IEA Heat Pump CENTRE
NEWSLETTER
VOLUME 19
NO. 1/2001

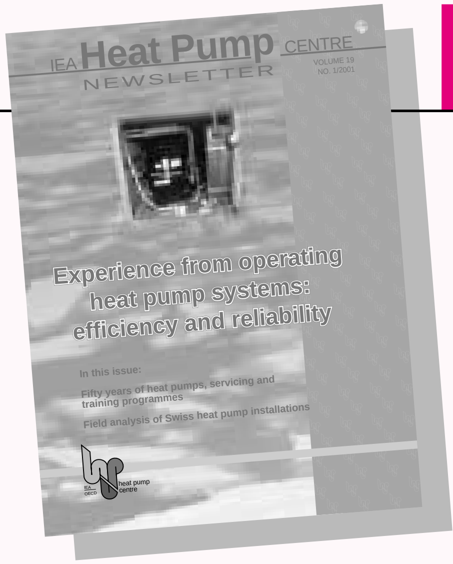
Experience from operating heat pump systems: efficiency and reliability

In this issue:

Fifty years of heat pumps, servicing and training programmes

Field analysis of Swiss heat pump installations

IEA
OECD
heat pump
centre



In this issue

Experience from operating heat pump systems

Heat pumps have already been used for saving energy for several decades. In order to accelerate implementation in the future, we have to evaluate and learn from the experiences of the past. The topical articles in this Newsletter address monitoring of installations, initiatives to improve heat pump operation in real-life situations, and the proven environmental benefits of a heat pump system with ice thermal storage in an office building. The Newsletter also reports on R&D on chemical heat storage/heat pump systems in Japan and on the results of the Climate 21 R&D programme in Sweden.

Front cover:
Heat pump equipped with small data logger, to record source and supply temperature. Heat pump monitoring in Switzerland, see page 15.

TOPICAL ARTICLES

HEAT PUMP NEWS

FEATURES

COLOPHON

Publisher:
IEA Heat Pump Centre
PO Box 17, 6130 AA Sittard
The Netherlands
Tel: +31-46-4202236, Fax: +31-46-4510389
E-mail: hpc@heatpumpcentre.org
Internet: http://www.heatpumpcentre.org

Editor in chief: Jos Bouma
Technical editing:
Gerdi Breembroek, IEA Heat Pump Centre;
Eli Birnbaum, Jac. Janssen, Derix**Hamerslag*
Production: Novem Support Group
de Vormgeverij, Meerssen

Frequency: quarterly
Printed: March 2001
Distribution in 27 countries
HPC Newletter subscriptions are automatically renewed unless written cancellation is received by 1 October

ISSN 0724-7028

Experiences from operating heat pump systems

Heat pumping, i.e. reversing the natural heat flow from a higher to a lower temperature level, is used in many applications for producing cold, heat or both. These different applications have different names and reputations. The production of cold (in refrigerators, freezers, air-conditioning systems) is fully accepted as a reliable technology. The production of heat is a different matter: MVR (mechanical vapour recompression) systems, dryers and dehumidifiers are nearly unknown, and reversible air-conditioner systems that are successfully operated in the cooling and heating mode are not fully recognised. And in some countries and regions, the heating-only heat pump is still viewed with serious doubt.

The heat pump unit itself cannot be the problem, as it uses the same equipment as a refrigeration system and operates with the same temperature lifts. The only difference is the system into which heat pumps have to be integrated. In Europe, hydronic distribution systems dominate the market. When heat pumps were introduced after the second oil price shock, many mistakes were made by all parties involved, but mainly by unskilled installers. However, many successful heat pumps were installed at the same time.

The market shakeout in the eighties helped solve the problem of unsuccessful systems through natural selection: only those manufacturers and installers survived who know how a heat pump works and what the criteria for a successful system are. By now about 1.5 million heating-only systems are operating in Europe, a number indicating that they are accepted as a reliable and energy efficient technology. Worldwide, 120 million heat pumps are in operation, mainly in Japan and the US. It is clear then that Europe is still a developing region, and that it will be a challenge to force a break-through of this technology, which saves energy, reduces CO_2 emissions and thus benefits the environment.

Hermann Halozan
Chairman of the IEA HPP Executive Committee

NON-TOPICAL ARTICLES

European Certification Charter proposed

France - "Certification of heat pump technologies and installers" was the theme of an international workshop in Paris on 13 December 2000, organised by France-based ADPM and co-sponsored by the IIR (Commission E2). The workshop marked the completion of the EU SAVE project on Certification of Heat Pump Technologies and Installers, a collaborative effort between partners from France, Norway and Germany, as well as EUROVENT Certification. Certification of both the equipment and the installation process is an essential factor in the decisions taken by customers. Around 50 participants from Europe participated in the workshop and roundtable discussions led by Prof. F. Steimle.

A major result of the project was the proposal for a European Charter that will guarantee the quality of heat pump installations. The Charter is an agreement to which manufacturers and installers from European countries that adopt the Charter will voluntarily adhere. The Charter covers the entire heat pump heating system, which is a great challenge. An appropriate organisation to manage the Certification Charter is being solicited, with the European Heat Pump Association being a strong candidate.

Source: IEA Heat Pump Centre

US minimum efficiency standards approved

US – The US Department of Energy (DOE) has issued new minimum efficiency standards for central air conditioners and heat pumps under the National Appliance Energy Conservation Act (NAECA). **Table 1** shows both the current regulation and the new regulation, which will be in effect from January 2006 onwards. Equipment that does not meet the minimum efficiency standards is not allowed on the US market.

▼ *Table 1: Current and future minimum efficiency standards for split central heat pumps*

	current	from 1 January 2006
Cooling SPF	2.93 (10 SEER)	3.81 (13 SEER)
Heating SPF	1.99 (6.8 HSPF)	2.26 (7.7 HSPF)

The new efficiency regulations correspond to a 30% increase in cooling performance and a 13% increase in heating performance. The merits of the new thresholds have been the subject of intense debate, as the new standards must be technologically, environmentally and economically justified.

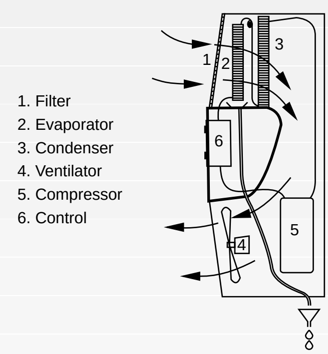
Residential appliance efficiency standards in the US cover the following products: refrigerators and freezers, room air-conditioners, central air-conditioners, clothes-dryers, clothes washers, dishwashers, water heaters, gas/oil furnaces, ranges and ovens and showerheads and faucets. It has been calculated that in 1997, the current efficiency standards were responsible for reducing total US residential energy consumption by approximately 2.5%, thus saving USD 3.5 billion in annual energy cost to residential consumers, and reducing CO_2 emissions in the residential sector by 2.5%. Benefits to consumers, the economy and the environment will continue to flow from these standards and their updates for years in the future.

Source: US National Team; Appliance Efficiency 4/3, 2000

Swiss laundry-room dryers get labelling scheme

Switzerland – Switzerland has recently developed a classification and labelling scheme for communal drying room equipment.

While most of the rest of Europe uses natural drying, electric tumble-dryers or drying cabinets to dry their clothes, the majority of Swiss households have traditionally used communal drying-rooms. Slightly less than 80% of Swiss households are in multi-family buildings and the large majority of these share communal clothes-drying facilities. Most of these drying rooms are equipped with application-specific dehumidifying electric heat pumps, known as laundry-room dryers, which use significantly less energy than conventional tumble dryers, see **Figure 1**.



▲ *Figure 1: Laundry-room dryer*

A recently completed research project has worked out a test procedure for laundry-room dryers, based as far as possible on standard IEC/EN 61121, which is valid for household tumble-dryers. The Swiss association for the promotion of laundry-room dryers has now created a voluntary energy label applicable to laundry-room dryers, with efficiency levels A1, A2, A3, B1, B2 and B3. The "A" and "B" ratings correspond to "A" and "B" ratings for household tumble-dryers.

Source: Appliance Efficiency 3/2000
More information: Jürg Nipkow
E-mail: juergnipkow@swissonline.ch

HPP and IIR sign formal collaboration agreement

UK – Fourteen November 2000 marks the beginning of enhanced collaboration between the IIR (Sections B and E) and the IEA Heat Pump Programme. During a special session of the Executive Committee meeting in Oxford, UK, a formal framework agreement was signed by the President of the IIR Management and Executive Committee, Mr H. van der Ree, and IEA Heat Pump Programme Executive Committee Chairman Mr H. Halozan (photo).

Figure 1: Mr Van der Ree (l) and Mr Halozan (r) signing the agreement

Collaboration between the two organisations in some areas has existed for a decade, but will now be extended to several new areas, including representation in committees, congresses and conferences, scientific cooperation, publications, the Internet etc. A Liaison Committee with representatives from both organisations has been formed to develop plans for future actions. The first steps on the way to extended collaboration are the decision of the IIR Scientific Council to co-sponsor the 7th IEA Heat Pump Conference in Beijing, China and the HPC co-sponsored Workshop/Round Table at the IIR conference on Refrigerant Management and Destruction Technologies in Dubrovnik, Croatia (see page 27). The most concrete and visible step is the "IIR column" in the HPC newsletter that you are now reading.

Source: IEA Heat Pump Centre

IIR Newsletter issued

France – The first issue of the *IIR Newsletter* came out on November 2000. The *IIR Newsletter* will be distributed bimonthly to IIR members and other subscribers. It covers IIR highlights, news on IIR events, an events list, general news, industry highlights and news on standards and regulations. The *IIR Newsletter* subscription is free for everybody. Highlights from the first issue are that the IIR has been appointed by the FAO to lead the revision of a code of practice on quick-frozen foods, and gives a brief summary of the 4th IIR Gustav-Lorentzen Conference.

Contact: Mr J.L. Dupont
Fax: +33-1-476317 98
E-mail: iifiir@iifiir.org

For information on IIR's Fridoc database, see page 26.

IIR Position on reducing global warming

The Netherlands - Director of the IIR, Mr F. Billiard, presented the IIR position statement at the 6th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 6) in The Hague, the Netherlands. An excerpt of his speech follows here:

"Today, HFCs are the refrigerants the most widely used by refrigeration practitioners in order to phase out CFCs and HCFCs. However, because of their global warming impact, HFCs are among the six greenhouse gases constituting the Kyoto Protocol-regulated basket.

The refrigeration sector's impact on global warming has two sources:

- about 20% from refrigerant emissions in refrigerating equipment, a percentage which varies greatly according to the application; for example, it can vary from about 3% for domestic refrigerators to about 30% in mobile air conditioning;
- about 80% derived from carbon dioxide emissions associated with energy consumption of refrigerating equipment. It is noteworthy that the refrigeration, air conditioning and heat pump sector consumes about 15% of all electricity produced worldwide.

Thus, the refrigeration sector is concentrating on:

- reduction of refrigerant emissions via improved equipment containment and systematic training of all stakeholders;
- further optimisation of equipment energy efficiency.

The refrigeration and air conditioning sectors are thus confronted with the choice of refrigerants. The two main approaches used to address it are: Continuing use of HFCs, which are global warming gases, or replacement refrigerants with no direct impact on global warming such as ammonia, or hydrocarbons for which an important choice criterion is the guarantee of the lowest safety and/or health risks associated with their use.

Rather than arbitrarily deciding in favour of HFC- or non-HFC refrigerants, a per-application approach is no doubt preferable. Thus, the optimal approach is, for each application, to opt systematically for the most environmentally friendly solution, taking into account the overall global warming impact. Overall equipment emissions, in CO_2 equivalents, throughout the life cycle of the equipment, must therefore be a benchmark consideration.

In conclusion, the IIR's recommendations to reduce global warming are:

- to opt for equipment with the least life cycle global warming impact;
- to establish energy efficiency standards for refrigerating equipment;
- to regulate tightness of refrigerating circuits and to ensure compliance with regulations;
- to train refrigeration technicians and users in new technology and to promote awareness of the need to contain, recover, recycle or destroy refrigerants;
- to step up research and development on replacement refrigerants and technology;
- to set up emission monitoring mechanisms;
- to take advantage of the Kyoto Protocol context to boost technology transfer and to train as many technicians as possible in developing countries, providing an opportunity to set up reliable cold chains."

Full text: IIR (E-mail: iifiir@iifiir.org) or IEA Heat Pump Centre.

Mid-priced houses with ground-coupled heat pumps

USA – An Oklahoma City metropolitan area developer is building houses in a new area, which use ground-coupled (geothermal) heat pumps for heating and cooling. Eleven houses have already been built, and a total of 270 are planned. The developer wanted to be the first to offer geothermal systems in mid-priced houses. Each house has its own loop pipes, which extend down to 55 m. The houses have areas between 175 and 230 m^2 and cost about USD 800/m^2.

For these houses, Oklahoma Gas and Electric (OG&E) will guarantee a heating, cooling and water-heating bill of USD 54 a month or less, for a year. That price will rise only if electricity rates go up. OG&E promoted the geothermal systems as well as building the houses according to “Energy Star” standards. The utility supports geothermal systems as a customer satisfaction issue and for peak shaving.

Source: Power Marketing Association Online Power Report.
For URL contact IEA Heat Pump Centre

UK commercial ground-coupled heat pump project wins Engineering Award

The Netherlands/UK – In the autumn of 2000, the British Engineering Council presented an Environmental Engineering Award to the closed-loop ground-coupled heat pump project in Croydon Surrey, UK. The project was realised by Applied Energy, UK, Clivet Ltd., UK and Groenholland BV, the Netherlands.

This largest UK ground-coupled heat pump system is installed in a commercial building of 3,000 m^2 with both offices and warehouse facilities. The building has an annual cooling load of 150 MWh and a heating load of 90 MWh. The maximum cooling capacity is 130 kWh per hour.

The investor opted for a low temperature ground-coupled heat pump and thermal storage system, as the capital costs were only slightly higher than for a conventional space-conditioning system (VRV, four pipe fan coils). However, advantages are a reduced plant size, low noise levels, improved aesthetics and a long life expectancy compared to a conventional system. Operating advantages include minimum maintenance requirements and lower running cost as well. The ground heat exchanger consists of vertical ground loops in 30 boreholes, drilled to 100 meters into the underlying chalk formations. The borehole field surface area of about 1000 m^2 is utilised as a parking facility. The operation and efficiency of the entire heat pump system is controlled and monitored by a building management system.

More information: http://www.groenholland.nl

▲ *Figure 1: The building in Croydon Surrey, UK*

Vuilleumier heat pumps endurance test

Germany – Four Vuilleumier heat pump prototypes are currently being subjected to 20,000-hour endurance tests. These air-source heat pumps were developed especially for retrofitting heating systems in residences. Until now, tests have shown that 44% of primary energy can be saved compared to a conventional gas-fired boiler. The heat pumps are also expected to achieve the reliability targets that have been set.

The major barrier to the increased use of Vuilleumier heat pumps was their insufficient long-term reliability, as homeowners expect 10-12 years of operation with little maintenance and repair (20,000 operating hours). In 1993, two German heating equipment manufacturers established the joint venture BVE Thermolift Gbr. In collaboration with materials science institutes and supported by the German federal government, the joint venture initiated research to develop a reliable and efficient Vuilleumier heat pump. It developed the prototypes which are now being tested, one of 4 kW heating capacity and three others with a capacity of 20 kW. The laboratory testing has been going on since spring 1998.

Source: Bine Informationsdienst, projectinfo 1/00
Fax: +49 228 923 7929
E-mail: bine@fiz-karlsruhe.de

Houseboats heated efficiently

The Netherlands – Many will be familiar with the typical sight of houseboats in Amsterdam, but their use is much more widespread than the Dutch capital. Houseboats with heat pumps are presently being tested in Kortenhoef.

In this village, the owner of a houseboat harbour took the initiative to install electric heat pumps for heating newly built houseboats. The utility Nuon supported this initiative. The heat pump is an excellent solution for heating houseboats, as a connection to the gas grid is problematic and the surface water in which the houseboat lies provides an excellent heat source.

Data on the first experiences with a spiral heat exchanger are now being collected. A builder of houseboats has already made plans for incorporating the heat exchanger in the concrete bottom of the boats.

Source: de Woonkrant, 18 October 2000

Sanyo unveils vending machine with CO_2

Japan – Sanyo Electric Co. has developed a new model vending machine with CO_2 as the refrigerant. A prototype was exhibited at VENDEX JAPAN 2000 in November. Sanyo aims to commercialise this new product in 2003.

While canned drinks vending machines are designed to only cool the containers, cupped drinks vending machines are designed both to heat water, for example from 20°C to 95°C, as well as cool water from 20°C to 0°C to make and store ice. CO_2 compressor technology can be used for both heating and cooling, and is therefore very suited for cupped drinks vending machines.

Sanyo has equipped a cupped drinks machine with a CO_2 compressor developed in 1999. The performance of the prototype is still being tested. The COP in the heating mode attained the target value, but the COP in the cooling mode as well as in the combined heating and cooling mode did not. Improvements to the prototype are therefore planned, including improvements on compressor, heat exchangers and controls.

Source: JARN, December 2000

New energy-efficient bottle cooler using isobutane

Denmark – A new bottle cooler using isobutane as refrigerant was developed in a joint project with the companies Vestfrost (bottle coolers), Coca-Cola, Danfoss and the Danish Technological Institute (DTI), supported by the Danish Government's Energy Agency. Compared to conventional products, the new bottle cooler reduces electricity consumption by 40%.

The following features ensure high energy efficiency and minimum contribution to global warming:

- variable speed compressor;
- a new control strategy;
- new larger condensers;
- natural refrigerant isobutane (R-600a);
- improved glass doors (U-value 1.28 W/m^2K);
- light source outside cabinet;
- efficient DC ventilators;
- reduced cooling load through less dissipation (ventilation, lighting) in cooled area.

A one-year field test of 40 prototypes and 20 conventional coolers, conducted by DTI, showed that the new cooler reduced electricity consumption by 40%. Its consumption was about 2.9 kWh per day, compared to 4.8 kWh for a conventional model. The payback period for an individual cooler is about 2 years.

▼ *Figure: The new bottle cooler in use*

HFC phase out by 2006

Denmark – A complete phase-out of HFCs by 2006, except for limited uses such as mobile air-conditioning systems and air-to-air heat pumps, has been approved by the Danish Parliament. The phase-out date for the use of HFCs in new equipment is as early as 2002 for domestic refrigerators, brine-to-water and air-to-water heat pumps, and air conditioning systems with more than 100 kg refrigerant. No phase-out date for the use of HFCs in new air-to-air heat pumps and mobile air-conditioning systems has been decided yet. A decision will be made when feasible alternatives are available on the Danish market.

In addition, an HFC taxation system came into force 1 March 2001. The tax must be paid on the substances which are manufactured and imported into Denmark. Taxes range between USD 1.75-47.00 per kg refrigerant according to Global Warming Potential. As an example, the tax for R-134a is USD 15 per kg.

Source: H.J. Høgaard Knudsen
Fax: +45 45 935 215, E-mail: hk@mek.dtu.dk

UK Government endorses: HFCs not sustainable

UK – The UK government has toughened its stance on refrigerants that contribute to global warming by including a series of HFC (hydrofluorocarbon) reduction measures in its official Climate Change policy. The policy also shows no softening of the official line on replacing global warming gases such as R-134a and R-410A with more environmentally benign alternatives.

The government acknowledges that HFCs were necessary as one of a number of technologies deployed to help phase out ozone-depleting substances such as CFCs and HCFCs, but "believes that continued technological developments will mean that HFCs can eventually be replaced in the applications where they are used".

Under the terms of its new policy, the UK government will seek to strengthen the voluntary agreements it has with industry by setting definitive targets for reducing HFC emissions and creating "robust reporting mechanisms". It wants industry to draw up a 'use list' showing where HFCs are not necessary.

Source: Daniel Colbourne, Calor Gas
E-mail: Dcolbour@calorgas.co.uk

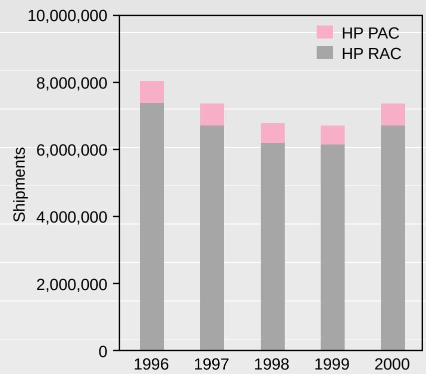
Japanese domestic shipments on the rise

Japan – Data of the Japan Refrigeration and Air Conditioning Association, JRAIA, show that the market in Japan has turned upward in the refrigeration year 2000 (October 1999-September 2000), after 4 years of recession; see **Figure 1**. Shipments of air conditioning equipment were favourably affected by the intense heat wave in summer.

As was the case in 1999, shipments of gas-fired heat pump systems and of ice storage assisted packaged air conditioners showed favourable results in 2000. The numbers shipped increased 15.2% to 48,593, and 31.1% to 10,146 respectively, compared to 1999.

The year 2001 began favourably, as shipments of room air conditioners (RACs) were 7.4% higher in October 2000 than in the year before. Japanese manufacturers recognise that achieving high sales results in the winter season is the key to successful business. RACs should achieve more recognition as excellent space heaters in winter.

Source: JARN, December 2000



▲ *Figure 1: Domestic shipments of heat pump type room air conditioners (RAC) and packaged air conditioners (PAC) in Japan*

More choice of heat-pump household tumble-dryers

Italy – At the 2nd International Conference on Energy Efficiency in Household Appliances and Lighting, held in Naples, Italy, some particularly interesting appliances were presented. Whirlpool announced a new heat-pump condensing clothes-dryer, which will be launched on the European market in 2001. This clothes-dryer will be an efficiency-class-A product, which implies that, with regard to energy use, it is over 29% more efficient than the overall European average and uses less than 0.55 kWh/kg wet clothes. This is one of the few appliances that meet this efficiency standard. AEG and Lare/Ecodry introduced heat-pump clothes-dryers back in 1999.

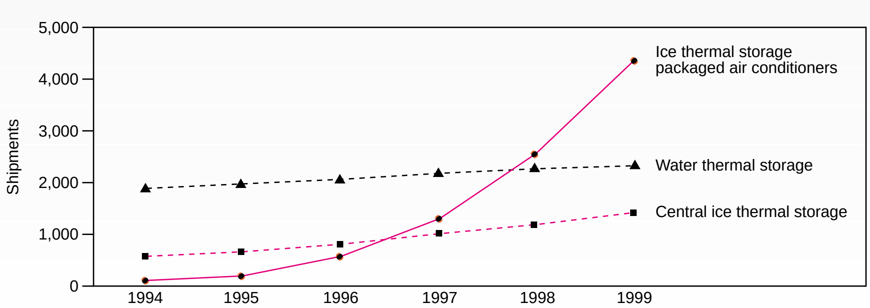
Source: Appliance Efficiency 3/2000.

Thermal storage increasing in South-East Asia

Japan – In Japan and other countries in South-East Asia, the demand for thermal storage systems is increasing. Recently, latent heat cold storage has become dominant, because of the larger storage capacity. Systems belonging to this category include ice-on-coil storage, encapsulated ice storage, ice harvesters/chillers and ice slurry systems. A packaged air conditioner assisted by ice thermal storage has been developed under the name of ‘Eco Ice’. Many large buildings constructed recently in Japan have adopted air-conditioning systems using ice thermal storage. Annual sales are shown in **Figure 2**.

In China, lower rates for night power were introduced in 1994. Since then, thermal storage systems have drawn attention and are steadily gaining ground. Nine water thermal storage and 91 ice thermal storage installations are known, almost all of them in central air-conditioning systems in large buildings. In Korea, newly constructed or renovated buildings with a floor area of more than 3,000 m^2 have been obliged, since 1992, to introduce an ice thermal storage system or absorption type air-conditioning system. The number of new installations in large Korean buildings has been between 50-60 per year for the last 6 years.

Source: JARN, August 2000; Japanese National Team (address - see back cover).



▲ *Figure 2: Sales of thermal storage systems in Japan*

New D-A-CH Quality label requirements

Switzerland – The German, Austrian and Swiss heat pump associations have decided to change the minimum COPs under standard conditions for the DACH heat pump quality label as follows as per 1 January 2001:

▼ *Table 1: New DACH quality label minimum COPs*

	temperatures (°C)	until 01-01-2001	new
air-to-water	A2/W35	3.0	3.0
brine-to-water	B0/W35	3.5	4.0
water-to-water	W10/W35	4.1	4.5

Furthermore, there are new regulations concerning the selection of the equipment which will be subjected to the tests, and concerning the submission of electrical safety test results and EU conformity declaration. Finally, it has been decided that one heat pump from a series must be tested anew when there is a change of component supplier (compressor, heat exchangers).

Source: Wärmepumpe News, winter 2000/01

Don’t miss the following HPC events:

The Netherlands – Two upcoming IEA Heat Pump Centre (HPC) events, covering different aspects of heat pump, air conditioning and refrigeration technologies are well worth your attendance:

The IIR conference *Refrigerant Management and Destruction Technologies* will be held 29-31 August 2001 in Dubrovnik, Croatia. This is a joint conference of IIR Commissions B1, B2, E1 and E2. Themes include: refrigerant management plans; CFC and HCFC incineration and separation technologies; control and quality of waste; gases, liquids and ashes; regulations and bylaws; current state of CFC and HCFC replacement in the world. There will be workshops/round table sessions on perspectives in destruction technologies and refrigerant management and regulations. The HPC will join in on the latter, and discuss findings from one of its ongoing projects: *Refrigerant recovery, recycling and reclamation – an international assessment*.

A two-day workshop *Hands-on experiences with heat pumps in residential buildings* will be organised 10-11 October 2001 in Arnhem, the Netherlands. It is organised in a joint effort by NUON on behalf of the International Power Utilities Heat Pump Committee (IPUHPC) and the HPC. The workshop aims to contribute to qualitative and cost-effective application of heat pumps by exchanging technical knowledge on heat pumps in the broadest sense, including adequate design, realisation, operating experience and monitoring. The workshop should also result in new heat pump initiatives under the IEA Heat Pump Programme.

For contact information see page 27 of this Newsletter.

Source: IEA Heat Pump Centre

Outlook for HPP

UK – At the Autumn 2000 meeting of the Executive Committee of the IEA Heat Pump Programme (HPP), several subjects with relevance for the future were discussed:

- The 7th IEA Heat Pump Conference will be held in Beijing, China, on 19-22 May 2002. The first announcement was distributed with the previous issue of this Newsletter. The information was also published on the Internet: http://www.heatpumpcentre.org. Abstracts are due 1 April 2001. The conference programme will be a combination of plenary and parallel sessions, as well as a poster session.
- Two new Annexes “Sorption-heat recovery systems, market and environmental impact -for cooling and heating with CHP and waste heat applications” and “Applications of compact heat exchangers based on the micro channel concept” were proposed. If you are interested in these topics, please contact the IEA Heat Pump Centre.

Source: IEA Heat Pump Centre

Residential heat pumps and energy-efficient heat and cold distribution and ventilation systems – now available

The Netherlands - How does the choice of a heat and cold distribution system influence the energy efficiency of the heat pump system? How do ventilation, heat and cold distribution, and the heating and cooling demands of a house interact? The results of a Heat Pump Centre survey on these topics are now available.

This report discusses energy-efficiency, economy, comfort and indoor air quality aspects of the various distribution systems and terminal units (radiators, fan-coil units, etc.) in combination with heat pumps. Trends in distribution system choices in all Heat Pump Programme countries are discussed and analysed. The report concludes with an outlook and recommendations for future work. The 140-page report can be ordered from the Heat Pump Centre, see page 27.

Source: IEA Heat Pump Centre

Ongoing Annexes

Annex 16 IEA Heat Pump Centre	16	AT, JP, NL, NO, UK, US
Annex 25 Year-round Residential Space Conditioning and Comfort Control Using Heat Pumps	25	FR, NL, SE, US
Annex 26 Advanced Supermarket Refrigeration/Heat Recovery Systems	26	CA, DK, SE, UK, US
Annex 27 Selected Issues on CO_2 as a Working Fluid in Compression Systems	27	CH, JP, NO, SE, UK, US

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

Experience from operating heat pump systems: efficiency and reliability

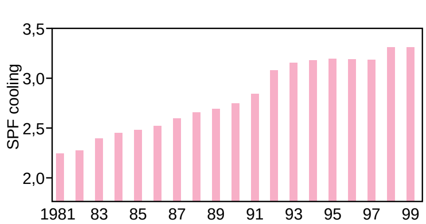
Gerdi Breembroek, IEA Heat Pump Centre

Heat pumps have been applied for energy and cost saving for some decades. In order to accelerate implementation in the future, we have to evaluate and learn from the experiences of the past. This article discusses monitored real-life efficiencies, reliability and maintenance of various heat pump systems, and identifies successes and lessons learned.

Learning from experiences

Experience with operating heat pump systems is a valuable source for improvement initiatives. In Japan, for example, the first heat pumps were introduced in the 1950's and 1960's. These were window type reversible air-source units. However, these units did not fit well into Japanese houses, as windows were generally of the sliding horizontal type. Users complained of insufficient thermal comfort, noise and frequent equipment breakdown. This was caused by insufficient building insulation and tightness, limited occupant space and equipment not able to deal with irregular operation.

Since then, manufacturers have improved their products markedly. From the 1970's, Japan adopted ductless split-type single-room heat pump systems, with indoor units mounted on the wall instead of the window. These units, with their flexibility of installation and limited space requirements, dominate the present residential heating and cooling market. After 30 years of improvements, the systems are highly reliable and user-friendly.



▲ *Figure 1: Shipment-weighted heat pump cooling SPF, USA*

Energy efficiency

Since the first and second energy crisis in the 1970's, high efficiency has been regarded as the major issue for heat pumps. Active development by manufacturers of enhanced compressor efficiency, heat exchangers, capacity control and defrosting control have contributed to achieving high efficiencies with present-day COPs of more than 5.0. In Japan, the development of the inverter-driven capacity-modulated heat pump in particular contributed to enhanced COPs and boosted the domestic Japanese heat pump market.

In the US, minimum efficiency requirements for residential air conditioners and heat pumps have shaped the shipment-weighted heat pump efficiency curve, shown in **Figure 1**. The efficiency of current heat pumps is more than 40% higher than in the early 1980's. Current minimum efficiencies are $SPF_{cooling}$ >2.93 and $SPF_{heating}$ >1.99. Federal requirements are kept constant over 7 years. However, the average SPFs for heating and cooling are slowly rising over time, as higher efficiency equipment finds favour in some applications. About 60% of the heat pumps sold in the US still have no more than the minimum allowable efficiency. The news item on page 4 discusses the new minimum efficiency requirements for 2006.

Further drivers towards efficiency improvements include procurement activities, e.g. in Sweden, the Netherlands and Switzerland, which amongst others aim to increase the COP of heat pump installations. Also, quality labels, such as the DACH quality label, and incentive programmes of governments and utilities mostly require a minimum efficiency. The new DACH requirements are discussed on page 8.

Installation and maintenance

Installation and maintenance quality is also important. This was recognised by the Alabama Power Company in the USA, which initiated a *Certified Dealer Program* and a *Ten Year Assured Service Contract* back in the 1960's. Today, the company operates an *HVAC Training Center.* The experiences of the Alabama Power Company are presented in the article on page 13.

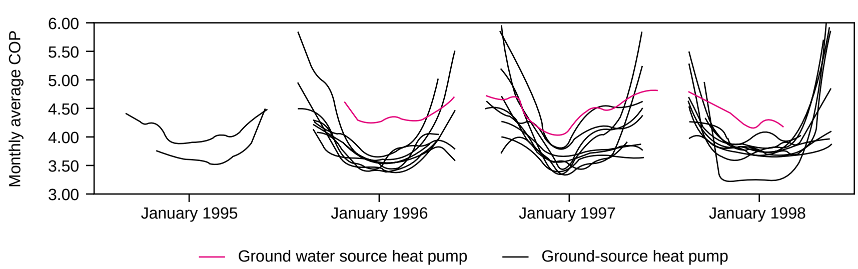
Today, efforts are ongoing to guarantee high installation quality. In the US, the national NATE (North American Technician Excellence Inc.) certificate, established in February 1997, is designed to promote professionalism and customer confidence. This testing network serves the US and Canada. The Austrian heat pump association has introduced a technician certification programme, and the news item on page 4 discusses the European heat pump charter, which is an initiative in the same direction. Certification will not be discussed in detail here, since it will be the topic of the next issue of this Newsletter.

Operational experience

Although the majority of heat pumps have performed satisfactorily, there have unfortunately been a number of

▼ *Table 1: Operational problems and their causes (Norway)*

RESIDENTIAL HEAT PUMPS		
Heat pump type	**Typical problem**	**Main cause**
Exhaust air heat pumps	Compressor failures	Excessive discharge gas temperatures for heat pump water heaters (R-22)
	Corrosion in hot water tanks	Use of non-stainless steel in tanks
Ambient air-to-air heat pumps	Heavy frost formation on outdoor unit (evaporator coil)	Insufficient fin distance, i.e. units not designed for cold-climate operation
	Refrigerant leakage	Frequent defrosting, corrosion etc.
	Compressor failures (R-22)	High temperature lifts and consequent excessive discharge gas temperatures, frequent on/off operation
	Low energy savings	Oversized heat pump unit, excessive defrosting, low ambient temperatures, inadequate air distribution, and incorrect use of peak load unit
Water-to-water heat pumps	Various problems with ground coupled systems	Blockage/breakage of plastic tubes, refrigerant leakage from DX-systems, undersized coils or wells (permafrost or low heat source temperatures)
	Compressor failure	High temperature lifts and excessive discharge gas temperatures (R-22)
HEAT PUMPS IN COMMERCIAL BUILDINGS AND DISTRICT HEATING SYSTEMS		
Heat pump type	**Typical problem**	**Main cause**
Sea water / sewage heat pumps	Corrosion of heat exchangers, pumps, valves, tubing etc.	Inadequate material qualities (stainless steel or titanium should have been used)
	Various types of fouling in pipelines and heat exchangers	Incorrect component and/or system design, low water velocities and inadequate cleaning systems
	Pump failures	Undersized pumps, inadequate material qualities and incorrect design of pump system
Ground water heat pumps	Excessive fouling of pumps and/or heat exchangers (open systems)	Use of ground water with a high content of iron and manganese ions
Ambient air heat pumps	Heavy frost formation on outdoor unit (evaporator coil)	Insufficient fin distance, i.e. units not designed for cold-climate operation
	Refrigerant leakages	Frequent defrosting, corrosion etc.
	Compressor failures (R-22)	High temperature lifts and consequent excessive discharge gas temperature, frequent on/off operation
All types	Compressor failures	High temperature lifts due to high temperature heat distribution systems, frequent on/off operation etc.
	Excessive part load operation	Low heating demand in district heating systems when the heat pump is installed – i.e. few buildings connected
	Low energy savings	Oversized heat pump unit, high distribution temperatures, incorrect use of the peak load unit (errors in the control system), incorrect system design etc.
INDUSTRIAL HEAT PUMPS		
Component	**Typical problem**	**Cause**
Heat source	Corrosion of heat exchangers, pumps, valves, tubing etc.	Inadequate material qualities (stainless steel or titanium should have been used)
	Various types of fouling in pipelines and heat exchangers	Incorrect component/system design, low fluid velocities and inadequate cleaning systems
	Improper operation	Incorrect system design, problems with control systems etc.



▲ *Figure 2: Monthly average COP, including auxiliary energy requirements, measured in ten German residences (data from utility RWE)*

plants with various problems, or where energy savings have been lower than expected. **Table 1** presents a Norwegian analysis of such problems and their causes in various application areas. The paragraphs below discuss a number of cases where the measured efficiency of heat pumps in residences was analysed.

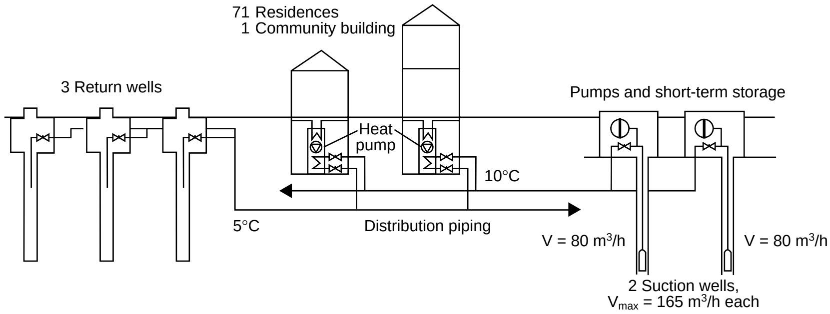
The first residential case analysed shows efficiencies of ten properly functioning and very efficient heat pump installations in ten residences in Germany. **Figure 2** shows the monthly COPs, including auxiliary energy use, during four heating seasons. All installations except for one used the ground as heat source and had a maximum supply temperature of 35°C to the hydronic heat distribution system. The remaining installation used ground water, and the maximum supply temperature was 45°C. The results are very good: COPs are much higher than 4 in autumn and spring, and in every case but one the COP is above 3.3 year-round. The results for the installation using ground water are even better than for the other ones. The conclusion is that these installations are excellent and save a substantial amount of primary energy.

The second set of relevant measurements comes from Switzerland and is discussed in the article on page 15. During five years, measurements were taken on 120 installations. The estimated mean value of the SPF of Swiss heat pumps, including auxiliary energy, was 3.2, for both air- and ground-source heat pumps.

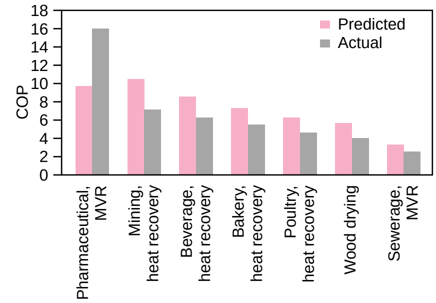
Table 2 shows the SPFs of state-of-the-art installations in Austria, determined within the framework of an evaluation of ground-coupled heat pump installations in 1997. Variations are due to differences in heating system design. An extensive measurement programme showed that

▼ *Table 2: SPFs for state-of-the-art installations in Austria, 1997.*

	heat distribution supply/return temperature (°C)		
heat pump	**35/25**	**40/30**	**50/30**
brine-to-water	3.8	3.5	2.8
direct evaporation	4.0 or higher	3.7	3.0



▲ *Figure 3: Collective system in Wulfen, Germany*



▲ *Figure 4: Actual SPFs for six industrial heat pumps, North America.*

the SPFs that are technically feasible are not always achieved and that measured SPFs ranged between 2.1 and 4.0 for ground-coupled heat pump systems.

A collective system

Seventeen years of experience with ground-water source heat pumps in a collective arrangement was gathered in Wulfen, Germany. Ground water was pumped from two wells with a depth of about 91 m and distributed to the individual buildings, each with its own heat pump. Heat is extracted and the water is injected back into three return wells; see **Figure 3**. The residences were built in 1979, and the community building was added in 1983. The residences have floor-heating systems with low supply temperatures. During 1981-1983, the performance of the heat pumps was measured. The SPF of the entire system, including the well pumps, was 2.9. Excluding the well pumps, an SPF of 3.5 was achieved.

The monitoring of the installation in Wulfen included maintenance and service. Average maintenance and service costs for 27 installations were USD 110 and USD 100 per year, respectively, over 1986-1997. This is significantly lower than the estimates in the design phase, which were USD 240 and USD 180, respectively. Fifty-four service calls were recorded over 27 installations in 11 years. During 17 years of useful service life and up to the present day, the reliability of these installations was shown to be quite high.

Twenty-three years experience

The ice maker heat pump system for the Reedsburg Technical School, Wisconsin, USA, was installed in 1978 and has operated successfully for 23 years. In winter operation, space heating and domestic hot water are produced, and ice is formed. Surplus ice is melted by the heat supplied by solar collectors. In summer operation, ice is used for cooling. There have been no operating or maintenance problems. It continues to be one of the most energy efficient and cost-effective of the 54 buildings in the Wisconsin Technical College System.

Industrial heat pumps

Figure 4 shows the actual SPFs of six industrial heat pumps in North America in their first year of operation, ranging from 2.3-16. These heat pumps were six out of 22 investigated sites. The sites with economic data reported payback periods ranging between 1.5 and 15 years, with seven sites reporting payback periods of 5.5 years or less. Of the sites surveyed, seven specified some special service or maintenance requirement, while ten specified only routine inspection or cleaning. Based on the management experiences with the heat pump after approximately one year, it appears that 16 of the 22 surveyed industrial heat pumps have been successful.

Conclusion

Many favourable experiences with heat pumps have been documented which show that heat pump systems are becoming even more efficient, and easier to maintain, and are a reliable technology. SPFs of 4 and higher are a reality for specific systems. Systems which have been operating successfully for more than 20 years are documented. The energy efficiency, and therefore the profitability of a heat pump system depends heavily on correct design, installation and operation.

Acknowledgement

The input of Jørn Stene, Norway, is gratefully acknowledged.

References

G. Agne et all., *20 Jahre Betrieb-serfahrungen mit 73 Wärmepumpen und der "kalten Nahwärmeversorgung" Wulfen*, Elektrowärme International, 55, A3/1997, 107-114

D. Cane, B. Clemens, *Industrial heat pump operating experiences in North America, in industrial heat pumps, recent experiences, environmental and production benefits*, HPC, the Netherlands, 75-91 (HPP-AN21-4)

Fifty years of heat pumps, servicing and training programmes

Nance C. Lovvorn, USA

The Alabama Power Company (APCo), a 'Southern Company', is one of the largest producers of electricity in the United States of America. APCo recognised the heat pump's potential in the late 1940s, when the equipment was used only for cooling. The management had the vision to become involved in research, development and marketing of this electric appliance. Today, over fifty years later, the management feels customer satisfaction with heat pumps is vitally important; heat pumps continue to be marketed to customers and a strong commitment remains to training HVAC industry personnel through its state-of-the-art HVAC Training Centre. This article briefly sketches APCo's history of involvement with heat pumps.

History

Alabama Power Company first became involved with heat pumps in the nineteen forties and is still actively involved. A brief survey of the past six decades yields the following highlights on the company's activities in the heat pump business:

Forties
- cosponsored a grant in 1946 with Southern Research Institute in Birmingham, Alabama, to develop the heat pump's heating capability;
- installed Alabama's first commercial heat pump in our General Office building in Birmingham in 1949.

Fifties
- installed heat pumps in five company offices in the early 1950s;
- documented heat pump sales in residential (1,275), commercial (443) and industrial (26) applications in the late 1950s.

Sixties
- initiated a Certified Dealer Program in 1964 to encourage support from builders. Standards for installation, application and service were written which implied: "If these select dealers install the equipment, the customers could expect to get it installed and serviced correctly";
- offered residential customers a Ten Year Assured Service Heat Pump Contract in 1967 to ensure that maintenance costs were reasonable; APCo would maintain detailed service records.

Seventies
- refined the Assured Service Program because it was determined that "All heat pumps are not created, installed or serviced equally;"
- worked with EPRI to produce the verifiable report: "Heat Pump Life Expectancy", "Heat Pump Component Reliability", and "Heat Pump Compressor Life and Reliability".

Eighties
- The Heat Pump Training Centre was conceptualised in 1985 and opened for business in 1986. Since that time, over 12,000 persons from 35 states have received hands-on performance-based training.

Nineties
- last Assured Service Contract expired;
- expanded the Heat Pump Training Centre to include other HVAC equipment, see **Figure 1**.

The Assured Heat Pump Service Program

During the 1967 to 1985 period, the Alabama Power Company had over 10,000 heat pumps under service contract. The detailed service records were the source of information to identify problems by brand, model, split or package heat pumps. In addition to tracking cost of service, routines were established to track component failure rates for major problem areas, such as defrost controls, fan motors, motor circuit components, compressors and refrigerant controls. All service records were coded as follows: 1. Customer Complaint; 2. Service person's Analysis; 3. Corrective Actions; 4. Defect Codes.

▲ *Figure 1: Alabama Power Company's HVAC Training Centre uses hands-on, performance-based training to simulate realistic situations.*

Some people labelled this initiative as a "reactive" programme, in which we reacted to problems after they were found during application, installation or service. While true (service is by definition reactive), it also provided service at a guaranteed cost for customers at a time when they could not get this service elsewhere. It also provided the factual basis for manufacturers and others to make informed decisions on improving product performance and reliability.

Asking service companies to provide detailed information to a third party caused some dealers to express concern, as other customers did not require these types of records. In the end, however, these detailed records proved an invaluable source of factual information that provided a catalyst for candid discussions with appropriate parties. Most of the manufacturers valued the information and made dramatic improvements over a relatively short time frame. Those who ignored these findings and trends or did not address their problems proactively were no longer eligible to have their products covered by the Assured Service Program.

The database also provided the basis for EPRI research on heat pump reliability. A brief sampling of the EPRI research (see **Figure 2**) in the mid-eighties showed that:

- the median service life of heat pumps in Alabama varies from 16-20 years;
- for all units surveyed by APCo, the service life was 20 years;
- an overwhelming majority of owners were satisfied with heat pumps;
- the life expectancy for the original heat pump compressors was determined to be greater than 15 years.

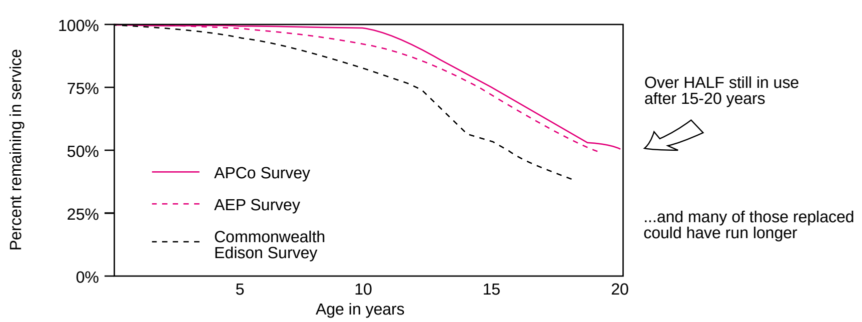
The HVAC Training Centre

The Heat Pump Training Centre's (now called the HVAC Training Centre) initial mission targeted dealer technicians and intended to increase customer satisfaction by assuring the technicians who serviced their units were properly trained in a hands-on, performance-based setting (as close to the real thing as possible). The three levels of courses were designed to answer three questions, as follows:

- Does a problem exist? (foundations)
- What is the problem? (troubleshooting)
- How do you repair the problem? (service)

Initially, the core curricula focused on electrical and refrigeration courses in relation to residential air source heat pumps. In addition to a name change in the nineties to 'HVAC Training Centre', the curriculum has been changed and enlarged in other ways as well. In addition to air-to-air heat pumps, it deals with water-to-air, air-to-water and water-to-water systems. Also, training is done on a variety of equipment including geothermal, integrated heating and cooling equipment, dual fuel systems and commercial heat pump water heaters. Training has also been expanded to include commercial and residential load calculation and duct design, duct fabrication, air infiltration diagnostics and repair for the technicians and design engineers and business management, customer service and computer training for the owner/manager teams. In 2000, over 1400 persons received training in one of the 23 course offerings. The number of participants is projected to increase in future years.

New training methods and curriculum are very important to the customer, the dealer/contractor and the utility as we enter the 21st century. Industry issues including technician certification (ACE test – Air Conditioning Excellence - as administered by NATE - North American Technician Excellence Inc.), consolidation of distributors and dealers, and electric industry deregulation are among the reasons why training is so important. Couple that with the renewed focus on hiring and retaining employees for the HVAC industry, and the mission of the HVAC Training Centre becomes clearer than it was in the mid-eighties.



▲ *Figure 2: Heat pump service life is 15 years to more than 20 years, according to surveys conducted for the Electric Power Research Institute by American Electric Power Service Corporation (AEP), Commonwealth Edison Company, and Alabama Power Company (APCo).*

Next steps

A new EPRI report on the life expectancy of heat pumps in Alabama is being prepared and will be based on data for heat pumps installed over the past 15 years. Most people involved would agree that products have been much improved. With improvements in service expected to come from technician training and certification, all customers should expect to realise higher efficiency levels and longer life spans for heat pumps and related compressor-driven appliances.

Nance C. Lovvorn
Manager Training for Alabama Power Company, Birmingham, Alabama
HVAC Training Centre
2388 Country Road # 93
Verbena, AL 36091
Tel.: 1-800-634-0154
Fax: 1-205-755-6168
E-mail: nclovvor@southernco.com
Internet: http://www.southernco.com/alpower/hvac/

References (EPRI reports:)
Heat Pump Life and Compressor Survival in Diverse Climates (AEP). CU-6254, December 1988
Heat Pump Repair Costs in Alabama (Alabama Power). EM-5328, July 1987
Heat Pump Life and Compressor Survival in a Northern Climate (Commonwealth Edison), EM-4660, July 1986
An Analysis of Heat Pump Compressor Life (Alabama Power), EM-4659, July 1986
A survey of Heat Pump Service Life (Alabama Power), EM-4163, July 1985
Heat Pump Life in Alabama – Revisited (Alabama Power), to be published

Field analysis of Swiss heat pump installations

Markus Erb and Peter Hubacher, Switzerland

On behalf of the Swiss Federal Office of Energy, the project FAWA (Field Analysis of Heat Pump Installations) has systematically surveyed small heat pumps installed in Switzerland for a period of over five years. The data presently available represent measurements taken on a total of 120 installations. Statistical analysis has led to interesting conclusions on the energy conversion efficiencies of the heat pumps surveyed and successful installation designs:

- during the period 1994/1995 to 1998, the mean energetic efficiency of heat pumps in Switzerland, taken as a whole, as expressed by the seasonal performance factor, improved from 2.6 to 3.2;
- systematic measurements taken on individual installations over five years have shown that the value of the seasonal performance factor remained constant over this time frame - in other words ageing was not a significant factor.

Introduction

The analysis of data collected on heat pumps in Switzerland on behalf of the Swiss Federal Office of Energy and reported on in this article is limited to heat pump installations with a maximum capacity of 20 kW. This group dominates the heat pump market with a share of 75%.

The FAWA project started testing installations in 1995 in order to judge their technical aspects, document their energetic efficiency over time, gather guidelines for good installation designs and monitor new developments in the field. The aim was to select and analyse, if possible at random, about 30 new installations each year, in order to ensure that the data collected is representative for all new installations in Switzerland. This was not always easy to achieve due to the relatively low number of samples and the demands made on owners (weekly meter readings). For this reason, random deviations from the mean value can be considerable in individual years.

A total of 120 heat pump installations provided the data that form the basis for the results presented in this article.

Energetic efficiency over time

Depending on the definition of the system boundaries, FAWA uses several different seasonal performance factors (SPF) to characterise the energetic efficiency of a heat pump installation. The one used in this article is SPF2, which is defined as the ratio between the quantity of heat supplied by the heat pump and excluding buffer losses and the amount of electricity used by the heat pump installation including all auxiliaries.

Field measurements

Two types of installations are in general use: brine/water (B/W) and air/water (A/W). On average, B/W installations have a 25% higher SPF2 than A/W installations. **Figure 1** presents data for newly constructed as well as retrofitted A/W installations. Over the period measured, 1994/1995 to 1998, the mean SPF2 value increased from 2.4 to 2.8, corresponding to an annual increase of 6%.

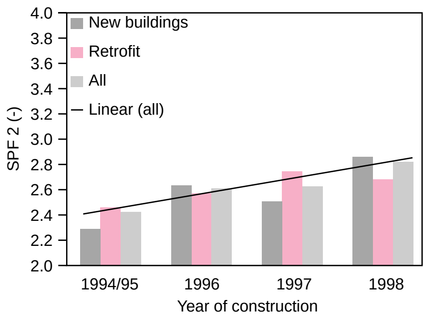
Figure 2 presents comparable data for B/W installations. The variation between individual years is considerable, and this decreases the precision with which the regression line can be calculated. The large variability in energetic efficiency of B/W installations, in combination with the relatively low number of samples taken, causes the considerable variation between individual years. The regression line plotted in Figure 2 shows an increase in the mean SPF2 value from 2.9 to 3.7 during the period studied, corresponding to an annual increase of almost 9%.

There appears to be considerable potential for improvements to the circulation pumps of the brine cycle. Studies presently being carried out aim to quantify this potential.

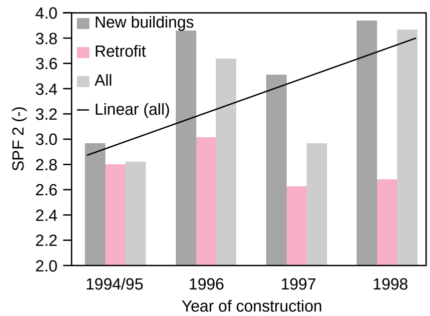
Aims of Energy 2000

Within the framework of the Swiss 'Energy 2000' programme, the objective was to achieve a 3% increase (compared to 1990) of the renewable energy share in the field of heat generation. To reach this aim, the Swiss Federal Office of Energy promotes heat pumps, as systems which use renewable energy. The strategy comprises of marketing activities and technical projects. The here presented FAWA project was set up in the frame of this strategy.

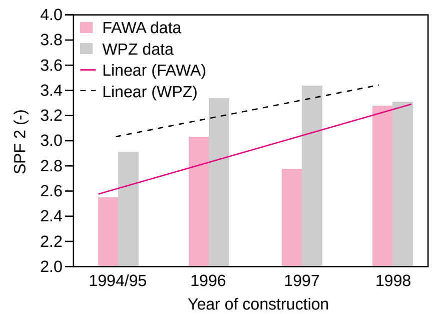
Energy 2000 led to a mean annual growth of the renewable energy produced by heat pumps of 4.5%. This is mainly due to the increase of the demand for heat pumps in new houses. The share of heat pumps in new houses is about 40%.



▲ *Figure 1: Mean SPF2 for A/W installations per year of construction and type of building. The regression line shows an annual increase in SPF2 of 6%.*



▲ *Figure 2: Mean SPF2 for B/W installations per year of construction and type of building. The regression line shows an annual increase in SPF2 of almost 9%. Due to the large standard deviation in this group, this trend is subject to considerable uncertainty.*



▲ *Figure 3: Estimate of overall SPF2 (FAWA = field measurements of SPF2; WPZ = 'normalised' COP measurements of Heat Pump Test Centre, Töss, Switzerland)*

Estimated overall mean values for Switzerland

To arrive at an estimate of the overall mean SPF2 for Swiss installations of a specific installation year, the mean annual values for the A/W and B/W installations were averaged by weighting each with its respective sales figure. The FAWA data in **Figure 3** present the results calculated in this manner. The overall mean SPF2 increases from 2.6 in 1994/95 to 3.2 in 1998, corresponding to a mean annual increase of almost 8%.

Results of the Heat Pump Test Centre

The Swiss Heat Pump Test Centre (WPZ) also determined the energetic efficiency of various heat pumps under standard laboratory conditions and in accordance with the European measuring standard EN255. The COP (Coefficient Of Performance) values thus measured were corrected to reflect overall mean annual conditions in the field - i.e. a source temperature of 2°C and a supply temperature of 42°C. The overall COP values thus calculated are presented in Figure 3 under the heading WPZ. The values show an annual increase of about 5% under these conditions. This increase is due to the improvement of the installations – 3% COP improvement per year for both A/W and B/W installations – and the increasing popularity of B/W which is more efficient than A/W.

It should be noted that the COP value differs from SPF2 in that the COP takes into account only the electricity used by the heat pump itself, whereas the SPF2, as mentioned earlier, takes into account the electricity used by the entire installation including auxiliary components.

For 1998, the difference between the overall mean COP value calculated as above and the overall mean SPF2 value actually measured in the field was less than 10%, which is about half as large as the difference for 1994/1995.

Ageing

At present, SPF2 values measured over several years of operation are available for a considerable number of installations. Since the number of installations increases every year, the database for operation year 1/2 is much larger (90 installations) than for year 4/5 (10 installations). In order to determine whether the energetic efficiency of the installations decreased over several years of operation, the values were climate-normalised (nSPF2).
The variations, presented in **Figure 4**, between the years of operation for all installations are not significant: no deviation from a value of 1.0, i.e. from a constant operational quality, can be determined. This is also true for the individual air/water or brine/water systems. As to the remaining types of installations (using water or a horizontal earth heat exchanger as heat source), no conclusions can be reached due to the small number of installations.

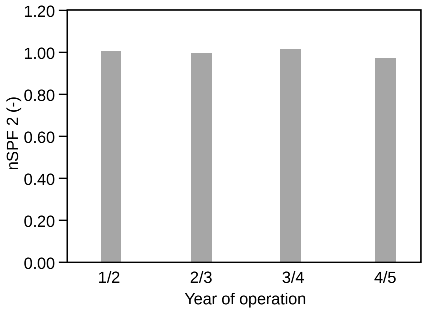
Types of operation and SPF2

Monovalent heating

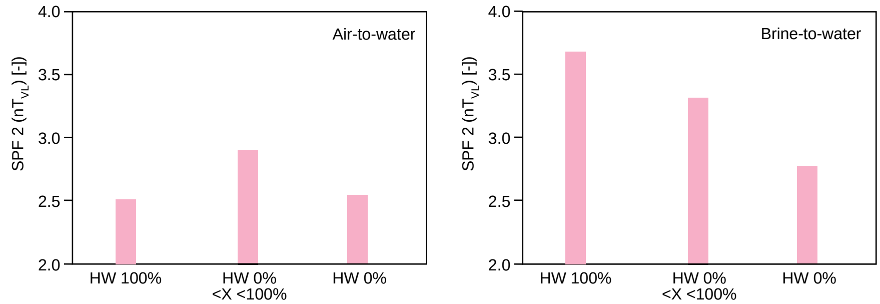
The thermal output of air/water installations decreases when the outside temperature goes down. For this reason, many installations use a backup auxiliary (electric resistance) heater that provides extra heat in case of low outside temperatures. Of all installations tested, over 50% were equipped with such a device. However, since the start of the project, less than 20% of the installations made use of it once, and only for a few hours. This means that in daily practice the great majority of the installations operate in a monovalent fashion, and that the heat pump generates sufficient heat even at low outside temperatures.

Hot water production

Half the installations tested also provide



▲ *Figure 4: Variation in percent of nSPF2 normalised to 1 over the years of operation for the total number of installations.*



▲ *Figure 5: SPF2 of A/W and B/W installations providing hot water (HW) at a ratio X between 100% and 0%. SPF2(nT_{VL}) stands for supply-temperature-normalised SPF2.*

some of the heat input used to supply domestic hot water. One quarter of the installations tested provide 100% of the heat input needed for the supply of hot water (100% ratio). **Figure 5** shows that installations that provide space heating and hot water are more efficient than those for space heating only. Also, brine-to-water heat pumps that supply 100% of the hot water demand are more efficient than the other types. The reasons for these findings have not yet been fully clarified. As the share of hot water in the total demand for heat in the installations tested is only about 20%, one would not expect this factor to have a major influence on the SPF2. The explanation may be found in the variations of the COP values of individual heat pump installations and systematic deviations of the mean temperatures of brine. These effects remain to be quantified.

Conclusions and perspectives

Between 1994/1995 and 1998, the overall energetic efficiency of newly installed heat pumps in Switzerland has continually improved from year to year. The improvement determined on the basis of field measurements was greater than that determined on the basis of measurements made under standard laboratory conditions and then corrected for overall mean field conditions. For 1998, this difference was reduced to less than 10%. Studies are presently underway to quantify the absolute differences between ‘normalised’ measurements under standard conditions and field measurements for individual heat pumps.

For heat pumps installed in 1998, an overall mean energetic efficiency of 3.2 was determined. This means that, from the perspective of CO_2 emission, heat pump systems already give better results than fossil energy operated heating systems. According to a life-cycle analysis using a European electricity mix, the break-even value is reached at an SPF2 value of around 2.3 when compared to oil heating and around 2.4 when compared to gas heating. Due to the physical advantages of brine/water installations with respect to the heat transition on the side of the evaporator, the overall mean SPF2 value for such installations is about 25% higher than for air/water installations.

Existing heat pump systems provide varying percentages of heat input (0 to 100%) for domestic hot water. The percentage of hot water supplied by the heat pump seems to improve the energetic efficiency of the system as a whole, but it is not clear in what manner or why. More work is needed in this respect. In some cases the field measurements revealed rather unsatisfactory results for SPF2. In the coming months, the causes of this will be investigated, too.

Markus Erb,
Dr.Eicher+Pauli AG
Kasernenstrasse 21
CH 4410 Liestal, Switzerland
Tel.: +41 61 921 9991
Fax: +41 61 923 0025
E-mail: markus.erb@eicher-pauli.ch

Peter Hubacher
Hubacher Engineering
Tannenbergstrasse 2,
9032 Engelburg, Switzerland
E-mail: he-ko@bluewin.ch

Ice thermal storage for energy conservation and reducing environmental load

Atsushi Suzuki, Japan

A dynamic type of ice storage system, named CLIS (Crystallized Liquid Ice thermal Storage unit), was installed in combination with an air-conditioning system using natural circulation of refrigerant, named VCS (Vapor Crystal System), in the Hanasaki Building in Yokohama. A supplementary cogeneration power unit was also installed to further increase peak shaving effects. As a result, 66% of the total electricity consumption by this building's heating and cooling plant is now consumed during the night. When compared to a heat pump system without thermal storage, the annual cost of electricity was reduced by 53.2% due to the lower cost of nighttime electricity. CO_2 emissions were reduced by 12.7% due to lower nighttime rates of CO_2 emission, because the share of nuclear power is larger.

Introduction

Today's air-conditioning systems should contribute to flattening the demand for electricity during the day-night cycle (i.e. reducing peak demand), reducing both global environmental load and running costs and improving the quality of the indoor environment. One solution that is expected to be capable of achieving these aims is the ice storage system. In 1986, the Japanese Takenaka Corp. together with the Sunwell Engineering Company Ltd. in Canada introduced the 'super chiller', which produces fine ice grains. Takenaka then developed a heat pump system incorporating the super chiller, called CLIS. CLIS is a closed system that can provide cooling and heating as well as reclaim heat energy. The Sunwell Japan Corp., established in 1990, has since worked to improve the quality and reduce the cost of these air-conditioning systems.

▲ *Figure 1: Hanasaki office building.*

The Hanasaki office building, completed in 1996, provides an example of the application of the above technology. Its gross floor area is 18,500 m2, and it has one story below ground and twelve stories above ground.

The following technological innovations were introduced in order to reduce both the running costs and the environmental load due to heating and cooling the building:

- CLIS (Crystallized Liquid Ice thermal Storage unit) dynamic type ice storage system;
- cogeneration using city gas;
- VCS (Vapor Crystal System) air-conditioning system using natural circulation of refrigerant;
- under-floor air-conditioning system;
- air barrier system preventing down draught at windows;
- control system for adjusting lighting according to daylight intensity.

The cooling and heating plant, the electrical system and cogeneration system are contained in a two-story steel structure on the roof, which increases the area available for office use when compared to standard office buildings.

Cooling and heating plant

The thermal storage system used in the cooling and heating plant is of the CLIS type (Figure 2). It contains a super chiller that generates ice by evaporating a refrigerant at the annulus of a double pipe. The refrigerant cools down a brine of low concentration in the inner pipe, where sherbet-type ice crystals are formed with a diameter between 50 and 150 μ. Since this sherbet type ice forms a suspension and has a very large total surface area, the system can adjust to variable demand loads quite well. Four modes of operation are possible: generating ice, cooling, heating and reclaiming heat. Ice can be generated and heating supplied simultaneously.

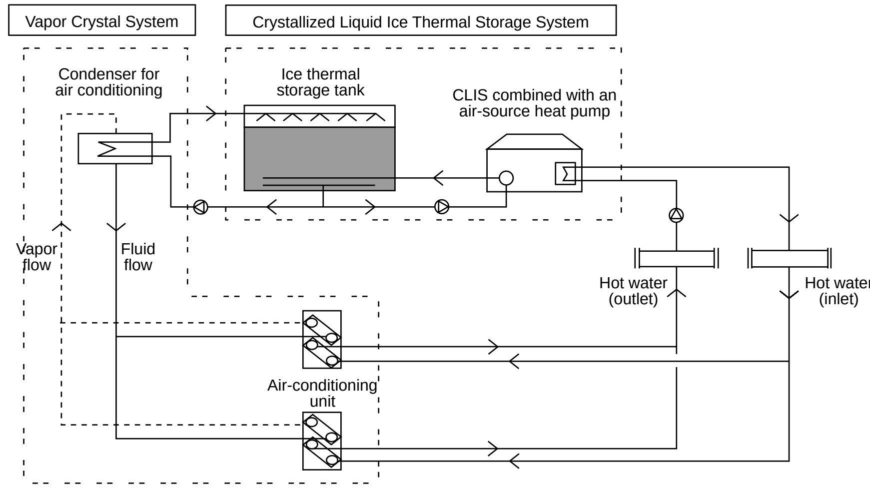
Although cooling is based on night-time ice storage, if insufficient ice has been stored to satisfy daytime cooling demand, the heat pump system can be operated to provide additional cooling. This mode of operation is controlled by the temperature in the ice storage tank. Heat is supplied by means of reclaiming heat from the storage tank as well.

Specifications of air source heat pump and thermal storage system:

- ice generating/cooling capacity: 109 kWx9
- heating capacity: 186 kWx9
- thermal storage capacity: 10,595 MJ ($90m^3$x3)

Cogeneration system

The power generating capacity of the cogeneration system using city gas is 200 kW. The aim of this system is peak shaving and reducing running cost of electricity. The cogeneration system works between 8.00 hrs and 22.00 hrs and is especially effective in reducing peak demand for electricity in summer.



▲ *Figure 2: Flow chart of the cooling and heating plant.*

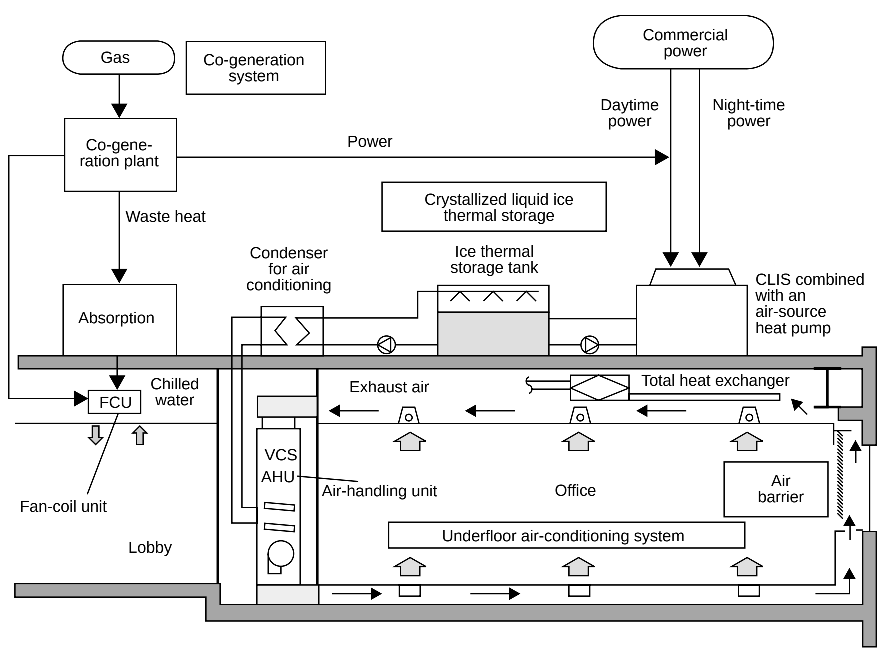
Air-conditioning system

Interior zone:
The VCS (Vapor Crystal System) air-conditioning system works with natural circulation of the refrigerant. This reduces the energy consumed, as no pump is needed for circulating the refrigerant. The VCS system works as follows. Refrigerant gas enters the upper part of the condenser placed on the roof. The gas is then condensed in the heat exchanger by the brine from the ice storage tank. The liquefied refrigerant flows into an air conditioning unit in each room, where it is evaporated by gaining thermal load from the room air. Then the vaporised refrigerant flows back to the condenser, due to the density difference between gas and liquid. This circulation does not consume any energy and continues as long as the system operates in cooling mode.

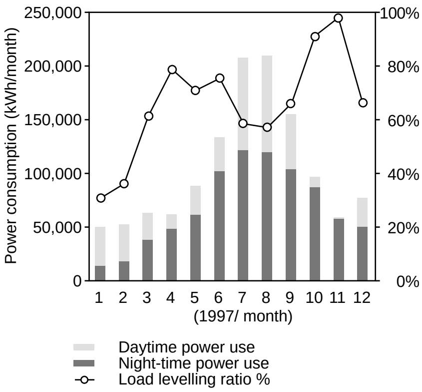
An under-floor air-conditioning system (**Figure 3**) is utilised to provide increased thermal comfort and reduce running costs. The characteristics of the under-floor air-conditioning system are as follows:

- high adaptability: in the case of changing partition walls or increasing or decreasing cooling and heating load, only the floor panel mounted outlet needs to be adapted;
- thermal comfort: air supplied from floor outlets immediately reaches the occupied zone and maintains the temperature difference between ankle height and neck height for a sedentary person at less than 2°C. Since floor outlets are mounted close to the occupants, they can easily control the airflow rate to suit their individual needs;
- economy: the ductwork for the supply of air is considerably reduced and this results in lower cost. As the pressure drop in the supply duct system is quite small, the power consumed by the fan and running costs are also reduced.

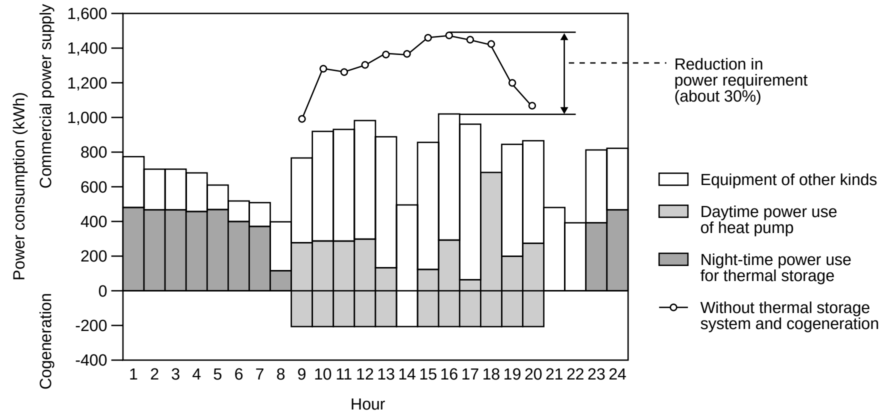
Perimeter zone:
In the perimeter zone, the air-conditioning system should both maintain thermal comfort and be energy-efficient. In the Hanasaki building, a so-called air barrier system was installed. Whereas conventional air barrier systems need special fans and ducts in the perimeter zone, the system in this building utilises an air curtain as a thermal barrier. The air is supplied from an outlet mounted on the counter along the windows. The return air is taken in through return grilles above the window.



▲ *Figure 3: The entire system including air conditioning, heating and power supply.*



▲ *Figure 4: Monthly power use by CLIS system and load levelling ratio.*



▲ *Figure 5: Electric power use on a hot summer day.*

This system is quite effective in maintaining a comfortable indoor environment as it blocks thermal radiation and cold draughts. It also helps reduce construction and maintenance costs.

Percentage of night-shifted electricity

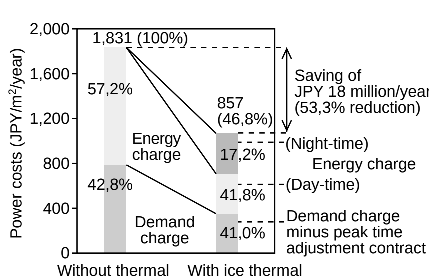
Figure 4 shows the monthly amount of electricity used for CLIS both in the nighttime (between 22.00 hrs and 8.00 hrs) and in the daytime (between 8.00 hrs and 22.00 hrs). The percentage of night-shifted electricity out of the total daily electricity used for CLIS was about 60% - even during July and August when the demand for cooling is at its peak. The average annual percentage of night-shifted electricity, including the heating season, was 66%. Since the cooling plant was dimensioned for a percentage of night-shifted electricity equal to 50%, the measured values were fairly close to the design values. The reason for the low percentage of night-shifted electricity between December and March is the necessity to operate the system in the heat recovery mode as well as cooling mode at the same time.

Benefits

Figure 5 shows the hourly consumption of electricity on a day of peak load. The thermal storage mode is operated from 10 PM to 8 AM. From 8 AM to 10 PM, stored ice is used for cooling, supplemented by the heat pump operating as a chiller. Power generated by cogeneration is indicated as minus values. Cogeneration provided 200 kWh of power for the heat pump chiller. Peak shaving effects are clearly demonstrated by the figure. The utilisation of thermal storage during nighttime and cogeneration during daytime made it possible to reduce peak demand for electricity by about 30%.

The annual cost of electricity was reduced by 53.2%, a saving of USD 170,000 (=18 million yen) when compared to a cooling and heating plant without a thermal storage system, see **Figure 6**.

Nighttime electricity consumption results in a reduced CO_2 emission rate. The reason is that some fossil-fuel fired plants are not operating at night, and the share of nuclear power, with zero CO_2-emissions, is larger than during daytime. The addition of a thermal storage system to the cooling and heating plant results in an overall nighttime percentage of electricity consumption equal to 66%. This works out to a reduction in CO_2 emissions from 22.8 kg CO_2/m^2 to 19.9 kg CO_2/m^2 or 12.7%.



▲ *Figure 6: Cost savings for heating and cooling.*

Conclusions

CLIS type thermal storage systems have already been installed in 198 buildings, including offices, hotels and museums. The total capacity of these systems for producing ice is now 96,650 kW. VCS type air-conditioning systems have been installed in over 60 buildings. These systems have by now proven their reliability and there is already sufficient experience with utilising them. This article makes it clear that in Japan such systems are already helping to flatten power demand, reduce running expenses for energy and reduce environmental load. The same systems can also be applied in factories that are controlled by HACCP (Hazard Analysis and Critical Control Points, a food hygiene practice standard) to deliver lower temperatures and optimise the heating and cooling systems.

Mr Atsushi Suzuki
Sunwell Japan Corporation
Tokyo Office
2-5-14 Minamisuna, Koto-ku, Tokyo, 136-0076 Japan
Tel.: +81-3-3646-0524
Fax: +81-3-5635-9350
E-mail: swsuzu@mta.biglobe.ne.jp

Climate 21 – A Swedish national research programme on heat pumps and refrigerating systems

Sara Dalenstam, Sweden

In July 1997, the Swedish National Energy Administration (STEM), in collaboration with partners from the Swedish refrigeration and heat pump industry and from universities, launched a national research programme called "Climate 21" and subtitled "Efficient refrigerating machines and heat pumps". The programme budget was estimated at USD 7 million, 40% of which was financed by STEM and 60% by its partners. The programme will run to March 2001. The framework for a three-year second stage of "Climate 21" has been prepared and presented to STEM.

Energy efficient systems in focus

"Climate 21" focuses on the development of state of the art technology for heat pumps and refrigerating systems that utilise energy very efficiently and are commercially viable. In judging environmental impact, the system as a whole is evaluated and not just a single unit. The area studied covers the entire technical chain from components to units and entire heat pump and refrigerating systems.

Collaboration between industry and universities

The programme's objective is to strengthen Swedish industry on a long-term basis through co-operation between universities and the industry, which leads to mutual exchange and transfer of knowledge. This will strengthen national development of heat pump and refrigerating technology and stimulate international collaboration in this field.

Activities

Six departments at four different universities and about 30 companies are currently involved in the programme. Sweden hosts some of the world's largest heat pump and refrigeration companies and they strongly support the programme. Many small companies with limited research budgets also play an important role. A total of thirteen projects are currently running. An open workshop has been held each year, where the project participants gather to exchange information.

The programme is now in its final phase. The final reports of the projects will be assembled on a compact disc. Some projects will continue in the second stage of Climate 21.

A summary of the current status and background of the most important projects follows.

Refrigerants

New refrigerant blends to replace R-22 in heat pumps for district heating

The Montreal Protocol, combined with special regulations in Sweden that restrict the use of HCFCs, forbids their use from 2002 onwards for heat pumps and cooling machines. R-134a is commonly used to replace R-22. In certain cases, for example larger heat pumps for district heating purposes, conversion to R-134a will result in reduced capacity. Therefore, tailor-made combinations of commercially available refrigerants have been developed to replace R-22.

The replacement of R-22 in new and existing facilities - energy efficiency, economy and environmental consequences

This project studied technical, economic and environmental consequences of replacing R-22 by new chlorine-free refrigerants from the perspective of the user/owner of the installation. A method has been developed, which the user/owner of the installation can use to gather information on the economic and environmental aspects of the options available.

Lubrication of rolling element bearings in refrigeration compressors

Replacing old refrigerants with new blends demands new knowledge of how different components' solubility in oil will affect the properties of the lubricant in a dynamic situation, such as in the bearing cavity of a screw compressor. Tests run at different loads show that there is a clear breakpoint at a certain concentration of R-134a, where the bearing will break down. Adequate knowledge of the minimum required viscosity will make it possible to design more efficient and reliable compressors.

Food sector

Energy-efficient solutions for supermarkets in theory and practice

In Sweden a state-of-the-art study identified various system solutions for supermarket refrigeration: direct systems, completely indirect systems, partially indirect systems, cascade systems and district cooling with special applications. These system solutions were used to develop computer tools for energy optimisation of supermarkets.

The display cabinet

Experimental studies of the display cabinet in the store identified two main influences on its operation and performance: the surrounding climate and the way the display cabinet is loaded. Future analyses based on (completed) experimental studies in a laboratory test cabinet and ongoing fluid dynamics modelling will provide improved knowledge of the air distribution inside the cabinet as well as the exchange with the surroundings.

The final goal is to develop an entirely new concept to reduce the energy use and simultaneously improve the quality of the merchandise by better temperature control.

The cooling-coils of the display cabinet
In order to develop a more efficient display cabinet it is also important to study the energy efficiency of its cooling-coils (the battery). This ongoing project aims to analyse the limitations regarding heat transfer and pressure drop in present-day indirectly cooled finned-tube coils and subsequently estimate the potential for improvement.

Systems

Low-temperature-driven absorption chiller
Absorption chillers make it possible to increase the use of renewable energy sources and the share of rational co-generation of power and heat. For these reasons, an absorption chiller was developed that uses low-grade thermal energy, primarily in the form of district heating, to produce district cooling. Three generations of chillers have been constructed, 1 kW, 30 kW, and 1.15 MW.

Simulation of heat pump systems behaviour
A factor crucial to the widespread introduction of heat pumps is the ability to compare the behaviour of different heating systems. This project developed a simulation model and a computerised tool that calculate performance, heating demand and electricity demand and energy savings for various residential installations. The computer program takes into account such characteristics as different heat sources, distribution systems, insulation, climate conditions, inertia etc.

Integrated control of refrigeration and heat pump systems
This project was started recently and will provide information useful for developing integrated control systems for heat pumps and refrigeration systems. The control system will contribute to a substantial reduction in the energy input to heat pump installations, while at the same time improving their operational reliability.

Components

Efficient evaporators for refrigerators and freezers
Swedish manufactures of refrigerators and freezers are interested in improving the design of the evaporators in order to maximise the system's energy efficiency. This project aims to extend the knowledge of the evaporation process. Correlations for pressure drop and heat transfer coefficients will be developed and incorporated in a design tool. Important results, for example regarding the flow regimes in the evaporator, have already been realised. Furthermore, cycling losses related to the evaporator were discovered, revealing a potential for energy savings (see **Figure 1** and text in box).

Heat transfer and pressure drop during evaporation in compact brazed-plate heat exchangers
Swedish manufacturers pioneered the development of the plate heat exchanger. The technique of brazing the plates together broadened the applicability of this type of heat exchanger and made it suitable for use in evaporators and condensers for refrigerating applications. This project investigates the mechanisms of two-phase flow and pressure drop during the boiling of the refrigerants inside compact brazed-plate heat exchangers, and thus obtains fundamental knowledge of the mechanisms during boiling. Experiments include visualisation studies and systematic investigation of the influence of different parameters, such as geometric and thermodynamic parameters. The ultimate goal is to arrive at correlations that predict heat transfer and pressure drop.

Climate 21–stage two

The framework for a second stage of "Climate 21" has been prepared and presented to STEM. The second stage will most probably aim at more efficient heat pump and refrigeration technology in systems. The intention is also to encourage international collaboration. Some projects in today's programme will continue in the next phase of "Climate 21".

M. Sc. Sara Dalenstam
Programme Secretary
Royal Institute of Technology, KTH
Dept. of Energy Technology / Climate 21
Brinellv. 60
SE-100 44 Stockholm, Sweden
Tel.: +46 8 790 7460
Fax: +46 8 20 30 07
E-mail: klimat21@egi.kth.se

Analysing refrigerant flow and evaporation

The Climate 21 studies on efficient evaporators for refrigerators made it clear that the efficiency of the evaporator can be improved. During the start sequence, a large part of the refrigerant is pumped out from the evaporator without evaporating. Furthermore, about 10% of the evaporator is used solely for superheating; this percentage needs to be reduced.

Measurements with infrared camera
An infrared camera was used to visualise refrigerant flow during start and stop sequences in both the evaporator and the condenser of a domestic refrigerator. Analysis of the pictures taken show for instance how the liquid refrigerant, after the compressor is started, moves from the evaporator to the condenser, where it is cooled down before it flows back to the evaporator.

Observations from the glass evaporator
The evaporator channels were opened up and partially replaced by glass coverings to allow visual observation of the refrigerant's flow regimes (see Figure 1). These observations confirm that after the compressor is started, the refrigerant leaves the evaporator in liquid phase and then gradually refills it.

▲ *Figure 1: Glass evaporator and camera on stand*

Recent trends in Japanese R&D on chemical heat storage/heat pump systems

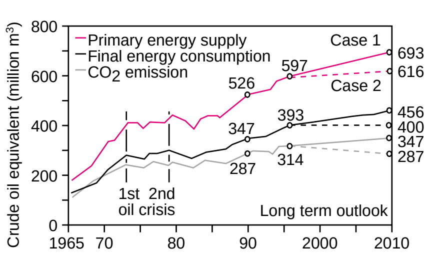
Mitsuhiro Kubota, Fujio Watanabe and Hitoki Matsuda, Japan

Concern about global environmental problems such as global warming and acid rain led to the adoption of the Kyoto Protocol UNFCCC-COP3 in December 1997. In this protocol, Japan committed itself to reduce emissions of six key greenhouse gases by 6% before the period 2008-2012. Recent Research and Development (R&D) efforts on alternative heat and energy sources have focused on chemical heat storage/ heat pump systems.

Introduction

Figure 1 presents an historical overview of energy consumption and CO_2 emissions in Japan. The oil crises of 1973 and 1979 made clear to Japan the fragility of its energy supply structure. Since then, Japan has promoted energy conservation measures – mainly in the industrial sector. From 1973 to 1992, the Japanese government implemented the Sunshine and Moonlight Projects, with the goal of developing alternative energy sources and highly efficient advanced energy utilisation technologies (**Table 1**). Figure 1 shows two scenarios for the development of energy consumption and CO_2 emission in Japan. Case 2 represents the intention of the government to stabilise the annual energy consumption growth rate at about 1% from 1997 to 2010 and to stabilise carbon dioxide emissions at 1990 levels. However, energy consumption in Japan continues to grow rapidly. If the present trend continues, it will be difficult to achieve the Kyoto Protocol goals on energy consumption and CO_2 emissions.

In Japan, heat loss accounts for over 60% of primary energy consumption. In theory, much of this heat, which is discharged into the environment, could be put to good use. However, due to the disparity in terms of both time periods and temperature available, between this supply of waste heat and the demand for heating and/or cooling energy, it is often difficult to utilise this very large supply of waste energy. Heat storage and heat pump systems are technologies for solving the problems of time lag and temperature differences by storing and upgrading heat energy. Chemical heat storage systems cannot only store energy at a high density; some systems can also operate over a wide temperature range as a heat pump.



Case 1: Business as usual (no additional energy conservation measures) scenario
Case 2: Scenario with additional measures for energy conservation and development and introduction of new energy

▲ *Figure 1: Energy consumption and CO_2 emission in Japan.*

▼ *Table 1: Milestones and programmes for energy and environment in Japan and the world.*

Year	International	Japan		
1973	1st oil crisis			
74		The Sunshine Project (New energy technology)		
78			The Moonlight Project (Energy conservation technology) **R&D on SHP**	
79	2nd oil crisis			
85	Vienna Convention			
87	**Montreal Protocol**	Ozone layer protection law		
89				R&D Project for Environmental Technology
90	IPCC - 1st report	Action programme to arrest global warming		
92	Copenhagen agreement (Phase-out of CFCs by the year 1996)			
93		**The New Sunshine Program** renewable energy, advanced utilisation of fossil fuels, energy transportation and storage, systematisation technology, environmental technology, basic & fundamental technology related to energy and environmental aspects		
95	UNFCCC-COP1			
	IPCC - 2nd report			
96	UNFCCC-COP2			
97	UNFCCC-COP3 **Kyoto protocol**			
98		Amendment of the energy conservation laws		
		Law concerning the projects of the measures to cope with global warming		
	UNFCCC-COP4			
2010	6% cut in the emissions of greenhouse gases in Japan			
2020				

These chemical heat storage/heat pumps systems are expected to play an important role in utilizing heat energy that would otherwise be wasted. In Japan, Research and Development (R&D) on chemical heat storage and chemical heat pump systems was carried out in the framework of the project '**S**uper **H**eat **P**ump Energy Accumulation System' or SHP.

Super Heat Pump Energy Accumulation System (SHP)

R&D on SHPs was carried out from 1984 until 1992 as part of the Moonlight Project, supported by the Ministry of International Trade and Industry. This project was aimed at developing super heat energy accumulation systems that could contribute to energy conservation and electric power load levelling by promoting utilisation of night-time surplus electric power. The following component technologies were considered:

a) Super high performance compression heat pump technology;

b) Chemical heat storage technology.

This was the first national project that focused on and recognised the importance of heat storage technology. In the project, chemical heat storage systems would store high or low temperature heat energy generated by heat pumps, driven by night-time surplus electric power. This stored energy would then be released in the daytime for air conditioning in large buildings, large-scale district heating/cooling, process heating in various industries etc. A summary of this research is presented in **Table 2**.

As shown in Table 2, the test results achieved for all the systems met the R&D goals established. However, no system has yet been commercialised. It was concluded that in order to commercialise such a system, additional R&D activities would have to be carried out aimed at reducing initial costs and running costs and downsizing the heat storage equipment.

▼ *Table 2: Summary of R&D on chemical heat storage and heat pump systems in the SHP Project.*

	Reaction	Type*	Temperature (°C) Input	Temperature (°C) Output	Storage capacity (kJ/kg) Target	Storage capacity (kJ/kg) Results	Heat recovery ratio (%) Target	Heat recovery ratio (%) Results
Clathrate formation reaction	HCFC-141b(l) + H_2O(l) =HCFC-141b•17H_2O(s)	HS	5-6	10	125.6	134.0	90	93.2
Solute mixture hydration reaction	*dil.* $CaCl_2$/LiBr(l) =conc. $CaCl_2$/LiBr(l)+H_2O(g) H_2O(g)=H_2O(l)	HP	85	7	125.6	152.0	75	79.3
Hydration reaction	$CaBr_2$•2H_2O(s) =$CaBr_2$•H_2O (s)+H_2O(g)	HS	150	150	192.6	206.0	61	66.4
	H_2O(g)=H_2O(l)	HP	150	200				
Ammonia complexes reaction	$NiCl_2$•6NH_3(s) =$NiCl_2$•2NH_3(s)+4NH_3(g) NaSCN•$n$$NH_3$($l$)+$NH_3$($g$) NaSCN•($n$+1)$NH_3$($l$)	HS	200	200	108.9	157.4	20	38.2
Solvation reaction	*dil.* TFE/E181(l) =*conc.* TFE/E181(l)+TFE(g) TFE(g)=TFE(l)	HS	85	85	144.4	157.8	57.8	60.5

*HS = Heat storage, HP = Heat pump

▼ *Table 3: Overview of more recent R&D on chemical heat storage/heat pump systems in Japan.*

Adsorption system	Temperature (K) Heat source	Output	Institute	Researcher	Contact
A-1 Silica gel/water	343-363	278-283	Nagoya University	Fujio Watanabe	watanabf@nuce.nagoya-u.ac.jp
A-2 Activated carbon/ ethanol	343-373	268	the same as above		
A-3 High-silica zeolite/water	373-423	423-513	National Chemical Laboratory for Industry	Ichiro Fujiwara	ifuji@nimc.go.jp

Organic reaction system	Temperature (K) Heat source	Output	Institute	Researcher	Contact
O-1 Hydrolysis of acetal	363	283	Tokyo Institute of Technology	TakayukiWatanabe	watanabe@o.cc.titech.ac.jp
O-2 Paraldehyde/ Acetaldehyde	303	283	the same as above		
O-3 Acetone/ 2-propanol	353	473	Science University of Tokyo	Yasukazu Saito	yassaito@ci.kagu.sut.ac.jp
O-4 Benzene/ Cyclohexane	473	623	Tokyo University of Agriculture & Tech.	Hideo Kameyama	tatkame@cc.tuat.ac.jp

Inorganic reaction system	Temperature (K) Heat source	Output	Institute	Researcher	Contact
I-1 $MgO/H_2O/Mg(OH)_2$	600	373-423	Tokyo Institute of Technology	Yukitaka Kato	yukitaka@nr.titech.ac.jp
I-2 $CaO/H_2O/Ca(OH)_2$	673	873	Nagoya University	Hitoki Matsuda	matsuda@nuce.nagoya-u.ac.jp
I-3	673	278 & 353	Kyushu Institute of Technology	Hironao Ogura	ograh@che.kyutech.ac.jp
I-4 $CaO/CO_2/CaCO_3$	773	1273	the same as I-2		
I-5 $BaO/CO_2/BaCO_3$	1273	1773	the same as I-2		
I-6 $CaCl_2$/Methyl amine	343	273-293	Osaka University	Yushi Hirata	hirata@cheng.es.osaka-u.ac.jp
I-7 Metal Hydrides	413	253	Sanyo Electric Co., Ltd	Kenji Nasako	nasako@ mech.rd.sanyo.co.jp

Recent trends in R&D on chemical heat storage/heat pump systems

The main focus of R&D in Japan has been on the environmentally friendly chemical heat pump and storage systems since the SHP Project ended in 1992. This is important because of the high demand for ‘cold energy’ and the need for more environmentally friendly energy utilisation systems.

Demand for cooling

In Japan, especially in summer, cooling below 10°C is in great demand for creating a comfortable working and living environment. It is impossible to supply this cooling without heat transformation. For this, the heat pump function is needed that can not only store thermal energy but also transform it to the desired temperature.

Need for more environmentally friendly energy utilisation systems

In the SHP Project, mainly chemical heat storage systems using CFC and HCFC were developed by large industrial companies. Such substances negatively impact the environment. Since the SHP Project, global environmental issues have come to the fore and more emphasis is being placed on overall environmental impact. Heat storage systems should not only be highly efficient; in order to save energy, they should also make use of environmentally friendly substances. At present, the HPTCJ (Heat Pump & Thermal Storage Technology Centre of Japan) is promoting research into heat storage and heat pump technologies using substances such as H_2O, CO_2, alcohol, NH_3 and H_2 as alternatives for CFC and HCFC. The universities and the national research institutes are carrying out their research mainly on a laboratory scale. Most of the proposed systems make use of adsorption phenomenon, organic chemical reactions or inorganic chemical reactions (absorption heat pump technology is outside the scope of this article). **Table 3** gives an overview of the heat storage systems proposed by researchers in Japan and the parties involved in the work.

Table 4: Technical problems and possible solutions for the different systems

Technical problems	Development & improvement	Reference no. in Table 3
Adsorption system		
• Low adsorptivity of adsorbent	Silica gel synthesized by the addition of Al-ion	
	Activated carbon coated with silica film	
• Heat/mass transfer resistance in adsorber	Silica gel-tube module	A-1
	Direct heat exchange silica gel module	
	Disk type module of activated carbon	
• Low desorption rate	Irradiation of microwave	
	Supplement of compressor	
Organic system		
• Low reaction rate		
• Low selectivity by side reaction	Preparation of high performance catalyst	O-2, 3, 4
• Low heat transfer rate	Finned tube reactor/heat exchanger coated with catalyst	O-3, 4
Inorganic system		
• Heat/mass transfer resistance in reactor	Copper fin	I-2, 3
	Copper mesh	I-3
	Mixture of graphite	
• Decrease in reactivity with repeated action	Reactant immersed in metallic ionic solution	
	Steam activation	I-2

Figure 2: Heat storage density as a function of heat source temperature.

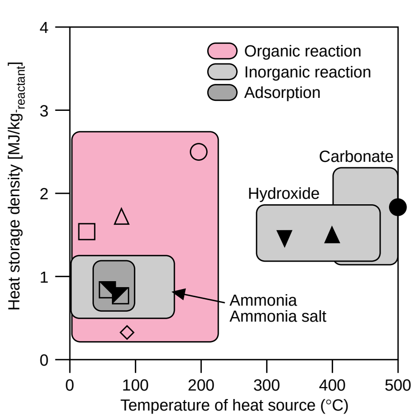
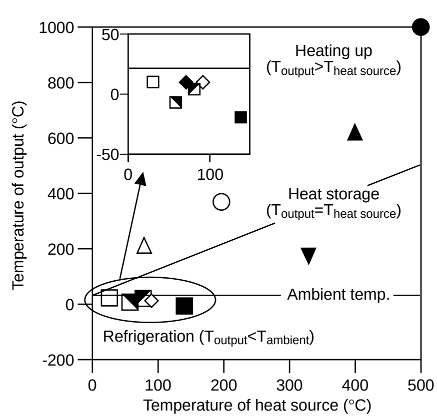


Figure 3: Relationship between output temperature and temperature of heat source.



Adsorption system
- ◩ A-1: Silica gel/water
- ◪ A-2: Activated carbon/ethanol

Organic system
- ◇ O-1: Hydrolysis of acetal
- □ O-2: Paraldehyde/acetaldehyde
- △ O-3: $(CH_3)_2CHOH=C(CH_3)_2CO+H_2$
- ○ O-4: $C_6H_{12}=C_6H_6+3H_2$

Inorganic system
- ▼ I-1: $Mg(OH)_2=MgO+H_2O$
- ▲ I-2: $Ca(OH_2)=CaO+H_2O$
- ● I-4: $CaCO_3=CaO+CO_2$
- ◆ I-6: $CaCl_2/CH_3NH_2$
- ■ I-7: Metal Hydrides

Figures 2 and 3 show heat storage density and output temperature as a function of the heat source temperature for the systems listed in Table 3. Figure 2 makes it clear that the adsorption, organic and inorganic reaction systems are aimed at operating mainly in, respectively, the low, middle and low to high temperature range. Figure 3 shows that chemical heat storage/heat pump systems, especially the inorganic ones, can operate over a wide temperature range.

Some adsorption heat pumps have already been commercialised for air conditioning, but most chemical heat storage/heat pump systems are still in the development stage. **Table 4** lists some of the technical problems still to be overcome as well as some of the proposed approaches and solutions.

Summary and outlook

An overview is presented of the trends in R&D on chemical heat storage/heat pump systems in Japan. Such systems have been the focus of much research due to their ability to store and upgrade large amounts of heat energy over a wide temperature range. More recently, the accent has shifted to developing more environmentally friendly systems. Many problems still have to be solved to realise the commercial development of highly efficient chemical heat storage/heat pump systems. The main problems are applicability, reliability, economics and social infrastructure. It is expected that chemical heat storage and heat pump systems can grow out to be key technologies in preventing the destruction of the environment.

Acknowledgement

Material provided by the Heat Pump & Thermal Storage Technology Center of Japan and the working party on Thermal Energy Storage, Heat Pump, Thermal Energy Transport Technology was greatly appreciated in preparing the present article.

Mitsuhiro Kubota, Fujio Watanabe and Hitoki Matsuda
Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603 Japan
Tel.: +81 52 789 3382
Fax: +81 52 789 5619
E-mail: matsuda@nuce.nagoya-u.ac.jp

Fridoc database
International Institute of Refrigeration (IIR), 177 Boulevard Malesherbes, 75017 Paris, France. Fax: +33-1-4763-1798, E-mail: doc@iifiir.org.

	IIR Associate members	Public, universities, schools
Fridoc CD-ROM[2]	FRF 4900-6400[1,2]	FRF 7500[2]
Fridoc via Internet	FRF 3000-3900[1,3]	FRF 7500[2,3]
Fridoc CD-ROM and Internet	FRF 5500-7250[1,2,3]	FRF 8500[2,3]

1 Prices depending on membership type: private, collective or benefactor. Please contact IIR for details
2 Discount for renewed subscription (approximately 40%)
3 Several passwords available to collective and benefactor associate members, and schools and universities

A wealth of information regarding refrigeration, air conditioning and heat pumps is available through the IIR Fridoc database. Fridoc is a bilingual database of over 60,000 international references (articles and books) on all refrigeration application areas published since 1982. All abstracts are in English and many also in French. Copies of documents cited in the database can be ordered. Fridoc enables multi-criteria and natural-language searches and is available in CD-ROM form and on the Internet. Subscribers who register through the HPC will be offered a special 10% discount on the normal retail price. For associate members, free search options are made available that provide the title of papers and the name of the author(s). Only full subscribers have access to additional information.

Heat Pumps in Cold Climates, Fourth international conference
Proceedings
Caneta Research Inc., 7145 West Credit Ave., Suite 102, Building 2, Mississauga, Ontario, Canada, L5N 6J7, Fax +1-905-542-3160, E-mail caneta@compuserve.com, issued on CD in Acrobat format, Price USD 75.

The proceedings from the August 2000 Conference held in Aylmer, Quebec contains a total of 34 papers, some presented by well known experts in the field, on both heat pump market and application topics such as market development initiatives, making ground-source heat pumps mainstream, design tool shoot-out, climate change, heat pump standards, monitored results from ground-source projects, deregulation update, regulatory and market issues and novel and advanced systems. If you missed the Conference, order your copy of the Proceedings now.

Selected issues on CO_2 as working fluid in compression systems
Workshop proceedings Trondheim, Norway
IEA Heat Pump Centre, address - see back cover, 140 pages, Price NLG 180 or NLG 60 in Annex participating countries

These proceedings of the first Annex 27 workshop discuss possible applications, compressors and fundamental aspects related to the use of CO_2 as a refrigerant. The presentations on applications include transcritical cycles for mobile air conditioning, tap water heating, residential and commercial space conditioning, CO_2 as a secondary working fluid in supermarkets and industrial applications, and CO_2 as a low temperature refrigerant in domestic freezers. There are two presentations on CO_2 compressors. Fundamental aspects discussed include heat transfer, pressure drop, and safety issues. The report further contains conclusions from the group work sessions, which identify challenges and opportunities related to CO_2 technology in the areas of applications, compression/expansion machines, heat transfer and safety.

Available from the HPC

PLEASE USE THE ATTACHED RESPONSE CARD WHEN ORDERING HPC PRODUCTS

NEW **Considerations in the selection of heating and cooling distribution and ventilation systems and their use with residential heat pumps**
HPC Survey report, December 2000
Order no. HPC-AR-8, NLG 240 or NLG 80 in HPC member countries.

NEW **Selected issues on CO_2 as working fluid in compression systems**
Workshop proceedings, January 2001
Order no. HPP-AN27-1, NLG 180 or NLG 60 in JP, NO, SE, UK and US. *see page 26*

Ab-sorption machines for heating and cooling in future energy systems
Annex 24 final report, November 2000
Order no. HPP-AN24-4, NLG 100. Only available in CA, IT, JP, NL, NO, SE, UK and US up to 1 December 2002.

Ab-sorption machines for heating and cooling in future energy systems – San Francisco and Turin workshops
Workshop reports, November 2000
Order no. HPP-AN24-3, NLG 180 or NLG 60 in CA, IT, JP, NL, NO, SE, UK and US.

Natural Working Fluids – a challenge for the future
Workshop Proceedings, February 2000
Order no. HPC-WR-21, NLG 180 or NLG 60 in HPC member countries

International Heat Pump Status and Policy Review: 1993-1996
Analysis Study, August 1999
Order no. HPC-AR-7, NLG 480 or NLG 160 in HPC member countries

Guidelines for Design and Operation of Compression Heat Pump, Air-Conditioning and Refrigerating Systems with Natural Working Fluids Final Report, December 1998
Order No. HPP-AN22-4, NLG 100. (Only available in CA, CH, DK, JP, NL, NO, UK and US until 5 June 2001).

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

2001

Arab-African Conference for Refrigeration and Air Conditioning
29 April-1 May 2001 / Cairo, Egypt
Co-sponsored by IIR, Commission B2, E1, E2
Contact: Prof. Dr M. Nagi Shatla
The American University in Cairo
PO Box 2511, Cairo, Egypt
Fax: +20-2-7957565
E-mail: Counslor@aucegypt.edu
Information: http://www.aac.com.eg

ASHRAE Annual meeting, including symposium "Experiences with Alternative Refrigerants in Unitary Split Systems"
23-27 June 2001 / Cincinnati, USA
Contact: ASHRAE Meetings Section
1791 Tullie Circle NE
Atlanta, GA 30329, USA
Fax: +1-404-3215478
E-mail: jyoung@ashrae.org

CIAR 2001 (Congreso Iberoamericano de Aire Acondicionado y Refrigeración)
15-17 August 2000 / Buenos Aires, Argentina
Co-sponsored by IIR commissions B1, B2, E1, E2
Contact: Comite organizador
Fax: +54-1-4362-2517
E-mail: rhmasche@volta.ing.unlp.edu.ar

Refrigerant management and destruction technologies of CFC
Joint conference of IIR commissions B2, B1, E1 and E2; HPC co-sponsored
29-31 August 2001 / Dubrovnik, Croatia
Contact: Zdenka Kuhta
Center of Technology Transfer
Fax: +385 1 611 8710
E-mail: r-conference@fsb.hr
Information: http://www.fsb.hr/r-conference

2nd International Heat Powered Cycles Conference – Cooling, Heating and Power Generation Systems
5-7 September 2001 / Paris, France
Contact: Dr Pierre Neveu, CNAM, Paris
E-mail: neveupi@cnam.fr
Information: http://www2.cnam.fr/iffi/hpc.htm

Thermophysical Properties and Transfer Processes of New Refrigerants
3-5 October 2001 / Paderborn, Germany
Co-sponsored by IIR, Commission B1
Contact: Mrs Dr Andrea Luke
Universität Paderborn, Warburger Straße 100
D-33098 Paderborn, Germany
Tel.: +49-5251602392
Fax: +49-5251603522
E-mail: luke@wkt.uni-paderbron.de

2002

International Sorption Conference 2002
24-27 September 2002 / Shanghai, China
Contact: Dr Wang Wen
Institute of Refrigeration & Cryogenics
Shanghai Jiao Tong University
1954 Huashan Road
Shanghai 200030, China
Fax: +86-21-62933250
E-mail: ISHPC@sjtu.edu.cn

5th Gustav Lorentzen Conference on Natural Working Fluids
5-8 October 2002 / Guangzhou, China
Contact: Yanhua Liu
Guangdong Association of Refrigeration,
48# Dongshan qu miao qian xi jie
Guangzhou 510080, China
Tel.: +86-20-87674286
E-mail: gdra@gdra.org.cn

IEA Heat Pump Programme events

Hands-on experiences with heat pumps in buildings
10-11 October 2001 / Arnhem, the Netherlands
HPC/IPUHPC (International Power Utility Heat Pump Committee) joint workshop
Contact: Ms Minie Wilpshaar, HPC
Novem, the Netherlands
Fax: +31 46 4510 389
E-mail: hpc@heatpumpcentre.org

7th IEA Heat Pump Conference
19-22 May 2002 / Beijing, China
Host: China Academy of Building Research
Contact: Ms Francien Somers, TSSU
Novem, the Netherlands
Fax: +31 46 4510 389
E-mail: hpp@novem.nl

Next Issue

Performance standards and certification of heat pump installations

Volume 19 - No.2/2001

International Energy Agency

The International Energy Agency (IEA) was founded in 1974 as an autonomous body within the Organisation for Economic Co-operation and Development (OECD) to implement an international energy program. Activities are directed towards the IEA Member countries' collective energy policy objectives of energy security, economic and social development, and environmental protection.

IEA Heat Pump Programme

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

Vision

The Programme is the foremost world-wide source of independent information and expertise on heat pump, refrigeration and air–conditioning systems for buildings, commerce and industry.

Mission

The Programme serves the needs of policy makers, national and international energy & environmental agencies, utilities, manufacturers, designers & researchers. It also works through national agencies to influence installers and end-users.

The Programme develops and disseminates factual, balanced information to achieve environmental and energy efficiency benefit through deployment of appropriate high quality heat pump, refrigeration and air-conditioning technologies.

IEA Heat Pump Centre

A central role within the Programme is played by the IEA Heat Pump Centre (HPC). The HPC contributes to the general aim of the IEA Heat Pump Programme, through information services and knowledge transfer. In the member countries (see right), activities are coordinated by National Teams.

The IEA Heat Pump Centre is operated by

Novem

Netherlands agency for energy and the environment

National Team Contacts

Austria
Mr Hermann Halozan
TU Graz, Inffeldgasse 25
A-8010 Graz
Austria
Tel.: +43-316-8737303
Fax: +43-316-8737305
E-mail: halozan@iwt.tu-graz.ac.at

Japan
Mr Takeshi Yoshii
Heat Pump & Thermal Storage
Technology Center of Japan
Kakigara-cho F Bldg.(6F)
28-5, Nihonbashi Kakigara-cho 1-chome
Chuo-ku, Tokyo 103-0014, Japan
Tel.: +81-3-56432401
Fax: +81-3-56414501
E-mail: yoshii@host2.hptcj-unet.ocn.ne.jp

The Netherlands
Mr Edward Pfeiffer
Novem, PO Box 8242
3503 RE Utrecht
The Netherlands
Tel.: +31-30-2393631
Fax: +31-30-2316491
E-mail: e.pfeiffer@novem.nl

Norway
Mr Rune Aarlien
SINTEF Energy Research
Refrigeration and Air Conditioning
N-7465 Trondheim, Norway
Tel.: +47-73-593929
Fax: +47-73-593950
E-mail: rune.aarlien@energy.sintef.no

United Kingdom
Mr Jeremy Tait
ETSU
Harwell, Oxon
Oxfordshire OX11 0RA, UK
Tel.: +44-1235-433611
Fax: +44-1235-433727
E-mail: jeremy.tait@aeat.co.uk

USA
Ms Julia Kelley
Oak Ridge National Laboratory
Building 3147, PO Box 2008
Oak Ridge, TN 37831-6070, USA
Tel.: +1-865-5741013
Fax: +1-865-5749329
E-mail: j4u@ornl.gov

IEA Heat Pump Centre
Novem, P.O. Box 17
6130 AA Sittard,The Netherlands
Tel: +31-46-4202236
Fax: +31-46-4510389
E-mail: hpc@heatpumpcentre.org
Internet: http://www.heatpumpcentre.org