HEAT PUMPS

Better by nature

IEA
OECD

Better use of energy resources

A ready supply of heat is something we take for granted. At home, at work, in industry, heat plays a vital role in maintaining our living standards. But when future generations look back on our current heating systems, they'll wonder at our wastefulness. For even the most efficient burning technology wastes fuel by failing to exploit abundant heat sources in our surroundings. And all this needless burning threatens the environment with damaging effects such as global warming and acid rain.

BETTER BY NATURE

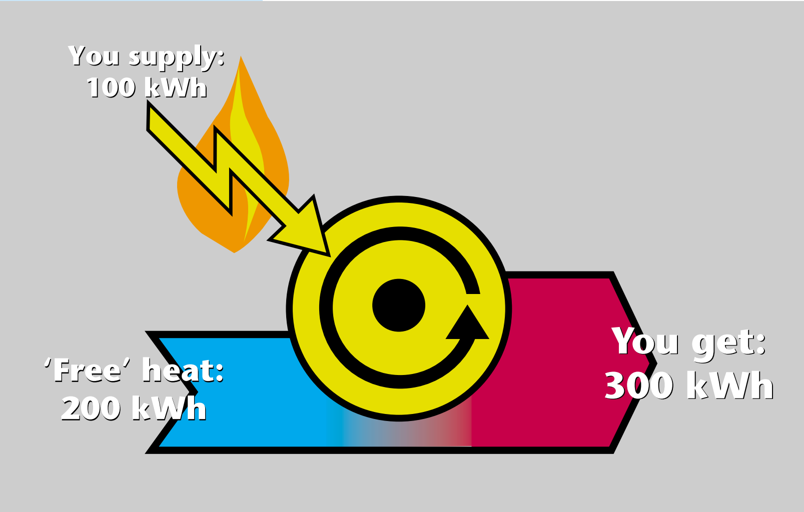
As a natural consequence of its design, a heat pump supplies more heat than is available in the energy which powers it. A typical electric heat pump (*see Figure 1*) supplies 300 kWh of heat with just 100 kWh of electricity - an efficiency of 300%! (a COP of 3 using conventional terminology). This seemingly impossible feat is achieved by exploiting the natural laws of thermodynamics: even at temperatures we consider to be cold, large natural bodies such as air, ground or water contain considerable heat energy. By applying a little more energy, the temperature of this heat energy can be raised to a level that allows it to be used in a building or industrial application.

LESS FUEL

The heat pump's high efficiency means that it consumes much less fuel than a conventional system. *Figure 2* illustrates that despite the energy lost when generating electricity, an electric heat pump can make much better use of fuel than today's most efficient gas boiler. And if the heat pump is powered by a high-efficiency CHP (*combined heat and power*) generator, fuel consumption is reduced by more than a third.

Figure 2 assumes a heat pump efficiency of 300% (*COP=3*) - in many situations heat pumps achieve 400% efficiency (*COP=4*) or more. Some prototype systems have realized efficiencies as high as 600%! (*COP = 6*).

Figure 1: By taking 200 kWh 'free' heat energy from the environment or a waste heat source, a heat pump can supply 300 kWh heat using only 100 kWh electricity.



REDUCED EMISSIONS

By consuming less fuel, heat pumps can reduce emissions of gases such as sulphur dioxide, methane and carbon dioxide (CO_2) that harm the environment. The plumes of smoke in Figure 2 illustrate the reductions in emissions of CO_2 when replacing conventional heating equipment in a society fuelled only by gas.

Of course, in most countries, electricity is produced using a mixture of fuels and other power sources. The environmental impact of heat pumps depends on the local situation: when gas, nuclear, hydropower or renewable energy predominate in electricity generation, electric heat pumps will significantly reduce emissions, even in comparison with modern condensing gas boilers. If coal or oil-fired power stations predominate, very high-performance electric heat pumps (such as those now in development) or gas-fired heat pumps are required for worthwhile emissions reductions.

Another potentially significant emission associated with a heat pump is the release of its working fluid. As with household refrigerators, heat pumps no longer use CFCs as working fluids. The working fluids used today are about 95% less damaging to the ozone layer and cause negligible global warming. Also, their threat has been further reduced by stringent legislation which outlaws the release of working fluids during or after a heat pump's working life.

A WISE INVESTMENT

While a heat pump will cost more than conventional technology, the user can make sufficient energy cost savings to pay back the investment. In some situations, a more long-term approach to investment is required which can be encouraged by financial incentive schemes from governments or utilities. When heat pumps combine heating and cooling they can save both heating energy and money since they re-place the two systems used conventionally. Thus the growing trend towards cooling in buildings is increasing the market for heat pumps. □

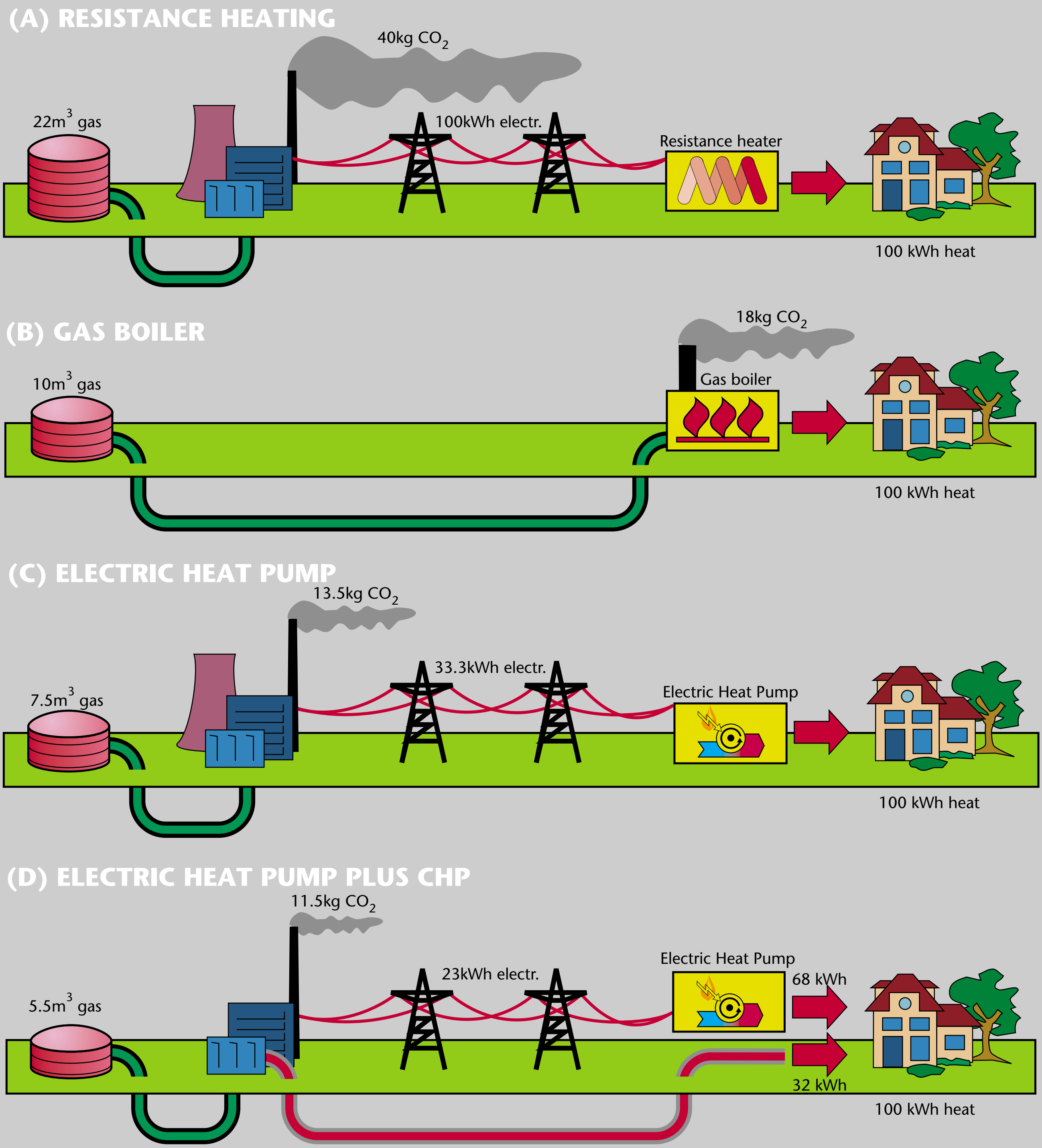


Figure 2: *By considering an energy system where gas is the only fuel, its clear to see the fuel savings made with an electric heat pump: Compare the gas consumed by resistance heating (A) or by a modern condensing gas boiler (B) with an electric heat pump (C). Even greater savings are made when heat pumps are used together with a combined heat and power (CHP) generator (D). As indicated by the plumes of smoke, heat pumps can also significantly reduce emissions of* CO_2.

Assumptions: Heat pump efficiency = 300% (COP=3); Power station efficiency = 45%;
CHP efficiency = 50% heat & 35% power; Boiler efficiency = 95%

Better energy policy

With growing evidence of the threat to the environment posed by emissions from burning fossil fuels, many governments and utilities are looking at policies to reduce energy consumption. Among the options available, a policy on heat pumps deserves special attention because heat pumps are widely applicable in buildings and industry, where they address the significant energy demand for low-temperature heat. But what measures can be taken to stimulate the use of heat pumps?

As shown below, a range of subsidies, tax incentives and favourable interest rates are being applied by governments and utilities, to reduce the cost of a heat pump system. In addition, more general legislation, tax and incentive schemes aimed at limiting CO_2 emissions or reducing heat losses are leading to greater application of heat pumps. Particularly important measures are the imposition of energy-efficiency standards on heating and cooling equipment, and regulations to limit heat losses from buildings.

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COOPERATION

Closer international cooperation leads to a better understanding of heat pump technology and will enhance the effectiveness of heat pump promotion measures. The box gives details on organizations concerned with heat pump technology.

WORLDWIDE ACCEPTANCE

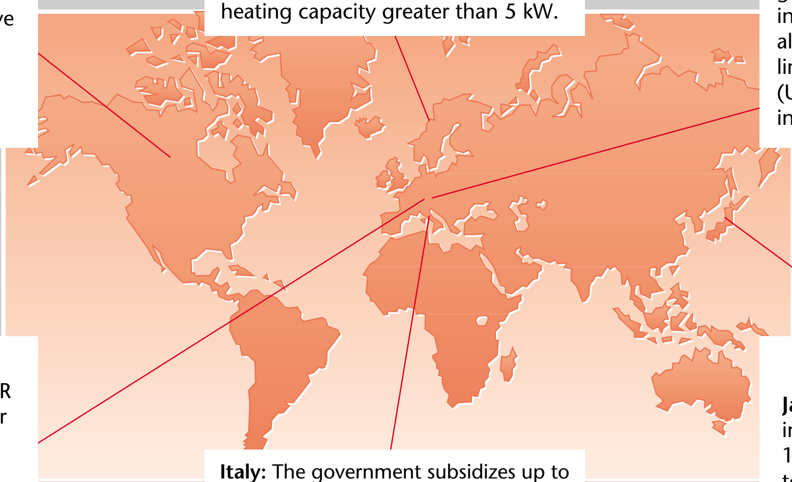
To talk of the energy-saving benefits of heat pumps is no longer the sole domain of heat pump enthusiasts. Today, more and more people view heat pumps as an important element of energy policy. Some of their views are shown on the opposite page.

Examples of Financial Incentive Schemes

Canada: Electric utility, Ontario Hydro offers a CAD 1500 (USD 1200) incentive for a ground-source residential heat pump in regions where gas is unavailable.

Norway: A 30% government subsidy is available for heat pumps with a heating capacity greater than 5 kW.

Austria: Many local governments offer a low interest rate credit for stand-alone heat pumps, typically limited to ATS 60,000 (USD 5,000) or 50% of the investment cost.



Switzerland: A government subsidy of SFR 300 (USD 200) is given for small (<18 kW) heating-only heat pumps meeting minimal efficiency standards.

Italy: The government subsidizes up to 40% of the cost of a heat pump when it replaces a conventional system.

Japan: Tax relief on investment is raised from 10% to 40% for heat pump technology.

INTERNATIONAL ENERGY AGENCY
Ms Helga Steeg
Executive Director
"Heat pumps reduce the environmental consequences of energy production per end-use service provided, in a way that need not interfere with or alter the tested performance characteristics of such service."

UNITED NATIONS ENVIRONMENT PROGRAMME
Ms Jacqueline Aloisi de Larderel
Director, Industry and Environment Programme Activity Centre
"In reducing fossil fuel consumption and related CO_2 *emissions, and in reducing the use of CFCs, heat pumps can make a solid contribution towards the concrete implementation of Agenda 21 and the international conventions on climate change and the protection of the ozone layer."*

JAPAN
Dr Shunzo Ishihara
Director General, Agency of Industrial Science and Technology
Ministry of International Trade and Industry
"From our long experience in the development of heat pumping technology, we are convinced of its present usefulness and its great potential in the future in dealing with energy problems, which include protection of the global environment."

NETHERLANDS
Mr Stan Dessens
Director General for Energy / Ministry of Economic Affairs
"Given today's environmental problems, and the need to increase energy efficiency, the Dutch government is giving new stimuli for the heat pump by starting up a programme in which we have digested the experience of the past to guarantee a successful implementation on a wider scale."

NORWAY
Ms Margit Pedersen
Political Advisor to the Norwegian Ministry of Environmental Affairs
"The Ministry of Environmental Affairs supports the increased use of heat pumps, since it clearly sees the energy-saving effect of this technology."

SWITZERLAND
Prof. Daniel Favrat
Swiss Federal Institute of Technology
"Getting good value for money is standard practice. Today, we must also get useful energy with less waste while making better use of the Earth's resources. Heat pumps are going to play a major role in this."

Better by nature

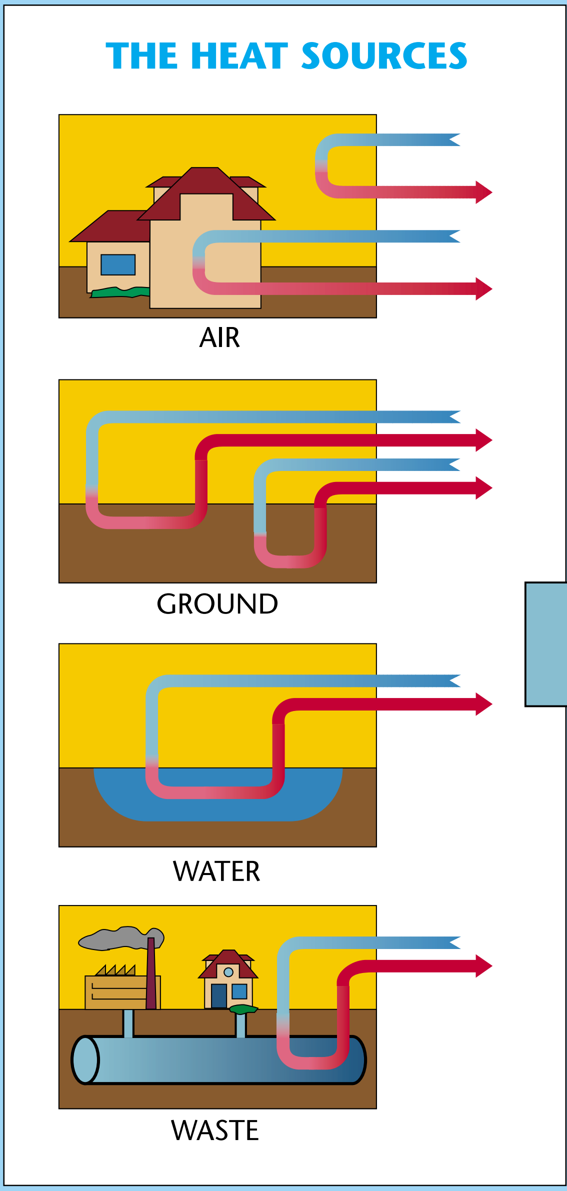
How a heat pump saves energy

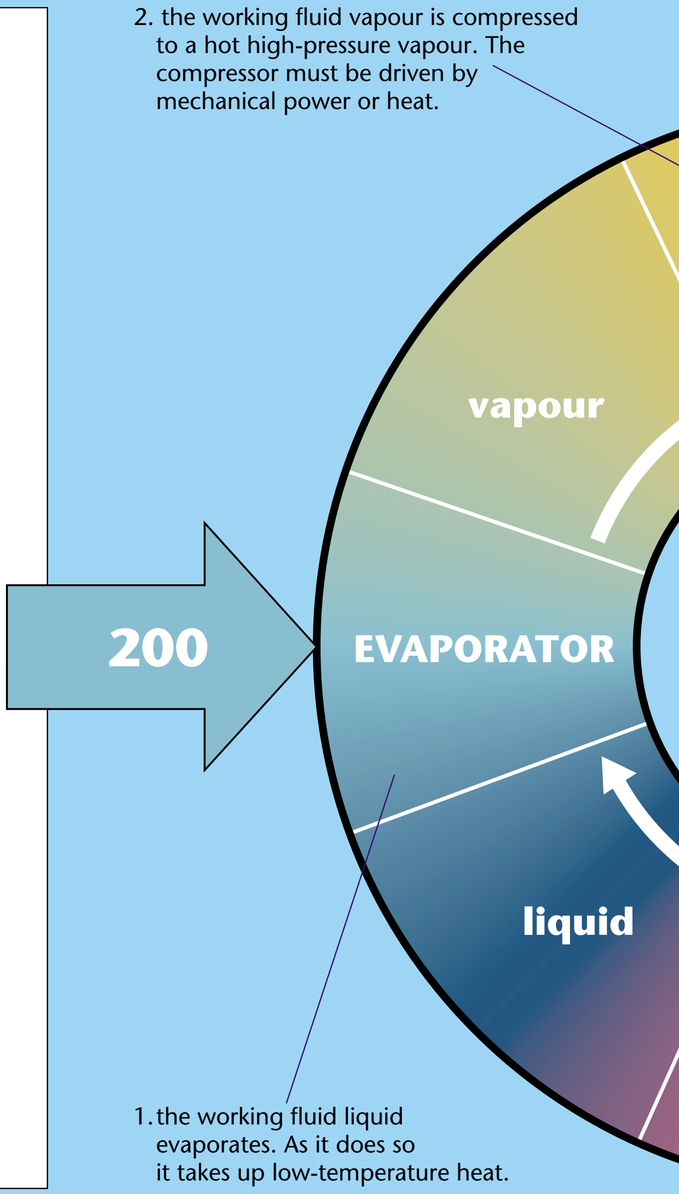
Heat pumps transfer heat from natural heat sources in the surroundings, such as the air, ground or water, or man-made heat sources such as industrial or domestic waste, to a building or industrial application. The highest efficiency is achieved when the warmest heat source is used.

In operation, a fluid (known as the working fluid) is circulated through four components as shown. At the compressor, the temperature of the heat is raised to the level needed. The energy needed to do this is provided by an electric motor, engine or heat, and is added to the energy transferred from the surroundings. For instance, in a typical ground-source electric heat pump, just 100 kWh electricity is used to turn 200 kWh low-temperature heat into 300 kWh useful heat.

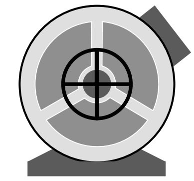
Cooling

A heat pump can also be used for cooling. It then transfers heat in the opposite direction, from the application to the surroundings. A space conditioning heat pump can often be switched to the cooling mode for operation as a conventional air conditioner. The dual function of this so-called reversible heat pump makes it especially attractive to the user since it reduces energy consumption when heating and avoids the need for a separate air-conditioning system.

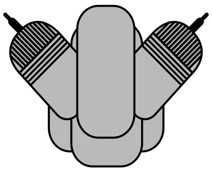




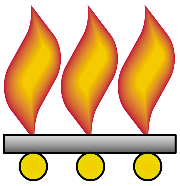
THE DRIVING FORCE



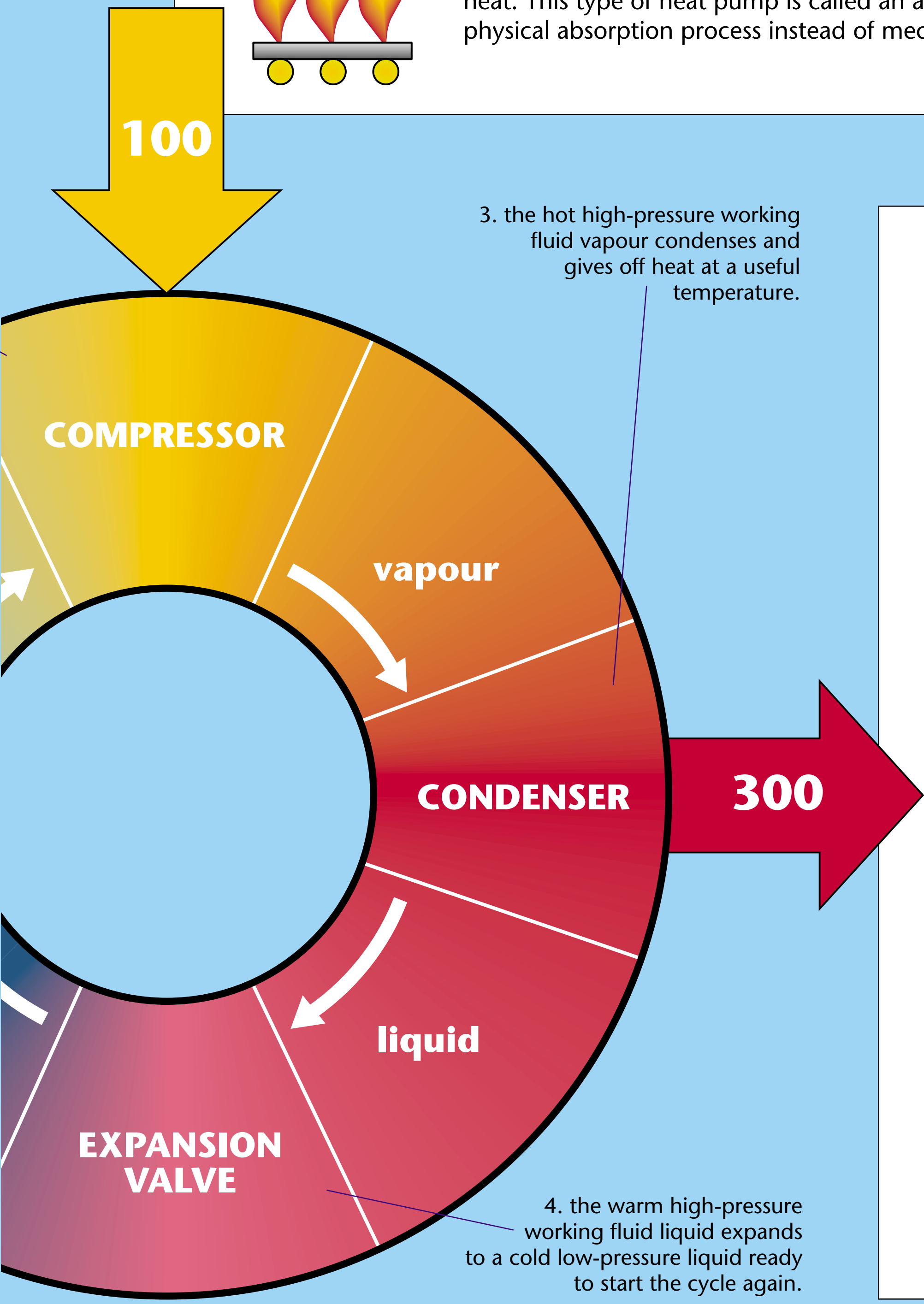
electric motor:
An electric motor drives the compressor with very low energy losses. The overall energy efficiency of the heat pump strongly depends on the efficiency by which the electrical power is generated.



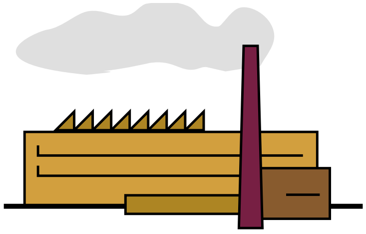
gas or petrol engine:
The engine drives the compressor. Heat from the cooling water and exhaust is used directly in the heating application in addition to heat from the heat pump cycle.



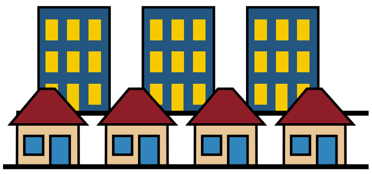
heat:
A heat pump can be powered by heat from a burner or by hot (>80°C) waste heat. This type of heat pump is called an absorption heat pump and uses a physical absorption process instead of mechanics.



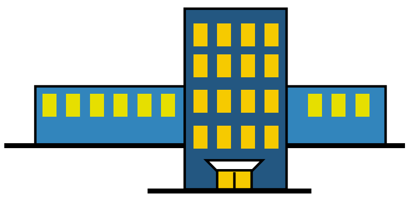
THE APPLICATIONS



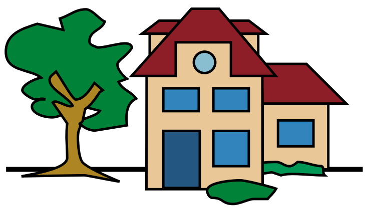
INDUSTRY



COMMUNITY



LARGE BUILDINGS



HOUSES

Better in buildings

Figure 3 (Top): Electric Heat Pump
Most space conditioning heat pump systems installed today are electric. The technology is very well established and benefits from the economics of mass production.

Figure 4 (Centre): Gas Engine Heat Pump
Heat pumps driven by gas engines (GHPs) are now on the market in the USA and Japan. At least 50% more efficient than a gas boiler, GHPs can substantially reduce fuel consumption in areas with a gas supply.

Figure 5 (Bottom): Absorption Heat Pump
Absorption heat pumps are driven by heat from a burner or another hot heat source. They use very few moving parts and thus have the potential for quiet and reliable operation.

For every building, a heat pump system offers an excellent way to meet comfort needs and save energy. In homes, heat pumps have a reputation for reliable operation and high performance - one half of new homes built in the USA and 40% of those in Sweden have a heat pump system. The occupants benefit from low energy bills for heating, and when appropriate, they can use the same system for cooling. *Figures 3 to 5* show examples of the different heat pump systems used.

In large buildings, where there is often both a cooling and a heating need, there is a rising trend in heat pump installations. Applications include offices, hospitals, schools and sports facilities.

Before installing a heat pump it's important to minimize the demand for heating and cooling. Measures such as insulation and careful building design can substantially reduce demand. Taking these measures in combination with a heat pump system will minimize not only the energy consumption, but also the size and cost of the heat pump.

HEATING

Even in countries with the coldest climates, a heat pump system can meet a building's heating needs with a choice of heat distribution systems, including forced air, central (hydronic) heating and under-floor heating. Taking a typical single-family house as an example, *Figure 6* compares the performance of a high-efficiency gas boiler with heat pumps using different heat sources. As shown, a typical day's heating needs of 100 kWh heat can be met with only 33 kWh electricity with a ground or water-source electric heat pump (the latest systems could reduce this to just 25 kWh). A similar gas-fired heat pump system reduces gas consumption by more than a third.

HEAT SOURCES

air-source

Using a fan intake, air-source heat pumps utilize heat from outside air. The efficiency varies with the outside air temperature.

ground-source

Much more heat is contained in the ground, which stores energy from the sun and, unlike air, keeps a fairly steady temperature throughout the year. Pipes laid horizontally or vertically under the surface, transport this heat to the heat pump.

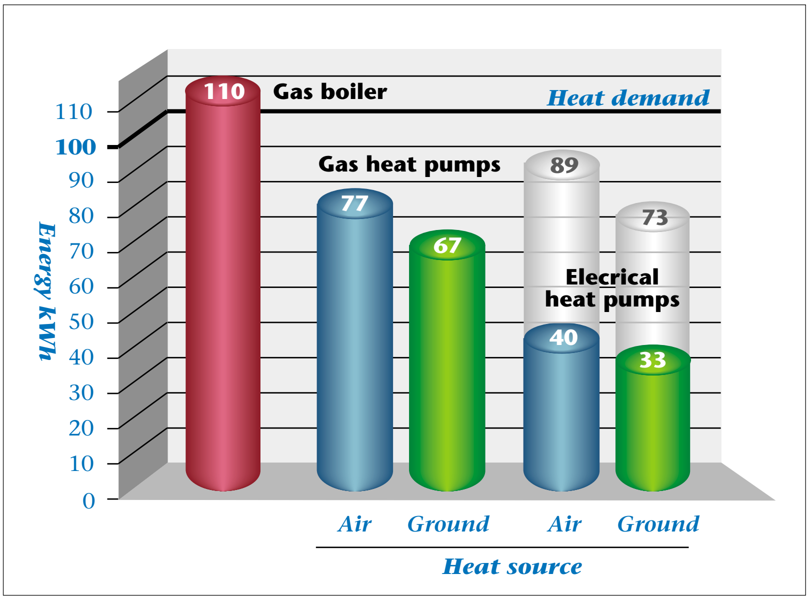


Figure 6:
Comparison of the daily energy consumption when different heating systems are used in a typical single-family home. The coloured bars show the energy consumption at the home. For electric heat pumps, grey extensions to the bars show the energy consumed in power generation assuming a power plant efficiency of 45 %.

water-source

Surface or ground water offers a convenient heat source since it can be pumped directly to the heat pump and has greater temperature stability than air. Even more energy savings can be made by using warm water sources such as industrial cooling water or treated sewage water.

ventilation air-source

Today's most energy-efficient homes are sealed units through which air is circulated at a comfortable temperature and continuously replenished with a fresh supply. A heat pump can extract heat from the ventilation air before it is vented outside. In winter, ventilation air is warmer than outside air so this type of heat pump is more efficient than a conventional air-source heat pump.

COOLING

In many houses and large buildings there is both a heating and a cooling need. This presents an opportunity for heat pumps to save both energy and equipment costs. By combining active cooling with efficient heating in a single unit, a reversible heat pump replaces the separate heating and cooling systems used conventionally. This saves installation and maintenance costs, and reduces energy consumption in the heating season. Even more savings are made in buildings where heat generating equipment such as computers mean that cooling and heating is needed simultaneously. Heat extracted in cooling one room is used for heating another.

HOT WATER

As well as meeting the space conditioning needs of a building, heat pumps can also be used to provide hot water. In North America, hot water heat pumps are popular in applications such as commercial kitchens and laundry facilities where they cool down a warm environment and use the extracted heat to provide water at around 60°C. Hot water heat pumps are also a good way to re-use heat from extracted ventilation air in energy-efficient houses.

Better in industry

The energy demands of industry are vast, representing about one third of all consumption in industrialized countries. Most of this energy ends up as waste heat - heat that's warmer than the natural environment but generally not convenient for industrial use. This not only represents a waste of energy resources, but also poses a major environmental threat, especially to rivers and other natural water resources that are used in cooling. Investment in heat pumps can be a cost-effective way to put this waste heat to better use.

PROCESS INTEGRATION

Industrial processes generally have a number of heating demands (and often cooling too) and have heat available at different temperatures. Methodologies such as process integration and pinch technology can be used to optimize heat use. Where possible, heat exchangers must be used to transfer heat to other, lower temperature applications.

However, heat is often not available in sufficient quantities at the temperature needed. By utilizing waste heat streams at different temperatures, or even low-temperature environmental heat, a heat pump can reduce the energy needs of an industrial process, or provide heating or cooling for space conditioning. Process integration shows how and where a heat pump should be used for maximum benefit. *Figures 7-10* show examples of the most commonly used technologies. □

Figure 7 (top left): *This Compression heat pump saves energy in timber drying by recycling the expelled heat.*

Figure 8 (top right): *This Mechanical Vapour Recompression (MVR) heat pump reduces the energy needs of a concentration process in a beer brewery.*

Figure 9 (bottom left): *This Absorption heat pump supplies a district heating system using energy from high and low-temperature heat streams from a chemical process.*

Figure 10 (bottom right): *This heat transformer is used in a steel mill to provide heat at 130°C for steam raising using cooling water at 90°C. Minimal external power is needed.*

Better for the community

Most human activities result in the release of heat into the environment: buildings, factories, refuse burners, sewage systems and power stations all produce heat which cools down and disappears into the atmosphere without being put to good use. In a better energy system, all energy sources in a society are used as much as possible. A power station, for instance, is only truly efficient when its waste heat is utilized.

OPTIMIZING THE SYSTEM

Energy experts examine the efficiency of a society's energy system by using the concept of energy quality. This quantifies the advantage of using low-temperature heat. For example, using industrial waste heat for space heating is more efficient than burning gas. The concept shows how to make best use of available heat to get an optimized system and minimal fuel use. Because heat pumps can utilize low-temperature heat sources such as treated sewage water, ventilation air, or environmental heat, they have an important role to play in system optimization. Heat pumps can also optimize the use of much hotter heat sources, such as from refuse burning or industry. For example, absorption heat pumps can use this heat to supply district heating or cooling systems. *Figure 11* illustrates the role heat pumps can play in an optimized energy system.

BALANCING ENERGY DEMANDS

An optimized energy system can exploit a community's need for both heating and cooling. Heat pumps can contribute by taking heat from refrigeration or air-conditioning systems and using it to supply hot water or heating. Often, heating and cooling is needed at different times of the year. Ground-source heat pumps use the heat stored in the ground during the cooling season for winter heating.

Thermal storage is also useful to balance the difference in energy demands between day and night. Heat pumps can use water or ice to store heat or cold energy made overnight for use during the day. Electric utilities benefit from a less varied demand (the technique is known as load levelling) and often offer financial incentives to the end-user.

BENEFITING SOCIETY

With its applicability in both the building and the industrial sectors, the heat pump looks set to play a major role in meeting the heating and cooling needs of society. And since these applications currently consume a significant proportion of the world's fossil fuel reserves, heat pump technology can make a major contribution to the limitation of associated environmental problems such as global warming.

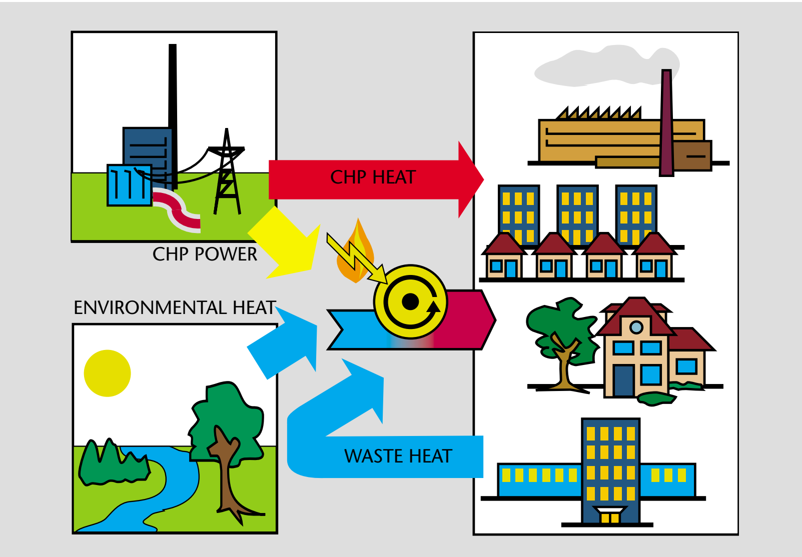


Figure 11:
By utilizing both waste and environmental heat, heat pumps can play a central role in an optimized energy system

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the 23 IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology, and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of 40 Implementing Agreements, containing a total of more than 80 separate collaboration projects.

The IEA's address is:
2, Rue André-Pascal
75775 Paris Cedex 16, France.

IEA Heat Pump Centre

The nine member countries of the IEA Heat Pump Centre (HPC) form a network for exchanging information on heat pump technology. By increasing awareness and understanding worldwide, the HPC aims to accelerate the implementation of heat pump technology and thereby optimize the use of energy resources for the benefit of the environment.

Member countries

Austria, Canada, Italy, Japan, The Netherlands, Norway, Sweden, Switzerland, USA.

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