Heat pumps can cut global CO_2 emissions by nearly 8%

IEA
OECD

RENEWABLE ENERGY FOR A CLEANER FUTURE

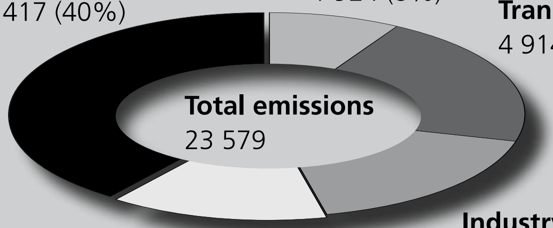
Potential benefits

Heat pumping technologies are widely used for upgrading low-temperature free heat from renewable sources, such as air, water, ground and waste heat, to useful temperatures. They are used for residential and commercial space and water heating, cooling, refrigeration and in industrial processes. In producing heat, they are called heat pumps, and they compete with fossil fuel-fired furnaces and boilers and with direct electric heating.

This brochure addresses the large potential contribution of heat pumps for reducing CO_2 emissions.

Global CO_2 emissions

(2002 by sector in million tonnes per year[1])



Potential CO_2 emission savings

Heat pumps could save 50% of the building sector's CO_2 emissions, and 5% of the industrial sector's.

This means that 1.8 billion tonnes of CO_2 per year could be saved by heat pumps, corresponding to nearly 8% of total global CO_2 emissions.

An 8% reduction of CO_2 emissions is equivalent to the yearly environmental benefits of:

Elimination of 244 GW of coal-fired steam turbine capacity[2]

Planting 50 million hectares of trees[3]

Reducing petrol consumption by 780 thousand million litres per year[4]

Taking 52 million cars off the road[5]

1) World Energy Outlook 2004, The International Energy Agency

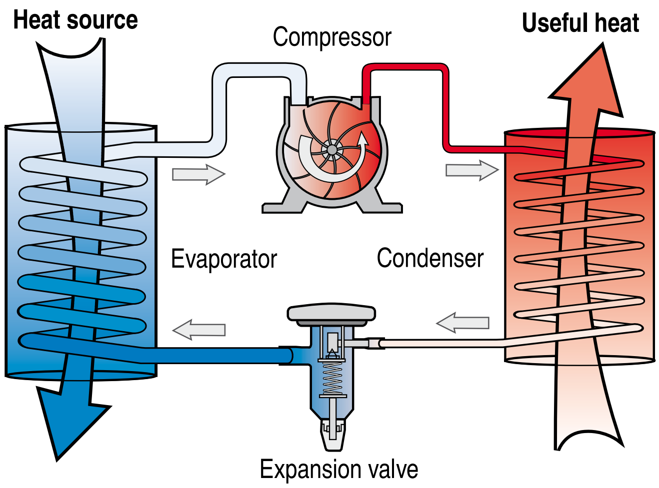
2) Assumptions: specific emissions 890 kg CO_2/MWh_{el}, operating time 8 400 h/year

3) 36 tonnes CO_2 per hectare trees and year abated, according to Myers, N., and T. J. Goreau. 1991. Tropical forests and the greenhouse effect: A management response. *Climatic Change*, 19: 215-26.

4) Use of 1 litre of petrol creates 2.3 kg CO_2, according to http://www.epa.gov/otaq/climate/420f05001.htm

5) Assumptions: 15 000 km per year, 0.8 litre petrol used/10 km, use of 1 litre petrol creates 2.3 kg CO_2

Heat pumps
– making low-temperature heat useful



In a typical heat pump cycle, shown in the figure, heat is extracted from the heat source by the evaporator, which is at a low temperature. In it, the heat is transferred to a working fluid, changing it from liquid to gas. A compressor then increases the gas pressure, causing the temperature to rise. The hot gas flows to the condenser, where heat is given off as the working fluid changes back from gas to liquid. The working fluid, which is still at a high pressure, is then passed through an expansion valve, which lowers the pressure. In doing so, the fluid becomes cold and returns to its liquid state before once again entering the evaporator.

In refrigeration and air-conditioning applications, the process is reversed, supplying useful cooling instead.

Application areas
Heat pumping technologies can be used for space and water heating, as well as for refrigeration or cooling applications. In many industrial processes, heat pumps are applied to recover process waste heat.

Renewable heat sources
Heat pumps lift heat from a low-temperature renewable source (ground, water or air), or from a waste heat source, to a high useful temperature. Heat pumps stand out because they can convert low-grade heat into useful heat. Even in winter, the outside air, water and ground still contain heat which can be extracted and upgraded by a heat pump. This natural heat can be used to heat buildings or for hot water production. The heat sources are continually replenished by the sun, and so the extracted heat is renewable energy. Heat pumps can also extract waste heat, e.g. from ventilation air, and make it suitable for reuse. The energy needed to drive a heat pump is only about one third or less of the useful heat produced. Most heat pumps are driven by an electric motor. However, a growing number of heat pumps are gas-fired or waste-heat driven.

Small reversible heat pumps dominate
The largest numbers of heat pumps currently being used are small reversible units which can provide both heating and cooling, in individual rooms, houses, retail stores, offices, schools and institutional buildings. It is estimated that around 30 million units are produced worldwide annually[6], and over 130 million units are in operation in Japan, the USA, China and Europe[7]. These heat pumps are cost-effective in many regions of the world, as they cost little more than a cooling-only air conditioner. In cold to moderate climates, heating-only heat pumps are used to heat tap water and homes.

In commercial buildings and industrial processes, heat pumps are often applied where simultaneous heating and cooling is required, or heating in winter and cooling in summer. Worldwide, over 15 million systems are installed in commercial and institutional buildings[8].

Performance of heat pumps
The performance of heat pumps is usually described by the Coefficient Of Performance (COP), which is the ratio of useful heat produced to the drive energy of the heat pump. The Seasonal Performance Factor (SPF) is the average COP taken over a heating season.

6) Groff, J. 8th IEA Heat Pump Conference, Las Vegas, 2005 and personal communication with Groff, J.
7) International Heat Pump Status and Policy Review 1993-1996 Part 1 and 2 (HPC AR-07, ISBN: 90-74741-34-3)
8) International Institute of Refrigeration, Refrigeration Report, 2002

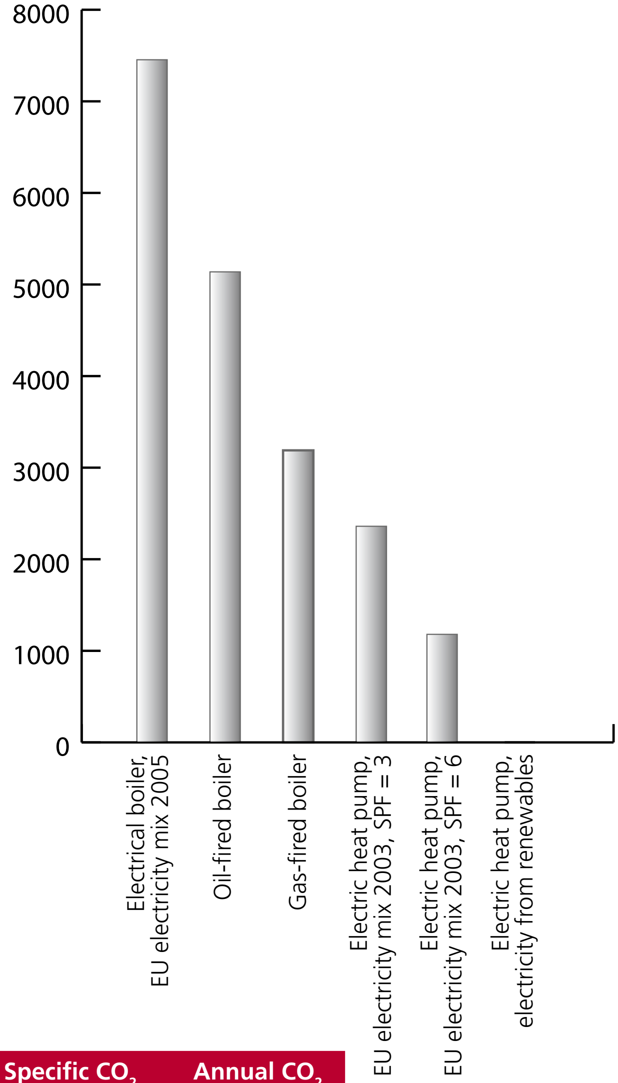
Environmental benefits of heat pumps

To emphasize the potential which heat pumps offer, the International Energy Agency (IEA) Heat Pump Centre has assessed the global environmental benefits of heat pumps.

The environmental impact of an electric heat pump applied in a building is compared with that of a conventional boiler. The building is assumed to have an annual heating demand of 15 000 kWh. The single most important CO_2 emission source is the local combustion of oil or gas in a boiler, and the generation of electricity for driving the electric heat pump or the electric boiler. The emission rates of a boiler and an electric heat pump depend on the energy efficiency of the equipment, and on the fuel mix and efficiency of electricity generation. The CO_2 emissions of conventional heating systems are compared with heat pumps with two levels of efficiency, shown in the figure. The SPF=3 case represents typical systems today, SPF=6 represents efficiencies that can be expected in the future. Assumed is an average European CO_2 emission of 0.47 kg CO_2/kWh_{el} for electricity generation[9]. Boiler and heat pump efficiencies are shown in the table below. An electric heat pump operating on electricity from renewable energy sources does not emit any CO_2 at all. All heat pump cases emit considerably less CO_2 than the boiler cases. This effect will increase with the greening of electricity production (secondary effect).

In conclusion, heat pumps offer a distinct advantage over conventional heating equipment in terms of CO_2 emissions.

Annual CO_2 emissions for a domestic home with 15 000 kWh annual heating demand (kg CO_2/year)



Type	Heat demand (kWh)	Efficiency (%)	Input energy (kWh)	Specific CO_2 emissions (kg CO_2/kWh)	Annual CO_2 emissions (kg)
Oil-fired boiler	15 000	80	18 750	0.274	5 138
Gas-fired boiler	15 000	95	15 790	0.202	3 189
Electric boiler, EU electricity mix 2005	15 000	95	15 790	0.472	7 454
Electric heat pump, SPF = 3	15 000	300	5 000	0.472	2 360
Electric heat pump, SPF = 6	15 000	600	2 500	0.472	1 180
Electric heat pump, electricity from renewables	15 000	300	5 000	0	0

9) EU Energy and Transport in figures, http://ec.europa.eu/dgs/energy_transport/figures/pocketbook/2007_en.htm

Saved by current heat pump stock - residential heat pumps

There are over 130 million heat pumps installed in residential buildings.

If we assume that:
- the average household's heating demand is 15 000 kWh/year, and
- 50% of the replacements are gas boilers, and 50% are oil boilers

Heat pumps save today
157 million tonnes CO_2 per year, corresponding to 0.7% of global CO_2 emissions[10]

Saved by current heat pump stock - commercial heat pumps

There are over 15 million heat pumps in commercial buildings.

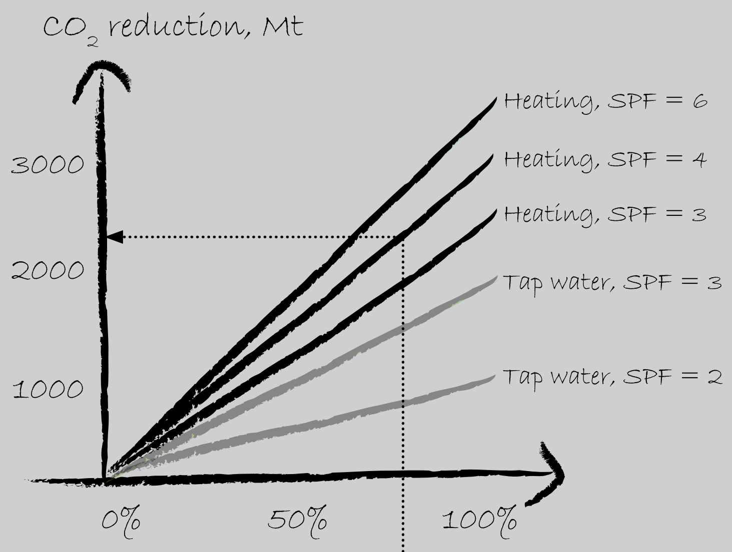
If we assume that:
- the average heating demand is 100 MWh/year, and
- 50% of the replacements are gas boilers, and 50% are oil boilers

Heat pumps save today
120 million tonnes CO_2 per year, corresponding to 0.5% of global CO_2 emissions[10]

CO_2 savings as a function of the percentage of retrofitted homes

The figure shows CO_2 savings as a function of the percentage of homes, retrofitted with heat pumps, in the OECD countries, and heat pump performance factor (SPF). Savings in tap water and heating can be added together. It is assumed that an electric heat pump with European emissions replaces an oil-fired boiler with 80% efficiency.

The potential contribution of heat pumps to CO_2 emissions reduction increases with improved technology and market penetration, as well as greening of electricity production.



Example
If 80% of the homes in the OECD countries replaced their oil boiler with a heat pump with an SPF=4, 2374 Mt of CO_2 could be saved, corresponding to 10% of global CO_2 emissions.

10) Assumptions: SPF=3 for both heating and tap water in already installed units, oil boiler efficiency = 80%, gas boiler efficiency = 95%

Application areas of heat pumps

Residential buildings

In Central and Northern Europe, with a moderate to cold climate, residential heating-only heat pumps provide an energy-efficient way of heating with low emission levels. Many of these heat pumps extract (solar) heat from the ground.

In the Nordic countries, for example, replacing an oil-fired boiler by an electric heat pump reduces CO_2 emissions by 90%[11]. This high proportion is the result of low-CO_2 electricity generation.

Commercial buildings

In many countries, space heating and cooling are two vital elements for creating a comfortable working atmosphere.

In Sweden, a small shopping mall with a heating demand of 550 MWh and a cooling demand of 1 350 MWh per year a ground-source heat pump system was installed with thermal energy storage. The system efficiency (SPF) of this installation was measured as 6.2, resulting in 91% CO_2 emissions reduction in heating mode and 65% CO_2 emissions reduction in cooling mode. The total CO_2 emissions reduction amounts to 185 tonnes per year.

Industry

In many industrial processes, heat pumps are applied to recover process waste heat. They are used in dehumidification, distillation and evaporation processes, and also for water heating and combined heating and cooling. There are major opportunities in the food and chemical industries.

One of the largest heat pump installations in the world is integrated in a propylene/propane distillation process operated by Shell in Pernis, the Netherlands. This heat pump saves 37 million m^3 of natural gas annually, and cuts CO_2 emissions by 90 000 tonnes.

District heating and cooling systems (DHC)

In many countries, heat pumps are successfully applied in district heating systems or in combined district heating and cooling systems. Typical heat sources and heat sinks for the systems are sea water, ground water, rock or sewage.

The largest district heating heat pump in the world utilizing untreated sewage as a heat source is a 28 MW R134a two-stage system installed in 2006 in the district heating grid of Viken Fjernvarme AS in Oslo, Norway. Compared to direct electric heating systems based on the mean European (UCPTE) electricity mix, this heat pump cuts CO_2 emissions by 50 000 tonnes annually.

11) This assumes a heat pump with an SPF=3.5 and average Nordic CO_2 emission for electricity generation of 0.11 kg CO_2/kWh_{el}.

Prospects for future CO_2 emission savings

The CO_2 emissions reduction potential of nearly 8% will increase in the near future, as both heat pumps and power plants become more efficient as a result of technology development. The efficiency of a fossil-fuelled boiler based on the higher heating value of the fuel can never exceed 100%. However, for domestic space heating and tap water production, heat pumps with COP values of up to 10 are possible. For industrial processes with small temperature lifts, COP values of 25 and higher could be reached. This implies that heat pumps can be more efficient than fossil-fuelled boilers by factors of 10 and 25 respectively. Consequently, heat pumps will become more attractive and take a larger share of the heating market.

Future CO_2 emission reduction potential in residential buildings in Europe

Eurostat reports a total annual refurbishment rate of almost 4.9 million units in the EU 25, Norway, Switzerland and Liechtenstein together.

During the next ten years, by replacing oil or gas burners with heat pumps, it should be possible to save 15 to 90 million tonnes CO_2 per year[12].

	CO_2 reduction if all homes have oil-fired boilers (Mt)	CO_2 reduction if all homes have gas-fired boilers (Mt)
30% of residential buildings choose heat pump	23	10
50% of residential buildings choose heat pump	38	17
80% of residential buildings choose heat pump	61	27

By producing electricity from renewables, heat pumps save even more CO_2 emissions. For Europe, if the electricity generation emissions decreased by 20%, the CO_2 emissions of each home, with a heat pump with an efficiency of SPF=4, would decrease by more than 180 kg/year additionally.

Conclusion

There is a considerable potential for extending the present environmental advantage of heat pumps over conventional heating systems. This potential is an invitation waiting for realisation, through R&D, the support of governments and utilities, and through market transformations.

Heat pumps are better by nature and a way forward to a better environment.

12) Assumptions: SPF=6 for heating, SPF=3 for tap water, oil boiler efficiency = 80%, gas boiler efficiency = 95%

Established under the umbrella of the International Energy Agency in 1978, the Heat Pump Programme is a non-profit organisation funded by its member countries. The aim of the Heat Pump Programme is to accelerate the use of heat pumping technologies as practical and reliable systems that can save energy resources while helping to protect the environment.

The Heat Pump Centre is the central information activity of the Heat Pump Programme. The Centre links people and organisations worldwide in support of heat pumping technology.

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