IEA Heat Pump CENTRE NEWSLETTER
VOLUME 16
NO. 3/1998

Alternative Working Fluids

In this issue:

Trends in the use of working fluids

The role of heat pumps in a deregulated energy market

Evaluation of the potential of CO_2 as a working fluid for heat pumps

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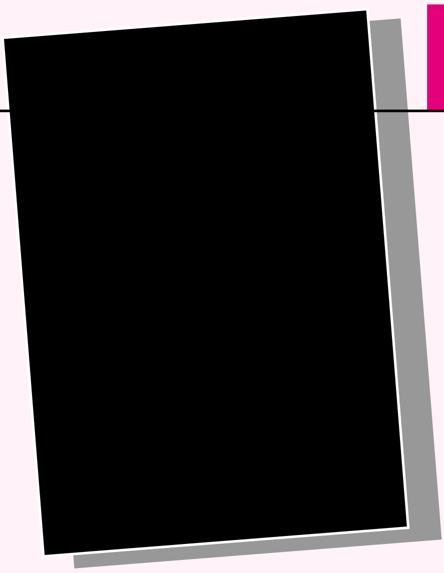
OECD
heat pump centre



In this issue

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Alternative Working Fluids

The discovery of the ozone depleting potential (ODP) and later the global warming potential (GWP) of CFCs and hydrochlorofluorocarbons (HCFCs) has led to a tremendous worldwide increase in research and development of alternative working fluids for use in pumping applications. This issue describes the current trends in research and applications of new refrigerants, both natural and synthetic.

TOPICAL ARTICLES

This overview analyses the current status in various countries and shows which factors influence the selection of a working fluid. Current developments are reviewed as well as some applications using alternative working fluids.

Agreements have been made for the phased elimination of environmentally harmful refrigerants. The characteristics of conventional and alternative groups of working fluids and the current trends in Switzerland are discussed.

Natural working fluids, particularly CO_2, are considered environmentally friendly long-term alternatives in Japan. A study performed by CRIEPI confirmed that CO_2 has great potential as a working fluid for heat pumps.

A large ammonia heat pump has been installed at the new Oslo Gardermoen Airport in Norway. This application illustrates the trend in Norway that ammonia is the preferred working fluid in larger heat pumps.

This article stresses the importance of installation guidelines for propane heat pumps for the further dissemination of heat pumps in the Netherlands and promotion of other steps such as certification.

This article compares the energy efficiency, cost aspects and environmental impact of three absorption systems with three compression systems using different working fluids.

Front cover:
Heat pump plant at Oslo Gardermoen Airport.
See the article on page 20.

COLOPHON

Publisher:
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Editor in chief: Jos Bouma
Technical editing:
Hanneke van de Ven
Production: Novem Support Group

Frequency: quarterly
Printed September 1998

HPC Newletter subscriptions are automatically renewed unless written cancellation is received by 1 October

ISSN 0724-7028

NON-TOPICAL ARTICLES

HEAT PUMP NEWS

FEATURES

20th Anniversary IEA Heat Pump Programme

In 1974, one year after the first oil price shock, the International Energy Agency (IEA) was founded and 23 OECD countries joined this intergovernmental organisation. The objective was to reduce member country dependence on imported oil. The Implementing Agreement (IA) for a Programme of Research and Development on the Application of Heat Pump Systems to Energy Conservation was launched and the first IEA project on heat pumps, the 'Programme on Heat Pump Systems with Thermal Storage', was implemented. In 1978 the follow-up IA was established, and was renamed in 1992 to the IA for a Programme of Research, Development, Demonstration and Promotion of Heat Pumping Technologies. This 'IEA Heat Pump Programme' (HPP) has now been in operation for 20 years.

However, heat pumping technologies are much older than this. In 1824 Carnot invented the theoretical basis of heat pumping, i.e. reversing the natural heat flow from a higher to a lower temperature level by adding high-grade energy. This process is suitable for producing both heat and cold. Around 90 million units with a thermal output of 570 TWh/a are currently in operation worldwide, reducing CO_2 emissions by 0.12 Gt/a. The potential for reducing CO_2 emissions in the building sector alone, using currently available technology, is about 6% of the total worldwide CO_2 emissions of 20 Gt/a. Comparing heat delivery via heat pumps with conventional methods, i.e. fossil fuel burning boilers, heat pumps can cut the primary energy consumption by at least half. This is one of the largest CO_2 reduction potentials for a single technology. Therefore, heat pumps are one of the key technologies for reducing CO_2 emissions resulting from burning fossil fuels.

Both the IEA HPP and its focal activity, the IEA Heat Pump Centre (HPC), are promoting heat pumping technologies, covering heat pumps and air conditioning as well as refrigeration. Promotional tools include this Newsletter, Annexes, i.e. international collaborative projects, on special heat pump related topics, analysis studies and international workshops. The HPP has organised five three-yearly international IEA Heat Pump Conferences. Starting in 1984 in Graz, Austria, conferences have been organised in Orlando, Tokyo, Maastricht, and Toronto. The next one will take place in May 1999 in Berlin, Germany. The goal of the HPP is to increase knowledge regarding heat pumps and enlarge the market share of this technology for energy conservation, reducing CO_2 emissions and thereby improving the environment in the future.

Hermann Halozan
Chairman of the IEA HPP Executive Committee
Graz University of Technology

Natural working fluids experts meet in Oslo

Norway - Under the auspices of the International Institute of Refrigeration (IIR), four Norwegian HVAC&R societies and research institutions, headed by SINTEF Energy, joined forces and put together an interesting programme for a conference on natural working fluids which was held 2-5 June 1998. The event attracted around 350 participants from all over the world. The conference was aptly named after the late Prof. Gustav Lorentzen and the meeting reflected this in many ways.

The five most common natural working fluids (CO_2, ammonia, water, air and hydrocarbons) were discussed, some at great length, others quite briefly. The focus was clearly on CO_2. Without doubt, an extensive amount of R&D on CO_2 is under-way, but real breakthroughs were not presented. Although the core of CO_2 R&D activities is still in Norway, institutions and companies in various countries have now embarked on CO_2 projects, including Japan and the USA. Promising technology developments include new compressors, heat exchangers and controls, while CO_2 products, including water heaters and residential and vehicle space conditioners, will enter the market over the next few years.

The Scandinavian conviction of the strength and potential of natural working fluids was demonstrated by the statement from the Norwegian Minister of the Environment, Ms Guro Fjellanger, that plans are being developed to tax all refrigerants. The tax rate will depend on the global warming potential of each refrigerant, but will be considerable (around USD 13 per tonne CO_2). For natural working fluids, this would work out very favourably.

Prof. P.E. Frivik presented the award for the best conference paper to the authors of the paper entitled “Turbo chiller with water as refrigerant” for their excellent work, which contributes to science, engineering and the community as a whole. It was announced that the following Natural Working Fluids/ Gustav Lorentzen Conference will be held in conjunction with the next Purdue conference, scheduled for 24-28 July 2000, in the USA. The IIR will publish the proceedings of the Oslo conference.

Source: Jos Bouma, IEA Heat Pump Centre

New EU proposal for R-22 phase-out

The Netherlands - The latest European Commission proposal for an accelerated phase-out of R-22 in new installations and the use of newly produced R-22 for maintenance purposes may have considerable impact on the heat pump and air-conditioning industry.

The unchanged parts of the proposal include the phase-out of R-22 by the following dates.

- Per 1 January 1996 for new open direct-expansion systems, domestic refrigerators and deep-freezers, as well as air-conditioning systems in motor vehicles.
- Per 1 January 1998 for new air conditioning systems for public rail transport.
- Per 1 January 2000 for new applications in cool storage centres and warehouses, and for applications with a mechanical capacity of over 150 kW.

The new proposal states that, per 1 January 2001, R-22 will be forbidden for use in all other new cooling and air-conditioning systems except for reversible air conditioning and heat pump systems, and that per 1 January 2004 its use in all new equipment will be banned. The current phase-out date for these applications is 1 January 2015.
A second new regulation in the proposal is that per 1 January 2008 the use of newly produced HCFCs for maintaining existing systems will be banned. In the current agreement this aspect is not included.

Source: NVKL, Mr Hoogkamer, e-mail:joh@fme.nl

1998 annual meeting of Absorption Users Club

The absorption system users club met for their annual meeting in Uppsala, Sweden in May. Members reported on the experiences gained with their installations, most being steam or hot-water-powered absorption heat pumps (MW-size) using waste heat from refuse incineration processing or geothermal energy. These installations are located in Sweden, Denmark, Germany and Poland. Most systems are of Japanese design, though a few are Finnish. It was concluded that these installations are operating very reliably and performing well. Much has been learned and this information was relayed back to equipment manufacturers, enabling them to improve their designs further.

A new installation consisting of four single-stage units went into operation (late 1997) at Uppsala Energi. The units use water/lithium-bromide and the total heating capacity is 18 MW. The company has also operated three electric heat pumps for many years now, each supplying 13 MW heating capacity and extracting heat from river and city waste water. All heat pumps supply heat to the district heating network.

Source: Jos Bouma, IEA Heat Pump Centre

New Dutch funds for reduction of CO_2 emissions

The Netherlands - New funds have been made available for a large government reduction programme for CO_2 emissions, initiated by the Dutch Ministry of Economic Affairs, and for a new programme entitled Investment subsidies for non-industrial waste heat infrastructure’. The emissions reduction programme includes the use of industrial waste heat, heat pumps and advanced cogeneration, renewable energies and industrial technology. A total extra budget of around USD 250 million is available.

Source: Netherlands Agency for Energy and the Environment (Novem)

Heat pumps and geothermal energy

On 12-15 May 1998, approximately 180 participants attended the 5th Geothermal Conference in Straubing, Germany, organised by the Geothermal Association (GtV). Heat pumps are an important tool for using geothermal water with temperatures below around 60°C, or to further cool the water in plants with higher geothermal temperatures and thus to increase thermal capacity of a given well.

One of the examples discussed at the conference is located in Erding, Germany, where good quality water at 65°C is cooled by direct heat exchange and a gas-fired absorption heat pump. The water (at around 20°C) is then treated for use in the municipal drinking water distribution. All pipes and heat exchangers carrying geothermal water, including the relevant parts of the heat pump, had to comply with the German drinking water standards. The heat produced by the heat pump and a gas boiler for peak loads is used in a local district heating net. A technical visit was organised to this plant on the final day of the conference.

Deep borehole heat exchangers (1,000 m deep and more) in abandoned boreholes can only be used with heat pumps. Three such plants already exist in Switzerland and Germany and new Swiss projects were presented for a municipal building in Noréaz, a hospital in Genève-Thonex and a horticultural plant in Fehraltdorf.

Shallow geothermal energy played a substantial role at the conference, mainly with ground-source heat pumps (GSHP).
Dr Paul-Georg Gutermuth of the German Federal Ministry of Economics reported a very favourable experience from the programme for the market introduction of renewable energies. In 1997 a total of 1,106 electric heat pump plants were supported by this programme, with a bias towards GSHP (818 plants with ground heat exchangers and 180 plants with ground water use).
Dr Gutermuth concluded that the impact on the market was remarkable, and promised continuation of the programme over the coming years.

The conference showed the further progress of geothermal energy into the heating market. The proceedings (in German) are available through the secretariat of GtV, Gartenstrasse 36, D-40744 Geeste, Germany.

Source: Dr Sanner, Justus-Liebig University, Giessen

Swiss heat pump expo

Switzerland - Around 60 companies which support environmentally compatible heating and heat pumps are preparing their exhibits at the third national Heat Pump Exhibition in Bern. Heat pump manufacturers, suppliers, electrical power companies, installers and even consultants and technical colleges form a compact information platform for specialists, home owners and builders.

The exhibition is a competitive trade exhibition, aimed at providing information on innovations, trends and technology at first hand. How to find the most economical way of renovating a heating system, how pollutants can be reduced with heat pumps, the quality and services for heat pumps, and the correct dimensioning of geothermal sensors are practical subjects will be discussed in the workshops, held in both German and French. A special workshop on heat pumps in the open energy market is primarily aimed at electrical power companies, but is also open to other interested parties. A detailed programme with application form will be available from mid-September.

The high quality standards demanded of heat pumps are supported by strict testing at the Heat Pump Test and Training Centre in Winterthur-Töss. A total of 155 heat pumps with heat outputs between 4 and 62 kilowatts have been tested to date. The results are published quarterly in the WPZ Bulletin, as well as on the Internet (http://www.wpz.ch).

Source: FWS, Dieter Wittwer, 8021 Zurich
Fax: +41-1-2994140
Internet: http://www.fws.ch

UK Heat Pump Awards

UK - On 25 June the UK heat pump awards 1998 were presented in London. This event was organised by the Heat Pump Association (HPA) to promote the benefits of heat pump technology, by increasing the awareness and application of heat pumps as a means of using energy efficiently, cost-effectively and with the minimum impact on the environment.

There were two types of competition. The first concerned a Student Award, for which students were invited to submit a proposal for a heat pump system to satisfy the requirements of a property development project. The competition for the Heat Pump Application Awards was open to building owners and developers. Three categories were established.

For the category ‘unitary systems’ applications using standard unitary reverse cycle air-to-air heat pumps up to 15 kW per unit could be submitted. This award was won by the Leeds Metropolitan University, using a packaged roof-mounted heat pump air-conditioning unit installed in the reprographic laboratory, which until recently had suffered from severe overheating. The reverse-cycle 40 kW heat pump now provides year-round heating and cooling, and has also improved the indoor air quality within the laboratory.

The category ‘applied systems’ included total building applications using heat pump technology, heat recovery or other energy-saving features. The award was given for an application at Stonecourt, Middlemarch Business Park in Coventry, UK. One of its advantages is the ability to move, add or reduce the number of terminal units or the size of units on the water loop, while the system remains fully operational.

The last category for ‘original solutions’ was an award for the most original use of heat pump technology in a unique or unusual application. This award was won by the Women’s Royal Voluntary Service.

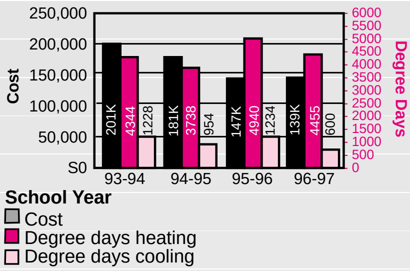
Source: Hanneke van de Ven, IEA Heat Pump Centre

Ground-coupled system for school

At the Daniel Boone High School in Washington County, Tennessee, USA, a ground-coupled system was installed to replace the original system, which used a two-pipe chilled water system (R-11 chiller) for cooling and electric resistance heat. From several alternatives, a system containing a water loop heat pump and a closed loop geothermal heat exchanger was chosen. The project won a 1998 ASHRAE Technology Award in the category for alternative and/or renewable energy use.

To reduce energy consumption for the circulation pumps, a pair of two-speed circulating pumps are controlled by a combination of loop flow and system differential pressure using a programmable logic controller. Before the retrofit energy use averaged 3,481 MWh per year (with 4,344 degree days heating and 1,228 degree days cooling). In the first full year of operation (96-97) this was reduced to 2,298 MWh with 4,455 degree days heating and 600 degree days cooling. The annual energy costs can be seen in the Figure. The investment has an estimated simple payback period of six years. Because the project was very successful, the technology has been implemented at two other locations.

▼ *Figure: Annual energy costs.*



Source: ASHRAE Journal, May 1998

Russian patent claims highly efficient heat pump

Russia Federation - A patent registered by the Russian Federation Committee for Patents and Trademarks claims that if its design and method were developed it would lead to a heat pump with a COP of 23. This is much higher than any other available alternative. According to the patent, this factor is reached by selecting the energy transfer medium so that its critical temperature is close or equal to that of the medium being cooled. The medium, which can be CO_2, is brought to a critical state before compression.

The patent proprietors are looking for partners to implement this method. Interested parties should contact the Institute for Physics and Power Engineering (IPPE) in Obninsk, Russian Federation.

Source: Mr E. Boudylov, IPPE
Fax: +7-95-883-3112; E-mail: postbox@ippe.rssi.ur

New CD-ROM illustrates GAX technology

USA - A CD-ROM just released by the Department of Energy (DoE) explains how heat pumps using generator absorber heat exchange (GAX) technology with ammonia and water can heat and cool homes and businesses 50% more efficiently than today's gas furnace technology, without causing global warming.

Heat pumps designed with GAX technology are being developed by DoE and the gas industry, and a prototype heat pump is expected in the year 2000. GAX heat pumps use natural gas, which burns cleaner than oil or coal. According to DoE this technology can save consumers more that USD 17 billion in heating and cooling costs annually by the year 2010. The energy savings are enough to heat 14 million homes per year. Unlike conventional heat pumps with traditional refrigerants, GAX heat pumps use an ammonia/water solution which is environmentally friendly and does not contribute to global warming or deplete the ozone layer.

The GAX partnership programme includes DoE, the American Gas Cooling Centre and the US gas industry. The programme, run by Oak Ridge National Laboratory (ORNL), is completing the development necessary to introduce GAX technology to the residential and light commercial markets within the next two years.

Builders, suppliers, utilities and educators can learn more about the technology by requesting the CD-ROM through DoE's Office of Building Equipment (E-mail: james.fremont@ee.doe.gov or fax: +1-202-5865557) or ORNL's Energy Division (fax: +1-423-5742694).

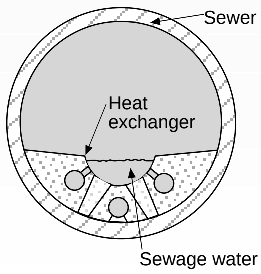
Source: Programme contact,
Mr Ronald Fiskum, tel.: +1-202-5869154

Heat recovery from sewage water

Switzerland - An installation in Zürich, Switzerland, heats 800 houses using heat recovered from sewage water. This annually saves almost half a million litres of fuel oil.

The simple installation consists of a 200 m long heat exchanger built into larger sewers (see cross section in the Figure). The water has an average temperature of around 15°C. Per cubic metre of sewage water, 5 kWh heat is extracted. In a central heating plant, the heat is upgraded by heat pumps for space heating. Two 625-kW heat pumps are used, which supply 3.1 million kWh of the total yearly heat demand of 8.6 million kWh. The rest is supplied by two conventional oil boilers. The investment costs for the total heating system amounted to USD 2.1 million, of which 1.3 million was for the heat recovery system and heat exchanger.

▼ *Figure: Cross section of the sewer with heat exchanger.*



Source: Wärmepumpen, 2/98

Market revival in Germany

Germany - Since the collapse of the domestic heat pump market in Germany in the 1970s, the industry has tried for years to improve sales, but with little success. Now the prospects for a renaissance look good. Total sales in Germany rose from 400 units in 1990 to 3,000 units in 1997, with the expectation that 1998 will show a record 4,200. The latest revision to the structural insulation regulations in Germany has created a new generation of low-energy houses. For a ground-source installation using scroll compressors a yearly average COP of 4.0 is becoming the rule rather than the exception, according to compressor manufacturer Copeland.

However, the Swiss market for heat pumps is still relatively larger. The German Information Centre for Heat Pumps and Refrigeration (IZW) has founded a new group to cooperate closer with representatives from the various target groups. This new group will formulate IZW's new three-year programme. Three main tasks have been defined for 1998. The first involves researching practical data on primary energy use and greenhouse gas emissions of modern heat pumps. The second task is updating the primary energy demand and greenhouse gas emissions in the buildings sector, to compare different heating systems. The third task involves supporting measures for government stimulation programmes.

Source: Wärmepumpen, June 98 / JARN, July 1998

Japanese RAC shipments increase

Japan - According to the Japanese Refrigeration and Air Conditioning Industry Association (JRAIA), Japanese domestic shipments of room air conditioners (RACs) in May 1998 numbered 939,305 units. This was 4.9% higher than in May 1997. It was the first time in 13 months that the figures showed an increase. However, the cumulative total for the period October 1997 - May 1998 shows shipments are still 20% lower than in the same period last year (see Table). Sales of packaged air conditioners dropped in May 1998.

Source: JARN, July 1998

Three major gas companies jointly market R-407C GHP units

Japan - Tokyo Gas, Osaka Gas and Toho Gas have released gas engine-driven heat pumps (GHPs) adopting R-407C, which has no ozone depleting effect. GHPs using natural gas as an energy source emit less CO_2 and NO_x than appliances using oil or coal, and also comply with the national policy for energy demand/supply levelling. These are outdoor units of 3.7 kW and 7.5 kW. Besides the adoption of R-407C, the reliability and capacity of the equipment have been secured through improved compressors, new lubricants and heat exchangers.

Source: JARN, July 1998

Table: Japanese domestic shipments of RACs and PACs

	May 1998 (growth)		October 1997 - May 1998	
	Number units	Change from 1997	Number units	Change from 1997
RAC	**939,305**	**(4.9%)**	**3,832,110**	**(-20.2%)**
Cooling only	60,714	(-20%)	150,836	(-26.8%)
Heat pump	878,591	(7.2%)	3,681,274	(-19.3%)
(Inverter type)	813,078	(11.3%)	3,269,617	(-14.2%)
PAC	**60,689**	**(-14.7%)**	**408,245**	**(-16.8%)**
Cooling only	11,519	(-22.9%)	53,378	(-16.8%)
Heat pump	49,170	(-12.5%)	354,867	(-13.7%)

UK partnership deal for gas AC

United Kingdom - British Gas and Mitsubishi Electric are combining forces to sell and install domestic gas air conditioners/ heat pumps. Incentives to households include low deposit and a period of interest-free credit. The target is 1,600 units in the first year rising to 20,000 units by 2003. Mitsubishi already holds 6,500 units in stock.

Source: JARN, July 1998

China's market statistics

China - Production figures announced by the China Association of Refrigeration showed that 8.5 million room air conditioners are produced annually in China, of which 50% are of the split-type. Building construction rates in larger cities have reached an all-time high: in Beijing and Shanghai new living space increased at an annual rate of 10 million m^2 over the past five years.

Source: JARN, July 1998

ASHRAE projects

USA - At the ASHRAE Annual Meeting in Toronto, Canada last June, the budgets for the 1999-2000 Research Plan were approved. The total budget is USD 3.2 million. Some of the funds were allocated to indoor air quality, comfort and health (20%), energy conservation (20%), environmentally safe materials (15%) and refrigeration systems (5%).

The Swiss Federal Institute of Technology has received a grant of USD 143,000 from ASHRAE to study the effects of oil on the performance of positive displacement compressors with R-410A and R-507A. If oil separation is not 100% efficient, the influence of oil on heat transfer performance is significant. Until state-of-the-art compressor technology offering 'oil-free' bearings is available on the market, heat transfer research must continue to determine the characterisation of oil effects. The work is to be completed in 2.5 years. ASHRAE Technical Committee 8.5 (Liquid to Refrigerant Heat Exchangers) is monitoring progress.

Source: ASHRAE News – July 1998

Workshop on deployment activities for heat pumping technologies

Sweden - In May 1998 a workshop on deployment activities for heat pumping technologies was held in Stockholm, Sweden. It was organised by the Royal Institute of Technology, the Swedish Council for Building Research and the Swedish National Energy Administration, all based in Stockholm, in collaboration with the IEA Heat Pump Centre. The workshop provided a platform for discussing the successes and setbacks of promotional programmes, the influence which deregulation of the energy sector has had on the heat pump market, opportunities for specific technologies, and actions to remove technological barriers in collaboration with researchers and industry. Obstacles for successful market introduction include lack of information, attitudes of the different target groups, lack of experience and barriers relating to various regulations, standards and energy/environmental policies.

Although all countries need a marketing strategy tailored to the requirements of its population, international cooperation is a good way for countries to learn from each others' strengths and weaknesses. Through international collaboration problems can be solved quicker and cheaper. Possible international activities include defining and meeting international information needs, developing user-friendly computer programs, discussing successes and setbacks to the introduction of heat pumps and the need for activities to overcome these obstacles, etc.

The workshop provided a useful overview of a broad range of deployment activities, which will form a practical basis for further international collaboration.

Source: Gerdi Breembroek,
IEA Heat Pump Centre

Ongoing Annexes

Red text indicates Operating Agent. Japan is the Co-operating Agent of Annex 18.

Annex 16 IEA Heat Pump Centre	16	AT, ES, JP, NL, NO, CH, US
Annex 18 Thermophysical Properties of Environmentally Acceptable Refrigerants	18	CA, DE, JP, SE, UK, US
Annex 22 Compression Systems with Natural Working Fluids	22	CA, DK, JP, NL, NO, CH, UK, US
Annex 23 Heat Pump Systems for Single-Room Applications	23	CA, FR, CH, US, SE
Annex 24 Ab-Sorption Machines for Heating and Cooling in Future Energy Systems	24	CA, IT, JP, NL, SE, UK, US
Annex 25 Development of Practical Concepts for Year-round Residential Space Conditioning and Comfort Control Using Heat Pumps	25	FR, NL, US

IEA Heat Pump Programme participating countries: Austria (AT), Belgium (BE), Canada (CA), Denmark (DK), France (FR), Germany (DE), Italy (IT), Japan (JP), The Netherlands (NL), Norway (NO), Spain (ES), Sweden (SE), Switzerland (CH), United Kingdom (UK), United States (US).

Successful Annex 23 workshop held

Canada - At a two-day workshop on 'Heat Pump Systems for Single-Room Applications' (environmental leadership with smart heat pumping systems for residential and commercial buildings), approximately 80 participants from 10 countries got together to discuss heat pump issues for single-room applications. The workshop was held June in Niagara Falls, Canada. The programme included 22 speakers, 10 poster papers, 10 exhibitors and a panel session involving several attendees. Many novel heat-pumping ideas were presented at the workshop. The clear message was that distributed heating and cooling systems have a tremendous potential to save energy and improve comfort in residential and commercial buildings.

Utility sponsored research suggests that energy savings as high as 30% can be achieved just by moving from a central system to a distributed system with individual room controls. Research in the Pacific Northwest suggests that these savings could be even higher for many regions of the USA. This is before applying the COP of the heat pump. Despite the plentiful supply of single-room systems and the favourable economics for many of these products, they are far from achieving their market potential.

One of the questions discussed was: 'Are heat pumps a renewable energy technology?' Switzerland is the only country of the Annex 23 participants that has clearly identified heat pump systems in this way. The consensus was that heat pumps are indeed a form of renewable energy and should therefore be given the same status as other renewable technologies. Other discussions covered refrigerant issues, energy efficiency, duct standards, and the importance of training for designers, installers and engineers.

A submission will be made to the IEA to continue Annex 23 and to test some of the novel products identified in the first phase.

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Alternative working fluids

An international overview

Hanneke van de Ven, IEA Heat Pump Centre

The search for sustainable working fluids is a major challenge for the industry involved in heat pumping technologies. This overview analyses the current status in different countries and shows which factors influence the selection of a working fluid. Current developments are reviewed as well as some applications using alternative working fluids.

Chlorofluorocarbons (CFCs) were introduced in the 1930s as a 'safety option' to limit the use of ammonia, which is toxic and flammable. The discovery of the ozone depleting potential (ODP) and later the global warming potential (GWP) of CFCs and hydrochlorofluorocarbons (HCFCs) has led to a tremendous worldwide increase in research and development of possible substitutes.

In a series of international conferences global agreements were made to limit the use of environmentally harmful substances. **Table 1** shows the phase-out schedule of CFCs and HCFCs for industrialised countries, which was agreed under the Montreal Protocol and its amendments and adjustments. HCFCs should be phased out for industrialised countries by the year 2020, and should be phased out entirely by 2040. The European Union has adopted an accelerated phase-out schedule for these substances, which requires them to be phased out by January 2015. Some countries in Europe (Sweden, Germany, Denmark, Switzerland and Austria) also have an accelerated schedule and will phase out R-22 for new systems between 1998 and 2002.

Alternative working fluids can be categorised in 'synthetic' substitutes (hydrofluorocarbons or HFCs), their mixtures and 'natural' refrigerants. HFCs do not contain chlorine and therefore do not have an ozone depleting effect, but they still have a global warming potential. Natural refrigerants are those that occur naturally in the environment, and include hydrocarbons, CO_2, ammonia, air and water. These refrigerants do not have an ODP and no, or very limited, GWP. However, flammability, toxicity and high vapour pressures restrict their application.

▼ *Table 1: Phase-out schedule for HCFCs and CFCs for developed countries.*

Date	Control Measure
1 January 1996	• CFCs phased out (1) • HCFCs frozen at 1989 levels of HCFC + 2.8% of 1989 consumption of CFCs (base level)
1 January 2004	• HCFCs reduced by 35% below base levels
1 January 2010	• HCFCs reduced by 65%
1 January 2015	• HCFCs reduced by 90%
1 January 2020	• HCFCs phased out allowing for a service tail of up to 0.5% until 2030 for existing refrigeration and air-conditioning equipment

(1) With exemptions for essential uses.

Source: UNEP IE 1998 Internet site
(http://www.unepie.org/ozat/protocol/countdow.html).
This source also contains information on the phase-out schedules for developing countries.

Refrigerant choices

The **box** on the next page contains specific factors that should be taken into consideration when selecting a new working fluid for a retrofit or new application. The factors include thermodynamic, technical, economic, environmental and safety criteria.

Although general selection criteria can be defined, the same choices are not made in all regions, as individual factors are valued differently in certain countries. In fact the world is divided into four regions as far as working fluids are concerned: USA uses safety refrigerants; Japan also uses safety refrigerants and 'hardly' flammable mixtures to achieve higher energy efficiencies; Europe uses both safety refrigerants and an increasing amount of natural refrigerants (both flammable and/or toxic); and the developing countries, which are still allowed to use (H)CFCs, although flammable refrigerants are used as well. The pink boxes on the following pages describe the status of some countries in more detail. The refrigerant trends in Switzerland and the Netherlands are described in the articles on pages 15 and 23 respectively.

In the USA manufacturers have collaborated to identify and investigate substitutes in the Alternative Refrigerants Evaluation Program (AREP), initiated by the Electric Power Research Institute (EPRI) and the Air Conditioning and Refrigeration Institute (ARI). Canadian, Japanese and European manufacturers joined the programme later. The US choice to focus mainly on HFCs is driven by a combination of regulatory and legal obstacles in addition to technical considerations. In the US legal climate where product liability suits and jury awards for millions of dollars in damages are common, manufacturers are held strictly liable for the safe use of their products, so they are not likely to choose the risks associated with hydrocarbons. Ammonia, which is toxic in low concentrations and mildly flammable at high concentrations, has similar problems. However, attitudes towards ammonia may be slowly becoming more positive.

In Japan manufacturers have chosen HFCs and their blends. However, some new ammonia installations have been built, due to relaxation of the regulations governing these systems. Other natural working fluids will not be an option in Japan in the short term, but development of safer systems may change attitudes as far as hydrocarbons are concerned. Developments on CO_2 as a refrigerant for heat pumps are also ongoing.

Europe has a more positive climate for the use of natural working fluids, although HFCs and blends are also used. Examples of natural working fluid applications are discussed below.

Aspects of refrigerant selection

Global environmental aspects
- Ozone depletion potential
- Global warming potential
- Leakage indicator

Thermodynamic properties
- Projection of boiling curve; P/T relation
- Critical and freezing temperature
- Volumetric performance
- Compression work and temperature after compression

Safety
- Flammability of vapour in air
- Toxicity
- Leakage indicator
- Damage to products

Technical issues
- Compatibility with construction metals and plastics/rubbers
- Chemical stability, influence of water, oil and materials
- Miscible with oil for dry expansion system
- Flow resistance and heat transfer

Economics
- Refrigerant and component availability
- Price of the refrigerant
- Resulting equipment costs
- Energy consumption

Applications

It is obvious that choosing a certain working fluid always depends on the type of application. In 1997 the IIR carried out a survey to find out what equipment was available to run on ozone-safe refrigerants. The main refrigerant trends for each application area are reflected below.

Refrigerator-freezers have been changed from R-12 to R-134A. In Europe, especially in Germany, isobutane and mixtures of isobutane and propane are used, with similar efficiencies. Tests have shown that flammability is not a severe problem. These household appliances normally have an extremely low leakage rate due to the hermetically sealed system and small refrigerant charge (<150 g).

In *commercial refrigeration* a variety of systems are offered: in direct evaporation systems R-12 and R-502 have been replaced by R-22 or mixtures based on R-22. R-404A and R-507 are used nowadays for low-temperature direct evaporation systems. For medium-temperature cooling R-404A, R-507 and R-407C are becoming more popular, although R-22 is still the favourite. For reducing the refrigerant charge (and refrigerant losses) of commercial refrigeration systems, secondary loop systems are gaining ground in Europe. These indirect systems enable the use of flammable and/or toxic refrigerants such as ammonia, propane and propylene in the primary circuit. Reducing the number of compressors in such systems means that the capacity of the two compressors most commonly used can be increased, which also increases the efficiency. This, and an improved control strategy, can overcome the disadvantages of the additional heat transfer loss and the brine circulation pump, so that these new systems are more efficient than traditional direct evaporation systems.

Centrifugal *chillers*, originally working with R-11, were modified initially to R-123, but now the favourite seems to be R-134A. In Europe new large systems are equipped with screw compressors and use ammonia. Rooftop installations are very common. One new development involves direct evaporation/ condensation systems with centrifugal compressors using water R-718 as refrigerant and heat/cold carrier. Due to the high pressure ratios required, the cooling capacity should be higher than 1 MW. The smaller capacity range is globally dominated by reciprocating compressors which use R-22 and, especially in the US, manufacturers and consumers are very reluctant to change to alternatives. In Europe this is enforced by regulations. Alternatives are the non-azeotropic mixture R-407C and ammonia, propane or propylene.

Unitary equipment is mainly based on the use of R-22. The possible synthetic alternatives for direct evaporation/ condensation systems are R-134A for larger units, R-410A for small units, and R-407C across the whole range. For indirect units, usually water-based systems, ammonia, propane and propylene are also used. R&D is ongoing regarding the utilisation of CO_2 for small reversible systems for water heating.

For *heat pump applications in industry* and for *district heating networks* with condensing temperatures up to 84°C, HFC-134A is most commonly used.
To allow the use of ammonia for higher condensing temperatures 40-bar compressors for condensing temperatures of 74°C are available, and 60-bar compressors will follow soon.

Direct-evaporation ground-coupled heat pumps (mainly used in Austria) and outside-air heat pumps are using R-407C or, increasingly, propane and propylene. Heat pump water heaters were initially changed from R-12 to R-22, but now R-134A or propane is being used. New developments on utilising the transcritical CO_2 cycle look promising. By using the temperature glide, and thereby reducing heat transfer losses, highly efficient systems can be realised.

In *air-conditioned vehicles*, the choice of R-134A equipment is a universal choice in cars. For train and bus air conditioning, the choice for replacing R-22 equipment may not be definitive yet. German companies have installed several air systems in trains.

R-410A and R-407C

Two of the most promising alternative working fluids for eventually replacing R-22 in heat pumping applications are the blends R-410A and R407C. The main difference between the two is the chemical composition: R-410A is a mixture of R-32 and R-125 with minimal temperature glide, while R-407C consists of R-32, R-125 and R-134A and has a large temperature glide.

R-407C is the only refrigerant available for immediate use in existing R-22 plants – thermal properties and operating conditions are close to those of R-22. However, because of its temperature glide it is only suitable for certain systems. The use of this refrigerant is increasing, although there are still some engineering difficulties for service companies and manufacturers.

Research has shown that the use of R-410A can result in an improved COP compared to R-22. Using R-410A means that overall cost reductions can be achieved, because the system components, particularly the compressor, can be significantly downsized since it has a higher volumetric capacity. The main disadvantage is the higher operating pressure compared to R-22, which indicates that the pressure-proof design of most components should be reviewed. R-410A is very popular, mainly in the US and Japan, for packaged heat pumps and air-conditioning units. Commercial R-410A components for small- and medium-sized refrigeration systems are either already available or under development.

Hydrocarbons

Leading countries in the application of hydrocarbons are the UK, Sweden, Germany and Austria. The Netherlands are also using residential heat pumps charged with propane in certain projects. From one of the previous paragraphs the reader can conclude that hydrocarbons are mainly used in applications which require a small refrigerant charge, such as residential heat pumps, refrigerators, etc., and in indirect systems. However, Europe also has some doubts about the safety of using flammables. This is illustrated by a statement from the Association of European Compression Manufacturers (ASERCOM) in 1997, that they do not (yet) promote the use of hydrocarbons in refrigerating systems with a charge of over 150 g.

The Sånga-Säby Conference Centre, located just outside Stockholm, Sweden, is equipped with a propane heat pump system. The conference centre is certified according to ISO 14001 and ISO 9002 standards and has received the International Hotel Association's 'Green Hotelier' award. The system consists of three heat pump units with a total charge of 24 kg propane. The calculated heating capacity delivered by each heat pump is 70 kW at a heat sink temperature of 54/63°C and a heat source temperature of -1/-5°C. 'Free cooling' by sea water is applied in the summer. If there is still a demand, one of the heat pump units is reversed and may be used for cooling. The system has been in operation since August 1997.

Ammonia

Ammonia has been used for a long time, mainly in food preservation and industrial applications, but in several countries, especially Norway, ammonia is becoming the dominant working fluid for larger commercial and institutional installations, such as heat pumps in district heating and cooling systems, and for heat pumps and liquid chillers in commercial buildings.

An example project using an ammonia heat pump system is given in the article on page 20, which describes the installation at the new Oslo Gardermoen Airport. In Frankfurt, Germany a large installation using ammonia was installed for air conditioning in a large office building, replacing the 24-year old R-11 system. The cooling capacity of 4,400 kW is provided by three liquid chillers with screw compressors of 1,340 kW each and a chiller with a reciprocating compressor of 400 kW. This installation, which is unique in Germany, is located on the 40th floor of the building. All kinds of safety measures have been implemented. The operating costs are much lower than in the past, because the new efficient compressors ensure that the electricity consumption is reduced from 1,400 kW to 700 kW under a constant load capacity.

The renewed attention to ammonia is illustrated by the fact that around 950 people attended the annual meeting of the International Institute of Ammonia Refrigeration. In a plenary session, Mr Pearson of the Institute of Refrigeration in the UK defined five common characteristics of well-designed and efficient ammonia systems:

- simple design;
- low charges;
- easy to maintain;
- good venting;
- good access and escape routes.

The statement concluded that if these design rules are complied with, the safety record of ammonia systems will be as good, if not better, than comparable halocarbon systems. The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) also has four ongoing research projects involving ammonia refrigeration. The contract value of the research is around USD 400,000.

CO_2

CO_2 is a potentially strong refrigerant that is attracting growing attention from all over the world. This is illustrated by the many participants at the IIR workshop held in Norway, May 1997 (proceedings are available from the IEA Heat Pump Centre), and the amount of CO_2-related papers at the IIR Conference on Natural Working Fluids in June 1998 in Oslo, Norway. However, CO_2 products are still under development, and research continues to improve systems and components. Outside Europe, CO_2 research is also conducted in Japan, New Zealand and the US (see the article from Japan on page 17). A prototype heat pump water heater has already been developed in Norway (see Newsletter Vol.15/04). CO_2 is now being used as a secondary refrigerant in cascade systems for commercial refrigeration. Within the IEA Heat Pump Programme a proposal has been launched for a new international collaborative project on ‘Selected issues on CO_2 as a working fluid in compression systems’.

Water

The main application area using water as a working fluid is in mechanical vapour recompression (MVR) systems in industrial processes. Several water chillers and industrial heat pumps using water as the working fluid have been installed in Denmark and the United Kingdom. Ice-slurry and binary-ice are gaining popularity as secondary refrigerants for air conditioning and commercial refrigeration. The main problem regarding water as a working fluid is to find reasonably priced and efficient compressors capable of handling large volumetric flows in combination with high pressure ratios and high discharge temperatures.

The IIR Conference on Natural Working Fluids in June 1998, at ILK in Dresden, Germany, presented the first test results of a ready-to-use, compact, hermetic water cooler. The cooler uses water as a refrigerant and is driven by a turbo compressor. This new machine has a performance range between 500 and 1,000 kW, depending on the chosen vaporisation temperature. Cold water can be provided in a temperature range between 0°C and 20°C.

The process takes place in vacuum. Proper functioning has been demonstrated using a full-sized experimental unit.

Austria

Copenhagen 1994 marked the agreement to end the production of CFCs by 1 January 1996, at least in the industrialised countries, and to phase out HCFCs by 1 January 2030. However, the European Union (EU) directive of December 1995 requires accelerated phase-out of HCFCs by January 2015. Austria, being an EU member, must comply with this regulation. Additionally, the Austrian government has decided to ban HCFCs for new equipment by 1 January 2002. Within this framework, Austrian manufacturers and distributors of heat pumping equipment have had to make the following decisions.

Heat pumps for space heating purposes: the market is divided into two sectors, one using synthetic alternatives such as R-404A and R-407C, the other using the hydrocarbons R-290 (propane) and R-1270 (propylene). Most manufacturers and distributors are currently using hydrocarbons, using units designed for outdoor installation to comply with the regulations for flammable working fluids.

Heat pump water heaters: units designed for R-22 still use this refrigerant, the former users of R-12 have changed to R-134A.

Split air conditioners: the majority still use R-22, although one company already offers a unit using R-407C which gives better performance than the old R-22 unit. The interesting thing is the background of this decision: R-407C seems to be only an intermediate solution for Europe with its accelerated phase-out scenarios. The final refrigerant will be R-410A, a high-pressure fluid requiring 40-bar technology.

Air-conditioning systems: R-22 is still the main refrigerant. When replacing R-11 units, R-134A is one possibility, though systems using ammonia or hydrocarbons are also being considered.

Refrigeration systems: there is a trend away from direct evaporation towards secondary loop systems using synthetic working fluids such as R-404A and R-507 as well as natural working fluids such as ammonia, propane and propylene. Secondary fluids are usually brines (with the disadvantage of high mass flow rates, especially at low temperatures, high pressure drops, and low heat transfer coefficients), but systems using ice slurry and CO_2 as secondary fluids are also being considered.

Refrigerators and freezers: Most new equipment, imported mainly from Germany, uses R-600A as working fluid, the others use R-134A.

By incorporating this variety of solutions, Austria is reflecting developments around the world: these are split into synthetic “safety” refrigerants (North America and parts of Europe), “hardly” flammable refrigerants to achieve higher efficiencies (Japan) and natural refrigerants. Some of these are flammable and/or toxic (hydrocarbons and ammonia), but some are “safety” refrigerants such as water and CO_2 (parts of Europe).

Source: Hermann Halozan, Austrian National Team (see back cover)

Air

An air system can be applied for both heating and cooling purposes. Even though current systems are very reliable, compact, lightweight and have no problems with leakages and loss of charge, they suffer from a relatively low energy efficiency compared to vapour compression systems. The expected development of high-efficiency oil-free compressors and expansion machines, as well as recuperators (heat exchangers), may alter this picture, and make the air-cycle systems an interesting and competitive alternative to conventional systems for certain applications. The most promising new applications using air as a working fluid include industrial blast freezing for the food manufacturing industry (-30/-40°C), transport refrigeration (rail transport etc.) and industrial drying processes.

Commercial refrigeration

A large application area for natural working fluids is commercial/supermarket refrigeration. Within the IEA Heat Pump Programme, a new Annex has been proposed which aims to demonstrate advanced systems for food refrigeration and space heating and cooling for supermarkets. The goals are to significantly reduce the total refrigerant charge requirements, thus reducing the total energy use and significantly reducing the total equivalent warming impact (TEWI). Annex 22 on Compression Systems with Natural Working Fluids has also given attention to supermarket refrigeration using natural working fluids. A number of systems with a central ammonia plant with different brines or secondary refrigerants, such as CO_2, already exist. Propane is also used as a primary refrigerant.

There are many variations in the way secondary systems in commercial refrigeration installations are used. Some use single-phase secondary fluids such as glycol solutions, others use two-phase secondary fluids such as CO_2 or ice slurries. Retail refrigeration requires two temperature levels: one for frozen produce and one for chilled produce. Generally, two loops will be required, one for each level. A schematic of a basic system is shown in **Figure 1**. A single-phase secondary fluid is pumped around a

Japan

Due to the ozone depletion problem of HCFCs, the Japanese government plans to phase them out by 2010. Since the 1980s, Japanese industries have been involved in the research and development of new refrigerant substitutes for HCFCs. Various refrigerants have been evaluated by manufacturers under the international alternative refrigerants evaluation programme (AREP) and the Japanese alternative refrigerants evaluation programme (JAREP). Manufacturers now seem to have settled on using HFCs and their blends as substitutes: azeotropic high-pressure R-410 for room air conditioners and zeotropic blend R-407C for packaged air conditioners. All HCFCs used in both room and packaged air conditioners will be replaced by the aforementioned new HFC blends over the next 5-6 years.

However, at the 1997 Kyoto Conference HFCs were named as greenhouse gases which must be reduced by 6% during 2008-2012, compared to the 1995 level. Therefore, natural working fluids such as ammonia, hydrocarbons, CO_2, air and water have been considered as alternative refrigerants. As a result of relaxing the regulations for ammonia, some new systems using ammonia have recently been installed in Japan. Examples include an ice thermal storage heat pump chiller for space conditioning, refrigeration for cold storage facilities and ice making chillers for the 1998 Nagano Winter Olympic Games.

Reluctance to use hydrocarbons as alternative refrigerants stems from their flammable characteristics. However, it is conceivable that development of safer systems could allow their use as refrigerants. As for other natural working fluids, research and development activities are still rather sporadic.

Source: Mr Takeshi Yoshii and Ms Xiaomei Li, Japanese National Team

Norway

Ammonia is the preferred working fluid for larger heat pumps in Norway. All district heating and cooling systems installed since the early 1990s have used ammonia. Because investment costs are higher than for HFCs, the use of ammonia is limited to units with heating capacities of 200-250 kW.

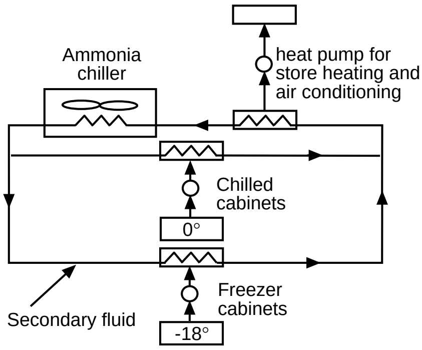
For units with heating capacities of 50-100 kW and temperature requirements over 55°C, HFC-134A is the dominant choice of working fluid. With a condensing temperature of 78°C at 25-bar pressure, outlet water temperatures of more than 70°C can be reached. HFC-134A gives high COPs, and is well proven as a working fluid.

For smaller units with lower temperature requirements and less than 100 kW heating capacity, HCFC-22 is still one of the most popular working fluids. Beside the Montreal Protocol, Norway has decided to follow the European Union phase-out schedule, and prohibits HCFCs in new equipment from the year 2000. The HFC blends R-404A, R-407C and R-410A are the most promising replacement candidates, and units with HFC blends are already on the market.

Several suppliers are offering small heat pump units for residential use with the hydrocarbons propane and propylene as working fluids. Hydrocarbons are flammable, so their use is limited to small hermetically sealed units with low refrigerant charge. Hydrocarbons are natural working fluids with zero ODP and GWP. Norway has carried out extensive research on CO_2 for more than a decade and has identified several promising applications. Pilot plants are being designed for tap water heating in hotels and commercial buildings.

Source: Jørn Stene, Norwegian National Team

▼ *Figure 1: Schematic of integrated refrigeration and store heating system for a supermarket.*



Note: Heat pump and cabinet refrigeration units use hydrocarbon refrigerants

ring main. This acts as a heat sink and heat source for freezer, chiller and heat pump compressor packs. Any surplus heat from the secondary fluid is rejected to the outdoor environment via a primary chiller.

Conclusion

In the past few years tremendous efforts have been made in the research and development of alternative working fluids. These efforts have resulted in considerable improvements in the efficiency and applicability of alternatives. However, over the next few years optimisation of heat pump systems using alternative working fluids will continue to be a very important issue for the heat pumping industry, to achieve the highest possible efficiencies, while keeping the impact on the environment as low as possible.

Hanneke van de Ven,
IEA Heat Pump Centre

Sources:
H. van der Ree, Replacement of R22, *IIR Bulletin 98/01, pp. 5-17.*
IIR Gustav Lorentzen Conference, Natural Working Fluids 1998, pre-prints.
Environmental Benefits of Heat Pumping Technologies, HPC Analysis Study, due for publication end 1998.

Spain

One of the activities concerning natural working fluids currently being implemented in Spain is a project to develop a high efficiency air-to-water reversible heat pump for commercial applications in southern Europe. This project aims to develop a solution for commercial applications which is appropriate in terms of size, efficiency and type of working fluid used. Propane has been suggested,which has already been used in other applications in northern and central Europe. This project will provide European manufacturers – in particular those in southern European countries – with tools and equipment tested under conditions and for applications typical of the region.

It is hoped that these objectives can be achieved by using computational optimisation tools and the experimental characterisation of the main components necessary to construct an industrial prototype. There are three main phases in the project. The characterisation and testing phase focuses on the main components and includes the design and construction of the necessary test setups. The modelling and design phase centres on developing the appropriate computational tools to optimise and design the individual components. The construction phase involves producing the individual components in their improved design and assembling the entire heat pump plant. Both industrial and research partners are involved in the project, which will enhance the widespread use of the technology.

Source: Mr Juan de Blas, Spanish National Team

USA

The United States is focusing primarily on HFCs as replacement refrigerants for CFCs and HCFCs. The choice to move toward HFCs is driven by a combination of regulatory and legal obstacles, as well as technical considerations.

Total equivalent warming impact (TEWI) analyses covering five air conditioning and refrigeration product application areas have recently been completed. These indicate that more efficient systems, which reduce CO_2 emissions associated with power generation, are the most effective means of controlling global warming for areas with low levels of refrigerant leakage (domestic refrigeration, large commercial chillers, and unitary/light commercial air-conditioning products). Use of a near-zero GWP refrigerant would be effective in automotive air conditioning and direct-expansion commercial refrigeration systems used in supermarkets, where significant annual refrigerant losses occur. Advantages associated with reduced refrigerant charge size, reduced leakage, maintenance/servicing advantages, and better product temperature stability are enough to make secondary loop systems more attractive than the direct-expansion refrigerant systems they are displacing in supermarket installations. Once customer confidence in secondary loop distribution systems grows, industry insiders speculate that the use of ammonia in supermarket refrigeration systems may follow. One US commercial refrigeration manufacturer has installed several secondary loop systems in supermarkets. Research projects are underway at the University of Illinois-Urbana, Purdue University, and the University of Maryland on secondary loop commercial refrigeration and the use of CO_2 as a refrigerant.

Existing governmental codes, standards, and regulations in the United States influence the use of flammable and/or toxic natural refrigerants in refrigeration or air-conditioning products. A recent report by Keller, et. al., states that the increased costs associated with additional safety features, required when propane is substituted for R-22 in a 10.5 kW (3 ton) unitary split air conditioner, cannot be economically justified by the resulting TEWI reduction.

Source: Jim Sand and Kathryn King-Jones, Oak Ridge National Laboratory

Trends in the use of working fluids

Erwin Ochsner, Switzerland

Research has revealed that refrigerants containing chlorine contribute to the depletion of the upper ozone layer and the greenhouse effect. Therefore plans have been drawn up for the phased elimination of environmentally harmful refrigerants. As a result, refrigerant manufacturers have introduced a number of substitutes and mixtures onto the market, the sheer number of which has served to confuse the user. Today, the situation has calmed down somewhat because practical experience has been gained with the main substitutes. This report illustrates, from a Swiss perspective, the current trends in the use of working fluids.

Refrigerant groups

CFCs belong to the group of prohibited refrigerants. Due to their high ozone depletion potential the manufacture of these refrigerants, and their use in new plants, is now banned although they are still permitted in existing plants. However, only purified (recycled) refrigerants from decommissioned and retrofitted plants are available. It is therefore expected that these refrigerants will become more and more expensive, and at some point will no longer be available. This group includes the following refrigerants: R-11, R-12, R-13, R-113, R-114, R-115, R-500, R-502, R-13B1.

HCFCs are so-called transitional refrigerants. These are also sometimes categorised as retrofit and service refrigerants. Since they are blends based on R-22, they still contain chlorine. They should therefore only be used for retrofit applications. HCFCs include R-22, R-401, R-402, R-403, R-408 and R-409.

HFCs can be considered long-term alternative refrigerants. This means that they are chlorine-free refrigerants such as R-134A, R-404A, R-407A/B/C, R-410A/B and R-507. Since they do not contribute to ozone depletion, these are long-term alternatives to R-12, R-22 and R-502. However, they do still contribute to global warming. Special attention must be given to the use of lubricants. Mineral oils are non-miscible with these refrigerants. Normally only ester-based lubricant oils recommended by the refrigerant manufacturer should be used. Mineral oil residues must be completely removed during retrofitting.

The group of *natural refrigerants*, such as propane (R-290), butane (R-600), carbon dioxide (R-744), and ammonia (R-717), are characterised by an ozone depletion potential (ODP) of zero, and very limited, or no, direct global warming potential (GWP). Apart from temporary effects, they are environmentally neutral. Their application, however, is restricted by their flammability, toxicity and high vapour pressures. In Switzerland, the general opinion is that if the installation instructions and constructional requirements are adhered to, their application and use should present no problems.

In Switzerland CFC refrigerants such as R-12 and R-502 have been banned for new plants since 1 January 1994. HCFC refrigerants such as R-22 will not be allowed for new plants after 1 January 2002.

Characteristics

Depending on their characteristics, refrigerants are suitable for different applications. Manufacturers recommend R-134A as a substitute for R-12, because its thermodynamic properties are similar. The coefficient of performance (COP) and the compressor discharge gas temperatures are comparable to those for standard refrigeration and air conditioning. R-134A is also suitable for heat pump applications. Due to the lower refrigeration capacity, the compressor tends to be larger than for R-12. This factor is even more pronounced at lower evaporation temperatures. Its use for deep-freeze applications is therefore not recommended.

All series R-4xx refrigerants have a smaller or larger temperature glide, which should be taken into consideration when designing and operating the refrigeration cycle. R-404A is often used as a substitute for R-22 and R-502. This quasi-azeotropic blend is suitable for air conditioning, standard refrigeration and deep-freezing, but is seldom used for air conditioning. The direct GWP is relatively high.

Other possible substitutes for R-502 and R-22 are R-407A, B and C. These non-azeotropic refrigerants can also substitute R-505 in deep-freeze applications. The COPs for R-407A and R-407C are approximately 2-6% lower than those for R-502. As R-22 substitutes, R-407C and R-410A are energetically the most favourable compared to other alternative refrigerant mixtures. The cooling COPs are lower than those for R-502 or R-22. However, the comparatively high discharge gas temperatures restrict their range of application.

R-410A can also serve as a substitute for R-22. In the lower evaporation temperature range (less than -30°C), this quasi-azeotropic refrigerant provides performance advantages over R-22. Nevertheless, the working pressures are approximately 51% higher than those for R-22. In air conditioning, its application is currently generally limited to small units.

The mixtures of the R-5xx series have an azeotropic point. The thermodynamic properties of R-507 are similar to R-502. It is especially suitable for commercial refrigeration at evaporation temperatures from -45°C to 0°C. It can be used in new plants and retrofits.

Ammonia (R-717) has been used as a refrigerant for more than 120 years, and has a wide range of applications. Since the advent of synthetic refrigerants, it has been used principally in industrial refrigeration plants and for the production of ice. Today, refrigeration units using water or brine as heat transfer medium in the secondary circuit are increasingly coming back into fashion.

The hydrocarbons propane (R-290) and butane (R-600) have similar properties as R-22 and have been used as working fluids in the petrochemical industry for decades. Their flammability means that these substances are seldom used in commercial and air-conditioning applications. To date, domestic refrigerators have been running mainly on R-600. Propane is also being used today in small residential heat pump units.

Trends

The following trends are currently evident in Switzerland:

- domestic equipment with a small refrigerant charge use R-600A;
- Industrial units use R-717, R-407C or R-134A;
- heat pumps for building technology use R-407C, R-134A and R-290;
- commercial refrigeration applications use R-407C and R-404A;
- the use of R-410A in compact air-conditioning units is becoming more common. Units with capacities up to 500 kW are available in the USA and Japan.

▼ *Table 1: Environmental aspects of refrigerant groups.*

Refrigerant	Status	ODP	GWP
CFCs	prohibited	high	high
HCFCs	temporary	low	moderate to high
HFCs	chlorine-free/ allowed	zero	low
Non-HFCs	natural/ allowed	zero	zero

Selecting a refrigerant

When selecting a refrigerant for a specific application, several questions must be answered:

1. Which refrigerants are available for the foreseen operating conditions?
2. Can HFCs (or natural refrigerants) be used?
3. Which refrigerants from the refrigerant groups (HCFC/HFCs) can be put on the shortlist?
4. Must the refrigerant currently being used be substituted?
5. Which refrigerant results in the lowest overall costs?

Selection process

Due to the wide range of refrigerants currently available on the market, the refrigeration industry and plant operators are faced with the problem of finding the right substance for a specific application. The **box** above includes a checklist which may be helpful in selecting the appropriate refrigerant.

From compressor and refrigerant manufacturer data a list is available that shows properties such as volumetric refrigeration capacity, COP, pressure ratio etc. for different working fluids for specific combinations of evaporating and condensing temperatures can be calculated. These tables can be of help in the selection process. For example, the volumetric refrigeration capacity determines the size of the compressor: low capacities require larger compressors and vice versa. Another example is the pressure ratio, which determines the number of compressor stages. Normal pressure ratios are in the range of 2-6. Ratios higher than 9 indicate that it is not economic to use reciprocating compressors, while for screw compressors values up to 20 can be achieved. High pressure ratios require special consideration.

Preferred refrigerants are those which operate with a small compressor suction volume (i.e. high volumetric refrigeration capacity), have a low energy consumption (i.e. high cooling COP) and have no or very low GWP. If a good choice between two refrigerants is to be made, choose either one with a high volumetric refrigeration capacity at a slightly lower energy efficiency or one with a very good energy efficiency at a slightly lower volumetric refrigeration capacity (where possible without a step in compressor size).

Systems which are currently operating with CFCs should only be changed to more environmentally friendly refrigerants if problems with the refrigerant cycle occur. The choice of a retrofit refrigerant is influenced by various parameters; the age and condition of the plant being critical factors.

The environmental impact must be taken into account when selecting a refrigerant for new plants. **Table 1** compares properties of different types of refrigerants. An ODP of zero is a prerequisite, but also the direct and indirect global warming potential combined in a TEWI value (total equivalent warming impact) should be as low as possible. When choosing and designing a plant, it is important to balance environmental and economic considerations. The possibility of using natural refrigerants should be examined in every case.

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Acknowledgement:
Mr G. Reiner of Sulzer Friotherm AG, Rothenburg, Switzerland, supplied valuable information for the paragraph on selecting refrigerants.
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Evaluating the potential of CO_2 as a working fluid for heat pumps

Michiyuki Saikawa and Katsumi Hashimoto, Japan

Environmental protection is becoming increasingly important and heat pumps with natural working fluids are being developed eagerly. After surveying the current R&D of heat pumps with natural working fluids, the Central Research Institute of Electric Power Industry (CRIEPI) in Japan focused on developing heat pumps with CO_2 as a working fluid. CO_2 is neither toxic nor flammable and is said to have unique characteristics. CRIEPI started the study in 1995.

Because the critical temperature of CO_2 is very low, using CO_2 as a working fluid in a heat pump for space conditioning or domestic hot water results in a transcritical cycle (i.e. the pressure on the high-pressure side is supercritical). To evaluate CO_2 as a working fluid, research focused on the following topics:

- the characteristics and the COP of a transcritical CO_2 cycle;
- the behaviour and control methods of transcritical CO_2 cycles;
- the evaluation of CO_2 heat transfer under supercritical conditions.

This paper reports on the results of the initial phases and the research plan for the future.

CO_2 cycle

Under supercritical conditions CO_2 has a temperature glide, i.e. the temperature of the CO_2 decreases gradually as it gives off heat. So, even a simple cycle consisting of an evaporator, a compressor, a gas cooler and an expansion valve, is expected to result in a high COP for domestic hot water supply if a gas cooler with counterflow is used. The results of COP calculations for such a cycle are presented in **Figure 1**. When the domestic hot water temperature is set at 65°C, then the COP is 3.8, which is approximately 15% higher than that of R-22. For 85°C (the same temperature as an electric resistance water heater for residential use in Japan) the COP is 3.4, which is still quite high. The CO_2 heat pump is very promising for heating applications with such a high temperature lift, and is therefore suitable for room heating.

For a CO_2 cycle the minimum temperature difference of the gas cooler DT_{min} is important because it determines the compressor outlet pressure P_h. For a higher COP, the outlet pressure must be low. However when P_h is too low, the maximum temperature that can be reached by the cycle is limited. After setting DT_{min} at 5°C, P_h is automatically determined.

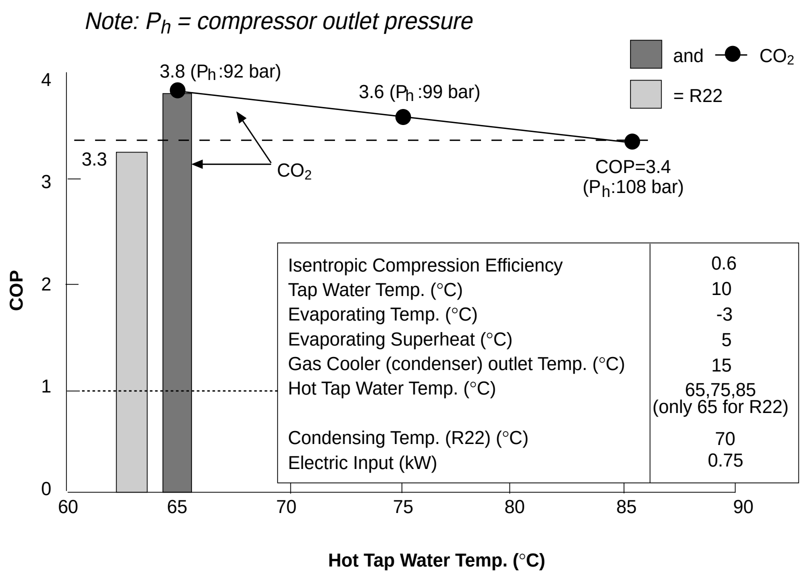
For room cooling, some improvements are needed to obtain a system with a high COP. Using a heat pump cycle with expansion turbine or two-stage compression is necessary, as well as adapting the design of components more precisely to the characteristics of CO_2. With such modifications a CO_2 system is expected to have almost the same performance as a system based on R-22.

Experimental loop

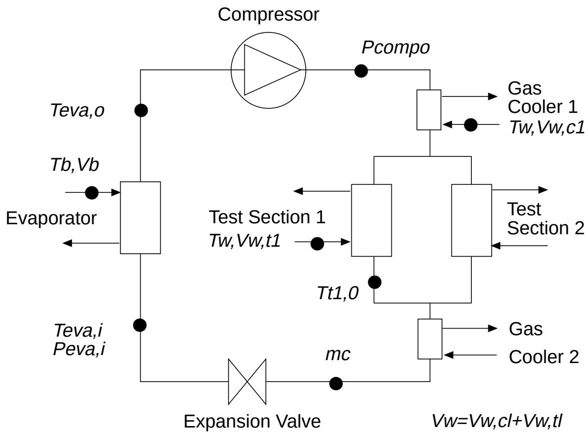
CO_2 cycle control might be difficult because, compared to conventional working fluids, variations in properties (density etc.) of CO_2 at the gas cooler outlet are larger under varying conditions. Control of the high-pressure side is also very important to obtain the maximum COP.

To study the behaviour and control methods, as well as the heat transfer under supercritical conditions, a CO_2 heat pump experimental loop was installed in

Figure 1: Calculation results of COP for hot tap water supply, with calculation conditions for winter season in Japan.

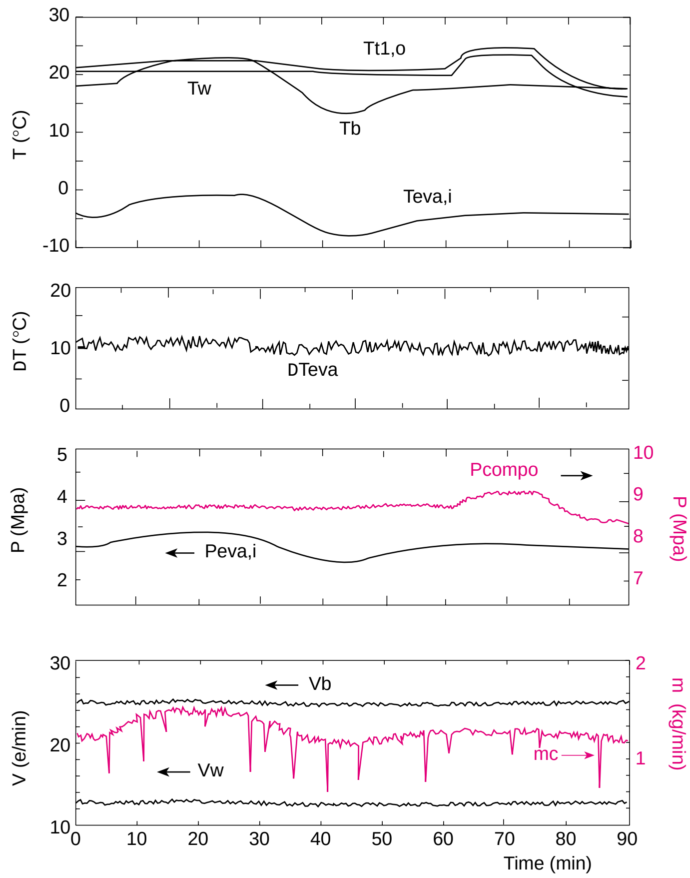


▼ *Figure 2: Schematic Diagram of the Loop.*



Test section 1: Heat transfer test section
Test section 2: Flow visualisation test section

▼ *Figure 3: Result with Varing Brine and Water Temperature.*



▼ *Legend Figures 2 and 3:*

mc = CO_2 mass flow
Teva,i = inlet temperature evaporator
Teva,o = outlet temperature evaporator
DTeva = pressure difference over the evaporator
Tt1,o = outlet temperature test section 1
Tb = brine temperature

Tw = water temperature
Vw,t1 = flow rate water test section 1
Vw,t2 = flow rate water test section 2
Vw = total flow rate water (Vw,t1+Vw,t2)
Vb = flow rate brine
Pcomp,o = outlet pressure compressor
Peva,i = inlet pressure evaporator

the Yokosuka Research Laboratory. **Figure 2** shows a schematic diagram of the loop.

The loop contains a compressor, gas coolers, an expansion valve and an evaporator. The heating capacity of the loop is 4-7 kW. The variable-speed compressor uses an inverter and is an oil-free reciprocating type with two cylinders.

The compressor was very expensive because it was tailor-made for this loop. The performance is therefore very low: around 50% lower than for conventional heat pump compressors. However, CRIEPI expects that a high-performance compressor can be developed if the characteristics of CO_2 are taken into consideration. The expansion valve consists of a needle valve and a stepping motor, so it functions automatically to keep a constant CO_2 temperature difference between the evaporator inlet and outlet. It can also be controlled manually.

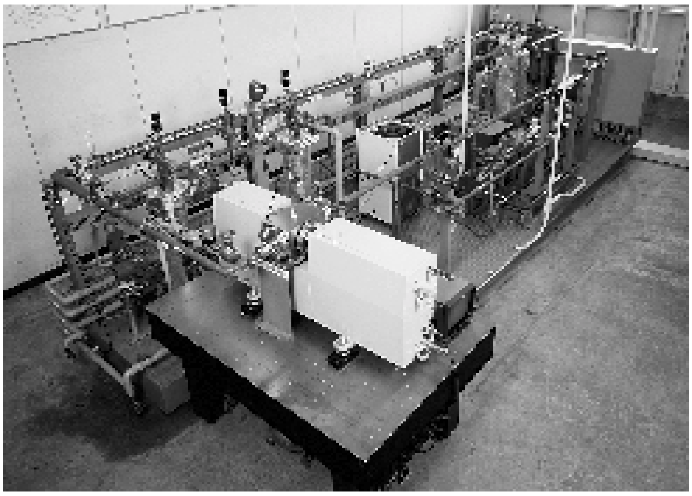
Control methods

First, some introductory experiments were carried out to become familiar with the behaviour of the loop. No large differences with conventional working fluids were experienced.

Secondly, tests were performed using an automatically controlled expansion valve. For these tests only one gas cooler and one test section were used, therefore no CO_2 came through test section 2 and no water was supplied to gas cooler 2. The upper part of **Figure 3** shows the varying temperatures of the heat source (brine) and the heat sink (water), while the compressor speed was kept at a constant level. The temperature difference between the evaporator inlet and outlet (DT_{eva}) was set at 10°C. As shown in the lower part of the figure, the flow rates of the brine and water were constant.

The CO_2 temperature and pressure at the evaporator inlet ($T_{eva,\,i}$ and $P_{eva,\,i}$) and the CO_2 mass flow (mc) varied as a result of the variation of the heat source temperature, with a constant temperature difference over the evaporator. The CO_2 temperature at the outlet of test section 1 ($T_{t1, o}$) and CO_2 pressure at the compressor outlet ($P_{comp, o}$) varied according to the changes in the temperature of the heat sink. From the figure it is clear that DT_{eva} was well controlled at 10°C by the automatic expansion valve. In another successful experiment the loop was operated with varying compressor speed.

The conclusion from these tests was that a CO_2 cycle can be successfully controlled by the combination of an automatic expansion valve and a variable-speed compressor.



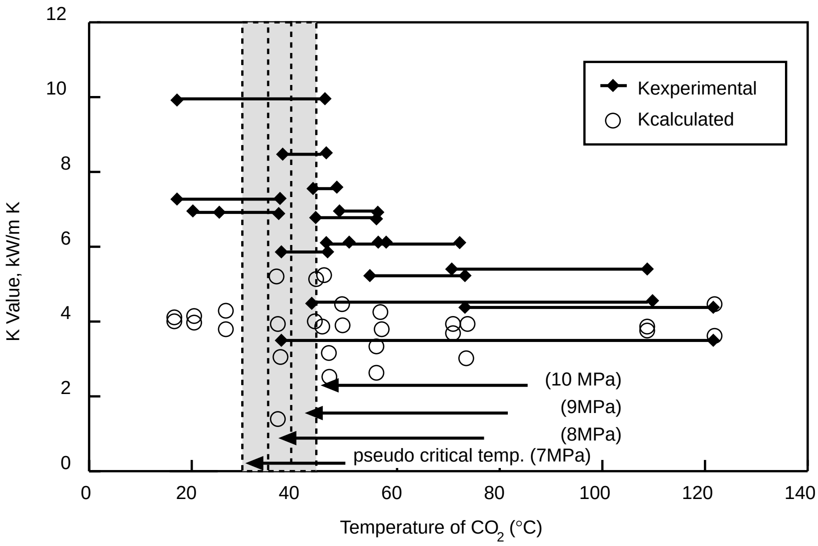
▶ *The experimental CO_2 loop.*

Evaluation of heat transfer

The loop had a second test section for studying CO_2 heat transfer under supercritical conditions. Again, brine was used as the heat source and water as the heat sink. Temperatures and flow rates of these fluids were controlled automatically. The test section consisted of four units. The heat transfer units consist of concentric tubes. The CO_2 in the copper tube was in counterflow with the water flowing in the outer cylinder. The water temperature was measured at both the inlet and the outlet of each heat transfer unit.

Figure 4 shows the results. It shows both the experimental and calculated overall heat transfer coefficients (K-value). The calculated values are obtained by using conventional correlation equations, which do not take the variations of thermophysical properties near the heat transfer wall into account. It is clear from the figure that the experimental heat transfer coefficient is higher than the calculated values. Secondly, the experimental K-value seems to have a maximum near-pseudocritical temperature.

▼ *Figure 4: Experimental results of heat transfer coefficient in gas-cooler.*



Conclusion and research

Throughout the first phase of this research, it was understood that the CO_2 cycle had unique characteristics and could achieve a higher COP than conventional working fluids for domestic hot water production, and almost the same COP for room cooling or heating. This also applies if the characteristics of CO_2 are taken into account during the design process. The CO_2 cycle can be effectively controlled by the combination of an automatic expansion valve and a variable-speed compressor. Furthermore, it was found that the CO_2 heat transfer under supercritical conditions is high. These results confirmed that CO_2 has a large potential as a working fluid for heat pumps.

The study of cycle control methods and heat transfer under supercritical conditions will be continued in detail. In addition, a study will begin regarding heat transfer in the evaporator. The complete study should result in an overview of the basic characteristics of CO_2, which would enable the design of a complete system. CRIEPI is also planning to develop a hermetic compressor with lubricant and a prototype CO_2 heat pump system.

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Oslo Gardermoen Airport – ammonia heat pump using ground water as heat source and heat sink

Trude Tokle, Norway

An 8 MW ammonia heat pump has been installed at the new Oslo Gardermoen Airport in Norway. The heat pump, which holds a refrigerant charge of 2,500 kg, uses ground water from the large Gardermoen ground water reservoir as its heat source. The ground water is also used to store excess heat during the summer season. The estimated annual energy supply from the heat pump is 4.55 GWh for heating and 3.9 GWh for cooling.

Oslo Gardermoen Airport, which on its opening will be one of the most modern airports in Europe, will open for passengers in October 1998. The initial planning began in autumn 1985, was approved by the Norwegian Parliament in October 1992, and the construction started in August 1993. The total investment of USD 3 billion includes railways, roads and the armed forces.

The 137,000 m^2 terminal building will include a railway station with a connection to Oslo Central Station, and is designed to handle up to 18 million passengers a year. Operational buildings cover another 18,000 m^2. The new airport also includes multistorey car parks and outdoor parking areas, control towers and operational buildings, a hotel and a conference centre.

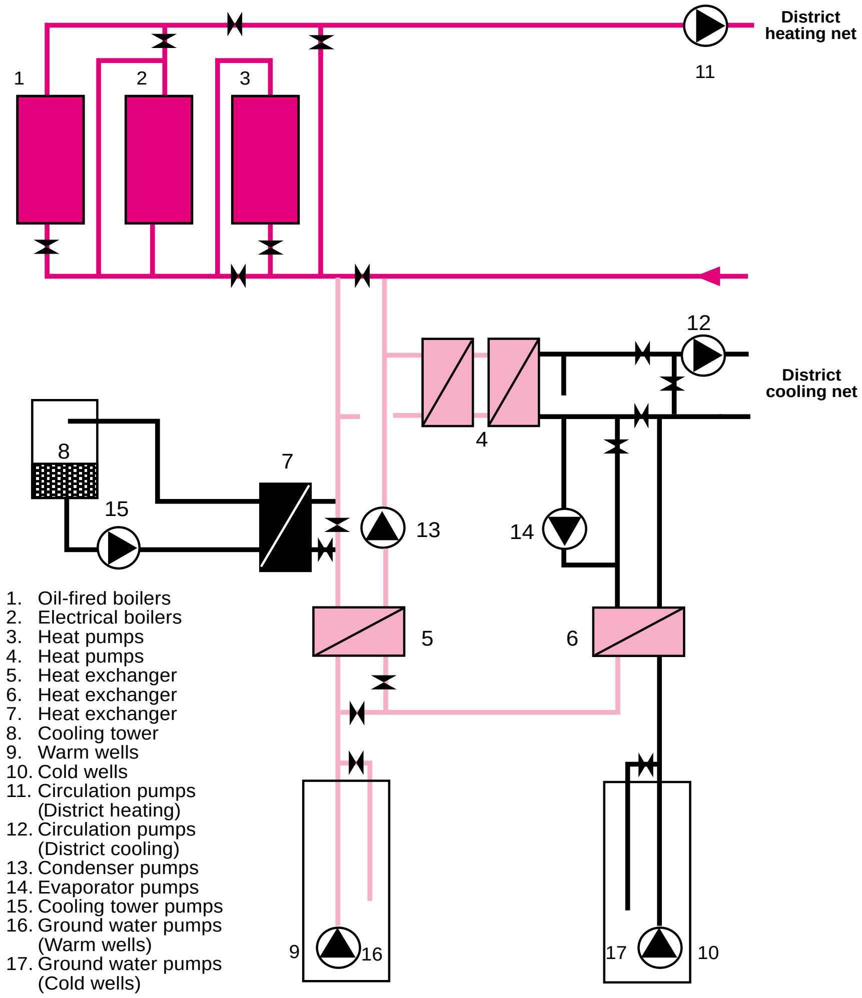
Central energy plant

The central energy plant will provide heating and cooling for the entire airport via a district heating and cooling system. This includes the terminal building, control tower, hotel, conference centre and operational (police and administration) buildings. The energy plant uses a combination of biomass (wood chips), fuel oil and electricity and heat pumps to cover the heating demand of the buildings. It is also used to melt snow on some road and apron areas at the airport.

In addition to direct ground water space cooling, heat pumps are used to provide space cooling during the summer. The heat pumps are primarily designed to cover the total cooling demand, and the excess heat is delivered to the district heating net. In winter, besides the cooling function, the ground water also serves as a heat source. **Figure 1** shows the layout of the energy plant.

The total heating capacity of the plant is 64 MW, with an annual heating demand of 32.6 GWh. The total cooling capacity is 9.6 MW, with an annual cooling demand of 5.2 GWh (see **Table**). The supply and return temperatures in the district heating system are 70/40ºC during winter, and decrease to 60/40ºC during summer. The district cooling supply and return temperatures are

▼ *Figure 1: Principal scheme of the energy plant at Oslo Airport Gardermoen.*



▼ *Table: Heating and cooling capacities*

Thermal energy heating capacity:	
Electric boiler:	10 MW
Biomass (heat exchangers/external district heating)	20 MW
Oil-fired boilers	26 MW
Heat pumps	8 MW
Total heating capacity:	**64 MW**
Thermal energy cooling capacity:	
Heat exchanger, ground water	3.3 MW
Heat pumps – cooling	6.3 MW
Total cooling capacity:	**9.6 MW**

3/17ºC in winter and increase to 7/17ºC in summer.

The ground water system

The ground water system is used both as heat source and heat sink for the heat pump, and as energy storage during summer. Due to the relatively low temperatures of the reservoir and low inrush due to low precipitation, the ground water system operates at limited heat withdrawal (0.32 GWh annually) during the first 5-6 years until a thermal balance is established. Heat extraction in the winter will then be balanced by the heat accumulation during summer. Because of the large amount of ground water in the reservoir and the relatively low flow velocity, the ground water temperature is expected to be little influenced, except in the areas very close to the wells.

The ground water system consists of cold wells and warm wells (nine of each), which are placed in parallel lines with the direction of flow, and will have little influence on each other. The distance in the lines of cold and warm wells is 50 m, while the distance between the lines of cold and warm wells is 180 m. The depth of the wells is 45 m, and the ground water level is, on average, 15 m. The ground, consisting of gravel in streaming ground water, was a challenge with regard to drilling the wells. The wells were drilled without casing, with a diameter of 450 mm. A filter tube with a diameter of 250 mm was inserted and the outside filled with gravel and crushed masses to ensure a high flow rate.

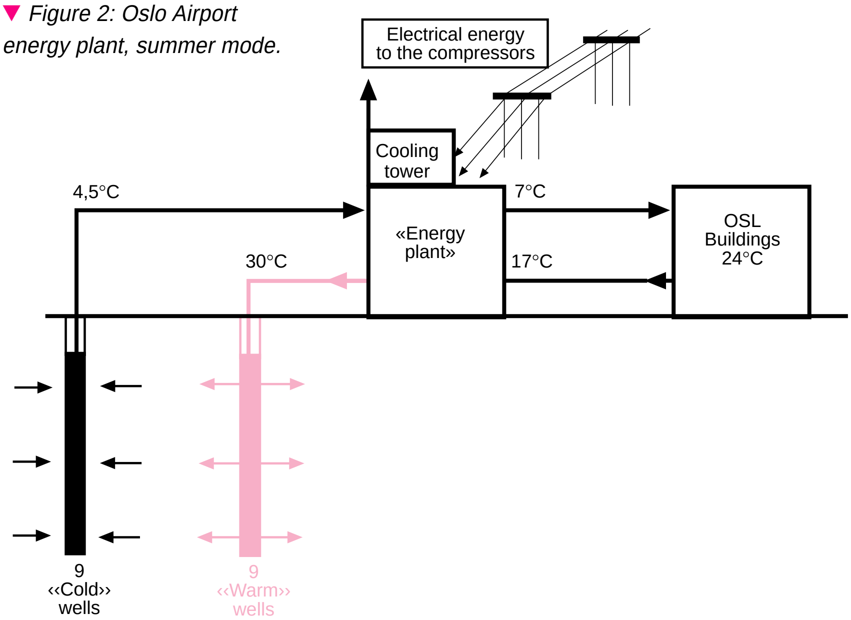
During the winter season 735 million litres of ground water is circulated, while in summer this is 90 million litres. The maximum pumping capacity is 270,000 litres/hour, which will only be required in the middle of winter and in the middle of summer.

Operation

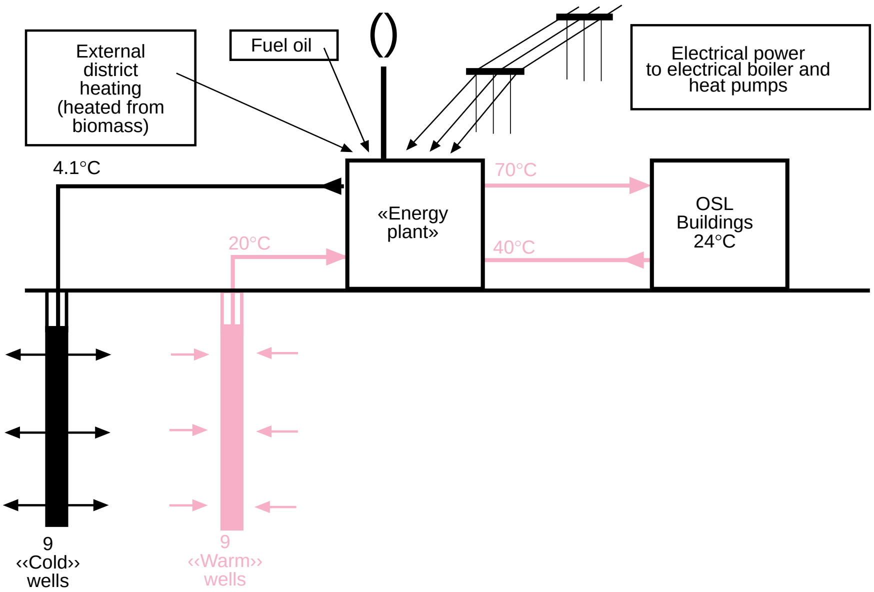
In cooling mode, ground water is pumped from the cold wells and heat exchange takes place in two stages. Firstly, the ground water is used to cool the return water in the cooling net (heat exchanger 6 in **Figure 1**), and heat is extracted from the return flow of the heating net (heat exchanger 5) for heat storage. After heat exchange, the heated ground water is led down to the warm wells where the excess heat is released. A cooling tower (8) of 4 MW can be used if further heat rejection is required. This is necessary to avoid growth of bacteria, which occurs at temperatures over 30°C. Of course the use of the cooling tower should be limited, since less heat accumulation in summer means a lower heat takeout in winter. **Figure 2** shows the typical temperatures during summer mode operation.

In heating mode, ground water is pumped from the warm wells and heat is given off to the supply water in the district cooling net in heat exchanger 6 **(Figure 1)**. The reason this occurs with the supply water rather than with the return water, which has a higher temperature, is the limited supply of the heat source. Because of the limited volume of ground water the heat has to be taken out with a large temperature difference. Direct use of the ground water is not allowed, to avoid any possibility of leakage into the ground water reservoir. **Figure 3** shows typical temperatures during winter mode. The heat pump cools the return water of the

▼ *Figure 2: Oslo Airport energy plant, summer mode.*



▼ *Figure 3: Oslo Airport energy plant, winter mode.*



cold distribution system by using it as a heat source, and the heat is delivered to the heat distribution system.

Ammonia

It was decided to use ammonia (NH_3) as the working fluid, partly because it is a natural and environmentally safe working fluid, and partly because it is very suitable, with excellent thermodynamic properties. The total working fluid charge is 2,500 kg, which equals a relative charge of 0.31 kg/kW installed heating capacity.

The ammonia heat pump is a traditional ammonia design for large systems, with shell-and-tube heat exchangers for the evaporator and condenser, although plate heat exchangers could have substantially reduced the refrigerant charge. All necessary safety precautions have been taken to ensure safe operation of this plant with its very high ammonia charge. First of all, the energy plant is situated in a separate building not open to the public, located 1 km away from the terminal building. The machine room is gastight, and has a fail-safe emergency ventilation system. Gas detectors and sprinkler systems are installed, and the drain is closed in the event of an ammonia leakage. The heat pump system consists of two separate units on the ammonia side, each with a 1,250 kg charge.

The total heating capacity is approximately 8.1 MW, at water temperatures of 23/42ºC on the condenser side and 14.6/7ºC on the evaporator side. Estimated annual energy supply by the heat pumps is 4.55 GWh heating and 3.9 GWh cooling. The guaranteed COP is 5.8 when the heat pumps are in heating mode with temperatures of 1.3°C and 48°C for evaporation and condensation, respectively. Mostly due to high heat source temperatures, the heat pump works with a smaller temperature lift for most of the year. The SPF (seasonal performance factor) for heating is estimated at 7, and SPF for both heating and cooling is estimated at 13.

The water flow rate in the heat exchangers varies according to temperature and capacity demand. When the heating or cooling demand drops below 50% of full load, motor-controlled valves in the district heating or district cooling system shut down one unit.

Because of higher efficiencies during part load operation, reciprocating compressors were selected. A total of seven 8- and 16-cylinder compressors have been installed. The compressors are all from the same series and use the same spare parts, making maintenance more convenient. Another option for achieving even better energy efficiencies might have been to use screw compressors for base load and reciprocating compressors for peak load.

Environment

The ground water system has been the subject of extensive studies, to ensure that the use of ground water does not have any negative environmental impact on the ground water reservoir or the ecological systems in and around the reservoir. The ground water system is closed, and the pumped ground water is not in contact with inhibitors or oxygen.

The consequences of use of the groundwater system for flora and fauna have been studied and evaluated, using published national and international information. The conclusion so far is that due to minimal surface temperature changes the use of the ground water system will have little or no consequences for the local flora or fauna. A monitoring programme will be set up after the airport opens, whereby the temperature changes will be monitored in the wells, the surface areas close to the wells, and in the central ravines of the ground water reservoir.

With regard to microbiological processes, the growth is determined more by the amount of oxygen and nutrients present than by small changes in temperature level.

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Natural refrigerants for residential heat pumps in the Netherlands

Bram van Straalen, the Netherlands

For new building locations in the Netherlands electric heat pumps are becoming more competitive when compared to boilers using natural gas. A dozen demonstration projects have already been launched, almost all using natural refrigerants such as propane. Guidelines for the installation of this kind of heat pump are necessary to expand the dissemination of heat pumps in the Netherlands and to promote further steps such as certification.

The Dutch government has allocated around 50 locations for the realisation of new homes (so-called Vinex areas). This means that more than 630,000 new houses will be built during the period 1995-2005. This is a substantial number for the Netherlands since it represents around 10% of the existing housing stock. This development, combined with the fact that the government stimulates sustainable buildings and the use of sustainable energy, clears the way for new heating concepts.

Traditionally all buildings were connected to the dense natural gas grid in the Netherlands, and space heating was supplied by high-efficiency gas boilers. For existing locations, alternative heating technologies cannot economically compete with gas heating. However, at the new Vinex locations, a gas grid is no longer self-evident. There are opportunities for all-electric concepts for space heating, meaning that investments for a gas grid are avoided. Electric heat pumps will therefore have a chance to penetrate the space heating market. Twelve subsidised demonstration projects are planned.

Demonstration project

One of the demonstration projects using electric heat pumps consists of 12 residences in Deventer. The housing association and the electricity distribution company have chosen a concept of individual ground-coupled heat pumps. The selected system is based on experiences with the so-called heat pump competition, which ended a year ago. The results of this competition were described in IEA Heat Pump Centre Newsletter Vol.15/3.

The natural working fluid propane (R-290) was chosen as the refrigerant because it has good thermophysical properties, which make it possible to achieve a high water temperature, without using additional electric heating. The heat pump provides both space and water heating. This natural working fluid is environmentally benign.

The refrigerant circuit of the implemented compact heat pump, that has 5.5 kW heating capacity, contains approximately 0.7 kg of propane. In the ground loop a mixture of water and glycol is used, which transports heat to the evaporator. Each house has four vertical ground heat exchangers of the U-type that consist of high-pressure PE tubes with a diameter of 25 mm. The tubes lower end are installed at 33 m depth. The tubes have a total installed length of approximately 550 metres and occupy a surface area of 45 square metres. The heat exchangers are interconnected and linked with the heat pump.

A 145-litre storage vessel for hot water forms part of the heat pump system. One of the condensers is placed inside the vessel. The water can therefore be heated to over 60°C. For space heating floor heating on the ground floor is used and enlarged radiators on the upper floors. Heat from the ventilation air is recovered with heat exchangers.

Guidelines

The Dutch Platform Natural Working Fluids (PlaNK) is a platform for knowledge transfer and activities concerning natural refrigerants. This platform operates under Annex 22 ‘Compression Systems with Natural Working Fluids’ of the IEA Heat Pump Programme. PlaNK initiates and stimulates the development of practical guidelines for flammable refrigerants.

National standards on the use of natural working fluids have already been developed in some European countries. A project has now started to develop a Dutch Practice Guideline (NPR) for flammable refrigerants. For NH_3 a draft version of a guideline for the prevention of calamities with dangerous substances, CPR 13-2, will be published (ammonia, application as a refrigerant in cooling machines and heat pumps). However, at the moment the development of the NPR for flammable refrigerants is still ongoing. There is no clarity on the need for certification, inspections and competent institutions to certify heat pump systems.

A future certification system for heat pumps with flammable working fluids might be similar to the existing certification of gas installations in the Netherlands. Each new installation connected to the national gas grid must be inspected by a certified installer. However, steps towards certification can only be taken once the NPR for the installation of heat pumps with flammable refrigerants has been published.

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Energetic, economic and environmental viability of absorption air-conditioning systems in Spain

M. Izquierdo, P. Rodríguez, A. Lecuona, E. Martín and M. de Vega - Spain

The air-conditioning market shows a growing trend, especially in countries such as Spain where the income per capita is high and the climate is relatively warm. The most common systems are those based on mechanical compression (using electric energy) and absorption systems (using heat). This article compares large- and medium-capacity ammonia/water and water/lithium-bromide absorption systems with mechanical compression systems using HCFC-123, HFC-134A and HCFC-22 refrigerants. The comparison covers the energy efficiency of each system, costs and environmental impact (ozone depletion potential and the direct or indirect global warming potential).

Compression

Table 1 shows the coefficient of performance (COP) for various refrigerating systems that use electricity as the drive energy, as well as the costs per kWh of cold produced. For every kWh of electricity consumed by an electrical cooling unit driving a centrifugal compressor using R-123, approximately 4 kWh of cooling are produced. In the case of a reciprocating compressor using R-134A or R-22 refrigerants, around 3 kWh of cooling are produced. The same minimum price of electric power (USD 0.11/kWhe) is assumed for all the systems. This price does not take taxes, etc. into account. The primary energy ratio (PER) includes the efficiency in the power plant, and the electrical energy consumed by the auxiliary equipment.

Table 1: Mechanical compression systems - cooling efficiencies and cost per kWh cooling.

	R-123	R-22	R-134A
COP_{m-c}	4.0	2.8	2.9
PER	1.1	0.78	0.81
USD cts/kWhcold	2.6	3.8	3.6

Note: power plant efficiency ($h_{power\ plant}$) = 33%; electrical energy consumed by auxiliary equipment (h_{aux-cm}) = 15% price per kWhe = USD 0.11.

Absorption

Table 2 shows the PERs and costs per kWh of cold for absorption cooling systems. For each kWh of heat consumed by the single-effect units, around 0.35 kWh of cooling is produced if ammonia is used as the refrigerant and 0.5 kWh if water is used. The double-effect unit produces 1 kWh of cooling for every kWh of heat used. The low PER of the single-effect units is the main drawback to acceptance by the market. Also the larger size and weight are disadvantages compared to mechanical compression systems. When the unit runs on waste heat, the lower PER is not a disadvantage as the viability of the system is ensured by the low cost of the energy source.

If fossil fuels are used, absorption units can only effectively compete with mechanical compression chillers if their efficiency is comparable. The fuels used in Spain are natural gas, fuel-oil and liquefied petroleum gas (LPG). It is assumed that the cost per kWh of the last two fuels is the same as for natural gas. In the Spanish tariff system the minimum cost of natural gas before tax is slightly different for the single-effect and double-effect absorption units (USD 0.024 and USD 0.025/kWh_{ng}) because of the varying consumption.

Comparing the results from the two tables, it is clear that the cost of cooling with double-effect units is slightly cheaper than for electric compression chillers operating with R-123. The cold produced by single-effect absorption systems is in all cases more expensive than that produced by electric-driven compression systems. The absorption systems driven by free waste heat were not included. In these cases the viability of absorption chillers is guaranteed.

Environmental impact

The most important environmental effects caused by the cooling systems used in air conditioning are the depletion of the atmospheric ozone layer and the increase of the man-made greenhouse effect.

Considering the *ozone depletion potential (ODP)*, absorption systems using

Table 2: Absorption systems - cooling efficiencies and price per kWh cooling.

	NH_3 - H_2O single-effect	H_2O - LiBr single-effect	H_2O - LiBr double-effect
PER	0.35	0.50	1.0
USD cts/kWh cold	6.8	4.8	2.5

Note: price per kWh_{ng} = USD 0.024 for single-effect and USD 0.025 for double-effect.

▼ *Table 3: CO_2 released by mechanical compression cooling (electricity mix Spain).*

Refrigerant	kg CO_2 / kWh cooling
R-123	0.15
R-22	0.21
R-134A	0.21

ammonia or water should be preferred over compression systems using R-123, R-22 or R-134A because these absorption systems do not have an ozone depleting effect.

The cooling systems used in air conditioning contribute to the global warming of our planet in a direct and indirect way. The *direct global warming potential (GWP)* is the effect that the refrigerant itself has on the atmosphere. The absorption systems that use ammonia as refrigerant do not have a GWP, and those that use water only produce the natural effect of this refrigerant. For this reason, absorption systems are good candidates to replace compressions systems using R-123, R-22 or R-134A in air-conditioning applications.

The *indirect global warming potential (IGWP)* is the carbon dioxide produced as a result of burning fossil fuel either to generate electricity used to drive mechanical compression system or to produce heat to drive an absorption system. In Spain, electrical energy is produced from various primary energy sources. The energy mix for Spain is: 55% fossil fuel, 13% hydro, 30% nuclear and 2% from renewable sources (mini-hydro, wind and solar farms). Electric power from hydro, nuclear and renewable sources, 45% of the overall mix, does not contribute to the production of CO_2 and therefore does not contribute to the greenhouse effect. The remaining 55%, is from burning coal and fuel oil. Natural gas is currently being introduced. In 1995 the breakdown of the fossil fuel share *(55%)* was as follows: 87% coal, 12% fuel oil and 1% natural gas.

Comparison

The mass of CO_2 released into the atmosphere to produce 1 kWh of electricity is assumed to be 1.12 kg for coal, 0.94 kg for fuel oil and 0.57 kg for natural gas. With the electricity mix given above, calculations can be made for the mass of CO_2 released into the atmosphere for a kWh of cooling for each of the refrigerants used in mechanical compression systems. The results are shown in **Table 3.**

Absorption systems using waste heat from thermal processes do not release CO_2. Since waste heat is not always available to drive air-conditioning systems, this is not included in the comparison. Table 2 shows that the single-effect ammonia absorption unit needs 2.86 kWh of fuel for each kWh of cooling produced (PER = 0.35). In the case of a water/lithium-bromide system and a single-effect unit, 2 kWh of fuel is needed to produce 1 kWh of cooling (PER=0.5). Only 1 kWh of fuel is required for a double-effect unit. **Table 4** shows the amount of CO_2 produced by different types of absorption systems with different fuels, in kg CO_2 per kWh cooling. It is assumed that around 0.31 kg of CO_2 is produced by burning 1 kWh of fuel oil, 0.25 kg by burning 1kWh of LPG, and 0.19 kg by burning 1 kWh of natural gas.

When these results are compared to those in **Table 3** it is clear that in general absorption systems using fuel oil produce more CO_2 than electric compression systems. This is due to the high percentage of nuclear, hydro and other renewable energy sources in the mix of the average Spanish kWh. Double-effect lithium bromide units can compete in terms of CO_2 emission with mechanical compression units using a reciprocating compressor with R-22 or R-134A. Compared to centrifugal units operating with R-123, the double-effect unit produces 27% more CO_2. However, if we take into account the fact that the absorption unit does not have a direct GWP, while the centrifugal system using R-123 has a GWP of 310 at 20 years, and that it depletes atmospheric ozone, that the double-effect lithium-bromide absorption unit is more or less competitive with the electric centrifugal units using R-123.

▼ *Table 4: CO_2 produced by different types of absorption systems using different fuels, in kg CO_2 / kWh cooling.*

	gas oil	natural gas	LPG
H_2O-NH_3 (SE)	0.89	0.54	0.71
LiBr-H_2O (SE)	0.62	0.38	0.50
LiBr-H_2O (DE)	0.31	0.19	0.25

Conclusions

Single-effect absorption units (NH_3/H_2O and H_2O/LiBr) using fossil fuels are not competitive from an energetic, economic and environmental point of view. They are only competitive when they use waste heat as an energy source. However, double-effect absorption air-conditioning systems, driven by natural gas or LPG, can compete with mechanical compression systems using reciprocating and centrifugal compressors.

The current mechanical compression systems are changing from CFCs to HFCs or HCFCs. HFCs do not deplete the ozone layer and HCFCs reduce depletion by 98%. With regard to the greenhouse effect, their GWP is important and, as the substitutes operate at lower energy efficiency than CFCs, the IGWP increases. Double-effect absorption air-conditioning systems do not deplete the ozone layer and their direct GWP is zero. For the Spanish situation those driven by natural gas are competitive as they produce less IGWP than systems with reciprocating compressors and a little more than centrifugal models. In the latter case the shortfall is more or less compensated by their superior qualities with regard to ozone and direct GWP. Those driven by LPG are at the limit of competitiveness.

In addition, the electric power consumed by absorption systems is small, so they are useful for reducing electricity demand peaks, which leads to better functioning of the power system.

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The role of heat pumps in a deregulated energy market

Gerdi Breembroek, IEA Heat Pump Centre

The energy sector is currently being deregulated and privatised in many industrialised countries. This is a major change, not only for the energy sector, but also for its customers. The Swiss company Electrowatt Engineering and the IEA Heat Pump Centre have carried out an analysis study entitled 'The role of heat pumps in a deregulated energy market'. This article presents the highlights of the analysis report, which will be available in October 1998.

In many OECD (Organisation for Economic Cooperation and Development) countries, the energy sector is going through a period of fundamental change as a consequence of deregulation. Utilities may change from nationalised, horizontally and vertically integrated, to privately owned companies, obliged to separate their integrated activities. Companies may access foreign energy markets to strengthen their position.

The deregulation process may affect the heat pump market in two ways:

- the energy price structure may change, which affects the economy of heat pumps;
- utility market strategy may change, which can stimulate or hinder the heat pump market.

As electricity is the most important drive energy for heat pumps, this analysis focuses mainly on the electricity market.

Status of deregulation

Energy markets differ worldwide in size, ownership and structure (horizontal and vertical integration). Deregulation processes and the final structure of the market will therefore also differ from country to country. In the UK, Norway, Sweden and some US states, electricity market deregulation started before 1997. In these countries, except for the UK, power exchanges exist today, where electricity can be bought and sold. The price changes hourly. Deregulation in the European Union countries, Japan and Switzerland is ongoing.

For the market of heat pumps in a specific country, the following factors are important:

- more competition will evolve;
- energy prices will change;
- new market players: new players as well as those offering extended services;
- utilities must actively gain and retain customers.

Energy price

Electricity prices today vary by a factor of 3-4 in OECD countries. Some price differences will remain in a deregulated energy market (caused by technical constraints in the transmission grid and taxes), but in general price differences will become smaller.

From the forecasts of future electricity prices, and experiences from the UK and Norway, maximum price changes in the order of 10-20% are expected in the next 10-15 years. In countries with a phased introduction of an open market, prices for retail customers may increase initially, and drop a few years later.

Not only the electricity sector, but also the gas sector is being deregulated. Gas prices are therefore also expected to fall and the differences between countries will decrease as a result of market deregulation. Oil prices have shown a decreasing trend over the past few years.

Impact on economy

The annual costs of a typical electric heat pump system and a typical competing system are compared for various countries at different electricity price levels. Competing systems include (depending on the country) gas- and oil-fired boilers, direct electric heating, district heating, and chillers for countries with a cooling demand. Actual systems and circumstances can of course deviate from the 'typical' examples. The box below shows the formula for calculating annual costs.

Figures 1 and 2 show ratios for the economic comparison of all countries included in the economic analysis:

- the ratios electricity/oil price and electricity/gas price for retail customers (**Figure 1**);
- the ratio annual energy cost/ amortisation cost for a residential heat pump (**Figure 2**).

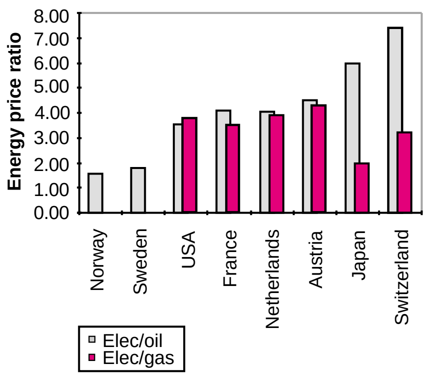
The annual cost ratio of a heat pump versus a competing system is illustrated in **Figure 3** for typical residential heat pumps in four countries: Austria, Norway (both heating only), France and Japan (heating and cooling). The competing system is indicated in **Figure 3.**

As the energy cost is only part of the annual cost of a heat pump, a decreasing electricity price has only limited impact on heat pump economy. The factor

Annual cost = energy cost + amortisation =

$$\text{energy price} * \left(\frac{\text{heat demand}}{\text{efficiency}}\right) + \text{energy price} * \left(\frac{\text{cooling demand}}{\text{efficiency}}\right) + \text{amortisation}$$

▼ *Figure 1: Energy price ratios (residential) 1995 (Source IEA Statistics).*



electricity price alone will not cause a major breakthrough in the heat pump market. Other factors, such as investment costs and efficiency, are also important. The analysis report contains an economic analysis of residential and commercial heat pump systems for the countries mentioned in **Figure 1** and **2.**

Utility policy

In many countries, utilities are important actors in the heat pump market. In the regulated energy market some have supported heat pumps, for instance by offering grants or special electricity tariffs. These policies were in line with governmental energy-efficiency programmes.

However, in the deregulated energy market, the market strategies of utilities will change. Experiences from the UK show that initial competitiveness focuses on price, and that some activities are abandoned after the introduction of a free market. Only when the market matures and energy prices drop to a stable level will utilities start to distinguish themselves by offering incentives such as other products/bonuses or energy-efficiency services.

On the UK industrial energy market, utilities have now broadened their portfolio to include offering services such as heat (steam). Independent power companies, many of them operating internationally, also offer this energy service.

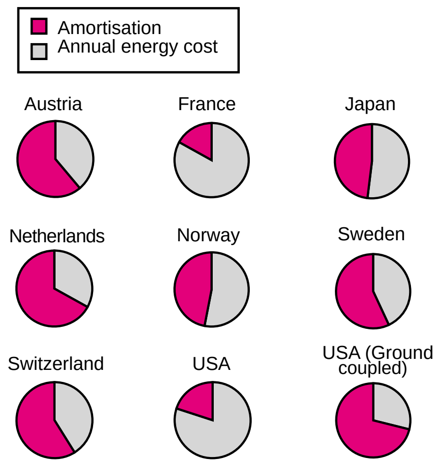
With this in mind, many expect that offering suitable energy services will be the key for the future energy market. Examples of such services include energy audits, security alarms, third-party financing of heat pumps, offering high-efficiency equipment and appliances, equipment surveillance, home automation, green electricity, etc. However, services will only be offered when they are a proxy for economic efficiency and support marketing efforts of utilities. An important market strategy for utilities will be to form alliances and partnerships, for instance with HVAC service companies or manufacturers.

Offering heat pumps as one of the services will mainly be based on economic prospects. For instance, when utilities have access to inexpensive surplus electricity (current situation in Europe) a role in the heat pump market may be attractive. Through proper sizing, storage and/or applying bivalent systems, deployment of heat pumps can contribute to load levelling. Under such conditions, utilities may become involved in the heat pump market.

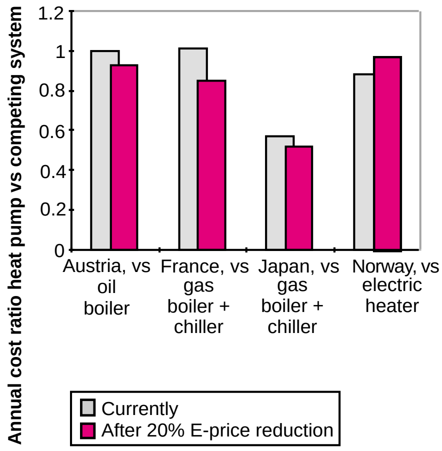
A more detailed analysis of the situation in various countries reveals marked differences in expected utility policies. Factors favourable for utility involvement in the heat pump market include:

- previous experience with heat pumps;
- eligible customers;

▼ *Figure 2: Annual energy cost/ amortisation cost for typical residential heat pump systems.*



▼ *Figure 3: Economy of a typical residential heat pump system in four countries.*



- competition in the heating market;
- existence of a heating and cooling demand (extended services);
- environmental consciousness of the public.

The analysis report includes predictions for the development of the heat pump market in individual countries.

Conclusions

The heat pump market is affected by deregulation in two ways, by changing energy prices and by changing market strategies of utilities. The expected electricity price change will not be enough to cause a major breakthrough in the heat pump market. As for the future role of the utilities, it is generally expected that they will provide additional energy services to satisfy and retain customers. The likely role of the utilities in the heat pump market differs from country to country, depending on their previous experience with heat pumps, competition in the heating market, etc. To ensure an increased use of heat pumps, it remains very important that utilities include heat pump technology in their marketing strategies.

References:
The role of heat pumps in a deregulated energy market, IEA Heat Pump Centre, Sittard, The Netherlands, to be published October 1998.

21-CR: A recently launched North American R&D programme

Glenn Hourahan, USA

This paper outlines a new aggressive R&D programme – *HVAC&R Research for the 21st Century* (21-CR) – initiated by the North American heating, ventilation, air-conditioning and refrigeration (HVAC&R) industry. The areas of research, programme organisation, and way in which interested experts can participate in the effort, have now been identified. The 21-CR initiative aims to undertake research that will enable industrial manufacturers to offer equipment and services in the next decade that, once integrated into building and process applications, will use far less energy (compared to today's applications), while addressing the refrigeration needs, comfort and indoor environmental quality (IEQ) needs of building occupants.

The 21-CR effort is guided by experts from industry, related trade and professional organisations, national laboratories, governmental agencies, universities, utilities, and other interested stakeholders. The Air-Conditioning and Refrigeration Technology Institute (ARTI), a research entity associated with the Air Conditioning and Refrigeration Institute (ARI), is the 21-CR administrator. ARTI provides guidance and cohesiveness to the overall investigation, while providing an umbrella for related research by others which advances the goals of the 21-CR programme.

The 21-CR programme fosters an environment where technical barriers are identified, research priorities set, solutions investigated, and information shared. The effort will undertake precompetitive research that focuses on resolving technological hurdles and difficulties that prevent or impede manufacturers from introducing next generation systems and components. Once these technical challenges have been addressed, the various stakeholders can apply the 21-CR research results and produce the products/services that satisfy market needs within the HVAC&R sector.

Background

The US HVAC&R industry is a mature one in which product innovations have been gradually accepted by the marketplace. Achieving rapid marketplace acceptance of new innovations is complicated in that HVAC&R products are generally viewed as commodities where sales are extremely price sensitive; a small price difference can sway a purchase decision. However, industry's long-term viability, as well as the needs of its customer base, is dependent upon the development of novel, breakthrough technologies. Implementation of innovative ideas into HVAC&R products will offer customers added benefits by reducing energy consumption costs, improving indoor comfort for building occupants, and further reducing the impact that operation of HVAC&R equipment has on the environment.

Energy reduction is a large component of this HVAC&R initiative. Some statistics on site-consumed energy usage (excluding conversion and distribution losses) within the US are given below.

- In US commercial buildings approximately 5,800 PJ of energy (i.e. electricity, natural gas, fuel oil, and district steam or hot water from a central plant or utility) are consumed each year at an annual cost of USD 71,800 million. Comfort conditioning (heating, cooling, and ventilation) and refrigeration is the single largest component of this overall requirement. It uses 48% (2,700 PJ) of the site-consumed energy.
- In residential applications approximately 10,500 PJ of energy (i.e. electricity, natural gas, fuel oil, and liquefied gas) are consumed each year at an annual cost of USD 124,000 million. Comfort conditioning (e.g. heating and cooling) is the largest component (45%, or 4,700 PJ/year) of the site-consumed energy.
- Buildings consume around 35% of the country's total energy (all fuel types). If we include fuel used to generate electricity, commercial buildings account for over 15% of the US carbon dioxide emissions; residential buildings account for 19%.

The direct payback from improved HVAC&R products is dramatic. Annual US energy bills for comfort conditioning and refrigeration equipment are approximately USD 90,000 million. Increasing overall HVAC&R equipment efficiencies by 25% (a reasonable target if a concentrated research programme is pursued) could ultimately yield annual energy savings of USD 22,000 million. There would also be a proportionate decrease in the emissions of gases associated with global warming, as carbon dioxide emissions from power plants would decrease by nearly 60 million metric tons per year.

The envisioned research is on the 'cutting-edge' of the HVAC&R industry and entails a high degree of technical risk. Currently, personnel and testing resources within individual HVAC&R companies are spread very thinly because of the pace of product changes necessitated by developing new equipment using alternative refrigerants and/or offering improved efficiencies. Precompetitive collaboration among HVAC&R companies and other interested entities will enable significant resources to be applied to strategic research areas. As a result, substantial savings should be realised by building owners and operators through reduced operating costs, greater equipment reliability, and improved comfort levels.

Focus areas

Through this new HVAC&R initiative, it is anticipated that the development and marketplace introduction of advanced equipment and applications will be greatly accelerated. In recognition of the need for energy efficiency and minimal adverse environmental impact, five areas of strategic focus have been identified:

- *alternative equipment* (systems other than fluorocarbon vapour compression cycles;
- *high-efficiency equipment* (improved heat exchangers, motor systems, compressors, controls and sensors, air handlers, testing, diagnostics, pumps and pump controls, etc.);
- *system integration* (improved distribution systems, zone control, waste heat recovery, integration of envelope and lighting with mechanical systems, advanced controllers, communications, etc.);
- *indoor environmental quality* (enhanced control of temperature, moisture, indoor contaminants, ventilation, sound, lights and drafts); and
- *environmentally friendly working fluids* (refrigerants, lubricants, secondary heat transfer fluids, eutectics, etc.).

The scope of each of the focus areas is described in the box on this page.

Organisation

A committee structure has been established to guide the 21-CR initiative and to monitor the research. The

The scopes of the subcommitees

Alternative Equipment::
This subcommittee advocates R&D aimed at ascertaining the role that nontraditional equipment can play in future HVAC&R applications. This includes recommending investigations to identify and evaluate alternative concepts and, for those that appear viable, recommending research to resolve specific limitations that affect their commercialisation. Examples would include desiccant cooling, hybrid systems, absorption, etc.

Equipment Energy Efficiency:
This subcommittee focuses on research needed to improve the efficiency of existing HVAC&R equipment used in various applications (e.g. unitary, chillers, refrigeration, etc.). Heat exchangers, motor systems, compressors, controls and sensors, air handlers, application of working fluids (cycle analysis, heat transfer, etc.), testing, diagnostics, efficiencies across the operating range, pumps and pump controls are examples of specific areas falling under this subcommittee.

System Integration:
To provide substantial improvements in energy consumption and comfort levels, there is a need to treat buildings, with their individual subsystems, as complete optimised entities, not as the sum of a number of separately designed and individually optimised components. This subcommittee identifies precompetitive research that will facilitate better integration of HVAC&R equipment with other related systems into the various applications. Examples of project interests are distribution systems (e.g. air duct systems and water circulation systems), zone control, advanced application and equipment controllers, identification of ways to recover and reuse waste energy within buildings and refrigeration processes, standardised external communications (i.e. for standardised diagnostics, utility control, mating with building systems, etc.), and influences and impacts of lighting, thermal envelope, etc. on HVAC&R equipment. The initial emphasis will be on residential applications with commercial and refrigeration applications planned later.

Indoor Environmental Quality:
The IEQ subcommittee fosters investigations that support industry's ability to provide high-quality indoor environments for comfort, health, and productivity. This encompasses air quality, sound quality (i.e. noise control), etc. The primary concern is undertaking research that will position manufacturers to offer equipment that recognises, measures, and controls defined indoor environmental concerns. Main areas would include indoor air quality control strategies, identification of antimicrobial materials, improved concepts for particulate or gas-phase filtration, and enhanced control of temperature, moisture and humidity, ventilation, sound, and air velocity.

Working Fluids:
Refrigerants, absorption fluids, lubricants, and secondary heat transfer fluids are required for the successful operation of HVAC&R equipment. Contaminants (including cutting oils, detergents, lubricants, and anti-rust compounds used to manufacture component parts) can affect the reliability of HVAC&R equipment. New refrigerants, absorption fluids, lubricants, secondary heat transfer fluids and new process fluids are likely to be needed in the future. This subcommittee will anticipate the need for precompetitive research to provide and apply new working fluids. In assessing new fluids and applications the subcommittee will consider issues including system efficiency, equipment reliability, compatibility, safety, and environmental impacts.

committees consist of authorities on research drawn from industry, research organisations, universities, utilities, scientific laboratories, and government. A Steering Committee will ensure that the work will be of value to the industry and that it has a path to commercialisation. It will also assign priority levels and approve funding support of individual projects recommended by its five subcommittees, each covering one of the focus areas. In addition to identifying project needs and providing technical oversight of contractors' efforts, the subcommittees will review/monitor and coordinate (where possible) industry/public-sector pre-competitive research projects. The purpose of this ancillary focus is to encourage other entities (e.g. government laboratories, university researchers, etc.) to perform work of interest to the industry and to minimise duplication of effort.

Instead of serving on a subcommittee, there are other ways interested industry experts can be involved in the 21-CR effort:

- specific projects can be identified for the 21-CR programme to consider;
- pertinent research efforts of others can be identified for possible 21-CR support or to assist in the minimisation of duplicate effort;
- researchers can respond to *requests for proposals* (RFPs) and seek contracts to perform specified work;
- unsolicited research proposals can be considered for appropriateness.

Additionally, in 1999 there will be opportunities for individuals to serve on monitoring subgroups for various research projects.

Conclusion

The HVAC&R industry, which has been experiencing evolutionary growth for the last 40 years, is currently undergoing a period of unprecedented change. The pressures driving these changes – protection of the environment and conservation of our natural resources will only become more pronounced in the future. Developing new technologies in response to these pressures will necessitate a large concerted effort. By providing a solid basis for industry collaboration in pre-competitive technology areas, the 21-CR programme will stimulate progress in a number of strategic areas. When carried out as part of a coherent plan, this emphasis on precompetitive investigations advances the capabilities of the HVAC&R industry to meet the broader objectives of reducing energy consumption, increasing indoor environmental quality, and safeguarding the environment.

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Refrigerants for the 21st century
Available from: ASHRAE Customer Service, 1791 Tullie Circle NE/ Atlanta, GA 30329, USA. Fax: +1-404-3215478, e-mail: orders@ashrae.org. Price: USD 53. Order code: 90097.
This conference proceedings presents refrigerant options for the air-conditioning and refrigeration industry in response to the ozone depletion and climate change issues as well as technology advances. It includes contemporary and future fluorochemical, natural fluids including hydrocarbons and carbon dioxide, secondary loop systems using ammonia and other chemicals, and not-in-kind technologies.

Eurovent directory of certified products - air conditioning and cooling
1 February 1998 - 31 January 1999
Available from: Eurovent Certification Company, 15 rue Montorgueil, 75001 Paris, France. Fax: +33-1-40137544.
This edition of the Eurovent directory of certified air conditioners, fan-coil units and liquid chilling packages contains a list of companies which are committed to the certification of their products within the scope of certification programmes in which they participate. Performance data have been included for participants whose products were tested during 1997. Included are (close control) air conditioners up to 100 kW, fan coil units and liquid chilling packages.

ASHRAE TransactionsCD, Annual Meeting
June 1998
Available from: ASHRAE Customer Service, 1791 Tullie Circle NE/ Atlanta, GA 30329, USA. Fax: +1-404-3215478, E-mail: orders@ashrae.org. Price: USD 147.
The CD-ROM features full-text images of 141 technical and symposium peer-reviewed papers from the 1998 Annual Meeting, including full text, tables, graphs, illustrations and equations. It also includes all discussions from the 1998 ASHRAE Winter Meeting. The CD allows full-text searches by title, author, topic and subject matter, as well as browsing for specific citations.

INTERNET SITE

For a list of all publications and events, visit the HPC Internet Site at

http://www.heatpumpcentre.org

Available from the HPC

PLEASE USE THE ATTACHED RESPONSE CARD WHEN ORDERING HPC PRODUCTS

The Role of Heat Pumps in a Deregulated Energy Market
Analysis Study, October 1998
Order No. HPC-AR-5, NLG 160 or NLG 80 in HPC member countries.

Deployment Activities for Heat Pumping Technologies
Workshop Proceedings, August 1998, Order No. HPC-WR-20.
NLG 120 or NLG 60 in HPC member countries.

CO_2 Technologies in Heat Pumps, Refrigeration and Air Conditioning Systems
Workshop proceedings, January 1998
Order No. HPC-WR-19.
NLG 120 or NLG 60 in HPC member countries.

HPP Annual Report 1997
Order No. HPP-1997

Renewable Energy for a Cleaner Future
Order No. HPC-BR-5
Brochure. Free of charge.

Compression Systems with Natural Working Fluids
Annex 22 Workshop Proceedings, January 1998. Order No. HPP-AN22-3.
NLG 120 or NLG 60 in member countries and in Ca, Dk, Se and UK.

Ab-Sorption Machines for Heating and Cooling in Future Energy Systems Annex 24 Proceedings, December 1997
Order No. HPP-AN24-1.
NLG 120 or NLG 60 in HPC member countries and in Ca, Ja, It, UK.

For further publications and events, visit the HPC Internet Site at http://www.heatpumpcentre.org

Hygiene, quality and security in the cold chain and in air conditioning
16-18 September 1998 / Nantes, France
Contact: Symposium Nantes 98.
Fax: +33-2-51882020

Refrigeration/Air Conditioning and Regulations for Environment Protection - a Ten Years Outlook for Europe
7 October 1998 / Nuremberg, Germany
Organised by the Association of European Refrigeration Compressor Manufacturers.
Contact: ASERCOM, Motzstrasse 91, D-10779 Berlin, Germany.
Fax: +49-30-21479871

Wärmepumpen-Expo
5-7 November 1998 / Bern, Switzerland
Contact: Informationsstelle Wärmepumpen, 3000 Bern 16 Tel.: +41-31-3524113

1999 IIAR Annual Meeting
21-24 March 1999 / Dallas, Texas, USA
Organised by the International Institute of Ammonia Refrigeration.
Contact: IIAR Headquarters, 120019th St., NW, Suite 300, Washington, DC 20036.
Attn. Chris Combs. Fax: +1-202-2234579
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1999 International Sorption Heat Pump Conference
24-26 March 1999 / Munich, Germany
Contact: Dr Martin Hellmann, ZAE Bayern, Walther-Meissnerstrasse 6, D-85748 Garching, Germany
Fax: +49-893294-4212 E-mail: martin.hellmann@physik.tu-muenchen.de

World Sustainable Energy Trade Fair Clean Energy for the 21st Century.
25-27 May 1999 / Amsterdam, The Netherlands
Contact: European Media Marketing Ltd, PO Box 259, Bromley, BR1 1ZR, UK.
Tel.: +44-181-2898989
Fax: +44-181-2898484
E-mail: sustain@emml.co.uk
Internet: http://www.emml.com

20th International Congress of Refrigeration of the IIR Refrigeration into the 21st century
19-24 September 1999 / Sydney, Australia
Contact: ICR99 Secretariat, 52 Rosslyn Street, West Melbourne, Vic 3003, Australia.
Tel: +61-3-93282399
Fax.: +61-3-93284116
E-mail: icr99@airah.org.au
Internet:http://www.airah.org.au/icr99
Paper abstracts due December 1998.

IEA HEAT PUMP PROGRAMME EVENTS

Ab-Sorption Machines for Heating and Cooling in Future Energy Systems
2nd Annex 24 Workshop
29-30 October 1998 / Tokyo, Japan
Contact: Magnus Gustafsson, Royal Institute of Technology, Stockholm, Sweden. Fax: +46-8-105228
E-mail: magu@ket.kth.se

Heat Pumps - A Benefit for the Environment
6th IEA Heat Pump Centre Conference
30 May - 2 June 1999 / Berlin, Germany
Technical visits on 3 June 1999
Conference Secretariat: VWEW, Rebstöcker Straße 59, D-60326 Frankfurt, Germany. Tel.: +49-69-6304460
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Session 1: Opening plenary session
Session 2: Markets
Session 3: Technology
Session 4: Heat Pump Systems
Session 5: Applications
Session 6: Market Strategies
Invited speakers and call for posters.
Information is also available from the Heat Pump Centre.

Next Issue

Concepts for heat pump marketing

Volume 16-No. 4/1998

National Team Contacts

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among its 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 consumption 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. In the member countries (see right), activities are coordinated by National Teams. For further information on HPC products and activities, or for general enquiries on heat pumps and the IEA Heat Pump Programme, contact your National Team or the address below.

The IEA Heat Pump Centre is operated by

Novem

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