heat pump programme

IEA
OECD

INDUSTRIAL HEAT PUMPS

A Means to Mitigate Global Industrial Emissions

What they are

Figure 1a: Closed-Cycle Compression

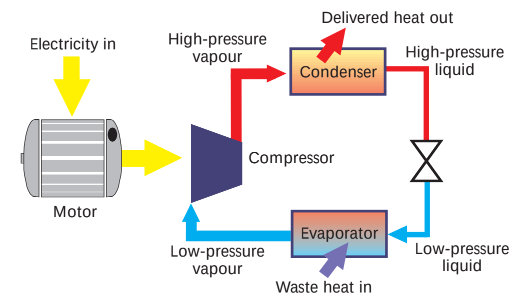


Figure 1b: Mechanical Vapour Recompressor (With Condenser)

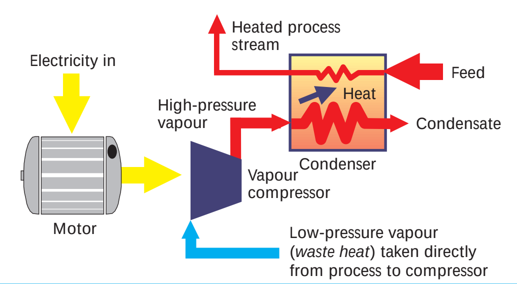


Figure 1c: Thermal Vapour Recompression

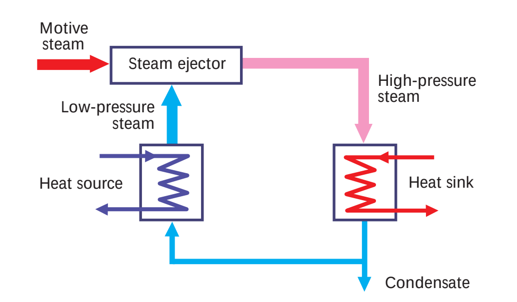


Figure 1d: Absorption Heat Pump

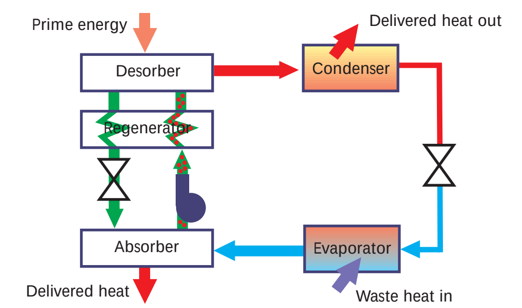
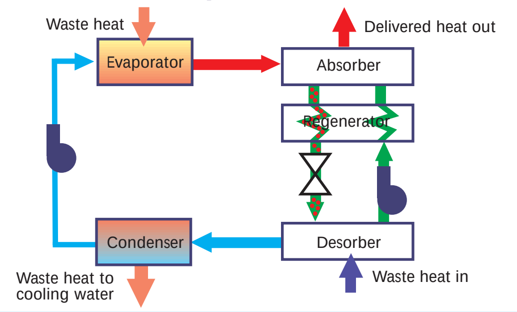


Figure 1e: Absorption Heat Transformer



Industrial heat pumps (*IHPs*) perform a similar function to the space conditioning heat pumps that are sold in large numbers in Japan and the USA in that they transfer heat to a higher temperature in a process similar to that of a domestic refrigerator. However, IHPs are especially designed for industrial applications and come in many variations. The five primary configurations are shown on this page.

Compression

Technically, the closed-cycle compression machines (*1a*) are most similar to the conventional space conditioning heat pumps and domestic refrigerators. Indirect heat exchange takes place with a refrigerant undergoing phase changes circulating in a closed loop.

In vapour recompression machines a process vapour stream, typically steam or hydrocarbon, is directly compressed to upgrade its pressure and temperature. The upgraded vapour can, for instance, give off its heat in a condenser to another process stream. For compression, a mechanical compressor may be used (*1b*), but steam ejectors are also common (*1c*).

Absorption

Absorption machines use a working fluid, and are thus akin to the closed-cycle compression machines. However, here compression is achieved by a heat driven absorption process. In the absorption heat pump (*1d*), working fluid vapour is absorbed by a second fluid in the absorber, giving off useful heat. The working fluid/absorbent mixture is pumped to a higher pressure (this requires relatively little energy), and then prime energy is used to boil off the working fluid at high pressure and temperature in the desorber. Additional useful heat is then available at the condenser.

The absorption heat transformer (*1e*) works on the same absorption principle, but in this configuration the highest temperature is reached in the absorber. Thus the heat transformer can be driven by waste heat of an "intermediate" temperature supplied to the desorber, producing high temperature useful heat in the absorber, and low temperature waste heat that has to be cooled away in the condenser.

Based on these five primary types, and taking into account different IHP drives (e.g. electric motors, diesel/gas engines, steam turbines, waste heat) and refrigerants, there are well over 50 IHP configurations. In some industry sectors, IHPs are often not recognized as "heat pumps", but are more commonly referred to as steam ejectors (TVRs), mechanical vapour recompressors (MVRs), or dehumidification kilns (closed-cycle compression IHPs).

Why use them

Mitigating the pollutant emissions associated with fossil fuel combustion is becoming a worldwide priority. The affect of sulphur dioxide or nitrous oxide emissions, which cause acid rain, can already be witnessed. And there is growing evidence that methane and carbon dioxide emissions could radically alter the global climate.

Reducing emissions

As one of the largest consumers of fossil fuels, the industrial sector is a logical focus for reducing combustion-based emissions. A cost-effective strategy to reduce this sector's fuel consumption is to recover process waste heat and use it to meet heating requirements that would otherwise be met by burning fossil fuels.

Industrial heat pumps (IHPs) are a very useful tool for recovering industrial waste heat. While heat exchangers can often be used to transfer waste heat to lower temperature applications, heat pumps have the unique ability to upgrade this heat for use in a higher temperature process. A variety of technologies are available to do this. The main categories of IHP are outlined on the opposite page.

Many other benefits

IHPs are now well established in industry, and the operating experience from thousands of installed units have shown that IHPs are one of the most cost-effective alternatives for improving industrial energy efficiency and environmental performance. Furthermore, they have been shown to be reliable and also versatile, meeting many different needs and being compatible with other energy saving options. The major benefits of IHPs are highlighted in the box on this page.

Major benefits of IHPs

- *They reduce the consumption of fossil fuels, saving resources, lowering fuel costs and reducing harmful emissions*
- *They are built using commercially proven technologies, such as compressors, condensers, evaporators, electric motors, and pumps*
- *They can be used in both new and retrofit situations*
- *They have a range of design options, including direct and indirect heat exchange, electric motor or gas/ diesel engine drives, and vapour compression or absorption designs*
- *They are applicable to numerous industrial processes and unit operations*
- *They can be used to provide process heat across a wide and growing range of process temperatures*
- *They recover heat from process heating and cooling operations and thereby reduce both process heating and cooling costs and investments*
- *They are compatible with other industrial waste heat recovery options (e.g. cogeneration, waste heat recovery boilers)*

Recognizing the potential significance of IHPs, eight IEA Heat Pump Programme member countries (see back cover), joined forces in the collaborative project "Global Environmental Benefits of Industrial Heat Pumps" - or Annex 21 of the IEA Heat Pump Programme. This brochure is based on the results of that project. The brochure highlights the worldwide experience with the technology, discusses potential benefits from a global, a country-by-country, and an industry perspective, and closes with some suggestions to widen the application of IHPs.

Below: Distillation is a common application for IHPs. This one is for whisky production in the UK.

Where they are

Industrial heat pumps are already extensively used. They use proven technologies and provide wide-scale benefits for some industrial processes. Additional benefits can be achieved simply by their wider deployment.

Country wide

Part of the collaborative project Annex 21, was a survey of IHPs in the eight participating countries. The survey found that more than 4,600 IHPs are now in use in these countries. The division per country is shown in *Figure 2a*.

Industry wide

The survey also found that while IHPs are employed in all major industries, the largest number of installations are in the lumber industry. Their other major applications to date are in food, chemicals, petrochemicals/ petroleum refining, pulp and paper, and textiles (*Figure 2b*). Heat pumps are also now found in electric utilities and water/ sewage treatment plants (e.g. waste concentration).

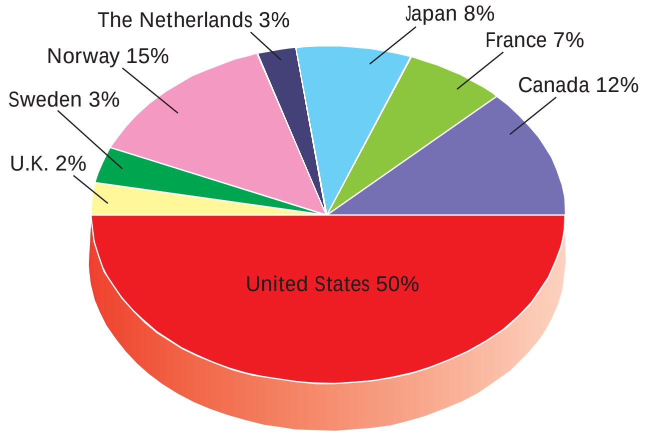
Within these industries, IHPs are being applied for a variety of industrial operations. Some of the more common ones are highlighted in the box.

Industrial operations suitable for IHPs

- *cooking*
- *dehumidification*
- *distillation*
- *drying*
- *evaporation/concentration*
- *fired-heaters*
- *furnaces/ovens*
- *kilns*
- *process water heating*
- *refrigeration (heat recovery from condensers)*
- *waste heat recovery/district heating*

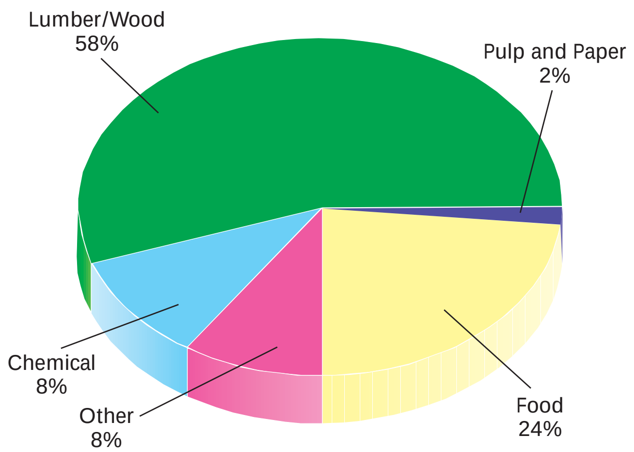
While it is encouraging to see that IHPs are widely used in some industrial processes, their overall use to date has been far below their true technical and economic potential. This low rate of utilization partly results from the lack of information and industrial experience with heat pump technology in some industrial sectors, and also from misperceptions of the technology based on poorly designed installations dating back more than 10 or 20 years.

Figure 2a: IHPs in use per country



Total # IHPs = 4,600

Figure 2b: IHPs in use per industry



Total # IHPs = 4,600

Potential benefits - worldwide

IHPs can reduce the energy consumption for industrial process heating by 2 to 5% worldwide. This equates to 1300 to 3100 PJ/year. Given this energy saving potential, IHPs can provide substantial global net emission reductions by 2010.

Large savings

As highlighted in *Figure 3*, the projected environmental benefits of IHPs are equivalent to eliminating the yearly emissions from 50-150 GW of fossil fuel-based electric generating capacity. The estimated benefits would also be comparable to saving 120-380 billion kWh/year of electricity, planting 30-85 million trees, removing 15-40 million cars from the road, or reducing petrol consumption by 40-95 thousand million litres per year.

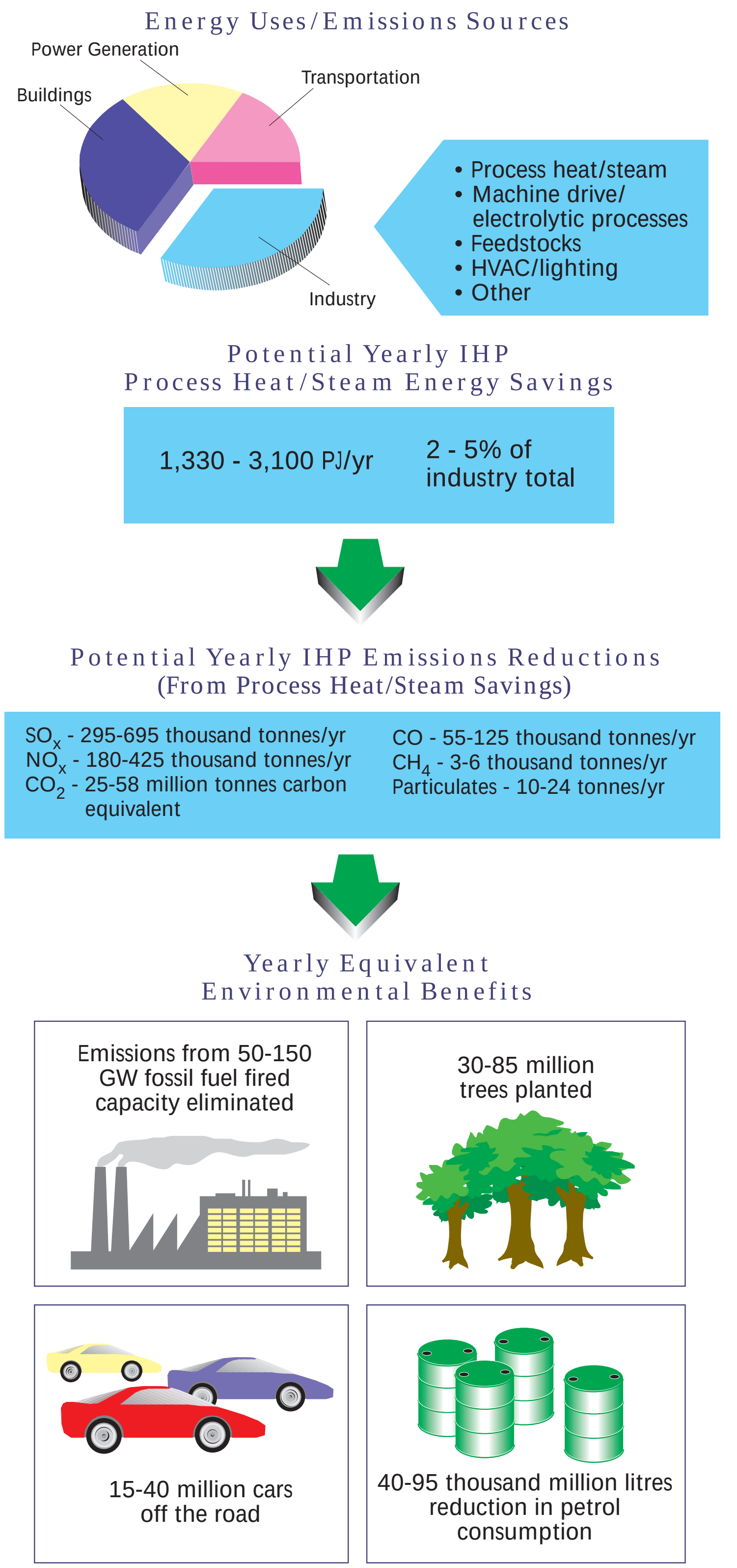
Realistic

These estimates of potential IHP benefits are based on detailed assessments of the applicability of heat pumps in a great number of countries and industry sectors. The estimates can be viewed as both realistic and conservative.

Their realism is ensured by the detailed procedure used to estimate IHP potential at the individual process level. In this procedure, IHP economics and competition with other technologies were taken into account, and it was assumed that IHPs will be installed after improved heat exchanging. Market factors that would likely limit the use of IHPs were also considered, such as technology risk aversion and penetration rates over time.

Conservatism was introduced by not taking credit for reductions in waste fuels used for process heating (e.g. biomass, wood, process waste gases), which can be as much as 20-50% of the energy used in some industrial processes.

Figure 3: Projected Environmental Benefits of IHPs

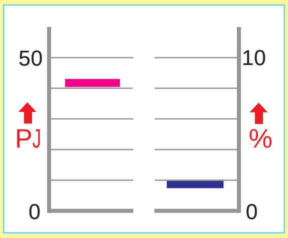


Potential benefits - to countries

In any industry, but also in a country as a whole, the benefits of IHPs will depend on the energy mixes used for process heating and for driving IHPs, and on the cost of fossil fuels relative to electricity. Most advantageous are applications where IHPs offset the process heat generated from coal or oil. Similarly, IHPs that use electricity generated from renewable energy sources, nuclear energy, or low-emission fuels such as natural gas will realize most emissions reductions.

For the eight countries that took part in Annex 21, realized and potential IHP applications are highlighted, along with the most important environmental benefits they can give. For each country the estimated potential energy savings through the use of IHPs in 2010 are shown. The savings are given in PJ (left bar), and in % of the total national energy consumption for process heating in 1992 (right bar).

CANADA



Applications

As many as 540 IHPs may now be in use in Canada, where their predominant application is lumber drying. Other major uses are found in liquor distilling, paper production, and cheese/milk production. Large potential energy savings were found in food, chemical/petrochemical, pulp and paper, wood and metals applications such as chlorine, caustic soda, petroleum refining, speciality paper and newsprint, and iron and steel blast furnaces.

Environmental benefits

A major driver for IHP use is emissions reductions and product quality. Reduced CO_2 emissions would be the largest benefit from IHPs, because process heating is often natural gas-based in Canada. IHPs would typically be generating smaller offsets of SO_x and NO_x emissions, as there are relatively fewer cases where they replace coal- or oil-based process heating.

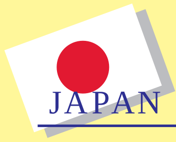
FRANCE

Applications

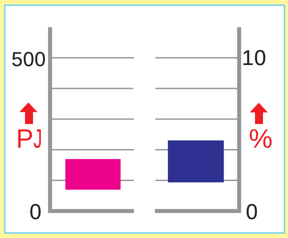
About 200 MVR IHPs are installed in France, along with several hundred closed-cycle IHPs. To date, the main IHP applications have been in evaporation and drying in the food and chemical industries. IHPs have also been found to be suitable for timber drying and district heating, along with specialized industrial applications such as in the electronics industry for simultaneous hot and cold water production.

Environmental benefits

No detailed evaluation was performed on potential environmental benefits of IHPs in France.



JAPAN



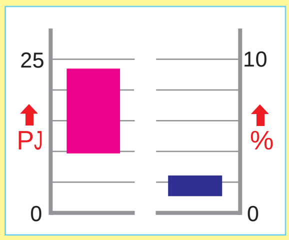
Applications

Japan has between 350 and 500 installed IHPs. MVRs are the most common, but Japan also has a relatively high proportion of absorption heat pumps - 6% of IHPs are absorption heat pumps, and 3% are absorption heat transformers. Typical applications include distillation, evaporation, and wort boiling in the chemicals, pulp and paper, and food industries. Promising opportunities include kraft pulp, textile dyeing, ethylene, naphtha splitting, and caustic soda production.

Environmental benefits

Environmental benefits should be quite large because IHPs would typically displace oil-based process heating and use non-fossil fuel-based electricity.

THE NETHERLANDS



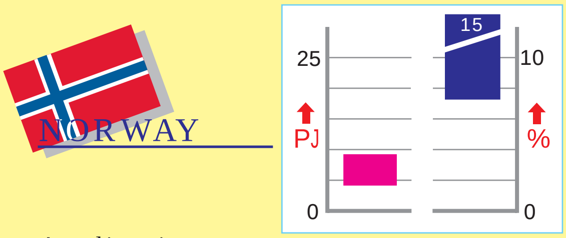
Applications

At least 150 IHPs are in use in the Netherlands, including closed-cycle, MVR and TVR systems. Most applications have been in the food and chemicals industries, with some in agricultural-type processes (e.g. greenhouse heating). There are good opportunities for energy saving in petrochemical, chemical, paper, and food and drink processes, in particular those involving evaporation or drying.

Environmental benefits

The largest environmental benefits from IHPs would be lower CO_2 and NO_x emissions, because process heating is often natural gas-based and electricity generation is substantially based on fossil fuels. Other environmental benefits include the reduction of cooling water needs, and the concentration of waste flows such as sludge or manure.

NORWAY



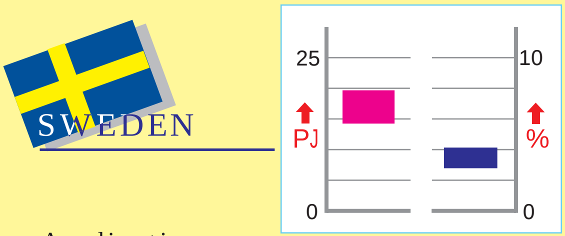
Applications

Norway has nearly 700 IHP installations of which more than 95% are electrically-driven, closed-cycle systems. Most IHPs are used in food industry processes (e.g. fish farming, fish processing, dairies, meat products) or for lumber/wood drying. Attractive IHP applications include aquaculture/fish farming, dairy cream/cheese evaporation, fish drying, lumber drying, and general food process heat recovery for hot water.

Environmental benefits

IHPs can provide large environmental benefits in Norway because they would typically be reducing oil-based process heating and because IHP energy consumption is derived from hydroelectric power.

SWEDEN



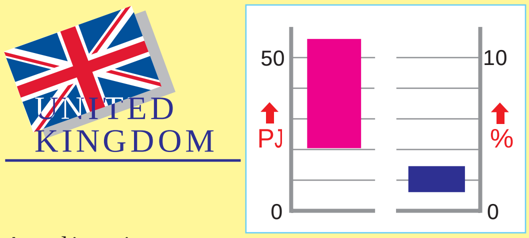
Applications

Of the nearly 150 IHPs installed in Sweden, the vast majority are closed-cycle systems. Common applications include waste heat recovery for hot water production and district heating. MVR IHPs are generally found in evaporation processes in the food, chemical, and pulp and paper industries. Strong potential for energy saving was estimated for district heating, ethanol distillation, biomass drying, and general food industry utilities (e.g. central heating, hot water).

Environmental benefits

The high costs of fossil fuels (from large import taxes) create favourable conditions for IHPs. Environmental benefits could be quite significant, since IHPs would mostly displace oil- or coal-based process heating; however, the shift from nuclear to fossil fuels for electricity will reduce the potential emissions reductions somewhat.

UNITED KINGDOM



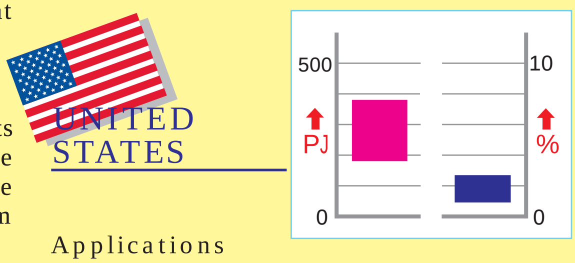
Applications

There may be 100 or more IHPs installed in the United Kingdom, including both MVR and closed-cycle systems. To date, most IHPs have been used for drying or evaporation operations in the food industry. Promising potential IHP applications include sugar refining, chlorine/caustic soda production, paper and paperboard production, brewing, and liquor distilling.

Environmental benefits

Reduced CO_2 emissions would be the primary environmental benefit of IHPs because industrial process heating is typically natural gas-based. IHP potential would increase dramatically if electricity-to-fuel price ratios were to decrease.

UNITED STATES



Applications

Of the participating countries in this project, the United States has the largest industrial sector and the most IHP experience to date, with more than 2,300 IHPs now in use. The dominant application has been lumber dehumidification, with an estimated 2,000 units installed. Major industrial process applications of IHPs include distillation and evaporation heat recovery, in the dairy, corn milling, pulp and paper, and chemical industries. Potential energy savings would derive from wide-scale IHP use in corn milling/starch, pulp and paper (bleached and unbleached kraft pulp, thermo-mechanical pulp), sugar refining, corn syrup, synthetic rubber, polyethylene, lumber drying, and cheese production processes, among others.

Environmental benefits

With a reliance on coal-based electricity generation, increased electricity consumption for IHPs would mean that the largest national environmental benefit from IHPs would be reduced CO_2 and NO_x emissions. Smaller reductions would be obtained for SO_x, CH_4 and CO. At the process level, depending on the energy mix for process heating, IHPs could yield large reductions in CO_2 as well as SO_x and NO_x.

Potential benefits - to industry

IHPs will help reduce the energy consumption of an industrial process and will consequently offer economic benefits. And they will offer many other benefits as well.

Energy savings

At the individual plant level an IHP will, on average, make energy savings of 15-30% of that required for process heat. In some plants, the savings will be considerably greater. The economic benefits of these savings will depend on energy prices and on the cost of installing the IHP.

The potential for energy saving also varies considerably from one process to another. For the countries of Annex 21 the energy saving potential, from a national perspective, has been estimated for more than 30 potential processes. The results are shown in *Figure 4*, which graphically portrays the potential range of savings in the total energy demand for providing heat for each of these processes.

For some processes, the potential savings exceed 30%. Overall, the potential for saving energy with IHPs, for all the processes examined under Annex 21, is estimated at 5-10% of the combined energy consumption used to supply heat to these processes.

Below:
A closed-cycle vapour compression IHP used in vegetable oil processing, Sweden.

Environmental benefits

The environmental benefits of energy savings will depend on the energy mix used for process heating and, for electrically driven IHPs, on the energy mix for power generation.

Interestingly, the environmental benefits of IHPs will often go beyond combustion based emission reductions. Their ability, for instance, to reduce the cooling water demand, or concentrate liquid wastes such as sludge and manure is in some countries a major driver for their application. This is notably so if cooling water use or waste disposal are taxed or regulated.

Optimization

The sound application of IHPs can give many other benefits, besides energy and environmental savings. They can significantly contribute to the complete technical and economic optimization of plants and processes. Some of the benefits for industry are given below.

- Increased production - IHPs can help debottleneck unit operations, such as evaporators or dryers, enabling increased production capacity;

- Improved product quality - IHPs can contribute to better product quality and reduced product loss by, for example, providing higher concentrate levels in evaporated products or by increasing drying rates;

- Increased capacity - By recovering waste heat, IHPs can reduce process steam, hot water, or refrigeration demand, thereby providing an effective increase in the generation capacity for these energy streams. This in turn can delay the need for new equipment. And extra steam capacity can be used to increase the power generation capacity;

- Reduced water requirements - By reducing the requirements for process heat or steam, IHPs can, in some instances, also help lower overall requirements for process make-up or cooling water.

Figure 4: Estimated Energy Savings by Industry and Process

Industrial Process	Countries Analyzed	Estimated Total Process Heat Energy Savings — % Saving by Process: <5	5-10	11-15	16-20	21-25	26-30	>30
Food:								
Beet/cane sugar refining	CD, JPN, UK, US	■	■	■	■			
Cheese production	CD, NOR	■	■	■	■	■	■	■
Corn syrup/starch production	NL, US		■	■	■	■	■	■
Dairies	CD, NL, NOR	■	■	■	■	■	■	■
Fish products	NOR				■	■	■	■
Food industry (general)	SWE	■						
Liquor distilling	CD, JPN, UK	■	■	■	■	■	■	■
Malt beverage brewing	UK, US	■	■					
Meat products	NOR	■	■					
Potato processing	US	■						
Poultry processing	CD	■						
Vegetable processing	US	■						
Chemicals:								
Chlorine/caustic soda	CD, JPN, UK, US		■	■	■	■	■	■
Ethanol distillation	SWE, US		■	■	■	■	■	■
Ethylene	JPN, NL, US	■						
Phosphoric fertilizer/acid	US	■	■					
Polyvinyl chloride	JPN	■						
Surfolane	JPN	■						
Synthetic rubber (polybutadiene)	US		■					
Urea	NL, US	■						
Viscose rayon	US	■						
Petrochemicals:								
Aromatics: BTX	CD, US	■						
Naphta desulphurization	JPN	■						
Naphta splitter	JPN	■						
Petroleum refining	CD, US	■	■					
Pulp & Paper/Lumber:								
Lumber/wood drying	CD, NOR	■						
Paper/paperboard production	CD, NL, SWE, UK, US	■						
Pulp production	CD, JPN, SWE, US	■	■	■	■	■		
Textiles:								
Textile finishing	CD, JPN, NL, US	■	■	■				
Other:								
Aqua culture/fish farming	NOR			■	■	■	■	
Biomass drying	SWE	■						
Building ceramics	NL	■						
District heating	SWE	■	■					
Iron and steel-blast furnace	CD	■						
Wastewater concentration	SWE	■						

The next steps

Realizing the large potential benefits offered by IHPs centres on the wider deployment of the technology. The question arises *"How can this be achieved?"*.

Practical information

To answer this question it must be recognized that the use of heat pumps has been hampered by several factors, including a lack of information on how to identify potential applications, and misperceptions about IHP benefits and reliability (based on early poor designs).

Above: Innovations are leading to high-temperature IHP applications. This Japanese prototype delivers heat at 200°C.

The participants in Annex 21 have endeavoured to address these factors, first of all by providing more information on the benefits and applicability of IHPs, and secondly by developing a screening tool to help identify potential applications for them. A thorough report on IHPs was published, and an IHP screening program was developed (more information on these products on the facing page). A wide dissemination and use of this information will aid the sound deployment of IHPs.

Sound application

Realistically, IHPs will not be applicable to every industrial process and they may not be feasible for all plants within the same industry. The environmental benefits will also be variable. Many issues can affect IHP implementation, with two key issues being local energy prices and capital availability:

- relative electricity-to-fuel price ratios will directly influence the economics of electrically-driven IHPs (e.g. closed cycle, MVR). A ratio of 3:1 or less is often needed to yield a payback of two years or less;
- capital for IHP-type investments (often involving several hundred thousand dollars or more) may often come from discretionary funds. Such an investment may be viewed as too costly, despite an attractive rate of return.

The application of IHPs will only be optimum if they are considered as a part of an overall plant heat integration study. Heat exchanger improvement opportunities, which are generally lower-cost than IHPs, must first be identified, and then the potential for heat pumping can be identified. Such a process will lead to the minimum plant-wide energy consumption and the maximum environmental benefits at the lowest total investment cost.

Effective support

Organizations that support the industrial sector, particularly those with the capacity to provide financial assistance (e.g. government agencies, utilities) can play important roles in helping to realize the potential benefits of IHPs. These organizations can:

- help reduce the perceived risk or uncertainty associated with IHPs by sponsoring demonstration projects and by helping in the information dissemination and awareness raising process;
- increase the financial attractiveness of IHPs by providing financial assistance to defray investment costs or by providing energy rates to lower energy costs.

Organizations outside of industry (e.g., government, utilities, engineering and energy service companies) can also actively support continued IHP technology development to help ensure improvements in performance and to extend the range of IHP applications such as in high-temperature processes.

The Annex 21 products

The Annex 21 Final Report:
Industrial Heat Pumps - Experiences, Potential and Global Environmental Benefits

The comprehensive final report of Annex 21 stands out as an excellent reference book on IHP technology, applications and potential, and is essential reading for process engineers, industrial parties, policy makers and utilities concerned with the application of heat pumps in industry. The report discusses in detail the various types of IHPs that were touched upon in this brochure. It provides guidelines for the sound integration of IHPs in plants and processes, and contains an application guide for the Annex 21 IHP screening programme . It reviews today's experience with the technology, and concludes with an assessment of the potential energy and environmental benefits.

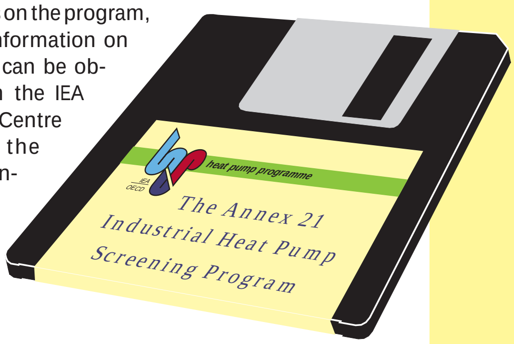
The report gives industrial companies and process engineers information that will highlight opportunities for using IHPs in their industries. The estimates of the potential worldwide and country-by-country benefits will be of particular interest for policy makers and energy programme managers in both governments and utilities. The 250 page report is published by the *IEA Heat Pump Centre* and costs NLG 100. It can be ordered by sending the reply form at the bottom of this page to the IEA Heat Pump Centre. You may also contact one of the Annex 21 country contacts. Addresses are shown on the back cover.

The "Annex 21" Industrial Heat Pump Screening Program

The Annex 21 computer program was developed to assist in a preliminary screening of the technical and economic suitability of IHPs in industrial process applications. The program is based on pinch technology theory.

The program identifies IHP opportunities that are consistent with fully optimized plant heat exchange systems to provide the most economic IHP designs and the lowest possible plant-wide energy consumption. The program contains data on more than 100 industrial processes in five industries: food, chemicals, petroleum refining, pulp and paper, and textiles. These data can be used directly, or modified as needed to assess site-specific IHP opportunities. The program contains data on more than 50 types of IHP, divided into five main categories: closed-cycle compression, mechanical vapour recompression, thermal vapour recompression, absorption heat pumps, and absorption heat transformers. An application guide for the program is contained in the final report.

More details on the program, including information on availability, can be obtained from the IEA Heat Pump Centre or from the country contacts for Annex 21 (*see back cover*).



To order:
Tick the boxes and send to the IEA Heat Pump Centre (*address on the back cover*)

☐ Please send me the final report of Annex 21: ***Industrial Heat Pumps - Experiences, Potential and Global Environmental Benefits***. Price NLG 100,-- (*in August '95, 1 Netherlands Guilder was about 0.6 US$*)

Payment via
☐ Bank transfer (you will be billed)

☐ Eurocard Card No: ____________________
☐ Mastercard Card Holder: ____________________
☐ VISA Expiry date: ____________________

☐ Please send me more information on the IHP screening software program
☐ Send me __ free brochures "Industrial Heat Pumps - a Means to Mitigate Global Industrial Emissions"
☐ Send me more information on IEA Heat Pump Centre products and services

Name ____________________ Company ____________________
Address ____________________ Post/Zip code ____________________
City ____________________
Country ____________________
Date ____________________ Signature ____________________

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 its 23 participating countries, to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development.

IEA Heat Pump Programme

Set up by the IEA in 1978, the IEA Heat Pump Programme carries out a strategy to accelerate the development and use of heat pumps, in all applications where they can reduce energy consuption for the benefit of the environment. Within the framework of the programme, participants from different countries collaborate in specific heat pump projects known as Annexes.

IEA Heat Pump Centre

A central role within the programme is played by the IEA Heat Pump Centre (HPC), itself an Annex. The HPC contributes to the general aim of the IEA Heat Pump Programme, through information exchange and promotion. For more information on HPC products and activities, or for general enquiries on heat pumps and the IEA Heat Pump Programme, contact the address below.

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Industrial Heat Pump / Annex 21 Country Contacts

This brochure is based on the results of the international collaborative project *Global Environmental Benefits of Industrial Heat Pumps* - or *Annex 21* of the IEA Heat Pump Programme. The following countries participated in this project, the US being the Operating Agent. Contact addresses are shown below:

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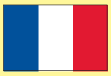

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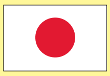

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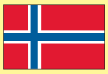

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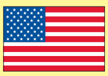

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