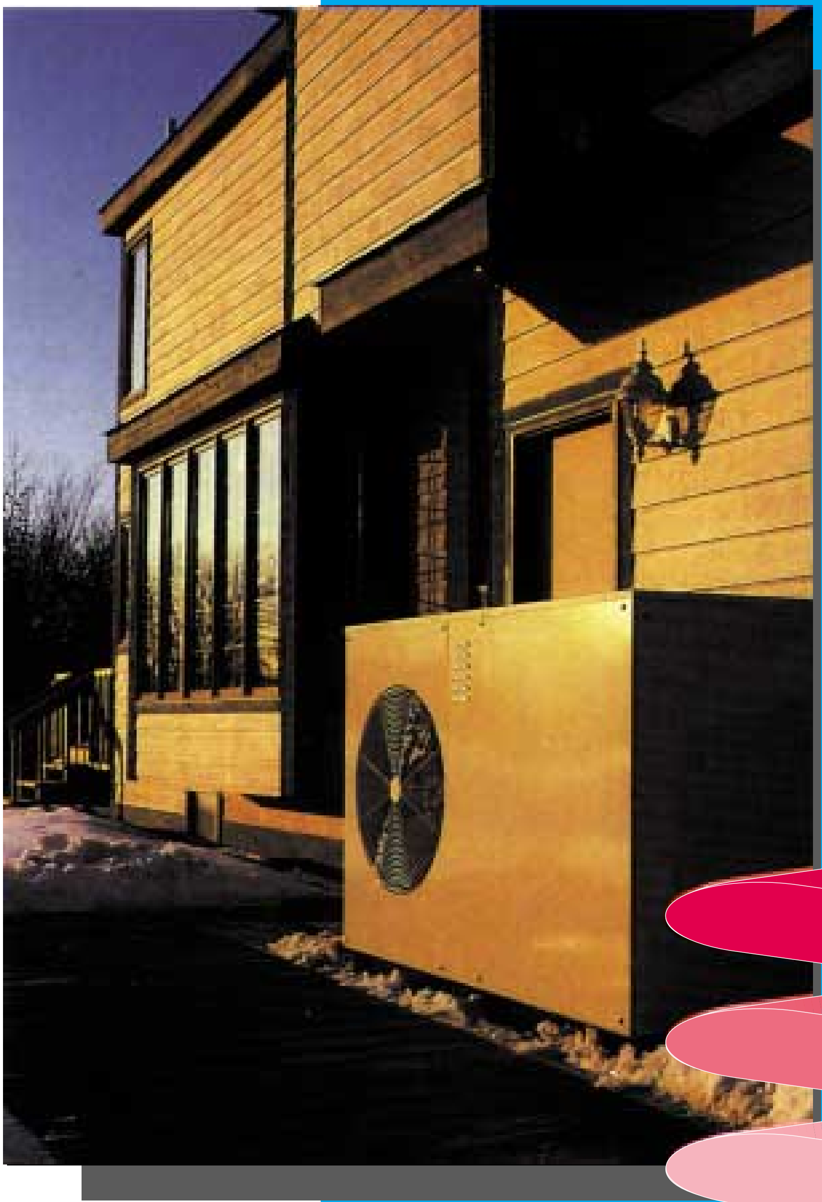


Heat Pumps

An Opportunity for Reducing the Greenhouse Effect

IEA
OECD

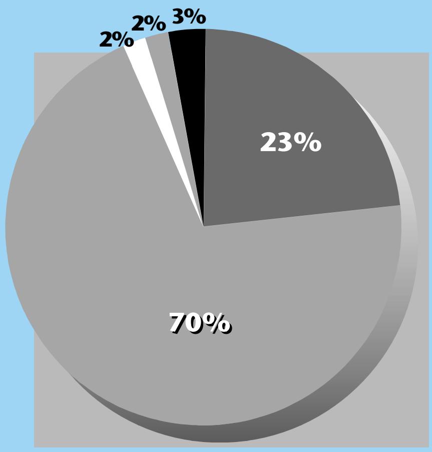
The Greenhouse Effect

At 150 million km from its heat source, the sun, our planet should have a mean surface temperature of only -18 °C - a temperature which would make much of the world uninhabitable. Fortunately, a natural phenomenon, known as *the greenhouse effect*, traps heat near the Earth's surface to raise the surface temperature to the comfortable level of +15 °C that we experience today. The effect is caused by a number of trace gases that are found naturally in the Earth's atmosphere, in a region known as the troposphere. These gases, known as greenhouse gases, are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Their contribution to the *"natural"* greenhouse effect is indicated in *Figure 1a*.

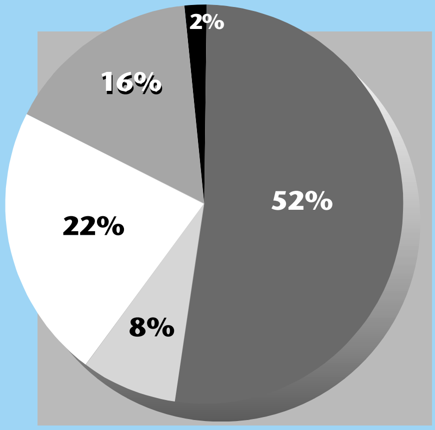
Global Warming

Records suggest that since the industrial revolution, human activities, including the burning of fossil fuels and deforestation, have caused surface temperatures to rise by about 2 °C. This effect is known as global warming and is caused by the gases shown in *Figure 1b*. Note that the natural greenhouse gases are joined by additional CO_2 and man-made CFCs (chlorofluorocarbons). Today, the concentration of greenhouse gases continues to rise, and with it global warming, at a rate estimated to be at 0.4 °C or more per decade. Although this may not seem very much, it should be remembered that a difference of only five degrees separated ice ages from interglacial periods.

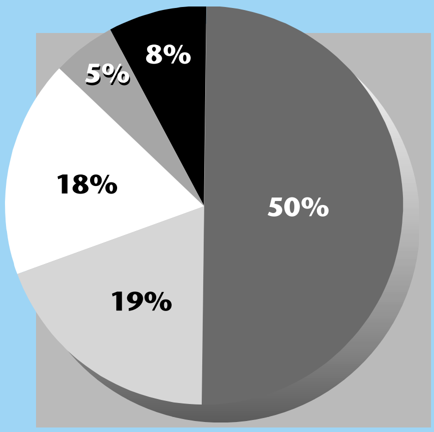
At any one time, the contribution of gases to the instantaneous increase in the greenhouse effect can be found. *Figures 1c* and *1d* illustrate this for 1987, and the year 2000 with the assumption that CFCs are phased out by then. Clearly, the phasing out of CFCs is significant. However, unless effective measures are taken, the emission of the two most significant greenhouse gases, CO_2 and CH_4 will continue to grow and is expected to more than compensate for the benefit of the CFC ban and cause additional global warming.



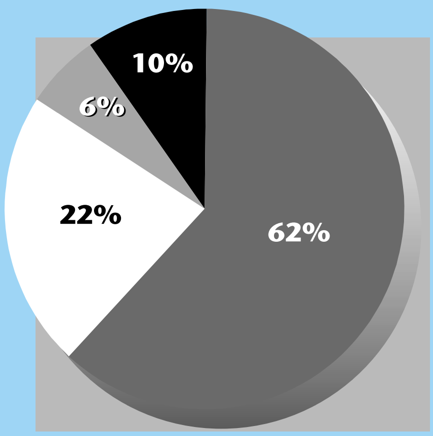
1a: Natural greenhouse effect.



1b: Global warming caused by man up until 1988.



1c: Instantaneous increase in 1987



1d: Instantaneous increase in 2000

Figure 1a,b,c,d: Contribution of greenhouse gases to global warming.

LEGEND

- Water
- CFC
- Ozone
- Nitrous oxide
- Methane
- Carbon dioxide

an Opportunity

"As a result of the increasing concentrations of greenhouse gases, it is now believed that in the first half of the next century a rise of global mean temperature could occur which is greater than any in man's history".

So concluded the WMO international conference[1] in Austria in 1985, which was a landmark in the perception of the greenhouse effect. Today, there is mounting evidence supporting the forecast of a rapidly rising global surface temperature - *global warming*.

Opinions vary on the likely consequences of global warming, but climatic models show that many areas of the world will suffer from the catastrophic effects of floods, storms and droughts with far-reaching environmental, economic and social consequences. It is clear that the concentration of the greenhouse gases which contribute to global warming is increasing and that efforts must be taken to curb this increase.

The greenhouse effect, and its significance for global warming is explained on the facing page.

With a large proportion of man-made greenhouse gases resulting from burning fossil fuels to generate energy, policies to reduce global warming must include measures to reduce energy consumption.

Among the technologies available to reduce energy consumption, heat pumps stand out because they have high efficiency, and are applicable in the highly significant (in energy terms) area of building and industrial heating. A policy to increase the use of heat pumps could significantly reduce the greenhouse effect. Heat pumps are thermodynamic devices similar in operation to domestic refrigerators. By making use of available thermal sources in our surroundings, heat pumps offer a very energy efficient system for heating and cooling in many applications *(see Figure 2)*.

But by how much is the emission of greenhouse gases reduced by a heat pump? The question is complex since many factors influence emission levels. The answer is vital to policy makers who must spread limited resources between a multitude of options.

To help find the answer, the *IEA Heat Pump Centre (HPC)* set out to quantify the impact of heat pumps on the greenhouse effect by conducting an analysis using data based on studies of heat pump applications from around the world.

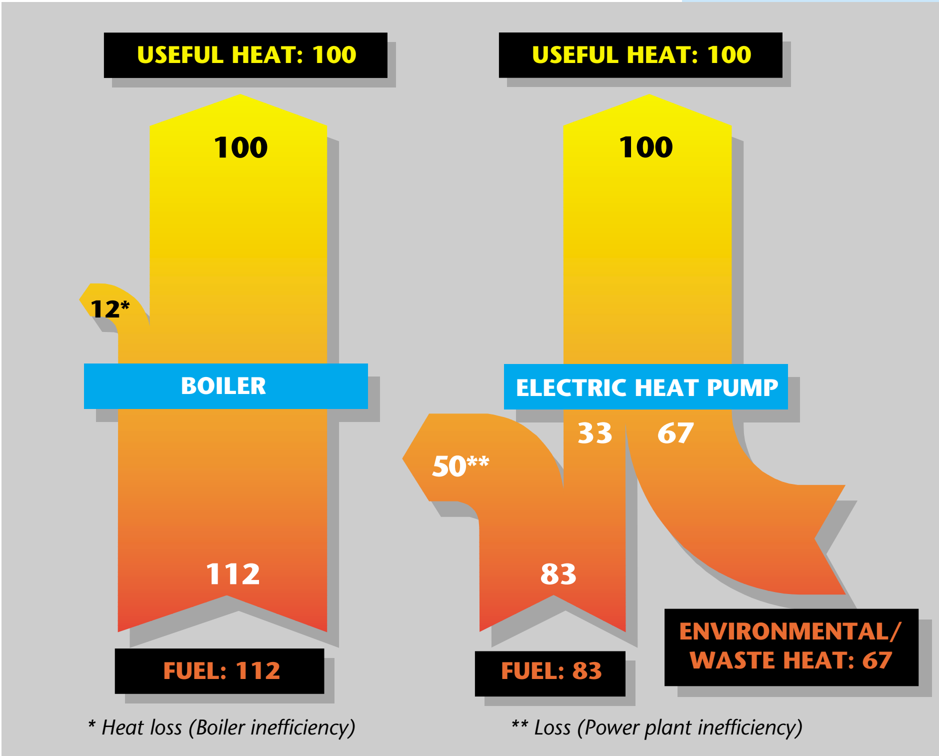


Figure 2: How an electric heat pump reduces fuel consumption by using environmental/waste heat. (Assumptions: same fuel for boiler and power plant, boiler efficiency 90%, electricity generation efficiency 40%; heat pump performance factor: 3.)

The findings of this analysis, are published in a report[2] and summarized in this brochure. The analysis found that heat pumps in use today already contribute significantly to reducing the emission of greenhouse gases and that heat pump technology offers a major opportunity for further reductions.

[1] *World Meteorological Organization (WMO) International Conference on the Assessment of the Role of Carbon Dioxide and of other Greenhouse Gases in Climate Variations and Associated Impacts.*
[2] *"The Impact of Heat Pumps on the Greenhouse Effect". Ordering details are given on page 11 of this brochure.*

the Options

GLOBAL WARMING

It is now widely recognized that a policy to limit global warming must concentrate on reducing the emission of CO_2 due to the burning of fossil fuels. In 1988, this concern encouraged the Toronto Conference to propose a 20% reduction in world CO_2 emission rates by the year 2005, and a 50% reduction by 2050. More binding agreements are expected in the near future.

In working towards the aims of these agreements, a range of options are open to policy makers - *see facing page*.

Choosing the Best Option

Policy makers must decide on the most effective option to reduce the greenhouse effect. Resources should be focused on the policies offering the best possible return on the money invested, in terms of CO_2 reductions. To do this, policy makers need to be able to evaluate the effectiveness of the available options.

Below: Installation of an industrial absorption heat pump in a steel works.

THE HEAT PUMP OPTION

Heat pumps reduce CO_2 emissions by supplying heat energy with minimal energy consumption. Of all the heating systems available, only a heat pump can supply more energy than it consumes. This seemingly impossible feat is realized because a heat pump utilizes heat from its local environment. Even during winter periods, air, ground and water outside a building, although relatively cold compared to the desired room temperature, contain useable heat energy. A heat pump can extract this energy and deliver it to the building at the desired temperature.

The centre pages of this brochure outline the different types of heat pump available and their operation.

The HPC's analysis on *"The Impact of Heat Pumps on the Greenhouse Effect"* uses global experiences on heat pumps to allow policy makers to evaluate the effectiveness of the heat pump option in their own area.

A GLOBAL ANALYSIS

Through its international network, the HPC has been able to examine the results of heat pump studies from all over the world. Most of the studies looked at the impact of heat pumps for building heating. Less information is available on industrial applications - an area where the use of heat pumps could be highly significant. To provide better information on this important application area, the *IEA Heat Pump Programme*[3)] has recently begun a task entitled *"Global Environmental Benefits of Industrial Heat Pumps"* which will examine and widen the knowledge base on this topic.

The analysis focused on studies on reducing greenhouse gas emissions by replacing conventional building heating systems with heat pumps. By combining the results of many studies, the analysis draws on the widest available knowledge base. These experiences include various types of heat pumps operating under different conditions. The results were analyzed to allow, for the first time, the impact of heat pumps on the greenhouse effect to be estimated using the experiences of a global range of local circumstances.

The Knowledge Base

The analysis looked at some 46 studies relating to the impact of heat pumps on the greenhouse effect. The studies were made in Austria, Canada, Germany, Japan, Norway, Sweden, Switzerland and the USA. There were also studies by the *World Energy Council (WEC)* and the *International Institute of Applied Systems Analysis (IIASA).*

3) The IEA Implementing Agreement on Heat Pumping Technologies.

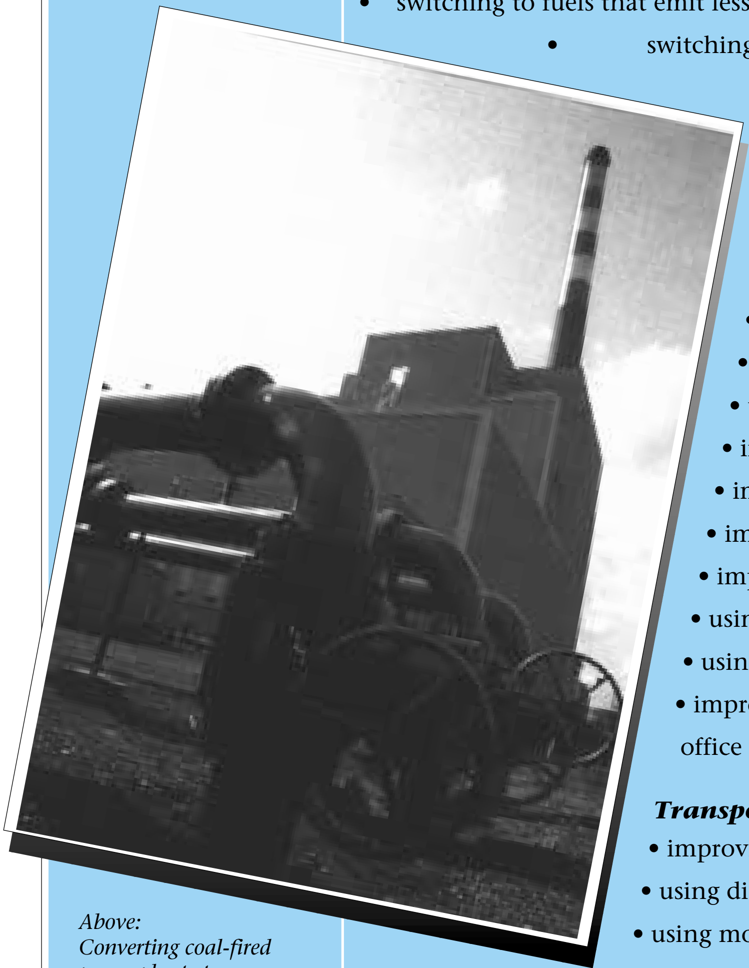
Measures for limiting CO_2 Emissions

Measures to reduce CO_2 emissions from the burning of fossil fuels fall into two categories, namely:

- reducing CO_2 emissions from power generation
- reducing CO_2 emissions from the end-use of energy.

Power Generation
Measures include:

- improving power generation and distribution efficiency
- using combined heat and power (CHP) (also known as cogeneration) *
- using CO_2 removal techniques
- switching to fuels that emit less CO_2 (e.g. from coal to gas)
- switching to non-fossil fuel energy sources such as nuclear, hydro, wind and solar energy.



Above:
Converting coal-fired power plants to gas reduces CO_2 emissions.

End-Use
Measures include:

Buildings:

- using district heating *
- improving building design
- improving insulation
- using heat recovery in ventilation *
- improving lighting efficiency
- improving space heating efficiency *
- improving water heating efficiency *
- improving cooling efficiency *
- using renewable energy sources *
- using local thermal sources including waste heat *
- improving the efficiency of household goods and office equipment.

Transport:

- improving efficiency
- using different fuels
- using more mass transport systems

Industry:
The diverse needs of industry offers a vast range of energy saving options. The more significant measures include:

- heat recovery *
- improving steam raising efficiency
- improving process efficiency
- using industrial design techniques such as process integration and pinch technology *

** These measures may include the use of heat pumps.*

Heat Pump Technology

Heat Pump Types

The majority of heat pumps work on the principle of the *vapour compression cycle*. These compression heat pumps may be driven by electric motors *(Figure 3a)* or gas engines *(Figure 3b)*. Gas engine heat pumps are not as common even though they can achieve a high efficiency when the waste heat from the engine is recovered.

Another type of heat pump uses the *absorption cycle (Figure 3c)*. This more complex system is driven by heat energy instead of a motor or engine. Absorption heat pumps are often fired by gas, but any other heat source can be used - in industrial applications, absorption heat pumps can be driven by waste heat sources. Current research into high-temperature operation is expected to widen their application further. For building applications, the cost of absorption heat pumps needs to be reduced and performance improved before they will find widespread use.

Heat Sources

The difference between the temperature of the heat source and the desired temperature is known as the *temperature lift*. The most energy-efficient performance is achieved when the temperature lift is small. In general, a higher energy efficiency is achieved from ground- or water-source heat pumps than when outside air is used as the heat source. The highest efficiency is achieved when waste heat sources are used. Waste heat sources include:

- *sewage or factory effluent*
- *exhaust air from machinery or electronic equipment*
- *ventilation air from buildings.*

Above: Gas engine driven heat pump for the Amsterdam World Trade Centre.

Applications

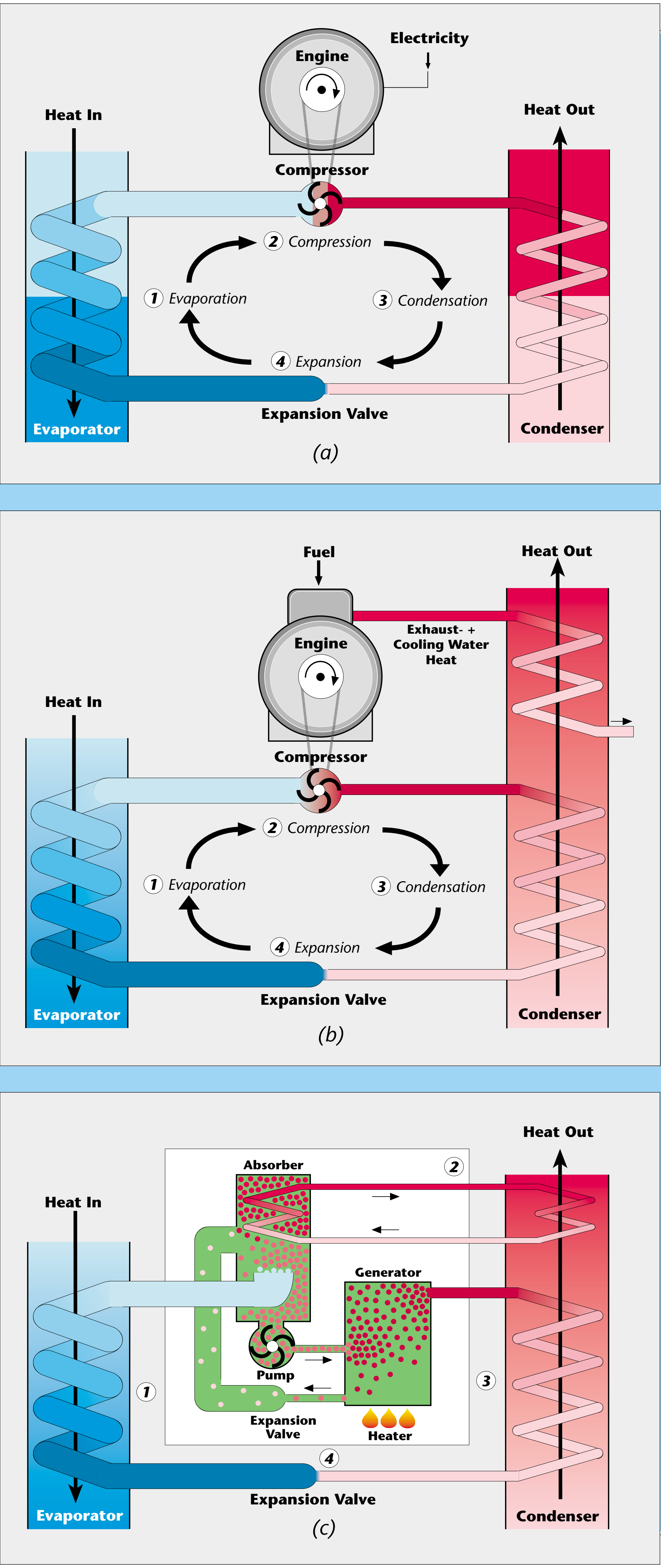
Heat pumps are used for heating and cooling in both the building and industry sectors.

Industry

Industrial processes need heat (and often cooling too) at different temperatures. In many situations, heat pumps can raise the temperature of waste heat so it can be used in another process. This not only reduces energy requirements, it also helps the local environment by reducing the emission of waste heat streams and the demand for cooling water.

Buildings

In buildings, heat pumps can provide space conditioning and supply hot water. Both forced air and hot/cold water (hydronic) space conditioning may be supplied by a heat pump. In warm climates, reversible heat pumps provide either heating or cooling according to the season.



HOW A HEAT PUMP WORKS

A heat pump transfers heat from a low temperature heat source to a higher, useful temperature. Most heat pumps do this by circulating a fluid through four main components *(Figure 3)*. They make use of the fact that the boiling temperature of a fluid rises with increasing pressure.

1. Evaporator

A volatile liquid, known as the working fluid or refrigerant, evaporates, taking up heat from a low termperature heat source.

2. Compressor

Here the working fluid vapour is compressed to a high pressure and temperature.

In the absorption heat pump shown, compression is achieved thermally rather than mechanically. The working fluid vapour is absorbed in a solution (this absorption process gives off heat); the solution is pumped to a higher pressure and then heat is applied in the generator to release working fluid vapour at high pressure and temperature.

3. Condenser

Here the compressed vapour condenses, and gives off useful heat. Due to the higher pressure the temperature of condensation is higher than the temperature of evaporation.

4. Expansion valve

Here the working fluid is reduced to a low pressure, and returns to the evaporator.

Figure 3: Three types of heat pumps: an electric driven compression (a), an engine driven compression (b), and an absorption heat pump (c).

the Evidence

To make an objective comparison of heat pumps and conventional fossil fuel-fired boilers, the analysis examined information on the following:

- *CO_2 emissions from fossil fuel-fired boilers*
- *CO_2 emissions from directly-fuelled (gas and oil-driven) heat pumps*
- *CO_2 emissions from electric heat pumps*
- *emissions from heat pump working fluids.*

CO_2 FROM FOSSIL FUEL-FIRED BOILERS

The CO_2 emission from a conventional boiler depends on the chemical composition of the fuel and on boiler efficiency. These two factors determine the mass (in kg) of CO_2 emitted for a given amount of heat (in Megajoules [MJ]).

Figure 4 indicates the range of values for CO_2 emitted from conventional boilers in kg/$MJ_{thermal}$.

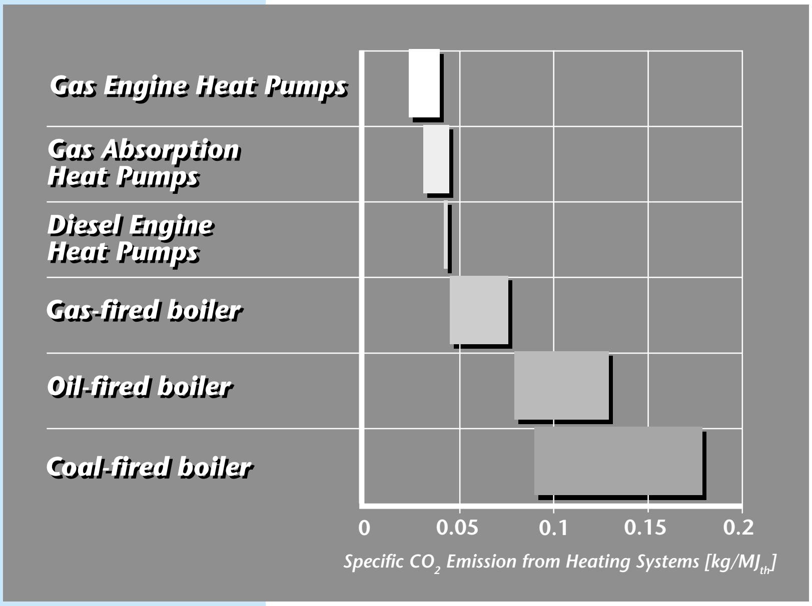


Figure 4: Comparison of the range of CO_2 emissions from various directly fuelled heating systems.

CO_2 FROM DIRECTLY-FUELLED HEAT PUMPS

As explained earlier, a heat pump provides more energy, in the form of useful heat, than it receives. For gas and oil-driven heat pumps, this means that the amount of CO_2 emitted is always less than that from a conventional boiler using the same fuel. This effect is graphically illustrated in Fig. 4. Even the most modern condensing boilers, which can achieve efficiencies close to 100% by using the condensation heat of the water in exhaust gases, produce more CO_2 than gas or oil-driven heat pumps.

CO_2 FROM ELECTRIC HEAT PUMPS

CO_2 emission from electric heat pumps is more complicated. CO_2 is not emitted at the point of use. It depends on how electricity is generated. Electricity from nuclear energy and renewable energy (hydro, solar, wind, wave etc.) does not generate CO_2. Burning fossil fuels to generate electricity emits CO_2 according to the type of fuel burnt.

Electric Heat Pump Performance

The Seasonal Performance Factor (SPF) allows electric heat pumps to be compared independently of how electricity is generated. The SPF expresses the performance of an electric heat pump and is defined as:

$$SPF = \frac{\text{Heat Output (MJ)}}{\text{Electrical Energy Input (MJ)}}$$

and averaging this value over the operating period of the heat pump. The resulting SPF value depends on the equipment efficiency and the temperature lift - the difference between the desired temperature supplied by the heat pump (e.g. the air in a room) and the temperature of the heat source.

An SPF of 3.0

The studies examined in the analysis indicate that an SPF of 3.0 can be achieved with currently available electric heat pumps using ground or water as heat source, even in countries with a cold climate.

CO_2 from Electric Power Generation

Most countries generate electricity with a mixture of both fossil and non-fossil fuel energy. Taking *OECD* countries in total, the share of electricity from fossil fuels is about 56%. The local electricity generation mix in different countries varies enormously and with it the amount of CO_2 emitted for every kilowatt-hour (kWh) of electricity generated.

For example, in Austria where 70% of electricity is generated by hydropower, the rate of CO_2 emission for generating electricity is about half that of Japan, where over 60% of electricity is from fossil fuels. The electricity mix is a crucial factor for determining the CO_2 emissions from an electric heat pump. But with the introduction of modern efficient power stations, and as energy policies turn to non-fossil fuels, the CO_2 emissions from each kWh of generated electricity is likely to diminish in most countries.

EMISSIONS FROM HEAT PUMP WORKING FLUIDS

A heat pump uses a working fluid (also known as *the refrigerant*) to transfer heat from the heat source to where it's needed. Until recently, the most commonly used working fluids in compression heat pumps were CFCs. By their nature, working fluids are highly volatile liquids that will rapidly evaporate into the atmosphere when exposed. Some heat pumps lose working fluid during operation. Leakage can also occur when a heat pump is serviced and when it is dismantled at the end of its working life.

Leakage of these apparently inert gases was not considered to be harmful, either to health or to the environment. But, in 1976 when the effect of CFCs on the ozone layer was first postulated, the environmentally friendly image of the heat pump, as a tool for limiting the consumption of energy resources was threatened. This situation worsened when data was uncovered suggesting that CFCs contribute to the greenhouse effect.

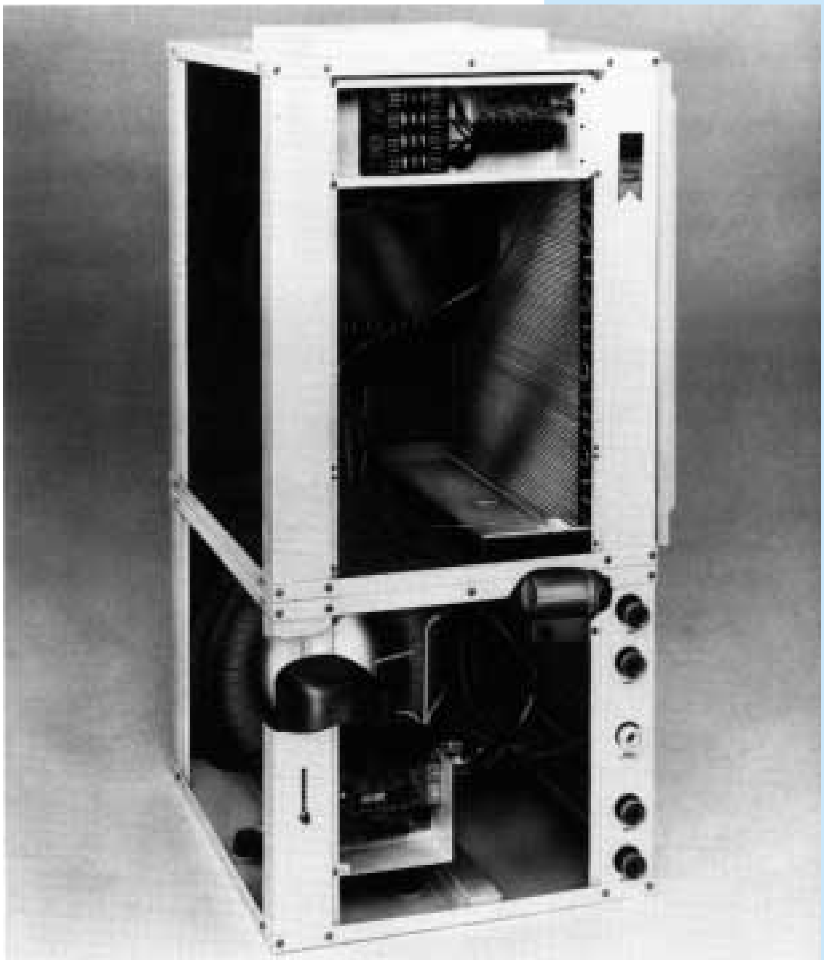
Since these revelations, the environmental consequences of heat pump working fluids have been substantially reduced by taking the following measures:

- *converting heat pumps for operation using less damaging working fluids such as those known as HCFCs and HFCs*
- *ensuring that heat pump working fluids are not vented to the atmosphere during servicing or shut down*
- *improving heat pump design to reduce the release of working fluid during operation.*

A Net Gain for the Environment

Even with these measures, currently available heat pump technology has both favourable and unfavourable influences on the greenhouse effect. One purpose of the HPC's analysis was to determine whether the detrimental effects of working fluid emissions are significant with respect to the environmental benefits associated with the energy saved by using heat pumps.

Data uncovered by the HPC's analysis shows that, with all leakage factors taken into account, compression heat pumps for heating buildings lose working fluids at a rate of about 6% per annum. This value is likely to significantly reduce with the introduction of new equipment with tighter seals and the implementation of stricter maintenance procedures to prevent venting. Furthermore, the impact of this loss will reduce with the accelerated introduction of working fluids with negligable greenhouse effect. Analysis shows that, in comparison with the CO_2 emitted by conventional fossil fuel-fired boilers, the impact of a heat pump's working fluid on the greenhouse effect is negligible. So the benefit from the reduction of CO_2 emissions by replacing conventional heating equipment with heat pumps far outweighs the negative effects from working fluid emissions. The result is a net gain for the environment.



Above: Modern electric residential heat pump using an HCFC working fluid.

the Verdict

Directly-fuelled Heat Pumps

The evidence of the studies examined in the HPC's analysis suggests that gas and oil-fired heat pumps have a high potential for reducing the emission of greenhouse gases. Typically, a gas engine heat pump emits 30% less CO_2 than a modern condensing gas boiler. However, directly-fuelled heat pumps are not widely used today and a drive to commercialize this type of equipment is needed before they can make a significant impact on the reduction of greenhouse gas emissions.

Electric Heat Pumps

Figure 5 shows the percentage reduction of CO_2 emissions achieved when a conventional gas, oil or coal-fired boiler for room heating is replaced by an electric heat pump. Flags indicate how this reduction varies between countries according to how electricity is generated.

Figure 5 uses normalized data obtained from the studies. An SPF of 3 - shown by the studies to be achievable with current equipment, is assumed. The effect of emissions from working fluids is considered to be negligible. By combining data from all the studies examined, Fig. 5 gives a fair picture of the achievable CO_2 savings with today's technology and allows a number of conclusions to be drawn:

Replacing a coal or oil-fired boiler by an electric heat pump will always reduce CO_2 emissions, whatever the local electricity mix. However, in

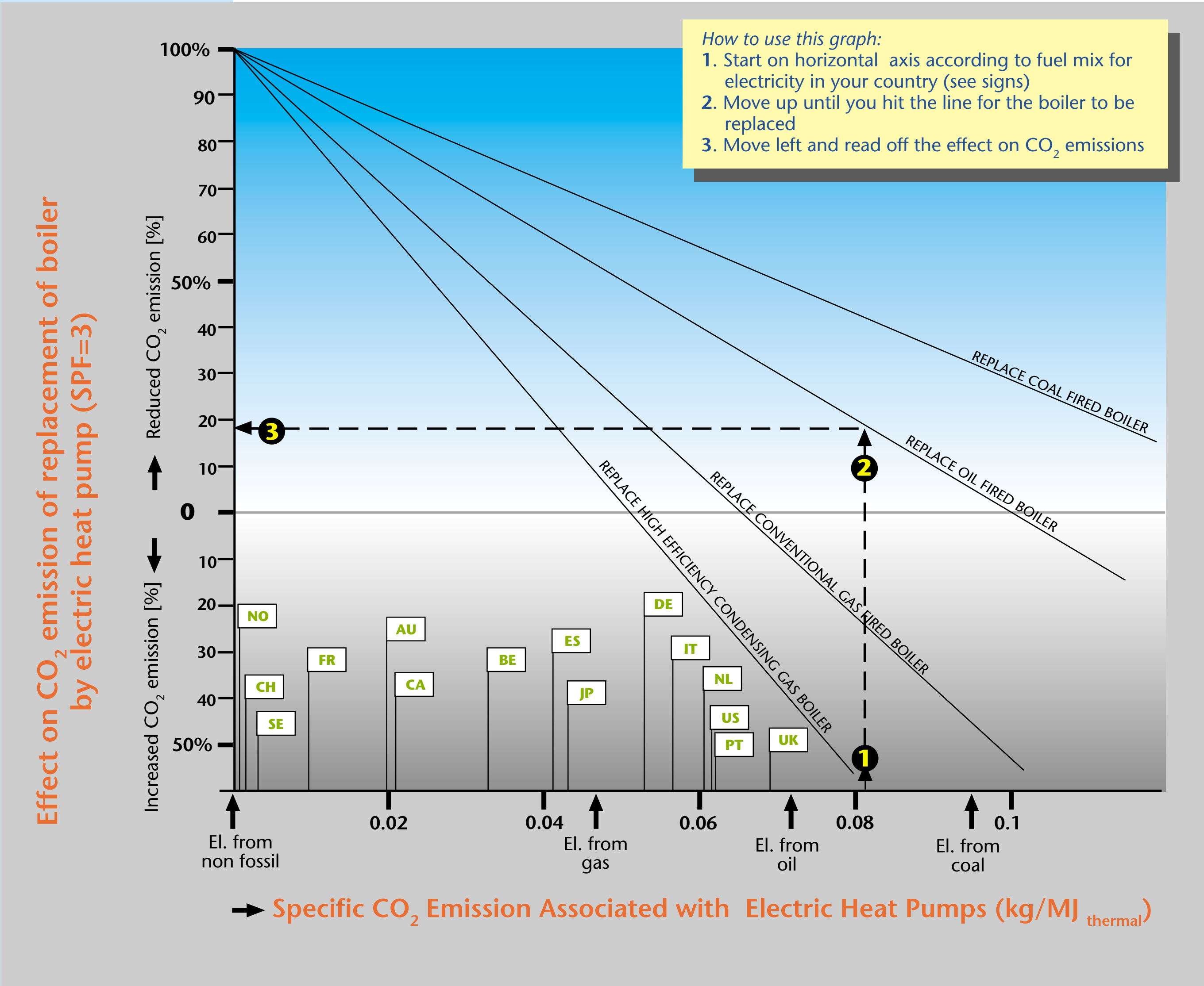


Figure 5: Impact on CO_2 emission when replacing a boiler by an electric heat pump with SPF-3 (boiler emissions averaged over all studies).

countries where a large proportion of electricity is generated from fossil fuels, better savings in CO_2 emissions can be made by using gas or oil-driven heat pumps.

If the conventional heating system is a gas boiler, electric heat pumps can only reduce CO_2 emissions if a substantial proportion of electricity is generated without burning fossil fuels.

In countries such as Norway, Sweden, France and Switzerland, that generate virtually CO_2-free electricity from nuclear or hydropower, electric heat pumps can offer huge reductions in CO_2 emissions when replacing fossil fuel-fired boilers, even in comparison to the most modern condensing gas boilers.

Two other conclusions were drawn from the analysis study:

30% Less CO_2 When Using the Same Fuel

Many of the studies examined compared CO_2 emissions from space heating boilers with those from heat pumps using electricity generated from the ***same fuel****. In this situation, a heat pump offers an emissions reduction of about 30%. This can be seen in Fig. 5: For example using electricity from oil saves 28% when replacing an oil boiler.*

Although this situation rarely occurs in reality, this conclusion provides a good base mark for a rule-of-thumb calculation of potential emission reductions from using electric heat pumps.

Emissions Reduction Potential

Several studies estimated the potential reduction in total CO_2 emissions in their country if heat pumps were used to their full potential:

- *the economic potential is estimated to be up to 4.2%*
- *the technical potential is estimated to be up to 9%.*

Clearly, heat pump technology offers a major opportunity for reducing the greenhouse effect. □

Above: A gas engine-driven heat pump in a residential application.

the Outlook

Current development work indicates that heat pump performance is likely to improve over the coming years. Improvements to component design, plus the exploitation of waste heat sources such as sewage water, will raise heat pump performance above the values found in this analysis and further reduce emissions of greenhouse gases. In contrast, the efficiency of modern gas-fired boilers is close the theoretical maximum, so a significant decrease in greenhouse gas emissions from conventional heating systems cannot be achieved. And, for electric heat pumps, the predicted downward trend in CO_2 emissions from electricity generation among OECD countries means that they will be increasingly valuable as a measure for reducing the greenhouse effect.

Inquiries

If you have questions on heat pump issues contact the HPC and benefit from the HPC's international knowledge base. (*Information on back cover*)

Analysis Report

"The Impact of Heat Pumps on the Greenhouse Effect" was published in September 1992 and can be purchased from the HPC *(Price NLG 80,-)*. The main findings are summarized in *Analysis Summary Report ASR1* which is available free of charge.

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 22 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 35 Implementing Agreements, containing a total of more than 60 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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Cover design, lay-out and illustrations: Jo Engelen, Kerkrade, the Netherlands

HPC-BRI October 1992