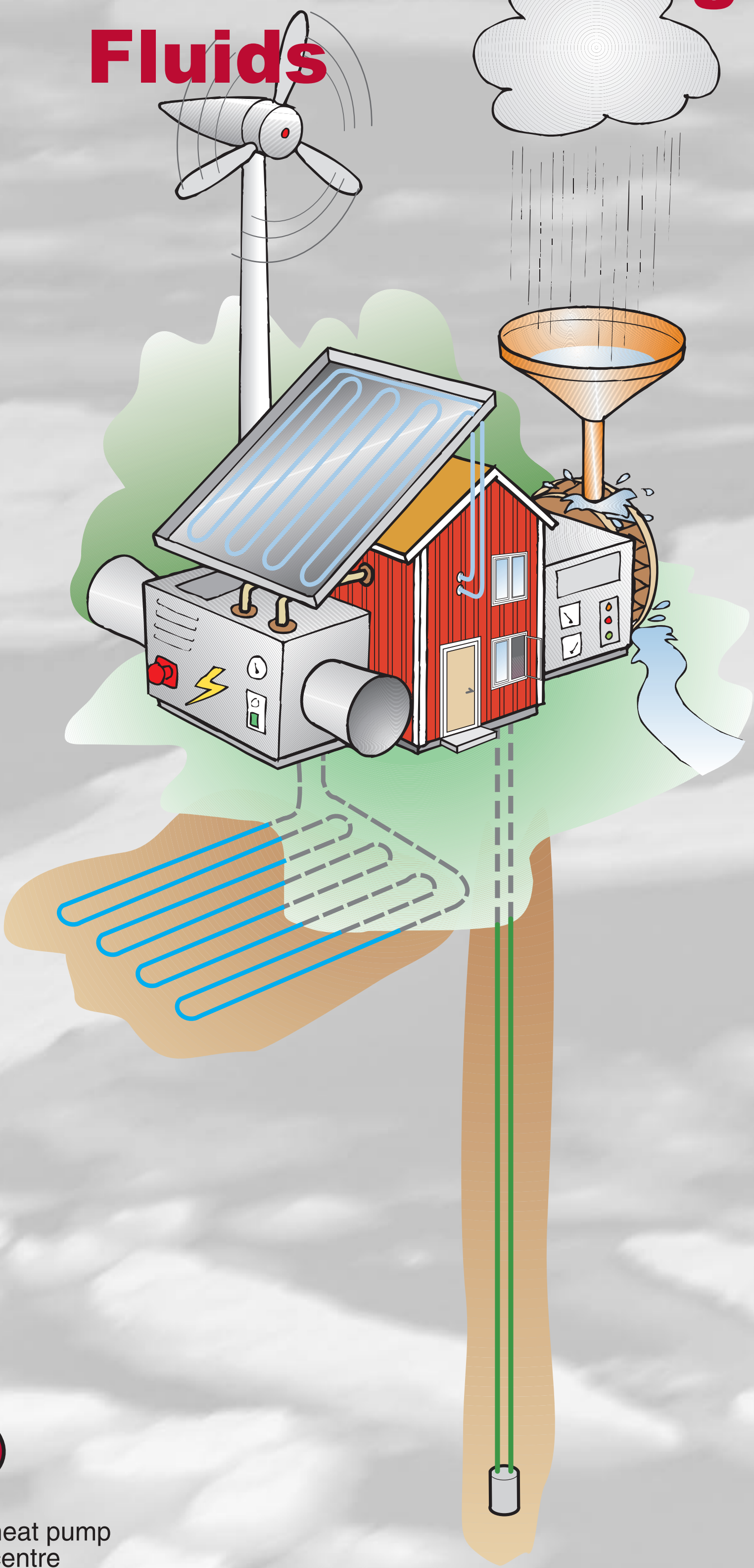
IEA Heat Pump CENTRE NEWSLETTER

Volume 22
No. 1/2004

Natural Working Fluids



IEA
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IEA **Heat Pump** CENTRE
NEWSLETTER

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In this issue

Natural working fluids

Over the years, the refrigeration and heat pump industry has seen its choice of refrigerants reduced by restrictions and bans on the use of various substances. It looks as if HFC refrigerants are now next in line for this treatment, with limitations on their use in several European countries. There will be little choice but to use natural working fluids. This edition of HPC Newsletter is therefore concentrated on research into natural working fluids.

Heat pump news

Features

Topical article

Non-topical article

COLOPHON

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IEA OECD heat pump centre

Foreword

The Heat Pump Centre moves to Sweden

Dr. Monica Axell
SP Swedish National Testing and Research Institute
Borås, Sweden

We'd like to start by extending a very warm welcome to old and new readers of this, the new Heat Pump Centre Newsletter. We at SP Swedish National Testing and Research Institute in Sweden appreciate the honour of being asked to operate the Heat Pump Centre. We'd like, too, to take this opportunity of thanking Novem and Jos Bouma in particular for their help in transferring activities from Novem to SP.

Our main output in the future will be our web site and this Newsletter, which will be published four times a year. In today's information society it can be difficult to draw full benefit from the increasing flood of information. To help you, our readers, we have therefore decided to introduce a new feature in the form of a brief electronic letter, which will summarise the contents of the Newsletter. You can then quickly see which items are of interest and go directly to the full article on the web site. To subscribe to the e-mail letter, simply contact us by e-mail or through the web site. You'll find, too, that the web site has been given a new layout, which we hope will improve clarity and make it easier to find the information that you're looking for. Please feel free to circulate it to your friends and colleagues who are interested in the latest news of heat pump technology.

Pressure to achieve a sustainable society has encouraged the development of refrigerants, which has in turn affected the technology of heat pumps and the market for them. We have therefore chosen 'Natural Working Fluids' as the main theme of our first number. Dr. S. Forbes Pearson presents an interesting review of the potentials and limitations of various natural working fluids, and discusses the question of the obstacles and opportunities for heat pump technology in competition with other methods of heating. An important conclusion is that conditions differ widely from one country to another, to which point Professor Erik Granryd, IIR, returns in his report. Carbon dioxide is a natural working fluid which is making strong gains, which was reflected in the contents of the 21st International Congress of Refrigeration in Washington. The IEA Heat Pump Programme and IIR continue to work together, and there is an invitation to the next IEA Heat Pump Conference in Las Vegas in 2005 in this issue. Professor C. Bullard describes the potentials for carbon dioxide as a refrigerant, and emphasises the importance of developing components and systems tailored to each individual refrigerant. All this, and more, is in this issue.

With best regards

Monica Axell
Manager IEA Heat Pump Centre

Columnist

Heat Pump Center – Important hub for Heat Pumping Technologies...

Photo: Claes-Göran Flinck

Eric Granryd
Professor (emeritus) of Applied Thermodynamics and Refrigeration, The Royal Institute of Technology, Stockholm, Sweden.
President of the General Conference of the IIR

The Heat Pump Center (HPC) has been in operation in various forms since 1982. It has now been re-organized. The Center has played, and will continue to play, an important part assisting policymakers, researchers and engineers in the work of fully utilizing the potential of the technology.

Different markets require different solutions:

"*Heat-only heat pumps*" are intended for use in for cold climates, and have to compete with other methods of heating. "*Reversible heat pumps*" are the logical solution for moderate and warmer climates, where comfort cooling is also required. Systems or solutions where both the cold and the hot side of the system can be utilized (at the same time, or with heat/cold storage between periods of heating/cooling) can be extremely energy-efficient. Condenser heat recovery from refrigerating plants is just one example.

It follows that there are a variety of approaches to heat pump units and systems around the world. There are also considerable variations in how well the technology is established and has exploited its potential. It is often difficult to understand why there are such major variations between markets. One of the roles of the HPC may be to analyse reasons for this and suggest how to promote the technology.

There has been enormous *development* over the last decades. We have seen new working fluids evolve. More efficient components – heat exchangers, compressors and controls - have reached the market. There are opportunities for more improvements. Cost-effective heat exchangers, able to operate with low temperature differences and with small refrigerant charges, need to be developed. Compressors have improved, but we can hope for even more efficient, reliable, vibration-free and quiet units in the future. Microprocessors have entered the scene and revolutionizwed controls. Still more can be done to make the whole system operate as efficiently as possible in the different modes of operation over the seasons. And we have not heard the last about refrigerants for the future.

The market will grow as living standards rise. All of us working in the field have a responsibility to contribute so that the technology develops safely, efficiently and with minimum environmental impact, locally and globally. The HPC can play a very important role in this.

Heat pump technology is international: HPC is a good example of this. IIR is another international organization dealing with the whole range of application and technologies of refrigeration, of which the heat pump area is one. There has been close collaboration between the IIR and HPC for several years on an informal basis, in recent times formalized by an agreement. I am confident that this will prove to be of value for the future.

With every best wish for the success of the new HPC organization.

Eric Granryd

General

IIR Recommends Ambitious Objectives Regarding Emissions and Efficiency at COP-9 Meeting

IIR's President Francois Billiard recommended that ambitious objectives should be implemented by 2020, including halving the impact of fluorocarbon emissions and a 30-50 % reduction of the energy consumption of refrigeration plants. This objective was announced at the Ninth Conference of the Parties to the United Nations Framework Convention on Climate Change (COP-9) in Milan on December 10. The conference took place on December 1-12 and was attended by 5000 participants, including 95 ministers. Further, Dr. Billiard reminded the audience that refrigeration plays a vital role in many sectors of developed and developing countries.

On the issue of HFC or non-HFC refrigerants, the IIR recommended favouring the most environmentally-friendly solution, based on the Life Cycle Climate Performance, bearing in mind user safety and cost-effectiveness.

Source: Koldfax, January 2004 and the IIR web-site www.iifiir.org

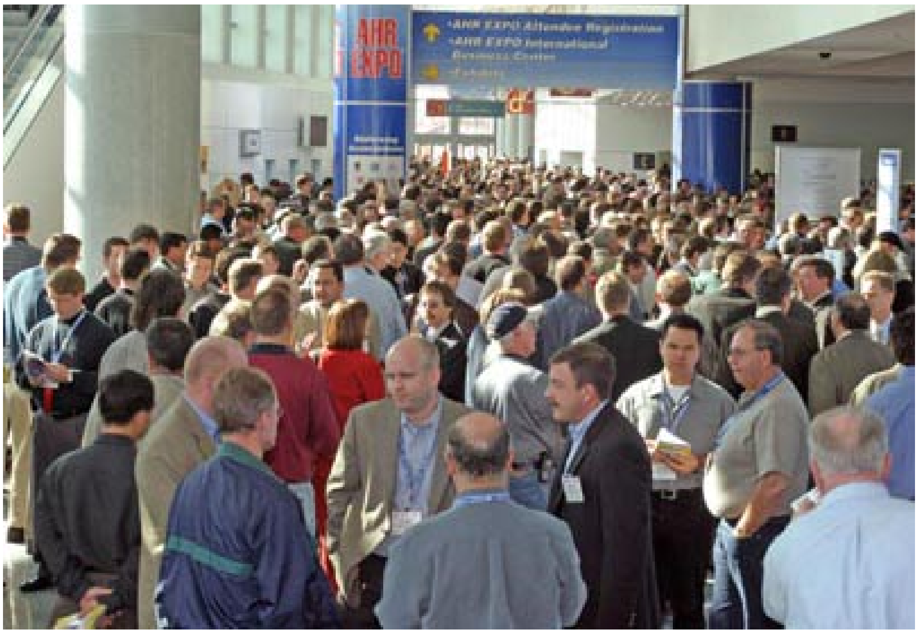
2004 International Air-Conditioning, Heating, Refrigerating Exposition, (AHR Expo) and ASHRAE Winter Meeting

USA - The ASHRAE 2004 Winter Annual Meeting was held in conjunction with AHR Expo from January 23–January 28, 2004, in Anaheim, California. The program at the ASHRAE meeting consisted of 63 seminars, 11 symposia, several poster sessions and professional development seminars and short courses for members. A highlight of the ASHRAE meeting was a public session, *Improving Residential HVAC Energy Efficiency*, presented by 4 key speakers with expertise in forced air distribution systems, high-efficiency air conditioners, system maintenance and changes to the building envelope. Papers from the symposia and poster session are available through ASHRAE headquarters in Atlanta (www.ashrae.org).

The AHR Expo featured products from more than 1,600 leading HVAC & R manufacturers around the world. For the second time in its 56 years history, the expo feted a small number of products with an Innovation Award in the categories of heating, cooling, refrigeration, ventilation, indoor air quality, energy management, tools and instrumentation, and software. Combined attendance at the meeting and Expo was estimated to exceed 40,000.

The 2004 Summer ASHRAE meeting (no expo) is scheduled for June 23–30, in Nashville, Tennessee.

Source: US National Team



The ASHRAE 2004 Winter Annual Meeting and AHR Expo was held in Anaheim, California

Global Partnership Promoting Sustainable Energy Launched

UK – The Renewable Energy and Energy Efficiency Partnership (REEEP) aims to develop innovative policies, regulations and financial mechanisms that will accelerate the development and use of sustainable energy systems. The REEEP was initiated by the UK Government at the World Summit on Sustainable Development in Johannesburg, August 2002. It was launched in London on October 23, with energy and environment ministers from several countries among the guests and speakers.
- "The aim of the REEEP is ambitious – to develop a global network to promote the spread of renewable energy and more efficient use of energy" said the UK's foreign minister Jack Straw.

The work of REEEP focuses on overcoming the barriers for development of sustainable energy systems. Three key areas have been identified: policy and regulations, innovative finance, and communications. Among the actions under these three headings are:

- *Sustainable Energy Regulators Network*
  This implies co-ordination of regional networks aiming to enhance the ability of national regulators to identify and adapt effective policy and regulatory mechanisms to promote local sustainable energy industries.

- *Market-based incentives*
  Stable and secure financial support is crucial for developing sustainable energy systems. REEP will therefore support the development of market-based tradable renewable energy certificate schemes etc.

For more information: www.reeep.org

Energy Efficiency in the EU is Improving

EU - According to data from Eurostat, the statistical office of the EU, the EU has become more energy-efficient over the last ten years. Since 1993, the energy intensity, which measures energy used per unit of economic output produced, has decreased by approximately 12 %. On the other hand, the total energy used in the EU has increased by 9.4 % over the same period, although the increase has been slowing down over the last couple of years. Between 2001 and 2002, energy usage actually decreased by 1.4 %. However, on an overall basis, the EU has increased its dependency on energy import, with only Denmark and the UK being net energy exporters.

Source: www.euractiv.com

Energy Labelling Mandatory from 2004

China – It will become mandatory for manufacturers of air-conditioners to declare the energy saving class in order to sell them in China. The energy saving labelling is required in 37 countries, but not yet in China. However, the Chinese Government has decided to introduce the energy label, and it will probably be brought in during the second half of 2004. It is likely to follow the EU standard and include five classes, A to E. According to Mr Li Aixian from the China National Institute of Standardisation, this system will probably weed out 10 % of Chinese air-conditioners.

Source: JARN no 12, December 2003

Award Winners

USA - ASHRAE honoured 45 people for their contributions to ASHRAE and the HVAC&R industry at the ASHRAE Winter Meeting held on January 24-28. Professor Clark Bullard, University of Illinois at Urbana-Champaign, was presented with the Paul F Anderson reward for outstanding work in the fields of the Society, and Gerald Groff, Groff Associates, was presented with the ASHRAE/ALCO medal for distinguished public service.

Source: ASHRAE News Release, January 24

Sweden – Professor Emeritus Eric Granryd was presented the Major Energy Award (Stora Energipriset) for his achievements in heat pump technologies. The award was presented for the 20th time this year. Anders Rydåker, who initiated the first commercial free cooling plant in Sweden, was also presented with the award for his efforts in the field of free cooling.

Source: Heat Pump Centre

Technology & Applications

Development of a Packaged Ammonia Chiller with Hermetic Scroll Compressor

Japan - Mayekawa Mfg. Co., Ltd. and Hitachi Air-Conditioning System Co., Ltd. have jointly developed a globally and environmentally friendly refrigerating and air-conditioning packaged ammonia chiller unit with a hermetic scroll compressor, under the name of 'MYCOROLL', suitable for small-scale cold storage facilities, supermarket display cabinets, convenience stores, low-temperature air-conditioning for food handling chambers in cold stores and general medium-scale air-conditioning applications ranging between 5 and 15 kW and up to 20 kW (5.49 USRt) of rated refrigerating capacity.

Development of the new chiller has been based on the advanced scroll compressor technology of Hitachi Air-Conditioning System Co., Ltd. and a wealth of experience in industrial refrigeration technology of Mayekawa Mfg. Co., Ltd. who have an approximately 80 % market share of large-scale ammonia freezing and cold storage installations in Japan.

In 1988, Hitachi developed the Scroll-22 compressor, a highly reliable chamber-type scroll compressor with a powerful refrigerating capacity (Fig. 1). Oil foaming at start-up of the unit was eliminated by enclosing the lubricating oil in the high pressure side. Operation of the scroll compressor at low evaporating temperatures between -45 and +5 °C with HCFC22 refrigerant, became possible through utilization of a liquid injection system. The experience gained in developing the Scroll-22 compressor contributed greatly to the collaborative creation of the Natural Refrigerant (Ammonia) hermetic scroll compressor.

For its part, Mayekawa carried out its own development work on a high-efficiency hermetic can-less motor suitable for ammonia refrigerant. Ammonia is an extremely attractive refrigerant due to its environmental safety, coefficient of heat transfer, coefficient of performance (COP) characteristics and low cost.

However, major drawbacks to its extensive use have been its corrosivity on copper and copper alloys, its combustibility and toxicity. Taking these factors into consideration, Mayekawa developed, and has been supplying, a high-speed screw compressor complete with a semi-hermetic canned motor for many years.

The world's first hermetic single-packaged units (MYCOROLL) are available for outputs from 5 kW to 15 kW for small-scale commercial use in industrial refrigeration facilities and air-conditioning applications (Fig. 2, Table 1). It is estimated that the demand for these products could reach 60 000 sets in total for cold storage and air-conditioning applications. Mayekawa believes that annual MYCOROLL sales will reach approx. 500 units within the next two to three years.

Figure 2. MYCOROLL, packaged unit

Table 1 Specifications of the MYCOROLL

MODEL	EK-1	EK-2
CONDENSER	AIR COOLED	EVAPORATION
COMPRESSOR	SCROLL	
CHLLER OUT LET TEMP.	+10 t40	
MOTOR	7.5 kW	
REFRIGERANT	AMMONIA	
REF.CHARGE	3 kg	
DIMENSIONS	1700mm(L) 800(W) 1800(H)	
WEIGHT	450 kg	500 kg

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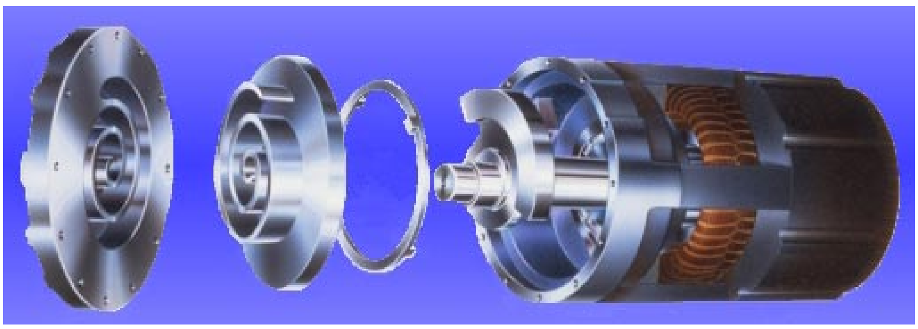
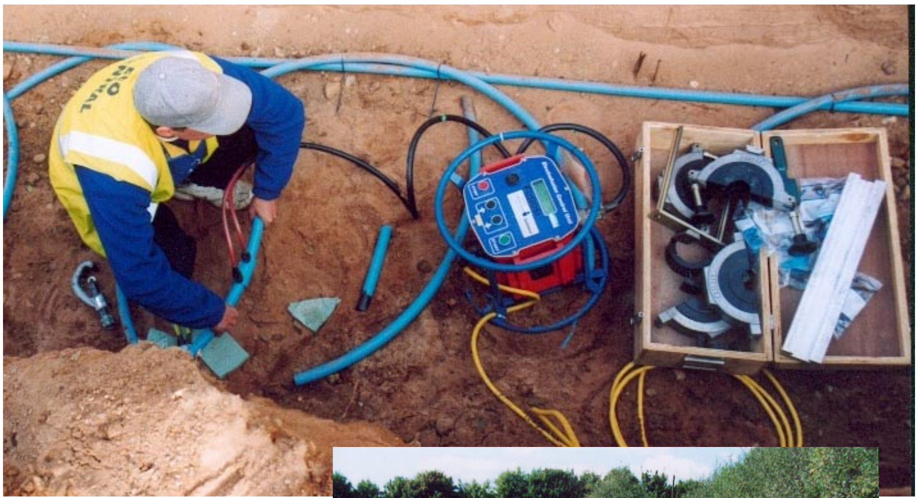


Figure 1. Chamber type scroll compressor

Propane as Refrigerant in Ground-Source Heat Pump



UK – A ground-source heat pump using propane as its refrigerant has been installed to heat the Buntingsdale Infant School in North Shropshire, UK. Due to the local geological conditions, a horizontal ground heat exchanger was used instead of vertical boreholes. What are known as "slinky coils" were arranged in 50 m long trenches, 1.3 m deep and 1.5 m wide. The system is indirect, with a glycol solution circulating in the coils. Fan coils are used for supplying the heat to the building. The heat pump, an Earthcare Wesper CWP21, is claimed to provide 36.4 kW with a COP of 4.3 when the outgoing heating water is 46 °C and the incoming glycol temperature is 0 °C. This installation is one of the few large ground-coupled heat pumps in the UK, and one of even fewer to use a natural refrigerant.

For more information: Nicholas Cox, Earthcare Products Ltd, njc@earthcareproducts.co.uk

Source: Earthcare Products press release, 21 November 2003 and the UK National Team

Room Air-Conditioner with Photovoltaic Cell

Japan – Sanyo Air Conditioners Corp. has developed a photovoltaic cell (PV) as optional equipment for one of its room air conditioners. The cell was developed by Clean Energy Corp. Two PV-modules can be connected to one outdoor unit, to provide power supply. The modules, generating a maximum of 63 W each, will be released in March 2004.

Source: JARN no. 12, December 2003

Compressor with Direct Linear Motion

South Korea – LG Electronics has introduced refrigerators with linear compressors. Conventional compressors convert rotary motion into linear motion, but these new compressors features direct linear motion. LG claims that refrigerators with these compressors reduce power consumption by 30 %.

Source: ASHRAE Journal, November 2003

Markets

All Time High for China's Air-Conditioning Industry

China – China's domestic sales and exports of air-conditioners in RY 2003 (Refrigeration Year, September 1, 2002 to August 31, 2003) is estimated to have reached 34 million units, which is an all-time high both for domestic sales and for export. China's sales account for over 60 % of the world market for air-conditioners. Export has boomed during RY 2003, with 15 million units being exported, representing an increase of 7 million units over RY 2002. A further trend is for the air conditioners to be sold under the Chinese manufacturer's own names, instead of the OEM brands that are the most common today. The boom has also led to increased competition between manufacturers, resulting in a 20 % drop in the average price since RY 2002, thus decreasing the companies' profits.

Three large Chinese companies, supplying 50 % of the market, dominate the domestic market. A few foreign companies, mainly from the USA, Japan and South Korea, have approximately 15 % of the Chinese market, which is actually a decline of almost 3 % since RY 2002.

The market saw an inflow of cheap low-end models, thus pushing down the use of high-efficiency inverter models. The market share for inverter models decreased from 8.2 % in RY 2002 to 4.8 % in RY 2003. One explanation for the difficulty in selling high-efficiency inverter models is that the air-conditioners in China are used only for cooling during the summer and not for heating during the winter, which means that the annual energy efficiency and cost is not as important as a low purchase price.

Source: JARN no. 1, January 2004

The Air-Conditioning Market in Japan Continues to Decline

Japan – Total sales of room air-conditioners in Japan last year (October 02 to September 03) were_6,774,002 units, which is down by 1.9 % from last year. This is the second year in a row that the AC market has declined; in 2002, the market declined by 10.1 %. One explanation for the decline this year is the unusually cool summer in Japan.

The giant electronic companies Matsushita, Mitsubishi Electric, Toshiba and Hitachi have dominated the room air-conditioner market in Japan over the last years, with a combined market share of 15 %. These four have been followed by Sanyo, Mitsubishi Heavy Industries, Daikin, Sharp and Fujitsu General. However, since 2000, Daikin has gradually increased its market share and claims this year to have 16.9 % market share of room air-conditioners, thus making Daikin the market leader. One explanation for this is that Daikin sells its products through a different dealership structure than do the other companies.

Source: JARN no 12, December 2003

Record for Air-Conditioners and Heat Pumps in the USA

USA – Shipment of central air-conditioners and air-source heat pumps set a new record in 2003 with 6,807,262 units shipped. This is an increase of 1 % from last year. The total number of heat pumps shipped was 1,626,365 units, which is also a new record and is an increase of 10 % over 2002.

Source: ARI Statistical Release, February 1, 2004

Working Fluids

International Seminar on Natural Refrigerants was held successfully in Tokyo

Japan - An "International Seminar on Natural Refrigerants " was successfully held on February 5 and 6, 2004 in Tokyo, attended by about 140 persons, including delegates from China, Korea, France and the USA. The seminar was organized and sponsored jointly by the University of Tokyo and the Heat Pump & Thermal Storage Technology Center of Japan (HPTCJ). It was planned as a two-day event; focusing on the latest technology, international standards, market trends and future prospects for natural refrigerants.

On the first day of the seminar, four invited speakers from Norway, Denmark, the USA and Japan presented lectures on topics as follows:

- "Research and Development of Carbon Dioxide Technology in Europe", Petter Neksa, SINTEF Energy Research A.S., Norway
- "Developments within Natural Refrigerants in Europe", Kim Christensen, Danish Technological Institute, Denmark
- "Transcritical R744 systems -- Challenges and Recent Achievements", Predrag Hrnjak, University of Illinois at Urbana-Champaign, USA
- "Research and Development of Natural Refrigerant Technology in Japan", Eiji Hihara, University of Tokyo, Japan

The second day of the seminar was mainly for Japanese participants, with introductory lectures primarily by Japanese experts, presenting a brand new publication "New Trends of Natural Working Fluids" (in Japanese), which had been written by the lecturers. Professor R. Radermacher, University of Maryland, USA, also joined on the second day as a special guest lecturer, and presented "Alternative Refrigerants Research at CEEE -- Two-stage CO2 System and Hydrocarbon Alternatives".

The main topics in this seminar were current developments in CO2 refrigerant, advanced refrigerant system for improved energy efficiency, new developments in water heating heat pumps, mobile AC, space conditioning and commercial & industrial refrigeration.

Other main topics of the seminar included current trend in regulation for HFCs and safety standards development for flammable refrigerants.

The seminar was the climax of several years' work by the "Natural Refrigerants Study Group" in the Heat Pump & Thermal Storage Technology Center of Japan, lead by Prof. Hihara of the University of Tokyo.

Source : Japanese National Team (HPTCJ)

The Ozone Layer Recovers

Observations from NASA show that the rate of ozone depletion in the Earth's upper atmosphere is decreasing, and thus the ozone layer may be in an early phase of recovery. Ozone depletion in the upper atmosphere started to slow down in 1997, ten years after the Montreal Protocol came into force. The decrease is consistent with the decrease of chlorine and bromine in the atmosphere. Even though the rate of ozone depletion is slowing down, the time for total ozone recovery is still decades away.

Source: OzonAction, no. 45, October 2003

Air as Working Fluid in New Refrigeration System

USA – A commercial air cycle refrigeration system, producing air with a temperature as low as –77 °C has been introduced by Earthship USA Inc. The system includes two compressors and one expander. The air is drawn from the refrigerated space by the first compressor and then chilled before entering the second compressor, followed by two stages of cooling before entering the expander. After expansion, the condensate is separated before the air returns to the refrigerated space. The system can be used in various applications, such as refrigerated or frozen warehouses, ship containers, air cargo and air-conditioning systems. The air cycle also produces a considerable quantity of hot water that may be used in hotels etc. The dimension of this system is 2 x 2 x 2.2 meters.

Source: JARN no.1, January 2004

Ozone Layer Protection Award

China - Carrier Corporation and the State Environmental Protection Administration of China (SEPA) have established the China Stratospheric Ozone Layer Protection Awards, which were presented for the first time at a ceremony marking the ninth World Ozone Protection Day. The awards were given to individuals and organisations that have contributed to China's ozone protection efforts.

IEA Heat Pump Programme

New Operating Agent for the Heat Pump Centre

The Operating Agency of the IEA Heat Pump Centre has been taken over by SP, the Swedish National Testing and Research Institute, in Sweden since 1st January 2004. SP is active in almost every field of technology, and is divided into the following nine departments: Building Technology, Certification, Chemistry & Materials Technology, Electronics, Energy Technology, Fire Technology, Measurement Technology, Mechanics and Weight & Measures. SP has about 600 employees, of whom approximately 16 % hold a Ph.D or licentiate degree. The HPC will be operated by the Department of Energy Technology, which plays an active role in testing, standardisation and research in various fields related to energy technologies. SP has been involved with heat pumps and refrigeration since the late 1970s. For more information, visit the web-site www.sp.se

The new Heat Pump Centre will continue to publish the IEA Heat Pump Centre Newsletter, with four issues per year. The structure will be as before, but with a new layout, as we hope you have noticed. The Newsletter will continue to be electronic and available via the web site.

A new feature is a short version of the Newsletter that will be distributed via e-mail. This will contain short summaries of the articles and news, and will be linked to the full Newsletter. The layout and structure of the web site has been changed in order to make it more consistent and easier to find information. In addition, all the publications from the HPC and Heat Pump Programme are now searchable via the web site.

Source: IEA Heat Pump Centre

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Would you like to subscribe to the short version of the Newsletter, distributed via e-mail? If so, please send an e-mail with the title "*I want to subscribe to the short version of the Newsletter*" to hpc@heatpumpcentre.org.

Meetings for the Boards of the IEA Heat Pump Programme and the Swedish eff-Sys (Efficient Refrigeration and Heat Pump Systems) research programme were held simultaneously at SP in November. The two groups held a joint lunch and a joint dinner, encouraging the exchange of experience and networking.

New National Team in Norway

Norway - The Norwegian Heat Pump Association (NOVAP) is the new National Team Leader in Norway. The first meeting was held in Oslo on November 13, attended by 14 persons from organizations, science, education, magazines and Government.

For many years, there has been little interest in heat pumps in Norway due to low energy prices, with a production capacity that exceeded electricity demand. The situation today is that, in a normal year, Norway imports electricity from other countries.

With higher energy prices and limited potential for new production capacity, both the Government and consumers are increasingly interested in energy saving. Enova SF was established by the Ministry of Petroleum and Energy in 2002. Its main mission is to contribute to environmentally sound and efficient use and production of energy, relying on financial measures and incentives to encourage the market and mechanisms to achieve national energy policy goals.

Higher energy prices and increased interest in energy saving are also the main reasons for increased sales of heat pumps in Norway. With subsidies from the Government, and high energy prices, NOVAP expects that sales in 2003 will exceed 40.000 units, of which over 90 % will be outside air split units.

Source: Norway National Team

8th IEA Heat Pump Conference 2005 – Call for papers

The 8th IEA Heat Pump Conference will be held on May 30 to June 2, 2005 in Las Vegas, Nevada, USA. The conference goal is to "promote the worldwide implementation and improvement of heat pump technologies via exchange and discussion of technical, market, policy and standards information with respect to the environmental and energy-conserving benefits of these technologies". The conference will consist of invited keynote and plenary speakers, oral presentations on the state-of-the-art in various fields of heat pumping technologies, poster presentations, exhibition, technical visits and social programs.

There is a call for papers to complement the invited speakers. Abstracts should be submitted before April 30, 2004 and full papers before June 1, 2004. Regional coordinators to whom abstracts and papers should be submitted are:

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For further information about the conference: http://www.ornl.gov/hp2005

Task 1 of IEA HPP Annex 28 Finished

Switzerland - IEA HPP Annex 28 started in January 2003, with the objective of developing comprehensive test procedures as a basis for the calculation of the seasonal performance factor for heat pumps with combined space heating and domestic hot water production.

Task 1 of Annex 28 was concerned with determining what systems were on the market or under development, and how far standardisation had proceeded in each of the participating countries. Its work has now been concluded, with a valuable exchange of information at the second working meeting at CETIAT in Villeurbanne, France, in October 2003.

Results will be available in an Annex 28 Interim Report, to be delivered to the Executive Committee of the IEA Heat Pump Programme in February 2004. The report will be available for downloading on the IEA HPP Annex 28 web site, under the URL http://www.annex28.net–, which will go on-line soon.

Work will continue with developing the respective test procedures (Task 2) and calculation methods (Task 3) to be introduced in the standardisation. External liaison has already been established with CEN Technical Committee TC 113, which is in charge of heat pump testing, in order to transfer interim results of the Annex to standardisation committees immediately. Further external liaison with CEN TC 228 for calculation methods is under way.

The next working meeting, with a discussion of interim results of Task 2 and Task 3, will be held in Tokyo in June 2004.

Source: Carsten Wemhöner Fachhochschule beider Basel, Institut für Energie, Operating Agent Annex 28

Ongoing Annexes

Bold text indicates Operating Agent.

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IEA Heat Pump Programme participating countries: Austria (AT), Canada (CA), France (FR), Germany (DE), Japan (JP), The Netherlands (NL), Norway (NO), Spain (ES), Sweden (SE), Switzerland (CH), United Kingdom (UK), United States (US). All countries are member of the IEA Heat Pump Centre (HPC). Sweden is Operating Agent of the HPC.

Natural Refrigerants for Heat Pumps

Dr S Forbes Pearson, UK

Natural refrigerants take part in various environmental cycles on a huge scale. Therefore they cannot damage it when released on a human scale, unlike some synthetic substances, which have no natural sinks and which produce undesirable effects out of all proportion to the quantities in which they may be released.

Some natural refrigerants are relatively stable, like carbon dioxide, and some, like ammonia, combine readily with other substances. This paper summarises the properties and applications of natural refrigerants and explains their particular advantages when used as working fluids in heat pumps and refrigerating systems.

Introduction

All refrigerating systems are heat pumps. They transport heat from regions of low temperature and they reject it to regions of higher temperature. When the main purpose is to cool, the system is called a refrigerator. When the main purpose is to produce heat, the system is called a heat pump. On some rare occasions heating and cooling can be utilised together, as when an artificial ice rink is situated beside a heated swimming pool. Such heat pumps are truly economic because the heat going into the swimming pool is being rejected as an inevitable consequence of refrigerating the rink.

In general it is difficult at present to make heat pumps economic, because we are in the habit of selling fossil fuel at less than the cost of clearing up the mess we make by burning it. When the price of fossil fuel is regulated to match the cost of using it, rather than being fixed by supply and demand, then it will be much more profitable to use heat pumps, especially if the power to drive them comes from renewable sources at competitive prices.

There is no such thing as an ideal refrigerant. Fortunately, it is usually possible to select a refrigerant having properties suited to any particular application. Properties of particular relevance to heat pump applications are pressures of evaporation and condensation, the latent heat of evaporation, and the specific volume of refrigerant vapour at evaporating pressure. Knowledge of these properties allows us to answer two important questions. "How big does it have to be?" and, "How strong does it have to be?" A third important question is, "How efficient can it be?"

The third answer depends on the ratio of energy required to compress refrigerant vapour to the heat extracted by evaporating refrigerant liquid. In general it is found that refrigerants of low molecular weight and high critical temperature tend to produce high efficiencies when used in the vapour compression cycle. Some natural refrigerants have rather favourable properties compared to synthetic refrigerants because they tend to have low molecular weights and high critical temperatures.

Heat pumps can be used in a wide variety of applications requiring a variety of refrigerant properties. The example of the artificial ice rink and the heated swimming pool is one of the simpler applications because the temperature of pool water is within the range of temperatures normally available for heat rejection from refrigerating systems.

The mass market for heat pumps is for heating buildings and for provision of hot water. Buildings heated by circulation of warm air require lower condensing temperatures than are required for the heating of circulating water. Condensing temperatures for heating of process water or domestic water are even higher. For each type of application there are optimum refrigerant properties.

Natural Refrigerants

Definition of Natural Refrigerant

For the purposes of this article, natural refrigerant is defined as a refrigerant which occurs naturally in significant quantity and which would normally be present in the atmosphere in quantities which remain steady. The article covers only those natural refrigerants which are deemed to be important or potentially important.

Table 1 lists some of the relevant properties of the natural refrigerants covered in this article.

Air

Air is one of the original classical refrigerants but it has almost gone out of use, except for certain niche markets, such as aircraft air conditioning. Air cycles are of very low efficiency compared to vapour compression cycles but have applications where there is a plentiful supply of

Table 1 – Natural Refrigerants

Substance	Ref Number --	Chemical Formula --	Molecular Weight --	NBP °C	Latent Heat KJ/Kg	CT °C	$\frac{C_p}{C_v}$ --	Required Volume Flow relative to CO_2	COP --	TLV ppm	LFL %	Safety Group --
Air[1]	R-729	--	29	n/a	n/a	-221	1.4	83.0	1.1	n/a	n/a	A1
Water	R-718	H_2O	18	100.0	2500	375	1.33	477.0	4.1[3]	n/a	n/a	A1
Carbon Dioxide	R-744	CO_2	44	-55.6[2]	231	31	2.14	1.0	2.56	5000	n/a	A1
Ammonia	R-717	NH_3	17	-33.3	1262	132	1.4	3.44	4.76	25	14.8	B2
Sulphur Dioxide	R-764	SO_2	64	-10.0	376	157	1.35	9.09	4.87	2	n/a	B1
Butane	R-600	C_4H_{10}	58	-0.5	385	152	1.12	15.5	4.68	800	1.9	A3
Isobutane	R-600a	C_4H_{10}	58	-11.6	356	135	1.13	11.2	4.55	800	1.8	A3
Propane	R-290	C_3H_8	44	-42.1	374	96.7	1.22	4.09	4.74	2500	2.3	A3
Propylene	R-1270	C_3H_6	42	-47.7	378	92.4	1.26	3.03	5.07	375	2.0	A3
Pentane	R-601	C_5H_{12}	72	36.2	-	196.4	-	-	-	600	1.4	A3
Isopentane	R-601a	C_5H_{12}	72	27.8	-	187.4	-	-	-	600	1.4	A3
Neopentane	R-601b	C_5H_{12}	72	9.5	-	160.6	-	-	-	600	1.4	A3
Di-ethyl Ether	R-610	$C_4H_{10}O$	74	34.6	-	214	-	55.4	4.9	400	1.9	A3
Di-methyl Ether	E-170	C_2H_6O	46	-24.8	-	129	-	-	4.5	1000	3.4	A3

1 Brayton Cycle 2 Triple Point 3 +5/30°C

compressed air or where cooling or heating is required through a large temperature range. In the author's option, it is unlikely that air will find acceptance as a working fluid for heat pumps, except in special applications.

Water

Water is in many respects the ideal natural refrigerant, having a very high latent heat and a high critical temperature, as well as being non-toxic and non-harmful to the environment.

Water suffers from one major disadvantage; it has a very high specific volume of vapour under normal operating conditions. Despite this disadvantage, water has been used as a refrigerant for air conditioning and for the production of ice, using steam ejectors, large centrifugal compressors, and large high-speed axial compressors. The future of water as a refrigerant for vapour compression heat pumps depends, to a large extent, upon the success of those who are developing high-speed axial compressors to operate at the very low pressures required for such refrigerating systems. If compressors are successfully developed, one can imagine that many toxic and polluted sources, such as urban waste water, could be a valuable source of energy for large-scale heat pumps. The author is not aware of any such pumps being used in practice at present.

Carbon Dioxide

Carbon dioxide is a unique refrigerant in that it cannot exist as a liquid at atmospheric pressure. It is also unusual in that the critical temperature, above which it cannot be liquefied, is as low at 30.98 °C. This implies that, when used as the working fluid in a vapour compression heat pump, the cycle will be a transcritical one. Transcritical cycles tend to be inefficient compared to more conventional reversed practical Rankine cycles because of the relatively low latent heats involved. However, there are several ways in which this disadvantage can be overturned or even used to significant advantage. Efficiency of transcritical cycles can be improved by the provision of heat exchange between supercritical fluid emerging from the gas cooler heat rejection process and suction vapour about to enter the compressor. This has the effect of increasing the refrigerating effect by more than the increase in work of compression which results. An additional benefit is that the temperature at which vapour leaves the compressor is higher than it would otherwise have been. This is of no benefit when the cycle is used for refrigeration but could be of considerable benefit if the cycle is being used as a heat pump.

CO_2 compressor

Another method of improving the efficiency of heat pumps using carbon dioxide as the working fluid is to "economise" the cycle by using some of the mass flow through the gas cooler to sub-cool refrigerant liquid before the expansion valve. This sub-cooling can easily be produced in compressors of the screw, scroll, or two stage reciprocating type but can also be accomplished in multi-cylinder single stage reciprocating compressors by allocating some cylinders to the sub-cooling duty and some to the main cooling duty. Such systems are the subject of various patents and patent applications.

A major heat pump application using carbon dioxide as the working fluid is the production of high temperature, domestic or process, hot water. The supercritical heat rejection has major advantages for this purpose. The supercritical fluid being discharged at very high temperatures in the region of 80 to 90 °C and cooled to temperatures in the region of 25 to 30 °C by heat exchange with incoming mains water. The large temperature range through which the carbon dioxide has to be cooled makes it practicable to heat the mains water through a similar temperature range. This feature is unique to transcritical cycles, of which the carbon dioxide cycle is the most readily imagined.

There are already three or four types of such system being used in Japan, which has no significant indigenous fossil fuel. The writer has no doubt that such water heating systems will become much more common in future. Such systems could be of relatively large size. This would open the way towards the use of carbon dioxide for the air conditioning of buildings, coupled with the production of domestic and process hot water. Such systems would be genuinely economic, even at present when fossil fuels are being sold too cheaply.

Another possible application of carbon dioxide in heat pumps is associated with automotive air conditioning. Several factors combine to suggest that carbon dioxide will be the working fluid of the future for car air conditioning. One advantage of carbon dioxide, which might more than offset its several disadvantages, is that it is capable of providing relatively high-grade waste heat. Modern car engines are so efficient that heating the passenger compartment has become a problem at start-up in cold weather. A carbon dioxide air conditioning system could provide high-grade waste heat almost instantly.

There would appear to be a long-term future for the use of carbon dioxide as a working fluid in various types of heat pump.

Ammonia

Ammonia is unique in that it is the only refrigerant in common use today which has been in continuous use since the early days of refrigeration. This indicates that ammonia has properties which make its use as a working fluid very desirable, despite its high toxicity, unpleasant smell, and generally corrosive nature. The properties which set ammonia apart as a desirable refrigerant are its low molecular weight, its high latent heat, its relatively high vapour density, and its excellent heat transfer properties. Ammonia is likely to continue in use as working fluid for heat pumps for the foreseeable future. Ammonia compressors are currently available for discharge pressures up to about 40 bar A, which is equivalent to a condensing temperature in the region of 80 °C. The development of compressors capable of reaching even higher pressures for use with carbon dioxide will also make it possible to use ammonia at even higher pressures, perhaps even up to the boiling point of water. Ammonia has a relatively high critical temperature of 132 °C so that thermodynamic efficiency remains relatively high at high condensing temperatures.

The major disadvantage of ammonia is that it cannot easily be used in fully sealed systems because ammonia is corrosive to copper. This restricts the use of this highly toxic substance to "open" type systems dependent on rotary shaft seals to keep the refrigerant in its appropriate place.

The place of ammonia as a working fluid for heat pumps is already established and it will continue for the indefinite future.

Sulphur Dioxide

Sulphur dioxide is one of the classical refrigerants, which fell out of use in the 1930s with the advent of the non-toxic, non-flammable, halocarbon refrigerants. Sulphur dioxide is present naturally in the atmosphere as a result of volcanic activity but it is readily absorbed by atmospheric moisture and eliminated as acid rain. The main disadvantage of sulphur dioxide as a refrigerant is its relatively high toxicity but, as it is suitable for use in fully sealed systems and has a high critical temperature, it could efficiently be used in heat pumps. Another disadvantage of sulphur dioxide is its relatively low normal boiling point, which could result in the refrigerating system operating under vacuum on the low-pressure side. The danger of operating sulphur dioxide at pressures below atmospheric is that any atmospheric moisture drawn in would form sulphurous acid, which is highly corrosive. However, the use of sulphur dioxide in a hermetically sealed heat pump system would be relatively immune from such problems and would probably not evaporate at pressures below atmospheric, provided appropriate sources of waste heat could be found.

The writer believes that there could be a future for sulphur dioxide, both in heat pumps and in sealed refrigerating systems, under jurisdictions where there is unreasonable prejudice against the use of flammable refrigerants.

Butane

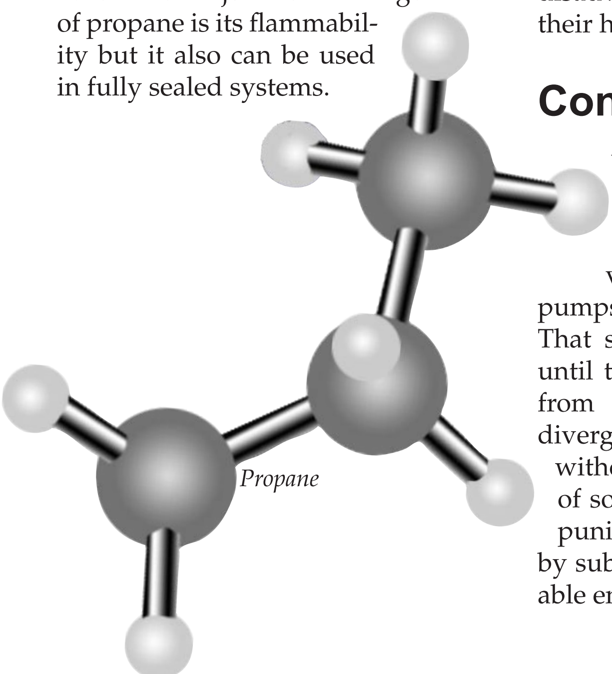
Butane is an excellent refrigerant with only two disadvantages. The more important disadvantage is that it is highly flammable. The second disadvantage is that is requires a large swept volume and operates at relatively low pressure. This need not be a disadvantage in high temperature heat pumps, where the properties of butane might allow conventional refrigeration compressors to be used at unconventional temperatures.

Isobutane

Isobutane is an isomer of normal butane, which operates at significantly higher pressure and requires rather less swept volume. Isobutane has become the refrigerant of choice in many parts of the world. This is because of its benign environmental properties, its relative cheapness, and its ability to operate in fully sealed systems. Provided appropriate precautions are taken there is no reason why isobutane should not be used in heat pump systems where waste heat is available at relatively high temperature.

Propane

Propane is a refrigerant having properties rather similar to R-22. It can be used as a refrigerant in systems where the heat source is at relatively low temperature. Insofar as the critical temperature is only 96.7°C it is not likely to be highly efficient at high condensing temperatures but it should be more efficient than substances such as R-410A, which have critical temperatures in the region of 70°C. The major disadvantage of propane is its flammability but it also can be used in fully sealed systems.



Propane

Propylene

Propylene is a substance which has not received general acceptance as a refrigerant despite its relatively good thermodynamic properties. The reason for this is probably that it is significantly more expensive than propane and is thought to be much less stable. However there have been no reported problems as a result of instability. It must therefore be concluded that this objection is more theoretical than practical.

Pentanes

The natural substances Pentane, Isopentane, and Neopentane would be suitable for use in high temperature heat pumps. Their main disadvantage is their very high flammability. The writer is not aware of any attempts being made to use these substances in heat pumps but their use might be appropriate should fuel prices change in such a way as to make high temperature heat pumps appropriate.

Ethers

The substances Di-ethyl Ether and Di-Methyl Ether were among the classical refrigerants which fell out of use when safer alternatives, such as ammonia and carbon dioxide, became available. Both substances would be suitable for use in high temperature heat pumps. Again, the disadvantage of these substances is their high flammability.

Conclusions

Apart from rare cases, where heat rejection from a required refrigerating system can be utilised, it has proved very difficult to market heat pumps without government subsidy. That situation is likely to continue until the cost of fossil fuel diverges from the cost of electricity. Such divergence is not likely to occur without government intervention of some kind, either by even more punitive taxation on fossil fuel or by subsidy for nuclear or for renewable energy.

There is a possibility that heat pumps using carbon dioxide may be accepted for domestic water heating and as car heaters, more or less in their own right, but even this will depend to some extent on government discouragement of the use of halocarbon refrigerants for car air conditioning.

There are no significant technical problems which militate against increased use of heat pumps. The technology dates back to the 19th century and is eminently practicable. The major problems which hinder the uptake of heat pump technology are political and financial.

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Alternative refrigerants: progress in carbon dioxide systems

Prof. Clark Bullard, USA

The state of the art for the transcritical CO_2 cycle technology in various refrigeration, air-conditioning and heat pump applications has been critically reviewed in a recent article [1]. The article covered the history and re-emergence of the natural refrigerant CO_2, its thermodynamic and transport properties, basic CO_2 transcritical cycles and some options of cycle modifications (advanced cycles), heat transfer and pressure drop characteristics in CO_2 systems, and issues and design characteristics related to high operating pressure. It also explored component design issues and possible applications for the earliest markets, and those barriers to be overcome before commercialization. Key results and conclusions are summarized here.

Introduction

The prospects for carbon dioxide and its transcritical cycle are still uncertain, mainly because of the many simultaneous component and system innovations required, e.g. to handle the high pressures, and to develop microchannel evaporators that tolerate frost and condensate while distributing refrigerant uniformly. Thermodynamically the greatest obstacle it faces is its inherently high temperature of heat rejection, which explains why its first commercial opportunities are occurring in water heating, and in space heating applications where high delivery temperatures are required. Its inherent advantage – negligible global warming impact – has focused most of the early research on automotive air conditioning applications where direct refrigerant leakage has been a significant contributor to global warming.

Background

Research conducted during the last decade has included detailed side-by-side comparisons of prototype CO_2 systems with their conventional counterparts, mainly in residential and automotive applications. More detailed studies of heat transfer and pressure drop have revealed opportunities for designing heat exchangers to exploit the unique properties of CO_2 in subcritical and supercritical flow, e.g. extremely high evaporative heat transfer coefficients, minimal effect of pressure drop on cycle efficiency, and extremely high specific heat near gas cooler outlet. Control systems have been developed to enable efficiency to be traded for additional capacity when needed, e.g. for faster temperature pull-down in automotive a/c. This is accomplished by controlling high-side pressure with a backpressure valve, an extra degree of freedom offered by the standard transcritical cycle shown in Figure 1 (from [1]). Additional experiments revealed the importance of achieving low approach temperature difference at the gas cooler exit, leading to development of multislab cross-counterflow microchannel heat exchangers. Because the standard transcritical cycle deviates considerably from the Carnot ideal, research has also focused on cycle modifications, exploring such options as internal heat exchange, expanders, two-stage compression and flash gas bypass.

Initial concerns about high pressures and safety have been resolved by recent research, in which experiments have shown how the high energy density of CO_2 enables compressors to be smaller despite their thicker walls, heat exchangers to be lighter due to their microchannel tubes, and explosion energies to be comparable due to low volumes offsetting high pressures. The high pressure differences experienced inside the compressor have resulted in most prototypes being of recipro-

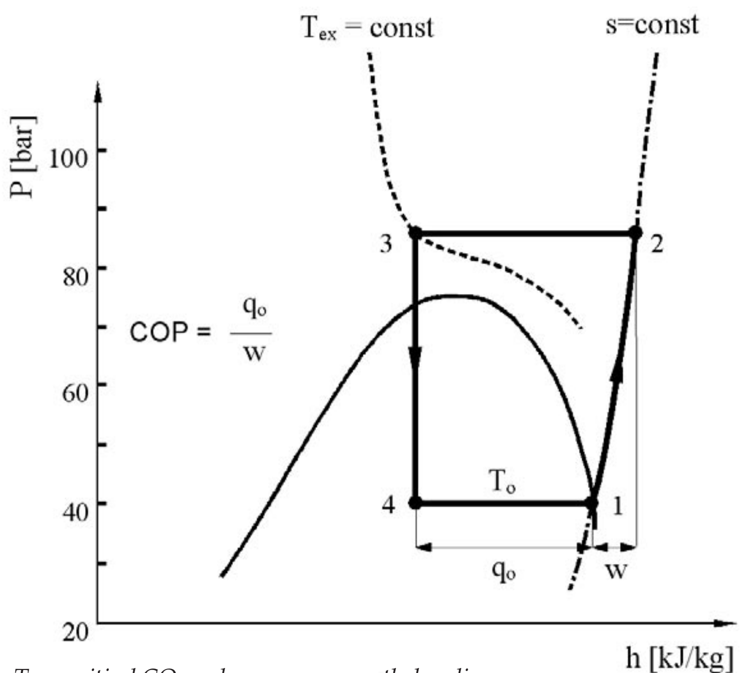

Figure 1. Transcritical CO_2 cycle on pressure-enthalpy diagram

cating or 2-stage rotary design. The assessment of lubricants for the transcritical cycle is still underway, with polyalkylene glycol (PAG) favored for its lubricity, aromatic ester derivatives for their tolerance of high temperatures and polyolesters (POE) for their miscibility throughout the transcritical cycle. The poor miscibility of synthetic mineral oils is offset by their superior flow properties at low temperature, so the ultimate choice may involve blending two or more lubricants.

The re-emergence of the "old refrigerant" carbon dioxide provides a historical context for making several important observations about the path of technological innovation in air conditioning and refrigeration systems and components. A century ago, the earliest engineering development efforts focused on the compressor because it was the most costly component, and efficiency improvements accompanied cost reduction. With the advent of CFC's that could operate at low pressures with reasonable thermodynamic cycle efficiencies and avoid the toxicity or flammability risks of ammonia and hydrocarbons, system costs dropped to the point where mass production became feasible. Declining real energy prices over most of the twentieth century expanded the market for air conditioning, enabling the industry to capture economies of mass production by 1) focusing on the simple "standard" vapor-compression cycle to minimize the number of components, and 2) optimizing the components to make the actual cycle approach the refrigerant's ideal thermodynamic efficiency, for example by tailoring heat exchangers for compatibility with the particular refrigerant's conductivity and viscosity.

Recent developments

Over the last decade the situation began to change dramatically as chlorofluorocarbon refrigerants were phased out, and the prospect of global warming signaled higher energy costs and controls on fluorocarbon refrigerants. In parts of the world where energy prices are already high, the simple vapor-compression cycle efficiency has been increased by adding sensors, actuators and controls to modulate refrigerant flow rate, thereby minimizing temperature differences across the heat exchangers at all operating conditions. Unfortunately the maximum efficiency attainable through this approach is refrigerant-specific: the COP of that particular refrigerant on the standard cycle. Today's research is focusing on ways to modify the standard vapor-compression cycle, for example through use of multi-stage compression, intercooling, internal heat exchangers and expanders as is now done routinely in industrial-scale systems where energy costs dominate.

As the cycle is modified by addition of such components and controls, the system COP depends less on the thermodynamic properties of the refrigerant and more on the cost of manufacturing and controlling the more complex systems. Therefore refrigerants will be chosen in the future for their environmental safety and compatibility with various cycle-improving component designs, rather than their simple-cycle ideal efficiency. If the cost of sensors, actuators and microprocessor controls continue to decrease, along with the cost of embedding them in mass produced items, it may diminish the cost advantage now enjoyed by refrigerants having favorable standard-cycle thermodynamic properties. Modern manufacturing technologies (e.g. for making small diameter tubes) have already reduced the weight and volume penalties once associated with high-pressure refrigerants like carbon dioxide, and various methods for refrigerant-side area enhancement have further decreased the importance of refrigerant transport properties.

Strictly speaking, the Carnot cycle is not always the ideal because heat sources and sinks are finite in all heat pumping applications. This is especially true in heating mode where substantial increases in air or water temperatures are required; the temperature glide of the transcritical CO_2 cycle provides a distinct advantage in such cases. While such loads are generally met today by direct fossil fuel combustion at COPs less than one, in the future they are likely to be met by heat pumps at COP>1 as regulation of greenhouse gas emissions requires that fossil fuels be used more efficiently. The early introduction of transcritical CO_2 systems into the Asian domestic water heating market is providing the first test of this hypothesis, since earlier attempts to introduce subcritical heat pump systems have failed.

Conclusions

Research on alternative refrigerants is continuing on many parallel paths, including explorations of the use of hydrocarbons or ammonia by minimizing charge or using secondary refrigerant loops. Each of these paths efforts is yielding surprising results, as illustrated by the case of carbon dioxide. What these efforts have in common is that they bring fundamental research to bear on a technology whose historical development has proceeded incrementally in the interest of reliability. Since the Montreal and Kyoto Protocols rendered refrigerant-specific empirical data obsolete, the industry has entered an era of discontinuous technological change. With CO_2 and other new refrigerants, we have now moved beyond the horseless carriage stage of technology development, when new refrigerants were simply "dropped in" to old systems. We are learning that different systems require fundamentally different components and controls to bring their simple thermodynamic cycle closer to the ideal Carnot efficiency.

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CO_2 as a Working Fluid in Compression Systems

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Various issues of CO_2 as a working fluid in compression systems have been investigated in an international research project, Annex 27 "Selected Issues on CO_2 as a Working Fluid in Compression Systems". This project, which was carried out in cooperation between five countries have just been finished. The final report can be ordered from the IEA Heat Pump Centre. This article gives a short description of this project.

Introduction

The main objective of Annex 27 was to bring CO_2 heat pumping technology closer to commercialisation, by addressing issues of both basic and applied character. The scope of the work included *compression heat pumps, refrigeration and air-conditioning systems and components*. Each of the contributing research teams conducted individual projects. The work was carried out as a common study, with both task-sharing and cost-sharing activities. Participating countries were: Japan, Norway, Sweden, Switzerland, and the USA. The following is a short description of the research projects.

The projects are grouped in six different categories:

1. Literature survey
2. Systems
3. Heat transfer
4. Compressors/machinery
5. Safety issues
6. Other issues

Annex projects

1 LITERATURE SURVEY

The literature survey presents recent developments and a state-of-the art for transcritical CO_2 cycle technology in various refrigeration, air-conditioning, and heat pump applications. The focus is on fundamental process and system design issues, including discussions of CO_2 properties and characteristics, cycle fundamentals, methods of high-side pressure control, thermodynamic losses, cycle modifications, component and system design, safety factors, and promising applications. Advanced cycle design options are introduced, suggesting possible performance improvements of the basic cycle.

2 SYSTEMS

Feasibility of transcritical CO_2 systems for mobile space conditioning

This project explores the feasibility of transcritical CO_2 systems in mobile space conditioning. Focus areas are: 1) combining validated component sub-models into a system simulation model; 2) validating the system model; and 3) using the validated model to design a truly reversible transcritical CO_2 heat pump system.

Use of CO_2- and propane thermosyphons

This project evaluated the use of a compact cooler in a standard freezer. The objective was to design systems for both evaporator and condenser that are driven by density difference (*thermosyphons*). The appliance used was a standard freezer. Two thermosyphon systems were designed. The first system was for cooling the compact cooler's warm side. This cooling system used propane as refrigerant. The second thermosyphon system (with CO_2) was used for heat extraction from the cabinet. The first results from the tests show that the output capacity of the cooler was smaller than expected: only 70 % of the expected output could be reached. A lowest cabinet temperature of -11 °C was reached, while the saturation temperature in the CO_2 thermosyphon was –18 °C and the surface temperature of the compact cooler was -37 °C. The tests definitely show a potential to use the compact cooler as a replacement for the standard compressor system.

3 HEAT TRANSFER

Heat transfer of carbon dioxide in an evaporator

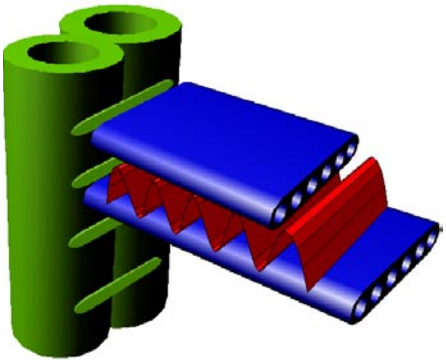
An experimental apparatus for CO_2 was constructed for measurement of boiling heat transfer characteristics inside horizontal tubes. The test sections were horizontally arranged smooth tubes with inner diameters of 0.7, 1.0, 2.0 and 4.0 mm. Experimental conditions were as follows; evaporating temperature was 15 °C, quality was from 0.1 to 0.9, heat flux was between 9 and 36 kW/m^2 and mass flux was between 360 and 1440 kg/m^{2}s. The heat flux mainly affected the heat transfer, and mass velocity mainly affected the quality at onset of dry-out. The experimental results of boiling heat transfer and pressure drop were compared with those of fluorocarbons, but did not provide a good match. A new correlation of heat transfer coefficient was proposed.

Correlating the heat transfer coefficient during in-tube cooling of turbulent supercritical carbon dioxide

An extensive study of the heat transfer and pressure drop characteristics of supercritical CO_2 during in-tube cooling was carried out as part of ASHRAE RP-913. A new correlation for predicting the heat transfer coefficient of supercritical CO_2 was developed as part of this study, based on numerical predictions and experimental data. It uses a mean Nusselt number that is calculated using the Gnielinsky correlation, which is determined using the thermophysical properties at the wall and the bulk temperatures respectively. The majority of the numerical and experimental values predicted by the new correlation were within ±20%.

Heat transfer and pressure drop characteristics of super-critical carbon dioxide in microchannel tubes under cooling

This project provides heat transfer and pressure drop data for CO_2 at supercritical pressures in a multi-port extruded (MPE) aluminium tube. The tube had 25 circular channels, each of 0.79 mm internal diameter. Data are presented for the following range of



Design of multiport extruded type heat exchangers

variables: Mass flux 600 - 1200 kg/m²s, pressure 81-101 bar and heat flux 10 – 20 kW/m². The temperature range was 15 to 70 °C. The measured heat transfer coefficients were in the range of 5,000 to 17,500 W/m²K, and the measured pressure drops in the range of 0.05 to 0.32 bar, corresponding to a mean pressure gradient of 10,000 to 64,000 Pa/m. In addition, the measured values were compared to correlations available in the literature. Gnielinski's correlation for the single-phase heat transfer coefficient and Colebrook & White's correlation for the pressure drop showed a satisfactory agreement.

Flow vaporization of CO_2 in microchannel tubes

Flow vaporization heat transfer coefficient and pressure drop of CO_2 were measured in an extruded microchannel tube. Test principles are discussed, and special emphasis is given to measurement uncertainties, including the propagation of uncertainty through the water-side regression. Studies of two-phase flow pattern were conducted in a separate test rig. Heat transfer and pressure drop measurements were conducted at varying vapour fractions for temperatures 0-25 °C, mass flux 190-570 kg/m²s, and heat flux 5-20 kW/m². Heat transfer results show significant influence of dryout, particularly at high mass flux and high temperature. Nucleate boiling dominates prior to dryout. Two-phase flow observations show increasing entrainment at higher mass flux, and a dominance of annular flow. Heat transfer data can be correlated reasonably well with a combination of models for nucleate boiling, convective evaporation, dryout incipience, and post-dryout heat transfer.

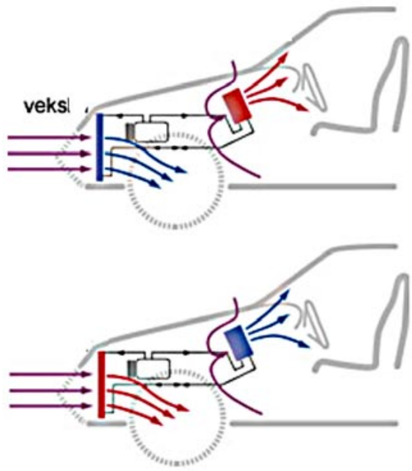
Two-phase flow patterns during microchannel vaporization of CO_2 at near-critical pressures

A test rig was built in order to observe two-phase flow patterns, using a horizontal quartz glass tube, externally coated with a transparent resistive film. Flow patterns were recorded at 0 °C and 20 °C, and for mass flux values ranging from 100 to 580 kg/m²s. The observations showed a predominance of intermittent (slug) flow at low x, and wavy annular flow with entrainment of droplets at higher x. At high mass flux, the annular/entrained flow pattern could be described as dispersed. Stratified flow was not observed in the tests with heat load. Bubble formation and growth could be observed in the liquid film, and the presence of bubbles gave differences in flow pattern compared to adiabatic flow.

4 COMPRESSORS/MACHINERY

Small oil-free piston type compressor

The objective of this project was to prove the feasibility of a small oil-free semi-hermetic piston-type CO_2 compressor for supercritical heat pump applications. The study covered: design and manufacturing, performance tests over the full range of speed and pressure, and manufacturing cost estimate. The compressor was designed for domestic water heating applications, and had no external cooling. The tests confirmed the feasibility of the technology for use in small oil-free compressors. The compressor operates quietly and without vibration. It is able to handle outlet pressures up to 150 bar and outlet temperatures up to 200 °C. The isentropic efficiency is comparable to that of oil-lubricated compressors on the market. The volumetric efficiency is fairly low. This CO_2 compressor technology is a promising alternative to oil-lubricated compression systems in automotive air conditioning, domestic water heating, and applications in the food industry.

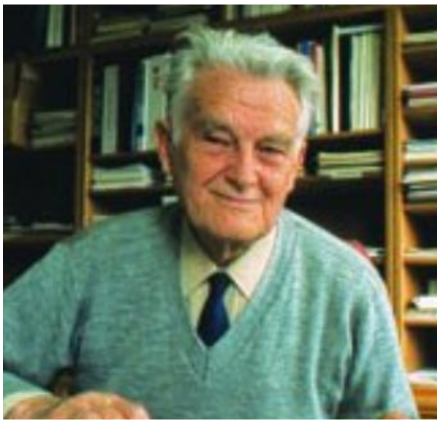


CO2 heat pump used in automobiles (providing both heat and cold)

5 SAFETY ISSUES

Some safety aspects of CO_2 vapour compression systems

A major safety issue for CO_2 is that of the high operating pressure. In the event of a component rupture, the explosion energy may determine the extent of potential damage. The explosion energies of baseline systems and CO_2 systems were calculated and compared. Results show that the explosion energies are not as different as the large difference in pressure would indicate. It has been suggested that a Boiling Liquid Expanding Vapour Explosion (BLEVE) may occur when a vessel containing pressurised liquid or supercritical fluid is rapidly depressurised. The overpressure from a BLEVE may be high enough to rupture the whole vessel. Some tests on CO_2 were conducted at varying initial conditions and liquid fill levels, and with varying vent areas. No significant overpressure peaks above the initial pressure were observed in the test programme.



Professor Dr.Techn. Gustav Lorentzen (1915-1995) was one of the initiators behind the reintroduction of CO2 systems

Boiling liquid expanding vapour explosions (BLEVE) in CO_2 vessels: initial experiments
This is an experimental study aimed at improving the understanding of BLEVE in CO_2 systems. A test vessel was built in order to measure transient pressures during initial depressurisation and possible subsequent overpressure peak(s). Some tests were conducted at varying initial conditions and liquid fill levels, and with varying vent areas. The project plotted typical transient pressure recordings, and the report discusses the practical relevance of the results. A maximum overpressure peak of 3 bar above the initial pressure was observed.

Experimental study on boiling liquid expansion in a CO_2 vessel
This project provides results from an experimental study aimed at clarifying the possible occurrence of BLEVE/BLCBE (Boiling Liquid Collapsed Bubble Explosion) in CO_2 systems. A test vessel was built and instrumented in order to measure transient pressures during initial depressurisation, and to record possible subsequent overpressure peak(s). A test program was conducted at varying initial conditions and liquid fill levels, and with varying vent areas. The report shows typical transient pressure recordings, and discusses the practical relevance of the results. No signs of BLEVE/BLCBE were recorded.

6 OTHER ISSUES

CO_2 as secondary refrigerant
This project suggests that CO_2 could be successfully used as an alternative to the artificial refrigerants used for supermarket refrigeration. In addition to the obvious environmental advantages of using such systems, an extra economic benefit was also noted. The power consumption of the CO_2 secondary system was very close to that of a DX system. If the plant was designed from the start with a CO_2 secondary system, then smaller pipes could be used for the return and liquid lines, which would offset the cost of the additional equipment in the secondary loop and the safety devices needed for the use of ammonia or propane. The power needed for the CO_2 pump is very small compared to the compressor power. From the safety analysis, it is clear that using CO_2 in supermarket refrigeration does not introduce health risks for persons in the shopping area.

Conclusions

This article provides a short summary of the individual projects reported under Annex 27. Results are of both fundamental and practical character. The projects show that CO_2 is a very promising refrigerant candidate in a series of application areas. It is the hope of the Operating Agent that Annex 27 has contributed to filling some of the holes in the CO_2 technology. The Annex report can be ordered from the IEA Heat Pump Centre.

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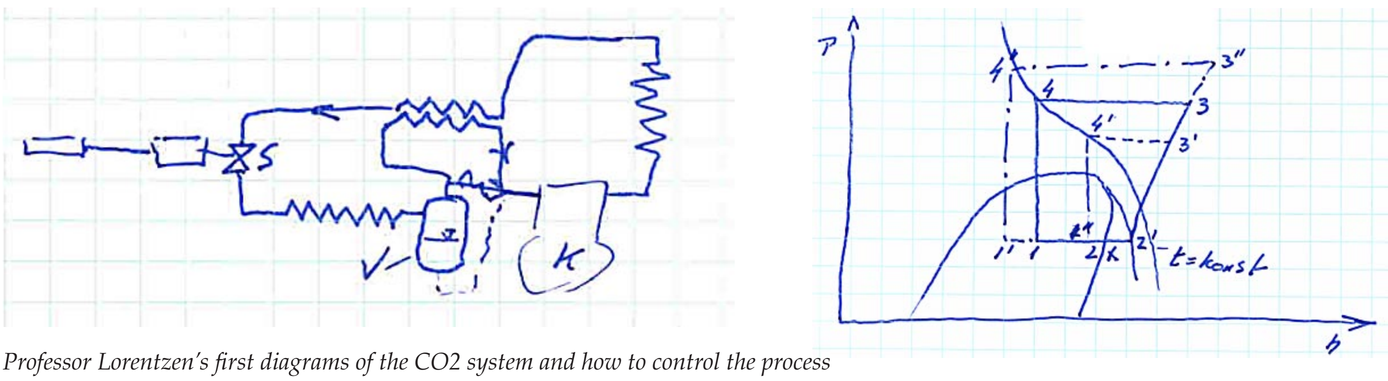

Professor Lorentzen's first diagrams of the CO2 system and how to control the process

A Small Heat Pump with Ammonia as Working Fluid

Prof. Dr. Thomas. Kopp, Switzerland

Ammonia is a natural working fluid, and has been used in industrial refrigeration plants for a long time. Although it has significant thermodynamic and environmental advantages, it has not been used in small heat pumps so far. The reason for this is the need to use copper-free materials and the fear of leaks. The Institute of Energy Technology at the University of Applied Sciences in Rapperswil (Switzerland) is presently conducting a research project for the development of a single-stage compression ammonia heat pump with a rotating blade compressor and a thermal power of 17 kW.

Introduction

In 1998, the Swiss Federal Office of Energy supported a theoretical study to compare heat pumps using the working fluids propane, ammonia, R 407C and R22 [1]. It turned out that the COP of an A-12/W60 heat pump with ammonia was 25 % better than one using R407C, 20 % better than one using propane and 15 % better than R22. On the other hand, the ammonia cycle has the highest compression ratio and the highest gas discharge temperature. This temperature could theoretically be lowered by injecting up to 15 % of liquid ammonia in the compression process. At that time, MCC, Mobile Climate Control Inc., in Toronto, Canada, launched a new rotating blade compressor with an economizer port, which offered the ability to manage the high compression ratio by using the economizer circuit and to cool the discharge gas by a non-soluble oil, which was required for lubrication and blade-sealing anyway. It was decided in 2000 to continue this project by building a research heat pump with a thermal power of 17 kW, for the purpose of replacing older oil and gas heating systems in residential buildings to prove the theoretical results of the first study.

An ammonia heat pump with the RotoVaneR rotating blade compressor

This article describes the development and the results of an ammonia heat pump with a RotoVane[R] rotating blade compressor (Figure 1). The compressor is lubricated and sealed with an oil flow which is fed into the compressor through a separate oil entrance and is removed via the gas discharge. A non-soluble oil was recommended, and Shell Clavus G68 was used in the project. This oil stream adds complications to the components circuit and requires the installation of an oil separator (to avoid excessive reduction of heat transfer capacity in the heat exchangers) and an oil cooler. Because of the very high oil flow, of up to 400 kg/h, which is up to eight times as much as the gas mass flow, oil separation was not easy.

In the first project phase, the prototype was planned by a company with experience in copper-based heat pumps and fabricated by a company with experience in large ammonia plants for artificial ice rinks and industrial ammonia refrigeration plants. The oil separation was planned with a commercially available oil separator. Welded, cylindrical UNEX plate heat exchangers were used as heat exchangers. Unfortunately, this prototype did not work properly: the oil separation circuit in particular was inadequate. There were also severe problems when the compressor motor was turned off, as the high pressure forced the compressor into reverse. The built-in non-return valves were unable to stop the backward flow to the evaporator. This was due to manufacturing

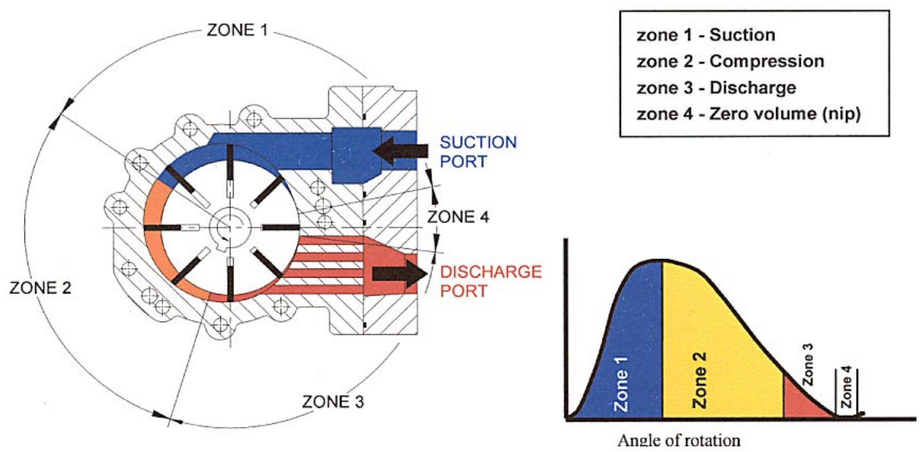

Figure 1: Rotovane[R] rotating blade compressor, MCC Canada

flaws of the steel piping, with quantities of residual dirt from cutting and welding. Only a few measurements could be made, which showed that the compressor was able to work from an evaporation temperature of -21.6 °C to a condensing temperature of 50.3 °C, which is a compression ratio of 11.4 in one stage. Unfortunately, experience from manufacture of larger refrigeration plants does not automatically transfer to an ability to manufacture smaller heat pumps.

Improved prototype

The Institute of Energy Technology of the University of Applied Sciences in Rapperswil decided to plan and build a new prototype. To attempt to avoid the problems identified in the prototype, the new prototype was built of stainless steel material and subdivided into sections which were assembled with tongue and groove flanges. Some industrial sight-glasses with a maximum pressure level of 40 bar were very useful for the first runs (Figure 2). The two-stage oil

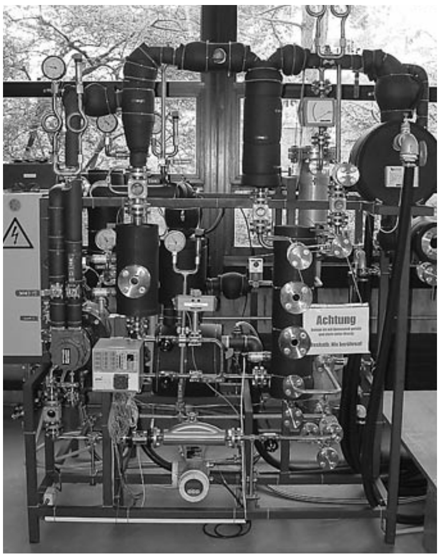

Figure 2: research heat pump with ammonia and Rotovane[R] compressor

separation consisted of a centrifugal oil separator and a coalescence filter as the second stage. Because the pressure drop of the second-stage separator was not known and could change during operation, the separated oil from the first separator had to be expanded to the pressure of the oil coming from the second stage.

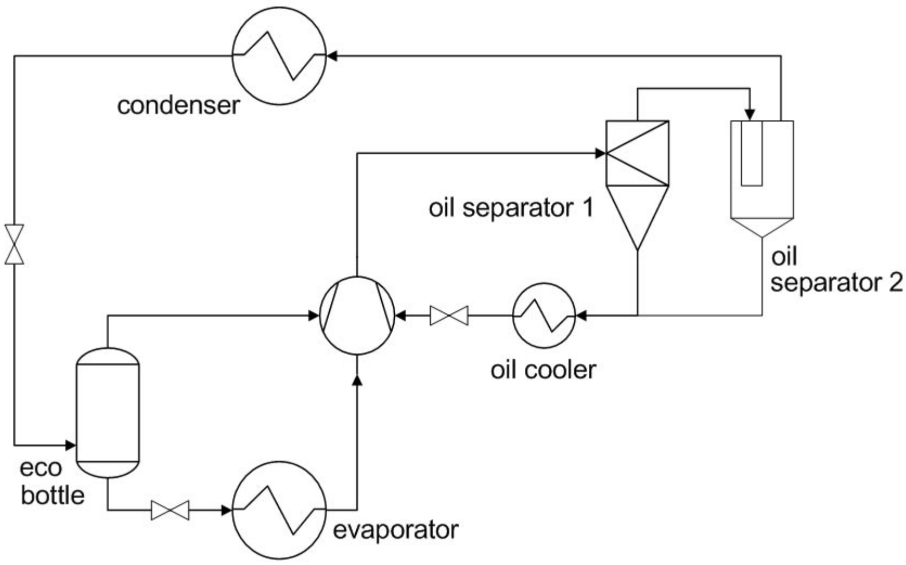

Figure 3: schematic process diagram of the ammonia and the oil circuit

After this, the oil flowed through the oil cooler. The compressed ammonia passed through the oil separators and condensed in the condenser. After the first expansion into an intermediate pressure vessel, the vapour phase was fed to the economizer port of the compressor and the liquid phase was expanded via the second expansion valve into the evaporator, see Figure 3. The cooling water (= heating water for the building) was passed through the condenser and the oil cooler, having been preheated in the motor cooler. Although quite complicated, the new prototype worked well and several measurements could be taken during 2002 and 2003. The prototype was equipped with data acquisition for pressures and temperatures, oil flow, electric power and water and brine flows to calculate the COPs. The expansion valves were controlled by liquid level sensors.

Main results

The main results of this study [2] were:

- The COP was slightly influenced by the oil flow if the oil outlet (= gas outlet) temperature was kept constant at 100 °C. For B2/W50 operating conditions, an oil flow of 160 l/h gave a COP of 2.5, while a flow of 400 l/h gave 2.9. The increased COP was due to better sealing because of the higher oil flow.
- The liquid level in the flooded evaporator had no influence on the COP.
- The COP was influenced by the temperature of the gas outlet: 85 °C gave a COP of 2.8, while 130 °C gave a COP of 2.2 (again for B2/W50 conditions). The gas outlet temperature was controlled by regulating the oil flow, which meant that cases with low outlet temperature were run with high oil flow. High oil flow produces good sealing and so far a high volumetric efficiency.
- The COP does not depend on the speed. The thermal heat pump capacity and the power demand of the motor were linearly proportional to the motor speed. The maximum speed was 4000 r/min.
- The circuit with an economizer gave only a maximum improvement of 6 % in COP, and a maximum improvement of 12 % in thermal power output.
- The R140AL compressor, with a volumetric compression ratio of 3:1 (which was under-pressurising) was better than the R140AH compressor with a high volumetric compression ratio of 5:1 (which was over-pressurising).
- The B-20/W60 conditions could be run, but the COP reached only 1.4: see Table 1.

B10/W35	B2/W35	B2/W50	B-7/W50	B-12/W50	B-20/W60
3.8	3.0	2.6	2.3	1.9	1.4

Table 1 COP with economizer at 3000 r/min (B = brine, W = water, temperatures in °C)

- All experiments fitted a relationship between the COP and the quotient of heat flow out of the oil cooler related to the total heat production. This is the key result of this study; the more heat that is produced through the oil, the lower the COP. The heat of the oil was produced either by a high oil flow or by a high temperature difference between oil inlet and oil outlet. The sensible heat from the oil has no multiplication potential to the mechanical energy of the compressor in contrast to the potential coming from the condensation of the refrigerant. In the case of complete oil flow, and therefore no refrigerant, the plant would become an electric resistance heating system and the COP (of course) would be 1.0: see Figure 4.

A small screw compressor with an internal volume of 135 cm^3 was also investigated in the same study. The results were similar to those for the RotoVane^R compressor.

Conclusions

This project, with the two rotating compressors with a large oil flow for sealing and lubrication, could not produce the results that had been anticipated through previous theoretical study. It was still a challenge to make the prototype work. Due to the high ratio of surface to volume in smaller scale compressors, which means that the effect of the gaps between rotor and casing are much more important than in a large machine, it seems to be unadvisable to use compressors with a high oil flow ratio in small-scale heat pumps where the COP is crucial. The results of this project are not representative of the use of ammonia refrigerant as such, but show attributes of the compressors.

The project has also shown that two schools effectively exist: one which is used to working with ammonia, and one which uses other refrigerants. The second school is invited to reconsider either the use of ammonia or the use of carbon dioxide. We have never had any handling problems since starting to work with ammonia in the Institute. Ammonia does require researchers and workers to be cautious, but there is no reason for fear if proper care is taken.

Although the Swiss heat pump industry is not likely to continue research work on small heat pumps with ammonia, the environmental benefits of ammonia with ODP=0 and GWP=0 are considered so valuable as to justify continuation of this research. The Swiss Federal Office of Energy will support an additional project with the aim of a small heat pump with ammonia. Unfortunately there are not many options left as to the types of compressor in the future project. At the moment, we are favouring an oil-free piston compressor.

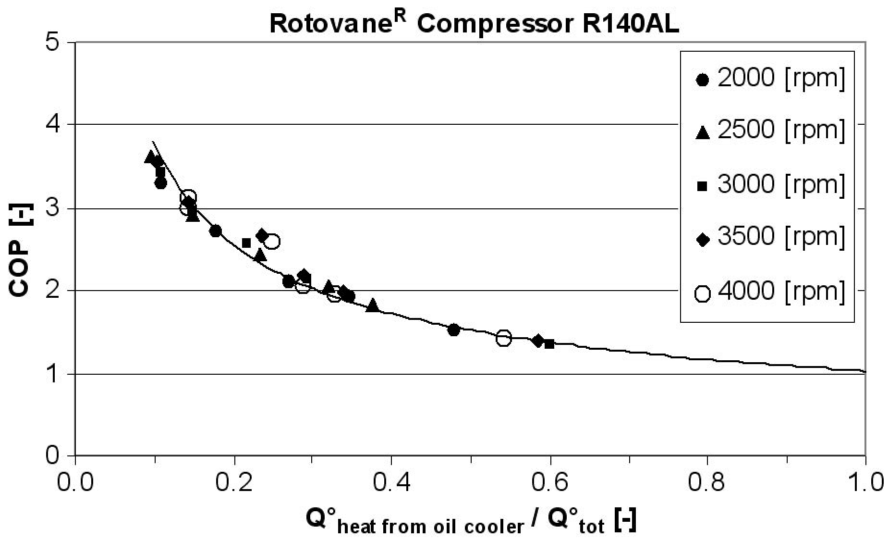

Figure 4 COP versus the quotient of heat from the oil cooler to total heat

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[2] Geisser E., Kopp Th. et al. 2003. "Kleinwärmepumpen mit Ammoniak, Phase 3: Flügelzellenverdichter und Schraubenverdichter".
Final Report, Swiss Federal Office of Energy (in German).

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Competitive strength of renewable energy in the building sector

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Erik W.J. Wissema *(Ministry of Economic Affairs), the Netherlands*

After a long period of supporting the development of renewable energy sources (RES) through option-specific programmes, the Dutch Government initiated the general RES DEN programme (Renewable Energy Netherlands) in 2001. Within the programme, projects compete on the basis of innovation and contribution to energy production in 2020. Novem was given the task of developing a method of comparing the competitive strengths of the various renewable energy options in buildings, in order to make policy choices on priorities. With the support of consultants, installation contractors, manufacturers and end users, Novem has been able to provide solid advice for new policy instruments, which will be implemented in 2004 and subsequent years, such as the long-term Energy Research Strategy (EOS) and Transition programmes.

Introduction

The Dutch Government has set a 10 % target for renewable energy in the Netherlands by 2020. The technologies selected to achieve this goal are bio-energy, wind energy and what are known as 'Building-integrated Renewable Energy Systems' (BIRES). Typical BIRES-technologies are thermal solar heating and cooling, heat pumps, solar photovoltaics, cold energy storage, geothermal energy and small-scale wind energy.

In the past, the Dutch government has supported these renewable energy technologies for domestic and commercial buildings in specific technology programmes. Given the Governmental budget cuts and the idea that the market should be more self-supporting, the Ministry of Economic Affairs introduced a new support programme in 2001, which is not RES-specific. The main evaluation criteria for this programme are innovation and the ratio of Government support to the contribution of the projects to the RES objectives (or CO_2 reduction targets) for 2020.

The market should make its own choices, depending on the type of building and its use. This has led to relatively rapid development of the heat pump market for large commercial buildings and, though less significant, for new domestic buildings. However, most of these developments are still in the first or second market phase and mainly of interest to the innovators and/or early adopters in the market. With no additional support, they will probably stay in these phases and will not significantly contribute to the policy goals for 2020. The major questions posed for Government policy are therefore: what will have to be done to make renewable energy technologies and systems attractive to the mainstream of the market, and which technologies will require the least effort in proportion to expected contribution in 2020?

The Ministry therefore asked Novem to develop a method of comparing the competitive strength of different BIRES. The results were presented to, and discussed with, representatives of all market sectors involved.

Competitive Strength Analyses

The competitive strength of a BIRES is based on various factors. For this investigation, these factors have been divided into two groups:

- Financial factors (cost per GJ), such as price, interest, maintenance costs, etc.
- Subjective factors (attractiveness), such as self-esteem, aesthetics, image, etc.

As these factors differ for each target group and each market segment, Novem analysed the competitive strength for two of the most important target groups, innovators and early adopters, in the nine largest market segments:

- Existing domestic buildings (semi-detached, terraced and apartment)
- New domestic buildings (sem detached, terraced and apartment)
- New commercial buildings (small and large office buildings), *and*
- Industrial buildings.

Based on the BCG (Boston Consultancy Group) matrix and the Directional Policy Matrix (Shell). Novem has developed a model to present

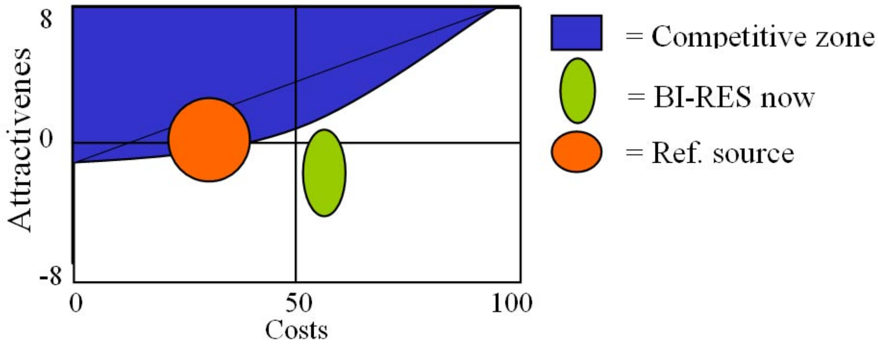

Fig. 1: Example of an attractiveness / cost competitiveness matrix

the findings of these analyses, where financial competitiveness and the attractiveness are put into a two-dimensional model, as shown in Figure 1.

The majority of the BIRES are installed in buildings for heating and cooling and thus compete with heating technologies such as condensing boilers, CHP and district heating, or with advanced technologies such as like micro-CHP and fuel cells. Building-integrated solar PV and wind energy compete with electricity generation based on fossil fuels or RES and with the import of RES. The ”traditional” technologies are used as reference.
In total, approximately 150 RES - segment / target group combinations were analysed. For each combination, both the cost per GJ and the attractiveness were investigated.

Costs

The first set of factors influencing the competitive position of a BIRES is the financial factors, as these are the first factors used to compare RES with other standard building energy systems.

The most important cost aspects are the fixed costs (such as the total investment), the economic life span, interest rate and the availability of subsidies. For the end user, it is the variable costs for energy, such as the electricity and gas tariffs, base rate / connection costs, service costs and, where applicable, the refunds for electricity production that are of importance.

Using these financial factors, a dedicated calculation method was developed to determine the total energy costs for a building with a specific energy system.

To determine the competitive position of a BIRES in a specific building - target group combination, the total energy costs for such a building, using an energy system with that specific type of BIRES, was compared with the total energy costs for a similar building using a reference energy system. For example: for determination of the competitive position of an absorption heat pump in an existing terraced house, the costs of the standard total energy consumption for a standard terraced house were compared with the total cost of energy for the same house with an absorption heat pump instead of a standard high-efficiency boiler.

An important aspect for governmental policy makers are the costs of the reduction of fossil energy or CO_2, expressed in Euro per GJ or Euro per Mtonne CO_2 respectively. The primary energy use for the various energy systems can be calculated, using the efficiency data from demonstration projects with these technologies. An important variable for the calculation of energy conservation, and particularly for heat pumps and CHP, is the efficiency of power generation (and the CO_2-emissions thereof). In the Dutch standard, the average power plant efficiency of 43.9% (expressed as a function of lower calorific value of the fuel) is used for the consumption of electricity (in heat pumps), whereas for generation (CHP, wind and PV) it is the best power plant efficiency (54%) that is used as the reference.

Attractiveness

Apart from financial factors, the competitive strength of BIRES is also determined by the perception of the market of its advantages and disadvantages compared to a standard reference technology. In the development of a new market for BIRES, innovators have a different perception of, and attitude towards, new technologies than have the main-stream market players. An analysis of these differences can give an insight into the policy instruments to use in order to bridge this gap.
This second set of factors is thus a set of subjective factors, which can be divided into four sub-sets:

- practical business factors for the real estate developer and installer, such as contribution to EPC (Energy Performance Coefficient), permits and legislative procedures, familiarity with the technology, pre-financing, chain profit and commercial margins, availability of the technology;
- ‘emotional’ factors for the real estate developer and installer, such as company image;
- practical factors for the end user, such as service level, reliability, environmental impact;
- ‘emotional’ factors for the end user, such as comfort, space requirements, self esteem, aesthetics.

For each BIRES – segment/target group combination, these criteria are scored on a scale of -2 to +2, where -2 is very negative and +2 is very positive, and weighted from 0 to 4, where 0 means not applicable or not of interest for this combination, and 4 means of great interest / very important against the reference technology. This results in an attractiveness score per BIRES – segment/target group combination in the range of -8 to +8. The scores and weightings for attractiveness have been discussed with the market in several workshops.
For heat pumps, for example, a permit is needed to use the ground as a heat source. This procedure takes 6 – 9 months. In a small building project, this will be an serious obstacle (score: -2; weighting: 3; attractiveness: 3 x -2 = -6) for the majority of the real estate developers, whereas for innovators it will be only an unimportant minor obstacle (score: -1; weighting: 1; attractiveness: 1 x -1 = -1). Looking at the attractiveness for the end user, heat pumps and solar PV give a high score. Heat pumps can significantly increase the comfort in domestic buildings, while solar PV scores high on aesthetics.

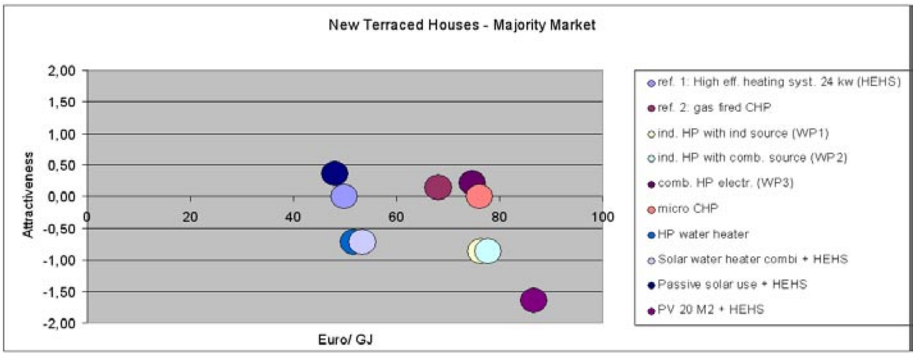

Fig. 2: Competitive strength of the various BIRES in new terraced houses for the majority market

Results of the study

The results were collected in 18 attractiveness / cost-competitiveness matrices. (see fig. 2)

Out of 72 BIRES - segment combinations, only nine are at present financially competitive with the conventional reference sources:

- Passive solar energy in all three forms of new houses
- Aquifer-based heat pumps in both existing and new apartment buildings, medium size- and large office buildings and public buildings
- Daylight application in medium size- and large office buildings.

Six BIRES - segment combinations are nearly financially competitive:

- Solar water heaters in all three forms of new houses
- Heat pump water heaters in all three forms of new houses

The other combinations are still far from financial competitiveness, and will remain so in the medium term unless market situations or support programmes change.

Sensitivity for market developments

Sensitivity analyses can be performed, using the Competitive Strength Analyses model, by varying the costs for:

- Investments for technology and systems.
- Financial arrangements between end users, housing corporations, real estate developers and energy companies
- Energy tariffs, for example by decreasing the costs for electricity and increasing it for gas.
- Efficiency of power generation, for example by using the state of the art for the latest power station as a future average.

Conclusions

The Competitive Strength Analyses method can give a good insight in the market, and gives the Government a good instrument for setting priorities. The instrument can be used as a transparent model in which sensitivity to policy instruments can be investigated. New technologies and new expertise based upon the latest figures, experiences, etc. can easily be implemented to update the analysis and refine or adjust policy instruments.

The analysis for the Netherlands clearly showed different competitive positions for the BIRES in the different market segments. The main conclusions are:

- Only very few BIRES - segment combinations are competitive.
- For some options, the higher attractiveness compensates for the higher costs per GJ.
- Some BIRES - segment combinations may never become competitive.

The approach with Competitive Strength Analyses for Building-Integrated Renewable Energy Systems gives insight in the relative strength of heat pumps and other renewable energy systems in market segments, and provides background information for deciding marketing and policy focus to increase the application of BIRES.

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Table 1: overview of the Competitive Strength Analysis for BI-RES

Segment:	BI-RES:
New apartment buildings	Competitive: passive solar energy, aquifer based heat pumps. Nearly competitive: solar water heaters, heat pump water heaters.
Existing apartment buildings	Competitive: aquifer based sorption and electric heat pumps.
New terraced houses	Competitive: passive solar energy, heat pump water heaters. Nearly competitive: collective electric heat pumps, solar water heaters.
Existing terraced houses	No competitive option in this segment.
New (semi-) detached houses	Competitive: passive solar energy, heat pump water heaters. Nearly competitive: solar water heaters, photovoltaic solar energy.
Existing (semi-) detached houses	Nearly competitive: solar water heaters, heat pump water heaters, photovoltaic solar energy.
Medium size office buildings	Competitive: aquifer based heat pumps, daylight application.
Large office buildings	Competitive: aquifer based heat pumps, daylight application.
Industrial corporate halls	Competitive: aquifer based heat pumps. Nearly competitive: small scale wind energy.

Natural Working Fluids 2002: 5th IIR Gustav Lorentzen Conference, Guangzhou, China. Proceedings (CD-ROM)

These proceedings include 65 papers on natural working fluids regarding CO_2 theory, experimental work on CO_2, other natural working fluids and research on and applications of environmentally friendly refrigerants.

Available from the IIR at:
http://www.iifiir.org
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Rapid cooling of food. Proceedings (CD-ROM)

These proceedings contain 45 papers presented at an IIR conference held in Bristol on the latest equipment available rapid cooling processes. It gives an insight into the quality of aspect of food cooling as well as the benefits of rapid cooling.

Available from the IIR at:
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How to improve energy efficiency in refrigerating equipment

This is the 17th Informatory Note from the IIR. It provides useful information on how to reduce the energy consumption of refrigeration systems. Energy efficiency plays a vital role in mitigating greenhouse-gas emissions in the refrigerating sector. Considerable progress can be achieved and this is an encouraging avenue to explore.

This informatory note can be downloaded from the IIR web-site at:
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Handbook for the international treaties for the protection of the ozone layer. The Vienna Convention (1985). The Montreal Protocol (1987).

This handbook includes the texts of the Ozone Treaties and their Amendments, as well as the decisions taken by the Parties during the meetings of the Conference to the Parties to the Vienna Convention and to the Montreal Protocol up to the end of 2002. The handbook is divided into five main sections:

- The Vienna Convention
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The handbook can be downloaded at:
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Handbook of air conditioning and refrigeration

This goal of this handbook is to provide a useful, practical and updated technical reference for the design, selection and operation of air conditioning and refrigeration systems. It provides:

- Design information
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- A system-wide approach
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GS2000™ loop design software

GS 2000™ is a software program for the sizing of ground heat exchangers for ground-source heat pumps. The user can either input the monthly loads or use the simple residential load model. The user can specify heat pump design information, type of soil, anti-freeze and pipe properties. The GS 2000™ version 2.0 also includes on-line help. This software is provided by CANMET Energy Technology Centre.

The software can be downloaded at:
http://www.buildingsgroup.nrcan.gc.ca/software/gs2000_e.html

Video documenting the quality of life improvements from air conditioning, heating and refrigeration

In a new, 10-minute video entitled “Improving Life” it is described how advances in air conditioning, heating and refrigeration help people to live healthier, happier and longer lives. It is explained how innovative energy-efficient equipment has made possible products and services that range from fresh food shipped from distant markets to refrigerated medicines and vaccines, 24-hour surgical suites, computer chips etc. The video is being used to recruit workers and students to careers in the HVAC&R industry.

The video (VHS or DVD) is available from the ARI at:
ARI
4100 North Fairfax Drive, suite 200
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ASHRAE GreenGuide

The GreenGuide offers essential reference and guidance to those involved in green or sustainable design of buildings. The Guide provides direction to designers of HVAC&R systems in how to participate effectively on design teams charged with producing green buildings. It also covers green design techniques applicable to related technical disciplines, such as plumbing and lighting. And it addresses how mechanical and electrical systems may interact with and be influenced by architectural design. It starts with the very earliest stages of a green building design project and carries through to the resulting structure’s construction, operation and maintenance, and eventual demolition.

Available from AHRAE at:
http://www.ashrae.org/
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Fax:+1 765 494 0787
E-mail: herlconf@ecn.purdue.edu
http://www.ecn.purdue.edu/Herrick/Events/Conference

10th International Refrigeration and Air Conditioning Conference at Purdue
12 – 15 July 2004
West Lafayette, USA
Tel: +1 765 494 6078
Fax:+1 765 494 0787
E-mail: herlconf@ecn.purdue.edu
http://www.ecn.purdue.edu/Herrick/Events/Conference

World Renewable Energy Congress VIII
28 August - 3 September 2004
Denver, Colorado, USA
Tel: +1 303 275 3781
Fax: +1 303 275 4320
E-mail: ivilina_thornton@nrel.gov
http://www.nrel.gov/wrec

Natural Working Fluids - 6th IIR Gustav Lorentzen Conference
29 August-1 September 2004
Glasgow, UK
Contact: Miriam Rodway, secretary
Institute of Refrigeration
Kelvin House, 76 Mill Lane
Carshalton, Surrey SM5 2JR
Tel: +44 (0)20 8647 7033
Fax: +44 (0)20 8773 0165
E-mail: oir@ior.org.uk
http://www.ior.org.uk/gl2004

5th International Conference on Compressors and Coolants – Compressors 2004
29 September-1 October 2004
Nitra, Slovak Republic
Contact: Peter Tomlein
SZ CHKT, Hlavnà 325
900 41 Rovinka, Slovak Republic
Tel: +421 2 4564 6971
Fax: +421 2 4564 6971
E-mail: zvazchkt@isternet.sk
http://www.isternet.sk/szchkt

2005

8th IEA Heat Pump Conference 2005
30 May – 2 June 2005
Las Vegas, Nevada, USA
Contact: The Conference Secretariat
Oak Ridge National Laboratory (ORNL)
P.O.Box 2008, MS-6067
Oak Ridge, TN 37831
Tel: +1 865 576 8620
Fax: +1 865 574 9331
E-mail: hp2005@ornl.gov
http://www.ornl.gov/hp2005

2006

Natural Working Fluids 2006: 7th IIR-Gustav Lorentzen Conference
E-mail: Trygve.M.Eikevik@sintef.no

2007

22nd IIR International Congress of Refrigeration
21 – 26 August 2007
Beijing, China
http://www.iifiir.org

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

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International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among its participating countries, to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development.

IEA Heat Pump Programme

International collaboration for energy efficient heating, refrigeration and air-conditioning

Vision

The Programme is the foremost world-wide source of independent information & expertise on heat pump, refrigeration and air–conditioning systems for buildings, commerce and industry. Its international collaborative activities to improve energy efficiency and minimise adverse environmental impact are highly valued by stakeholders.

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 & 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 exchange and promotion. In the member countries (see right), activities are coordinated by National Teams. For further information on HPC products and activities, or for general enquiries on heat pumps and the IEA Heat Pump Programme, contact your National Team or the address below.

The IEA Heat Pump Centre is operated by

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IEA OECD heat pump centre

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