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Mitigating ozone depletion and global warming

Produced jointly with United Nations Environment Programme
Division of Technology, Industry and Economics
OzonAction Programme

on the occassion of the International Ozone Day

In this issue:

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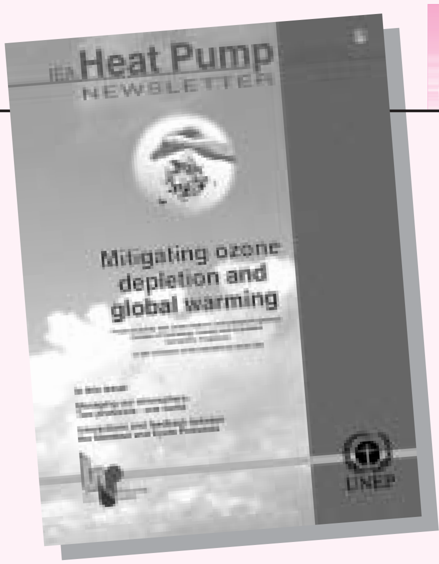

In this issue

Mitigating ozone depletion and global warming

This Newsletter was produced jointly with UNEP DTIE (United Nations Environment Programme Division of Technology, Industry and Economics) OzonAction Programme on the occasion of International Ozone Day, 16 september 2001. The collaboration with this organisation has a tradition of many years, with e.g. contributions from the IEA Heat Pump Centre to the Montreal Protocol Reassessment/Technical Options Committee Refrigeration report. This Newsletter focuses on the interlinkage between ozone depletion and global warming and successful strategies to mitigate either or both.

Front cover: *Courtesy OzonAction Programme of UNEP DTIE (United Nations Environment Programme – Division of Technology, Industry and Economics)*

TOPICAL ARTICLES

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HEAT PUMP NEWS

FEATURES

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Mitigating ozone depletion and global warming

Although it is clear that the Montreal Protocol on Substances that Deplete the Ozone Layer has already achieved considerable success, there remains a number of technical and economic challenges to be faced. The developed world has successfully phased out CFCs in virtually all applications, including heat-pumping technologies. Developing countries, however, are just beginning to confront the substantive issues of control, implementation etc. that will take them down a similar path. There is a pressing need for developed countries to share their expertise and experience with less developed countries, and to assist them in choosing and implementing sustainable technologies. This is all the more pressing because the global environmental issues addressed by agreements like the Montreal and Kyoto Protocols are often interlinked in nature.

One such issue linking the two Protocols is the use of HFC-based working fluids in refrigeration, air-conditioning and heat pump applications. On a policy level, HFCs are considered desirable alternatives from an ozone protection standpoint but undesirable from a climate change perspective due to their global warming potential. The Intergovernmental Panel on Climate Change (IPCC) and the Montreal Protocol's Technology and Economic Assessment Panel (TEAP) are already cooperating to address such interlinked issues through workshops and information exchange.

Heat pump technologies in the heating mode offer clear benefits for the environment - they can help reduce CO_2 emissions by utilising renewable sources of energy and conserving fossil fuels. In the cooling mode, i.e. refrigeration and air conditioning, they offer benefits in an indirect, but not less important way, like preservation of food, reduction of food wastage, climatic comfort and hygienic conditions, etc. To achieve real sustainability, one must look at the broader picture and not just a few components, which means also considering the design of buildings and structures as well as of entire community systems. One can then reduce demand and provide for the remaining demand in a highly efficient way.

The need to further share experiences and information about such interlinkages prompted the IEA Heat Pump Centre and UNEP DTIE's OzonAction Programme to collaborate on this joint issue. In doing so, we wish to encourage continued cooperation, discussion and action by the heat pump community with regard to the impact of their technology on the environment - both globally and locally.

Rajendra Shende,
UNEP DTIE Energy and OzonAction Unit

Hermann Halozan,
IEA Heat Pump Programme

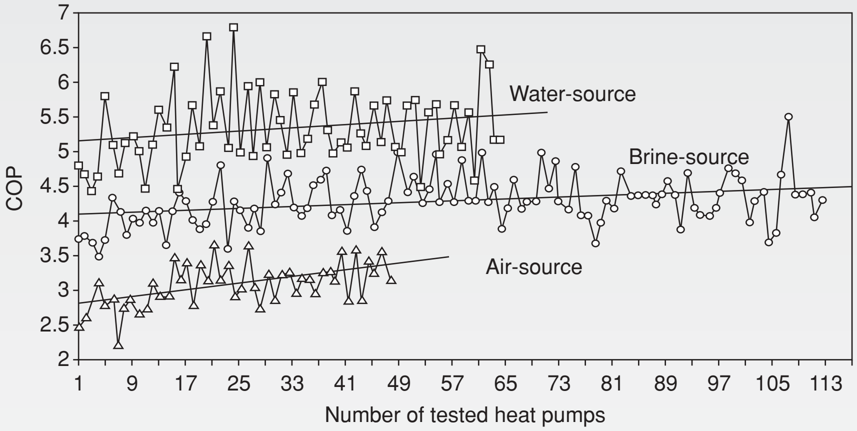
ARI proposes 20% efficiency increase in 2006

USA - The US Department of Energy (DOE) is expected soon to issue a proposal to lower the 30% increase in minimum efficiency standard for central air conditioners and heat pumps to 20%. The 30% increase was previously discussed in Newsletter 19/1. The new minimum efficiency standards will go into effect in 2006.

In a petition filed 23 March, the ARI (Air-Conditioning and Refrigeration Institute) said that the DOE's new rule requiring the installation of equipment that is 30% more efficient, beginning in 2006, would be so costly to consumers and small businesses that it "would price many people out of the market when it comes to purchasing decisions." According to the ARI, the 30% rule "would cause many consumers to delay replacing older, less efficient systems. This would have the reverse of the intended effect, by keeping less efficient units in operation." Therefore, the ARI asked a 20% increase, in order to encourage conservation of electricity while at the same time easing the burden on all consumers, particularly low and fixed income consumers.

Source: Koldfax, April 2001

Better and better



▲ *Figure 1: COP of tested heat pumps 1993 - 2000.*

Switzerland - Since the heat pump test and training centre in Winterthur-Töss was established in 1993, heat pump performance has improved significantly. About 220 heat pumps have been tested and the results published. The historical data on COP measurements show performance improvements for all types of heat pumps (air-to-water, brine-to-water and water-to-water) over the past 7 years (**Figure 1**).

The average steady-state COP of the '2000-generation' of residential heat pumps is surprisingly good:

- air-to-water at A2/W35: 3.3
- brine-to-water at B0/W35: 4.5
- water-to-water at W10/W35: 5.5

In this overview A2 = ambient air at 2°C; B0 = brine at 0°C; W35 = water at 35°C etc.

Source: Wärmepumpe News 1/01

Great potential for geothermal energy in Prague

Czech Republic - The city of Prague energy plan (CPEP), drawn up last year, has provided a wealth of interesting information, especially regarding the potential of ground-coupled energy. The total potential of ground-coupled energy is summarised in **Table 1**.

▼ *Table 1: Technical potential of renewable energy sources in Prague.*

Use of solar energy	431,045 GJ/year
Use of water energy	161,979 GJ/year
Use of biomass energy	891,421 GJ/year
Use of municipal waste energy *	1,650,000 GJ/year
Use of geothermal energy **	7,776,000 GJ/year
Total	10,910,445 GJ/year

* used in the Malešice incineration plant
** of which 1,941,120 GJ/year is necessary for driving heat pumps

The conclusions of the analysis of the renewable energy potential include the following:

- ground-coupled energy is the most important renewable energy source available, with a lot of high-quality sites located in central Prague, where a large number of buildings can be heated;
- to improve the environmental situation in Prague, it is advantageous to use heat pumps in places where no natural gas is available, particularly for the replacement of fossil fuels (lignite);
- many localities are suitable for the use of water-to-water heat pumps; under certain conditions, they can successfully compete with gas heating and, in addition, have zero emission production;
- facilities heated by heat pumps should comply with thermal and technical standards to avoid a decrease in the effectiveness of heat pumps;
- implementation of heat pumps in places where until now direct electric heating has been used will allow significant reduction of the power supply system's load.

Source: News at SEVEn, March 2001
Contact: Martin Dašek, SEVEn
E-mail: martin.dasek@svn.cz

IIR Working Parties and Sub-commissions

France - IIR Working Parties bring together specialists with expertise in the topical domains handled by the Institute in all fields of refrigeration. Their aim is to promote development and provide knowledge in these spheres. They provide solutions to problems encountered and give recommendations.

Members of working parties come from industry, university and research-centre settings or are active in the practical refrigeration field.

Working Parties cover issues dealt with by one or several Commissions, and operate on a temporary basis. IIR Working Parties presently active include:

- *"Test Stations for Heat Pumps and Air Conditioners"*
  This Working Party is chaired by Mr Per Fahlen, Sweden (per.fahlen@sp.se) and relates to Commissions E1 (Air Conditioning) and E2 (Heat Pumps, Energy Recovery). Its purpose is to provide a forum for presenting information and experience acquired on the use of measuring and testing techniques in refrigeration and air conditioning and on the viability of new methods and new equipment.

- *"Ice slurries"* chaired by Peter Egolf (Peter.egolf@eivd.ch)
- *"Frozen foods"* chaired by Leif Bøgh-Sørensen (lbs@FDIR.DK)
- "*Mobile Air Conditioning*" chaired by Gabriel Haller (haller.g@arsenal.ac.at)

IIR Sub-commissions operate on a semi-permanent basis within the scope of one Commission, for example:

- *"Refrigerated Display Cabinets"* (Commission D1) chaired by Sietze van der Sluis (s.m.vandersluis@mep.tno.nl)
- *"Test Stations"* (Refrigerated transport) chaired by Frans van der Rijst (frans.van-der-rijst@bilprovningen.se)

Source: IIR
Fax: +33-1-47631798
E-mail: iifiir@iifiir.org

International Ozone Day

In 1995, 16 September was proclaimed the International Day for the Preservation of the Ozone Layer in order to commemorate the date in 1987 on which the Montreal Protocol on Substances that Deplete the Ozone Layer was signed. Parties to the Montreal Protocol are invited to devote this special day to the promotion of concrete activities at the national level in accordance with the objectives and goals of the Montreal Protocol and its amendments.

This Newsletter has been published jointly with UNEP DTIE OzonAction Programme on the occasion of International Ozone Day.

IIR Dictionary to be updated

France - The IIR has embarked on a process to update its Dictionary, which dates from 1975. It contains some 3,200 terms that have been translated in seven languages: English, French, Russian, German, Spanish, Italian and Norwegian.

Several new terms and expressions have emerged in the field of refrigeration since the current version was made, which justifies the update. The dictionary currently has chapters relating to air conditioning and refrigeration, reflecting IIR's working areas. However, a chapter on heat pumps is not present, but will be in the updated version. Member experts from Commissions have been invited to collaborate in this important project, which should be finalised in about 2 years.

More information: IIR
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E-mail: iifiir@iifiir.org

Use of heat pump in polar circle

Norway - The health care centre in the Norwegian city of Kautokeino, 500 km north of the polar circle, uses two 145 kW heat pumps to supply 3,000 m^2 of floor heating.

Despite outdoor temperatures as low as -40°C and ground temperatures as low as -10°C, the two heat pumps installed in the health care centre work very well, bringing the indoor temperature to a comfortable 21°C. Heat is extracted by 16 vertical piles. A total of 4,600 m of co-axial double piles are placed up to 145 m in the ground, and 5,000 litres of a mixture of water and (30%) glycol circulate through the piles. The mixture enters the evaporator at a temperature of -4°C and returns into the ground at a temperature of -10°C. Water at a temperature of 45°C is delivered to the floor heating system in the complex.

The main reason for using heat pumps in this area, instead of conventional oil or gas heating systems, is climate related. On calm polar nights, there is a large chance that so-called inverse weather conditions will occur. If accompanied by the production of fossil fumes, such conditions can, even in thinly populated areas, lead to smog formation. Such situations can last for weeks. With the use of heat pumps, this risk is minimised.

Source: KI Luft- und Kältetechnik 4/2001

In memory of Dieter Wittwer

Switzerland - The HPC Newsletter regrets to report the unfortunate death of Dieter Wittwer. On 4 June 2001, Dieter made a flight together with a friend in a glider, when suddenly they collided with a second glider. Dieter and his friend both lost their lives.

Dieter was the successful manager of the Fördergemeinschaft Wärmepumpen Schweiz (FWS), and he put a lot of time and energy into the promotion of heat pumps in Switzerland. He was also a regular contributor to the HPC Newsletter.

The staff of the HPC extends their condolences to his family, friends and colleagues.

CO_2 ground-coupled probe

Germany - Based on the technology of the heat pipe, the 'Forschungszentrum für Kälte- und Umwelttechnik' (FKU) in Berlin is developing a novel technique for ground-coupled earth probes (i.e. vertical ground heat exchangers). Aim of the research project is to develop a system for heat transfer, based on a CO_2-heat pipe that operates with a higher efficiency than conventional systems.

The probe consists of a metallic pipe, filled with CO_2, which is available both as a fluid and as a gas in the pipe. The probe is placed in the ground vertically. Heat transfer from the soil to the fluid CO_2 takes place by means of thermal conduction. The CO_2 evaporates and rises in the pipe because of its low density. Once it gets to the top of the pipe, the CO_2 transfers its heat to the evaporator of the heat pump. The gas condenses as it transfers its heat and the fluid CO_2 then falls back down the pipe, where it can pick up heat and begin the cycle again.

The following advantages can be attributed to the CO_2 earth probe:

- environmentally friendly transport medium with phase change;
- no pump energy for the transport medium required;
- small temperature differences between the transport medium and the working fluid of the heat pump are possible.

To demonstrate that the principle of the heat pipe also works for the CO_2 probe, the FKU built a prototype test plant. A heat pump was connected to a probe of 3.65 m length. The ground-coupled energy was simulated with a 150 W heat output. In various tests, both the start-up behaviour and the long-term performance of the system were tested. The basic functionality of the system was successfully demonstrated in these tests.

▲ *Figure 1: Prototype CO_2 earth probe.*

The next step in the process was a series of field tests with a CO_2 ground-coupled earth probe. To arrive at a reliable evaluation of the energetic efficiency of the CO_2 probe, a second probe was installed - a commercial probe with brine circulation. Both probes were connected to identical heat pumps. The ground-coupled earth probes used in these test were 18 m long. The results of the field tests confirmed the initial laboratory tests and indicated that the efficiency of vertical heat exchangers can be significantly improved using this technique, mainly because there is no need for a circulation pump.

In order to be able to market the earth probes, a cost analysis is being performed simultaneously with the field tests. In both the tests and the cost analysis, the production of the probe will be investigated as well as the installation of the probe into the ground, in order to show maximum potential savings.

Source: Wärmepumpe Aktuell 2/2001

City hall Zurich

Switzerland - The oldest working heat pump in Switzerland is located in the city hall of Zurich (a protected monument) and uses the water of the river Limmat, which runs underneath the building. It has been in use since 1937. The last time the heat pump was renovated, together with the ventilation system, was in 1983-84. The heating capacity of the installation is about 70 kW at source/sink temperatures of 6/48°C; the cooling capacity is 55 kW at 20/12°C. The working fluid used in the heat pump is R-12. The energy performance of the heat pump is only 50% of that achieved in modern systems. In order to provide the maximum heating requirement of 160 kW, the input of a 105 kW electrical backup system is needed.

The cost of maintaining the installation and supplying the electricity required was extremely high. The electronic components in both the ventilation and the heating system have become obsolete. As a result, the obsolete measurement and control technology as well as the heating and ventilation system will be renovated in the summer of 2001. A new heat pump will be installed. The old heat pump will be retrofitted and will use R-134a as the new working fluid. The electric backup system will no longer be needed, as it will be replaced by the retrofitted older heat pump as backup system.

Source: Wärmepumpe News 1/01

Ground-coupled energy for hospital

US - The condition of the Indian Health Service hospital (which dates back to the 1930s) in Albuquerque, New Mexico, and the sheer volume of people in the building forced the Indian Health Service to begin renovating the hospital in 1995. The result is that 56 heat pumps are installed throughout the building with more to come.

When the renovation began, the hospital had asbestos insulation that needed to be removed. As the project got underway, it was decided to replace the mechanical heating and cooling system as well. The hospital's steam-based heating system was very expensive to maintain and the air-conditioning systems were beginning to fail. The system chosen was based on ground-coupled heat pumps. This technology is efficient and provides the hospital with the flexibility it needs. As the project proceeded, the system was able to meet changing room configurations and changing loads.

At present, 56 heat pumps are installed, with each one heating and cooling a different zone in the building. If one area of the hospital is too cold or too warm, only that part of the building is heated or cooled. The four-story, 4,500 m^2 hospital and the 1,100 m^2 adjacent building use heat pumps varying in size from 1.8-10.5 kW. Plans call for 13 or 14 more heat pumps to be installed by the end of the year. The closed loop system that supports these heat pumps rests underneath the hospital's parking lot. The Indian Health Service hopes to finish renovating the hospital by December 2001.

Source: Earth Comfort Update, Volume 8, Issue 2

Italian manufacturers request unrestricted usage of HFCs

Italy - Co.Aer, the Italian Association of Air Treatment Equipment Manufacturers, together with the Association of Refrigerating Plant and Equipment Manufacturers, have issued a position paper on refrigerants, May 2001. In the paper, intended for discussions at a European level, they plead for no phase-out of HFCs. Both issuing organisations are affiliated to Anima, the Federation of the Italian Associations of Mechanical and Engineering Industries.

In the statement, the industry makes it clear that it has a tradition of actively improving equipment, for example in terms of energy efficiency. Recently, it has completed the switch from CFCs and HCFCs to HFCs. The industry points out that the use of CFCs in old equipment is by no means over, and that the decision to change the phase-out dates for HCFCs in the EU has led to considerable difficulties.

The Italian industry holds an important position in Europe, and the markets for some product types are growing by 20% per year. This favourable prospect could turn sour very quickly if more restrictive measures on HFCs, such as those in Denmark, are implemented.

The industry is aware that ozone depletion and global warming need to be mitigated. However, it pleads for real solutions, opposes expensive changes within a limited time frame, and underlines the need for viable alternatives. Ammonia and hydrocarbons have disadvantages for use in residential and small commercial air-conditioning systems, and CO_2 has not yet reached the commercial stage. HFCs, however, provide a high operating energy efficiency which helps mitigate global warming. Containment is the keyword.

Source: Letizia Ambrosoni, Anima
Download: http://www.anima-it.com/coaer/ita/index.html

Update on Denmark's environmental plans

Denmark - In early March 2001, the Danish Ministry of Environment and Energy notified the European Commission of its intention to implement regulations banning the following greenhouse gases: HFCs, PFCs and SF_6. This was reported on in HPC Newsletter 19/1.

The new regulations stipulate: "import, sale and use of the specified greenhouse gases - new and recovered - and new products containing these gases are prohibited after 1 January 2006." For certain products using HFCs, e.g. "vaccine coolers, mobile cooling plants, air conditioning in cars, medical spray cans" or certain applications such as "servicing of cooling plants, air conditioning in cars and heat pumps," no date for prohibition has been specified due to the unavailability of commercially available alternatives.

Over a three-month period, the European Commission will be able to consider its position and other member states will be able to make their views known. Following the notification of the Danish intentions, the European Partnership for Energy and the Environment (EPEE) has made clear its concerns to the European Commission and the press. EPEE stresses that HFCs are viable and safe refrigerants, provided their emissions are reduced through responsible use and end-of-life recovery.

In the meantime, EPEE's secretariat has received information that the Danish Tax on HFCs has entered into force as of 1 March 2001.

Source: IIF-IIR Newsletter, May 2001; EPEE News, Newsletter Vol. 2 No. 4, 2001

Zero leakage - minimum charge

Sweden - The first announcement and call for papers for the IIR conference, "Zero leakage - minimum charge; efficient systems for refrigeration, air-conditioning and heat pumps", is out. It is available online at http://www.egi.kth.se/zero/.

The conference will be held in Stockholm, 26-28 August 2002, at the Royal Institute of Technology. The conference aim is to present and discuss research results and progress concerning systems and components that have a minimal impact on the environment.

A policy meeting may also be organised, but no plans have yet been confirmed.

More information: Per Lundqvist, organising committee
E-mail: elksne@egi.kth.se
Fax: +46 8 20 30 07

Purity of hydrocarbon refrigerants

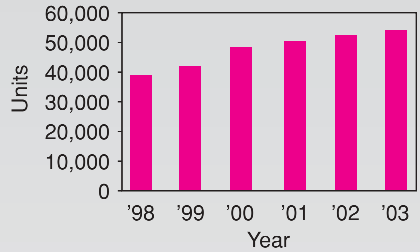
Germany - Because of the environmental benefits involved, the hydrocarbons isobutane and propane are often used as alternatives for HFCs and HCFCs, in spite of their flammability. This is especially true for smaller refrigerating systems and heat pumps. Isobutane 2.5 (R 600a) and propane 2.5 (R 290) are often used in this context. Although these compounds are generally available at low cost, their cost is increased by the high purity of 99.5% specified for refrigerants by DIN 8960.

It was demonstrated that commercial grade hydrocarbons of lower purity can be used without detrimental effects on machine wear or ageing of machine oils. Model calculations on the commercially available hydrocarbons isobutane and propane with different levels of purity show no significant difference in performance (purity between 88.9 and 99.6%).

Source: KI Luft- und Kältetechnik 6/2001

Japanese gas-fired heat pump market growing steadily

Japan - Demand for gas-fired heat pump air conditioners (GHPs) is growing nicely (see **Figure 1**). For 2001 (Oct. 2000 ~ Sept. 2001) an increase of 3.6% is expected compared to 2000. The total increase in shipments expected over the period 1998 to 2001 is almost 28%.



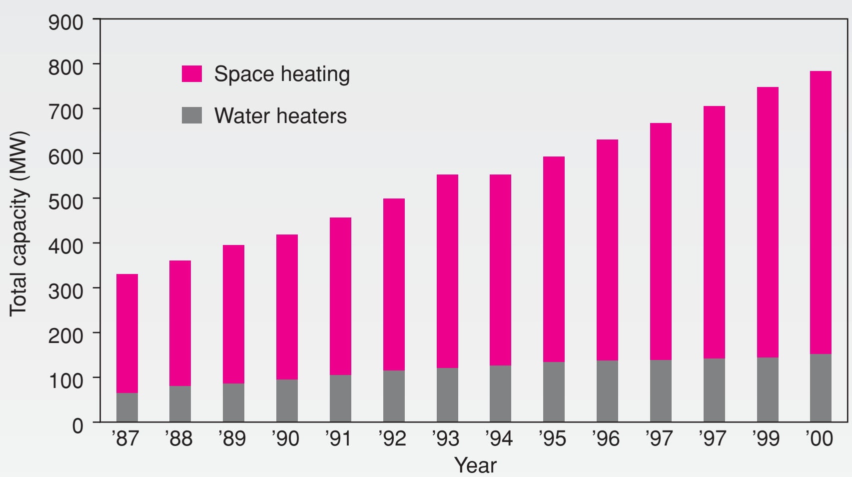
▲ *Figure 1: Gas-fired heat pump shipments and forecasts in Japan.*

Total domestic demand for GHPs, which totalled 39,393 units in 1998, is likely to reach 50,350 units in 2001. GHP shipments in 2000 totalled 48,593 units. The GHP market is predicted to grow continuously at an annual average rate of 3.8%, reaching about 54,300 units in 2003.

Source: JARN April 25, 2001

Austrian market keeps growing

Austria - Sales of heat pumps for space heating have risen by 8% in Austria in 2000 compared to 1999. A total of 1,986 heat pumps for space heating with a capacity of up to 40 kW were installed in 2000. Also, 39 heat pumps for space heating with a capacity of over 40 kW were installed, as well as about 93 heat pumps for dehumidification of swimming pools. Finally, some 2,690 heat pump water heaters were installed in the same year.



▲ *Figure 2: Total installed capacity in Austria, 1987-2000*

In 2000, 37 MW of heating capacity was added to the installed capacity of heat pumps for space heating in Austria (see **Figure 2**). By the end of 2000, the total stock was 632 MW for space heating, while the stock of heat pump water heaters was 155 MW.

The positive developments in the Austrian market have convinced the producers of heat pumps to raise production. In the year 2000, a total of approximately 1,800 heat pumps for space heating (+13%) and approximately 1,900 heat pump water heaters (+3%) were produced.

Source: LGW Aktuell, 2/2001

The world market for RACs & PACs

For the year 2000, world shipments of room air conditioners (RACs), used mainly for individual rooms, and of packaged air conditioners (PACs), used for light commercial service and for entire houses, were estimated to be 39.7 million units. This represents an increase of 1.4 million units compared to 1999. The number of RACs shipped was 29.9 million units, and the number of PACs, including unitary types (applied mainly in the US), was 9.8 million units.

The main reason for the increase in 2000 is the fact that the USA and China have both become huge markets. Total shipments in the US in 2000 alone numbered 13.2 million units, an increase of 0.4 million units over 1999. The rapid growth of the Chinese market and manufacturers is almost as important. It is estimated that about 9.2 million units were shipped in China in 2000. In the last few years, air conditioner production in China seems to have increased at a rate higher than 20% per year. This upturn is continuing through 2001. Since Chinese production is expanding at a higher rate than the Chinese domestic market, manufacturers will have to concentrate more on export.

The Japanese market recovered to 7.7 million units in 2000, up about 9% from 1999. The Japanese market has become a mature market that will not grow much in terms of numbers. The European market also showed stable growth in 2000. It is estimated to have grown to 2.5 million units, up about 3.2% compared to 1999. If the US market continues to be stable and the markets in China, Europe and India continue to grow, the total world market is expected to reach 40 million units in the near future (**Table 1**).

▼ *Table 1: Estimated RAC/PAC shipments for 2001.*

Country/area	Estimated units 2001 (million)
Europe	2.7
Middle East	1.8
Africa	0.5
China	10.0
India	0.7
Japan	7.4
Other East Asia	3.7
Oceania	0.5
US	11.8
Central/South America	1.9

Source: JARN, May 25, 2001

Programme 7th IEA Heat Pump Conference available

The programme of the 7th IEA Heat Pump Conference "Heat Pumps – Better by Nature", which will be held 19-22 May 2002 in Beijing, China, has been finalised and will be distributed widely. It will also be available on http://www.heatpumpcentre.org.

The goal of the conference is to promote the worldwide implementation and improvement of heat pump technologies through discussion and the exchange of information. Relevant information focuses on technical aspects, standards, market issues, and policy choices with regard to the environmental and energy benefits provided by these technologies.

The programme includes the following sessions:

- opening plenary session, with regional reports on status and trends;
- energy and environment;
- technology (including components and systems for heat pumps, air-conditioning and refrigeration);
- applications (absorption machines, ice storage, retrofit heat pumps etc.);
- working fluids (selection, natural working fluids, conservation, safety etc.);
- ground-source heat pumps;
- technical and market developments in China.

To register for the conference, please contact the conference secretariat, or go to http://www.heatpumpcentre.org.

Source: IEA Heat Pump Centre
Conference secretariat: see page 27

Annex 28 "Sorption and heat recovery" seeks participants

The Netherlands/Norway - An international collaborative project on sorption technology and heat recovery will start soon, as Annex 28 to the IEA Heat Pump Programme. The Netherlands and Norway will be joint project leaders.

The new Annex aims to stimulate the market for heat recovery with sorption systems, where such applications are economically and environmentally advantageous. The Annex starts where Annex 24 (Ab-sorption systems for heating and cooling in future energy systems) left off. Possible activities include:

- establish methods to assess the environmental and economic benefits of integrated sorption systems;
- survey existing design tools and develop strategies to fill the gaps;
- establish a database of possible projects;
- provide a platform for discussions between manufacturers, end-users and system designers.

The work programme is still open for discussion and comments are welcomed. A document that discusses background and proposed work in more detail is available from http://www.heatpumpcentre.org.

A meeting of participants from all countries that are interested will be held in the Netherlands. The provisional dates are 4-5 October 2001.

Source: Onno Kleefkens, the Netherlands
Fax: +31 30 2316491
E-mail: o.kleefkens@novem.nl

Proceedings Annex 26 workshop now available!

Annex 26 "Advanced supermarket refrigeration/heat recovery systems" workshop proceedings are available from the IEA Heat Pump Centre. Sixteen papers presented at a workshop held in Stockholm, Sweden, October 2000, are available on CD-ROM, with additional information on Annex 26, its participating countries and the IEA Heat Pump Programme.

Please go to http://www.heatpumpcentre.org for more information, or consult page 27 for ordering information.

Source: IEA Heat Pump Centre

Ongoing Annexes

Red text indicates Operating Agent.

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

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

Interactions and feedback between the Montreal and Kyoto Protocols

Gérard Mégie, France

Changes in the ozone concentration of the atmosphere can influence global warming, and greenhouse gases influence ozone depletion. The nature of these interactions is fairly complex and is shaped by a dynamic system of processes involving radiation, absorption, emission, physical transport and chemical reactions. The Montreal and Kyoto Protocols are in fact linked, and decisions made under one Protocol have an impact on the aims of the other.

Introduction

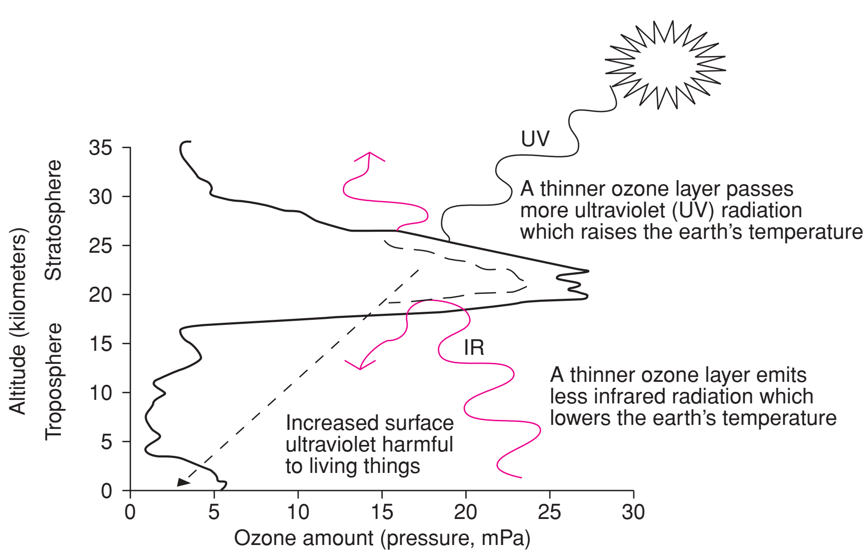
The decrease in chlorine abundance in the stratosphere, which should result from compliance with the Montreal Protocol and its Amendments and Adjustments, should lead to a recovery of the ozone layer by the middle of the 21st century. However, other environmental changes such as climate change may impact the time frame of this recovery. Ozone depletion and climate change are actually linked in many ways.

The interactions between ozone concentration and climate change are the result of a host of dynamic processes involving radiation, absorption, emission, atmospheric transport and various chemical reactions. These processes take place both in the troposphere (atmospheric layer between 0 and 10-16 km altitude) and the stratosphere (atmospheric layer between 10-16 km and 50 km altitude). Some of the feedback effects are positive, meaning that they either reduce ozone depletion or global warming, whereas other effects may be negative. The issue of the physical and chemical linkages that exist in nature between the Montreal and Kyoto Protocols is a complex one, of which many aspects are not yet fully understood or quantified.

Atmospheric ozone depletion and climate change

Primary effect

Over the past decade, increasing attention has been given to the effects on our climate of the observed ozone change. A loss of ozone in the lower stratosphere (where it is most abundant) leads to an increase in visible and ultraviolet radiation reaching the troposphere, which increases the global warming effect. However, ozone in the lower stratosphere also absorbs the infrared radiation emitted by the earth, effectively trapping it and preventing it from radiating into the outer layers of the atmosphere, thereby increasing the global warming effect, see **Figure 1**. A loss of ozone in these layers will therefore decrease global warming at the same time. In support of this latter effect, there is continuing evidence of a long-term cooling of the lower stratosphere over the past decade or so.



▲ *Figure 1: Primary effect of ozone depletion on climate change.*

The reduced emission of infrared radiation from stratosphere to troposphere as a result of ozone depletion is, at least in simple models, the dominant factor. The net effect of stratospheric ozone loss is thus a reduction of global warming. Using extrapolations based on observed ozone trends until 1994, one can estimate that the changes in stratospheric ozone since the late 1970s have had a net negative effect on global warming equal to -0.2± 0.15 Wm^{-2}. Stratospheric ozone depletion may thus have offset, by about 30% or more, the global warming effect due to increases in other greenhouse gases for the period since 1979.

Secondary effects

In addition to influencing the global climate through direct changes in the balance of atmospheric radiation, absorption and emission, changes in stratospheric ozone can exert an effect by influencing the tropospheric abundance of other radiatively important constituents. The primary mechanism by which stratospheric ozone influences the troposphere is through control of the ultraviolet radiation reaching the troposphere. This UV radiation produces the hydroxyl radical (OH) via tropospheric ozone photolysis. OH is an important species in the troposphere as it is highly reactive. It acts to cleanse the atmosphere of pollutants and affects the concentration of a number of radiatively important gases (e.g. methane and the hydrofluorocarbons). An increase in the UV flux reaching the troposphere increases the OH concentration, which in turn reduces the lifetime of methane in the troposphere. This reduction results in a decrease in global warming in the order of 30-50% of the decrease associated with the primary effect of ozone depletion.

Another way in which tropospheric OH can influence climate is through its involvement in the production of cloud condensation nuclei (CCN) and the resultant modification of cloud albedo (reflectance). The production of CCN is thought to be controlled by the oxidation of sulphur dioxide and dimethyl sulphide by OH to yield liquid sulphuric acid particles. These new particles can then grow to become cloud condensation nuclei. An increase in the production rate of sulphuric acid particles (due to less stratospheric ozone and therefore more tropospheric OH) could produce more CCN and increase the albedo of, for example, marine clouds, which would lead to more radiation being reflected and a decrease in global warming. This potential climate impact of tropospheric OH on the number of CCN could be greater than the impact of OH on the methane lifetime.

Finally, the basic circulation of the atmosphere is such that air enters the stratosphere primarily in the tropics and returns to the troposphere at higher latitudes. Reductions in ozone amounts in the lower stratosphere could therefore result in less ozone being transported into the troposphere at mid and high latitudes. This would partly offset any increases in tropospheric ozone caused by changes in the chemical concentrations of gases such as the nitrogen oxides or methane.

Greenhouse gases and ozone depletion

CO_2

Carbon dioxide is the major contributor of infrared radiation in the stratosphere as it is 70 times more abundant than water vapour in this region. In fact, the global radiative equilibrium achieved in the stratosphere results from the balance between heating via the absorption of solar radiation by ozone and cooling via the infrared emissions of carbon dioxide and, to a lesser extent, of ozone and water vapour. Therefore an increase in carbon dioxide concentration will lead to a cooling of the stratosphere. This cooling will have two opposing effects. On the one hand, lower temperature will slow down reaction rates and thus ozone destroying catalytic cycles in gas phase chemistry. On the other hand, it will also increase the probability of occurrence of polar stratospheric clouds and thus enhance chlorine activation (and resulting ozone destruction) through heterogeneous processes in the polar atmosphere, and to a lesser extent in middle latitude regions, by accelerating hydrolysis reactions on stratospheric aerosols. Calculations show that the latter effect will dominate in the lower stratosphere at high latitudes and thus induce net ozone losses. The first effect, a slowing down of the gas phase catalytic cycles, will only influence ozone concentration in the 40 km altitude range where ozone abundance has already decreased by an order of magnitude compared to the maximum value in the 20-25 km altitude range. The net effect of an increase in carbon dioxide concentration in the stratosphere will thus be increased ozone depletion. Therefore, limiting the increase in carbon dioxide concentration as planned in the Kyoto Protocol will have a positive long-term effect on ozone depletion.

Methane

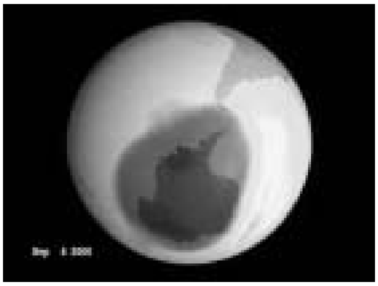
Methane is one of the sources of hydroxyl radicals (HO_x) in the stratosphere. These radical species include the OH radical which can induce ozone destruction through catalytic cycles in the upper stratosphere and in the mesosphere (atmospheric layer outside the stratosphere). However, the ozone concentrations in these regions are very low and thus the effect will be very limited in terms of total ozone content. At lower altitudes, an increase in methane will induce an increased production of HCl through reaction with chlorine atoms. This effectively sequesters active chlorine in a reservoir of inactive HCl, which in turn leads to reduced catalytic chlorine destruction of ozone and a reduction of ozone depletion.

The oxidation of methane in the stratosphere also leads to the formation of water vapour. As this process occurs in the lower stratosphere, increased methane concentration could induce an increase in the frequency of polar stratospheric cloud formation and in aerosol growth at middle latitudes, thus leading to chlorine and bromine activation and enhanced ozone depletion.

At present, the net effect of the above two processes is thought to be a reduction in ozone depletion. Limiting the increase in methane emissions, as planned in the Kyoto Protocol, could thus have a negative long-term effects on ozone depletion, although the magnitude of such an effect is largely uncertain.

Nitrous oxide

Oxidation of nitrous oxide is the main source of NO_x radicals in the stratosphere. The effects of these radicals on stratospheric ozone are strongly differentiated with altitude. Above about 30 km, gas phase ozone destroying cycles dominate, leading to increased ozone depletion as a result of an increase in nitrous oxide concentration. At lower altitude, the nitrogen-halogen chemistry in both



▲ *Figure 2: Ozone image Antarctica*

homogeneous and heterogeneous processes is rather complex. One major effect of these interactions is the formation of chlorine reservoirs, such as chlorine nitrate, whereby chlorine is temporarily held in an inactive form. However, the net effect on ozone depletion is dependent on the environmental conditions and is still a matter of debate.

CFCs, HCFCs, halons, HFCs

CFCs and halons are both ozone depleting substances and greenhouse gases. This is also the case for the hydrochlorofluorocarbons (HCFCs), although their impact is strongly reduced due to their much shorter lifetime in the troposphere. The ban on the emissions of CFCs and halons, and in future of HCFCs, will certainly have a beneficial effect on both ozone depletion and climate change. The main problem lies with the hydrofluorocarbons (HFCs), which do not contain chlorine. Their timely introduction on the market will further reduce ozone depletion, as they contain neither chlorine nor bromine. However, these compounds are also greenhouse gases with a large global warming potential due to their radiative properties in the infrared wavelength range, and are thus included in the Kyoto Protocol.

Ozone recovery

Worldwide compliance with the Montreal Protocol and its amendments is rapidly reducing the yearly emissions of ozone-depleting substances. As these emissions cease, the ozone layer will recover over the next several decades. This recovery will only be gradual, primarily because of the long times required for CFCs and halons to be removed from the atmosphere. The recovery can also be impacted quite significantly by the Kyoto Protocol and future climate changes.

At present, the main issue in terms of ozone recovery and the possible effect of the Kyoto Protocol and future climate change can be summarised as follows. In the absence of other changes, stratospheric ozone abundance should rise in future as halogen loading falls in response to regulation. However, the future behaviour of the ozone layer will also be affected by the changing concentrations of carbon dioxide, methane, nitrous oxide etc. as well as changes in climate. Thus, for a given halogen loading in the future, the atmospheric abundance of ozone may not be the same as that found in the past for the same halogen loading.

Preliminary calculations with coupled chemistry-climate models suggest that the recovery of the ozone layer could be delayed by the presently observed cooling of the stratosphere, which is a result of the increase in CO_2 concentrations. This is especially so in the Arctic regions where winter temperatures in the lower stratosphere are close to the (lower) threshold for substantial chlorine activation, making Arctic ozone concentrations particularly sensitive to small changes in temperature, and thus to a cooling of the lower stratosphere by increased greenhouse gas concentrations. Therefore, it should be possible to detect the onset of ozone recovery from halogen-induced depletion sooner in the Antarctic than in the Arctic or globally, as there is less variability in the ozone losses in the Antarctic.

Estimates of the timing of the detection of the onset of ozone recovery are uncertain. However, it is clear that unambiguous detection of the beginning of ozone recovery will be delayed beyond the time of maximum loading of stratospheric halogens, which occurred at the turn of the century.

Conclusions

The issues of ozone depletion and climate change are linked, and because they are, so are the Montreal and Kyoto Protocols. Changes in ozone affect the earth's climate, and changes in climate and meteorological conditions affect the ozone layer. Ozone depletion and climate change are linked through a dynamic set of physical and chemical processes. The impact of decisions taken under one Protocol on the aims of the other are summarised in **Table 1.** As shown in this paper, decisions made under the Kyoto Protocol concerning the reduction in emissions of carbon dioxide, methane and nitrous oxide will most probably have a positive effect on the rate of recovery of the ozone layer. Decisions regarding the control of hydrofluorocarbon emissions, as in the Kyoto Protocol, may affect decisions regarding the ability to phase out ozone-depleting substances in due time, which is an issue in the Montreal Protocol.

▼ *Table 1: Interlinkages Montreal and Kyoto Protocols*

Kyoto Protocol and global warming		
CO_2 emissions ↓	Global warming ↓	Ozone depletion ↓
CH_4, N_2O ↓	Global warming ↓	Ozone depletion ?
HFC ↓	Global warming ↓	Ozone depletion ↑ (if delay in substitution of HCFC)
Montreal Protocol and ozone depletion		
CFC, HCFC emissions ↓	Ozone depletion ↓	Global warming ↓
HFC emissions ↑	Ozone depletion ↓	Global warming ↑

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Managing our atmosphere: Two protocols - one world

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Atmospheric science includes the study of a vast array of interlinked natural processes and is by its very nature complex and multidisciplinary in character. This complexity is further heightened by the extent of human interventions in natural atmospheric processes. In addressing the adverse impacts of these human interventions, we seem to be trying to untie each interconnected "knot" as we come across it. However, the more we learn about atmospheric processes, the clearer it becomes that what we really need is a carefully thought out and proactive strategy rather than a "cross each bridge when it comes" approach. UNEP (United Nations Environment Programme) tries to assist in formulating and implementing such a strategy.

Interlinkages: scale of the problem

Interlinkage and feedback effects between environmental issues are predicted to be one of the most formidable challenges for human society in the new millennium. Almost 200 separate multilateral environmental agreements (MEAs) already exist and more are in various stages of being negotiated. These different MEA pathways, including the design, assessment, negotiation and implementation phase, have until now largely remained divorced from one another. Separate institutions have been created to address each environmental issue, and the dialogue between these institutions has not yet reached the level required to address the complexity of the issues involved. The end result is that each MEA, focused on a separate issue, can turn out to be a method of solving one knot only to further entangle others.

Montreal and Kyoto Protocols: interlinked siblings

For very different reasons, two MEAs dealing with atmospheric issues are currently receiving much attention:

- The Vienna Convention on Protection of the Ozone Layer (VC) resulting in the Montreal Protocol on Substances that Deplete the Ozone Layer (MP); co-ordinated through UNEP, this agreement (1987) is generally considered a model of successful international co-operation;
- The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol to the UNFCCC; born during the 1992 Rio summit, the 1997 Kyoto Protocol has been the subject of intense political discussion; only recently, after many ups and downs, 178 countries meeting in Bonn finally agreed on a compromise text.

Institutional dialogue

To varying extents, the governing bodies of the above two MEAs, as well as their subsidiary bodies for the assessment of science and technology and implementation issues, have been addressing the relationships between atmospheric issues. The MP assessment panels, for example, have been providing the necessary scientific information to governments. Notably, the Scientific Assessment Panel of the MP (SAP) has been active in exploring the interlinkages between climate change and ozone depletion. Its first assessment in 1989 mentioned this issue and reported the relative global warming potential (GWP) of various ozone depleting substances (ODS). In subsequent reports, published in 1991, 1994, and 1998, it closely examined:

- The impact of temperature change in the stratosphere and troposphere, due to global warming, on the rate and extent of ozone layer depletion;
- The impact of nitrous oxides and other chemical compounds (see page 10).

In its 1999 report *Aviation and the global atmosphere*, the International Panel on Climate Change (IPCC), which from its inception has collaborated with the SAP, presents a striking assessment of the potential impact of emissions from aircraft travel. This is just one example of the way in which leading scientists all over the world are cooperating in analysing environmental interlinkages.

Within the framework of the MP, the Technology and Economic Assessment Panel (TEAP) and its technical options committee have also been active in reporting on the implications of the use of ozone-friendly technologies for climate change and vice versa. For example, the technical options committee on refrigeration and air conditioning and heat pumps has highlighted the GWP of refrigerants as well as elaborated in detail the concept of total equivalent warming impact (TEWI).

Landmark recommendations and future challenges

As the MP was being implemented and new technologies were being introduced, it became essential to know whether

Box 1

Dialogue between siblings: mirror decisions

"Decision X/16 under the MP (1998): Implementation of the MP in the light of the Kyoto Protocol.
To request, with a view in particular to assisting the Parties to the MP to assess the implications for the implementation of the MP of the inclusion of HFCs and PFCs in the Kyoto Protocol, the relevant MP bodies, within their areas of competence:

a To provide relevant information on HFCs and PFCs to the Secretariat of the Framework Convention on Climate Change by 15 July 1999 in accordance with operative paragraph 1 of the above-mentioned decision;
b To convene a workshop with the Intergovernmental Panel on Climate Change which will assist the bodies of the Framework Convention on Climate Change to establish information on available and potential ways and means of limiting emissions of HFCs and PFCs in accordance with operative paragraph 2 of the above-mentioned decision;
c To continue to develop information on the full range of existing and potential alternatives to ozone depleting substances for specific uses, including alternatives not listed in Annex A of the Kyoto Protocol;
d To otherwise continue to cooperate with the relevant bodies under the United Nations Framework Convention on Climate Change and IPCC on these matters; and
e To report to the Open Ended Working Group at its nineteenth meeting and to the Eleventh Meeting of the Parties to the MP on this work."

"**Decision 13/CP.4 under the Kyoto Protocol (1998):** ***Relationship between efforts to protect the atmospheric ozone layer and efforts to safeguard the global climate system.***
The Conference of the Parties,

1. Invites Parties, relevant bodies of the MP, the IPCC, intergovernmental organizations and non-governmental organizations to provide information to the secretariat, by 15 July 1999, on available and potential ways and means of limiting emissions of hydrofluorocarbons and perfluorocarbons, including their use as replacements for ozone-depleting substances;
2. Encourages the convening of a workshop by the IPCC and the Technology and Economic Assessment Panel of the MP in 1999 which will assist the SBSTA to establish information on available and potential ways and means of limiting emissions of the hydrofluorocarbons and perfluorocarbons, and invites the IPCC to report on the results of such a joint workshop to the SBSTA at its eleventh session, if possible;
3. Requests the secretariat to compile the information provided, including, if available, the conclusions of the workshop, for consideration by the SBSTA at its eleventh session;
4. Requests the SBSTA to report on this information to the Conference of the Parties, at its fifth session, and to seek further guidance from the Conference of the Parties on this matter at that session."

these new technologies also had an effect on global warming. Examples of such issues that surfaced include the use of hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) as alternative refrigerants. As these gases have zero ozone depleting potential, they are a solution to one aspect of the ozone issue. However, they are also included in the basket of greenhouse gases whose emissions the Kyoto Protocol seeks to limit.

In 1998, the Parties to both the Montreal and Kyoto Protocols took 'mirror decisions' on HFCs and PFCs (see **Box 1**). A dialogue then took place between the technical and policy bodies of both Protocols, which encouraged further global discussion on the subject. Subsequently, a joint IPCC/TEAP expert meeting on options for the limitation of emissions of HFCs and PFCs was held in May 1999. A task force on HFCs/PFCs was also set up to carry out the assessment requested by the Parties. Its recommendations represent a milestone in the history of the study of interlinkages between MEAs (see **Box 2**).

The bodies responsible for implementation of the protocols have recognised the need for harmonisation. Yet, concerted action to address interlinkage and feedback issues between the Montreal and Kyoto Protocols has been limited to date. This is partly due to the fact that the Kyoto Protocol has yet to enter into force. In addition, the compartmentalised mandates and essentially separate territories of these two MEAs make it difficult for the Parties to take proactive steps toward harmonising implementation, even though assessment debates have demonstrated that the will to do so is present. The atmosphere and our environment are clearly the victims of such blockades.

UNEP activities

UNEP DTIE's (Division of Technology, Industry and Economics) Energy and OzonAction Unit, is an implementing agency under the Multilateral Fund of the MP and the Global Environmental Facility (GEF), as well as the agency responsible for promoting sustainable and harmonised solutions to environmental problems. As such, it advises governments and industries in developing countries on integrated solutions to atmospheric problems. The delay in implementation of the Kyoto Protocol must not be allowed to hold up the implementation of the MP or any other MEA. UNEP has embarked on a number of activities, including an information clearinghouse, training activities and networks of national ozone units, that address interlinkages between MEAs and that help both developing countries and countries with economies in transition to better understand such issues (see **Box 3**).

Conclusions

The Montreal and Kyoto Protocols are an excellent illustration of how environmental issues and measures taken in one area can influence those in another area. There is a real risk that implementation of a focussed, single-issue MEA in one sector may come at the expense of other MEAs. Nobel laureate Dr. Maria Molina is presently working on models of interrelated atmospheric issues, as he believes that atmospheric pollution due to anthropomorphic activity has created a host of interlinkages between the issue of ozone layer protection and climate change.

Threats to our finite and fragile ecosystems are numerous and still poorly understood. For this reason, it is important to explore how MEAs are interlinked and to use this knowledge in implementing and harmonising MEAs. To do so effectively, it is also necessary to explore ways of bridging the divides that exist with respect to areas of knowledge, competence and authority. This is essential if we really wish to create long-term, robust, integrated environmental solutions.

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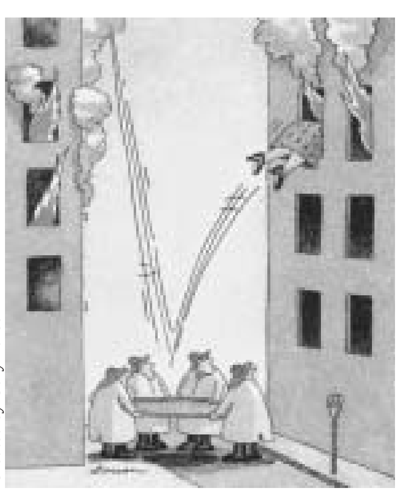

Created by Gary Larson

Ozone depletion *Global warming*

Box 2

Key Recommendations of HFC and PFC Task Force:

1. Ozone depletion and global climate change are linked through physical and chemical processes in the atmosphere. The Montreal and Kyoto Protocols are financially and technically interconnected because HFCs and CO_2 are included in the basket of six gases under the Kyoto Protocol and they are significant substitutes for some important uses of ODS;
2. Inclusion of HFCs and PFCs in the Kyoto Protocol need not interfere with the implementation of the MP given careful technology choices that need to be assessed based on concepts like LCCP (Life-Cycle Climate Performance);
3. Countries with economies in transition (CEITs) and developing countries depend on information, access to technology and financing to properly address and implement the inter-linkage issue. Scope of UNEP DTIE's OzonAction Programme in Paris, which is mandated under the MP to assist these countries to facilitate bilateral and multilateral co-operation, create environmental awareness and to collect and distribute up-to-date information, could be expanded to become Climate Action Programme; and
4. Further reduction in HFC and PFC emissions is possible through good practices and responsible use principle.

Box 3

UNEP OzonAction activities
undertaken to address the interlinkages between the issues of ozone layer protection and climate change

Harmonising information exchange:
- Discussion paper *Cross-cutting issues and options* (February 1998)
- Round Table on *Climate change and ozone protection policy - two Protocols, one response* (September 1999)
- Issue Paper on *Promoting integrated approaches to ozone layer protection and cross-cutting issues between other environmental conventions* (January 2000)
- Video on the safe use of hydrocarbons *Back to the future* (January 2001) (see page 26)
- Case studies on the *Win-win technologies that contribute to ozone layer protection and climate change* (to be published soon)

Integrated ozone protection/climate change training activities:
- *Training manual on refrigerant management in the chiller sector* that promotes mitigation of climate change and protection of the ozone layer (1995)
- *Training courses on refrigerant management in the chiller sectors* in Thailand, Indonesia, the Philippines, Mexico, Zambia and Bahrain (1995-1997). The projects of the World Bank for conversion of the chillers in Thailand (see page 18) and Mexico were approved by the Multilateral Fund of the MP (to finance the ozone layer protection part of the project) and the Global Environment Facility (GEF) (to finance the climate change mitigation part of the project)
- *The importance of military organisations in stratospheric ozone protection and climate protection*, organised in February 2001 in Brussels

Networking relationships between ozone and climate change officers:
- *Establishment of a network of ozone and climate change officers* with financial assistance from the government of Finland. Three meetings have been held so far and reports are available. (Oct. 1999 -ongoing)

Ozone- and climate-friendly technologies: Choices for sustainability

R. S. Agarwal, India

CFCs and HCFCs, which have been used extensively in refrigeration, air-conditioning and heat pump applications, are being phased out due to their negative impact on the ozone layer and global warming. In the short to medium term, HFCs (with zero ozone depletion) are a major candidate to replace CFCs and HCFCs, but suitable long-term replacements will need to have a limited impact on global warming as well. Alternative substances such as hydrocarbons, carbon dioxide, ammonia and water may, depending on the technological advances made, become the substances of choice in future, but in the meantime it is essential that specific local circumstances be kept in mind (e.g. in developing countries) when deciding on the best options.

Introduction

Halocarbon compounds produced by human activities are considered to have been the primary agent for the stratospheric ozone depletion observed in the past two decades. These compounds are used in many applications including refrigerants, foam blowing agents, solvents, process agents, aerosol propellants, fire extinguishers etc., with refrigeration being one of the largest users.

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) have been used in refrigerators and air-conditioners and as blowing agents in foam. CFCs and HCFCs are now being regulated because of their impact on ozone depletion and will have to be replaced fairly soon. Hydrofluorocarbons (HFCs) may be suitable as short to medium-term replacements, but may not be suitable for long-term use due to their high global warming potential (GWP). The refrigeration and automotive air-conditioning industries have already begun to address the long-term replacement challenge by developing alternative technologies using hydrocarbons (HCs) and CO_2 for their respective industries. Several issues will dictate the choice of long-term replacements for CFCs and HCFCs, but in the long term only those technologies are sustainable that can address the dual challenge of protecting the ozone layer and containing adverse climate effects.

Recent trends in technology

Depending on the particular application, each alternative to CFCs and HCFCs has advantages and disadvantages. Refrigeration and air-conditioning appliances must often satisfy national, regional and local requirements for energy efficiency, safety (operation, repair and disposal) and environmental acceptability. Currently, the main alternatives are HFCs and HFC blends, although there are potential non-HFC alternatives as well.

In certain applications, it is currently technically feasible to phase out ozone depleting substances (ODS) without resorting to HFC refrigerants. Hydrocarbons and ammonia are examples of possible replacements. However the use of such substances can result in a net negative impact on global warming. This is because, in some applications, replacing HFC-based substances by the alternatives results in a lower energetic efficiency of the equipment. The 'energy penalty' resulting form this lower efficiency outweighs the gain achieved by the reduction in HFC emissions. In this context, investigations are in progress to increase the energetic efficiency and economic viability of supercritical CO_2 cycle-based systems as well as hydrocarbon and ammonia-based systems with secondary loop systems. **Table 1** gives a summary of the

▼ *Table 1: Alternative refrigerants for various applications.*

Alternative refrigerants		
Application	HFCs	Other than HFCs
Domestic refrigeration	R-134a	HC-600a
Commercial refrigeration		
• Stand-alone systems	R-134a, R-404A, R-507A, R-407C,	HC blends, HCFC-22*, CO_2**
• Central systems	R-134a, R-407C	
• Indirect systems	R-404A	NH_3, CO_2** , HCs
Cold storage, food processing and industrial refrigeration	R-134a, R-404A, R-507A	NH_3, HCFC-22*, HCs, CO_2**
Unitary air conditioners	R-410A, R-407C	HCFC-22*, CO_2**, HCs
Centralised AC (chillers)	R-134a, R-410A, R-407C	HCFC-22*, HCFC-123* NH_3, HCs, CO_2**, water**
Transport refrigeration	R-134a, R-404A	HCFC-22*
Mobile air conditioning	R-134a	CO_2**, HCs
Heat pumps (heating only)	R-134a, R-152a, R-404A, R-407C, R-410A	NH_3, HCs, CO_2**, water**

* Transitional
**Advanced development stage

alternative refrigerants for various applications.

Medium to long-term solutions

HFCs are free from chlorine and have zero ozone depleting potential (ODP) but relatively high GWP. As a result, even though HFCs are currently the main candidates to replace CFCs and HCFCs, especially in refrigeration, air-conditioning and heat pump applications, HFCs have been included in the Kyoto basket. Although the GWP of most HFCs is lower than that of CFCs, it is much higher than the GWP of natural fluids such as hydrocarbons, carbon dioxide, ammonia and water. The latter are therefore the most likely long-term candidates for replacing HFCs. **Table 2** gives the environmental characteristics of various refrigerants.

The production and consumption of HFCs and their blends is continuously increasing in developed as well as developing countries. Efforts are also being made to minimise emissions of HFCs by adopting recovery and recycling procedures as well as better fabrication and servicing practices. There is also a slow but growing trend towards other alternatives such as hydrocarbons, carbon dioxide and ammonia.

▼ *Table 2: Environmental characteristics of refrigerants and foaming agents.*

Refrigerant	Atmospheric lifetime (years)	ODP	GWP (100 year ITH*)
CFCs			
CFC-11	50+5	1.0	3800
CFC-12	102	1.0	8100
HCFCs			
HCFC-22	12.1	0.055	1500
HCFC-123	1.4	0.02	90
HCFC-141b	9.4	0.11	600
HFCs			
HFC-134a	14.6	0	1300
HFC-32	5.6	0	650
HFC-152a	1.5	0	140
HFC-245fa	7.3	0	820
HCs			
HC-290 (propane)	—	0	3
HC-600 (butane)	—	0	3
Cyclo-pentane	—	0	3
Zeotropes and azeotropes			
R-404A	—	0	3260
R-407A	—	0	1770
R-407C	—	0	1530
R-410A	—	0	1730

* ITH = integrated time horizon

▲ *Figure 1: Implementation of hydrocarbon technology in a domestic refrigeration industry*

Sustainable technologies for developing countries

The issue of sustainability has to be viewed in a different perspective when it comes to developing countries. In contrast to developed countries, most of the developing countries have a large unorganised but innovative informal sector. The informal sector represents a significant proportion of the total industry. It is also a substantial consumer of ODS and would be a major stakeholder in the adoption of alternative refrigerants for sustainable growth. Due to the nature of this large informal sector, the technology chosen must be environmentally friendly, cost effective and easy to adopt.

In spite of the highly flammable properties of hydrocarbons, hydrocarbon technology, accompanied by appropriate safety measures, appears to be the best option. Such technologies have already been adopted by some developed countries, particularly in Europe, and are also slowly penetrating the formal and informal sectors of developing countries such as China, India and Indonesia. **Figure 1** gives an overview of the implementation of hydrocarbon technology in a domestic refrigeration industry in India.

Outlook

HFCs are free from chlorine and have zero ozone depleting potential (ODP). However, their GWP is much higher than the GWP of natural fluids such as hydrocarbons, carbon dioxide, ammonia and water. The latter are therefore the most likely long-term candidates for replacing HFCs. They may well become the future standard in their sector in the developed as well as developing regions of the world. A case in point is the use of supercritical carbon dioxide technology for mobile air conditioning and other applications, which is under active consideration, particularly in developed countries.

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The Thai Chiller Replacement project: Benefiting the economy and the environment

Steve Gorman, USA

The Thai Chiller Replacement Program was launched in order to help develop a market in Thailand for highly energy-efficient chillers. The project aims to save energy as well as reduce ozone depletion and global warming. It is financed by international institutions that support the Montreal Protocol.

Introduction

The Thailand Chiller Replacement Program Concessional Lending Pilot Project will replace existing CFC-chillers (with chlorofluorocarbons as refrigerant) in air-conditioning systems with high-efficiency, non-CFC chillers. The project is financed by the Multilateral Fund (MLF) of the Montreal Protocol and the Global Environment Facility (GEF) on a loan basis. This is an example of new, non-grant or partial-grant financing projects the World Bank has developed. These projects form an alternative approach to the existing grant-financing scheme for possible future ODS phase-out projects. These initiatives are in response to the request of the Executive Committee of the MLF to explore new financing mechanisms for future projects in order to include countries and enterprises that might not otherwise be eligible for assistance.

Overall project goal

The primary goal of this project is to develop a market for highly-energy-efficient chillers in Thailand. In the initial pilot phase of the project, 24 chillers will be replaced. This phase is meant to demonstrate the economic feasibility of the new technology (in a non-grant framework) given the perceived risks. If the pilot phase is successful, a larger-scale programme will follow aimed at replacing about 30% of the remaining CFC chillers. It is expected that the experience gained through the programme and the positive message sent to the markets by its initial success will in turn lead to the increasing adoption of energy-efficient chillers by the chiller market as a whole. This spin-off effect is difficult to quantify. However, it is expected that a contingent, interest free GEF/MLF loan of $5 million will help remove financial barriers and leverage about $85 million in World Bank and commercial co-financing. Money that will be used to transform Thailand's chiller market from one dominated by low-efficiency CFC chillers to one using more and more climate- and ozone-friendly models.

Specific project goals

The economic goals of the project can be summarised as follows:

- to reduce peak power demand and thereby free up peak capacity, save energy and generate long term financial savings for the Electrical Generating Authority of Thailand (EGAT);
- lower electricity bills for the consumers while retaining the same service level; according to experience gained in some OECD countries, the estimated energy needs may be about one third lower for the new systems;
- economic spin-off from developing a new market for economical, technologically advanced and environmentally friendly air-conditioning systems.

In addition to economic benefits, the project would lead to a significant reduction in greenhouse gas emissions. By replacing CFC chillers with 30% more energy-efficient systems, the CO_2 emissions from air conditioning can also be reduced by about 30%. This would translate into a reduction of about 130 ton Carbon per system per year. The energy benefits of the project are shown in **Table 1**.

In addition to saving energy, the project would result in the phasing out of a total of 220 tons of CFCs, which have quite a high Global Warming Potential (GWP) as well as Ozone Depleting Potential (ODP). The proposed substitute refrigerants, HCFC-123 and HFC-134a, also have significant GWP but much less than that of CFCs. The ODP of the proposed substitutes is very low or zero. The net effect of the project then would be a further reduction in GWP and a significant reduction in ODP.

The Thai Context

For fiscal year 1997, peak power demand in Thailand was 14,506,300 kW, a 9% increase from the previous year. At the end of fiscal year 1997, the total electricity generating capacity of the EGAT was 14,686,898 kW. Although electricity demand will most likely grow less strongly in the near future than in recent years, the economic crisis has also limited Thailand's ability to expand its power generating capacity and power shortages could therefore become a problem.

The chiller sector has grown dramatically in the past decade due to the large amount of building construction that has taken place. About 1,500 CFC chillers are currently operating in Thailand, more than 80% of which are located in Bangkok. Chillers of a wide variety exist in Thailand, but most (95%) are centrifugal and utilise CFC-11 as a

▼ *Table 1: Carbon abatement benefits as a result of energy savings*

Parameter	Value
Average cooling capacity of chiller	1,759 kW
Average consumption, baseline chiller	0.26 kW_{el}/kW_{th}*
Energy consumption, alternative	0.12 kW_{el}/kW_{th}*
Estimated operating time	12 hrs/day
Estimated remaining lifetime	17 years
Carbon intensity of Thai power sector	0.22 kg C/kWh
Energy savings per chiller per year	591.3 MWh
Carbon savings per chiller per year	130.1 ton C
Initial reduction in carbon emissions (24 systems)	53.1 kton C
Longer term reduction in carbon emissions (444 systems)	981.9 kton C

* kW_{el}/kW_{th} = kW electric / kW thermal

refrigerant for cooling large buildings. CFC-12 is used for most of the others.

Centrifugal chillers installed before 1993 were found to consume significantly more energy than more recent models: approximately 0.23-0.28 kW_{el}/kW_{th} more. In order to deal with this within the framework of the government strategy for this project, a ministerial order was established relating to energy consumption standards for building air-conditioning systems (centrifugal chillers) for existing and new installations. Depending on cooling capacity, the energy consumption of existing (centrifugal) chillers may not exceed 0.23-0.26 kW_{el}/kW_{th}, and for new installations the maximum is 0.19-0.21 kW_{el}/kW_{th}.

Perceived risks of the new approach

- high up-front costs and lack of access to commercial credit;
- unfamiliarity with the technology/ perceived technology risk under tropical conditions;
- need to demonstrate a track record that energy savings will materialise;
- lack of capacity to service and maintain the new systems.

Risk management

The following measures can help limit the risks:

- provide a lease-to-own arrangement with a performance guarantee to owners, allowing consumers to spread the high up-front cost over a longer period;
- provide funding in the form of an interest-free loan to set up a revolving fund for the installation of a first series of 24 chillers;
- set up workshops and information channels to inform stakeholders in the sector of developments in the pilot phase;
- seek arrangements with chiller suppliers to provide service and maintenance as well as sufficient training and technical assistance (at present, routine maintenance is not common for old chillers).

In the pilot phase, emphasis will be put not only on the investment aspect but also on the build-out of capacity. As mentioned above, available capacity of servicing technicians is also one of the risks. Requiring equipment suppliers to guarantee performance of their equipment provides an incentive to ensure that equipment suppliers' servicing technicians (or those employed by their contractors) are well trained and capable of handling the new technology.

Criteria for replacement

In selecting CFC chillers to be replaced under this program, the following criteria should be met:

- existing centrifugal chillers have *CFCs as refrigerants*;
- *energy consumption of the existing chillers* should be within the range of 0.23-0.28 kW_{el}/kW_{th} or higher;
- *energy consumption of the new non-CFC chillers* (Integrated Part Load Value, IPLV, or Average Part Load Value, APLV) should not exceed 0.18 kW_{el}/kW_{th} (any heat loss from compressors, particularly in the open-type centrifugal chillers, should be taken into account when calculating the overall energy efficiency of the system);
- funding priority should be given to chillers with cooling *capacity of 1,759 kW* or more, and preferably in operation less than 15 years;
- funding priority should be given to replacement projects that have the shortest *payback period*;
- existing centrifugal chillers should be replaced by *non-CFC units* only;
- all chiller replacement proposals should take into consideration the performance of the existing chilled water plants to ensure optimal *cooling performance* of the new air-conditioning systems.

Criteria for installers

Chiller replacement should be done by suppliers or contractors that meet the following preliminary set of criteria:

- installation, commissioning, and after sales service including routine maintenance shall be carried out by technicians certified by the United States Environment Protection Agency or other equivalent agencies;
- suppliers and contractors must follow codes of good practice to be jointly established by the industry, the Ministry of Industry, and UNEP's Regional Office for Asia and the Pacific;
- suppliers and contractors must have a proper refrigerant recovery and recycling facility;
- suppliers and contractors must guarantee performance of their equipment; they are required to provide IFCT with a performance bond (the value of the performance bond will be established during project implementation).

Perspectives

Successful completion of the project will yield substantial benefits with regard to designing similar future projects elsewhere. The project will provide economic benefits and help leverage GEF/MLF funds. Last but not least, it will benefit the environment by reducing energy consumption, GWP and ODP and help Thailand sustain the 1999 freeze in ODS consumption required under the Montreal Protocol.

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Comparison of TEWI of alternative fluorocarbon refrigerants and technologies in residential heat pumps and air-conditioners

James R. Sand, Steven K. Fischer, and Van D. Baxter, USA

Recent US studies on the impact of alternative refrigerants and HVACR technologies (heating, ventilating, air-conditioning, and refrigeration technologies) on global warming have focused on TEWI, which is the total equivalent warming impact. These studies have shown that the largest contributors to global warming by far are the CO_2 emissions, resulting from the generation of electricity or the use of fossil fuel sources (e.g. natural gas) to power HVACR equipment, rather than the emissions caused by leaks of refrigerant in space-conditioning equipment. It follows then that the most effective way of reducing the atmospheric build-up of global-warming gases is to increase the energy efficiency of HVACR equipment.

These studies have provided policy makers with arguments to push for higher equipment efficiencies as a means of attacking global warming rather than more restrictive laws on the suitability of various chemical classes of refrigerants. In April 2001, the US Department of Energy proposed an increase in the minimum seasonal energy efficiency rating of air conditioners and heat pumps (see page 4). This will give a large push toward increasing the efficiency of unitary cooling equipment in the United States and reducing their global warming impact.

TEWI

Use of conventional space-conditioning systems can lead to the emission of greenhouse gases via two different paths:

- release of CO_2 as a result of energy production;
- loss or leakage of refrigerant from the systems.

The concept of TEWI was developed to combine and compare the effect of CO_2 released over the lifetime of the system (indirect effect) with the effect of lifetime refrigerant loss (direct effect).

Researchers at Oak Ridge National Laboratory (ORNL) conducted a study to examine TEWI of unitary residential space-conditioning equipment in the United States. The study compared the TEWI of conventional R-22-based and R-22-alternative-based vapour compression systems under the same operating conditions.

Refrigerants and systems examined

A wide range of systems was analysed (see **Table 1**), including low- and medium-efficiency electric heat pumps and high-efficiency heat pumps. The R-22 alternatives examined were R-407C and R-410A. In addition, the study analysed the following space-conditioning systems:

- gas furnaces in combination with a centralised, vapour-compression air conditioner;
- a gas-engine-driven heat pump;
- a gas absorption heat pump under development (based on the generator absorber heat exchange [GAX] cycle) that uses an ammonia-water absorption cycle.

Propane (R-290) and ammonia (R-717), both good refrigerants, are sometimes mentioned in connection with unitary equipment applications. Propane was evaluated in combination with a secondary heat transfer loop and fluid, which are needed to keep this flammable fluid out of the conditioned space. Any advantage propane might have in reducing direct TEWI was outweighed by the increases in indirect effects resulting from the use of more energy for the secondary heat exchange loop. The same would be true for ammonia, which would also require a secondary heat transfer loop and fluid because of its toxicity. In addition, ammonia's incompatibility with the copper currently used in refrigerant tubing and electric motor windings makes it a poor choice for unitary equipment as a replacement for R-22.

Assumptions

System efficiency data used for calculating TEWI values for electrically driven and gas-powered residential

▼ *Table 1: System efficiencies for residential electric and gas heating and cooling equipment, 1996–1997*

System	Efficiency SPF/PER cooling	Efficiency SPF/PER heating and gas furnace efficiency
Electric systems (R-22 refrigerant)		
Air-to-air heat pumps		
a Minimum efficiency	2.9	2.1
b High efficiency	3.5	2.3
Premium technologies		
c Air-to-air heat pump	4.1	2.6
d Geothermal heat pump	4.6	3.5
Gas options		
Electric A/C and gas furnace		
e Minimum efficiency	2.9	80%
f High efficiency	3.5	92%
Premium technologies		
g Electric A/C and gas furnace	4.1	92%
h Engine-driven heat pump (R-22)	1.30	1.26
i GAX absorption heat pump	0.70	1.50

▼ *Table 2: Relative efficiencies for alternative refrigerants in residential air conditioning equipment (relative to R-22)*

Refrigerant	Refrigerant charge size[a]	Efficiency relative to R-22 (1996–1997)	
		Cooling	Heating
R-22	2.80 kg (6.27 lb)	100%	100%
R-407C	2.80 kg (6.27 lb)	100%	100%
R-410C	2.30 kg (5.07 lb)	105%	105%

[a] For a 10.5-kW (3-ton) heat pump or central A/C unit.

▼ *Table 3: Assumptions energy production*

Emission electrical power plant (including a 6% transportation and distribution loss factor)	0.650 kg CO_2/kWh [2]
Heat content of natural gas	38,200 kJ/m^3
CO_2 emission rate natural gas	51.1 g CO_2/MJ
Distribution efficiency natural gas	96.5%
CO_2 emission rate natural gas at point of use [3]	53.0 g CO_2/MJ (55.9 g CO_2/1000 Btu)

heating and cooling options are shown in **Table 1**. Published measurements were used for $SPF_{cooling}$ (seasonal performance factor cooling) and $SPF_{heating}$ (seasonal performance factor heating) of R-22 equipment. Unitary equipment is usually designed to meet $SPF_{cooling}$ and $SPF_{heating}$ targets with appropriate adjustments of hardware to fit the refrigerant and compressor performance. The American Gas Cooling Center listed the 1996 seasonal heating and cooling performance of a gas engine heat pump as 126% AFUE [1] and a PER (primary energy ratio) of 1.28. TEWI values for a gas engine heat pump were computed from these published efficiencies. For the GAX absorption heat pump, TEWI values were calculated using heating and cooling PERs applied in previous Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) and TEWI reports of the Department of Energy. The GAX PER values include electrical parasitic loads.

To calculate the SPF values for R-407C and R-410A mixtures, steady-state coefficient of performance (COP) data relative to R-22 were used (see **Table 2**). Further development of air conditioners specifically designed to use these alternative refrigerants could lead to more favourable comparisons relative to R-22.

Table 3 shows the assumptions for the emissions from energy production.

ORNL assumed 15-year lifetimes for US unitary equipment. Based on information from member companies of the American Refrigeration Institute, we used the maximum annual refrigerant leak rates of 4% for 1996–97 residential heat pump and air conditioner equipment. An end-of-life charge loss rate of 15% was calculated for residential units on the basis of recovering 90% of the charge from 95% of the field units, while allowing for a 100% charge loss from about 5% of field units.

Seasonal energy use is computed based on a typical 167 m^2 (1,800 ft^2) residence with the following heating and cooling loads shown in **Table 4**.

Results

TEWIs for various residential heating/cooling options were calculated for Pittsburgh, Atlanta, and Miami; the results are shown in **Figures 1–3**. The upper portion of each figure shows benchmark systems, i.e. heating/cooling options that represent baseline cost for a residential system in each of these cities. The lower portion shows options that are significantly more expensive than the baseline technology. Figures 1 and 2 also contain gas heating/cooling options for Pittsburgh and Atlanta, which have significant heating loads.

Using Figure 1 as an example, the advantages of increasing unit efficiencies become quite obvious if the R-22 minimum, high-efficiency, and premium options are compared. Total TEWI values for these three heat pump options in Pittsburgh are about 126,000, 111,000, and 100,000, respectively.

A 10 to 12% improvement in TEWI results for each step of efficiency improvement. TEWI decreases more sharply as a function of increased efficiency in climates with a higher cooling/heating ratio.

These figures also show TEWI results for the HFC mixtures R-407C and R-410A. In all cases, the direct contribution of refrigerant losses to TEWI is no larger than 7% of the total, with the average direct TEWI contribution being 3–4%. Essentially, little difference is seen between TEWI for R-22 systems and for R-407C or R-410A systems because unit efficiencies and global warming potential (over 100-year integrated time horizon) are very similar. The smaller charge sizes per unit of capacity for R-410A and early indications of system efficiency improvements over HCFC-22 will help reduce TEWI for the R-410A option.

The reduction of TEWI and relative energy savings associated with the added expense of a geothermal, or ground-source, heat pump are due mainly to increased efficiency rather than a smaller charge size. Combinations of gas furnaces with an electric central air conditioner show a slightly lower TEWI than electric air-to-air heat pumps under the conditions used for these calculations.

In climates with a short cooling season and an extended heating season, the gas-fired engine and GAX heat pumps have a significantly smaller TEWI than electric heat pumps with average $SPF_{cooling}$ (2.9–3.5) and $SPF_{heating}$ (2.0–2.3) ratings. The GAX option has a TEWI comparable to the values for conventional electric-driven compression systems in climates with

▼ *Table 4: Heating and cooling load in a typical residence*

	Heating load	Cooling load
Pittsburgh	78.8 x 10^6 kJ/yr (74.7 x 10^6 Btu/yr)	17.0 x 10^6 kJ/yr (16.1 x 10^6 Btu/yr)
Atlanta	36.7 x 10^6 kJ/yr (34.8 x 10^6 Btu/yr)	35.7 x 10^6 kJ/yr (33.8 x 10^6 Btu/yr)
Miami	0 kJ/yr (0 Btu/yr)	86.7 x 10^6 kJ/yr (82.2 x 10^6 Btu/yr)

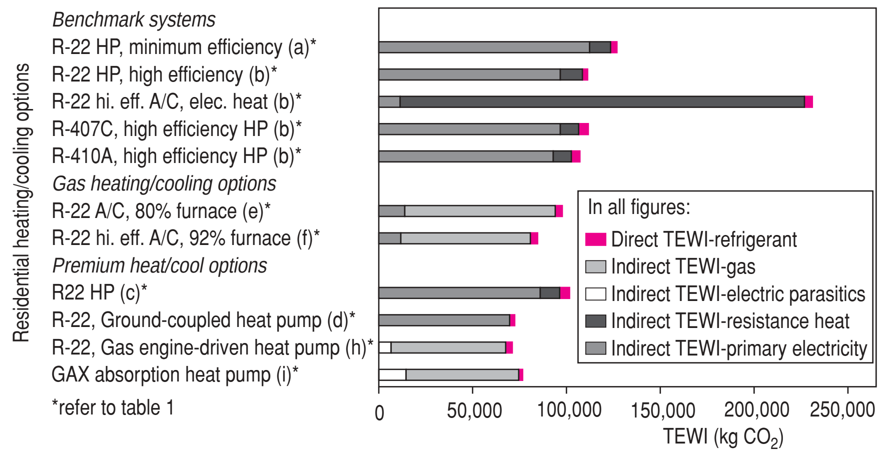
balanced heating and cooling loads, and a higher TEWI in cooling-dominated climates.

Nearly 80% of the direct TEWI results from the assumptions mentioned earlier with regard to loss of refrigerant due to leakage, accidents and maintenance practices. As regulatory procedures requiring conscientious maintenance and repair of leaks as well as strict adherence to refrigerant recovery become more widespread, the direct effect will diminish in significance.

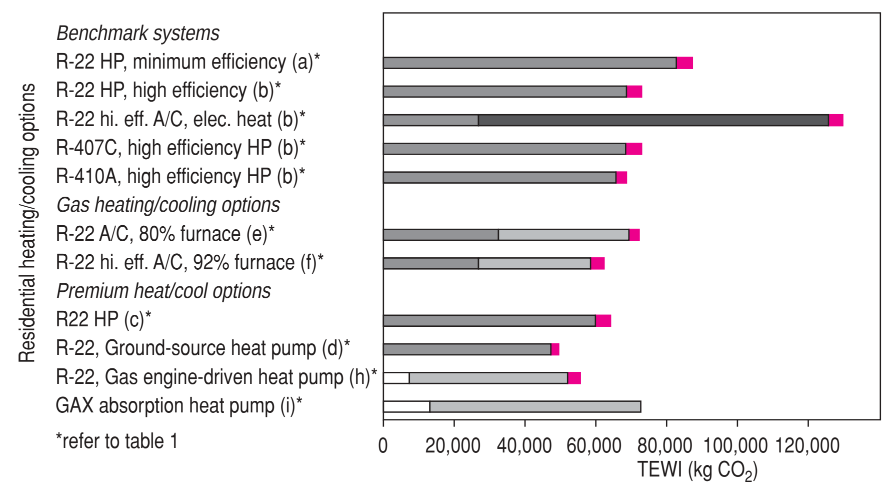
Conclusion

Total equivalent warming impacts (TEWI) for residential air conditioning systems using R-22, R-407C, R-410A and alternative technologies do not differ significantly. In climates with appreciable heating loads, gas furnace/ electric air conditioning systems and gas-fired heat pump systems show a smaller TEWI than standard electrically-driven air-to-air heat pumps. This advantage decreases as the balance shifts to higher cooling loads.

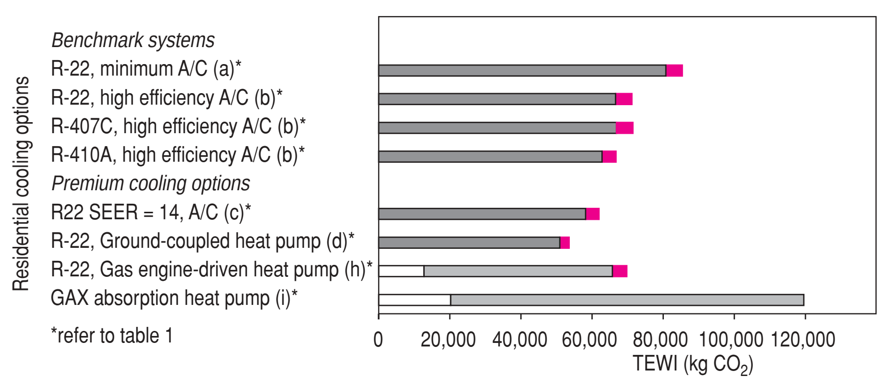
What the above analysis does underscore are the environmental benefits of the more energy-efficient technologies that decrease CO_2 emissions to the earth's atmosphere. Initial cost, projected operating costs, availability and climate, rather than TEWI, are likely to remain the principal criteria for selecting residential heating/cooling systems. However, in mandating higher efficiencies for these widespread residential systems, the United States is moving in the right direction to decrease its global warming impacts.



▲ *Figure 1: TEWI for residential heating/cooling options, Pittsburgh, Pensylvania, USA.*



▲ *Figure 2: TEWI for residential heating/cooling options, Atlanta, Georgia, USA.*



▲ *Figure 3: TEWI for residential cooling options, Florida, USA.*

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References and comments

[1] "AFUE" refers to annual fuel utilisation efficiency, a measure of appliance heating efficiency calculated by assuming that 100% of the fuel is converted to thermal energy and then subtracting losses for exhausted sensible and latent heat, cycling effects, infiltration, and pilot losses over the whole year. AFUE does not include electrical energy used for fans, pumps, ignition, exhaust, or blowers.

[2] Energy Information Administration, *Electric Power Annual, 1995*, vol. 2, DOE/EIA-0348(95)2 (Washington, D.C.: US Department of Energy, December 1996).

[3] Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(97/03) (Washington, D.C.: US Department of Energy, March 1997).

Combined cooling and heating using vertical ground heat exchangers

Dr Martin Zogg, Switzerland

A pilot project was carried out in which waste heat from cooling processes was used for heating purposes. Ground heat exchangers were used to store the excess heat produced in summer until it could be used in winter. A planning handbook was used to design the combined cooling/heating system. Overall energy savings of about 20% were realised.

Introduction

The use of waste heat from refrigeration and air-conditioning plants for the purpose of space heating and hot water production offers substantial potential for saving energy. Such a combined system will generally be more energy-efficient than a system in which the cooling processes are completely separate from the heating processes. For refrigeration (cold storage rooms and cooling cabinets), the cooling requirement is generally constant over the year. The heat requirement for hot water production is also roughly constant during the year. However, the cooling requirement for air conditioning occurs only in summer, and space heating is needed only during the heating season. These requirements also vary with ambient temperature. As a result, the amount of waste heat available from cooling processes does not generally correspond well with the heat requirement. This is illustrated in **Figure 1**, in which data are presented for a Swiss restaurant, which was the subject of the pilot project reported on in this paper.

Vertical ground heat exchanger - an ideal solution

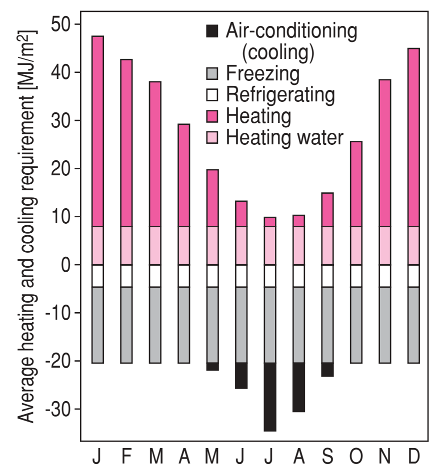
While water storage tanks may compensate for daily differences in supply and demand, the seasonal imbalance between the amount of waste heat available and the need for such heat may be dealt with by applying vertical ground heat exchangers - alone or in small groups. When the heat demand is low or tends to zero, the excess heat from the cooling plant's condenser can be stored in the ground (typical of summer operation). In typical winter operation, the heat requirement will dominate, and the ground can serve as a (supplementary) heat source. **Figure 2** is a diagram of a plant with combined heating and cooling for a situation that is typical of the commercial refrigeration sector - with refrigeration and deep-freeze units and hot water and space heating systems. The plant is of particular relevance here, having its own group of vertical ground heat exchangers to provide the buffer effect. Characteristics of the plant are: heating capacity at the design point, 32 kW; heating capacity for hot water production, 5 kW; cooling requirement for air conditioning at the design point, 62 kW, and for refrigeration and deep-freeze, 25 kW.

Increase in overall energetic efficiency

The energetic efficiency of a plant providing both cooling and heating can be expressed by the 'overall coefficient of performance'. It is defined as the ratio of the sum of all cooling and heating energy to the sum of all electrical energy supplied (all electric system). In the example described, the combined production of cooling and heating using ground heat exchangers resulted in an increase in the energetic efficiency of 21% compared to a conventional plant with separate cooling units and heat pumps; see **Table 1**.

Planning handbook

A planning handbook prepared on behalf of the Swiss Federal Office of



▲ *Figure 1: Measured average monthly values for heating and cooling in a restaurant*

▼ *Table 1: The energetic efficiency of a conventional unit and a combined unit for the production of cooling and heating in the case of a restaurant.*

	Overall coefficient of performance
Conventional: separate refrigeration units for cooling, and heat pumps for heating	2.4
Combined unit as in Figure 2	2.9

Energy deals with the design of the systems needed for the combined production of cooling and heating. The design process is explained in five main steps, using the Swiss restaurant in the pilot project as an example:

1. Heat requirement: determination of the heating capacity according to SIA (Swiss standard) 384/2, of the heating equirement according to SIA 380/1, and of the heat requirement for hot water production and – where needed – for processes with a low-temperature heat requirement.

2. Cooling requirement: calculation of the cooling capacity according to SIA 382/2, the cooling requirement of the building, and the cooling capacity and cooling energy requirement of the refrigeration and deep-freeze units.

3. Refrigeration units/heat pumps: determination of the evaporation and condensation temperatures, and dimensioning of the refrigeration units/ heat pumps based on the maximum cooling and/or heating capacity.

4. Dimensioning of the ground heat exchanger group based on the monthly quantities of heat delivered or extracted and on the peak delivery or extraction capacity.

5. Design of thermal storage (hot water, heating) to accommodate daily variations.

The handbook treats steps 4 and 5 exhaustively. It also provides valuable information on the selection of systems for the combined production of cooling and heating. Ordering information can be found on page 26 of this Newsletter.

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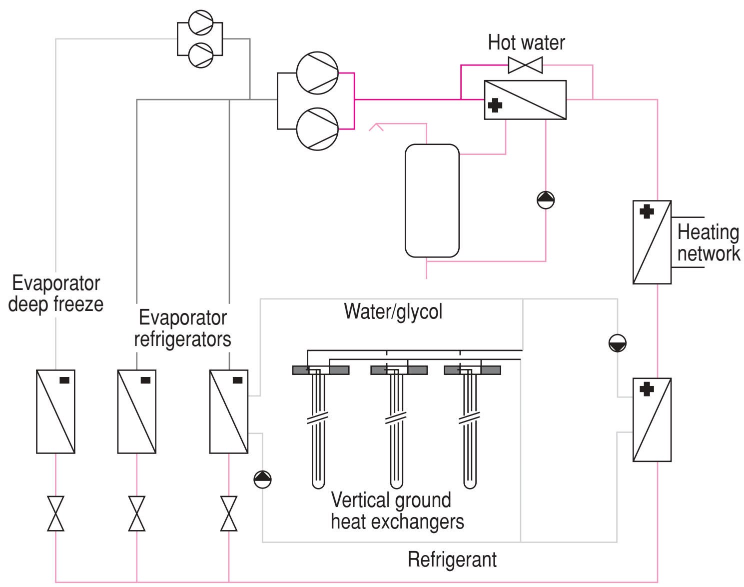

▲ *Figure 2: Flow diagram of the plant build by KWT, Belp (Switzerland) for a restaurant with combined heating and cooling, direct evaporation and small group of vertical ground heat exchangers.*

Highlights of the 2001 annual ASHRAE meeting

Jos Bouma, IEA Heat Pump Centre

The 2001 annual ASHRAE meeting was held in Cincinnati, USA, 23-27 June. This article summarises papers and discussions on heat pumps and refrigerants.

The new ASHRAE president for the year 2001-02 is William J. Coad. The theme he has chosen for his year is "Accepting the Challenge", meaning that "the greatest challenge to the human race in looking ahead to the 21st century will be to maintain our [US, ed.] quality of life as we face a dwindling reserve of energy resources. The HVACR engineers have created this quality of life, and they are the ones that have the knowledge and skill to keep it going."

Heat pumps were given plenty of space in the meeting programme with:

- a symposium on Design Issues for Ground-source Heat Pumps;
- a symposium on Applied Heat Pump/Heat Recovery Concepts for the new Millennium;
- a forum on the Impact of Minimum Energy Efficiency Standards on the Industry;
- a seminar on Refrigerant Enforcement Issues;
- a seminar on the Responsible Use of Refrigerants.

New refrigerants

In a US paper an overview was given of the most likely candidate refrigerants for applied heat pumps of the future including fluorocarbons and natural working fluids replacing CFC and HCFC refrigerants. Applied heat pumps cover a wide range of products from small domestic heat pump water heaters through unitary-sized water loop and ground-coupled systems, up to large centrifugal systems for use in process industry.

It was concluded that HFC-134a will likely be the refrigerant of choice in a wide range of heating applications, ranging from domestic to industrial-size systems. The use of ammonia in heating applications is likely to be secondary to its use for refrigeration purposes because of the high discharge temperatures. Ground-source heat pumps, both water-source and closed loop, will use HFC-410A. The driver behind this is the larger market for unitary air conditioners and heat pumps. Carbon dioxide will find use only in larger systems where system efficiency can be optimised in a cost-effective manner. Hydrocarbons may be used only where the flammability can be tolerated, such as in industrial processes. For the process industry, HFC-245fa is proposed as the most attractive candidate, from an energy efficiency viewpoint, for use in multistage centrifugal systems. HFC-236fa may find use in niche applications where its capacity characteristics enable a cost-effective solution. HFC-134a can be used here as well in many cases.

Ground-source heat pumps

Ground-source heat pumps in this context include both open loop (groundwater) and closed loop systems. Proper designing is a pre-requisite for successful systems. The effect of using simple design approaches was investigated. Simple design approaches for commercial/institutional buildings provide opportunities for initial cost and operating cost reductions, as well as a reduction of the number of components requiring maintenance. Traditional design approaches for larger buildings can be characterised as follows:

- use of centralised piping loops;
- building loop design separate from ground loop design;
- redundancy and overdesign of the heat pump and its components;
- ground loop design often fell to loop contractor or piping distributor by default.

The simple ground-source heat pump design approach recognises that unitary systems provide benefits superior to those of larger central loop systems because they are less expensive to install, consume less energy, require less maintenance, and can be serviced by technicians with modest skills. The conclusion was that unnecessarily complex systems continue to be designed and installed in commercial/institutional buildings, and that misinformation in this regard has resulted in excessive costs, lower performance and occasional owner dissatisfaction. Hence, a simple unitary loop design can be incorporated in many applications, resulting in lower initial and operating costs and requiring less maintenance than many popular conventional heat pump designs. It was also recognised that many applications might not be suited for simple unitary designs.

The relevance of proper design was also demonstrated in another paper. In a military base in the southeastern US, it has been proposed to retrofit more than 1,000 family residences with individual ground-coupled heat pumps. Each residence will have its own heat pump with a ground loop consisting of two or more boreholes. The maximum temperature of the water entering the heat pumps in the cooling mode will be 35°C. A system analysis using the independent TRNSYS simulation model revealed that the designer of the loop systems employed a number of experience-based margins of safety to ensure that the designs are conservative. These included:

- neglecting the effect of the desuperheater (some of the heat is rejected to the hot water tank);
- assuming a cooling setpoint of 22°C (uncomfortably cool);
- derating the heat pump by 5% (assuming 5% more input power).

The effect of the safety margins is an oversized (longer) heat exchanger and higher bore field cost (the effective maximum temperature of the entering water would be 32°C rather than 35°C).

The key elements of groundwater well specifications were discussed in a US paper. The background of the paper is the general HVAC design engineers' lack of familiarity with the topic, which results in wells that are rarely completed in the best interests of the owner. The paper discusses the key sections of a well-specification document. Two basic water well types are covered: the open hole well without casing completed in rock formations and the well lined with casings, screen and sometimes a gravel pack.

Heat island

In a paper from Japan, a solution was presented for the heat building up in cities caused by the discharge of heat from residential air-source heat pumps. The proposed system is meant for densely populated residential areas and consists of a new district heating and cooling network that uses water-source heat pumps and a large-scale underground thermal storage tank. Electricity consumption can be significantly reduced compared with individual air-source systems.

Heating towers

A Chinese paper presented a proposal for converting standard water-cooling towers so that they can be operated in reverse mode for heat extraction. The heat is used in colder seasons for domestic water heating to supplement heat recovery from air-conditioning systems in buildings with reduced cooling loads in subtropical regions. This eliminates the need for a back-up heating system. Tests have shown that the system can be used satisfactorily to produce hot water at around 55°C.

Jos Bouma
IEA Heat Pump Centre
Address see back cover

Back to the Future - Working safely with hydrocarbons
Video and booklet
UNEP TIE OzonAction Programme, 39-43 Quai Andre Citroen, 75739 Paris, France
Fax: +33-1-4437-1474, E-mail: ozonaction@unep.fr
Internet: http://www.uneptie.org/ozonaction.html

This 20-minute video highlights the necessary safety practices in the use of hydrocarbons as refrigerants and insulation foam-blowing agents. The main objective of the video is to help developing countries, via local refrigeration manufacturers, to understand and use hydrocarbons as an alternative to CFCs, HCFCs, and HFCs in domestic and small commercial refrigeration, especially regarding the safety aspects involved.

The video and booklet are available in English, French, Spanish, Portuguese, Chinese, Arabic, and Russian. This is a co-production of UNEP, GTZ, and Greenpeace International, executed by the Television Trust for Environment (TVE) with funding under the Multilateral Fund of the Montreal Protocol.

Combined Production of Cooling and Heating using Heat Wells: Handbook of Planning Procedures
J. Good, A. Huber, P. Widmer, Th. Nussbaumer, D. Trüssel, Ch. Schmid; Swiss Federal Office of Energy, 2001; Price CHF 40 (USD 23) under ENET number 210001 obtainable from ENET, Egnacherstrasse 69, CH-9320 Arbon, Switzerland.
Fax: +41-71-440-0256, E-mail: enet@temas.ch

This planning handbook, prepared on behalf of the Swiss Federal Office of Energy, deals with the design of the systems needed for the combined production of cooling and heating. The design procedure is explained in five main steps, based on a practical example of the plant described in the article on page 23 of this Newsletter:
1. Heating requirement
2. Cooling requirement
3. Refrigeration units/heat pumps
4. Dimensioning of the ground heat exchanger group
5. Design of storage

The handbook treats steps 4 and 5 exhaustively. It also provides valuable information on the selection of systems for combined cooling and heat production.

Het warmtepomp variantenboek – The heat pump options book
Novem, May 2001; Price NLG 33 (~USD 13), order number 2WPAL01.04, obtainable from Novem, Postbus 17, 6130 AA Sittard, the Netherlands.
E-mail: publicatiecentrum@novem.nl. Language: Dutch.

The heat pump options book introduces you to the world of possible heat pump systems: combinations of heat source, heat pump (monovalent, bivalent, reversible etc.), and heat sink, for individual applications or for small or large groups of buildings. The concept of the book makes it possible to combine various options with each other and encourages an open mind for potentially successful combinations. It is also beneficial for those who do not read Dutch, since illustrations are the heart of the book. The book concludes with a few case studies.

Cool thermodynamics: The Engineering and Physics of Predictive, Diagnostic and Optimization for Cooling Systems
Jeffrey M. Gordon and Kim Choon Ng
Price GBP 50 (USD 71), postage and packing GBP 3 (UK), GBP 4 (Europe), GBP 5.50 (World). ISBN 1898326 908, June 2000, 261 pages. Cambridge International Science Publishing, 7 Meadow Walk, Great Abington, Cambridge CB1 6AZ, UK. Fax: +44-1223-894539, E-mail: orders@cisp.demon.co.uk
Internet: http://www.demon.co.uk/cambsci/homepage.htm

In this book, analytical thermodynamic models are developed for a wide range of operating conditions. These models are easily implemented in the field or laboratory. Although the authors focus upon mechanical (electrically-driven) chillers - primarily reciprocating and centrifugal machines - there is also substantial material on heat-driven absorption chillers. Heat pumps and heat transformers are also addressed. A few less common chiller types are also treated, such as thermo-electric, thermo-acoustic and vortex-tube units.

Retrofitting with heat pumps in buildings
G. Eggen, G. Breembroek, IEA Heat Pump Centre, the Netherlands, 90 p. Price NLG 80. Only available in AT, JP, NO, NL, UK, US (from 1 July 2003 available without restriction). Please use the attached response card when ordering HPC products.

The market for heat pumps in new buildings has been expanding recently in some countries. Attention to the retrofit market is also increasing, in the wake of the market for heat pumps in new buildings. Several initiatives are also being undertaken to remove market barriers to increased heat pump deployment in retrofit applications.

The market potential for heat pumps in retrofit situations is substantially larger than for new buildings. Yet this potential is far from being realised in many countries, largely due to the high distribution temperatures required in existing heating installations. To achieve a worldwide reduction of CO_2 emissions, increased deployment of heat pumps for retrofitting is essential.

The report “Retrofitting with heat pumps in buildings” discusses markets, market barriers and technological developments, and concludes with several examples of successful retrofit projects using heat pumps. It will inspire market parties to stimulate the use of heat pumps for retrofit applications.

Energy conservation and alternative sources of energy in sugar factories and distilleries (2001)
P.J. Manohar Rao, P.J. International Group Consultants, A-101 Yamuna Apartments, Alaknanda, New Delhi – 110 019, India, Fax: +91-011-6474514, E-mail: scgtc@vsnl.com. 780 pages. Price: USD 110 (outside India).

This book covers the following subjects:
1. Energy conservation in sugar factories and alternative sources of energy
2. Energy conservation in distilleries
3. Non-conventional or renewable sources of energy and their possible uses in sugar factories and distilleries.

One chapter is dealing with the use of heat pumps for energy conservation in these industries.

Available from the HPC

PLEASE USE THE ATTACHED REPLY FORM TO ORDER HPC PRODUCTS

NEW: **IEA Heat Pump Programme Strategy Plan 2001-05**
HPP Brochure, August 2001
Order No. HPP-BR07. Free-of-charge.
To order please contact the IEA Heat Pump Centre, address see back cover.

NEW: **Advanced supermarket refrigeration/ heat recovery systems**
CD ROM Workshop proceedings, April 2001
Order no. HPP-AN26-1, NLG 180 or NLG 80 in CA, DK, SE, UK, US.

NEW: **Retrofitting with heat pumps in buildings**
HPC Survey report, July 2001
Order no. HPC-AR9, NLG 80. Only available in AT, JP, NL, NO, UK, US up to 1 July 2003.

Considerations in the design and selection of Domestic heating and cooling Distribution and ventilation systems and their use with residential heat pumps
HPC Survey report, June 2000
Order no. HPC-AR8, NLG 80. Only available in AT, JP, NL, NO, UK, US up to 1 June 2003.

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

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

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

2001

Thermophysical Properties and Transfer Processes of New Refrigerants
3-5 October 2001 / Paderborn, Germany
Co-sponsored by IIR, Commission B1
Contact: Dr Ing Andrea Luke
Universität Paderborn, Warburger Straße 100
D-33098 Paderborn, Germany
Tel.: +49-5251-60-2392, Fax: +49-5251-60-3522
E-mail: luke@wkt.uni-paderbron.de

2nd International Conference on Energy Research and Development (ICERD 2)
5-7 November 2001 / Kuwait City, Kuwait
Co-sponsored by IIR, Commission B2, E1, D2
Contact: Conference secretariat
Fax: +965-484-7131
E-mail: icerd@kuc01.kuniv.edu.kw
Internet: http://kuc01.kuniv.edu.kw/~icerd

Symposium on the Analysis and Applications of Heat Pump and Refrigeration Systems
(2 Sessions) ASME Congress
11-16 November 2001 / New York, USA
Contact: B.G. Shiva Prasad
Fax: +1-607-937-2390
E-mail: b_g_shiva_prasad@dresser-rand.com

2002

ASHRAE Winter meeting, Absorption/ sorption heat pumps and refrigeration systems
12-16 January 2002 / Atlantic City, USA
Contact: Jesse Killion
Program Chair, ASHRAE TC 8.3
Department of Mechanical Engineering
2025 H.M. Black Engineering Building
Iowa State University
Ames, IA 50011-2161
Tel.: +1-515-2940856, Fax: +1-515-2943261
E-mail: jkillion@iastate.edu

International Compressor Engineering Conference at Purdue
International Refrigeration and Air Conditioning Conference at Purdue
16-19 July 2002 / West Lafayette, US
Contact: Reena L. Fleischhauer, coordinator
Conference Division, Purdue University
1586 Stewart Center
West Lafayette, IN 47907-1586, US
Tel.: +1-765-494-9499
Fax: +1-765-494-0567
E-mail: rlfleischhauer@purdue.edu

Zero Leakage - Minimum Charge
26-29 August 2002 / Stockholm, Sweden
Contact: Per Lundqvist
IIR conference
Royal Institute of Technology
Fax: +46-8-20-30-07
E-mail: elksne@egi.kth.se
Internet: http://www.egi.kth.se/zero/

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

IEA Heat Pump Programme events

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

7th IEA Heat Pump Conference
19-22 May 2002 / Beijing, China
China Academy of Building Research (CABR)
Post code 100013, P.O. Box 752, Beijing, China
Tel: +86 10 84270568, 84272233 ext. 2331
Fax: +86 10 84283555, 84284720
E-mail: hp2002@sina.com
Web: http://www.chinahvac.com.cn (Chinese)

Next Issue

Adsorption and desiccant systems

Volume 19 - No.4/2001

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

Novem

Netherlands agency for energy and the environment

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