IEA Heat Pump CENTRE
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# Natural working fluids

The hydrocarbon revival

Cold storage with ammonia refrigerant

Vapour compression systems based on $CO_2$

Evolution of heat pumping in Japan

IEA
OECD
heat pump centre

# In this issue


***Front cover:*** *The equipment shown is a Norwegian fish drying system incorporating an ammonia heat pump. By recovering heat from extracted moisture, this system has exceptionally low power consumption. And by using a natural working fluid, the equipment poses no danger to the global environment from refrigerant leakage.*

## Natural Working Fluids

Because they occur in nature, chemicals such as ammonia, $CO_2$ and hydrocarbons can be released into the atmosphere, in moderate quantities, without fear of unforeseen environmental consequences. This philosophy has led to a growing interest in using these and other natural working fluids instead of new, apparently safe, synthetic chemicals such as HFCs. This issue looks at current experiences with natural working fluids in heat pumps, air conditioners and refrigerating machinery, and examines the factors that will determine future developments in this field.

### TOPICAL ARTICLES



### HEAT PUMP NEWS



### FEATURES




Colophon





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# A serious alternative

*Two very different approaches have emerged over the past years in the struggle to phase out CFCs:*

- *using new synthetic chemicals with no known negative effects to the local and global environment, and characteristics that allow replacement of present working fluids with little or no modifications to components or plants*

- *using natural working fluids, such as ammonia, carbon dioxide, hydrocarbons, water, air and noble gases, that have long been present in the biosphere and are therefore inherently safe for the global environment.*

*The first alternative is well taken care of by suppliers of CFCs and HCFCs, and an impressive amount of money and effort has been applied, resulting in a host of new fluids. The second must be pursued by independent research organizations and suppliers of components and systems. Much less money has been available for this work.*

*While many of the technical issues of using natural working fluids are solved, the biggest challenge and barrier appears to be safety. But no fluid is absolutely safe. Take water. It is safe to drink, harmless to your body and a basic requirement for life. But too much of it and you can drown, a leakage in a steam compression plant can scold you, and frozen on the road it could kill you.*

*Using risk analysis, the probability and consequences of an undesired event can be assessed, and either or both of these factors can be addressed to achieve a high safety level. Natural fluids can meet safety standards as long as we can meet the cost of safety measures.*

*Natural working fluids are gaining momentum in Europe. And on the world stage, cooperative efforts are being made under Annex 22 of the IEA Heat Pump Programme, and the International Institute of Refrigeration (IIR) will hold a conference in Denmark in September on "Applications for Natural Refrigerants." Later in the same month, more papers on this subject will be presented at the "5th IEA Conference on Heat Pumping Technologies" in Canada.*

*This issue of the Newsletter will hopefully be an eye opener to all those who still doubt that natural working fluids are to be a serious alternative in the years to come.*

*Prof. Per-Erling Frivik,*

*Head of SINTEF Energy, Norway, and Norwegian National Team Leader.*

Per-Erling Frivik

## NON-TOPICAL ARTICLE



The Heat Pump Technology Center of Japan (HPTCJ), was established ten years ago. This article looks back on a period of rapid progress for heat pumping technology in Japan, both in terms of technological development and market penetration.

# Norwegians forge strategic alliances to strengthen market

**Norway -** With the completion of the government-backed "Programme for the Implementation of Heat Pumps" at the end of 1992, and the withdrawal of subsidies in 1993, the Norwegian heat pump market has suffered from a lack of support in recent years. As shown in **Figure 1**, heat pump installations have continued to grow at a similar pace for the past decade, with less than 2000 units added each year.

But new developments in the energy sector, coupled with the formation of a new, revitalized Norwegian IEA Heat Pump Centre National Team, can help bring about a revival in the heat pump market. Especially important has been the establishment of Regional Energy Conservation Centres as well as the introduction of Energy Conservation Operators for the Buildings and Industry sectors.

Under an agreement reached in 1993, a special electricity tax can be raised to fund the Regional Energy Conservation Centres. Today, 14 of Norway's 19 counties have such a centre. Each one cooperates with local utilities and provides general information and consultancy to residential and commercial customers with regard to energy conservation, indoor climate and alternative energy. Their services include the provision of an energy preanalysis which can lead to the recommendation of feasible measures and the evaluation of technical solutions. In addition, they perform energy measurements and offer simple training schemes. All services are provided free-of-charge.

For 1996, around US$ 14 million has been granted from the government for energy conservation activities. Most of these funds are allocated to the Energy Conservation Operators. These are companies or institutions with a special competence such as in energy conservation in buildings and industry. The Energy Conservation Operators play a key role in overcoming one of the main barriers for energy conservation in Norway - a lack of know-how.

By forming strategic alliances with the Energy Conservation Centres and Operators, it is envisaged that the new Norwegian IEA Heat Pump Centre National Team will be able to play a key role in providing information on heat pumps directly to potential heat pump users as well as to decision makers.

Source: Jørn Stene, SINTEF Energy, Norway, Tel: +47-7359-3750, Fax: +47-7359-3950.

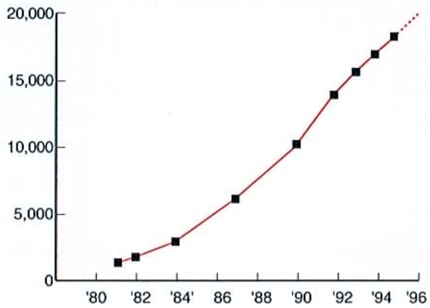



*Figure 1: Cumulative development of Norwegian heat pump installations since 1981.*

# Competition attracts wide interest

**Netherlands -** The launch of the Dutch heat pump competition for the residential sector at the building equipment exhibition "BOUW-RAI" in April this year generated much interest, enthusiasm and discussion among market parties. It is expected that the competition will stimulate the formation of "technology clusters" among installers, manufacturers, building companies and architects, through which cost-effective heating systems for the Dutch market will be developed. This market is especially difficult because of the large penetration of low-cost gas heating systems. By the end of 1996 it is expected that at least five to six systems which comply to the standards set by a group of experts will have been developed as a result of the competition. The developers of accepted systems will be awarded with contracts for demonstration projects.

Source: Mr Onno Kleefkens, Dutch National Team, Fax: +31-30-2316-491.

# British hold national seminar

**United Kingdom -** A seminar to be held on July 4 in Reading will bring together many of the key players in the heat pump market here. "Heat Pumps in the UK: The New Opportunities" is expected to attract a nation-wide audience from design, manufacturing and supply companies, plus equipment users and people from universities and research establishments. The stated aim is to assist manufacturers, users, researchers and associations in forming strategic alliances based on informed decisions, with the ultimate objective of stimulating the market in the United Kingdom.

The morning session will explore the market opportunities for heat pumps in the UK. In the afternoon, participants will disperse to attend separate sessions on industrial, commercial and residential heat pumps. The session on industrial heat pumps will act as a follow-up to the IEA Heat Pump Programme's work under Annex 21: "Global Environmental Benefits of Industrial Heat Pumps."

At the end of these sessions, everyone will reconvene to participate in a debate under the theme "How do we raise the profile of heat pumps in the UK?"

The proceedings will be published by the IEA Heat Pump Centre.

Source: Prof. David Reay, Chairman of the Steering Committee. Fax: +44-191-252-2229.

# Heat pumps for future buildings

**Switzerland -** Houses of the future, which are expected to have an annual energy demand of 200 MJ/m$^2$ or less, present both a challenge and an opportunity for heat pump designers. The challenge is to produce a heating system that can compete with conventional oil heating systems at such a low energy demand. An opportunity is presented because these houses will be ideally suited for using low-temperature heat distribution systems, which lead to efficiency improvements and other benefits for heat pump systems.

INFEL (The Information Center for Electricity Applications) has just begun the first phase of a research project called "Low-Cost, Low-Temperature Heat Pump Heating System" under contract to the Swiss Federal Office of Energy. The aim is to develop an easy-to-install residential system for use with underfloor heating, operating with a supply temperature of less than 30°C.

The heat pump is to be designed so as to minimize installation costs. An integrated "intelligent" controller should provide a self-regulatory characteristic without needing additional control equipment, and the unit must be suitable for direct connection to the hydronic heat distribution system. The low supply temperature should yield a seasonal performance factor (SPF) 30% higher than with conventional heat pumps. Ambient air or ground coupling may be used as the heat source.

In the first phase, simulation studies will be carried out using the software package TRNSYS with the heat pump model of YUM. The optimal design of the low-temperature heating system will be determined along with the building requirements and the control ranges for the heat pump. The interactions between building response, system dynamics, control system design and operation strategy will also be studied.

Particularly important for comfort conditions is to examine the effect of changes in outdoor temperature, heat source temperature and solar radiation. The project will also look at the impact of interruptions in the electricity supply which may be necessary to curtail peak power demand levels.

The results obtained from the simulation phase will assist in a second phase of feasibility study and problem analysis, which will lead to the development of the heating system. The achievable SPF and economic factors will be examined in order to estimate the cost-effectiveness and marketability of the complete system for both new buildings and for retrofit applications. Prototype and bench tests are planned for subsequent phases as well as the setting up of pilot projects. Eventually, workshops and open days will be carried out to market the new system.

Partners in this project are the Central Swiss Engineering College, Lucerne, which will carry out the simulation work, and the Swiss Federal Institute of Technology, Zürich, which will develop control technology. Building design considerations will be implemented by the planning engineers Basler & Hofmann, and Bircher+Keller will work on the design of the heat distribution system. The project partners will work together with an advisory board.

International collaboration on this project may take place under the IEA Heat Pump Programme. A proposal for an Annex has been made and will be worked out in more detail after completion of the first phase in September 1996.

Source: Dr Thomas Afjei of the Swiss National Team, Fax: +41-1-291-0903.

# Absorption heat pump for the home

**Austria -** The Tirol-based company, Heliotherm, has developed an absorption heat pump using ammonia/water as working pair for the residential market. Operating in heat pump mode, the unit can supply 16 kW of heat at 50°C. Alternatively, the unit can be switched to operate as a 25 kW boiler at 75°C. The company claims that the unit will exhibit a primary energy ratio of 1.5 to 1.6 in heat pump mode . The unit is ideally suited for buildings with existing gas or oil-fired heating systems. Mass production of gas-fired models will begin in the first half of 1997.

Source: Wärmepumpe from IZW, Germany, March 1996.

# 50 MW system sparks new initiatives

**Netherlands -** The successful installation of the largest system in the Netherlands has helped to encourage renewed interest in industrial heat pumps (IHPs). A mechanical vapour recompression (MVR) heat pump with an installed capacity of 50 $MW_{heating}$ and 44 $MW_{cooling}$ has been in use since November 1995, in a poprane-propylene splitter at the Shell chemical plant in Pernis. With a temperature difference over the column of only 10°C, a coefficient of performance (COP) of almost ten is achieved and over 37 million m$^3$ of natural gas are conserved per annum. Even more important to the plant operator is that the purity of the distillate has increased by around 8 to 10%. And the local environment also benefits since no thermal waste needs to be discharged into the surrounding surface water – a matter of great importance to government authorities.

This project is helping to change perceptions of IHPs in the Dutch industrial sector. Building on the work of the IEA Heat Pump Programme Annex 21 on industrial heat pumps, the Netherlands Agency for Energy and Environment, Novem, has been stimulating interest in IHPs among experts from various industrial sectors. An important strategy is to take them on excursions to successful systems.

Seeing successful heat pumps, some of which have been in use for over ten years, and the recent Shell MVR-system, has shown those who didn't have a heat pump that these type of systems can be run without problems. The picture drawn by the users of relatively problem-free operation is remarkably opposite to the belief of non-users. Not only can IHP users speak positively about their operational experience, they can also explain the many additional advantages of using heat pump technology.

The sharing of experiences has sparked off renewed interest in IHPs, particularly in the chemical industry for which at least four application and engineering studies are now being carried out.

Source: Mr Onno Kleefkens, Dutch National Team, Fax: +31-30-2316-491.

# Fish kept warm with 70% less energy

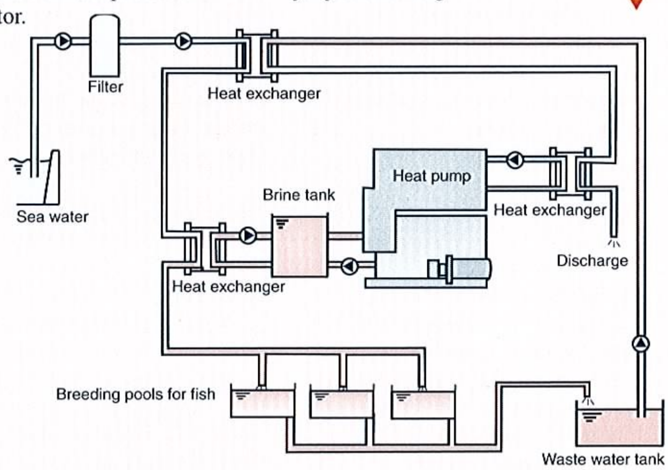
**Japan -** Fish breeding can be an energy intensive industry, especially in cold regions such as in Japan's north island of Hokkaido. But a demonstration project conducted by the Hokkaido Electric Power Co. Ltd., in cooperation with Mitsubishi Electric Co. Ltd. has shown how electric heat pumps, in combination with a heat recovery heat exchanger system, can reduce the consumption of primary energy by 80% in comparison to conventional systems using oil-fired boilers.

The heat pump uses sea water, typically at 8°C, as heat source, and supplies water to the breeding pools at 25°C. The water is preheated by recovering heat from waste water rejected from the pools via a heat exchanger (see **Figure 2**). In tests made under these conditions, the system registered a COP of 7.2 (this includes heat recovered by the heat exchanger). Even at sea temperatures of 3°C, the COP only dropped to 6.6. The heat pump system, uses a direct-injection screw compressor and flooded evaporator.

More information on this project is given in the brochure "Demo 38" published by IEA CADDET Energy Efficiency.

Source: IEA CADDET Energy Efficiency, The Netherlands. Tel: +31-46-420-2224; Fax: +31-46-451-0389.

*Figure 2: Outline of the heat pump system for fish breeding.*




# Low-cost absorption system in development

**Netherlands -** A new type of absorption heat pump is being developed that promises to offer a low-cost solution for many industrial applications. Based on the principle of reverse rectification, the new absorption heat pump will be designed to provide a temperature lift of 40°C or more up to a maximum temperature of 200°C.

By using non-corrosive working media, such as glycol/water, the developers expect to be able to keep the installation costs low, while offering energy savings of up to 70%. Applications are envisaged in distilleries, hot air dryers and cogeneration equipment.

The development work is being carried out by the engineering bureau HoSt, a daughter company of Holec Projects and Stork Ketels, with the help of TNO (the Netherlands Organization for Applied Scientific Research) and the support of Novem (the Netherlands Agency for Energy and Environment).

A pilot project will begin in 1996. More information is available from Mr Herman Klein Teeselink, HoSt, Hengelo. Tel: +31-74-2401807.

Source: Mr Onno Kleefkens, Dutch National Team, Fax: +31-30-2316-491.

# Total Energy System

**Switzerland -** A district heating scheme in Cham, combines a gas-driven cogeneration plant with an electric heat pump in a so-called "Total Energy System." In this system, a 543 kW Otto gas engine drives a 187 kW power generator. Some of the generated power is used to drive a 240 $kW_{heating}$ water-to-water heat pump, which extracts free heat from the nearby river. The rest is delivered to the local power utility. Measurements made over a one-year period showed an overall efficiency, for heat and power production, of 92%, including distribution losses. More information on this project is given in the brochure "Demo 37" published by IEA CADDET Energy Efficiency.

Source: IEA CADDET Energy Efficiency, The Netherlands. Fax: +31-46-451-0389.

# University installs GSHP

**Australia -** The soon to be completed Engineering Building of the Victorian University of Technology's Werribee Campus will be air conditioned by a geothermal, or ground-source heat pump (GSHP). The system, which will be the first of its kind in any Australian University, will use the ground, which remains almost constant at around 17°C, as both heat source in winter and heat sink in summer.

Some 42 boreholes have been drilled to a depth of 50 m and 4.2 km of piping is to be laid in the ground. Originally the holes were to be drilled to 100 m, but substantial water flows at 75 m meant that their depth had to be reduced to reduce drilling difficulties. All heating and cooling needs will be met by distributed water-source heat pumps. The university's energy advisors, Enersonics, estimate that the system will save 175 tonnes of $CO_2$ per annum and with a payback period of around 4.2 years, will prove to be a good investment for the university.

Further information is available from Mr Peter Dobney, Enersonics Pty Ltd. Fax: +61-3-819-5452.

Source: Australian Energy Management News, November 1995.

# EU embarks on $CO_2$ initiative

**Europe -** A new project has been set up under the European Union Joule Programme to push forward the development of heat pumping systems using $CO_2$ working fluid. Entitled "Energy Efficient and Environmentally Friendly Heat Pumping Systems Using $CO_2$ as Working Fluid", the three year project will bring about the development of prototype systems for the following applications:

- hot water heat pumps for residential applications
- commercial heat pumps for water heating and heat recovery
- space heating heat pumps for retrofitting in buildings with high-temperature heat distribution systems
- heat pumps for dehumidification and drying in residential and commercial buildings applications.

Beginning in February this year, the project involves a range of research activities, culminating in the construction and testing of the prototypes. A range of documentation will be generated including information on thermodynamic and transport properties, a safety and risk assessment of $CO_2$ systems, a design handbook and a final report. The project is coordinated by the Austrian Association of Electricity Utilities.

Source: Mr Jostein Pettersen, SINTEF Energy, Norway. Tel: +47-7359-3924; Fax: +47-7359-3926.

# Venting ban widens

**USA -** The intentional venting of CFCs and HCFCs has been outlawed under the clean air act since 1990. From November 15 this year, this law will be extended to include CFC and HCFC substitutes such as HFCs. To complement this provision, the Environmental Protection Agency is to publish rules on the recovery and recycling of these working fluids, such as evacuation requirements.

Source: Koldfax from ARI, February 1996.

# Impact of 'naturals' on GWP is marginal

**Switzerland -** A study carried out for the Federal Office of Energy (BEW) suggests that in terms of global warming potential (GWP), the advantages of using natural working fluids in heat pumps, instead of HFC-134a, are marginal.

In his report "Comparison of the Environmental Relevance of using Alternative Refrigerants in Compression Heat Pumps and Cooling Equipment", T. Weibel compares the environmental impact of using CFC-12 with HCFC-22, HFC-134a, propane, iso-butane, ammonia and $CO_2$. In his analysis, he takes account of all possible sources of environmental impact. Not only are emissions relating to the operation and maintenance of the equipment considered, including the impact of power generation and refrigerant leakage, but also the emissions related to the delivery and eventual recovery of refrigerant, and the environmental impact of equipment manufacture.

The analysis was carried out for heat pumps meeting an annual heating demand of 20,000 kWh and cooling equipment meeting an annual cooling demand of 30,000 kWh. **Table 1** shows the results of the study for heat pumps and indicates the assumed seasonal performance factors (SPFs) of using different refrigerants.

As shown in Table 1, the results are strongly dependent on the type of fuel mix used to generate electricity. For Switzerland, where the electricity mix results in low $CO_2$ emissions, a propane-charged heat pump has roughly half the GWP as one using HFC-134a for 100 years time horizon. But taking a European energy mix, which is dominated by power generation from coal and other fossil fuels, the variation in GWP from using different refrigerant alternatives becomes marginal.

Alongside GWP, the study also looks at other environmental factors including ozone depletion, acidification and radioactivity. However, the report does not claim to be a complete study of environmental impact since many effects, especially of HFCs, are not yet fully understood.

The German language report, entitled "Vergleichende Umweltrelevanz des Einsatzes alternativer Kältemittel in Kompressions-Wärmepumpen und -Kälteanlagen" (Order no. 9553849), is available from ENET in Bern (Fax: +41-31-352-7756).

Source: Dr Thomas Afjei of the Swiss National Team. Fax: +41-1-291-0903.

*Table 1: Comparison of the global warming potential from using electric heat pumps containing different refrigerants with that of a CFC-12 system.*

| | HCFC-22 | HFC-134a | Propane | Iso-butane |
|---|---|---|---|---|
| Assumed SPF | 4 | 3.6 | 4.5 | 3.5 |
| **Swiss electricity mix** | | | | |
| GWP - 20 years | 40% | 43% | 12% | 17% |
| - 100 years | 22% | 23% | 11% | 14% |
| - 500 years | 25% | 27% | 17% | 23% |
| **European electricity mix (UCPTE)** | | | | |
| GWP - 20 years | 74% | 81% | 58% | 75% |
| - 100 years | 66% | 73% | 56% | 72% |
| - 500 years | 74% | 82% | 65% | 83% |

# Metal hydride systems in development

**USA -** In two separate projects, progress is being made towards the development of heat pumps and air conditioners based on the metal hydride cycle.

Ergenics Inc. of Ringwood, New Jersey, is developing a thermally driven system which operates as a batch process. At the beginning of the process, air to be cooled passes over a metal hydride coil. The coil takes up heat from the air as hydrogen is desorbed from the metal hydride - an endothermic reaction. The hydrogen gas flows to a second metal hydride coil at a lower pressure where it is absorbed and gives off heat. In the second stage of the batch process, heat is applied to regenerate the hydrogen and send it back to the original coil, ready for the next cooling cycle.

Two pairs of coils are used so that one pair provides cooling while the other is regenerating. With Ergenics' patented technology, the system has a cycle time of just 15 seconds. This reduces the size of equipment such that a residential heat pump weighing less than 5 kg can be envisaged. The first application of this technology, however, is likely to be as a car air conditioner.

A separate research and development project on metal hydride cycles is to be carried out through a joint venture of the Westinghouse Savannah River Company and the Thermal Electric Devices Inc. (TED) of Albuquerque, New Mexico. With the help of funding from the Department of Energy, TED has already developed technology which it claims could result in a heat pump with a cooling SPF of 5 (under standard conditions).

The TED approach differs from that of Ergenics in that it only has one set of reactors and uses a compressor to pump hydrogen from a cold reactor to a hot reactor. The cycle is reversed periodically and a damper must be used to direct the air to be cooled over the cold reactor.

For more information on these two projects, contact Mr Phil Burghart, Ergenics, Inc. Tel: +1-201-962-4480; Fax: +1-201-962-4325, or K.Thomas Feldman Jr., Thermal Energy Devices Inc. Tel: +1-505-268-0154.

Source: Technologies for Energy Management, March 1996 from Cutter Information Corp.

# New support for Dutch 'naturals'

**Netherlands -** A national working group on natural working fluids has been set up to build on work conducted under IEA Heat Pump Programme Annex 22 "Compression Systems with Natural Working Fuids." The goal has been set of "stimulating the prudent use of natural refrigerants in refrigeration equipment and heat pumps, taking into account aspects of energy-use, environment, safety and economy."

Known as PlaNK, the group will be coordinated by a group of experts representing various market parties with activities financed by industry and government.

In addition to the coordination of Annex 22 activities, the group plans to make an inventory of European legislation and to list existing installations. It also intends to work with governmental offices in the formulation of relevant legislation. The first action of PlaNK will be the organization of a national workshop.

Source: Mr René van Gerwen, TNO (the Netherlands Organization for Applied Scientific Research), Apeldoorn. Fax: +31-55-5419-837.

# Unitary market tops 5 million

**USA -** Annual factory shipments of unitary air-source air conditioners, including heat pumps, exceeded five million units for the first time in history in 1995. Air-to-air heat pump shipments exceeded one million units for the second year running and registered a 2% growth on 1994 (see **Figure 3**). These data are provided by the ARI (Air-Conditioning and Refrigeration Institute).

Shipments data for packaged terminal heat pumps also reached a landmark figure, surpassing 100,000 units for the first time since 1990. Numerical shipments of water-source heat pumps fell from 105,000 in 1994 to 99,000 in 1995 according to the Bureau of the Census.

**Table 2** indicates the market share of the major manufacturers of unitary air conditioners, according to estimates made by the Air conditioning and Refrigeration News.

1995 also saw a massive increase in the value of heat pump imports to the USA. Bureau of the Census statistics show that imports of heat pump air conditioners with less than 17.5 kW (60,000 Btuh) cooling capacity rose from US$ 1.4 million in 1994 to US$ 8.6 million in 1995. Imports of larger heat pumps, however, were substantially lower in 1995. The total value of heat pump imports were up 30% to US$ 16.8 million in 1995 while exports climbed 8% to US$ 82.5 million.

Source: Air Conditioning and Refrigeration News, April 15 1996.

*Figure 3: US air-to-air heat pump shipments.*

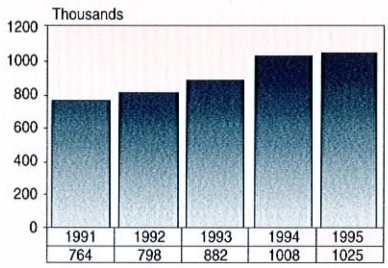



*Table 2: Estimate of the share of unitary air conditioner domestic shipments among the leading US manufacturers.*

| | |
|---|---|
| **Carrier Corp.** (including Bryant, Day & Night, and Payne) | 22% |
| **Goodman Manufacturing Co.** (including Janitrol) | 14% |
| **Rheem Air Conditioning** (including Ruud, and WeatherKing) | 13% |
| **The Trane Company** (including American-Standard) | 12% |
| **York International Corp.** (including Luxaire, Fraser-Johnston, and Coleman®Evcon) | 12% |
| **Inter-City Products Corp.** (including Heil, Tempstar, Arcoaire, and Comfortmaker) | 10% |
| **Lennox industries Inc.** (including Johnson, and AirEase) | 10% |
| **Nordyne** | 4% |

# Booming market in France

**France -** 110,000 air-conditioning units were sold in France in 1994 - an increase of 35% on 1993. Of these, 20,000 were reversible and 3,000 units were for low-temperature underfloor heating systems.

Water-loop heat pumps are being installed at the rate of 15,000 per year. These single-room units serve whole buildings and may share an outside heat source or transfer heat sources and sinks in a zone system. Around half of all rooftop units installed had a heat pump function and split systems, multi-split systems and VAV (variable air volume) units (up 26% to 700 units in '94) are also common. Residential units using underfloor heating are available, as are fresh ventilation air units. While the market continues to be dominated by commercial building applications, the residential sector is seen to be increasingly important. These observation were presented by Mr C. Chapon of EdF and Mr M. Guittard of ADPM at the 8th meeting of the Heat Pump Concerted Action Group of the European Commission, held in Paris in November 1995.

Source: EU Heat Pump Newsletter, January 1996.

# Heat wave boosts AC market

**United Kingdom -** High summer temperatures in 1995 led to increased demand for packaged air conditioners (ACs). Mitsubishi Electric reported a 66% increase in sales, which grew to GB£ 21 million in 1995. The company forecasts that sales will jump a further 50% this year and expects to have the largest market share for packaged AC products in the UK by 1997.

Source: JARN, March 25, 1996.

# Thermal systems continue to rise

**Japan -** Domestic s hipments of thermally-driven systems both gas engine and absorption equipment registered increases in the year to September '95. Shipments of gas heat pumps (GHPs) grew 15.8% to 32,173 units. The cooling capacity of these units totalled 836,605 kW, an increase of 29.6% on the previous year, thus indicating that the share of larger GHPs is increasing.

Absorption chillers accounted for 4,712 units in the year to September '95, up 4.9% on the previous year. The total cooling capacity of shipped absorption equipment was 2.63 GW, of which gas-driven units accounted for 1.44 GW and 0.65 GW was for oil-driven units. According to the Japan Gas Association (JGA), the nation-wide cooling capacity of gas-driven equipment grew 84% in the five years to March 1995, while the total capacity of air conditioners rose only 48%. Thus gas driven equipment is steadily increasing its share of the market.

Source: JARN, October and December 1995.

**Errata**

In the previous issue of this Newsletter, (No.1/1996), some of the figures depicting market data (on page 7) were wrongly labelled. For Japanese room air conditioner shipments, the vertical axis on Figure 3 should have been labelled from zero to 12 million so that, for example, 1995 shipments totalled 7.7 million of which 6.8 million were heat pumps. In Figure 5 on the world production of air conditioners, the labels for Japan and S.E. Asia were transposed. The figure should have indicated that in 1993, Japanese production fell to 6 million units while S.E. Asian production rose to 7.8 million units.

# HPWHs give way to space heating

**Austria -** As illustrated in **Figure 4**, the Austrian heat pump market has traditionally been dominated, in terms of numbers, by heat pump water heaters (HPWHs), with sales of space heating heat pumps at a much lower level. In recent years, this trend has changed with sales of HPWHs in steep decline and a steady rise in sales of space heating heat pumps.

In 1995, HPWHs sales dropped 17% to 3,650 units while sales of space heating units rose 7% to 1,448 units. In addition, 26 heat recovery heat pumps with a heating capacity greater than 40 kW were installed along with 114 dehumidification systems for swimming pools.

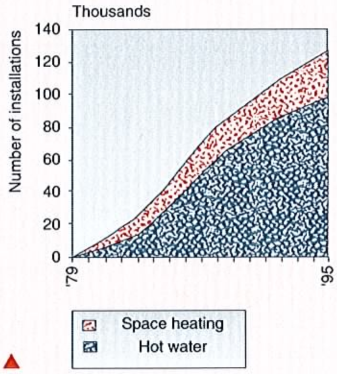


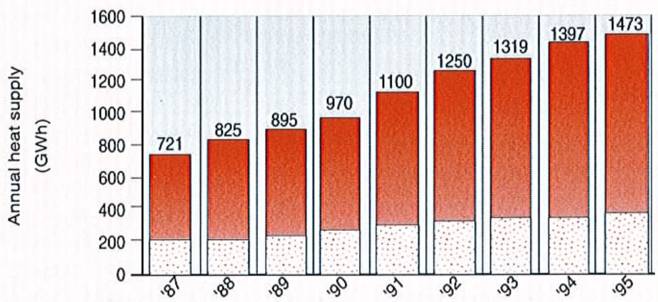

*Figure 4: Cumulative growth in Austrian heat pump installations.*

Production of HPWHs in 1995 was down 32% on the previous year to 2,150 units, while the manufacture of space heating systems grew 13% to 1,070 units.

As shown in **Figure 5**, heat delivered by installed heat pumps reached 1472 GWh (5.3 PJ) at the end of 1995, effectively saving 270 ktonnes of heating oil per annum. Data for power consumption reveal that the average seasonal performance factor for all installed equipment was 2.2 for HPWHs, and 2.6 for a space heating heat pumps.

Source: "Der Wärmepumpenmarkt in Österreich, Berichtsjahr 1995", April 1995, produced by the Forschungszentrum Seibersdorf for the Ministry of Science, Research and Art.

*Figure 5: Cumulative development of heat delivered by Austrian heat pump.*




| | '87 | '88 | '89 | '90 | '91 | '92 | '93 | '94 | '95 |
|---|---|---|---|---|---|---|---|---|---|
| Space heating | 532 | 601 | 645 | 697 | 802 | 930 | 981 | 1043 | 1106 |
| Hot water | 189 | 224 | 250 | 273 | 298 | 320 | 338 | 354 | 367 |

# Canadian shipments up 8%

**Canada -** Data from the Heating Refrigeration and Air Conditioning Institute (HRAI) of Canada show that shipments of unitary air conditioners totalled 146,887 units in 1995, an increase of 8% over 1994 shipments. Of these, 116,153 units had a cooling capacity of less than 17.6 kW (5 tons). Interestingly, data from the Canadian Gas Association (CGA) show that shipments of conventional gas, oil and electric heating equipment, fell 16% in 1995, to 183,497 units.

Source: Air Conditioning and Refrigeration News, April 15 1996.

# Workshop held on Systems & Controls

**Japan -** The IEA Heat Pump Centre's workshop on "Systems and Controls for Energy Efficiency", held in Tokyo on 7-8 May, brought together an international audience of experts in the fields of heat pumping equipment and control technology. A total of 14 papers were presented, covering a wide range of heat pumping technologies for residential and commercial buildings applications.

The presentations highlighted the many ways in which energy efficiency, economics, and customer comfort and conveniance can be improved through the use of systems and control technologies.

Proceedings of this workshop are available from the IEA Heat Pump Centre - see page 31.

Source: Mr Jos Bouma, IEA Heat Pump Centre.

# Internet site grows

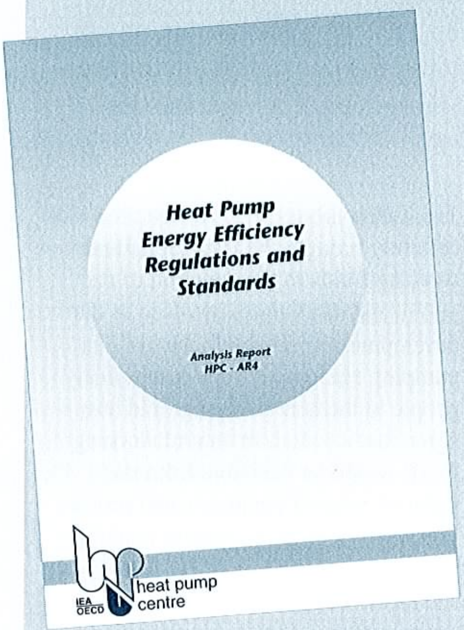
**HPC -** The HPC's Internet site continues to grow as more information is added. Many visitors come to view the pages describing how heat pumps work. And more and more are discovering the IEA Heat Pump Programme Library and contacting the HPC to get the book they need.

A new feature, now being added, is an international listing of heat pump manufacturers. Over the years, the HPC has received many enquiries from people looking for manufacturers to supply specific equipment to their region. Finding the right company has often resulted in a fruitful partnership. Through Internet, such contacts can be made more easily.

By providing information on all the world's manufacturers and their equipment at a single point, the HPC's Internet site offers an important new service for manufacturers and users alike. Only companies who register with the HPC are included in detail, so all manufacturers are urged to contact the HPC for a registration form.

The HPC home page is found at http//www.heatpumpcentre.org

# HPC completes standards analysis




**HPC -** A key element of the IEA Heat Pump Programme's "Strategy Plan" is to address the issue of standards and regulations, since they have a profound effect on the development of markets for heat pumping equipment. In its latest publication, "Heat Pump Energy Efficiency Regulations and Standards," the IEA Heat Pump Centre (HPC) provides a thorough review of regulations, standards and labelling requirements for heat pumps and cooling-only air conditioners in building applications.

The information is based on a survey of more than 30 countries, and will be highly useful to equipment manufacturers and installers, as well as to utilities and local and national authorities. While the focus is on energy efficiency regulations, safety measures, especially regarding working fluids, are also covered. By discussing the impact of the regulatory environment on heat pumping technology and market development, this report will make an important contribution to the development of tomorrow's regulations and standards.

The report can be ordered from the HPC - see page 31.

# Absorption system users exchange experiences

**Sweden -** Organized by the IEA Heat Pump Centre, the users club of large absorption heat pumps held their annual meeting in Eksjö, Sweden on March 13. This time the meeting was hosted by Mr Hans-Å ke Tilly, director of Eksjö Energi, AB, whose company runs a nearby refuse incineration plant. At this plant, hot water is used to drive an absorption heat pump which upgrades waste heat from the flue gas cleaning process for the production of hot water for the local district heating network.

At the meeting, views and opinions on various operational issues were exchanged and reports were given of some new installations that are in the pipeline. One report showed how absorption heat pumps can have more than one application. When it was installed in 1984, the 7 MW heat pump at Trolhättan was the world's largest absorption heat pump. However, after ten successful years in supplying a district heating system using waste heat from chemical plants, the system can no longer be utilized due to changes in the industrial processes which provided heat sources. But soon, the heat pump will be transported by barge to begin a second life in Mariastadt where it will be installed at a paper mill and will utilize process cooling water as the heat source.

Also at the meeting, it was reported that the heat transformer at the Hoogovens steel works in the Netherlands is continuing to perform well in its 5th year of operation. And a new geothermal heat pump has started operation in Pyrcyze, Poland. Several plans were unveiled for new installations in Germany and France, including a two-stage district heat driven chiller for Berlin, a heat pump for Munich airport, and heat pumps for the French navy.

The users club will meet again in 1997. This time in Berlin.

Source: Mr Jos Bouma, IEA Heat Pump Centre.

## Ongoing Annexes

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

| | | |
|---|---|---|
| **Annex 16**<br>IEA Heat Pump Centre | 16 | AT, ES, JP, NL, NO, CH, US |
| **Annex 18**<br>Thermophysical Properties of Environmentally Acceptable Refrigerants | 18 | CA, DE, JP, NO, SE, UK, US |
| **Annex 22**<br>Compression Systems with Natural Working Fluids | 22 | CA, DK, JP, NL, NO, CH, UK, US |
| **Annex 23**<br>Heat Pump Systems for Single-Room Applications | 23 | CA, ES, FR, SE, CH, 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).

# Natural working fluids

## An international overview

*Mike Steadman, IEA Heat Pump Centre*

Mother nature seldom offers us a perfect solution. The benefits of an engineering development are often tainted by drawbacks. For heat pumps, the environmental benefits from their low energy consumption are tempered by concerns about the effects of their refrigerants. By using natural refrigerants, this environmental drawback can be overcome. But the application of the most readily available natural refrigerants is hampered by safety issues. Will the perfect solution ever be found?

With the discovery of the ozone depleting effects of CFCs and HCFCs, the heat pumping industry has faced the biggest challenge since the introduction of the first refrigeration equipment in the last century. The first option has been for the chemical industry to develop new materials that are suitable as working fluids, but which do not cause ozone depletion. But some scientists have suggested that these new chemicals could pose a further, as yet unforeseen, threat to the environment. One answer is to use naturally occurring materials that already circulate in the Earth's biosphere and are therefore not going to cause environmental damage when released into the atmosphere in small quantities.

In just a few years, much progress has been made towards the adaption of heat pumping technologies (heat pumps, air conditioners and refrigeration equipment) for use with natural working fluids. For some applications, commercial equipment has already been realized.

This article looks at the background to today's thinking on natural working fluids and discusses the implications of using the different options. In the pink boxes, some information is given on the situation in various countries. Much of the information has been made available through the work of IEA Heat Pump Programme Annex 22 "Compression Systems with Natural Working Fluids."

### The natural philosophy

The consequences of using CFCs, which were considered to be totally safe substances when they were introduced as refrigerants in the 1930s, have highlighted how apparently benign synthetic chemicals can pose unforeseen problems when released into the biosphere. This has led to the idea that the quest for replacing CFC and HCFC replacements should focus on naturally occurring substances such as ammonia, hydrocarbons and $CO_2$ – substances which were used before CFCs were invented. Following this philosophy, synthetic chemicals, such as HFCs, should be avoided, or considered for use only as an interim measure to avoid ozone depletion.

### Green freeze

The idea of using natural refrigerants really came to the fore in 1992 when the German company FORUN introduced refrigerators, known as "green freeze" with an iso-butane/propane mixture as refrigerant. With the support of Greenpeace, the company was able to convince the public of the environmental benefits of a refrigerator using hydrocarbons. Consequently, the hydrocarbon refrigerant became a major selling point, making the refrigerator a market success. Soon, other European manufacturers joined this "marketing bandwagon" and now many of the major European refrigerator manufactures use hydrocarbon refrigerant for their entire range.

The hydrocarbon-filled refrigerator certainly brought the issue of natural working fluids to the attention of the public and of all those involved in the development and manufacture of heat pumping equipment. As a result, many people in the heat pumping field now agree that a switch to natural working fluids would be desirable from the point-of-view of environmental protection. But for most equipment manufacturers, the question of when, if ever, such a switch can be made, still remains unanswered.

### Implications of the naturals

When considering a new refrigerant, all the implications of its widespread application must be taken into account considered. These include:

- environmental impact
- performance
- safety
- economics
- maintenance requirements
- operating requirements
- market impact.

For equipment manufacturers these implications must be judged with respect to customer needs. This often means that economic implications have a high priority, although some customers may be prepared to pay more for a more environmentally acceptable system

Governments too may influence the choice of refrigerant, as is already the case for CFCs and HCFCs. Their judgement must be based on societal needs and will be strongly influenced by each refrigerant's environmental impact and safety implications.

In the remainder of this article, the implications associated with the main natural refrigerant alternatives, ammonia, hydrocarbons ,$CO_2$,,water and air are examined, and their current application trends are discussed.

## Ammonia: safety factors

A major reason for the successful introduction of CFC refrigerants in the 1930s was that they could be sold as "safety refrigerants" and replace the widely used ammonia refrigerant which is both toxic and flammable. The toxicity of ammonia, however, is relatively low, being for example 10 to 50 times less toxic than chlorine. Furthermore, its distinctive smell allows the gas to be detected with a concentration in air of as little as 5 parts per million (ppm). This is 1000 times less than the danger level. While this smell can cause panic in some situations, it is in fact an in-built early warning system that helps to reduce the risk of ammonia poisoning.

As to the flammability of ammonia, it has a lower explosion limit (LEL) of 15.5% by volume – 3 to 7 times that of natural gas. In many European countries ammonia is not classified as a flammable substance.

Nonetheless, the risk of accidents with ammonia must not be underplayed. According to the study conducted under Annex 20 of the IEA Heat Pump Programme, "Working Fluid Safety," historical evidence shows that the accident risk with ammonia heat pumping equipment (all applications) is about 1000 times greater than for a domestic gas boiler. It is therefore understandable that special precautions must be taken.

Building regulations vary, but when ammonia systems are allowed, they nearly always stipulate that the equipment must be isolated in a machine

## Austria

Ammonia and propane have an increasing share of both the heat pump and refrigeration markets. In contrast to HFCs, these refrigerants require only minor changes to existing technology, and this factor, rather than environmental concerns, has been the main driving force for their increased use.

Propane is used in outdoor installations of both air-source and direct-evaporation ground-coupled heat pumps. In the case of ground-coupled systems, the use of propane was spurred on by a licensing change introduced in 1993. This created difficulties for direct-evaporation with HCFC-22 as it is soluble in water, but not for propane which is virtually non-soluble.

The current, 30-year old, regulations prohibit the use of propane refrigerant in installations below ground or in residential and commercial buildings because of its flammability. This may change if Austrian regulation follow those of the German standard DIN 7002, currently available in draft form. This would allow propane heat pump installations not only in separated machine rooms in commercial applications but also in residential buildings.

Ammonia systems are increasingly used as new commercial refrigeration equipment. Most use open compressors, although a hermitic compressor using a separated-hood is now manufactured in Graz, Austria. To reduce the refrigerant charge, dry evaporation is used in place of flooded evaporation, and soluble oil is used in small systems. Combined with flat-plate heat exchangers, the refrigerant charge has been reduced significantly from about 0.1 to 0.05 kg/kW heating capacity.

In retail refrigeration, most systems use a secondary brine loop, and often incorporate some form of heat recovery. 40-bar compressors with maximum condensing temperatures of more than 70°C are typical.

In buildings, ammonia systems serve hydronic systems, using either single or two-stage compression according to the heat distribution temperature. Equipment is contained in a compact casing, where all safety features are installed.

*Source: Hermann Halozan, Austrian National Team*

## Germany

Approximately 20% of residential heat pump sales are for units charged with propane or propylene – 300 to 400 units per year. As an example, one supplier has installed approximately 200 propane heat pumps in recent years with heating capacities ranging from 12 to 50 kW. Hydrocarbons are also regarded as promising alternatives in supermarket refrigeration, and several prototype systems have been constructed. The units are placed in separate machine rooms and brine, ice slurry or silicone oil are used as the heat transfer medium in a secondary distribution system.

Ammonia-charged systems are attracting a growing interest for commercial buildings applications. About 20 chiller systems are currently in operation. Several ammonia systems have been installed in supermarkets. A 220 kW ammonia heat pump is operating at the ILK building in Dresden (see IEA Heat Pump Centre Newsletter Vol.13/No.1 p.8).

*Source: "International Status Report on Compression Systems with Natural Working Fluids," Report HPP-AN22-2 from the IEA Heat Pump Centre.*

room and that heat or cold is distributed via a secondary system. Other commonly applied safety measures include the installation of emergency shut-down systems, leak detectors, water spray systems and venting systems. The latter two measures make use of the fact that ammonia is soluble in water and lighter than air. The **Box** lists the safety measures imposed in Norway – a country where much work is being done in developing new applications for ammonia heat pumping systems. One further measure aimed at improving safety has been the development of systems such that the refrigerant charge is minimized.

## Economics of ammonia

All these measures lead to increased installation costs with ammonia systems. Furthermore, ammonia systems pose special requirements on component design because ammonia corrodes copper and zinc. This means all components must be made of steel and the copper windings of electric compressor motors must not be exposed to ammonia. This in turn means that all joints must be welded, which is costly, and that the low-cost hermetic compressors used with other refrigerants are not suitable for ammonia. Furthermore, the high pressures needed for ammonia operation also add to the cost of the compressor, although some savings are made through the use of smaller gauge piping.

Other practical difficulties posing cost increases are:

- the need to install multi-stage compression systems in some situations to avoid too high compressor outlet temperatures
- the need to install an automatic oil return system due to the fact that mineral oils are not soluble in ammonia.

**Table 1** compares the cost factors for a commercial chiller system using ammonia with $CO_2$ as transfer medium, with those for a direct evaporation system using the HFC mixture R-404.

In many applications, the additional costs of an ammonia system are offset by energy savings. As shown in **Figure 1**, the favourable thermodynamic properties of ammonia theoretically lead to a better efficiency than with other alternatives. This theoretical advantage is often realized in practice, although not in systems where a secondary thermal distribution system is required.

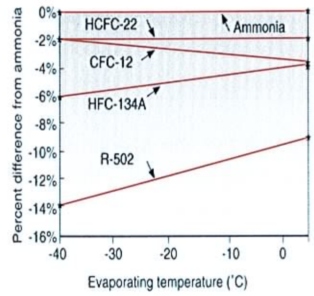



*Figure 1: COP of refrigerants based on isentropic compression (Source: Cole R.A., "Ammonia as a refrigerant in light of the CFC phase-out").*

## Ammonia in practice

Ammonia has been used in industrial refrigeration applications such as food processing, food preservation and cold storage for more than a century. Other traditional applications include ice rinks, and ice manufacture and storage. Today, new applications are being found for space conditioning in commercial buildings, in district heating/cooling systems, and in supermarkets. These applications are of course restricted to the countries and regions where the use of ammonia for non-industrial applications is allowed. In particular, strict regulations do not permit the use of ammonia for building applications in Japan and have severely restricted such applications in the Netherlands. In industry, ammonia refrigerant is finding new applications in the provision of heat for drying and other heating processes.

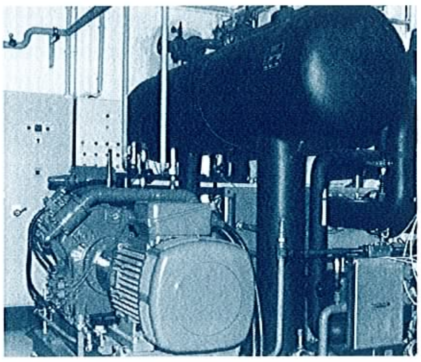
**Norwegian safety regulations for ammonia-charged equipment installed in a separate machinery room**

- Walls, floor and ceiling made of fire-proof materials
- No openings permitting $NH_3$ to circulate from the machinery room to other parts of the building
- Sufficient number of (fire-proof) self-closing, tight-fitting doors opening outwards
- Ammonia detectors with remote alarm (2 level alarm with shut-off system at highest level)
- Mechanical ventilation which can be started or stopped at the outside of the machinery room
- Emergency lighting
- Fire extinguishers
- Shut-off switches placed at the inside and outside of the machinery room
- Personal protective equipment stored at the outside of the machinery room including filter masks, protective goggles, gloves, protective clothing (gas protection suit, ABC suit), eye-cleaning system, emergency showers and first-aid equipment.

In addition, installation of sprinklers and an emergency shut-off system, and the sectioning of the plant should also be considered.

*Source: Norwegian National Team.*

*This ammonia-charged heat pump provides space conditioning for a German laboratory.*



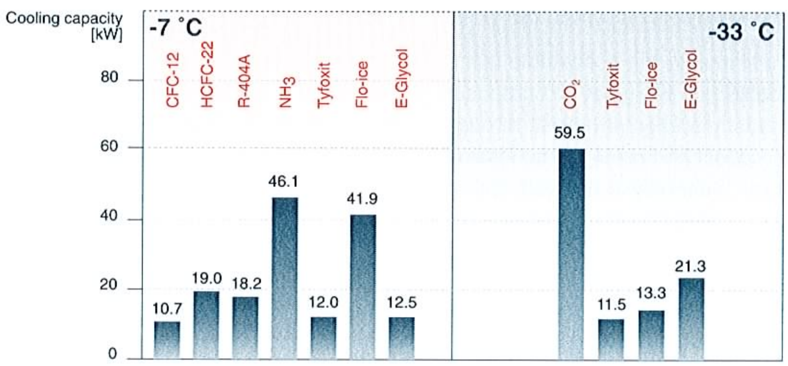
| | $NH_3/CO_2$ | R-404 |
|---|---|---|
| **Components:** | | |
| compressor | - | + |
| evaporators/ aircoils | + | - |
| condenser | + | -? |
| evaporator/ condenser | ++ | - |
| charge | - | ++ |
| pumps | ++ | - |
| piping | - | - |
| **Design** | - | - |
| **Site work** | - | - |
| **Starting up** | - | (+) |
| **Installation cost:** | | |
| small plants | + | - |
| "larger plants" | - | - |
| **Running cost** | -- | + |
| **Total cost** | - | + |

*Table 1 : Comparing the cost of commercial chillers using ammonia and $CO_2$ as a secondary fluid, with direct-evaporation systems using R-404 (Source: Article by Rolfsman from IEA HPC Workshop Proceedings "Compression Systems with Natural Working Fluids").*

The market drivers for these new applications are the need to use long-term CFC alternatives and the desire to improve energy efficiency. For large capacity applications, ammonia has an advantage over HFC-134a as the physical size of the compressor is smaller with ammonia.

Concerns about safety aspects and increased installation costs are the major market barriers. The requirement for a secondary distribution system can also be a barrier for applications such as industrial or retail refrigeration, where direct-evaporation systems are often used with synthetic working fluids. Secondary distribution systems can reduce efficiency and increase costs. To counteract this drawback, a number of new fluids are being tried out in secondary heat distribution systems in place of the traditional brine or glycol. In Switzerland, for example, $CO_2$ is used for low-temperature refrigeration (e.g. -33 °C) and ice slurry for moderate temperature refrigeration (e.g. -7°C). As shown in **Figure 2**, both these fluids offer a better refrigeration power than conventional fluids and can result in overall efficiencies comparable to direct-evaporation systems.

*Figure 2: Cooling capacity of various working fluids for secondary heat distribution when flowing in equal tube lengths and at equivalent pressure drops (Source: Günther Reiner of Sulzer Friotherm AG, Switzerland. Fax: +41-41-4625061).*



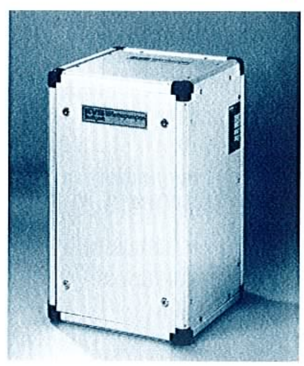

## Hydrocarbons: safety aspects

Like ammonia, the utilization of hydrocarbons is inhibited by safety issues - in this case flammability. It is often pointed out, however, that using a small quantity of hydrocarbon in small or medium-sized heat pumping equipment should pose no greater threat than that associated with the use of piped or bottled gas.

There are marked differences between the acceptance of flammable refrigerants in Europe and in North America and Japan. In Europe, the small quantities of hydrocarbon needed to drive a domestic refrigerator are not considered hazardous. Tests have shown that it is impossible to create a dangerous explosion with such equipment. In North America and Japan, tighter regulations and manufacturers' fears of litigation mean that no installations with hydrocarbons have yet been installed in these countries.

European regulations have allowed the "hydrocarbon revival" to spread from domestic refrigerators to equipment such as heat pumps which have larger fill weights. In Germany, for example, equipment using more than 150 g is permissable as long as the installer meets certain safety conditions, such as strict criteria on ventilation. Systems containing up to 1 kg of propane may be installed below ground and with up to 2.5 kg above ground.

*Example of a propane-charged heat pump from a German manufacturer.*



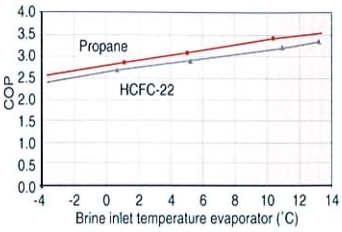



*Figure 3: COP comparison for propane and HCFC in a brine-to-water heat pump at 46°C heat supply temperature (Source: article by Lystad from IEA HPC Workshop Proceedings "Compression Systems with Natural Working Fluids").*

For all equipment, strict guidelines are in place to ensure a leak-proof design, such as using soldered joints and a hermetically-sealed compressor. And special measures must be taken during servicing and maintenance. For example, the refrigerant must be extracted and the systems flushed two times with nitrogen before any soldering work can be undertaken.

## Economics of hydrocarbons

For small equipment, the use of a hydrocarbon instead of a CFC or HCFC implies little or no changes either to components or manufacturing technique, and the cost should be much the same. Indeed, the cost price of propane heat pumps in Europe is generally no more than for the HCFC-22 alternatives. And when the heat pump is installed outdoors, no extra costs are incurred as no special safety measures need to be undertaken. Indoor installations may require some extra installation work to comply with regulations. Taking into account the higher energy efficiencies achievable with propane, see **Figure 3**, the actual cost of installing and operating a propane heat pump should be lower than with an HCFC-22 heat pump.

## Hydrocarbons in practice

Apart from flammability concerns, the requirements for using hydrocarbons as working fluids are no different than for CFCs and HCFCs. This has allowed

## Japan

At present, equipment manufacturers focus their attention on using HFCs or HFC blends as HCFC replacements. Their reluctance to use ammonia and propane is a result of strict regulations brought in to avoid toxic hazards or fire in densely populated areas. As to the use of ammonia as refrigerant, it has been virtually prohibited in new installations for more than 20 years, even for industrial refrigeration. However, during the last couple of years, the efforts of manufacturers to develop safer refrigeration systems, combined with some relaxation of the regulations, has allowed some ammonia-charged systems to be installed for industrial refrigeration within strict limits.

Other natural working fluids, such as carbon dioxide, water and air are also perceived as safe and environmentally friendly working fluids, and are under R&D. Of those systems, an air-cycle refrigeration system is at the most advanced stage with market introduction expected shortly.

So far, the market for natural working fluids is very limited. However, conceivable changes in government environmental policies may possibly accelerate the use of natural working fluids in the foreseeable future.

*Source: Mr Yoshio Igarashi and Mr Takeshi Yoshii of the Japanese National Team.*

## The Netherlands

The use of ammonia and hydrocarbon working fluids in building applications is severely curtailed by safety concerns. Strict guidelines for ammonia refrigerants have been imposed by the Commission for the Prevention of Disasters (CPR) under its directive CPR 13. Following these guidelines, ammonia-charged systems can only be installed when there is no safer alternative, disregarding any environmental benefits. This often means that the principle of "Best Technical Means" must be applied whereby all possible safety measures must be taken, regardless of the costs.

Despite these severe restrictions, there are a several examples of ammonia air conditioning systems, including two advanced GAX-type absorption systems. For industrial refrigeration, ammonia-charged systems have a prominent position, particularly in the dairy industry.

Apart from their use in domestic refrigerators, hydrocarbons are not used as working fluids in buildings due to concerns about flammability and a lack of legislation on their use. There is renewed interest in using propane in industrial refrigeration where it is perceived as a useful retrofit option for CFC-charged equipment.

To stimulate the acceptable use of natural refrigerants, a working group known as PlaNK has been set up composed of experts from market parties, and financed by industry and government, through the Dutch energy agency Novem. Its first action is to collect and disseminate information on European legislation and existing installations. Secondly, it will work with governmental offices on the development of legislation. Thirdly, it will look at how old CFC-charged installations, that are now being exported to developing countries, can be retrofitted with natural working fluids.

*Source: Mr Onno Kleefkens, Dutch National Team.*

## Norway

The total estimated ammonia charge in heat pumping systems is approximately 2,300 tonnes. Most is used in traditional application of industrial refrigeration where roughly 1,000 industrial ammonia refrigeration systems are used for food processing, food preservation and cold storage. In addition, there are approximately 55 heat pump, air conditioning and commercial refrigerating systems using ammonia. Seven ammonia heat pump systems are used in fish farms.

An interesting industrial heat pump, recently developed by SINTEF Energy in cooperation with Kværner Eureka AS, is used for drying fish meal (see **Figure** and **Photo**). The heat pump, which is now being commercialized, uses a 60 bar ammonia reciprocating compressor, and is operating with drying temperatures between -20°C and +100°C. At stable operating conditions the plant has a drying capacity of 100 kg water per hour, and the COP and SMER are 5.5 and 4.1 kg water per kWh electricity, respectively.

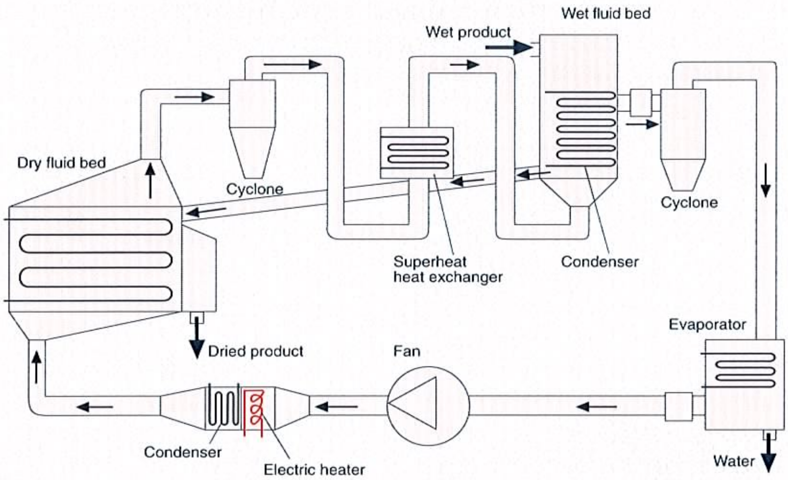



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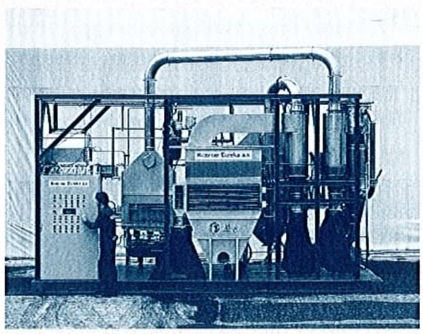
*Diagram of a fish-drying process in which an ammonia heat pump extracts heat as water is condensed out of moist air returning from the dryers (at evaporator) and reinjects this heat (at condenser) at a higher temperature to provide a hot air flow for drying.*

*The fish drying equipment with ammonia heat pump.* ▶



The only hydrocarbon heat pump for space heating is a 45 kW system installed in a church. $CO_2$ is expected to play a role in future heat pumping systems in Norway. SINTEF Energy has been doing research for a number of years on mobile air conditioning systems and a 45 kW hot water heat pump is currently being constructed in the laboratory.

*Source: Mr Jørn Stene of SINTEF Energy and the Norwegian National Team.*

manufacturers of small equipment to switch their production lines to propane systems, either completely, or so as to offer a choice of HCFC or hydrocarbon refrigerant.

German heat pump manufacturers have taken the lead in converting to hydrocarbons. Approximately 20% of residential heat pump sales are for units charged with propane or propylene - 300 to 400 units per year.

Hydrocarbons also have a strong position in the United Kingdom where a supplier of hydrocarbons has run progressive marketing campaigns that have resulted in a number of retrofits and new installations with hydrocarbons. Only installations above ground level are approved.

New applications for hydrocarbon working fluids are being found in industry. While hydrocarbon systems have been used in the petrochemical industry for many years, they are now stating to be used in other sectors such as for refrigeration applications in the food sector.

## Carbon dioxide

Although used extensively as a working fluid before the 1950s, particularly in marine installations, $CO_2$ has had no commercial use in recent years. Today, $CO_2$ is receiving renewed attention and is expected to be used in commercial heat pumping applications in the coming years.

With $CO_2$ there are no worries about safety. However, the design of heat pumping systems using $CO_2$ requires the development of new techniques and components. In particular, special measures are needed since $CO_2$ systems must operate using the so-called transcritical cycle – a somewhat different way of operation than for conventional heat pumping systems. Once this has been mastered, $CO_2$-filled systems have the potential to exhibit very high COPs. Possible applications include:

- automotive air conditioning
- heat pump water heaters
- district heating systems and hydronic systems where there is a high temperature glide
- packaged air conditioners (air cooled systems).

The only currently operational commercial applications of $CO_2$ working fluid are as a secondary refrigerant in supermarkets such as in combination with ammonia refrigeration units as described earlier in this article.

## Water

Water has long been the working fluid most commonly used in mechanical vapour recompression (MVRs) heat pumps for industrial applications. In these open or semi-open systems, the water is evaporated out of the material being processed, such as in a drying process, and is reheated by a compressor to temperatures ranging from 80 to 150°C. Closed-cycle compression systems are uncommon. One example is a steam heat pump in the United Kingdom which is used in the distillation of malt whisky. Two other interesting applications of water refrigerant have recently been installed at a plastics factory in Denmark. One provides heating at around 65°C and the other cooling at around 10°C.

## Air

The optimal working fluid from an environmental point-of-view, air can be used in open-cycle space heating and cooling systems in which the working fluid is directly extracted from, or rejected into, the building. Despite the elimination of heat exchangers between working fluid and indoor and outdoor air, air-cycle systems suffer from low energy efficiency.

Air-cycle systems, also known as cold air systems, are currently used to cool aircraft cabins. And a system for cooling railway carriages is being demonstrated in the United Kingdom. Large-scale refrigeration and freezing

## Switzerland

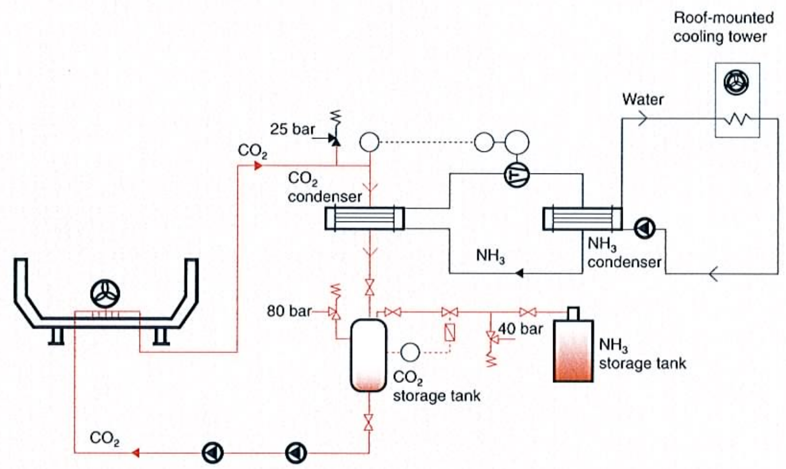
Ammonia is the most commonly used natural working fluid, with 32 tonnes consumed in 1994, mainly for use in refrigeration equipment. In addition, many imported refrigerators use isobutane (R600a).

The Swiss standard SN 253130 "Refrigerating Plants – Erection Site Requirements," which was revised and adopted at the end of 1995, specifies the maximum permissible fill-weights as:

- up to 2.5 kg ammonia in closed systems inside a building
- up to 1.5 kg hydrocarbons when regulations on explosion zones are met. These prevent smoking and the use of open fire or hot surfaces above 300°C inside the room.

Hydrocarbons are already used in outdoor heat pumps and will be used in future in small heat pumps and heat pump water heaters for indoor installation.

Ammonia is the preferred choice for refrigeration or process heating equipment. In these applications there is a trend towards using equipment with secondary cooling fluids such as flow-ice or $CO_2$.




*Supermarket refrigeration system with ammonia refrigeration cycle and $CO_2$ distribution system.*

Some benefits of using a $CO_2$ cold distribution system in combination with an ammonia refrigeration plant have been demonstrated by Frigorex at a supermarket in Lucerne (see **Figure**). An important benefit is that the temperature difference between the cooling medium and the air in the refrigerator cabinets is much lower than with direct expansion systems (this is because there is no superheating). This in turn leads to more efficient heat transfer, less frequent defrosting (every 2 to 3 days), and consequently a COP on a par with conventional direct-evaporation equipment. Also, the $CO_2$ system has a self regulating effect, providing a constant temperature even without temperature control in the refrigerator unit. And in the event of a power failure, the system will continue to operate for 1½ hours before the plant begins to blow off $CO_2$.

*Source: Thomas Afjei of the Swiss National Team and Günther Reiner of Sulzer Friotherm AG. Fax: +41-41-462-5061.*

## UK

The United Kingdom has a strong position in the use of hydrocarbons as working fluids, largely due to the efforts of hydrocarbon suppliers. A large number of reversible, split-type, heat pumps, air conditioners and glycol chillers have been retrofitted, with charge weights ranging from less than 1 kg up to 8 kg. Some 600 cascade laboratory freezers using ethane and propane are currently in operation, for cooling to -85°C. And around 200 automotive/agricultural air-conditioning systems using a propane/iso-butane blend have been installed.

The largest hydrocarbon chiller in the UK is a 140 kW roof-mounted system comprising three units, each charged with 8.5 kg of a propane/ethane mixture. Pressure from Greenpeace has also heightened awareness of natural working fluids, and this has led to trials of both hydrocarbon and ammonia-filled systems in supermarkets.

*Source: "International Status Report on Compression Systems with Natural Working Fluids," Report HPP-AN22-2 from the IEA Heat Pump Centre.*

## USA

Among the natural working fluids, only ammonia receives attention as an alternative to CFCs, HCFCs and HFCs. Concerns about the liability of manufacturers who sell equipment using flammable refrigerant mean that hydrocarbons are not a realistic option in the near term. Ammonia refrigerant is widely used for cold storage and food processing applications, as it has been for many years. However, it is now also seeing some increasing use in comfort cooling.

A promising market segment is in the district cooling market. One example is at Oklahoma City where two 7040 kW ammonia chillers, with gas turbine driven compressors and steel tube heat exchangers, provide district cooling. Interestingly, the ammonia approach was selected because it provided better efficiency than available HCFC-22 units of similar size and capacity.

A new ammonia application is in so-called dual-design chillers, which help to alleviate the concerns of equipment purchasers about the eventual HCFC-22 phase out. While dual-design chillers initially operate on HCFC-22, they can be switched over to ammonia operation once HCFC-22 is phased out or becomes too expensive.

One of the most exciting developments in ammonia technology is the advent of packaged systems. Sized to fit on a slab or rooftop, these units provide cooling capacities ranging from 107 kW to 704 kW, utilize air to cool the compressor motor, and offer a high level of safety and containment.

Economic factors, such as the extra cost of providing a secondary loop for heat distribution, mean that more widespread use of ammonia will be difficult. Simultaneous refinement of ammonia technology, as well as widespread efforts to revise codes and restrictions, will be necessary before this highly attractive and useful refrigerant can be employed to full advantage.

*Source: Mr Phillip Fairchild and Van Baxter, Oak Ridge National Laboratory, USA. Fax: +1-423-574-9338.*

systems using the air cycle are soon to be commercialized by a Japanese company.

## Towards commercial reality

In a few years, the idea of using natural working fluids has grown from a cause championed only by environment "enthusiasts" to a commercial reality.

For small applications, hydrocarbons have led the way, mainly because they require little equipment modification. But their use is hampered at present by regulations and legal considerations concerning the use of flammable refrigerants.

For large-scale applications, ammonia systems can offer a viable alternative to systems with synthetic refrigerants. But concerns about safety again present a barrier to market penetration.

A most promising natural working fluid is $CO_2$. Not only is it safe, it is also suitable for a wide range of applications. However, much more development work needs to be done before commercially viable systems can be marketed.

Of the other naturals, water can be expected to be used more widely in industry, especially in high-temperature applications. While air-cycle systems appear to be best suited for low-temperature applications.

The return to natural working fluids is at a very early stage. Presently, their use is limited to certain applications in particular countries or regions. More widespread use will come as experience is gained and as the technology matures. All efforts should be made to share experiences so that the benefits of natural working fluids are realized as soon as possible in applications where their use is appropriate.

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# The hydrocarbon revival

## The natural trend for European heat pumps and refrigerators

*Thomas Afjei and Helmut Reiner, Switzerland*

Prompted by the phase out of CFCs, and spurred on by environmental concerns about HCFCs and other alternative synthetic refrigerants, European manufacturers are rapidly switching over to hydrocarbons for much of their heat pumping equipment. This new trend, which is really a revival of the situation in the "pre-CFC era" of the early 20th century, is one of the most significant developments for the heat pumping world in recent years. This article discusses some of the implications of the hydrocarbon revival, including the influence of national and European standards and some of the practical consequences.

In Switzerland, HCFCs account for the largest share of refrigerant consumption, at a rate of 212 tonnes per year at present. Recently, however, the Swiss Executive National Council tightened up the "Regulation on Environmentally Hazardous Substances" such that HCFCs will no longer be allowed in new plants from 1 January 2002. And for new air-conditioning units in motor vehicles and for new domestic refrigerators and freezers, the discontinuation of HCFCs has been in place since 1 January this year.

In response to concerns about the use of HCFCs, hydrocarbons such as isobutane, propane, and propylene, are experiencing a revival in refrigerators and small heat pumps, not only in Switzerland but in many other European countries as well. Already, most European manufacturers have changed over to isobutane (R-600a) for their refrigerators and freezers.

In fact, the use of hydrocarbons in refrigeration units is nothing new. Owing to their good thermodynamic properties and excellent oil solubility, these refrigerants had already proved their worth as early as the turn of the century.

## Naturally advantageous

As natural working fluids, isobutane, propane, and propylene, and ammonia as well, have various advantages over the conventionally used synthetic substances:

- No ozone depletion potential
- Negligible greenhouse potential
- Long-term effects are known
- Compatible with mineral oils.

What's more, the coefficient of performance (COP) is generally 10-15% higher with propane than with HCFC-22. And only half as much propane is required.

Because it requires similar pressure and temperature conditions, propane (R-290), tends to be used in heat pumps as a substitute for HCFC-22. It also has a specific advantage, in that the comparatively low discharge gas temperatures at the compressor outlet allow hot water at 60-70°C . This possibility is of particular interest for heat pump water heaters because it reliably prevents the danger of bacterial infections, such as Legionnaire's disease, without requiring additional electric heating. For heat pumps for space heating purposes, propane is advantageous for retrofit installations wherever high supply temperatures are required.

The environmental compatibility of propane is rated so positively by the "Federal Office for Environment, Forest and Landscape" that approval has been given to the use of direct-evaporation ground-source heat pumps in Switzerland. In Austria, units of this type achieve annual efficiencies of more than four.

In converting a heat pump from HCFC-22 to propane, the change in the heat output and the COP must be taken into account. **Table 1** shows test results from a manufacturer, which show that the COP of a heat pump can be increased by almost 15% with propane after small design modifications are made [1].

## Standards and guidelines

A distinct disadvantage of the hydrocarbons is their high flammability. **Table 2** shows the concentrations of hydrocarbons in air at which a chemical explosion can occur - the upper and lower explosion limits (UELs and LELs). These data indicate that hydrocarbons are flammable over a wide range of concentrations when sufficient ignition energy is present. They are therefore

*Table 1: Performance of a brine-source heat pump using HCFC-22 or propane of tests made to Swiss standard SI 17 for B0W35.*

| | HCFC-22 | Propane with recuperator | Change |
|---|---|---|---|
| Heat output (kW) | 16.8 | 14.6 | -5.8% |
| Power consumption (kW) | 4.6 | 3.7 | -19.6% |
| COP | 3.4 | 3.9 | +14.7% |

| Refrigerant number | Name | Formula | Explosion limits | | | |
|---|---|---|---|---|---|---|
| | | | Lower (LEL) | | Upper (UEL) | |
| | | | by volume (%) | by mass (g/m2) | by volume (%) | by mass (g/m2) |
| R-170 | Ethane | $CH_3CH_3$ | 2.7 | 33 | 14.7 | 185 |
| R-290 | Propane | $CH_3CH_2CH_3$ | 1.7 | 31 | 10.9 | 200 |
| R-600 | Butane | $C_4H_{10}$ | 1.4 | 33 | 9.3 | 225 |
| R-600a | Isobutane | $CH(CH_3)_3$ | 1.8 | 44 | 8.5 | 210 |
| R-1150 | Ethylene | $CH_2$-$CH_2$ | 2.3 | 28 | 32.4 | 380 |
| R-1270 | Propylene | $C_3H_8$ | 2.0 | 35 | 11.1 | 200 |
| - | Dimethyl ether | $CH_3OCH_3$ | 2.7 | 51 | 32.0 | 610 |

*Table 2: Explosion limits for hydrocarbons at 20°C in atmospheric air (from draft German standard DIN 7003).*

subject to special safety regulations. In many European standards, such as Swiss standard SN 253130, they are assigned as Group L3 refrigerants which applies to substances with an LEL of less than 3.5% by volume.

## European standards

The most important standard in Europe concerning the use of hydrocarbon refrigerants is prEN 378 "Refrigeration Systems and Heat Pumps - Safety and Environmentally Relevant Requirements".

This four-part European standard is currently being circulated for comment. It is concerned with maximum permissible refrigerant fill volume (charge), requirements for the installation room and requirements relating to the mechanical and electrical safety. It will be binding for all member states of the CEN (European Committee for Standardization) - Switzerland is a member. The standard is likely to come into full force within a year.

## German standards

On a national basis, the German standards relating to flammable refrigerants are the most advanced. DIN 7003 "Refrigerating Systems and Heat Pumps with Refrigerants of Group L3 - Safety Requirements", which is derived from prEN 378, has been available as a revised draft since December 1995. Owing to the associated European standard prEN 378, it will be adopted only as a draft (yellow publication). It is concerned with safety systems and requirements relating to the installation room. Depending on the permissible refrigerant charge (the fill-weight) the following requirements are applicable:

For a refrigerant fill-weight of less than 0.150 kg, permanently-closed systems are not subject to any special requirements with regard to the placement of the installation.

For a refrigerant fill-weight of greater than 0.150 kg, ventilation is needed unless the room volume is large enough to disperse the gas to a safe concentration. Owing to possible inhomogeneities in the distribution of gas, the room volume is based on 50% of the lower explosion limit.

If the room volume is insufficient, natural or mechanical ventilation must be provided using a minimum cross-section 300 cm for fill-weights of less than 1.0 kg. For fill-weights greater than 1.0 kg, the ventilation cross-section for natural ventilation depends on the amount of refrigerant. And a mechanical ventilation system must provide a minimum volume flow according to the amount of refrigerant. The ventilation system must either be constantly in operation, or switched on in the event of a leak. This may be detected by a gas sensor or, for fill-weights smaller than 5.0 kg, by means of a safety pressure limiter responding to declining pressure due to refrigerant loss. In addition, a signal must be triggered.

As an additional explosion protection measure, the area within a radius of 1 m from the refrigerant-carrying components is designated an explosion hazard area (see **Figure**). This applies to permanently-closed and closed systems with refrigerant fill-weights of more than 0.150 kg. In the case of closed systems with an open compressor, further measures are required, such as "continuous mechanical ventilation" or "extraction close to possible points of emergence."

## Swiss standards

Swiss standard SN 253130 was revised and adopted at the end of 1995 [2]. In the new SN 253130, a maximum permissible refrigerant fill-weight of 1.5 kg is specified for class A installation areas. These are rooms, building sections and buildings in which:

- people are permitted to sleep
- people are restricted in their movement
- an uncontrolled number of people are present or to which any person has access without personally being familiar with the necessary safety precautions.

For heat pumps and refrigeration systems in which all refrigerant-carrying parts are arranged in the open air, there are no restrictions for the fill-weight of refrigerant above ground level.

For all rooms in which refrigeration systems with flammable refrigerants are installed, strict requirements are imposed to minimize the explosion risk. In particular, the use of open fires, hot surfaces and smoking must be prevented, and strict standards are imposed on electrical systems. These restrictions go well beyond those of prEN 378 and are not very practical for small refrigerant amounts of less than 0.150 kg. For example, it is difficult to meet these

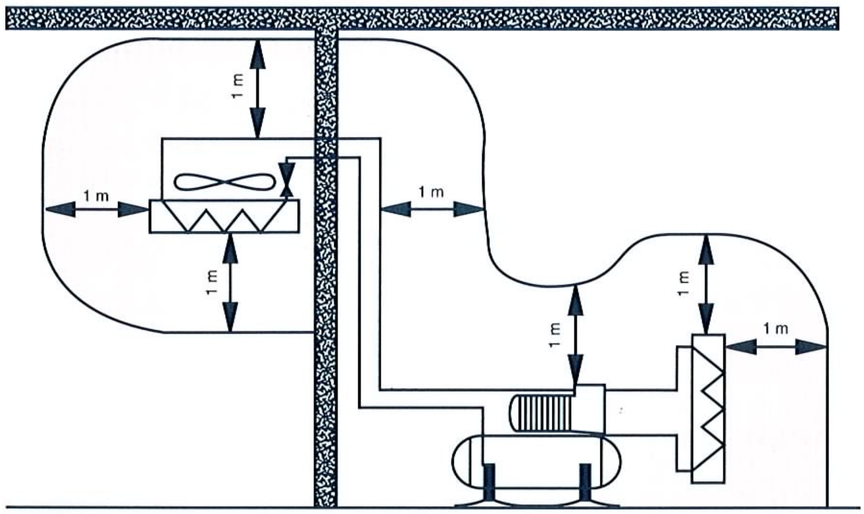


*Figure: Explosion hazard area for propane-charged equipment.*

regulations in kitchens, where there is a cooker, and where it is difficult to ensure that people do not smoke. Moreover, minimum requirements with respect to the room volume and the ventilation should be clearly defined in the standard. It is therefore to be expected that appropriate modifications and additions, as in the German standard DIN 7003, will be introduced into a revised version.

## Practical experience

The manufacture of heat pumps with flammable refrigerant requires special measures for safe handling. The heat pump manufacturers must carefully consider all safety aspects and construct the equipment accordingly.

Hermetic sealing of the refrigerant cycle is particularly important. Connections should be soldered or joined in a similarly safe manner. The filling unit is considered to be a liquefied gas unit and must therefore be accepted by a supervisory body. Usually, a special room at the manufacturing plant is required for filling the equipment, where a gas warning system must be installed for activating the mechanical ventilation in the event of a gas alarm. In addition, no ignition sources may be present in the filling room. Furthermore, the storage room for the heat pumps must be thoroughly ventilated.

For customer service, the soldered connections increase the cost of maintenance such as when a filter dryer is replaced. And for soldering work on the refrigeration cycle, the refrigerant must be extracted and the system flushed with nitrogen at least twice. When working with flammable media, three important rules must be observed:

- Avoid gas leaks
- Avoid ignition sources
- Ensure good ventilation.

During service, maintenance and repair, there is a very great danger of refrigerant emissions. Everything must therefore be done to avoid causing refrigerant loss. In Switzerland, the national regulation on materials stipulates that refrigerants may be handled only under instruction from specialists. The specialists must be in possession of a professional permit. In addition to the regulation on refrigerants, the provisions relating to the handling of liquefied gas must also be observed.

## Estimation of risks

Owing to the small number, to date, of systems using hydrocarbons, a definitive estimation of risks is not possible. Studies by the International Energy Agency (IEA) and by the Dutch Environment Ministry assume that the risks of systems using hydrocarbons are negligibly low if the appropriate safety precautions are taken. In industrial plants using ammonia, incorrect handling was the cause of more than 50% of accidents.

## A long-term future

The use of heat pumps and refrigerating equipment using hydrocarbons will soon become widespread provided that all required safety measures are carefully observed. As natural materials, hydrocarbons provide a long-term alternative to the synthetically produced substitutes with a complicated composition. Apart from their excellent ecological properties, there are also considerable technical advantages. More efficient heat pump systems can be designed for preparing hot water at the high temperatures needed to avoid bacterial problems. And systems using a wide range of environmental energy can be envisaged. With this article, the authors would like to show that when all conceivable safety measures are taken, the use of flammable refrigerants promises to have a long-term future.

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# Vapour compression systems based on $CO_2$

## A truly safe alternative

*Jostein Pettersen, Norway*

Ecologically safe, non-toxic and non-combustible, carbon dioxide is in many respects an ideal substance for use as a working fluid. And while the requirements for machinery and components are quite different from those of conventional systems with low-pressure refrigerants, $CO_2$ may be effectively used as a refrigerant in a number of applications. This article outlines the characteristics and properties of $CO_2$ and highlights some promising developments in vehicle air conditioning, heat pump applications, and in commercial refrigeration.

The use of "natural" and ecologically safe refrigerants is a robust strategy to eliminate the environmental problems and uncertainties associated with synthetic replacement fluids. This strategy is now applied to an increasing extent by industry and in the R&D sector in the search for better long-term technologies. In the international arena, the IEA Heat Pump Programme is playing an important role with the implementation of Annex 22 "Compression Systems with Natural Working Fluids."

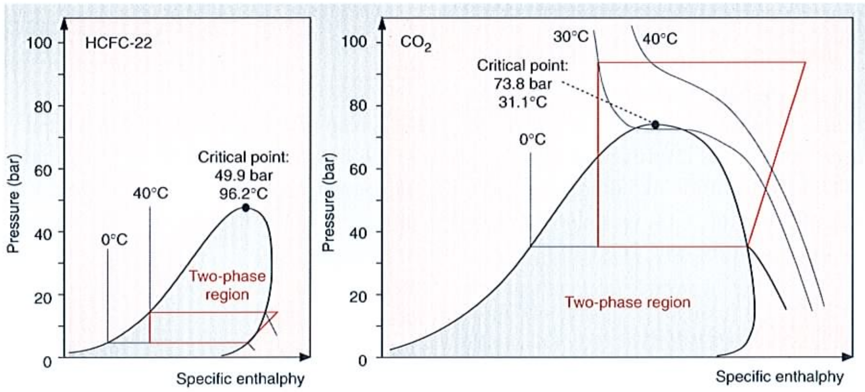


*Figure 1: Thermodynamic cycle of a transcritical $CO_2$ heat pump.*

So far, solutions based on ammonia or hydrocarbon fluids have dominated the picture, although air- and water-cycles are also considered for special application areas. Since ammonia is toxic and the hydrocarbons are flammable, the general conclusion is often drawn that "natural" fluids give safety problems and should be avoided.

As suggested by the late Prof. Gustav Lorentzen of the Norwegian research organization SINTEF, the use of $CO_2$ may provide a totally safe, economical and cost-effective "natural" solution in many applications. The "reinvention" of this inexpensive, widely available, non-flammable, non-toxic, environmentally harmless and well-documented working fluid can lead to a number of benefits. The development of $CO_2$-based technology is now a strategic priority area at SINTEF.

## Properties and characteristics

With a critical temperature of 31.1°C, the use of $CO_2$ involves cycles operating close to or partially above the critical point, i.e. transcritical cycles. **Figure 1** compares the single-stage vapour compression cycles for $CO_2$ and HCFC-22 in equal pressure-enthalpy coordinate systems. The most notable differences between $CO_2$ and conventional refrigerants are:

- higher saturation pressure with $CO_2$ for a given temperature
- heat rejection temperatures above the critical point for $CO_2$
- higher latent heat of $CO_2$.

The higher saturation pressure gives increased vapour density, and the compressor volume for a given capacity requirement is reduced by a factor of between 5 and 10 compared to other common refrigerants. Tube diameters are also greatly reduced.

Typical pressure ratios (outlet pressure divided by inlet pressure) with $CO_2$ are much lower than with halocarbon refrigerants. Together with the high mean effective pressure, this gives high compressor efficiencies. $CO_2$ heat transfer coefficients are also good, due to high pressure and favourable transport properties

## Historical background

During the first decades of this century, $CO_2$ was used as a refrigerant, mainly in marine systems but also in air conditioning and general refrigeration applications. The first reported $CO_2$ system was built in 1866 by the American Thaddeus S.C. Lowe, but it was the effort made in Germany by Windhausen in 1886 and in Great Britain by J. & E. Hall from 1887 that brought $CO_2$ systems into wider use.

One of the major benefits of $CO_2$ is its safety, which gave this refrigerant a preference on board ships and in public buildings. Compactness of machinery and tubing also contributed to the popularity. The commonly reported disadvantages were loss of capacity at high heat rejection temperatures, and lower coefficient of performance than with other refrigerants. However, by operation at supercritical high-side pressures, and by various two-stage arrangements, or by so-called multiple-effect compression, these disadvantages could be reduced or eliminated.

In the thirties and forties, CFCs, or "safety refrigerants", generally replaced the old working fluids in most applications. Although the major argument in their favour was improved safety compared to fluids like ammonia and sulphur dioxide, $CO_2$ was also displaced by this transition to CFCs.

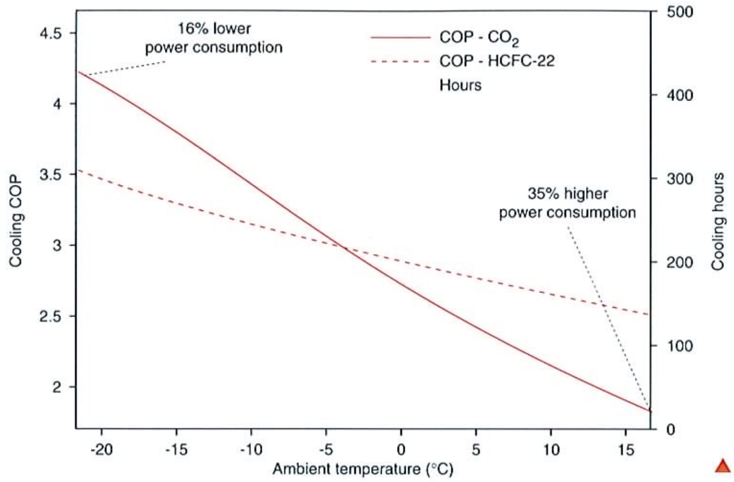


*Figure 2: Calculated COP and distribution of cooling hours for a $CO_2$-charged split-system heat pump.*

## The $CO_2$ revival

In recent years, $CO_2$ has been "rediscovered" as an attractive refrigerant, and a number of different development projects are in progress. A common motivation and goal is improved safety – both environmental and personal, as well as reduced environmental impact, total cost and energy use. Some of these studies are outlined further in this article.

## Cascade circuits

The use of $CO_2$ as a volatile secondary refrigerant gives a number of benefits compared to brine loops, and several projects are now focusing on this solution. Primary applications are for freezers in supermarkets and for other commercial refrigeration systems, but marine applications such as in reefer ships are also interesting. Very small tube dimensions, even in comparison to direct-evaporation systems, low pumping power, efficient heat transfer and absence of corrosion problems are important advantages of this concept.

$CO_2$ also offers advantages when used in the low-temperature stage of cascade systems. Compared to a two-stage ammonia plant, for instance, the low-temperature stage compressor volume will be reduced to about one tenth by converting this stage to $CO_2$. Temperatures as low as -45 to -50°C may be effectively provided by the $CO_2$ circuit. Furthermore, solutions have even been devised for operation with dry ice slurry down to about -80°C.

SINTEF is participating in a development project on commercial refrigerating systems based on ammonia and $CO_2$. One of the activities related to this project is the measurement of heat transfer and pressure drop characteristics of $CO_2$ for the purpose of developing efficient air coolers.

## Heating water

Owing to the gliding temperature during heat rejection, the transcritical $CO_2$ cycle is well adapted to heat pumps for water heating. It is especially suitable for hot service water production but also for hydronic space heating and district heating.

The $CO_2$ cycle can be adapted to the temperature requirements of the heating system by various two-stage arrangements and cycle modifications, and in larger systems the efficiency can be considerably improved by recovering the expansion work, for instance in a screw expander unit. Combinations of hot-water production and refrigeration or air conditioning is of course also possible, and preliminary calculations indicate that the economics for such systems would be favourable.

Investigations on transcritical heat pumps have been made at SINTEF since the late 1980s. Starting in1996, a European project with participants from Austria, Belgium, Germany and Norway will continue the development of $CO_2$ heat pumps. This 3-year project is partly funded by the European Union.

## Vehicle air conditioning

The application of $CO_2$ in a transcritical vapour compression system for motor-car air-conditioning has the subject of R&D for a number of years. Laboratory prototype systems have been built and tested, and the results indicate a competitive performance, size, weight and cost, with at least 40% lower TEWI (Total Equivalent Warming Impact) than with HFC-134a. Since 1994, a consortium made up of nine European companies has been working on the further development of this technology. In addition, prototype tests have been carried out on a bus air-conditioning system.

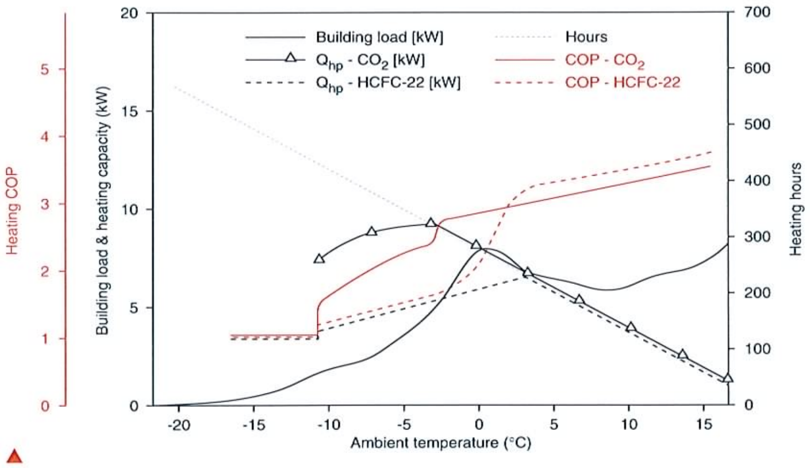


*Figure 3: Calculated system Heating Performance Factor (HPF), capacity, building load and distribution of heating hours (right) for a $CO_2$-charged split-system heat pump.*

There are currently about 300 million air-conditioned cars on the road worldwide, and this figure is expected to rise as climate cooling becomes more common in more car models and most geographical areas. As a consequence, the annual emissions of HFC-134a are likely to rise above 100,000 tonnes early next century. A transition to $CO_2$ will therefore contribute to important reductions in greenhouse gas emissions worldwide. The United States Environmental Protection Agency (EPA) has approved $CO_2$ as an acceptable substitute technology for motor vehicle air conditioning under its SNAP (Significant New Alternatives Policy) ruling.

A number of development projects worldwide are now bringing this technology forward. The activities at SINTEF are concentrated on prototype testing as well as investigations on specific subjects such as the transient behaviour of $CO_2$ refrigerant. Attention will also be given to the development of more efficient heat exchangers in work carried out in cooperation with Hydro Aluminium

## Split-system heat pumps

On the background of the good results that have been obtained with $CO_2$ in vehicle air conditioning, the prospects of using $CO_2$ in residential heat pump air conditioning systems have also been briefly analyzed.

The performance of a 7 kW split system based on $CO_2$ was calculated for varying operating conditions, and the results compared to typical data from a HCFC-22 unit of equal capacity. Equal heat exchanger dimensions and compressor efficiencies were used in the simulation of the two systems. A standard North-American climate was assumed, and seasonal performance data were calculated in accordance with ASHRAE/ARI standards. The main results are presented in **Figures 2** and **3**, showing cooling coefficient of performance (COP) (Figure 3) and heating COP (Figure 4) at varying ambient air temperature. The heating COP includes peak load resistance heating.

The results for cooling COP reveal that the calculated performance of the $CO_2$ system is equal to that of the HCFC-22 system at an ambient temperature of about 28°C. Above this temperature the HCFC-22 system is better and at lower ambient temperatures the $CO_2$ system exhibits a higher efficiency. With a distribution of the cooling hours as shown, the calculated cooling seasonal performance factor (SPF) becomes 3.0 for the HCFC-22 system and 3.3 for the $CO_2$ system. A major part of the cooling hours are at moderate ambient temperatures (20-28°C).

In heat pump operation, the $CO_2$ system is able to deliver a larger share of the building heat requirement than the HCFC-22 system. Capacity boosting in the $CO_2$ system is obtained by increasing the high-side pressure. The system COP (heat pump plus resistance heater) for the $CO_2$ heat pump therefore becomes quite high due to reduced peak load, although the COP for the heat pump circuit alone is generally lower. When the distribution of heating hours is taken into account, the heating SPF becomes 2.4 for the HCFC-22 system and 2.9 for the $CO_2$ system.

SINTEF is continuing to conduct experimental investigations on a laboratory prototype residential air conditioning systems based on $CO_2$.

## A truly safe alternative

The use of a non-flammable and non-toxic refrigerant is always a benefit, and when this is combined with the ecological safety, low price and good availability, there are many reasons to evaluate the options for its use. As shown by some of the examples in this article, a number of promising applications for $CO_2$ vapour compression systems have already been identified.

$CO_2$ systems can offer competitive energy efficiency, and due to reduced compressor displacement, small line dimensions and simple direct-expansion system design, the total cost is likely to be competitive. There is therefore good reason to believe that modern and properly designed $CO_2$ systems will be a solution for the future – a truly safe alternative.

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# Cold storage with ammonia refrigerant

*Norio Ota and Yasuhiro Hirao, Japan*

While HFC mixtures are considered to be the primary alternatives to HCFCs, there are still some problems to be cleared before they can be widely used in Japan. At the same time, ammonia is gaining considerable attention because of its more favourable environmental characteristics. Some of the latest techniques in the application of ammonia refrigerant are being demonstrated at a fish processing factory in Tokyo, where an ammonia-based refrigeration unit is used to provide cold storage. Using an indirect cooling system and advanced safety measures, this installation shows how ammonia refrigerant can become an acceptable option for the Japanese market.

Maekawa Mfg. Co. Ltd. has been working for several years on the development of a cold storage system with ammonia as the working fluid. With much emphasis put on the development of safety measures, the work culminated in the installation of the first system of its type at the Toto Suisan Corp. fish processing factory in Funubashi, Tokyo. The equipment has been operating successfully since August 1995.

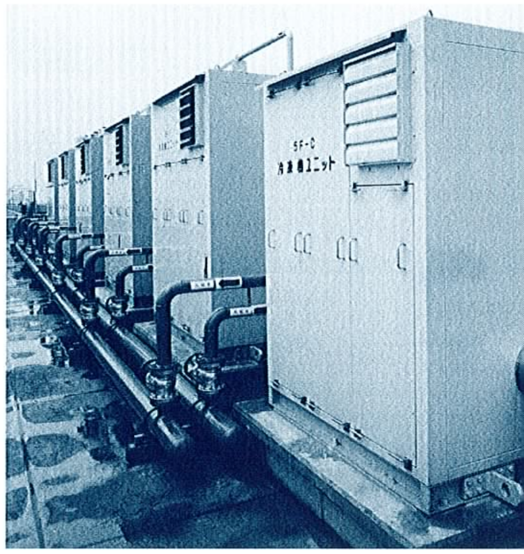
The newly developed system uses a compact refrigeration unit designed for installation on the roof of a store. By using brine as a secondary refrigerant, no ammonia is directed into the working environment of the cold store. All ammonia containing parts are completely sealed inside the casing of the roof unit. The unit has a 2.4 x 3.6 m footprint and a height of 1.9 m.

The **figure** shows the piping diagram of the refrigeration unit and the connected circuit. The refrigerating unit features two two-stage compressors with sealed electric motors. Calcium chloride is used as the secondary refrigerant.

## Minimal refrigerant

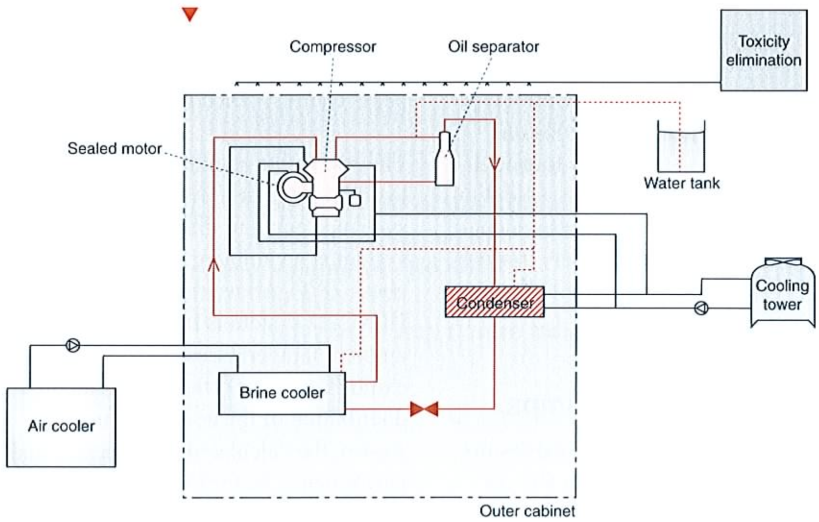
To enhance safety, the system has been designed so as to minimize the charge of ammonia. A key measure is the use of a synthetic oil (PAG) which is soluble in ammonia. This enables the use of a dry-type evaporator (shell and tube) which increases the overall heat transfer coefficient by more than 160% compared with using wet or pump type heat exchangers, and results in a 10% reduction in refrigerant content. A further reduction in refrigerant content is achieved by using an electronic expansion valve. The electronic valve results in stable superheat control, thereby reducing energy losses during compression.

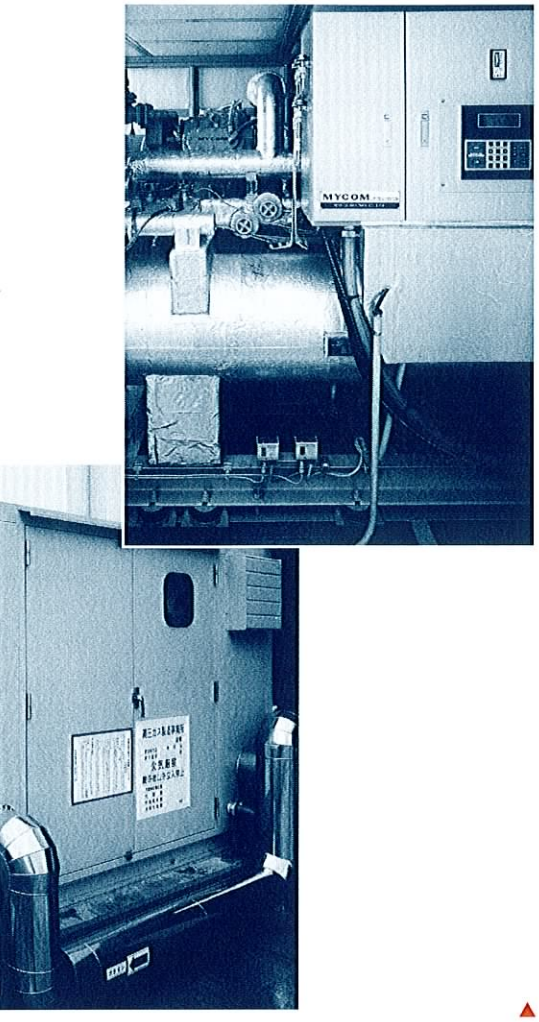
Refrigerant leakage is minimized by using a sealed electric compressor. For operation with ammonia, a special seal is provided between the rotor and stator to protect the copper wires of the stator.



*Mounted on the roof, the state-of-the-art in cold storage technology with ammonia refrigerant.*

*Figure: Piping diagram of a refrigeration unit.*






Inside view of a refrigeration unit.

## Automatic system

In conventional ammonia plants, valves are manually operated during start-up and shut-down. To improve safety, and to fulfil the requirements stipulated by the local government of Tokyo, an automatic system was developed including a leak detector together with an emergency shut-down system. Safe automatic control is thus provided and human error is eliminated.

## Fish factory

The Toto Suisan fish factory has a storage facility for 10,700 tonnes of frozen marine products, comprising five floors of storage rooms. Twelve rooms are for F-class storage (below -20°C) and three are for C-class storage (-20°C to -10°C).

Six of the newly-developed ammonia refrigeration units are installed on the roof. Five serve the F-class storage rooms, each one providing 18.5 RT (65 kW) of cooling capacity. The other unit supplies 19.7 RT (69 kW) of cooling capacity for the C-class storage rooms. The system operates with a single low-noise, closed-type, 175 RT (615 kW), cooling tower.

Data for the F class refrigerated rooms with room temperatures of -25°C was measured and compared with design data as shown in the **Table**. It can be seen from the table that the refrigeration capacity is about 5% higher than the design value and that the coefficient of performance (COP) is about 12% higher than the design value. These discrepancies are thought to be due to the fact that the actual operational condensation temperature was lower than the design value.

An even better COP would be achieved if the system used direct cooling. Use of brine as a secondary refrigerant results in lower evaporating temperatures compared with direct cooling. Considering the safety aspects, however, indirect cooling is preferred.

## Gaining more attention

Japanese legislation places tight restrictions on ammonia-filled heat pumping equipment. By developing a fully automated system using a sealed unit for installation on a roof, Maekawa Mfg. Co. Ltd. have not only met the demands of the legislators but have introduced a refrigeration system with a competitive performance. Given the increased emphasis on environmental protection, it can be expected that systems using ammonia will gain more attention in future.



| Condition | | Design value | Measured value |
|---|---|---|---|
| Evaporator temp. | (°C) | -37.0 | -36.9 |
| Condenser temp. | (°C) | 40.0 | 33.2 |
| Evaporator capacity | (kW) | 63.5 | 66.4 |
| Brine inlet temp. | (°C) | -31.8 | -29.8 |
| Brine outlet temp. | (°C) | -34.3 | -31.7 |
| Brine flow-rate | ($m^3$/min) | 0.454 | 0.501 |
| Condenser: | | | |
| Cooling water inlet temp. | (°C) | 32.0 | 24.0 |
| Cooling water outlet temp. | (°C) | 37.0 | 27.4 |
| Cooling water flow-rate | ($m^3$/min) | 0.300 | 0.390 |
| COP | | 1.00 | 1.12 |

*Table: Operating data for an F-class refrigeration system.*

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# Evolution of heat pumping in Japan

## A look back on ten years of the HPTCJ

*Yoshio Igarashi, Japan*

The occasion of a 10th anniversary presents a natural opportunity for reflection. For the Heat Pump Technology Center of Japan (HPTCJ), which was established in the summer of 1986, it presents the chance to look back on a period of rapid progress for heat pumping technology in Japan, both in terms of technological development and market penetration.

The diffusion of heat pumps has increased remarkably in the ten years since the HPTCJ was formed. In 1986, heat pump sales were already following the upward trend which begun five years earlier, after the introduction of variable speed units using invertor control. Leading up to that trend was the preparatory period of the widespread diffusion of the cooling-only air-conditioner in the 1970s.

In the early 1980s, as customers became aware that reversible, or heat pump, operation was a useful and cost-effective option, the heat pump type air-conditioner began to replace the cooling-only models. At the same time, many circumstantial conditions worked beneficially for heat pumps, such as national R&D projects, technology improvements, government support and the general rise in the Japanese standard of living. These "push factors" are illustrated in the **Figure**. Other developments, however, had a negative impact. The major impediments, or "check factors", are concerns about the greenhouse effect, ozone depletion and the rise in peak electricity demand. These are also illustrated in the figure.

### National projects

The Japanese government has been eager to support R&D in the field of energy-saving technology, and heat pumping technology is given considerable attention as being both promising and effective. In the past ten years, the national projects "Super Heat Pump", "Unused Energy Utilization" and "Broad Area Energy Network" have played a major role for heat pumping technology. Not only achieving significant technical development, these projects have done much to stimulate the heat pumping industry and have provoked interest in heat pumps amongst society in general. Moreover, much of the spin-off technology that has emerged from these advanced technology projects is said to have been very useful for application to normal heat pump products.

### Technology improvements

Competition between the similar products of various manufacturers is hard and severe. As a result, the performance of both the products and the manufacturing technology has advanced considerably. Today's Japanese heat pumps are thus highly cost-effective. The introduction of the invertor control method in the early eighties, and the recent trend of combining heat pumps with thermal storage systems, are good examples of such technology advances. Future developments can be expected to aim at greater energy efficiency and easier operation.

### Government policy

In addition to its support for national R&D projects, the Japanese government has made an effective contribution towards the evolution of heat pumps. A variety of financial incentives and taxation systems have been implemented to support the diffusion of heat pumps. Moreover, the good intention of the government is expressed by its support for participation in the IEA Heat Pump Programme and through the establishment of the HPTCJ. The heat pumping industry can be well satisfied with the government's course of action.

### Rising living standards

In the past 20 years, during which several economic recessions were experienced, the rising demand for room-air conditioners has hardly been weakened. There has been a continued demand for improved living standards that has been spurred on by the intense efforts of manufacturers of electric household appliances.

Once a household installs a heat pump or cooling-only air conditioner, it becomes an indispensable item for daily life. Today, the diffusion rate has developed such that 75% of households have one or more air conditioners, and 50% have heat pump type air conditioners. As most are room air-conditioners, further diffusion of heat pumps can be expected for use in other rooms. In fact, the current diffusion rate of air conditioners (heat pump and cooling-only) for applicable rooms is actually less than 30%.

Staff at the HPTCJ celebrate their 10th anniversary.

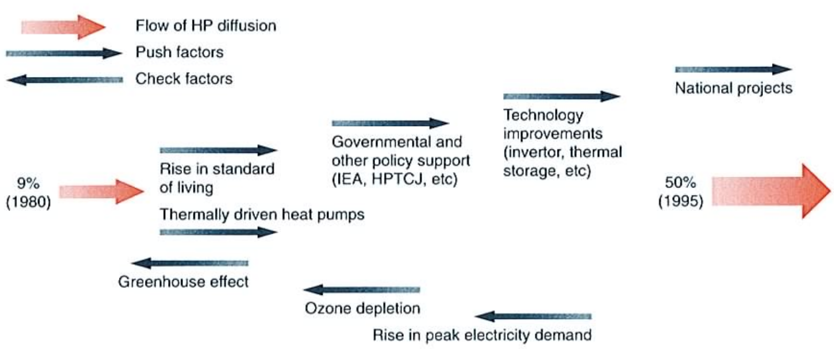
In 1995, domestic shipments of both room and packaged-type air conditioners, including cooling-only units, reached eight million units. This demand level is expected to continue.

## Peak electricity demand

While concerns about the greenhouse effect and ozone depletion are common to many countries, the problem of peak electricity demand is especially significant in Japan. The widespread penetration of air conditioners throughout the country, coupled with usage that is heavily biased towards summer days, means that the electricity demand curve has a very sharp peak. This requires a wasted investment in power generation plant. The levelling of the electricity demand has thus become one of the most critical energy problems for Japan, and is an important "check factor" for heat pumps.

One solution is the diffusion of ice thermal storage type air-conditioning systems, which use night-time electricity. Such equipment has made a steady and strong penetration of the market in recent years. Last year HPTCJ introduced a financial support system to encourage further diffusion of this technology by providing a government subsidy for air-conditioning systems with thermal storage.

Figure : the diffusion of heat pumps in Japan is influenced by "push factors" and "check factors".




## Thermal heat pumps

As the anti-theses to the "check factors" that inhibit heat pump diffusion, thermally driven heat pumping has grown in popularity. Firstly, absorption heat pumping is seen as an important option for solving the "Ozone Depletion" problem. Domestic shipments of absorption chillers reached 4,712 units in 1995. Recently a type 2 absorption heat pump (heat transformer) was commercialized for the first time as the result of a national project.

The other "check factor" - peak electricity demand - has urged the development and marketing of gas or oil-fired engine heat pumps. Today, these thermally driven heat pumps have become the "push factor" to explore a new market. Engine-driven heat pump installations in Japan have reached more than 2 million units already and sales figures continue to show a sharp upward trend.

## A fundamental job

In the ten years of operation of the HPTCJ, the aspect of heat pumping in Japan has evolved rather positively and brightly. The HPTCJ has been happy to follow the upward trend and to expand its work as well as its organization. The number of staff at the HPTCJ secretariat has tripled from 6 to 18 in this ten year period following enlarged activities. As highlighted in this article, a number of "push factors" have a positive influence on the diffusion of heat pumps in Japan. And several "check factors" act as impediments. How to promote the "push factors" and to restrain the "check factors" has been the HPTCJ's fundamental job, and will continue to be hereafter.

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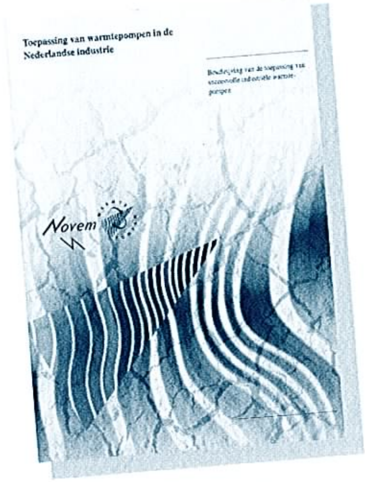
**Application of Heat Pumps in Dutch Industries**
(Toepassing van Warmtepompen in de Nederlandse Industrie)
Published by Novem, the Netherlands. Tel: +31-55-5277-877.
Report No. Dv3.4.30 95.10. October 1995, 42 pages (Dutch).
Free-of-charge.




*Under contract to Novem, (the Netherlands Agency for Energy and Environment), TNO (the Netherlands Organization for Applied Scientific Research) has carried out a study of ten operating industrial heat pumps (IHPs). The projects cover a wide range of industries including food processing, agriculture, dairy industry, brewing, and the chemical industry. Each project is described and illustrated in this report, with details given on energy savings and environmental benefits. The report has been produced under the Dutch Heat Pump Programme.*

**1995 International CFC and Halon Alternatives Conference & Exhibition**
Proceedings published by the United Nations Environment Programme (UNEP), Paris, France. Fax: +33-1-4437-1474.
October 1995, over 1,000 pages.
*These proceedings report on the conference held by UNEP in Washington DC, USA in October 1995. With more than 100 contributions, many issues concerning the phase out of ozone depleting substances (ODS) are addressed.*

**Hydrocarbons and Other Progressive Answers to Refrigeration**
Published by Greenpeace, October 1995, 216 pages.
*These proceedings include 31 papers, most of which were presented at a meeting held in parallel with the "International CFC and Halon Alternatives Conference" (see above).*

**Heat Pumps for Ventilation Exhaust Air Heat Recovery**
Limb M. Annotated bibliography published by the IEA Air Infiltration and Ventilation Centre (AIVC), United Kingdom.
Fax: +44-1203-416306. Order no. BIB5. 1995, 30 pages.
Available free-of-charge in AIVC member countries.
*This bibliography reviews the use and application of heat pumps in ventilation heat recovery systems, for both residential and commercial applications. Citing some 47 references, the report discusses experiences with air-to-air and air-to-water systems from many countries. All references are taken from AIVC's database, AIRBASE, and are listed in full, including abstracts, in this report.*

**The Fundamentals of Natural Gas Cooling**
Sweetser R.S. Published by AEE Energy Books of the Association of Energy Engineers, Dept. 231, PO Box 1026, Lilburn, GA 30226, USA. Order code 0369,
ISBN 0-88173-232-X. 1996, 212 pages. Price US$ 74.
*This reference book provides the fundamental information needed to evaluate gas cooling system characteristics, equipment costs, operating costs and general benefits, as compared with traditional electric motor driven systems.*

**International Statistical Profile of the Air-Conditioning and Refrigeration Industry**
Published by the Air-Conditioning and Refrigerant Institute, USA. Fax: +1-703-528-3816, E-mail: ari@dgsys.com .
March 1996, 80 pages.
*Compiles import and export data for equipment traded in the US, European and world markets. The data is classified according to equipment type, including heat pumps, and covers the years 1989 to 1993. Also included are useful contact details of sources of further market information.*

**Comparing Energy Technologies**
Published by the IEA, Paris, France. Fax: +1-45-248-176.
February 1996, 336 pages. US$ 114.
*This publication considers the state-of-the-art in methodologies for assessing and comparing energy technologies, and reports on energy R&D approaches and assessment criteria in several countries.*

**NIST REFPROP Version 5.0**
DOS compatible software from the National Institute of Standards and Technology (NIST), Gaithersburg, USA.
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**Refrigerant Database**
MS DOS compatible software available from James M. Calm, USA. Fax: +1-703-524-6351. Contact the Air-Conditioning and Refrigerant Institute ARI Internet home page at http://www.ari.org to download a demonstration copy.
Price: US$ 120 in USA, US$ 160 in Canada and Mexico, and US$ 200 elsewhere (price of individual user license).
*With the equivalent of 3,900 pages of reference matter, this database includes data summaries for over 360 refrigerants and blends, and bibliographic citations for more than 3,400 documents. It compiles summary physical and thermophysical data, and includes reports from ARI's R-22 Alternative Refrigerants Evaluation Program (AREP).*

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**TIEES-96**
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Fax: +90-462-325-7405,
E-mail: energy96@risc01.bim.ktu.edu.tr

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**Research, Design and Construction in Refrigeration and Air Conditioning for Eastern Countries**
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IIR Meetings. Contact: Prof. Florea Chiriac, AGFR. Fax: +40-312-6880

**International Absorption Heat Pump Conference**
17-20 Sep '96 / Montreal, Canada.
Contact: Darius Nikanpour, EDRL,
Fax: 1-514-652-5177;
E-mail: Darius.Nikanpour@cc2smtp.emr.ca

**Optimum Ventilation and Air Flow Control in Buildings**
17-20 Sep '96 / Gothenburg, Sweden.
Deadline for Abstracts: 14 Feb '96.
Contact: Rhona Vickers, IEA Air Infiltration and Ventilation Centre (AIVC), UK. Fax: +44-1203-416306;
E-mail:airvent@AIVC.org

**Geothermie - Energie der Zukunft**
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Fax: +49-7125-156133

**Analysis and Applications of Heat Pump and Refrigeration Systems**
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**Cold Climate HVAC '97**
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Commercial Buildings
Volume 14 - No. 3/1996

## 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 co-operation 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

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