IEA Heat Pump CENTRE NEWSLETTER

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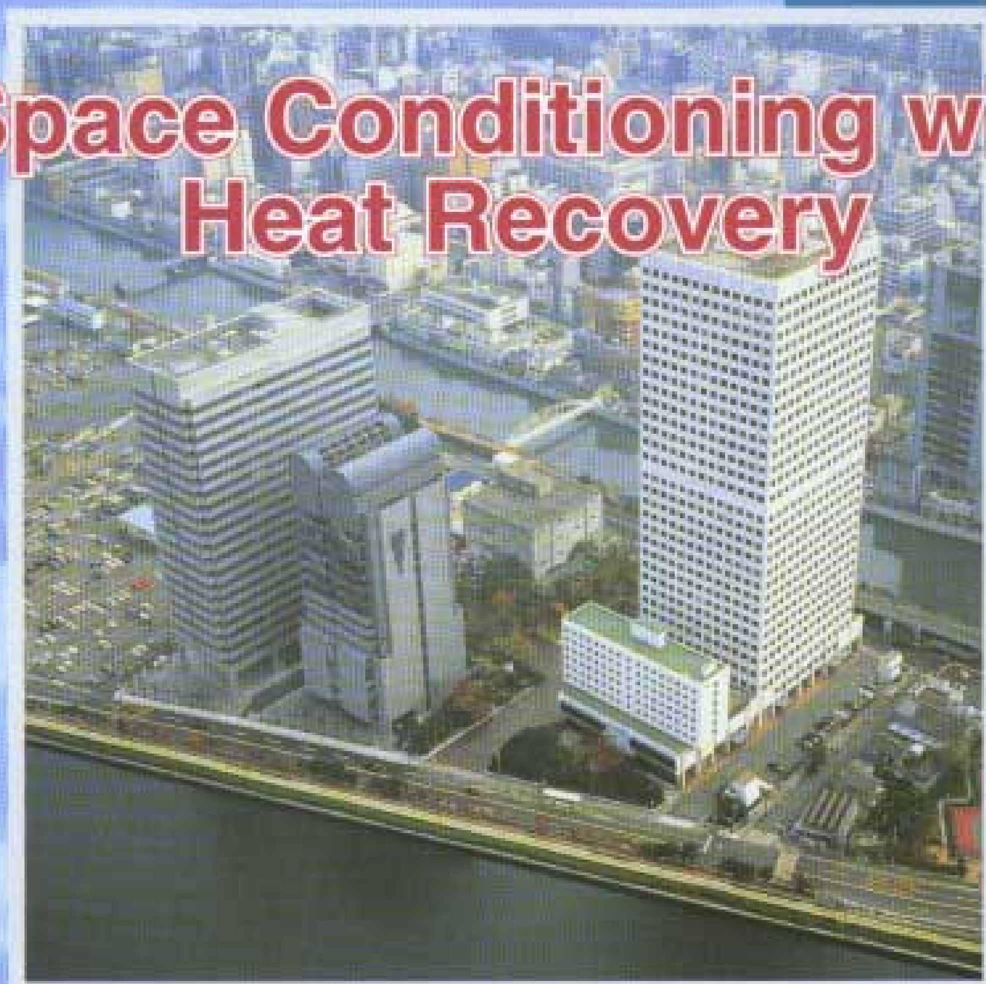
Space Conditioning with Heat Recovery



In this issue:

Air heating systems for low-energy buildings
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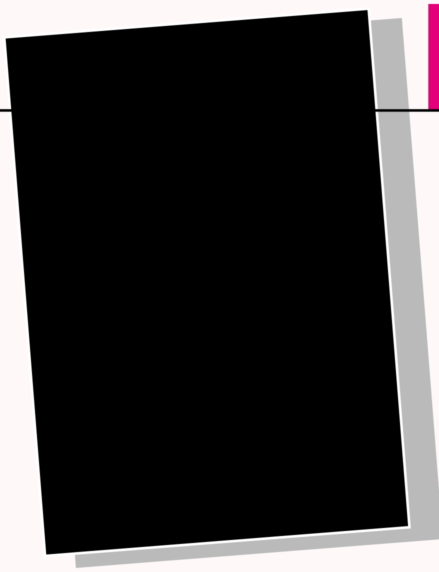
Highly efficient CO_2 heat pump water heaters

IEA OECD heat pump centre



In this issue

Space Conditioning with Heat Recovery

Modern building design, increased comfort demands, higher internal loads, more computer systems etc. have considerably increased the space cooling demand in commercial and institutional buildings. This has led to increased attention to heat recovery. This issue shows examples of how space conditioning with heat recovery can contribute to more economical and energy-efficient systems, increased comfort and reduced impact on the environment.

Front cover:
The cover shows a view on the supply area of the district heating and cooling system in Osaka, Japan that is described on page 19.

TOPICAL ARTICLES

HEAT PUMP NEWS

FEATURES

COLOPHON

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NON-TOPICAL ARTICLES

A better quality of living using space conditioning with heat recovery

Almost one third of fossil fuels consumed in Switzerland are used for heating. But heating produces 40% of the greenhouse gas emissions. Space conditioning with heat recovery not only helps to reduce these emissions, it also improves the quality of life, mainly by improving the air quality inside houses and reducing outside noise.

Modern buildings not only need less heating energy, they also have a much tighter building envelope than older buildings. Natural ventilation through gaps in the walls and windows is reduced. Windows must be opened periodically, otherwise air quality will be poor and humidity too high, which could lead to health problems. Controlled ventilation is a much appreciated technology in modern low-energy houses. Although the amount of ventilation cannot be below a certain minimum, heat recovery can reduce energy losses considerably.

In Switzerland a new standard for energy consumption in buildings has been mandated for the so-called 'Minergie' house. Heating and domestic hot water may not consume more than 160 MJ/m² per year (new houses), with a maximum of 320 MJ/m² per year for houses built before 1990. For electricity consumption, a correction factor is used to account for the amount of primary energy used for electricity production. Space conditioning with heat recovery is an economical way to achieve the values required by the new standards.

It is always difficult to compare different space-conditioning systems. Specialists sometimes tend to make unfair comparisons in favour of their own products. The only correct comparison is to take into account all the heat producing equipment and its energy consumption. The best and most cost-effective solution to achieve the target of low-energy consumption and better quality of living can then be chosen.

Dieter Wittwer

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Dipl. Ing. ETH, Head of Innovation Department
INFEL, Zürich, Switzerland

Heat pump news

IIR Meeting Linz

Austria - On 28 September to 1 October 1997 an IIR Meeting on "Heat Pump Systems, Energy Efficiency, and Global Warming" was held in Linz, Austria. Sixty participants from 18 countries attended this event which was sponsored by Commission E2 "Heat Pumps and Heat Recovery". Thirty papers were presented covering both synthetic and natural refrigerants such as CO_2, new components, advanced units of both the compression and the absorption type, new heat pumping concepts, applications in buildings and industry, and marketing concepts of utilities.

A technical visit was paid to the Austrian heat pump manufacturer NeuraTherm in Regau, which specialises in prefabricated direct-evaporation ground-source heat pumps that use propane as refrigerant. Participants also visited the Austrian Salt Production Plant near Ebensee, where, in 1855, Peter Ritter von Rittinger operated the first ever industrial heat pump. This was an open hydropower-driven mechanical vapour recompression system. In 1979, a new system was installed with two centrifugal compressors, each with an electric input of 4 MW. The COP of these heat pumps is 12-16.

The meeting, organised by Hermann Halozan and Ulrike Gerhard of the Institute of Thermal Engineering, Graz University of Technology, was cosponsored by the HPC and OKA, the electricity utility of Upper Austria.

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

All-electric service station proves heat pump benefits

USA - A ground-coupled water-source heat pump has been installed at a Texaco Star-Mart petrol station in Oklahoma. Integrated geothermal systems can meet needs for space heating and cooling, refrigeration ice making and even food preparation facilities. The Star-Mart was an excellent candidate for a heat pump-based all-electric facility: the 24-hours service station is equipped with a car wash, a fast food establishment and refrigeration equipment. Energy costs were cut by around one-third compared to a comparable gas-electric facility, while providing a consistent well-balanced power load. In addition, facilities that combine petrol stations with restaurants represent a fast growing market segment.
More information: Mukesh Khattar, EPRI, +1-415-8552699 or M. Lovett, Geothermal Design & Engineering, +1-405-2365721.

Source: EPRI Heat Pump News Exchange, Fall 1997

Renewed focus on heat pumps in Norway

Norway - In Norway electricity production is almost entirely based on hydropower. Last winter Norway experienced a shortage of electricity due to several years of drought and relatively cold weather. Over 30 TWh/year electricity is currently being used for space and hot water heating, and industry is expecting a considerable growth in electricity demand over the next few years. To avoid future electricity shortages and develop a more robust and flexible energy system, the Norwegian Ministry of Petroleum and Energy (OED) and the Norwegian Water Resources and Energy Administration (NVE) are now carrying out a number of in-depth studies to identify potential technologies and implement long-term strategies on energy use and energy production (heat and electricity). Key aspects are:

- reduced electricity consumption (peak shaving) in the residential, commercial and industrial sector by energy conservation in general and replacement of baseboard heaters and electric boilers by using *heat pumps*, bioenergy etc.;
- increased energy flexibility (peak shifting), replacing electric resistance heaters with hydronic heat distribution systems in combination with a number of energy sources, e.g. oil, natural gas, *heat pumps*, biomass, solar;
- increased electricity production capacity through new clean power plants that use hydropower, natural gas and wind energy.

To establish a common understanding of the considerable potential for heat pumps in Norway, the IEA Heat Pump Centre's Norwegian National Team has been active in providing unbiased information on heat pump technology to various target groups, including the government.

In the long-term strategy plan (1996/97) "Environmental Politics for a Sustainable Development - Climate and Energy" from the Norwegian Ministry of the Environment, renewable energy and energy conservation are regarded as important instruments for reducing electricity consumption and CO_2 emissions. One of the main goals is to increase heat production from *heat pumps* and bioenergy by 5 TWh over the next 5-10 years.

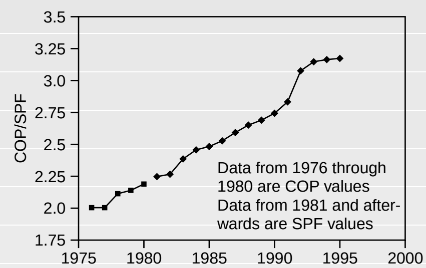
Source: Norwegian National Team, Jørn Stene, SINTEF Energy (see back cover).

Studies show increased efficiency in air-conditioning equipment

USA - Over the past two decades the US air-conditioning industry has made great progress in improving the efficiency of its products. For unitary products, average efficiencies have increased some 50% over the past 20 years, and there is some room for further improvement.

The **figure** shows the growth in the shipment-weighted average efficiency of unitary air-to-air heat pumps from 1976 through 1995. Between 1981 and 1995 the seasonal performance factor (SPF) increased by 42.5%. The large increase between 1991 and 1992 was in part due to government regulations requiring that all new equipment have an SPF of at least 2.9 for the cooling mode, as well as to technology improvements. Much of the growth in equipment energy efficiency can be attributed to motor and compressor improvements.

▼ *Figure: Shipment-weighted average cooling efficiencies of unitary air-to-air heat pumps.*



Source: Koldfax, October 1997.

European energy labelling of heat pumps

The Netherlands - For the European Community's SAVE II programme a project entitled 'Energy labelling of air-to-air domestic heat pumps' is being carried out by the Dutch Organisation for Applied Scientific Research (TNO), together with SP (Swedish National Testing and Research Institute) from Sweden and the Danish Technology Institute (DTI). The project aims at developing a detailed method of assigning energy labels to domestic air-to-air heat pumps, including the physical design of the label. This method could lead to obligatory application in EU countries. More information: TNO, fax: +31-55-5493740.

Source: Podium Warmtepompen, October 1997.

Young researchers awards at IIR Congress in 1999

France - At the 1999 congress of the International Institute of Refrigeration in Sydney, Australia, six special awards will be given to young researchers who have submitted original work on subjects relevant to the IIR. Nominations should be sent to the IIR by 15 May 1998. More information can be obtained from the IIR; fax: +33-1-47631798. E-mail: iifiir@ibm.net.

New office promotes geothermal technology

USA - The Electric Power Research Institute (EPRI) and Interstate Power Company have forged a partnership to promote geothermal energy technology for commercial and residential use, including a regional Geothermal Information Office (GIO) in Dubuque, Iowa. This GIO will be the first of what EPRI anticipates will be many regional information offices as utility and public interest in geothermal technology is growing. For more information contact: EPRIAMP, +1-800-4320167.

Source: EPRI Heat Pump News Exchange, Fall 1997.

HPC at Climate Conference Kyoto

Japan - The IEA Heat Pump Centre has produced a new brochure on CO_2 emissions reduction with heat pumps to bring the possibilities of heat pumps for emissions reduction to the attention of policy makers from all over the world, at the Conference on Climate Change in Kyoto, Japan. The brochure focuses on the current and potential contribution of heat pumps to reduce CO_2 emissions. It can be obtained free of charge from the Heat Pump Centre. Order No. HPC-BR5.

IIR and UNIDO sign agreement

France - The International Institute of Refrigeration (IIR) and the United Nations Industrial Development Organisation (UNIDO) have signed a cooperation agreement to promote common objectives in fields such as the production of refrigerating equipment, industries using refrigeration and the recovery and replacement of CFCs used as refrigerants or in insulating materials. Energy recovery and heat pumps is one of the sectors covered by the agreement, as well as air conditioning.

IIR Bulletin 97-6, October 1997.

Erratum

In Newsletter Vol.15/3, page 9, the article concerning an Annex 24 Workshop on Ab-Sorption Machines incorrectly stated that a general recommendation from all participants for R&D on heat and mass transfer was the proposed way to reduce investment costs. However, a general consensus was that training courses and national workshops, as well as R&D on new systems and applications, should be stressed.

Ammonia Heat Pump and Indirect Cooling with Sea Water

Norway - The Norwegian Pollution Control Authority (SFT), Division of Oil Protection, has installed sea water heat pumps and hydronic heat distribution systems in their new centre located in Horten near the Oslofjord.

The heating-only heat pump uses ammonia (NH_3) as the working fluid. Ammonia is a zero ozone depletion potential and global warming potential working fluid, with superior thermodynamic and transport properties. More than 20 ammonia heat pumps are currently in operation in Norway, mostly installed in commercial buildings. In order to ensure safe operation, the heat pump units are located in gas-tight machinery rooms with leak detectors, alarm systems and fail-safe ventilation. Scrubbers have been installed in some of the plants to absorb ammonia vapour in the event of a leak. The operational experience with ammonia heat pumps in Norway is very good, and no accidents have been reported.

The bivalent heat pump system at SFT in Horten is used for space heating and preheating of domestic water. The heat pump units have a heating capacity of 200 kW at design conditions, which is approximately 50% of the total peak load demand of 430 kW. Two oil-fired boilers with a total heating capacity of 450 kW serve as peak load and backup units. The seasonal performance factor (SPF) for the heat pump system is expected to be at least 3.7. The hydronic heat distribution system is connected to fan coils in the engineering workshop, with radiators and floor heating systems being used in the main administration building.

The buildings have a considerable cooling demand, which is entirely met by sea water cooling. Taken from a depth of 100 metres the sea water has a temperature of 6-9°C, which gives supply temperatures in the cold distribution system from 10-13°C.

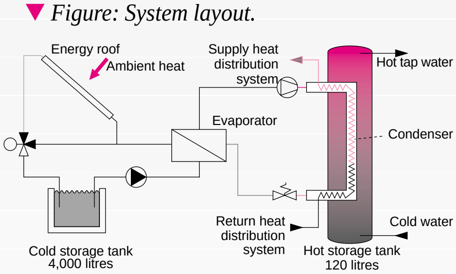
Source: Jørn Stene, Norwegian National Team (see back cover)

Combining a heat pump with an energy roof

The Netherlands - At Eindhoven University of Technology (EUT) a bivalent heat pump system and a buffer is being tested for space and tap water heating, using outside air and the sun as the heat sources. A monovalent air-source heat pump system would be less efficient when the heat demand is high (i.e. at low ambient temperatures).

The so-called energy roof improves heat extraction from the outside air. It consists of a metal sheet with pipes containing a fluid. Usually, an energy roof extracts heat from the sun and precipitation, but not from the air. In this case extraction is improved by creating air passages between the sheet and the roof boarding, where heat can be extracted from air that is circulated via a fan. The extracted heat is stored in a water tank. The heat pump uses this buffer as the heat source and heats water in a 120-litre boiler to a maximum of 55°C. The boiler is equipped with a gas burner which is activated when the capacity of the heat pump is not sufficient. A layout of the system is given in the **Figure**.

Figure: System layout.



EUT expects to extract 9,500 kWh of ambient heat with this system. This results in an estimated COP of 4, since the calculated electricity consumption of the heat pump is 3,200 kWh, with 800 kWh being used for the fan and pump of the energy roof.

Sources: Energie en Milieuspectrum, October 1997, Koude en Klimaattechniek, August 1997.

Heat pump with electro-osmosis

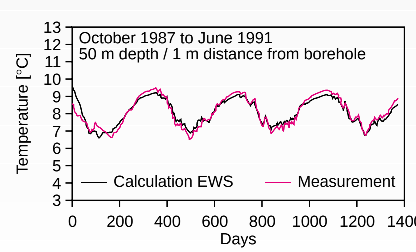
The Netherlands - The Organisation for Applied Scientific Research (TNO) has conducted a research project to investigate the feasibility of a heat pump cycle based on the principle of electro-osmosis. The concept has been demonstrated. This first phase also aimed to select possible application areas for the technology. TNO concluded that potential applications include room-type air conditioners, small heat pumps and recreational cooling equipment. TNO is looking for partners to continue the project.

Contact: Hans van der Stoel, TNO-MEP. Fax: +31-55-5493740.
Source: Podium Warmtepompen, October 1997

Computational model for vertical borehole heat exchangers

Switzerland - A new computational model named EWS has been developed to calculate the brine outlet temperature of ground heat exchangers. It serves to reproduce the behaviour of double-U-shaped borehole heat exchangers, including start-up and cyclic operation over several years. The effect of interruptions in the extraction of heat can also be calculated. Experimental validations were carried out for a single-family house (see **figure**) and by comparative calculations using the SBM program of Lund University. An advantage over other programs is that EWS is considerably faster. It can be used to simulate heat pump systems on modern personal computers.

Figure: Comparison between ground measurements and EWS calculations.



Further information: Mr A. Huber, Huber Energietechnik, Fax: +41-1-4227953, E-mail: huber@igjzh.com

Annex 22 workshop highlights CO_2 and supermarket refrigeration

USA - A workshop on “Compression systems with natural working fluids” was held under Annex 22 on 2-3 October 1997 in Gatlinburg, USA. The 38 participants came from the US, Japan, Norway, and various other European countries. The workshop included a visit to the Oak Ridge National Laboratory.

The first session was dedicated to general issues. In Japan, ammonia and water are often used as refrigerants for industrial or commercial applications. Specific ongoing Japanese research on these two fluids, as well as CO_2 and air, were discussed. Two Dutch applications of an ammonia/water secondary loop system, one for air conditioning in a commercial building and one for industrial cooling, were discussed, as well as a research project on retrofitting milk cooling machines with a propane-isobutane mixture.

Various presentations on safety aspects were given. In the US, the fact that there are non-flammable and non-toxic alternative working fluids available make it hard to defend another choice. The conclusion of a Dutch study on quantitative risk analyses was that the risks are negligible for the ammonia systems, and acceptable for the hydrocarbon systems.

Secondary loop systems were studied in the UK. Supermarket refrigeration was given much attention. A conclusion was that a single-phase secondary fluid can outperform conventional DX systems from both an energy and a TEWI-rating point of view. Refrigeration systems using an ammonia/ CO_2 secondary circuit and CO_2 cascade systems were discussed by Norway. The performance of a display case with potassium formate secondary loop was compared with a baseline mode (DX R-404a) by the US. The first system seems better, largely due to better controlled frost deposition.

In conclusion, the workshop provided many examples of applications and relevant data on heat transfer and equipment design. Perspectives for natural working fluids are good, especially for supermarket refrigeration.

Source: Gerdi Breembroek,
IEA Heat Pump Centre
Internet site: www.maskin.ntnu.no/kkt/annex22

Japanese group unveils new refrigerant

Japan - A new refrigerant (R-407X) that reportedly improves product performance and cost has been unveiled by JAREP, the Japanese counterpart to the Air Conditioning and Refrigeration Institute’s Alternate Refrigerant Evaluation Program (AREP).

According to a report in the newsletter Ozone Depletion Today, the refrigerant, R-407X, is more efficient than R-407C because it has a higher percentage of R-32 (the flammable component), and a lower percentage of R-125. The change came about because of new flammability test standards from Underwriter’s Laboratory. JAREP claim the composition shows a 3% improvement in efficiency over R-407C. The refrigerant is being called R-407X until it receives a refrigerant designation from ASHRAE.

Source: ASHRAE Journal, September 1997.

IIR Informative note on fluorocarbons and global warming

France - The International Institute of Refrigeration (IIR) has published an informative note on fluorocarbons and global warming, in preparation for the Kyoto summit on climate change in December. The IIR recommendations support incorporating historical emission data for CFC and HCFC refrigerants with HFCs in trend analysis of refrigerant emissions, and use of the TEWI concept for assessing the impact of refrigerants on global warming. It also urges measures for increased confinement, recovery and charge size reduction for refrigerants, and emphasises the importance of energy efficiency of refrigeration and air-conditioning plants commensurate with their indirect global warming impact. For details, or to order a copy, see the Books and Software section on page 30.

Sources: Koldfax, September 1997/IIR Informative Note.

Swedish supermarket giant switches to hydro-carbon refrigerant

Sweden - The 3,000 m^2 Ags Favor supermarket in Helsingborg, Sweden, uses only 35 kg of hydrocarbon refrigerants to cool its entire range of 140 kW freezers and 240 kW coolers. Seven units using semi-hermetic compressors and plate heat exchangers supply the plant, which cools two kinds of secondary refrigerant: carbon dioxide for the freezers and propylene glycol for the coolers. The CARE™ refrigerants were supplied by Calor Gas Refrigeration.

The system was installed by ABB Litzell AB which has also installed hydrocarbon-based systems in supermarkets in Lund and Landskrona. In the Lund supermarket, 14 kg of hydrocarbon refrigerants were used to replace R-404A, at the same time cooling capacity was increased by 30 kW and the freezing capacity by 10 kW.

Source: OzonAction, October 1997.
Contact: Calor, fax: +44-1926-318706.

Japanese manufacturers reduce production

Japan - Major Japanese electrical appliance manufacturers are reducing production of their room air conditioners (RAC). Matsushita, Hitachi and Sharp are among those likely to curtail production. It is quite unusual for these manufacturers to consider production curtailment from October, which is the start of the new refrigeration year. This step is due to the trade's total inventories reaching an all-time high of 2.6 to 2.7 million units (including those held by distributors).

Source: JARN, October 1997.

New energy-efficient room-type heat pumps

Japan - Toshiba Corp., Tokyo, has released three energy-saving RAC models adopting a hybrid inverter, giving optimum control . The three energy-saving models use far less power than their predecessors, in case of the 2.8 kW class 13% less. Even when the outside temperature is as low as 2°C they can produce a high heating capacity (5.1 kW maximum).

Sharp has also released four models of room air conditioners. The models are equipped with a 'non-water supply humidifying unit' which needs no water replenishment along with other comfort features. An interior permanent magnet (IPM) floating DC scroll compressor equipped with a newly developed high-efficiency, high-speed motor, allows a 5% reduction in annual power consumption.

Source: JARN, October 1997.

Quiet GHP models

Japan - Mitsubishi Heavy Industries Ltd., Tokyo, has released three split-type gas heat pump air conditioners in the capacity range of 10, 12 and 15 kW. Low noise levels have been realised for all three units. The 10 kW unit has a noise level of 60 dB, which is 2 dB lower than that of the corresponding electric heat pump packaged air conditioner.

The demand for gas heat pump air conditioners is expected to reach around 40,000 units during the refrigeration year 1997/98, which is 11% more than the previous year. The share of multi-zone split systems larger than 10 kW is growing significantly, representing 51% of the total demand volume and 65% in terms of cooling capacity.

Source: JARN, October 1997.

Avoiding excessive starting currents

Switzerland - The excessive start-up current of most air conditioners causes problems for many utilities (see **Figure 1**). In Europe, conformity with European Standards EN 61000-3-2 and EN 61000-3-3 must be guaranteed by CE (Conformité Européenne) certification.

Conformity with Electromagnetic Compatibility (EMC) can be achieved as follows. The circuit consisting of temperature-dependent direct resistances (NTCs) reduces the compressor contact voltage at circuit closing time to approx. 20-30% of rated voltage. Internal heat generation reduces the resistance value of the NTCs. As a result, the contact voltage of the compressor rises continuously until the starting point. The resulting starting current (see **Figure 2**) is free of grid interference as defined in the EMC regulations. Bridging of the NTCs following start-up is achieved by integrated contacts.

The circuit represents a full-wave soft starter and causes no phase shift or harmonics. It can be integrated in the existing circuit of a device. The maximum capacity for single and three-phase operation is approx. 60 kW. Other advantages are that the impulse-free start-up protects compressor and refrigerant piping, and a reduction of fusing capacity is possible. Also, costs for the CE test are avoided.

Further information: Mr R. Weigel,
Fax +41-71-9942813

Figure 1: ▶ *Direct start of a compressor.*

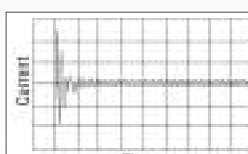
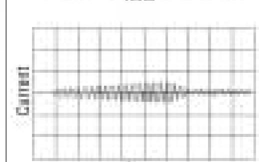


Figure 2: ▶ *Compressor with full-wave soft starter.*



UK air conditioning market studies

UK - The Building Service Research and Information Association (BSRIA) has published two new studies on the UK air-conditioning market. The reports cover split systems, variable refrigerant flow controllers and rooftops, window/wall units, mobiles and close control air conditioning, as well as a full range of central plant products, offering a comprehensive analysis for the period 1990-2000. The UK market for packaged air conditioners showed a 24% growth over 1995. For further information about these reports contact Louise Stapleton, BSRIA, fax: +44-1344-426511.

Robur develops GAX heat pump

Italy/US - At a convention in May of this year Robur announced plans to introduce a 10 kW GAX (generator absorber heat exchange) chiller unit within 12 months and a 17.5 kW model within 15 months. It was also announced that an operational prototype of a GAX heat pump would be on the market within 24 months. A southern California gas utility and the US Department of Energy offered to help market these products. Robur sold over 1,500 gas-fired absorption chiller units in Europe in 1996.

Source: Mr Carlo Formigoni, Robur SpA / Cooltimes, 20 May 1997.

New look HPC Internet site

The Netherlands - The IEA Heat Pump Centre's Internet site (www. heatpumpcentre.org) will have a new layout in January 1998. Please take a look at the new site and let us know what you think.

A new feature on the site is a special news section on natural working fluids (NWF), which is directly accessible from the home page. Since this is a very hot item in heat pumping technologies, it deserves special attention in a separate news category. This new section provides an overview of recent NWF developments and applications, with news items gathered from various sources, including those within the IEA Heat Pump Programme.

This is an open invitation to send us new, relevant information on NWF applications, technology developments and standards/ regulations concerning natural working fluids.

Other changes that can be expected in the near future include an improved search feature for the publications database and information on standards and regulations. Also, information on typical heat pump applications in buildings and industry will be added.

Contact: Hanneke van de Ven,
IEA Heat Pump Centre

Newsletter Topics for 1998/99

The Netherlands - At the Heat Pump Centre National Teams Working Meeting held in Utrecht, on 4-5 September, the following topics were selected for the Newsletter:

June 1998:	Heat Pumping Systems and Thermal Storage
September 1998:	Alternative Working Fluids
December 1998:	Concepts for Heat Pump Marketing
March 1999:	Ground-Source Heat Pump Systems

Contact: Hanneke van de Ven, IEA Heat Pump Centre

Properties of Alternative Refrigerants on the Internet

As a contribution to the Annex 18 "Thermophysical Properties of Environmentally Acceptable Refrigerants", the Fachinformationszentrum Karlsuhe and the Institut für Technische Thermodynamik und Thermische Verfahrenstechnik" (ITT), Universität Stuttgart have developed the $MIDAS_2$ database, financed by the German Ministry for Education, Science, Research and Technology (BMBF).

$MIDAS_2$ compiles worldwide literature references on thermophysical and environmental properties of alternative refrigerants substituting chlorofluorocarbons (CFCs). The database contains commercial and experimental refrigerants of HCFCs, HFCs and their mixtures, as well as natural refrigerants for domestic, commercial and industrial refrigeration, cold storage, air-conditioning, heat pump technology and other applications. A first version of $MIDAS_2$ is now available on the Internet at www.itt.uni-stuttgart.de/~krauss/midas.htm

Source: H.J. Laue. Fax: +49-7247-808134

HPP Workshops

Sweden/Canada - On 12 May 1998, a workshop on *Deployment Activities of Heat Pumping Technologies* will be held in Stockholm, Sweden. The workshop aims to identify common institutional problems with market introduction of heat pumps and market barriers. It could bring together people with different background, such as marketing, manufacturering and research. The contact person is Mr Magnus Gustafsson of the Royal Institute of Technology, fax: +46-8-105228.

Another workshop, titled *Heat Pump Systems for Single Room Applications*, will be held in Niagara Falls, Canada on 18-19 June 1998. The workshop will invite industry's experts to define markets, clarify trends, explore strategies and most importantly identify opportunities for heat pumps in single room applications. This Annex 23 workshop targets a global audience of designers, manufacturers, government representatives and utilities looking for energy efficient heating alternatives. For additional information on the workshop contact Mr Frank Lenarduzzi, Fax: +1-416-2076565, E-mail: lenarduzzi@oht.hydro.on.ca

Ongoing Annexes

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

Annex 16 IEA Heat Pump Centre	16	AT, ES, JP, NL, NO, CH, US
Annex 18 Thermophysical Properties of Environmentally Acceptable Refrigerants	18	CA, DE, JP, SE, UK, US
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Annex 23 Heat Pump Systems for Single-Room Applications	23	CA, FR, CH, US, SE
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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).

Heat Pump Space Conditioning with Heat Recovery

An International Overview

Jos Bouma, IEA Heat Pump Centre

In a way most heat pumps recover or reclaim heat energy for space heating and cooling, water heating or process heating. In the building sector, the natural heat sources which heat pumps transfer to useful heat, such as outside air, the ground, ground water and sea/lake/river water are in fact all heat sources that consist of solar heat and cannot be directly used for heating due to their temperature. Hence, one can argue that heat pumps which use these sources are (solar) heat-recovery devices. What is more, these heat pumps use renewable energy sources which are replenished continuously by the sun. However, the most obvious source for recovering heat is the building itself, locally and on a larger scale, e.g. districts, cities etc.

In the industrial sector, heat pumps by definition recover waste heat from processes in different types of operation. However, many industrial heat pumps recycle recovered heat within a process, rather than use it externally for space conditioning. These process applications are not discussed here.

Heat recovery by heat pumps for space conditioning can be categorised as follows:

- those that recover heat by using the heat as a heat source;
- those that recover heat for driving purposes, e.g. waste heat-driven absorption chillers.

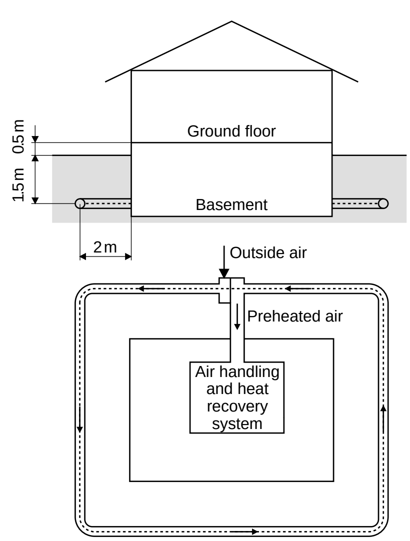
In this overview both types of heat recovery with heat pump technology will be covered, but the emphasis is on their use as a heat source.

Ventilation air

In an ideal building heat-recovery system, all system elements work year-round to recover all the internal heat before adding external heat. Any excess heat is either stored or rejected. Such an ideal system is called a balanced or controlled heat recovery system. When the outside temperature drops significantly, or when the building is closed, internal heat gain may be insufficient to meet the space heating requirements. Heat storage or an external heat source should then supply heat. Innovative use of heat pumping technologies can give large energy savings and high human comfort, as shown in the following.

An attractive heat source for a heat pump is building ventilation air. This heat source is becoming increasingly important. Imposed by frequently renewed building codes, the space heat demand of new houses is decreasing in many countries. Hence, in today's low-energy houses, the ventilation heat losses dominate in relation to the heat transmission losses. New regulations in Germany will further limit transmission heat losses in new houses to 10 W/m^2. On the other hand, driven by growing human comfort needs, the domestic hot water demand is increasing, as inhabitants live in larger houses and use more hot water than in the past. These combined effects lead to new design concepts for low-heating-energy houses with good opportunities for heat-recovery heat pumps. Incorporating a heat-recovery heat pump in a house with a balanced ventilation system can reduce ventilation losses considerably.

Figure 1: Austrian ground-collector for pre-heating air



In moderate climates, such a system can be designed for monovalent operation, if the fresh air is preheated by the ground in a ground collector. **Figure 1** shows a collector outline developed in Austria. The ground collector consists of plastic or concrete pipes buried at a depth of approximately 1.5 m.

Balanced ventilation systems with heat-recovery heat pumps are state-of-the-art in large air-conditioned commercial buildings in western Europe. Many buildings are equipped with such a system.

Forced by regulations aimed at high indoor air quality and energy efficiency, balanced ventilation with heat-recovery heat pumps is common in residences in the Nordic countries. In central/western Europe, many houses are traditionally ventilated in a natural manner. However, natural ventilation is not suitable in new, airtight houses, as this does not ensure sufficient air exchange in the building. A growing number of new houses in Europe are equipped with balanced ventilation heat-recovery heat pumps. Countries with building ventilation regulations include, but are not limited to, Switzerland, Sweden, Norway and the Netherlands.

Water-loop heat pumps

Throughout the world, water-loop heat pump systems are very successful in recovering heat within a building. These systems are mostly applied in commercial buildings. In these systems water-to-air and water-to-water heat pump units use the building water loop to supply or reject heat in conditioning another liquid or air source in each zone of a building. These installations have a common two-pipe system, to which the heat pump units are connected, which also comprises a common closed circuit evaporative cooling tower for rejecting excess heat, see **Figure 2**. Most of the time the water loop conveys rejected heat, but a secondary heat source is usually provided, typically a boiler. The water loop temperature is maintained at a temperature between 16 and 32°C. The application flexibility of these systems is tremendous. Their use varies from providing hot or cold water for preconditioning outside air, to providing space cooling or heating in a hydronic system. In a variation of the water-loop heat pump system in the US, the building sprinkler system is used as part of the loop water distribution system. On a technology level, tremendous progress has been made in the US to improve unit energy efficiency. Further efficiency gains can be achieved through system applications.

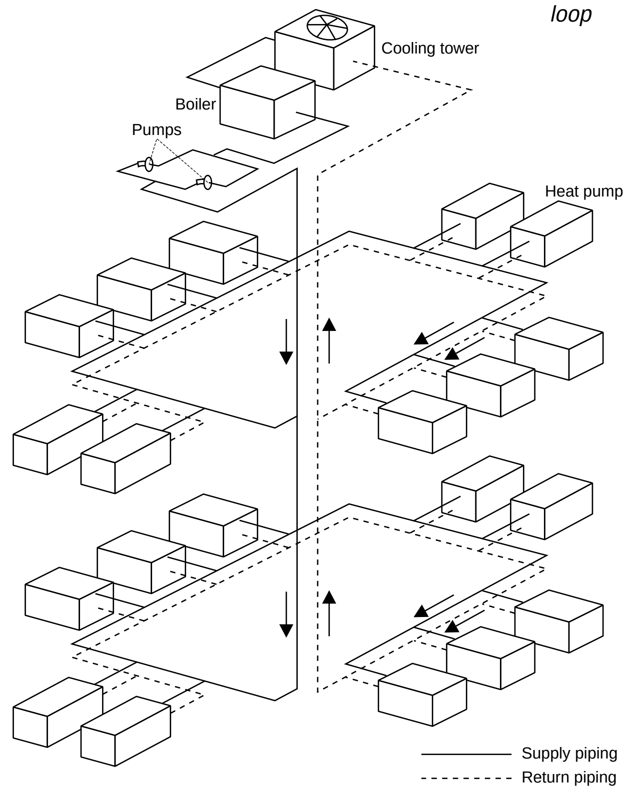


Figure 2: Heat-recovery system using water-to-air heat pumps in a closed loop

In Japan and increasingly in other regions of the world, multi-zone split heat pump heat-recovery systems are being installed. Such systems come in many varieties and configurations. See page 16 for further details of a typical Japanese system.

Swimming pools

A classical application of heat recovery for space heating with a heat pump is in swimming pools, both for private homes and public facilities. The UK and Australia are leading in heat-recovery heat pumps for swimming pools in private homes. The heat pump acts typically as a dehumidifier of the pool room ventilation air. Mainly latent heat is recovered from the humid air by the heat pump. The heat produced by the heat pump is supplied to air or water, depending on the design. Usually the heat is transferred to the air in winter only.

Energy storage

Integration of space heating, cooling and heat recovery in a system of heat pumps and underground energy storage is another solution for energy efficiency in commercial/institutional buildings. An example of such an installation in an office building located in the Netherlands was described in newsletter vol. 14/no. 3 (page 14). In summer, heat from ventilation air is transferred to ground water at 8°C which is reinjected in the warm well for use in winter. If the cooling capacity of the ground water is too small, the heat pumps provide additional capacity. In winter, the stored heat in the aquifer at 17-20°C is used as the heat source for the heat pumps, recovering heat from ventilation air. The cooled-off water is used for cooling the computer rooms and the rest is injected in the cold well for use in summer. The COP of the heat pumps is 4.1.

Retrofitting

Heat recovery for space heating with heat pumps is not only useful in new construction but also in retrofit situations, as the following two examples explain.

A 186-unit apartment building in Canada had been equipped with a 75 kW cooling capacity roof top chiller to provide space cooling, with four air make-up units fuelled by natural gas. A gas-fired boiler supplied hot water for domestic use to an 18 m^3 storage tank. The old system was inefficient for climate control and expensive to operate. The chiller was replaced with three water-source heat pumps which reclaim heat previously lost through the chiller. The heat pumps provide domestic water and air make-up heating. Each heat pump was designed to deliver 33 kW of heat at 53°C from a water source of 11°C. The original gas-fired boiler supplies backup heat. The energy required for the heat pumps to satisfy the total heating and cooling load was approximately equal to the energy consumption of the replaced chiller alone, without the benefit of reclaimed energy. The payback period of the system was only 1.9 years and, in addition, the building now has efficient climate control for year-round comfort.

In a Swiss village, 165 houses had oil-fired boilers which supplied heat for space and water heating and consumed 300 m^3 fuel oil annually. To reduce oil consumption and energy costs, the system was retrofitted with six heat-recovery air-to-water heat pumps, two of which are located in the garage and four on the roof of the building. Ventilation air from the kitchens, the bathrooms and the garage in the basement provide the heat source for the heat pumps. The heat produced is distributed by radiators. The amount of heat produced is sufficient to meet the water heating demand in summer and the space heating demand in the intermediate seasons. Fifty percent of the annual heat demand can be met by the heat pump. For peak loads, two high efficiency boilers with a total capacity of 1 MW have been installed. The replacement by heat-recovery heat pumps annually saves 40% energy, or around 120 m^3 fuel oil. The incremental investment costs of the system were 5-10% and the payback period of this retrofit was less than 10 years.

Various other examples of beneficial replacements can be given.

Large-scale heat recovery

Heat recovery with heat pumps is possible on any scale, i.e. in residences, commercial/institutional buildings and on a district scale. In Japan, district heating and cooling are common in large urban areas such as Tokyo, Nagoya and Osaka. Population growth in these areas has initiated new trends in building architecture and thus a new philosophy has developed for efficient and environmentally friendly energy supply systems for districts. Buildings changed from single structures to integrated structures with inter-connections via walkways, sky bridges etc. Underground streets, arcades, atriums etc. are all linked and conditioned for easy access and human comfort. The energy and control requirements of such building complexes are extensive, for a reliable and safe energy infrastructure. Often a simultaneous space heating and cooling demand exists in these districts due to internal heat gains in today's well-insulated, airtight buildings. On the other hand, large quantities of urban waste heat are produced and rejected unused, until recently. In Japan, the so-called unused energy sources are increasingly being exploited. A national programme supports the development of suitable technical solutions and applications. Typical waste heat sources are refuse incineration plants, sewage treatment facilities, power stations, transformer substations, underground power transmission cables and underground railway stations. Heat-recovery heat pumps are extremely suitable to meet the energy demands in such situations. Three examples of district energy infrastructures that apply heat pump technology are briefly described in the following.

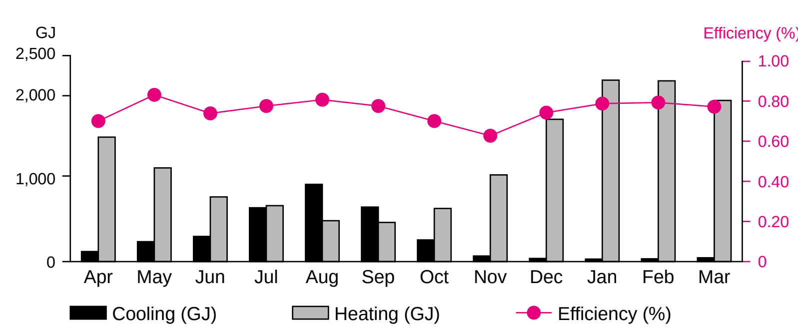
Hikarigaoka district

This is a redeveloped area of 186 hectare in metropolitan Tokyo. It consists of 42,000 residences, schools, hospitals and commercial zones. The dominating heat demand is from the residences. In winter and during the intermediate seasons, the waste heat from cooling the commercial/ institutional buildings is insufficient to meet the heat demand of the residences (see **Figure 3**). Additional heat is supplied by heat-recovery heat pumps which use the condenser heat from the power generation process in a refuse incineration plant and heat from cooling a super high-voltage power transmission line. The ratio of peak heating to cooling demand is 8.3 and the overall annual efficiency of the system is 80%.

Hakozaki district

This is a reconstructed area in Tokyo near the Sumida river and consists of apartment buildings, commercial and institutional buildings. In summer, domestic hot water is produced from cooling the buildings, however, there is still an excess of waste heat. This heat is rejected into the river to avoid hot areas in the district. In winter, heat pumps extract heat from both the buildings'

Figure 3: Monthly load profile and efficiency; Hikarigaoka district.



ventilation air and the river. The ratio of peak heating to cooling demand in this district is 0.15, and the annual energy efficiency is 127%.

Fuchu district

This district has been converted from an industrial site into a computer centre for service companies. Here the cooling demand exceeds the heating demand for most of the year. Only in winter does heat demand sometimes dominate. A large capacity heat storage system will be installed to store waste heat from space cooling for use in space and water heating. The heat pump will mainly operate at night during low-tariff periods. The peak heating to cooling demand ratio of this system is 0.06 and the annual overall energy efficiency is 151%.

Recovery from sewage water

An outstanding application of heat-recovery heat pumps are systems that extract heat from sewage water. Such heat pumps perform extremely well with high coefficients of performance (COP). A major technical challenge used to be the availability of these systems, as the heat extraction part required special solutions to avoid clogging and low evaporator temperatures. Many installed systems have demonstrated that these challenges have been met. A district-size system (14 MW heating) which also provides space cooling has been operating in Norway for several years now (see Newsletter Vol. 12/3, page 15). Several systems have been installed in urban areas in Japan over the past 10 years.

Absorption technology

A growing trend in recovering waste heat in an effective manner is with space cooling, especially in commercial and institutional buildings. Many utilities and building owners have discovered this new market for space cooling. Cold is produced by an absorption chiller powered by waste heat recovered from a cogeneration system that comprises an internal

Austria

In Austria, exhaust air heat recovery is very common in commercial/institutional buildings equipped with an air-conditioning system. Heat exchangers are generally used, some with the added function of recovering moisture. Heat recovery rates range from 50% to over 90%. For small and medium applications, systems using a combination of a heat exchanger with an air/air heat pump have been introduced in the market recently, either for residential buildings or for small commercial/institutional applications, such as restaurants and school buildings. At moderate outside temperatures such systems can be used for space heating.

Large commercial buildings can be split up in sections with different internal gains. This means that heating operation starts at different outside temperatures and that some sections need to be heated while other sections require cooling. Using a four-pipe heat/cold hydronic distribution system with fan coils, the cooling load can be shifted by heat pumps to the temperature level required for heating. Depending on the built-in volume and the equipment used, heat demand in such buildings can be met by utilising the internal gains only for outside temperatures down to 0°C (or higher).

In the case of integrated energy systems, all thermal waste produced by exhaust air, waste water, and refrigeration equipment is collected in stores. Using a heat pump, the temperature is shifted to the level required and used for space heating, and hot water production. Applications of such systems can be found in hospitals and recreation centres, as well as hotels and holiday resorts. Other heat sources are only required for peak load operation.

Source: Hermann Halozan, Austrian National Team

The Netherlands

In the Netherlands heat pumps are considered a powerful heat-recovery technology. Various low-energy housing projects are under construction in which small capacity heat-recovery heat pumps are installed, with ventilation air as the main heat source for the heat pump.

Because of the dense natural gas infrastructure in the building and industry sectors and the favourable tariff structure, cogeneration has penetrated widely in these markets. Unfortunately, these energy installations are not always the best solution from an energy quality point of view. However, the continued market penetration of cogeneration increasingly leads to new energy-efficient opportunities, such as combinations with heat pumps. Combining cogeneration and heat pumps can provide system energy savings as high as 46% compared to boilers.

An example of an advanced installation currently being built with the support of a national incentive scheme is a project in a holiday park, where the existing cogeneration plant will be expanded with three units, creating a total power capacity of 1.5 MWe. Six electric heat pumps will be installed, four of which are integrated in the buildings' air-handling system recovering heat from ventilation air. One will recover heat from swimming pool water, and one will recover heat from ventilating the cogeneration machine room at 30°C.

Combinations of cogeneration and electric (heat recovery) heat pumps for space heating are outstanding from an energy efficiency point of view. They provide cost-effective solutions in regions with a well-developed gas infrastructure or abundant gas from biomass.

Source: HPC

combustion engine or a gas turbine. Here the recovered heat drives the absorption chiller. Such installations have to compete with high efficiency electric compression chillers, but in many situations a cost-effective solution can be offered, depending on local energy tariffs and tariff structures. Typical application examples of these equipment combinations are found in hospitals and office buildings.

Absorption technology can also be effectively used to recover heat from flue gas cleaning in refuse incineration plants. In a typical installation the cooling water from the cleaning process is at a temperature of 43°C and provides an attractive heat source for the heat pump. The absorption heat pump is powered by saturated steam at 135°C , or hot water from the refuse-fired boiler. Most installations are found in Sweden and Denmark and, in recent years, new installations have been built in Japan. One company in Gothenburg, Sweden, operates five absorption units at their incineration plant. The heat produced by the heat pumps is supplied to the local district heating network. All heat pumps are single-stage water-lithium bromide systems. An overview of existing installations in Sweden is given in **Table 1**. At least two similar new installations are being designed in the Netherlands.

▼ *Table 1: Heat recovery with absoption heat pumps for space heating from refuse incineration (Sweden).*

Location	Driving energy	Year of installation	Total cooling capacity (MW)
Avesta	hot water	1988	2.5
Eksjö	hot water	1986	3.2
Gothenburg	steam	1988	28
Uppsala	steam	1997	18

Norway

Modern building design, increased comfort demands, higher internal loads, more computer systems etc. have increased the space cooling demand considerably in commercial and institutional buildings, even in cold climates.

Approximately 8,000-10,000 split air-conditioning units have been installed in residential and commercial buildings in Norway. The reversible units can provide both heating and cooling, but since they are not connected to central hydronic or ventilation systems, no energy recovery is accomplished during cooling operation.

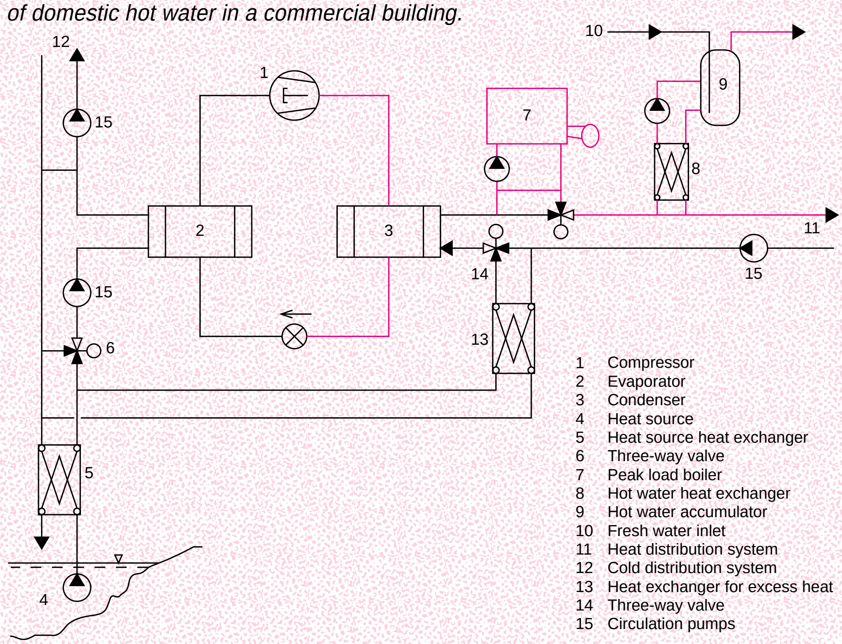
An increasing number of water chillers are installed in hotels, conference centres, office buildings etc. Combined chiller and heat pump systems (i.e. space conditioning heat pumps), that provide maximum flexibility, high energy efficiency and favourable profitability, are not widely applied. This is mainly due to lack of information and competence among building owners, consulting engineers, contractors etc.

Figure 1 shows an example of a bivalent heat pump system for simultaneous space heating, space cooling and preheating of domestic hot water in a commercial building.

The bivalent heat pump is operated in heating or cooling mode. When heating is the predominant load, the heat pump extracts heat from the cold distribution system (12) and the heat source (4). The three-way valve (6) is used to control the flow distribution between the two heat sources. The condenser heat from the heat pump (3) and heat from the peak load boiler are used for space heating (11) and for preheating of domestic hot water (8). In summer, when the cooling demand is the dominating load, the cold distribution system is used as the sole heat source, and the three-way valve (6) closes towards the heat-source heat exchanger (5). Surplus heat from the heat distribution system is given off to the heat source (4, serving here as the heat sink) via heat exchangers (13) and (5).

Jørn Stene
Norwegian National Team
c/o SINTEF Energy

▼ *Figure 1: Bivalent heat pump system for space heating, space cooling and preheating of domestic hot water in a commercial building.*



Switzerland

In Switzerland many cantons restrict space cooling. Special permits are rarely given. Nevertheless, controlled air ventilation (CAV) with heat recovery of the ventilation losses is becoming increasingly popular. The main benefits for CAV are summarised below.

In Switzerland, almost a third of primary energy such as oil, gas and coal is used for heating purposes. The CO_2 emissions related to heating are over 40%. To limit this high amount of heating energy, new buildings have a more airtight construction, thereby losing less energy due to natural ventilation of the building envelope. Nowadays the specific energy demand of residential buildings is, on average, over 500 MJ/m^2 per annum. For new buildings the requirement, according to the standard of the Swiss Engineers and Architects Association (SIA), is a maximum 370 MJ/m^2 per annum, with a target value of 280 MJ/m^2 per annum. The latter is almost half of the existing average.

However, the advantage of energy savings by new building structures has a drawback which should not be underestimated. Lower heat losses also mean a smaller ventilation flow rate in the building. This in turn means that air quality is reduced. The occupants open the windows more frequently and a large amount of the saving potential, gained by the tighter building structure, is lost.

Figure 1 shows an example of a CAV installation. Optionally the air can be preheated by an earth-pipe or by a small heat pump unit before entering the building. The disadvantage of this installation is the double-duct system for supply and exhaust air. There are also installations where the exhaust air is gathered in a central duct and directed across the evaporator without a heat exchanger between the exhaust and supply air. The fresh outside air enters the building through gaps in the wall or specially installed valves in the outside walls.

▼ *Figure 1: CAV with heat recovery.*

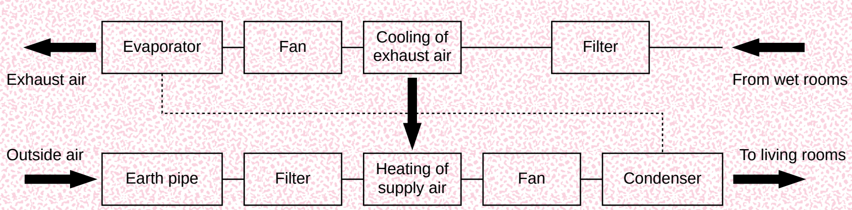
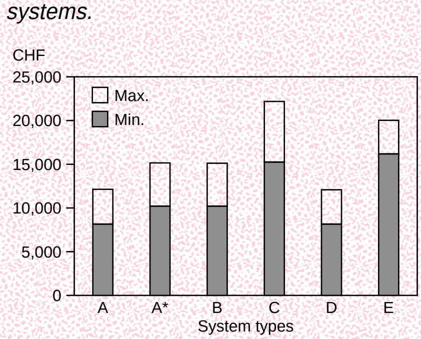


Figure 2 gives an overview of installation costs for various CAV systems in a new single-family house.

Source: Swiss National Team

▼ *Figure 2: Costs for various CAV systems.*



Legend:
A Plate heat exchanger
A* Plate heat exchanger with earth-pipe for preheating
B Exhaust air heat pump for heating of supply air
C Exhaust air heat pump for heating of supply air and hot water
D Exhaust air heat pump for hot water
E Exhaust air heat pump for hot water and support for space heating (outside air via wall valves)

Industrial heat recovery

Recovering heat from industrial processes for space heating has been common practice for years in many industries. Particularly in colder climates with a long heating season, the use of a space heating heat pump that operates on industrial waste heat can be cost-effective. Numerous systems are installed worldwide and have been documented in literature. Typical heat sources include the condenser heat from refrigeration systems, ventilation air from workshops and machine halls, process/equipment air cooling, process waste water, effluent streams etc. A heat-recovery heat pump for space heating in a Dutch washing facility for vegetable packaging is described below. It is a typical example of recovering low-temperature process heat.

Pallets and crates for vegetables need frequent cleaning with warm water. A study indicated that the best application for the waste heat from the cleaning process was space heating. A closed cycle air/water-to-air compression heat pump extracts the waste heat from the air-cooled washing machine. The heat stored in the process water settling tank can be used as an additional heat source by the heat pump. The heat produced is transferred to the ventilation air of the space to be heated. The heat pump has been added to the air heaters. The heating capacity of the heat pump is 80 kW. In peak demand situations, the existing air heaters (115 kW) are used parallel to the heat pump.

Conclusion

Using energy resources as efficient as possible is a 'must'. More than ever, this requires dedicated actions from governments, the energy sector and industry. Heat pumps should be their preferred choice as they represent a sustainable energy technology, which makes efficient use of renewable energy

Japan

With the increased year-round cooling load in office buildings, heat recovery with a heat pump system is widely used in Japan. Today, a variety of heat pump heat-recovery systems exist and these are incorporated in building space conditioning. They are basically classified into two types: central systems and decentralised unitary systems.

The typical central heat pump heat-recovery system is usually coupled to water thermal storage tanks, which are often located in the basement as part of the building structure. A double bundle water-to-water heat pump with a centrifugal or screw compressor is used for simultaneous heat and cold production. Air-source heat pump systems with heat recovery from ventilation air are also used for commercial buildings. These central heat pump systems are used as a large capacity all-electric district heating and cooling energy supply system, and they are ideal in a district with buildings that incorporate a computer centre or department store.

The current outstanding feature in Japan, in addition to the well-known water loop unitary systems, is the multi-split heat pump system with heat recovery function This has been developed in a variety of system configurations, as both air-to-air and water-to-air multi-split systems. An outdoor unit is used for heat supply or rejection. Each indoor unit can be individually switched to heating or cooling mode, responding to the requirement of the occupants. This results in a flexible system with heat recovery for simultaneous heating and cooling demand.

Source: Mr Takeshi Yoshii, Japanese National Team

USA

In 1996, the space conditioning market in the US grew for the fifth succes sive year. This growth is attributed to the replacement market for residential and light commercial products. With approximately 100 million housing units and 5 million non-residential buildings in the US, the majority of which have some kind of air conditioning, these systems are all potential candidates for replacement with newer, more efficient equipment. Interest rates in previous years also played a role in maintaining this trend by giving home owners enough disposable income to replace (rather than repair) central cooling systems.

In 1996, combined shipments of unitary products, room air conditioners, and central residential heating equipment reached 14.3 million units, (up 11% from 1995), and is 53% above the 1992 shipment performance. Unitary shipments totalled 5,670,665 in 1996, (up 12%). In addition, for the third year running, shipments of electric air-to-air heat pumps – a subset of unitary products – topped 1 million. Approximately every fifth unitary product in the US is a heat pump, a product now found in 10 million homes.

An example of this trend is an application of a heating, ventilating and air-conditioning system with water-source heat pumps and ozone-safe refrigerants at a new all-electric Wal-Mart “Supercentre” under construction in Moore, Oklahoma. The fully integrated mechanical system includes sophisticated ventilation and humidity controls, and heat recovery from refrigeration through water-loop heat pumps. Once construction is completed, the Electric Power Research Institute will monitor the mechanical system’s performance and make data available to those interested in pursuing similar projects. Wal-Mart personnel expect the annual energy savings to be USD102,000, given the cost of the combined electric and gas systems typically installed in Wal-Mart Stores. The bulk of the savings should come from the efficiency of the HVAC design with additional savings from the store’s refrigeration and lighting systems.

Source: Julia Kelley, Oak Ridge National Laboratory

and waste heat sources. Millions of units and systems demonstrate this every day.

It can be argued that most heat pumps are heat-recovery devices, as they regain low-temperature solar heat from natural stores and heat which has previously been used in space conditioning, cities and industrial processes. Not only do heat pumps recover heat for upgrading, they also recover heat for driving purposes, which makes them a highly flexible technology. Heat pumps are able to recover heat more effectively than most other technologies.

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Ecology and economy when retrofitting apartment buildings

Othmar Humm, Switzerland

This article describes the retrofitting of a five-family apartment building, implemented as a pilot and demonstration project for the Swiss Federal Office of Energy. The fact that this building on Mutschellenstrasse in Zurich is a listed building, imposes restrictions to the retrofitting process. However, the cellar ceiling, the roof and part of the building facade have been insulated, new windows have been installed and three apartments have been fitted with a mechanical ventilation system with heat recovery. Heating is provided by heat pumps. In the retrofitting process, materials and components have been selected according to housing comfort and environmental criteria. The heating energy requirement has been reduced by 50%.

The builders were only permitted to make minor adaptations to the roof and changes to the facade were out of the question, because the Art Nouveau style of the building facade, dating from 1913, should be preserved, according to the Zurich Historic Buildings and Monuments Department. The main aims for the architects were to increase the comfort level with a better energy efficiency, maintain the property value, and create a marketable cost/benefit ratio which includes environmentally orientated planning and maintenance.

The building has an extension on one side and covers a total of six storeys. The measures taken to improve the energy characteristics of the building, are described as follows.

▼ *Photograph:*
View of a storage room with a ventilation unit. The external wall opening and the external air duct can be clearly seen.

Insulation measures

As a first step, the roof, cellar ceiling and external walls on the third floor were insulated using cellulose fibres, so that heat transmission values considerably improved. Approximately 34% of the outer layer was not insulated. In fact, additional insulation of this 220 m^2 clay brick wall would only result in a reduction in the heating energy requirement (SIA 380/1) of 40 MJ/m^2 per annum. In practice, the heating energy requirement was reduced by 42 MJ/m^2 per annum by installing a mechanical ventilation system with heat recycling. This was considerably less expensive than reinsulation.

Mechanical ventilation

Mechanical ventilation has been installed in the lower three apartments. The decentralised ventilation units have been placed in small storage rooms which are positioned directly underneath each other. These rooms are ideal, enabling short circuits to be used since they are adjacent to the kitchens, bathrooms and the external wall facing the road.

Each of the compact units is fitted with two cross-flow heat exchangers connected in series, two fans (90 W each) and four connection brackets (125 mm wide). According to the manufacturer the heat recovery rate is 70%. Outside air passes through the external wall to the ventilation unit, through the heat exchanger, and from there - as supply air - through conduits and mufflers into the four rooms. Supply and exhaust air conduits have been installed in the suspended ceiling along the corridor. The exhaust air is extracted from the kitchen, bathroom and separate toilet, and led via heat exchangers across the roof, with a separate system for each apartment. The volume of exhaust air and consequently the rate of air change can be selected manually. In the event of frost the unit is automatically switched off, a disadvantage at low outside temperatures because of the considerable heat recovery potential.

Heating

For heating, two brine-to-water heat pumps are installed in the cellar. On the heat source side they are connected to two vertical borehole heat exchangers, each 150 m deep. At 5°C source and 50°C supply temperature the heat output per unit is 9.9 kW and the coefficient of performance (COP) is 3.8, according to measurements from the Heat Pump Test and Training Centre in Winterthur Töss. Under typical conditions on Mutschellen- strasse, the brine temperature is around 3°C and the supply temperature around 48°C. Output and COP therefore only differ slightly from the aforementioned test values during operation. The seasonal performance factor (SPF) is estimated at

3.2. Supply temperatures up to 55°C instead of 35°C cause a decrease in the SPF of 10-20%. Unfortunately, the higher supply temperatures are necessary because the old heaters, with insufficient capacity, have not been replaced.

Of the 9.9 kW heating output, 2.6 kW comes from the compressor and 7.3 kW originates from the ground heat exchanger, with its specific heat extraction of around 5 kW per 100 m tube length. The brine circulates in the four parallel polyethylene pipes - two each for supply and return - with a diameter of 30 mm. The flow rate is 1.5 m^3/h per tube and the circulation pump (for both tubes) has an electrical power consumption of 60 W, requiring 150 kWh electricity for 2,500 operating hours per year. (Around 500 hours are required for heating water outside the normal heating period.) The hot water container has a capacity of 1,000 litres and is equipped with additional electrical resistance heating to periodically increase the temperature to 60°C, to avoid the development of legionella bacteria.

Table 1: Data for calculation of heat energy requirement

	Prior to retrofitting	After retrofitting
Heat requirement for transmission	473	216 MJ/m^2 per annum
Heat requirement for ventilation	119	76 MJ/m^2 per annum
Heat gain	114	108 MJ/m^2 per annum
Heat energy demand (SIA 380/1)	478	184 MJ/m^2 per annum
Energy requirement for hot water	108	100 MJ/m^2 per annum
Energy requirement for space heating	**586**	**284 MJ/ m^2 per annum**
Energy reference area (ERA)	508 m^2	636 m^2
Efficiency / Seas. Performance Factor	0.85	3.2
Electricity demand		
• Heat pump	–	89 MJ/m^2 per annum
• Mechanical air circulation	–	6 MJ/m^2 per annum
• Photovoltaic system (gain)	–	8 MJ/m^2 per annum
Spec. energy demand for heating	690	87 MJ/m^2 per annum
Spec. energy demand according to definition of Minergie standard (use of electricity doubled)	–	174 MJ/m^2 per annum
Oil consumption (measured)	8,200 kg	–

Note: With the exception of the oil consumption all figures are calculated values. The ventilation heating losses amount to 118 MJ/m^2 per annum excluding*, 76 MJ/m^2 per annum* including *heat recovery. Assumptions: room temperature 20°C; temperature to start heating 12°C; change of external air: 0.4/h; energy requirement for hot water 100 MJ/m^2 per annum, prior to the retrofitting 108 MJ/m^2 per annum due to being densely occupied; occupancy per person 30 m^2.*

Swiss standards

The SIA (Swiss Engineers and Architects Association) guidelines indicate that a 37% reduction in the specific energy demand for heating can be achieved for buildings that were constructed between 1901 and 1940 (from 920 to 580 MJ/m^2 per annum). Before retrofitting, the apartment block had an energy characteristic of 690 MJ/m^2 per annum. The insulation and heat recovery using the ventilation system, have reduced the heat requirement for both transmission and ventilation, as shown in **Table 1**. Calculating an energy characteristic for the retrofitted building, assuming that heating is via fossil fuel (for comparison reasons), would result in a value of 334 MJ/m^2 per annum, which is 48% below the “old” energy characteristic.

Using heat pumps results in an even higher energy efficiency within the building. Consequently, the building now also meets the recommendations of Minergie, a joint standard mandated by the cantons of Bern and Zurich for energy-saving methods of construction and operation. Assuming a 50% efficiency for electricity production the electricity demand must be doubled in the calculations to account for the total amount of primary energy used. The recommended maximum energy consumption for heating for retrofitting is 320 MJ/m^2 per annum. It is clear that without the use of heat pumps, this standard would not have been met.

Ecological aspects

Throughout the project, which was supported by the *Pilot and Demonstration Programme* Energy 2000 of the Swiss Federal Office of Energy and the *Energy Saving Foundation* of the Zurich Electric Power Utility, ecological aspects were considered very important. Not only because a reduction in energy consumption was achieved, but because environmental aspects were taken into account throughout the entire process. This meant that manufacturers, suppliers and tradesmen had to specify all materials and components used. For example mineral-based paints and PVC-free electrical wiring were used, rainwater was and was applied for the toilet flush systems and the washing machine. Furthermore, many materials were refitted, such as the old clay roofing tiles (cleaned and then returned to the roof) and doorframes, heaters, blinds and shutters which were sanded down or treated with soda-based paint remover before being repainted.

Conclusions

The project can be seen as a successful example of a retrofit project, achieving considerable energy savings by improving insulation, installing a mechanical ventilation system with heat recovery, and using heat pumps for heating. The fact that environmental aspects were taken into account throughout the entire retrofitting process has contributed to the success and makes it a true demonstration project.

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Combining Air-Source Heat Pumps and an Ice Chiller for District Heating and Cooling

Kensuke Tokunaga, Japan

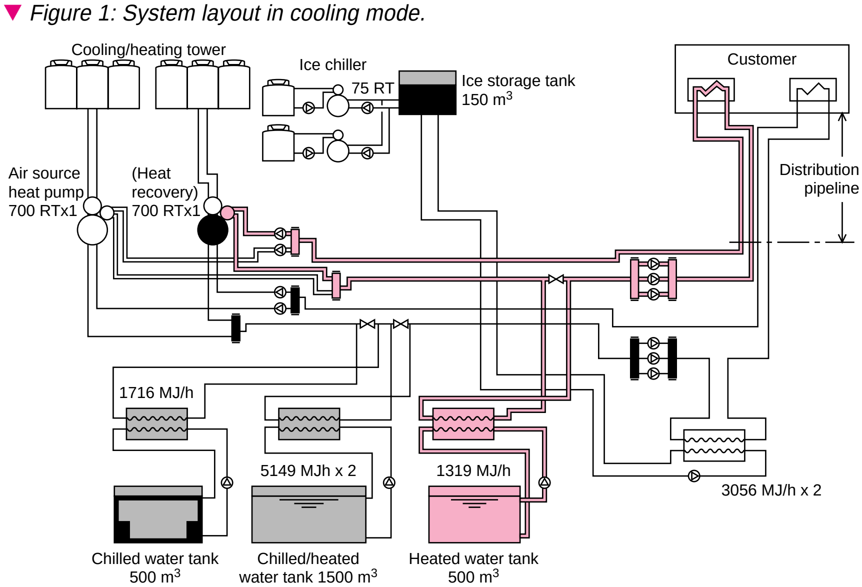
In Osaka, Japan, a combined hot/chilled water thermal storage air-source heat pump system and ice storage chiller system are being used for district heating and cooling (DHC). These two systems are linked to create a larger temperature difference between the supplied and returned chilled water. In order to reduce the system energy consumption, one air-source heat pump extracts ambient heat through a heating tower and the second heat pump operates in heat recovery mode while also producing chilled water. An ice thermal storage system contributes to load balancing by using night-time electricity. The system has been in operation since November 1992 and supplies cold and heat to two buildings. Another building will be added in the future.

System Outline

The hot/chilled water and ice storage systems are used simultaneously. The hot water storage is supplied by a dual compressor air-source heat pump with a common evaporator (cooling capacity: 2.5 MW). Another heat pump with the same capacity is used for heat recovery from the chilled water return line, especially during intermediate seasons and winter, when heating and cooling demands coexist. This heat pump is also connected to a cooling tower acting as an air-source heat pump.

A compact large capacity ice chiller storage system is also installed, consisting of a dynamic ice-making chiller with excellent flow features. The system links high-efficiency heat pumps with water and ice storage tanks, which increases the temperature difference between the supply and return chilled water for maximum efficiency. Furthermore, the system is cost effective because it uses inexpensive night-time electricity. The system configuration in cooling mode is shown in **Figure 1**.

▼ *Figure 1: System layout in cooling mode.*



Heat pumps

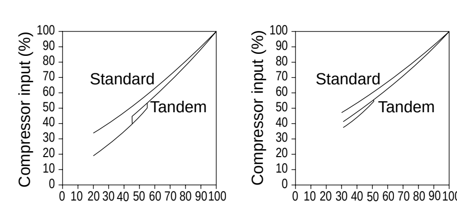
One of the two heat pumps is of the heat-recovery type. The other is a reversible heat pump that can provide cooling and heating. In cooling mode, the air-source heat pump rejects heat via the cooling tower.

In heating mode, heat is extracted from the ambient air in the heating tower via a brine loop. In the tower, the brine is heated from -11°C to -7°C. The heat-recovery heat pump uses the chilled water return line as the heat source, producing cold and hot water simultaneously. The brine-circuit of the heat-recovery unit also uses the ambient air as the heat source.

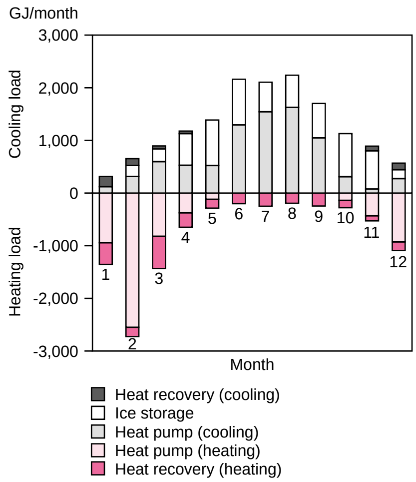
Both heat pumps are equipped with a tandem compressor, consisting of a main compressor and a booster. For high efficiency at partial load only one compressor is used. **Figure 2** shows the compressor characteristics at part load.

To optimise heat recovery and the use of night-time electricity, the heating load and the thermal storage volume required are predicted using the performance statistics of the past week. The heat pumps are programmed for priority operation from 22:00 to 08:00 hours, at night-time electricity tariff. The heat stored at night must be fully consumed by the end of the next day.

▼ *Figure 2: Part load characteristics.*



▼ *Figure 3: Monthly cooling and heating load in 1993.*



The space required to install the system is 60% less than for a conventional air-handling/heater system. The unit is designed to operate in bad weather conditions. Both the chilled and heated water generated by the two heat pumps is stored in water thermal storage tanks in the basement. One tank holds 1,500 m^3 chilled or heated water, another tank holds 500 m^3 chilled water and a third tank contains 500 m^3 warm water. They were installed to reduce the design capacity of the heat pumps and level out power consumption. The thermal storage tanks are equipped with vertical baffles for temperature stratification. This is efficient from an energy and space point of view.

Ice thermal storage system

The heat-recovery heat pump operates together with an advanced chiller acting as an ice-making unit. A low-concentration brine is used in the secondary circuit between the chiller and the ice tank. The solution is cooled by evaporating the refrigerant, at -8°C, creating a sub-cooled solution. When scooped with a blade, ice particles of 50-100 microns are formed, and stored in the tank as an ice/brine slurry.

The ice thermal storage tank consists of fibreglass reinforced plastic panels. Its construction is simple and highly reliable. A feature of the system is that it releases the stored cold easily. The ice volume stored in the tank is controlled by an ice packing factor (IPF) sensor, which measures the brine concentration. The concentration increases as the amount of ice grows.

Operation Results

Figure 3 shows the monthly cold and heat production in 1993. On average 12.6% of the total thermal load and 31% of the heat demand are met by recovered heat. Particularly during intermediate seasons and summer, most of the heat demand is met by recovered heat. **Figure 4** shows the electricity consumption of the system. This illustrates that 47% of the consumed electricity is shifted to night-time during an average year, which proves that the electricity use is well levelled out. Because the night-time electricity tariff is only one third of the daytime tariff, the running costs are relatively low. This results in a lower unit price for the heat produced. Averaged over 1993, the cost of a unit of heat/cold, i.e. the total electricity cost of the system divided by the generated heat and cold energy, was USD 0.07 per kWh.

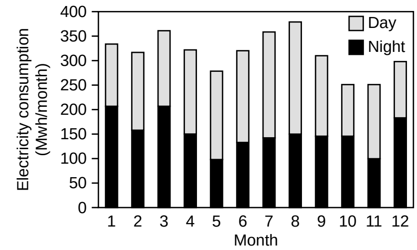
Environmental impact

This energy system uses electricity to drive the heat pump and the chiller. It is therefore a clean system without local emissions of CO_2, NO_X, and SO_X. When the environmental impact of the total system, including power generation, is compared with that of an absorption-type chiller and a boiler, this system reduces emissions significantly. CO_2 emissions are 72% less and NO_X emissions 86% lower than the joint emissions of an absorption chiller and boiler. This is shown in **Figures 5 and 6**, respectively. The application demonstrates that the heat pump heat-recovery system contributes to the reduction of global and local environmental pollution.

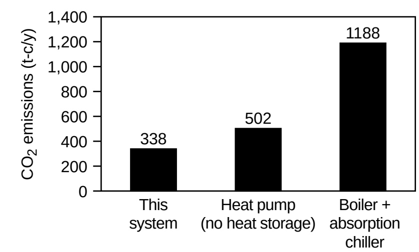
Conclusion

The energy system described efficiently combines air-source and heat-recovery heat pumps, water thermal storage tanks, an advanced ice-making chiller and an ice thermal storage tank. Operational experiences prove that the expected features of the system have been realised: the running costs were reduced by recovering heat from space cooling and by using inexpensive night-time electricity, in combination with water and ice thermal storage. Both the energy consumption of this all-electric system and the environmental impact are reduced considerably.

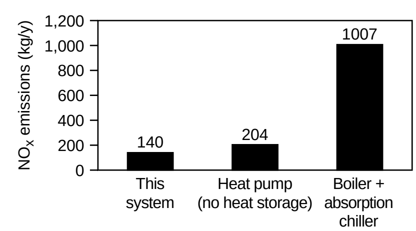
▼ *Figure 4: Electricity consumption; day and night.*



▼ *Figure 5: CO_2 emissions comparison.*



▼ *Figure 6: NO_x emissions comparison.*



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Air heating systems for low-energy buildings

Hermann Halozan and René Rieberer, Austria

Central Europe is, especially in the residential sector, a region using mainly hydronic systems with static heat transfer surfaces, which operate noiselessly and with slow air movements. Cooling is – as yet – not required. This implies that air-heating systems are not very common in Austria. However, new improved building standards may change this situation, because the specific heat load is significantly reduced. In the building sector, both energy savings and a reduction in CO_2 emissions can be achieved relatively quickly.

Current situation

Since the two oil crises, significant improvements have been achieved in the thermal insulation standard for buildings in Austria: Heat transmission values have been reduced to 0.35 W/m^2K for walls, 1.4 W/m^2K for windows, 0.25 W/m^2K for ceilings, and 0.5 W/m^2K for the basement floor. For single-family houses with heated areas of 130-180 m^2, this results in a specific heat load of approximately 60 W/m^2. With a ground-coupled heat pump – in Austria usually a direct-evaporation unit – in combination with a low-temperature floor heating system using supply temperatures below 35°C, a seasonal performance factor (SPF) of 4 or even higher can be achieved.

However, these energy-efficient buildings have one problem: air ventilation. In the past, buildings were supplied with fresh air via natural ventilation, through leaks in the building envelope. The windows usually constituted the main leaks, whereas in new buildings windows are sealed. This means that windows need to be opened periodically to exchange sufficient stale air for fresh air. As Pettenkoffer stated in 1858, people will not become ill from lack of ventilation, but they will become less resistant to other types of disease.

In the Nordic countries this problem is solved by regulations which require a controlled ventilation system with heat recovery in new buildings. These regulations are based on health care and energy conservation. In Austria such regulations do not yet exist.

urther improvements in specific heat load can be made by reducing the transmission losses through the building envelope. This results in a specific heat load of approximately 40 W/m^2, consisting of 23-28 W/m^2 ventilation losses (assuming an air exchange rate of 0.8-1.0/h, as required for hygiene reasons) and only 12-17 W/m^2 transmission losses.

Heat recovery methods

A further reduction of this load can be achieved by introducing a controlled ventilation system with heat recovery. There are generally two methods of exhaust air heat recovery:

- heat exchangers which reduce the ventilation losses by 50-90%, depending on the heat exchanger type used;
- heat pumps.

The optimum is a combination of a heat exchanger and a heat pump (see **Figure 1**). The warm exhaust air is first cooled down in the heat exchanger and then used as the heat source for the heat pump. The fresh air is preheated in the heat exchanger and then heated by the heat sink side of the heat pump.

For this concept, the air supply temperatures required to meet the overall heat load can be calculated. **Figure 2** shows these temperatures depending on the specific transmission losses and the air exchange rate. Assuming 10 W/m^2 specific transmission losses and an air exchange rate of 0.8/h, the air supply temperature required to meet the total heating demand, at design conditions of -12°C, is around 32°C. When assuming 20 W/m^2, the required temperature is 50°C.

Figure 1: Exhaust air heat-recovery system with an optional ground collector.

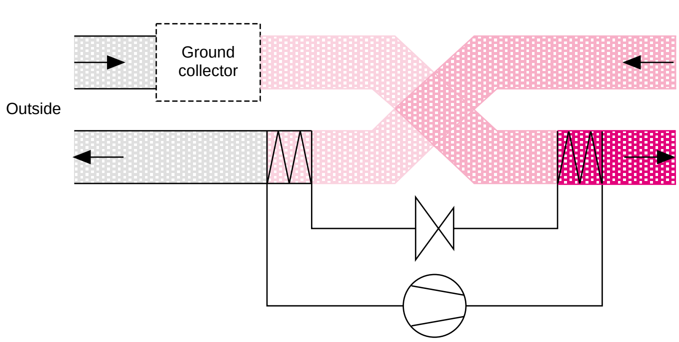
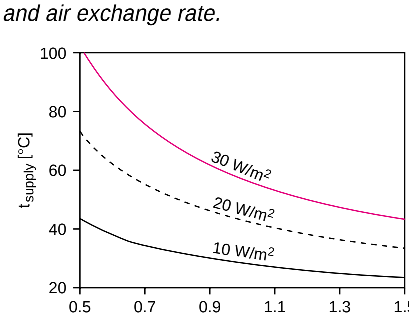


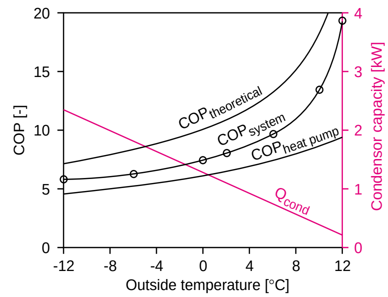
Figure 2: Air supply temperature depending on specific transmission losses and air exchange rate.



This type of operation offers ideal conditions for a variable-speed heat pump with CO_2 as refrigerant. CO_2 is a safe refrigerant, and both direct condensation and direct evaporation can be applied. Furthermore, the temperature glide at the condenser side can be used to heat air to the required temperature level without high energy losses.

Simulations have been carried out based on specific transmission losses of 10 W/m^2 and an air exchange rate of 0.8/h. **Figure 3** shows the coefficient of performance (COP) of the heat pump unit alone, the theoretical and practical COP of the system (including the heat pump and air heat exchanger) and the condenser capacity depending on the ambient temperature. The system COP is over 5 at -12°C and around 19 at an ambient temperature of 12°C. With this type of system, seasonal performance factors (SPFs) close to 7 can be expected.

▼ *Figure 3: Efficiency and condenser capacity of the heat pump air-heating system.*



Ground collectors

Using a ground collector would be another improvement. This type of air preheater primarily has to dampen the fluctuations of the ambient air temperature and preheat the fresh air at low outside temperature, thus reducing the heat load. For a single-family house, approximately 60 m of pipe (diameter 0.2-0.3 m) needs to be buried in the ground at a depth of approximately 1.5 m around the building. The exhaust air is cooled down first in the heat recovery heat exchanger, then in the evaporator of the heat pump. The fresh air is preheated first in the ground collector, then in the heat exchanger and finally at the heat sink side of the heat pump (as shown in Figure 1).

▼ *Figure 4: Efficiency and condenser capacity of the heat pump air-heating system with a ground collector.*

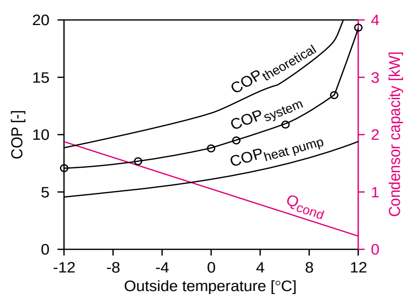


Figure 4 again shows the COP of the heat pump unit alone, as well as the COP of the system and condenser capacity depending on the outside temperature, this time for the improved system. The system COP is above 7 (at -12°C) and around 19 at an ambient temperature of 12°C. With this improved system, SPFs close to 8 can be expected and additionally the capacity of the heat pump can be reduced.

Both systems (with or without preheating in ground collectors) are suitable to meet the overall heating demand of a building by using the air flow produced by the controlled ventilation system only, without circulation air and without an auxiliary heating system. This also means a significant reduction in investment costs by omitting the conventional floor heating system. The cost savings can be used to install such a controlled ventilation system suitable for heating the building. Additionally, the internal air quality in the building will improve significantly compared to systems with natural ventilation.

Other important features of the new system are that it can be used for hot water production throughout the year, as well as for cooling, or at least dehumidification, during the summer. If this is implemented together with the hot water production, there will be no additional energy requirement.

Summary

Air-heating systems based on the controlled ventilation system with heat recovery via a heat exchanger and a heat pump seem to be the future solution for low-energy buildings. The high thermal insulation standard and controlled ventilation system provide excellent air quality, as well as high comfort levels for the consumer and a low energy bill.

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Heat pumps take off in China

Jos Bouma, IEA Heat Pump Centre

A 15-20% annual growth rate in the space conditioning and refrigeration market (for homes, office buildings, hotels, supermarkets, railroad cars and lorries); a predicted power shortage of 15-23 GW by the end of this century; the approaching implementation date of the Montreal Protocol, these are some of the striking challenges facing China's heat pumping industry over the next few years.

Chinese market

The main factors influencing the Chinese market for heat pumps and air conditioners include the rapidly expanding economy (average growth 10%), the large population (1.2 billion Chinese), and the transition to a market economy. Air conditioners are becoming increasingly popular in urban areas, particularly in the south east. Recent predictions expect over 20 million air conditioners to be installed by the year 2005. Approximately 8 million units have currently been installed in China, of which around 30% are heating-only or reversible. In 1995, China manufactured 6 million room-type air conditioners, of which 70% were split units. According to Chinese sources, over 12 million room-type units are now being produced annually. Unitary air conditioners are produced in much smaller quantities, only several thousand units a year. Imported design know-how and production and testing technology were used to develop these products.

In 1995, the production of water chillers for central air conditioning totalled 12,000 systems. Approximately 2,200 of these were large absorption chillers with water-lithiumbromide as the working pair. Today, more than 3,000 are produced annually, most of them are of the directly-fired type. The maximum capacity of a unit is 4.5 MW cooling. Absorption refrigeration is especially used in the textile and pharmaceutical industries, where they provide a solution for electricity shortages. The compression-type chillers are mainly equipped with imported compressors (centrifugal, screw and piston-types).

The main technological challenges facing the Chinese air-conditioning industry include noise, thermal comfort, energy efficiency and indoor air quality.

To keep electric power demand under control in summer, the operation of air conditioners is already restricted in some cities. Energy saving and peak power shifting are the main concerns of the sector. For example, by the year 2000, 10-12 GW of peak power should be shifted to night time. This explains the growing interest in thermally-driven heat pumps and thermal storage technology, especially for air conditioning and refrigeration.

Several types of heat pump are used in industry, including thermal vapour recompression, compression (open and closed-type) heat pumps and absorption heat pumps. They are mainly applied in refineries, the chemical industry and for timber drying.

Power industry

The State Power Corporation was established in January 1997, giving 94% of the country's rural households access to the power grid. During the period 1979-1996, the annual growth rate of electricity output was 8.3%. Annual capacity increased by more than 15 GW in the period 1991-1995.

China has an abundance of energy sources with rich coal resources and the world's top hydropower resources. The power generation industry consumes most of China's coal. The country has now an installed generation capacity of 230 GW, 75% of which is coal-fired power, 24% is hydropower and 1% (3 plants) is nuclear power. In the near future, 30% should come from hydropower. The share of nuclear power should be doubled by 2005. China's power industry will continue to grow over the next 15 years to keep up with the expanding national economy, social developments and needs of the population.

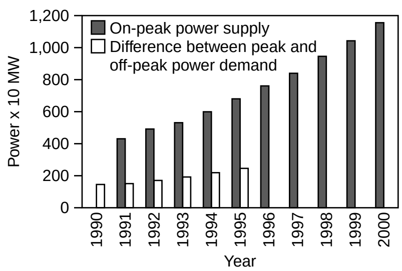
Combined heat and power (CHP) stations are applied in industry and for district heating. In 1990, the total generating capacity was about 10 GW. CHP systems are increasingly used in summer to provide absorption cooling for hospitals, business districts and commercial buildings.

New construction

The growth rate of new construction in the building sector is tremendous. In cities, more than 200 million m^2 of residential buildings and 150 million m^2 of commercial and industrial buildings are being realised annually. In non-urban areas 800 million m^2 of new building space is also realised annually. Many of these buildings are located in climatic zones that are favourable for heat pumps.

In Shanghai, the scale of new construction is unprecedented. In the city centre alone, more than 1,480 high-rise buildings were realised by the end of 1995. All these buildings are air-conditioned, using different types of systems, including water-loop heat pumps (2%). Thirty percent of the buildings have monovalent air-source heat pumps, mainly for environmental reasons (air pollution). In apartment buildings, room-type units are frequently installed.

▼ *Figure 1: Peak power supply, and the maximum difference between peak and off-peak power demand in Shanghai in summer.*



To relieve the summer power peak problem in Shanghai (see **Figure 1**), with an average annual increase rate in the demand of 19% in the early 90s, gas will increasingly be used for air conditioning, as well as thermal storage technology. A typical summer phenomenon occurring in central Shanghai is the so-called heat island effect. Due to the densely populated and built up area, the air temperature here is approximately 1-2°C higher than outside the city.

Equipment regulations

The Chinese government is planning to implement specific energy use regulations for chillers, household refrigerators and (perhaps) air conditioners. Chinese manufacturers are already using ARI standards for manufacturing unitary air conditioners and heat pumps, commercial and industrial unitary equipment and absorption chillers. Electrical safety of unitary air conditioners, heat pumps and chillers are now also included in the Chinese inspection programme.

Working fluids

The transition from CFCs is a slow process in China, which plans to eliminate production of CFCs before the year 2010. The switch to HCFCs and HFCs has not yet occurred in the air conditioning sector, although some Chinese manufacturers use R-22 in their products, while R-134a and refrigerant mixtures will replace R-22 in the future. A shift to HCs is not yet apparent. However, China has a long tradition of using ammonia for refrigeration.

Applications

Water loop heat pump systems, imported mostly from the US, are used in commercial buildings. Also a few domestic designs are applied. An 11 MW heating capacity water-to-water heat pump will soon be installed, which uses the Yellow Sea as a heat source and sink. A solar-assisted water-to-water heat pump is used for a swimming pool, with a COP of 5. Waste heat recovery applications include a heat pump water heater that uses waste heat from a power transformer substation. In Chinese industry heat pumps are applied for dehumidification and drying of wood, pottery, paper, printing and food products (tea, fruit). Approximately 400 wood dryer heat pumps are installed. Another application area is for evaporation and distillation. Both open and closed cycle heat pumps are applied. One installation in a petroleum refinery is driven by a steam turbine.

R&D

Heat pumps are considered a key energy technology in China for the near future. R&D in heat pumping technology is therefore quite extensive and covers many areas:

- thermodynamic properties of CFC replacements (R-134a, R-32, R-133a, R-143a, R-152a, mixtures, etc.);
- heat transfer characteristics of CFC replacements;
- compression cycle characteristics and applications;
- heat and mass transfer in absorption technology;
- simulation, design and analysis of absorption heat pumps;
- small and large triple-effect directly-fired absorption heat pumps;
- advanced ejector-absorption refrigeration system;
- heat transformer (40 kW pilot plant);
- new absorption working pairs (R-22/DEF, R-21/DEF, R-22/DMF);
- zeolite adsorption heat pump (13X-water);
- active carbon/methanol adsorption refrigeration;
- silica-gel bed adsorption technology;
- thermodynamic analysis of adsorption refrigeration;
- chemical heat pump ($CaCl_2/CH_3OH$; metal hydride);
- heat storage system (inorganic salt hydrates);
- ejector refrigeration systems.

International collaboration

The market for heat pumps in residential and commercial buildings is developing rapidly. China is very eager to use energy-efficient heating and cooling technologies with a minimal impact on the environment. International collaboration is considered an important vehicle for this. The IEA Heat Pump Programme has recently started a dialogue with representatives from China to develop practical ways to collaborate on heat pumping technologies.

Jos Bouma
IEA Heat Pump Centre

Opportunities for heat pumps in greenhouses

Marcel Klootwijk, the Netherlands

The greenhouse sector is a very large heating market, especially in the Netherlands. Since the energy crisis in the early 1980s much attention has been given to energy conservation in this sector. This was mainly achieved by using energy screens to avoid energy losses and combined heat and power. Since heat pumps have an even larger potential for energy conservation in greenhouses, several heat pump projects were developed during the 1980s. These mainly used gas engine compression heat pumps. Except for some problems with maintenance these heat pumps functioned very well. However, since the energy tariffs did not increase as much as expected (they actually decreased), the economic performance was poor. Nowadays, technology has changed. Cheaper and more reliable heat pumps are available and the possibilities for using ground water from aquifers as a long-term energy storage system have been further developed. With this in mind, the Netherlands Agency for Energy and Environment (Novem) has initiated a study on the 'Opportunities for heat pumps in greenhouses'. The results are described in this article.

Study approach

The study included an inventory of previous experiences of suppliers of heat pump systems and a model of the energy demand for three types of crop. For each of the three crops, calculations were made for several types of heat pump. Based on the results of these calculations the systems were evaluated. The sensitivity of the results with regard to reduced investments, changing tariffs and improvement of efficiencies was also calculated. Finally, the results of the study were checked and discussed with greenhouse owners, suppliers, policy makers and energy companies to create momentum for introducing heat pumps in greenhouses.

The study included greenhouses for producing tomatoes, roses and freesias. These crops were chosen because they represent large areas and the most common technologies and because they are energy-intensive crops with high energy costs (see **Table 1**).

Configurations studied

Heat pumps in greenhouses can be used for heating (all crops), heating in combination with ground cooling (freesia's) and heating in combination with dehumidification and greenhouse air cooling (particularly roses and tomatoes). When the heat pumps are gas driven, they can also supply CO_2 (roses and tomatoes) for improved growth rates. The types of configuration considered in the study are shown in **Table 2**. The reference system is a gas-fired boiler. For tomatoes and roses, 59.3 m^3 gas per m^2 per year and 54.3 m^3 gas per m^2 per year are used respectively. For freesia production, 24.7 m^3 gas per m^2 per year and 12.8 kWh electricity per m^2 per year is used in the reference case.

In greenhouses, cooling and heating are not only used to establish the correct space and ground temperature, but also to provide air circulation. This increases the amount of moisture evaporation from the crop, which in turn leads to a larger amount of water being consumed by the crops. This results in faster crop growth because more minerals are consumed along with the water. To achieve this effect, cooling and heating are applied simultaneously.

The investments, operating costs and savings were calculated in order to assess the feasibility of the heat pump systems. For the electric heat pumps, a special low electricity tariff of USD 0.04 /kWh instead of USD 0.08/kWh was assumed. **Table 3** shows the primary energy savings, investment costs and payback periods.

Calculation results

In the short term, the best opportunities for implementing heat pumps in the greenhouse sector exist for the gas-fired absorption heat pump. This system combines low investments with the production of CO_2 and possibly cooling. Without subsidies and with the current

Table 1: Basic energy and economy data for three different crops.

Economy				
Crop	Area [10,000 m²]	Income [USD/m²]	Profit [USD/m²]	Energy costs [USD/m²]
Tomato	1241	32	18	5
Rose	926	43	20	12
Freesia	282	20	12	2
Energy				
Crop	Gas consumption [m³/m²/yr]	Assimilation lighting [kWh/m²/yr]	Ground cooling [kWh/m²/harvest]	CO_2 supply
Tomato	44.5	—	—	yes
Rose	43.8	0.0121	—	yes
Freesia	15.3	—	11	—

Table 2: Heat pump system configurations used in the study

Configuration	Technology			Applications			
	Drive Energy	Heat source	Heat sink	Heating	Cooling	CO_2 supply	Dehumidification
Electric compression heat pump	Electricity	Ground water (aquifer) or surface water	Water (Polyethene tubes)	yes	only for freesias	no	no
Gas engine compression heat pump	Gas	Ground water (aquifer) or surface water	Water (Polyethene tubes)	yes	only for freesias	yes	no
Gas-fired absorption heat pump	Gas	Ground water (aquifer) or surface water	Water (Polyethene tubes)	yes	only for freesias	yes	no
Electric heat pump with low-temp. waste heat	Electricity	Low-temperature waste heat	Water (Polyethene tubes)	yes	only for freesias	no	no

Table 3: Results of calculations for different system configurations.

	Primary energy savings [%]			Investment [USD/kW]			Payback period [years]		
	tomato	rose	freesia	tomato	rose	freesia	tomato	rose	freesia
Electric compression heat pump*	26	36	54	329	329	354	26	19	17
Gas engine compression heat pump	34	50	64	623	623	575	21	13	12
Gas-fired absorption heat pump	27	40	38	277	277	303	8	6	9
Electric compression heat pump with low temperature waste heat	27	40	60	338	338	363	17	13	15

* Special low electricity tariff USD 0.04/kWh instead of USD 0.08/kWh.

tariffs and investment costs, the payback period ranges from 6 to 9 years. However, the energy savings with this type of heat pump are lower than for the other types.

In the long run, chances are probably also good for the gas engine-driven heat pump, since it combines high energy savings with the production of CO_2. At the moment however, this technology has to prove its reliability in greenhouse applications and its investment costs must be reduced, for example by developing ‘packaged’ systems.

Electric heat pumps appear less suitable for greenhouses in the Netherlands. However, in areas where no natural gas is available, electric heat pumps may be feasible.

Sensitivity analysis

The study assessed the effects of lower investments, a higher efficiency, changed tariffs for electricity and gas and tax reduction or subsidies. When investment in the heat source is smaller, the payback period for all types of heat pumps will be reduced. Considering current developments the cost of the source can be reduced from NLG 500 per kW to NLG 200 per kW. The payback period for the gas-fired absorption heat pump then ranges from 4 to 7 years. Development of a ‘packaged’ system for gas engine heat pumps will have a similar effect on the payback period for this technology, since a packaged system can reduce the cost of the heat pump with 50%. These measures would result in a payback period for gas-engine heat pumps of 7 to 10 years.

The effect of improving the efficiency of the most favourable heat pump, i.e. the gas-fired absorption heat pump for rose production, is a reduction of the payback period with only 1 year, to 5 years. This is a relatively small effect.

Tariffs have a significant influence on the payback period. When the gas tariff increases from USD 0.12/m^3 to 0.15/m^3, the payback period for the gas absorption heat pump is reduced to 4-8 years. Tax reductions and subsidies can also have a strong influence on the payback period. With an investment support of 25%, the payback period for the gas-fired absorption heat pump is reduced to 4-7 years.

Conclusions

In the Netherlands good opportunities exist for heat pumps in greenhouses, with high energy savings and rather good economy. In the short term, chances are best for gas-fired absorption heat pumps. With readily available ground water (aquifers) for use as a heat source and sink, payback periods of 4 years (tax reductions or subsidies included) can be achieved. With gas engine compression heat pumps, savings can increase to over 50% in the long run. The electric compression heat pump will only be economic in situations where electricity is relatively inexpensive or where natural gas is not available for heating and CO_2 production.

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Highly efficient CO_2 Heat Pump Water Heater

Petter Nekså and Jørn Stene

The phasing out of the ozone-depleting CFCs and HCFCs, as well as uncertainty regarding the environmental impact of new synthetic working fluids, have created a renewed interest in the use of environmentally safe working fluids. Carbon dioxide (CO_2) is an interesting alternative since it is inexpensive, not flammable or toxic, and has favourable thermodynamic properties. A 50 kW prototype heat pump water heater using CO_2 as the working fluid has been extensively tested at SINTEF Energy in Norway. The heat pump has proven to have a superior energy efficiency, and is able to provide hot water temperatures in the range of 55°C to 95°C.

The search for environmentally acceptable working fluids has been a major task in the heat pump, air conditioning and refrigeration industry since the late 1980s. CO_2 (R-744) is regarded as a promising alternative for a number of applications. Its ozone depletion potential (ODP) and global warming potential (GWP) are both zero. Due to the unique thermodynamic properties of the fluid a high energy efficiency can be achieved in a number of applications, given proper system design and operation.

Characteristics of CO_2

CO_2 is a high-pressure fluid with low critical temperature (31.1°C, 73.8 bar). In a heat pump process heat rejection occurs at a constant supercritical pressure with a certain temperature glide. The process is particularly favourable for heating domestic hot water, which involves a large temperature glide, since good temperature adaptation results in small energy losses. Other promising application areas are water heating in industrial processes, as well as in district heating systems and hydronic systems with variable flow and large temperature differences. **Figure 1** shows the principle of a process for hot water heating in a CO_2 temperature entropy chart.

While conventional heat pumps have a maximum operating pressure of 25 bar, the operational pressures for a CO_2 heat pump water heater will be approximately 35 bar on the low temperature side and 90-100 bar at heat rejection. The high operating pressures result in small volume flow rates, so the dimensions of compressors, valves and piping can be considerably smaller than in systems with conventional working fluids. Compression also occurs at low pressure ratios, and the thermodynamic properties generally tend to give small compression losses and good heat transfer characteristics. More information on CO_2 as a working fluid can be found in the HPC Newsletter 2/1996 article, "Vapour compression systems based on CO_2 - a truly safe alternative".

The prototype

SINTEF Energy, Refrigeration and Air Conditioning in Norway has designed and built a heat pump water heater with CO_2 as the working fluid. **Figure 2** shows the prototype system, which has a heating capacity of 50 kW. Water is heated in counterflow with CO_2 in the gas cooler of the CO_2-unit. The hot water is stored in three large accumulators or distributed directly to the end-users.

An electrically-heated water/glycol brine serves as the heat source in the prototype. In a commercial unit, air

▼ *Figure 1: Process for hot water heating in a CO_2 Ts-chart temperature - entropy chart.*

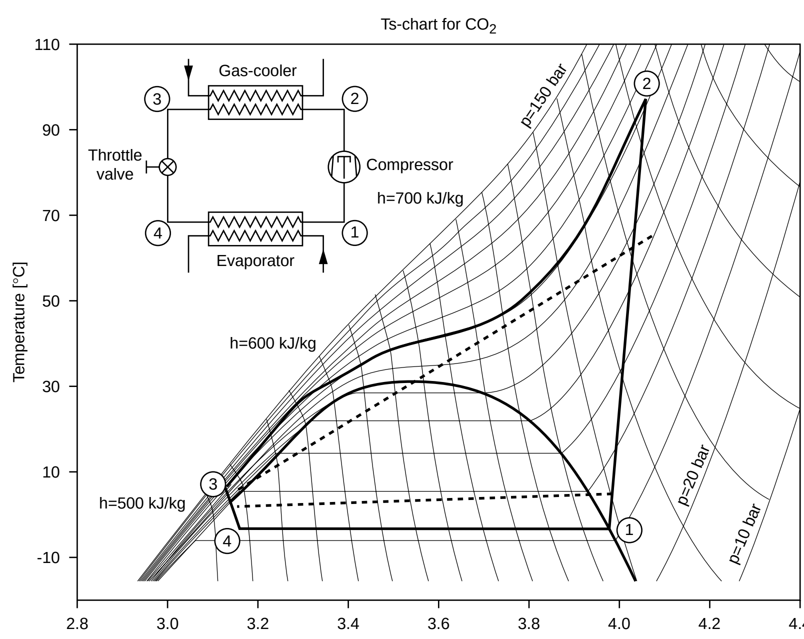
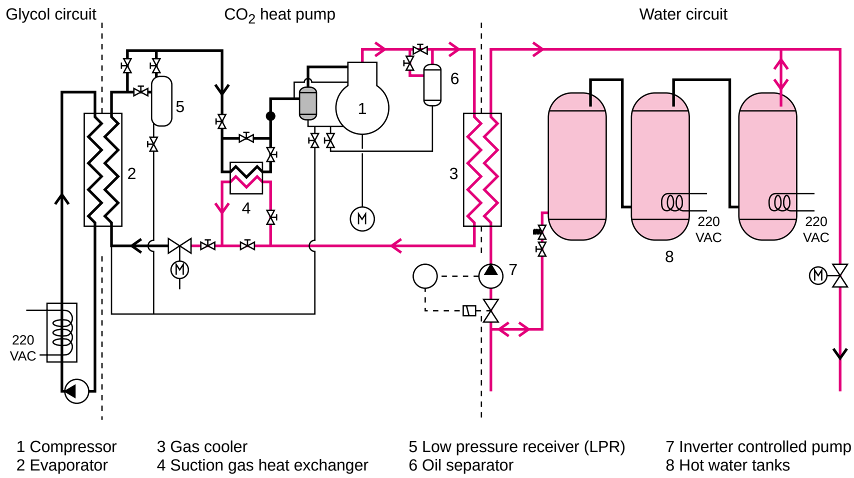


Figure 2: Prototype CO_2 heat pump water heater.



coolers (multiport microtubes type) or shell-and-plate heat exchangers will be used as evaporators, depending on the heat source and the system design. A low pressure receiver after the evaporator is used to accumulate liquid in the system at varying boundary conditions.

In order to obtain the best possible temperature match between the supercritical CO_2 and the water to be heated, the gas cooler is designed as a double-tube heat exchanger. The evaporator is a plate-and-shell heat exchanger with evaporating CO_2 on the shell side. All heat exchangers and tubing are made of stainless steel.

A prototype of an open single-stage reciprocating compressor has been developed during this project. Even before it is fully optimised, an isentropic efficiency of approximately 0.85 has been achieved at nominal operating conditions. This is within the efficiency range of large industrial piston compressors for conventional working fluids. The high compressor efficiency will contribute considerably to a high system energy efficiency. The rotational speed is controlled by a frequency converter and varies between 600 and 1,200 rpm. Maximum static pressures on the pressure and suction side of the compressor are 150 bar and 75 bar, respectively. The corresponding operational pressures are 130 bar and 45 bar. More information on the heat pump control and monitoring system can be found in the HPC Newsletter 2/1997 article, “Heading for improved reliability and performance”.

High COP

The prototype has been extensively tested, and **Figure 3** shows the coefficient of performance (COP) as a function of:

a) the evaporation temperature when heating water from 9°C to 60°C;
b) the hot water temperature, assuming an evaporation temperature of 0°C.

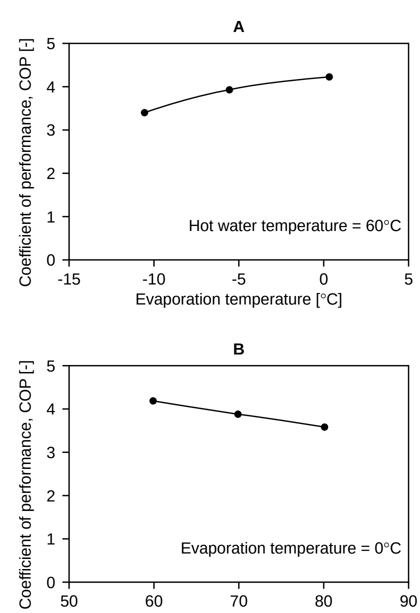
The heat pump is not yet fully optimised, but the components are similar to ones that would be used in a commercial installation.

When ambient air is used as the heat source, a seasonal COP is achieved in the range of 3.5 to 4.5, depending on the hot water temperature required. Consequently, the primary energy demand for hot water heating is reduced by 75% compared to conventional heating systems based on fossil fuels and electric resistance heating. When ground water, rock, exhaust air and similar heat sources are used, the COP will increase by 10-30%.

Conventional heat pump water heaters are often limited to a maximum water temperature of 55°C. However, in hospitals, institutional buildings, restaurants, industry etc., temperatures exceeding 80°C are often required. A considerable advantage of the CO_2 heat pump system is that it is capable of producing hot water at these high temperatures without any operational problems and with a high COP (see **Figure 3b**).

A key question when developing new heat pump systems is the production costs and the related energy savings of the unit. Preliminary calculations have shown favourable profitability compared to conventional heating systems. High pressure components are needed, but due to the high volumetric capacity of CO_2, the components can be produced at prices comparable to conventional ones..

Figure 3:
a) COP for the heat pump at various evaporation temperatures. Hot water temperature = 60°C;
b) COP for the heat pump at various hot water temperatures. Evaporation temperature = 0°C.



Industrial cooperation

The CO_2 heat pump water heater has been designed, developed and tested by SINTEF Energy, Refrigeration and Air Conditioning. The industrial partners in the development work were the Norwegian companies Finsam International Inc. a.s, Frostmann a.s, OSO Hotwater a.s, and Sperre Thermo a.s.

Financial contributions and consultancy during the development of the CO_2 heat pump were provided by the industrial partners, the Research Council of Norway (NFR/NYTEK) and a research project funded by the European Commission (“Energy Efficient and Environmentally Friendly Heat Pumping Systems Using CO_2 as Working Fluid”), where SINTEF is one of five partners.

Promising applications

Promising application areas for the CO_2 heat pump water heater are multi-family houses, commercial and institutional buildings, as well as industrial applications where there is a need for heating and hot water. Exhaust ventilation air, sea water, ground water, rock and ambient air are potential heat sources. If the evaporator is connected to a cold distribution system (see Norwegian National Topic Appraisal, page 14), the heat pump can also provide simultaneous heating and cooling with high energy efficiency.

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Saving Energy with Residential Heat Pumps in Cold Climates
Available from: CADDET Energy Efficiency, PO Box 17, 6130 AA Sittard, The Netherlands. Fax: +31-46-4510389.
E-mail: caddet@caddet-ee.org. 20 Pages, published 1997.
ISBN 90-7 2647-37-8.
This maxi brochure (No. 8) discusses the use of heat pumps in residential buildings located in areas with cold climates. It first gives an overview of various heat pump types, followed by a discussion on how to economically 'size' the heat pump correctly. Finally, a number of demonstration projects in different countries are described.

Learning from experiences with Industrial Heat Pumps
Available from: CADDET Energy Efficiency, PO Box 17, 6130 AA Sittard, The Netherlands. Fax: +31-46-4510389.
E-mail: caddet@caddet-ee.org. 112 Pages, published 1997.
ISBN 90-7 2647-38-6. Analysis Series No. 23.
This analysis report is concerned with preliminary studies and practical aspects of using industrial heat pumps, particularly the presentation of current experience. It identifies and analyses all major IHP categories: closed compression cycle, mechanical and thermal vapour recompression and absorption cycles. Demonstration projects for all categories are presented. Annex 21 of the IEA Heat Pump Programme formed the basis of this analysis.

Refrigerant Selection Guide
Available from: The Australian Institute of Refrigeration Air Conditioning and Heating (AIRAH), James Harrison House, 52 Rosslyn Street, West Melbourne, 3003, Australia. Fax: +61-3-93284116.
20 Pages, August 1997.
This guide provides information to designers and contractors in the refrigeration and air-conditioning industry on current requirements of the Montreal Protocol for ozone depleting substances. It also contains an overview of the document entitled "Revised Strategy for Ozone Protection in Australia 1994". The information is intended to provide a better understanding of the available alternative refrigerants and potential system performance changes which may result in the use of replacement refrigerants with little or no effect on the ozone layer.

Production, sales and atmospheric release of fluorocarbons through 1995
Available from: Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), The West Tower, Suite 400, 1333 H Street NW, Washington, DC 20005, USA.
This annual report covers CFCs 11, 12, 113, 114 and 115, HCFCs 142b and 141b and HFC 134a. Sales are divided into categories such as refrigeration. Some degree of geographical breakdown is also provided, along with calculations of atmospheric releases per section.

INTERNET SITE

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http://www.heatpumpcentre.org

Fluorocarbons and global warming
Available from: International Institute of Refrigeration, 177 Boulevard Malesherbes, F-75017 Paris, France. Fax: +33-1-47631798.
E-mail: iifiir@ibm.net. Free of charge, 2 pages. Available in French and English.
This 12th informative note from the IIR on Fluorocarbons and Refrigeration summarises the current situation in the light of the third UNFCCC meeting to be held in Kyoto, Japan in December.

Heat Pumps in Cold Climates - Proceedings 1997
Available from: Caneta Research Inc., 7145 West Credit Ave., Suite 102, Building 2, Mississauga, Ontario L5N 6J7, Canada.
Price: USD 50, 480 pages. Published November 1997.
Fax: +1-905-5423160. E-mail: caneta@compuserve.com.
The proceedings from the August 1997 Conference held in Wolfville, Nova Scotia contain a total of 44 papers on both market and application topics, such as measuring success of heat pump initiatives, lessons-learned from utility heat pump programmes, the new electric industry environment, heat pump reliability, heat pumps in commercial buildings and trends in heat pump efficiency. Technical topics include design tools, alternative refrigerants to R-22, gas-fired heat pumps and heat pump performance assessment.

Thermophysical properties of Liquid Secondary Refrigerants
Available from: International Institute of Refrigeration, 177 Boulevard Malesherbes, F-75017 Paris, France. Fax: +33-1-47631798.
Price: FF 150.
E-mail: iifiir@ibm.net. In French and English language. Published in 1997.
This book contains tables and diagrams with thermophysical properties of liquid secondary refrigerants.

Clima 2000 CD-ROM
Available from: Clima 2000, Attn. Lara Egli, Rue Ravenstein 3, B-1000 Brussels, Belgium. Fax: +32-2-5117597.
E-mail: clima2000@net4all.be. Price: BEF 1,350 (~ USD 41).
This CD-ROM contains both the full papers and the reporters' synthesis of the discussions (if available). It also includes the opening speech, the conference synthesis and the announcement of Clima 2000 Naples 2001.

ARTI Refrigerant Database
Available from: ARI. Fax: +1-703-524-6351 or visit their Internet site (http://www.ari.org) to obtain an order form. Updated versions.
Available on 3.5" diskettes, for use on microcomputers running DOS, OS/2, Windows or similar platforms.
The database covers alternative refrigerants, associated lubricants, and their use in air conditioning and refrigeration. It addresses property, compatibility, safety, environmental issues, applications and other factors. Technical reports from ARTI's Materials Compatibility and Lubricant Research (MCLR) Programme and ARI's R-22 Alternative Refrigerants Evaluation Programme (AREP) are referenced in - and are available through - the database.

Available from the HPC

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

HPP Annual Report
Order No. HPP-1996

CO_2 Technologies in Heat pumps, refrigeration and air conditioning Systems
Workshop proceedings, January 1998
Order No. HPC-WR-19. NLG 120 or NLG 60 in HPC member countries

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

Building HVAC Equipment Regulations and Standards
Workshop Proceedings, June 1997
Order No. HPC-WR-18 NLG 120 or NLG 60 in HPC member countries

Industrial Heat Pump Screening Program
Software program, April 1997
Order No. HPP-AN21-3
NLG 100 or free on ordering HPP-AN21-1. NLG 50 in HPC member countries and in Ca, Fr, Se and UK

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Heat Pumps
17-18 April 1998 / Terme Zreče, Slovenic
Contact: Prof. Dr. Alojz Poredoš̃,
University of Cjubljana,
Fax: +386-61-218567.

Natural Working Fluids '98
IIR Gustav Lorentzen Conference
2-5 June 1998 / Oslo, Norway
Contact: Turid Slotnaes, NWF '98,
Fax:+47-22067350

Air-Conditioning & Refrigeration New Tech '98 (ART'98)
Environmentally Friendly Refrigeration '98 (EFR'98)
June 1998 / Beijing, China
Organised by the Chinese Association of Refrigeration.
Contact: Beijing Onis Expo Co.,
Mr Liang Liang. Fax: +86-10-62172249.
E-mail: onis@public3.bta.net.cn

1998 International Compressor Engineering Conference; and 1998 International Refrigeration Conference
14-17 July 1998 / West Lafayette, Indiana, USA. Contact: Cynthia Quillen, Purdue University. Fax: +1-765-4940787.
E-mail: herlconf@ecn.purdue.edu

Eurotherm seminar on thermodynamics, heat and mass transfer of refrigeration machines and heat pumps
6-7 July 1998 / Nancy, France
Contact: Prof. M FEIDT, LEMTA - University of Nancy. Fax: +33-3-83595551.
E-mail: mfeidt@ensem.u-nancy-fr

1999 International Sorption Heat Pump Conference
24-26 March 1999 / Munich, Germany
Contact: Dr. Martin Hellmann, ZAE Bayern, Walther-Meissnerstrasse 6, D-85748 Garching, Germany. Fax: 49-893294-4212,
E-mail: martin.hellmann@physik.tu-muenchen.de

20th International Congress of Refrigeration of the IIR
September 1999 / Sydney, Australia
Refrigeration into the 21st century.
Contact: Congress Secretariat, GPO Box 128, Sydney NSW 2001, Australia.
Fax: +61-2-2622323.
E-mail: tourhosts@tourhosts.com.au

IEA HEAT PUMP PROGRAMME EVENTS

Annex 24 Workshop Ab-Sorption Machines for Future Energy Systems
21-23 January 1997/ San Francisco, USA
Contact: Magnus Gustafsson, Royal Institute of Technology, Department of Chemical Engineering and Technology, S - 10044 Stockholm, Sweden. Fax: +46-8-105228. E-mail: magu@ket.kth.se

3rd Annex 22 Workshop on Compression systems with Natural Working Fluids
16 February 1998 / Tokyo, Japan
Contact: Mr Jørn Stene, SINTEF Energy, N-7034 Trondheim, Norway.
Tel: +49-73591942. Fax: +47-73593950.
E-mail: Jorn.Stene@energy.sintef.no
See also: http:/www.termo.unit.no/kkt/annex 22

Deployment Activities of Heat Pumping Technologies
12 May 1998 / Stockholm, Sweden
Contact: Magnus Gustafsson,
Royal Institute of Technology, Department of Chemical Engineering and Technology,
S - 10044 Stockholm Sweden.
Fax: +46-8-105228.
E-mail: magu@ket.kth.se

Heat Pump Systems for Single-Room Applications
Annex 23 Workshop.
18-19 June 1998 / Niagara Falls, USA
Contact: Frank Lenarduzzi, Ontario Hydro Technologies.
Fax: +1-416-2076565

Heat Pumps - A Benefit for the Environment
6th IEA Heat Pump Conference
30 May - 2 June 1999 / Berlin, Germany
Technical visits on 3 June 1999
Planning sessions on Market Status / Strategy, Technology and Applications.
Invited speakers and call for posters.
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Next Issue

Large Energy Systems

Volume 16 - No.1/1998