and cold for residential, commercial and industrial uses, such as space heating and cooling, water heating, freezing and refrigerating. More recent uses also include generation of heated air (drying), steam at temperatures of up to 165°C and snow melting. A synoptic overview of heat pump applications with information on capacity (kW), temperature range, market scale and penetration is provided in Figure 1.

The physics of heat pumps is well-known. While heat (thermal energy) tends to flow naturally from high-temperature sources and bodies to low-temperature heat sinks, heat pumps can move heat from low-temperature to high-temperature heat sinks. The heat pump principle is based on the four phases of the *reverse Carnot cycle*[1]. Therefore, a heat pump can typically be used to extract heat from a refrigerator or an air-conditioner and provide heat for water- or space-heating, according to the scheme in Figure 2. The basic configuration of a heat pump consists of the evaporator (i.e. outdoor unit) where the process fluid evaporates, absorbing heat from the heat source (e.g. air), a compressor to compress the fluid and increase its temperature, a condenser (i.e. indoor unit), which releases heat by condensing, and an expansion valve to reduce the pressure and temperature of the process fluid to below the level of outside air temperatures in order to restart the cycle. The energy for the process is provided by the electric energy to run the compressor and circulate the fluid.

Heat pumps are highly efficient devices, as they can move and supply six units of thermal energy for each unit of electrical energy consumed. The ratio of the thermal energy provided for space cooling or heating to the energy consumed is the heat pump's co-efficient of performance (COP), one of the heat pump performance indicators. Another performance indicator for heat pumps is the seasonal performance factor. Because definitions of heat pumps' energy performance differ between Asia, North America and Europe, the International Organisation for

1 The *Carnot cycle* (Sadi Carnot, 1824) is a theoretical thermodynamic process to convert thermal energy into mechanical energy, using the thermodynamic transformations of an ideal fluid (i.e. perfect gas): a) the heat provided by a high-temperature source (e.g. combustion) is first absorbed by the isothermal expansion of the fluid; b) the fluid then expands adiabatically (e.g. in a piston or a turbine) and generates mechanical energy, while reducing its temperature; c) the residual heat of the fluid is then released during an isothermal compression; d) finally, an adiabatic compression increases the fluid temperature to the initial level to restart the cycle. In common practice, the theoretical *Carnot* cycle translates into the *Rankine cycle,* using a phase-change fluid.

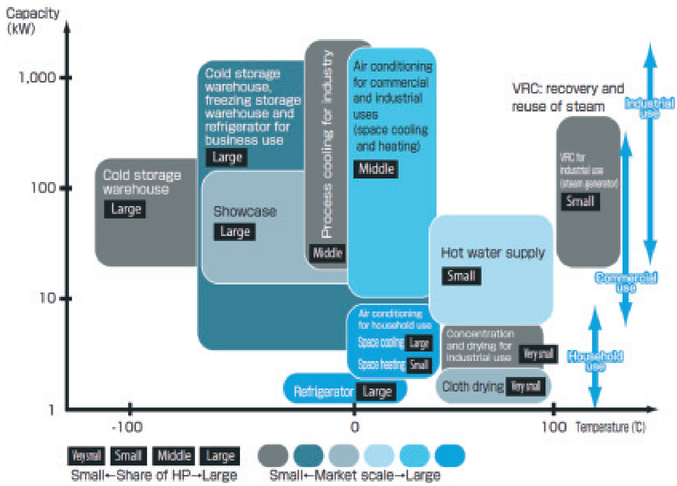

Figure 1 – Heat Pump Application Areas [1]

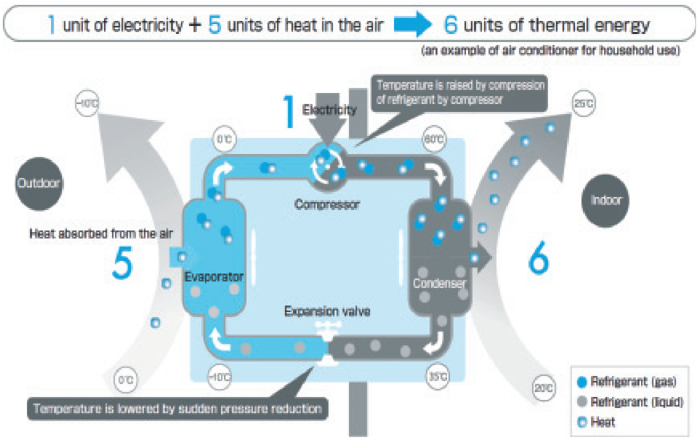

Figure 2 – Mechanism of Heat Pump [1]

Standardisation (ISO) is working to define a global standard - the annual performance factor (APF) - which is the ratio of the total amount of heat the device can remove from, or add to, space concened during the cooling and heating seasons (respectively) to the total amount of energy consumed for both heating and cooling services. The high efficiency of heat pumps can provide advantages in terms of energy and CO2 emissions, saving in comparison to other approaches (e.g. combustion) to space/water heating and cooling.

As a primary heat/cold source and sink, heat pumps can use outdoor air, river/lake/sea water or even ground (underground) heat and cold. All these sources can be regarded as renewable[2] heat/cold sources, which can be used for residential, commercial and industrial applications. There may be, for example, air-to-air or air-to-water heat pumps or even water-to-air and ground-to-water/air heat pumps. The efficiency of heat pumps based on water sources is generally high because surface water is usually colder than air when space cooling is needed (e.g. summertime) and warmer than air when space heating is needed (e.g. night time, wintertime). Of course, heat pumps can also use all kinds of waste heat, such as industrial and residential waste heat, or heat from sewage treatment.

Heat pumps for heat supply have been commercialised since the second half of the 20th century. In cold climates, their use has been limited to ground-source heat pumps as the outside air temperature is too low for using air-to-air heat pumps. However, more recent air-source heat pumps are able to supply heat even with outside air temperatures of -25°C, using injection circuits which bypass the evaporator and inject fluid into the compressor for cooling during compression or two-stage compression to increase fluid circulation volume. Freezing risks have been prevented by passing hot-leg fluid through the colder part of the heat exchanger in the outdoor units. The time needed for defrosting and from start-up to blow-off of heated air has also been shortened. These component technologies have significantly contributed to improving the space heating performance and efficiency of heat pumps. All these improvements have enabled the use of air-source heat pumps in cold climates for applications to space heating, floor heating, water heating and even road heating for snow melting. Figure 3 shows the market share of heat pumps by heat source in nine EU countries. The share of air-source heat pumps exceeded the share of ground-source heat pumps in 2007 [2].

2 The EU Directive on Renewable Energy provides a formula to calculate the amount of renewable energy used by a heat pump:

$E_{RES} =$ $Q_{USABLE}(1 - 1/SPF)$ where:

$E_{RES} =$ Heat from renewable energy;

$Q_{USABLE} =$ Total usable heat delivered by the heat pump; and

$SPF =$ Seasonal Performance Factor of the heat pump, which in turn depends on the average efficiency of power generation

Depending on heat pump applications, various process fluids have been used over time. While NH3, CO2 and ether were used in early heat pumps, freon-based gases (e.g. CFC, HCFC) have been widely used over the last decades of the 20th century because they are efficient, stable and safe. However, the regulations to protect the ozone layer have led to a phase-out of these gases since the Montreal Protocol in 1987. As an alternative, hydro-fluoro-carbon (HFC) gases have been developed and are currently used. Fluids with a lower global warming potential are now under development.

In some cases, thermal storage systems are used to increase the efficiency of heat pumps and reduce peak power demand for buildings. These systems typically consist of a thermal storage tank where the heat produced overnight is stored and used during the day. Various thermal storage media have come into practical use. Chilled and hot water storage is used in thermal storage systems for heat pump air-conditioning systems. More recently, air-conditioning systems with ice-based, latent heat storage (and small-size storage tanks) have been developed. Also, air-conditioning systems with thermal storage based on the building body and no storage tank have come into practical use.

Thermal storage (see ETSAP E17) is part of the wider energy storage topic, which is gaining more attention as a key component of smart grids to accommodate significant shares of variable renewable power (e.g. wind and photovoltaics) and to produce and accumulate heat and cold from renewable sources when available.

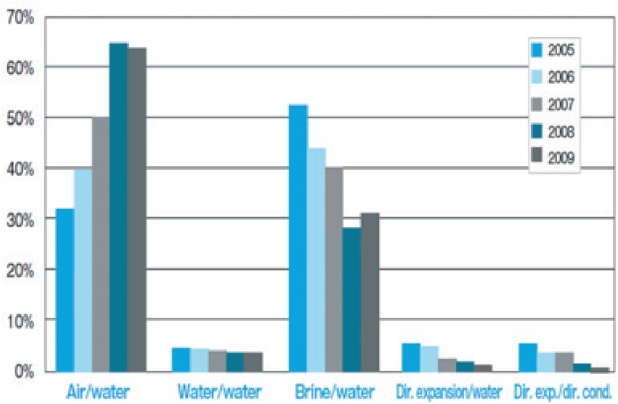

Figure 3 – Market Shares by Energy Source in Nine EU Countries (i.e. Austria, Finland, France, Germany, Italy, Norway, Sweden, Switzerland and the United Kingdom)

Performance and Costs

- **Technology Progress and Developments –** The efficiency of heat pumps has been substantially increased over the past years due to the improvement of components (e.g. compressors, heat exchangers, fans, inverters for operation control). Major developments for air-conditioning heat pumps, variable refrigerant flow (VRF[3]) heat pumps, centrifugal chillers and water heating heat pumps using CO_2 as the process fluid are shown in Tables 1 to 3 [3].

Most of the electricity consumed by air-conditioners for residential and commercial use is the electricity to run the compressor and, to a lesser extent, the fan motor of the heat exchanger of outdoor/indoor units. Early heat pumps were mainly equipped with AC induction motor-compressors. In the 1990s, a brushless DC motor (BLDCM)[4] was adopted to achieve higher efficiency. The BLDCM needs an inverter as a drive power supply; therefore, variable control of motor speed has become common. Furthermore, in the mid-1990s, the adoption of BLDCMs with high magnetic field magnets based on rare earth materials enabled even higher efficiency. Figure 4 compares the efficiency of compressor motors: current BLDCMs offer significantly higher efficiency in low/partial load operation. With this improvement, the annual performance factor (APF) of the heat pumps has significantly improved. The efficiency of fan motors and heat exchangers has also been improved by replacing AC motors with more efficient BLDCMs with inverters, by proper fan design and layout and by optimising the heat transfer within exchangers. These improvements have enabled the heat exchanger efficiency as a whole to increase by a factor of 2.5 over the past 30 years. Further improvements deal with the development of control technologies to optimise operating conditions of fans, compressors and heat exchangers according to air and room temperatures, and the optimisation of the thermodynamic cycle by decreasing condensing temperatures and increasing evaporation temperatures[5].

3 VRF (variable refrigerant flow) is a heat pump that connects a single outdoor unit to multiple indoor units and controls each indoor unit separately. VRF is also called "ductless mini-split heat pump" since air-conditioning ducts are not needed.

4 With a permanent magnet around the perimeter of the motor rotor.

5 The thermodynamic efficiency (η) of a heat pump for space cooling depends on evaporation and condensation temperatures Te and Tc (K), and is given by the formula η = Te/(Tc-Te).

- **Efficiency and Cost of Heat Pumps –** The seasonal performance factor (SPF) of most efficient heat pumps has recently reached the level of 6-7, depending on the heat source, technology and operating conditions. Figure 5 shows indicative SPF ranges of heat pumps for space cooling and heating, and water heating. The wide range of values reflects different technical specifications, meteorological conditions and operating temperatures.

Heat pumps based on air as the heat source or sinks (ASHPs) and used for space cooling/heating and water heating can be classified as air-to-air heat pumps and air-to-water heat pumps. In many countries and regions, air-to-air heat pumps have become a standard air-conditioning technology for single rooms and entire buildings. The latest models are highly efficient and offer a COP above six. Some types of VRF equipment with a COP above five are now commercially available for air-conditioning in mid-scale buildings. The latest models on sale can treat sensible heat and latent heat separately, thus further lowering energy use and CO2 emissions. Some types of VRF systems are also available for use in cold climates at outside air temperatures as low as -25ºC, with a COP higher than three at -10ºC. The COP of large-capacity ASHPs that are used for air-conditioning large buildings and for industrial cooling processes usually ranges from three to four, though the COP of highly-efficient ASHPs can be higher than six and equal to that of centrifugal chillers. ASHPs for water heating (also referred to as “Eco Cute”), using CO2 as the process fluid, came into practical use for the first time in Japan in 2001, with a COP of 5.1 (APF 3.9). ASHPs for air-conditioning can be used for space heating as well. They are very cost-effective options in regions where both space cooling and heating are required throughout the year. Compared with GSHPs, ASHPs are inexpensive because neither underground nor water equipment is needed. The capital cost of ASHPs for water or space heating is higher than the cost of traditional combustion equipment. However, it is compensated for in a relatively short period of time by the energy savings as the efficiency of ASHPs is three to six times the efficiency of combustion equipment.

Heat pumps based on ground heat sources or sinks (i.e. GSHPs) and used for space cooling/heating and water heating have characteristics similar to water-source heat pumps in that water or brine is pumped and circulated underground to exchange heat with the ground. As the ground temperature remains stable (10-15ºC) throughout the year, ground sources play an effective role for space cooling during summertime and space heating in winter. GSHPs are particularly cost-effective for air-conditioning and cooling applications as they can utilise underground heat without running the compressor when its temperature is lower than the outside air temperature (i.e. free cooling).

Centrifugal chillers are among the most efficient heat pump devices. Some devices currently on sale offer a COP higher than seven. If combined with thermal storage systems, they can significantly reduce peak power, energy consumption and CO2 emissions. The use of inverters can also reduce power consumption during low-load conditions. Depending on operating conditions (e.g. outlet temperatures of chilled water and cooling water temperatures), the COP at partial load operation can exceed 20. Centrifugal chillers to recover unused heat from sewage waste water and river water can be even more effective in saving energy and reducing CO2 emissions.

Table 4 shows typical capital cost ranges for heat pumps for space cooling/heating and water heating in the residential sector in different world regions [4]. Table 5 shows the typical cost range for heat pumps in the non-residential sector [5].

Table 1 Developments for Room Air-Conditioners and VRF Equipment

Compressor	• Loss reduction in sliding parts and fluid leakage • Use of BLDCMs and Nd magnets
Expansion valve	• Use of electronic expansion valves
Heat ex-changer	• Leveling flows of fluid and air • Fin shape optimisation
Fan	• Shape optimisation and use of DC motor
Efficiency of cycle	• Increase of evaporation temp. and decrease of condensation temp. • Use of two-stage compressors • Use of gas injection cycle • Improvement of super-cooling degree of liquid refrigerant(*)
Refrigerant conversion	• Development of element components suitable for respective refrigerant (R22, R407 and R410A)*
System opti-misation	• Optimised heat exchanger/fan installation • Optimised power requirement • Development of control technology for optimum operation of compressors according to air-conditioning load, outside air conditions and others(*)

* For VRF only

Table 2 – Technical Developments for Heat Pump-based Centrifugal Chillers

Compressor	• Improved aerodynamic performance by high-tech manufacturing • Reduction of gear and bearing losses.
Motor	• Use of higher efficiency motors • Use of inverter panels for high voltage (3-6kV)
Heat exchanger	• Leveling flows of fluid and water in heat exchanger and improved heat transfer
Efficiency of cycle	• Reduction in temperature difference between low-temperature and high-temperature sides • Use of economiser cycle
Adoption of inverter	• Improved efficiency at partial load operation and adoption of inverters for power supply • Use of control systems for motor speed, inlet vane and hot gas bypass

Table 3 – Technical Developments for Heat Pump-based Water Heaters using CO_2 as the Process Fluid

Compressor	• High-pressure compressors with high compression ratios
Heat exchanger	• Leveling flows of fluid and air • Improved counter-current heat exchange in the water heat exchanger
Fan	• Shape optimisation and use of DC motors
Efficiency of cycle	• Loss reduction in expansion process by using ejector cycles
System optimisation	• Optimisation of coordination between hot water storage tank and heat pump

Potential and Barriers

Currently, space heating and cooling and hot water supply are estimated to account for roughly half of the energy consumption in buildings, and related demand is rapidly growing, particularly in emerging economies. Most of the associated energy demand is met by combustion of fossil fuels with associated CO2 emissions. Therefore, highly efficient heat pumps have a key role to play in reducing the use of fossil fuels and related CO2 emissions in the residential and commercial sector. Heat pumps not only reduce the energy consumption for these services in absolute terms; they also enable an energy switch from fossil fuels to electricity, the production of which is (increasingly) based on a significant share of renewable energy in many countries. Currently, about one-third of the global electricity generation is based on non-fossil primary energy (e.g. renewable and nuclear energy sources), and the carbon intensity of electricity production at global levels (i.e. 0.507kgCO_2/kWh in 2007) is expected to decline quickly because of the rapid growth of renewable power in many countries [6].

Table 6 compares primary and secondary energy consumption, CO2 emissions and share of renewable energy for space and water heating by heat pumps and gas-fired heaters [7]. Figures in Table 6 assume heat pump SPFs of four and six and a COP for natural gas-fired heaters of 0.95. If the load is set at 100, the secondary energy consumed by the gas-fired heater is 105 and that consumed by the heat pumps is 25 and 17, respectively. The amount of primary energy needed is estimated taking into account the power generation efficiency (i.e. global average efficiency of coal-fired power plants of about 35% and efficiency of latest gas-fired power plants of about 60%[6]) and includes transmission and distribution losses. If the generation efficiency is set at 30%, the primary energy consumption of the heat pumps is 83 and 56 for SPFs four and six, respectively, to be compared with the primary energy consumption of the gas-fired heater (105). The associated CO2 emissions have been compared assuming different CO2 intensities for electricity generation and gas. Under all assumptions, heat pumps offer a significant advantage in terms of CO_2 emissions that is projected to increase over time with the decline of carbon intensity in electricity generation [6]. Estimates suggest that, if heat pumps are widely adopted for space and water heating applications in buildings, they could reduce global CO2 emissions by 1.25 billion tonnes by 2050 [4].

From a regulatory and policy perspective, heat pumps based on air-, ground- and (natural) water-sources are considered as renewable energy technologies in the European Union (Climate Change Package, EU Directive on Promotion of Renewable Energy). Governments and legislation offer incentives to promote the use of heat pumps [8]. In the EU, it is estimated that the use of heat pumps could account for 4.9% of the 20% renewable energy target that the European Union strives to reach by 2020. If so, the heat pumps' contribution to the EU target would exceed the contribution of photovoltaic energy (2.9%) [9].

Heat pumps are flexible and scalable devices that can be used for small-size household appliances, as well as for large-size facilities (e.g. conditioners, refrigerators, district cooling and heating). In addition to the traditional space cooling and heating, new applications include residential water heating (Eco Cute) based on CO2 heat pumps and industrial heat supply. Modular heat pump units can be assembled to reach a capacity of up to ten MW, with high operation reliability. If both heat and cold are needed at the same time, heat recovery pumps using waste heat from space cooling can be the technology of choice. As for industrial heat supply, today's heat pumps can produce hot air up to a temperature of 120ºC and steam up to 165ºC, and replace boilers in many industrial processes. Research is expected to further expand operation temperatures.

While heat pumps are a mature technology, their efficiency is expected to increase by 2030 by 30-50% for heating and 20-40% for cooling, and by 2050 by 40-60% for heating and 30-50% for cooling (see Table 7) [4]. Cost reductions are expected as a consequence of technology improvements, market penetration and synergy with thermal storage systems.

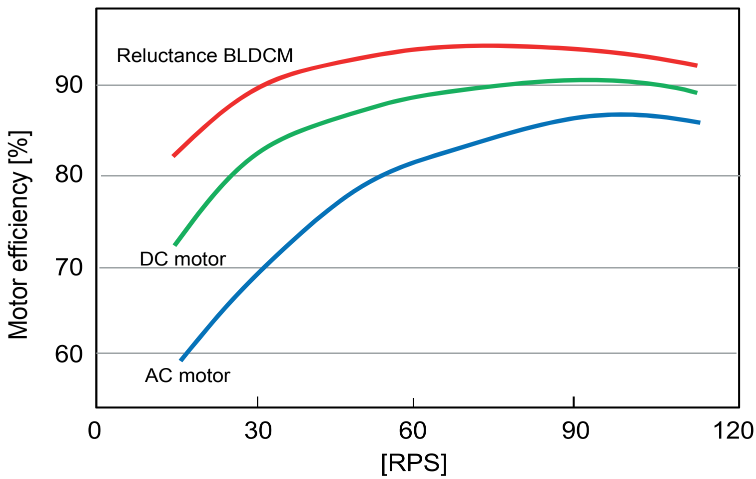

Fig. 4 – Efficiency of Compressor Motors

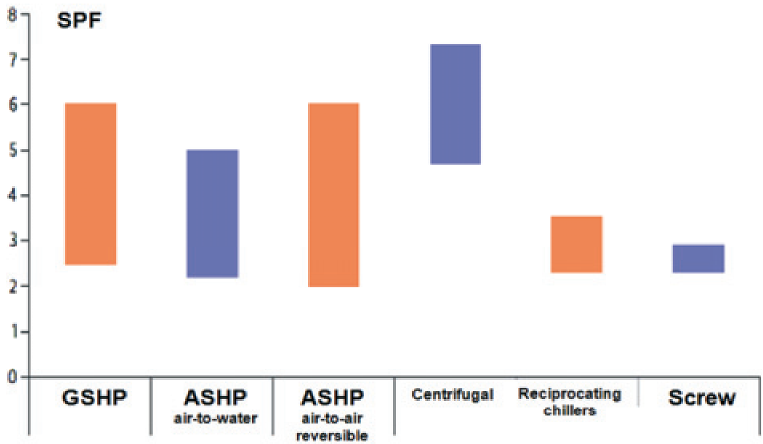

Fig. 5 – Typical Current Efficiency Ranges for Heat Pumps in Heating and Cooling Modes by Technology [4]

Major barriers to heat pumps include the high initial cost and insufficient recognition of benefits. Policy measures to promote the use of heat pumps include the standardisation of efficiency indexes, system labeling and incentives in the form of subsidies and grants. It is also essential to disseminate information on heat pumps' benefits and encourage research for cost reductions and efficiency improvements.

At present, some countries have incentives in place to facilitate the installation of heat pumps. In the United States, for example, tax reductions are granted for residential heat pumps. In the United Kingdom, according to the Act on Renewable Heat Incentive, which took effect in 2011, tariff benefits are returned in proportion to heat pump use that satisfies a certain level of efficiency. In Australia, part of the capital investment for the installation of heat pump-based water heaters is refunded. In Japan, incentives have been granted to Eco Cute installations until 2010, and subsidies are provided to develop new generation heat pumps.

The use of heat pumps would be greatly encouraged if the thermal energy they captured were recognised worldwide as renewable energy.

Table 4 – Typical Costs of Heat Pumps for Residential Space Heating/Cooling and Hot Water Wupply, [4]

Regions		North America	China & India	OECD Pacific	OECD Europe
Typical size(kW)		2-19	1.5-4	2.2-10	2-15
Economic life (yr)		15-20	15-20	8-30	7-30
Installed cost (USD/kW)	A-to-A	360-625	180-225	400-536	558-1,430
	ASHP	475-650	300-400	560-1,333	607-3,187
	GSHP	500-850	439-600	1,000-4,000	1,170-2,267

Table 5 – Typical Cost Ranges of Heat Pumps for Space Heating/ Cooling in the Non-residential Sector [5]

Types	ASHP Air-cooled	ASHP reversible	ASHP Water-cooled	Centrifugal chiller
Typical size (RT)	20-500	30-104	23-479	170-3,000
Market price* (USD/RT)	364-2,046	708-2,657	252-1,188	160-1,729

* Market price means wholesale price or manufacturer's retail price for standard models, excluding commission, setting and installation fees.

Table 6 – Comparing Heat Pumps and Combustion [7]

Technical Equipment		Heat pump SPF=4	Heat pump SPF=6	Gas-fired heater
Load (kWh)			100	
Efficiency[a]		4.00	6.00	0.95
Secondary energy use, (kWh)		25	17	105
Primary energy use (kWh) for different power generation efficiency (%)[b]	20%	125	83	105
	30%	83	56	105
	40%	63	42	105
	50%	50	33	105
	60%	42	28	105
CO_2 emissions (kg) for different CO_2 intensity,[c, d, e] in (kg/kWh)	0.507[c]	12.7	8.5	–
	0.459[d]	11.5	7.7	–
	0.067[e]	1.7	1.1	–
$kgCO_2/m^3$	0.208[f]	–	–	17.1
Heat from renewable energy (kWh)		75	83	–

a) SPF for heat pumps and COP for gas-fired heaters
b) Power generation efficiency, including transmission losses
c) CO_2 intensity of electricity generation in 2007
d) CO_2 intensity of electricity generation in 2050 (IEA ETP 2010 Base)
e) CO_2 intensity of electricity generation in 2050 (IEA ETP 2010 Blue)
f) CO_2 intensity of liquid natural gas (LNG) in Japan

Table 7 – Heat Pump Cost and Performance Targets [4]

	2030		2050	
	Heating	Cooling	Heating	Cooling
Cost reduction, %	20-30	5-15	30-40	5-20
COP increase, %	30-50	20-40	40-60	30-50
Delivered energy cost reduction, %	20-30	10-20	30-40	15-25

References and Further Information

1. [1] Data Book on Heat Pump & Thermal Storage Systems 2011-2012, HPTCJ, September 2011.
2. [2] EHPA: Outlook 2010 European Heat Pump Statistics/Summary, EHPA, 2010.
3. [3] White book on heat pump and thermal storage systems, HPTCJ, 2007.
4. [4] Technology Roadmap Energy–efficient Buildings: Heating and Cooling Equipment, International Energy Agency, May 2011.
5. [5] Survey based on price statistics, manufacturers' catalogues and information from manufacturers, HPTCJ, 2012.
6. [6] Energy Technology Perspectives 2010, International Energy Agency, July 2010.
7. [7] Trial calculation by HPTCJ, 2011.
8. [8] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on Promotion of the Use of Energy from Renewable Sources, amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.
9. [9] Renewable Energy Projections as published in the National Renewable Action Plan of the European Member States, EEA, 2011.

Table 8 – Summary Table: Key Data and Figures for Heat Pump Technologies

<table>
<tr><th colspan="5">Technical Performance</th></tr>
<tr><td>Heat sources</td><td colspan="4">Aerothermal, Geothermal (direct/indirect), Hydrothemal (surface/ground), Exhaust heat, Sewage heat</td></tr>
<tr><td>Power sources</td><td colspan="4">Electricity, Natural/Propane gas, Kerosene, etc.</td></tr>
<tr><td rowspan="4">Compressor types</td><td colspan="3">Dynamic</td><td>Centrifugal chiller</td></tr>
<tr><td rowspan="3">Positive displacement</td><td colspan="2">Reciprocating</td><td>Reciprocatingchiller</td></tr>
<tr><td colspan="2" rowspan="2">Rotary</td><td>Scroll chiller</td></tr>
<tr><td>Screw chiller</td></tr>
<tr><th colspan="5">Refrigerants</th></tr>
<tr><td rowspan="7">Freon</td><td>CFC</td><td>CFC-12</td><td>Refrigerators, car air-conditioners</td><td>Production ceased in 1995</td></tr>
<tr><td rowspan="2">HCFC</td><td>HCFC-22</td><td>Air-conditioners</td><td rowspan="2">Production to be terminated in 2020 (Production to be terminated in 2015 in Europe)</td></tr>
<tr><td>HCFC-123</td><td>Commercial air-conditioners</td></tr>
<tr><td rowspan="4">HFC</td><td>HFC-134a</td><td>Refrigerators, car air-conditioners</td><td rowspan="4">Release is regulated as these are substances causing global warming.</td></tr>
<tr><td>R410A</td><td>Residential/commercial air-conditioners</td></tr>
<tr><td>R407C</td><td>Commercial air-conditioners</td></tr>
<tr><td>R404A</td><td>Cold storage warehouses, etc.</td></tr>
<tr><td colspan="2" rowspan="5">Natural refrigerants</td><td>Ammonia</td><td>Cold storage warehouses, etc.</td><td>Pros: high performance/Cons: less combustible, toxic, odorous</td></tr>
<tr><td>Carbon dioxide</td><td>Car air-conditioners, water heaters</td><td>Pros: supercritical, non-toxic, non-combustible/ Cons: high pressure, supercritical</td></tr>
<tr><td>Hydrocarbon</td><td>Refrigerators, (Air-conditioners)</td><td>Pros: high performance, compatible/ Cons: explosive</td></tr>
<tr><td>Water</td><td>Chiller for industrial use, Ice-making</td><td>Pros: non-toxic, non-combustible, high performance/ Cons: enlarged</td></tr>
<tr><td>Air</td><td>Cold storage warehouses</td><td>Pros: non-toxic, non-combustible/Cons: enlarged</td></tr>
</table>

Cost of Heat Pumps for Residential Space Heating/Cooling and Hot Water Supply

Regions		North America	China and India	OECD/Pacific	OECD/Europe
Typical size (kW)		2-19	1.5-4	2.2-10	2-15
Economic life (years)		15-20	15-20	8-30	7-30
Installed cost (USD/kW)	A to A	360-625	180-225	400-536	558-1,430
	ASHP	475-650	300-400	560-1,333	607-3,187
	GSHP	500-850	439-600	1,000-4,000	1,170-2,267

Cost of Heat Pumps for Commercial Space Heating/Cooling

Types	ASHP air-cooled	ASHP reversible	ASHP water-cooled	Centrifugal chiller
Typical size(RT)	20-500	30-104	23-479	170-3,000
Market price (USD/RT)	364-2,046	708-2,657	252-1,188	160-1,729

Heat Pump Potential vs. Combustion Devices

Heat source equipment	Heat pump (SPF=4)	Heat pump (SPF=6)	Gas combustion heater
Load (kWh)	100		
Efficiency	4.00	6.00	0.95
Secondary energy consumption (kWh)	25	17	105
Primary energy consumption (kWh) at power generation efficiency of 30%	83	56	105
CO_2 emissions (kg) at CO_2 intensity of 0.459 kg/kWh or 0.208 kg/m^3	11.5	7.7	17.1
Amount of heat from renewable energy (kWh)	75	83	–

Heat Pump Costs and Performance Targets

	2030		2050	
	Space/Water Heating	Cooling	Space/Water Heating	Cooling
Installed cost	-20% to -30%	-5% to -15%	-30% to -40%	-5% to -20%
COP	+30% to +50%	+20% to +40%	+40% to +60%	+30% to +50%
Delivered energy cost	-20% to -30%	-10% to -20%	-30% to -40%	-15% to -25%

Disclaimer

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