IEA Heat Pump CENTRE NEWSLETTER

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The latest developments in the use of CO_2 as refrigerant

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Use of CO_2 in heat pump systems – practical experience with transcritical systems

Development of automatic drink vending machines with CO_2 refrigerant

IEA OECD heat pump centre

IEA **Heat Pump** CENTRE
NEWSLETTER

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In this issue

The latest developments in the use of CO_2 as refrigerant

The interest in CO_2 in the world is very high at the moment. Although CO_2 is generally regarded in a negative context, due to the greenhouse effect, it is regarded in the heat pump and refrigeration world as a natural refrigerant, i.e. one that it is naturally present in the environment.
After being "forgotten" for some 50-60 years, CO_2 is nowadays the "hottest" refrigerant in scientific publications. In addition, there is a large and growing industry in CO_2 components and systems, from small applications to large systems.
In this issue, a number of applications such as water heaters, drink vending machines, reversible air conditioners and heat pumps are presented in topical articles.
We also include an article on the F-Gas Directive in this issue.

Enjoy your reading!

Roger Nordman
Editor

Heat pump news

Features

Topical article

Non-Topical article

COLOPHON

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Foreword

Didier Coulomb
Director of the IIR

Over the past 20 years, scientific studies have demonstrated the impact of refrigerants on ozone depletion and climate change; the implementation of the Montreal Protocol followed by the Kyoto Protocol has obliged refrigerant manufacturers to develop new products that have less impact on the environment: CFCs are being phased out, HCFCs are being phased out in developed countries, and HFCs are replacing them.

These environmental issues have brought certain "old" natural refrigerants (CO_2, ammonia, hydrocarbons…) to the forefront again; these refrigerants have little or no impact on the environment when leakage into the surrounding atmosphere occurs.

Among these natural refrigerants, CO_2, is attracting the most attention, is also the refrigerant that is by far the most investigated in laboratories and is generating the greatest interest among potential users.

The aim of these studies is to improve the energy efficiency of plants, which must be the determining factor when choosing a refrigerant, for obvious economic reasons and also for environmental reasons: the electrical consumption of refrigeration and air-conditioning equipment is almost 15% of total global electrical consumption. Electrical consumption thus has a greater impact on climate change than refrigerant choice alone.

Optimization of refrigeration systems using CO_2, must be performed for all applications.

CO_2 has a very promising future
The International Institute of Refrigeration (IIR) has many actions in this sphere: a Bibliography on CO_2, was published in 2006 and is on sale via the IIR's Web site: www.iifiir@iifiir.org; Gustav Lorentzen Conferences on Natural Working Fluids (the next one in the series will be held in Copenhagen in September 2008); etc.

Beyond these specific actions, all IIR activities are focused on these issues. For this reason, I invite you to take part in the next International Congress of the IIR: it will take place in Beijing, Chine, on August 21-26, 2007 (Web site: www.icr2007.org). A joint session will involve the International Energy Agency Heat Pump Centre, thanks to an increasingly fruitful partnership between the Heat Pump Programme and the IIR.

Didier Coulomb

The carbon dioxide interest group, known as c-dig, met in Holland at the beginning of September for a seminar covering a wide variety of recent developments in the use of carbon dioxide as a refrigerant. The meeting started with a visit to the Kunstijsbaan in Haarlem for a tour of the refrigeration plant serving the 400m speed skating track. This was installed two years ago by Grenco BV to convert the existing ammonia plant, which dated from 1977, and extended the plant to include a small ice pad in the centre of the track. Much of the original installation was reused, including the direct expansion piping under the track, and in this way the ammonia charge in the plant was reduced from 7 tonnes to about 1.5 tonnes, with none of the ammonia in the publicly accessible parts of the stadium.

At the c-dig meeting it was noted that the majority of the papers at the recent Gustav Lorentzen conference had been on carbon dioxide, and that roughly one-third of these had concerned heat pumps. This significant increase in interest reflects a combination of the recent commercial success of smaller carbon dioxide heat pumps and the sudden increases in energy prices experienced all round the world in the last eighteen months. Several of the presentations made to the c-dig seminar reflected that heightened interest in high temperature applications, but as always the wide range of presenters and topics touched on commercial and industrial applications and ranged from supermarkets to trawlers. There were presentations from equipment manufacturers, contractors, end-users and academics, and as usual the days included many lively discussions and networking sessions.

Reciprocating and screw compressors with capacities ranging from $100m^3/h$ to $1000m^3/h$ are now available with design pressures of 45 to 50 bar abs., and this has greatly increased the options for system designers considering the defrost of refrigerating systems. Several types of freezer were reviewed including plate freezers and scraped-surface evaporators. Several studies showed that these types offered particularly good performance on carbon dioxide. In the heat pump field Bernard Thonon of GRETh reviewed the studies conducted by the Sherhpa network and Forbes Pearson described some possible applications of heat pumps particularly well suited to carbon dioxide.

Proceedings from the meeting are free to c-dig members, and the next seminar is planned for spring 2007. This is likely to be held in Southern Europe, and details will be published on the c-dig website www.c-dig.com in the near future.

Andy Pearson
c-dig, the carbon dioxide interest group
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General

Eco-labelling of heat pumps

The discussion about the possible criteria for applying the EU eco-label to various types of heat pump systems has reached an important stage, with the EHPA circulating a set of proposals to members of the ad-hoc working group set up by DG Environment. The various proposals are being reviewed by DG Environment. If a consensus can be reached, then heat pumps will become the first renewable energy system eligible for the EU eco-label. This is an important stage in the evolution of the market, because it would be sensible for grants (where these are available) to be given to systems which are awarded the eco-label.

Source: EUROPEAN HEAT PUMP NEWS ISSUE 7/2 August 2006

Researchers testing effect of 'cool'-coloured roofs on building temperature

Houses in Sacramento, California, are part of a study by the U.S. Department of Energy's Oak Ridge and Lawrence Berkeley national laboratories, funded by the California Energy Commission, to explore how well "cool" colours work. Researchers are comparing the houses against identical houses on the same street with roofs coloured in conventional pigments. They found the temperature in the attic of a house with "cool" concrete tiles to be lower than in the attic of a house with regular coloured concrete tiles.

Source: The HVAC&R Industry for August 24, 2006 Issue: 34 Volume: 5

UK Ground Source Heat Pump Association has been formed

Almost 200 delegates attended the inaugural meeting of the Ground Source Heat Pump Association, organised by the National Energy Foundation (NEF) in Milton Keynes on 20th June. The new association has been formed to promote and develop the Ground Source Heat Pump (GSHP) industry, which is growing rapidly, with installations in the UK increasing by at least 60 % each year.

Dr Tim Lunel of NEF said in his keynote address that "Demand for ground source heat pumps will continue to surge as more and more houses are built to a target of using at least 10 % renewables in response to local authorities' Energy Strategies".

Karl Drage of Geothermal International, who was elected as Chairman of the new Association, added "Recent gas price rises mean that homes with ground source heat pumps now cost less to run than any other fuel. The Metropolitan Housing Association, which has been installing GSHPs since 2001, has found that lifetime costs can also fall below those of gas, owing to the greater reliability of heat pump units compared to condensing boilers."

Many attendees at the launch event signed up as members to the newly formed Ground Source Heat Pump Association. The new Association is open to anyone involved in the industry, including potential customers, installers and suppliers. The Association will replace the Ground Source Heat Pump Club, which was set up in October 2004 by the National Energy Foundation.

Delegates enjoying a break during the GSHPA launch

Source: http://www.nef.org.uk/gshp

Work suffers when the heat is on

A nationwide survey of the optimum UK office working temperature has found that nearly two-thirds of workers are too hot during the summer, making them sleepy, lethargic and inefficient.

The survey conducted by YouGov on behalf of Daikin Air Conditioning UK Ltd., forms part of a campaign by the UK office of the Japanese air conditioning manufacturer to raise awareness of the business benefits of energy-efficient and cost-effective air conditioning systems.

The survey, which sampled over 2000 people across Britain, found that 62 % of office workers are too hot at work during the summer months, with an alarming effect on efficiency: 63 % of those surveyed stated that working in an environment that is the wrong temperature makes them sleepy and lethargic, whilst a staggering 59 % feel less productive. The survey also revealed that 28 % of office workers suffer from increased stress when their working environment is the wrong temperature, and a quarter of those questioned become miserable.

Source: ACR News 21/06/2006

Working Fluids

Natural refrigerants fund

During the upcoming IIR conference, Ammonia Refrigeration Technology - for Today and Tomorrow, an initiative for establishing a Natural Refrigerants Fund will be launched.

The aim of this fund will be promotion and implementation of technologies with natural refrigerants in developing countries and in developed countries.

There are opposing views and many hot debates about the present and future development in refrigeration and air conditioning regarding refrigerants. However, a major barrier is proper information regarding the use of natural refrigerants. This is particularly marked in developing countries, where the penetration of HCFC and HFC technologies is considerably greater.

Generally, the purpose of establishing the NRF is to:

- Promote the use of natural refrigerants (ozone-friendly and climate-friendly technologies) through dissemination of information;
- Organise workshops, give lectures (especially in developing countries);
- Provide financial and technical support to enable the use of new technologies with natural refrigerants;
- Arrange training courses (designing, maintenance, safety);
- Support demonstration projects aimed at the transfer of technologies from developed countries;
- Modernise existing ammonia refrigeration plants (especially in developing countries);
- Support research and innovation in natural refrigerant technologies by institutions and companies;
- Integrate research activities, dissemination of results from research to more stakeholders;
- Organise public campaigns;
- Operate a web site to present all activities and news, case studies, sponsors.

Source: Prof. Dr. Risto Ciconkov, Dipl. Ing. (mailto:ristoci@ukim.edu.mk)

DuPont ”encouraged” by MAC refrigerant tests

DUPONT'S proposed HFC-based refrigerant replacement for automotive air conditioning has a GWP of just 40, and will be a direct replacement for R134a, according to new information released by the company.
Designated DP-1, the new refrigerant is a response to the forthcoming European F-gas regulations, which will phase-out R134a from car AC systems.

As well as having a zero ODP, DP-1 is non-flammable and is said to have so far performed well in critical tests involving thermal stability, materials compatibility, lubricant miscibility and toxicity.
A two-component blend, DP-1's pressure/temperature profile is said to be very similar to R134a, thus avoiding the high pressures required by its 'natural' competitor, CO2. Temperature glide is said to be similar to that of R407C.
Mark Baunchalk, global business manager, DuPont Refrigerants, says "We are very encouraged by this initial testing because all indications are that DP-1 will be compatible with conventional 134a MAC system technology and, unlike other alternatives such as CO2, will have the potential to enable a cost-effective global transition across the entire MAC industry."

Source: ACR-News (www.acr-news.com)

Technology & Applications

PETD – A new acronym to learn for everyone who wants to be cool

A new technology to defrost and de-ice refrigerators has been invented by Professor Victor Petrenko of Dartmouth College. The technology, Pulse Electro-Thermal De-icing (PETD) removes ice instantly by a short (less than 1 sec) high-power electric pulse.
Read more and watch some really nice video clips at: http://engineering.dartmouth.edu/thayer/research/ice-engg.html

Source: RAC news, July, 2006

Inspection and auditing of air-conditioning systems

New documents and tools released by the AuditAC project Article 9 of the European Energy Performance of Buildings Directive require the regular inspection of A/C systems for energy efficiency. In line with the AuditAC project, which is supported by the EIE Program, EUROVENTCERTIFICATION now offers a register which lists the efficiency of EUROVENT-certified A/C products since 1995. This information will make it easier, when carrying out inspections, to provide a statement about the efficiency of an A/C system. The AuditAC team is also offering new technical guidelines to support the Audit process and an improvement in efficiency of A/C systems.

For more information, see http://www.energyagency.at/(en)/projekte/auditac.htm

Source: http://www.energyagency.at/

Church warms to green message

A historic church has started putting its green plans into practice, leading the renewable energy revolution in Hertfordshire.

St Mary's Church in Welwyn village has become the first church more than 100 years old to install a Ground Source Heat Pump (GSHP), slashing its carbon dioxide emissions by nearly 100 % from 44 tones a year to less than two tonnes a year. The GSHP system will replace the current standard boiler that heats the building and will use electricity from green suppliers. Members of the congregation put forward the idea of having a sustainable energy source while raising money for a £770 000 extension.

David Gregory, a member of the congregation and chairman of the sustainable heating group, said: "It was a desire on behalf of the church to do something that would help with climate change. We set up a committee to consider all our options, which were quite limited as the building is Grade Two listed. We also hope to encourage other churches to do the same."

The church has raised the £40 000 installation cost with the help of the public. The whole process has taken around two years, and will be completed in September when the building of new meeting rooms is finished.

With gas prices predicted to rise more quickly than those of electricity, the church could save money in the long run, but the main drive of the project is the benefit to the environment.
For more information on the church's plans, visit the specially made website http://www.gshp.welwyn.org.uk/

Source: http://www.nef.org.uk/gshp/

Dual Scroll - Copeland's solution for large systems

After the successful introduction of the large commercial scroll range (20 to 30 hp), Copeland is again setting the standard with the launch of the new Dual Scroll compressor for 50 & 60 hp in single applications, and 100/110/120 hp in Tandem applications. This innovative compressor is designed for application in chiller, rooftop and custom engineered systems.

The new Dual Scroll compressor draws on all the best of Copeland's compressor technologies: low noise semi-hermetic design, scroll efficiency and reliability, capacity modulation and electronic protection.
Electronic diagnostic and protection: The Dual Scroll compressor has an advanced electronic diagnostics and protection module. Data are acquired from an oil pressure sensor, six temperature sensors within the motor windings, and two discharge temperature sensors - one for each scroll set. The Compressor Alert module provides advanced warning, tripping and lockout facilities, depending on the level and repetition pattern of the fault, and information can be transmitted to the unit controller.

Source: http://www.jarn.co.jp/

Heat pumps to be tested in practice

Fraunhofer-Institut für Solare Energiesysteme ISE (Germany) is starting a four-year field test for heat pumps. It plans to measure the performance of 140 heat pumps installed in single-family houses.

In cooperation with seven heat pump manufacturers and two utilities, the researchers will investigate how efficient electric heat pumps can meet the heat requirements of low energy houses.

Source: EHPN (http://ehpn.fiz-karlsruhe.de/en/aktuell/kat1/akt218.html)

Improving the energy efficiency of food refrigeration operations

DEFRA-funded work starts at FRPERC accurately to determine the major food refrigeration sectors and identify technologies to reduce energy costs.

Since the UK is committed to reducing greenhouse gas emissions, a reduction in food refrigeration energy usage is paramount. The food and drink sector has a target to achieve a primary specific energy consumption of 899.6 kWh per tonne of throughput by 2010. As it is estimated that about half the sector's electricity is consumed in refrigeration processes, this gives a target of approximately 450 kWh per tonne of refrigeration energy use, from a current base level of approximately 500 kWh per tonne.

The Food Refrigeration and Process Engineering Research Centre (FRPERC) at the University of Bristol has recently become the coordinator of a DEFRA (Department for Environment, Food and Rural Affairs) funded project to identify, develop and stimulate the development and application of more energy-efficient refrigeration technologies and business practices for use throughout the food chain, whilst not compromising food safety or quality. In this critical project, Bristol is partnered by Brunel, London South Bank and Sunderland Universities.

The research programme will concentrate on three topics:

* Mapping of energy use in different parts of the chain
* Identifying the most promising technologies, systems and business practices
* Undertaking feasibility studies on the most promising technologies

The mapping exercise aims to identify and rank the top ten processes (commodity/operation combinations) in terms of the potential for achieving the greatest total improvement in energy use. The first task is to complete an energy efficiency matrix for each of the major food categories and processes (e.g. Meat and meat products, Dairy, Fruit and vegetables, Bread and pastry products, Oils and fats, Beverages etc.).

The first part is already under way, and is using a 'broad brush' approach to identify which food sectors are the major consumers of energy for refrigeration processes throughout the chain. A survey is being carried out of published and readily available data from collaborating organisations using, for example, both industry production figures and household consumption figures to determine the largest commodity sectors that use refrigeration.

Source: Fperc (http://www.frperc.bris.ac.uk/)

Markets

Chinese air conditioning market overview

Market overview - room and packaged air conditioning

The Chinese market for packaged air conditioning in 2005 is estimated at around USD 7800 million, marking a 12 % increase from 2004. Growth is expected at 9.1 % CAGR till 2010. The faster-growing markets will shift from first or second tier cities to third and fourth tier cities and rural areas, with more demand for top-end market products as income levels rise.

The vast majority of products in the packaged air conditioning market are still mini-split systems; among them, 96 % are the single split type. Window units are slowly receding from the market, while the moveable market remains small at 78 400 units in 2005. The vast majority of window and moveable units made in China are for the overseas market.

High demand from the upper end of the residential housing market and offices has doubled the market for VRF units since 2004, with Daikin expanding its local Chinese production and some Chinese manufacturers now starting to sell significant quantities. Meanwhile, the rooftop market has remained static, although some manufacturers are now making this type of unit in-house rather than importing.

Exports are expected to soar in the next few years, with China having become the 'world factory' for air conditioning products. There is also a trend that the Chinese manufacturers are investing more on building up a strong brand in order to yield better margins than they would obtain by selling to OEMs.

Market overview - central plant air conditioning

The Chinese market for central plant air conditioning in 2005 was estimated at USD 1400 million, representing an increase of 8.2 % from 2004. The active construction sector, hot summers and generally strong economy are all factors favouring continuous growth. Chillers accounted for around USD 1000 million of this, representing growth of 12 % in the same period. The trend of reciprocating chillers being substituted by other types, mainly screw chillers, is becoming more and more obvious.

Modular chillers, mainly made up of small scroll chillers, have become more and more popular due to their low cost and flexibility, and account for much of the growth in chiller sales generally. The market for centrifugal chillers increased 12 % by volume from 2004 to 2005, helped by some large projects relating to the forthcoming Olympic Games in Beijing.

The central plant market is expanding as a whole, and Chinese manufacturers gained share in newly developed markets, both in geographical and product terms. There was significant growth in exports of central plant units in 2005, due to international companies regarding their Chinese factories as a production base for export, and some Chinese manufacturers exporting very aggressively.

Drivers

The Chinese economy has been growing strongly with around 8-9 % GDP increase each year. The construction industry has been booming in both the residential and commercial sectors.

Some new National Energy Efficiency Standards were introduced in March 2005 by the Standardization Administration of China, forcing Chinese manufacturers to make more energy-efficient units. Companies able to exceed the new requirements have been using this as a new selling point.

The Chinese government has a clear strategy to develop the western and inland areas of China, and there are plans for 60 % of the Chinese population to live in towns and cities by 2020. Thus there will be a big demand coming from the west and these new urban areas, which could overlap.

The Beijing Olympic Games are expected to be a boost to the central plant market. However, Beijing represents less than 10 % of the population of China, so the boost effect will not be as obvious as in Greece before the last Olympics. There is expected to be some decline in sales later, particularly in screw and centrifugal chillers, but (for the same reason) it will not be so obvious.

Brands

Many brands have disappeared from the residential market, falling from over 300 manufacturers in 2002 to just 45 in 2005. Only half of these brands have national sales coverage. This phenomenon is attributable not only to fierce price competition, but also to crippling increases in raw material costs.

Market share in the room and packaged sector has become more and more concentrated towards top brands such as Midea, Gree and Haier, whose combined market share increased to 40 % in 2005. These manufacturers are also expanding their production capacities and anticipate further sales growth. In total, local Chinese manufacturers dominate the domestic market with around 70-75 % market share. International brands are more likely to provide products for niche markets.

Since entering the central plant market some 10-15 years ago, established international companies such as Carrier, York (Johnson Controls), Trane and McQuay (Daikin) have dominated with their advanced technology. However, many Chinese manufacturers have made rapid progress in this market, following their success with residential products. Companies such as Haier, Midea and Gree are aiming to be world-class air conditioning manufacturers in the same league as their foreign rivals.

BSRIA`s fully updated Chinese Market for Air Conditioning study was published in July 2006, with separate reports available for Windows and Moveables, Mini-splits, Large Packaged and Close Control, Chillers, Air Handling Units and Fan Coils. For further information, please contact Simon Hurst at BSRIA.
Source: http://www.bsria.co.uk/

Danfoss A/S: Half-year report 2006

"Danfoss set a record in both net sales and profit in the first half-year of 2006 so, naturally, we are pleased with the results. We have chosen to increase our expectations for the net sales and profit, even though we do not expect to have the same growth rates for the second half-year. We note that our long-term targets are nearer fulfilment because of the reasonable growth in net sales and profit, and at the same time we successfully acquired a number of companies in the first half-year. We are glad that these acquisitions are in place, because the expansion and strengthening of our activities through acquisitions are important elements of our long-term strategy."

Jørgen M. Clausen, President and CEO, Danfoss A/S

Source : http://www.danfoss.com/

Japanese EcoCute demand surges

Latest results for shipments of water heater heat pumps based on Shecco technology, EcoCute, show an 80 % increase compared to last year.

Shecco has supplied the technology which has enabled this success story: changing from simple electric water heating to sophisticated hot water supply centres in Japanese homes. The reasons? The Shecco-based EcoCute Heat pumps can save up to 30 % of the electricity bill to the consumer, and 50 % of CO_2 emissions to the atmosphere.
By 2010, it is expected that over 5 million units will be installed. Shipments of EcoCute during the second quarter of 2006 show an increase of 80 % compared to the same period last year. Given this growth, by 2010 EcoCute Heat Pumps could represent a 35 % of the total water heater market in Japan.
This huge potential becoming a reality explains why leading manufacturers, such as Denso, Daikin and Sanyo, among others, are deeming it a priority. They all plan to launch newer, even more efficient models to satisfy the growing demand.

The Tokyo Electric Power Company and DENSO Corporation introduced EcoCute, based on Shecco Technology, to the Japanese market in 2001.
Last year, nearly 200 000 units were sold, and it is estimated that between 300 000 and 400 000 units will be installed in Japanese homes in 2006.
Water heating is responsible for 30 % of total household emissions of CO_2 to the atmosphere in Japan. Using EcoCute can reduce emissions from this segment to a half, helping the country to comply with its Kyoto protocol targets.

Source: http://www.shecco.com/

Demand for scroll compressors increases

Since the 13 SEER Regulation came into force this year, sales of scroll compressors have increased dramatically. One manufacturer has even shifted stocks from Asia to the US. The main reason for this increase is that there are highly efficient scroll compressors for R410A. The market growth rate for R410A has been estimated at more than double that of 2005, due to the 13 SEER. (An article on 13 SEER is available in HPC Newsletter, issue #2, 2006).

Source: JARN, vol. 38, #8, 2006

IEA Heat Pump Programme

GENERAL

Successful NT meeting in Gothenburg September 7-8th

22 NT members and researchers met in Gothenburg on September 7-8th to discuss new working areas for the IEA HPP, and to exchange information and discuss research topics. Presentations of ongoing research and future directions from the eight different countries were given on the first day, with the second day being reserved for brainstorming activities and discussions. Many ideas came up, of which three were selected for further work and refinement before presenting them to the executive committee at the November meeting as proposals for new annexes. A number of ideas will also be developed further.

Discussions during the brainstorming session

New on the web site

Final report from Annex 28 now available

The final report from Annex 28, 'Test procedure and seasonal performance calculation for residential heat pumps with combined space and domestic hot water heating', is now available via the web site.
Read more about the report in the Books and Software section.

Introductory page in a number of languages

As a service to non-English speaking people, the introductory home page is now available in the following languages: Chinese, German, Spanish, French, Italian, Japanese and Portuguese. We hope this will raise awareness not only of the heat pump centre, but also of heat pumping technologies to more persons worldwide.

Ongoing Annexes

Bold text indicates Operating Agent.

Annex 29 Ground-Source Heat Pumps - Overcoming Market and Technical Barriers	29	AT, CA, JP, NO, SE, US
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IEA Heat Pump Programme participating countries: Austria (AT), Canada (CA), France (FR), Germany (DE), Japan (JP), The Netherlands (NL), Norway (NO), Sweden (SE), Switzerland (CH), United Kingdom (UK), United States (US). All countries are members of the IEA Heat Pump Centre (HPC). Sweden is Operating Agent of the HPC.

Technology and Market Development of CO_2 Heat Pump Water Heaters (ECO CUTE) in Japan

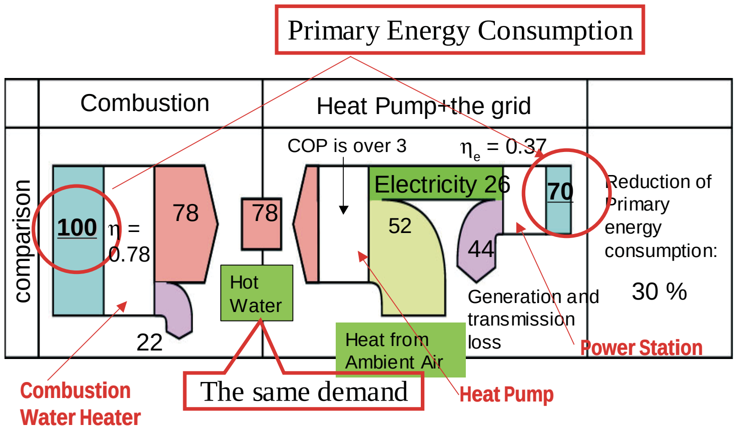
Katsumi Hashimoto , Japan

*In Japan, numerous heat pump water heaters for the residential sector have been developed in recent years, and are growing rapidly in popularity. Of these water heaters, the ECO CUTE*1 variety using CO_2 as a refrigerant is attracting attention for its ability to save energy and reduce greenhouse gas emissions. ECO CUTE technology was developed commercially in collaboration between TEPCO, Denso and CRIEPI in 2001. Several other manufacturers have also joined the market, and a government support program has been introduced with a target to increase total ECO CUTE installation to 5.2 million by 2010.*

Introduction

In Japan, energy demand for hot tap water accounts for about 30 % of the total residential final energy consumption, but most of this demand (over 90 %) is met by the direct combustion of fossil fuel. The development of high-performance heat pump water heaters using natural working fluids is thus eagerly anticipated for energy conservation and greenhouse gas reduction. If the COP of a heat pump water heater is 3 or more, the heater uses about 30 % less primary energy than a combustion water heater (Fig. 1).

Figure 1: Comparison of primary energy consumption between heat pump water heater and combustion water heater.



The Central Research Institute of Electric Power Industry (CRIEPI) has been studying heat pumps using CO_2 as a refrigerant since 1995, and has found by theoretical analysis that the CO_2 cycle has unique characteristics and can achieve a higher COP than conventional refrigerants for domestic hot water production, and by experiments that the CO_2 cycle can be effectively controlled by the combination of an automatic expansion valve and a variable-speed compressor [1].

Joint development of a CO_2 heat pump water heater

Using CO_2 heat pump technologies developed independently by CRIEPI and Denso (Denso possessing compressor technologies for car air-conditioning systems), a CO_2 heat pump water heater for residential use was jointly developed by the Tokyo Electric Power Company (TEPCO), Denso Corporation and CRIEPI, starting in 1998. In this collaboration, TEPCO mainly provided the concept for the product, while the main Denso contributions were the research and development of components and methods of improving heater performance. CRIEPI concentrated on evaluation of the prototype and finding ways to improve performance.

Modification of the prototype and improving its performance

Components such as the compressor and heat exchanger were developed and modified, and a prototype built using these components was installed in the test chamber and tested (Fig. 2). As a result, COP improved from 2.1 (first prototype) to 3.4 (final prototype) under winter conditions (heat source air temperature: 8 ^oC, tap water temperature: 8 ^oC and hot tap water temperature: 65 ^oC). Fig. 3 shows test results for both prototypes in a T-s (temperature - specific entropy) diagram. The T-s gradient of the compression stage was higher for the final prototype than for the first prototype (Fig. 3 (1)) and the compression efficiency increased (Figure 4 shows a cutaway model of compressor). The ^oC temperature at the outlet of the CO_2 - water heat exchanger was lower than that of the first prototype (Fig. 3(2)). A CO_2 - water heat exchanger with a small temperature difference, a capillary tube (inner diameter 0.5 mm) heat exchanger, was developed for the final prototype (Figure 5 shows the capillary tube heat exchanger) [2].

**1:"ECO CUTE" is a name used by electric power companies and water heater manufacturers, and refers only to heat pump water heaters using CO2 as a refrigerant.*

Evaluation of the annual average COP of the final prototype

The annual average COP was evaluated using performance test results for the final prototype (Table 1). The evaluated system COP, which includes the power input to the air fan and water pump, was 3.4. This value was better than the targeted value of 3.0. In addition, it was confirmed that the final prototype could produce hot water at 90 °C at an ambient air temperature of -15 °C [2].

Putting ECO CUTE on the market

From May 2001, Corona, Sekisui Chemical, Mitsubishi Electric, Shihen Technical, Kyuhen and other companies started selling ECO CUTE water heaters (Fig. 6), with Denso as the original equipment manufacturer. This was the world's first CO_2 heat pump water heater on the market.

ECO CUTE can reduce primary energy consumption by about 30 % and CO_2 emissions by about 50 % in comparison with combustion water heaters (Fig. 7). These features were recognized and ECO CUTE technology was awarded various prizes, including the Energy Conservation Grand Prize awarded by the Minister of Economy, Trade and Industry (Jan. 2002), and the US EPA Climate Protection Award (Mar. 2002). In addition, ECO CUTE water heaters usually operate during the night and the hot water produced is stored in a hot water storage tank. The system can use cheap night rate electricity, saving on running costs drastically (Fig 7). Note, however, that the actual running cost of the water heater may vary, depending on the amount of hot water consumed, family composition and season of the year.

Figure 2: Photograph of the test chamber and the prototype.

Test Chamber

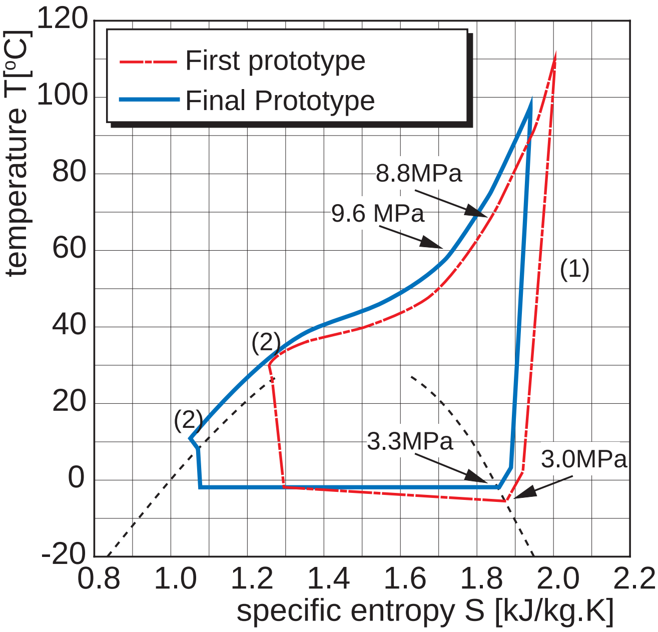
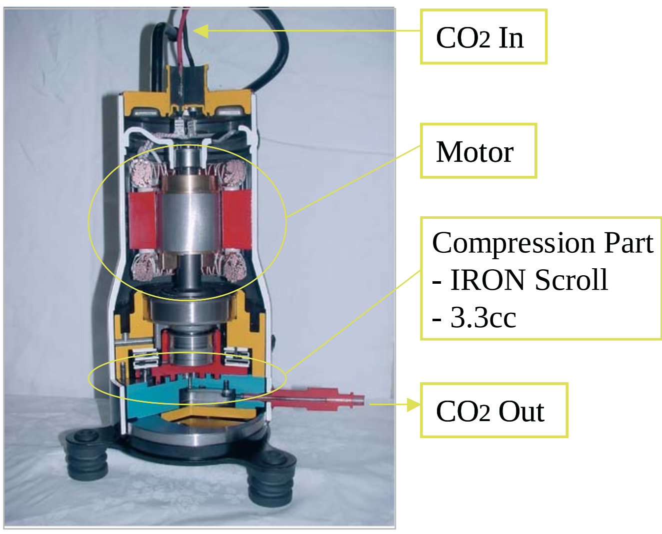


Figure 3: Performance improvement of the final prototype in comparison with the first one

Figure 4: Photograph of compressor.



Market development and new development

Market development of heat pump water heaters

Fig 8 shows the trend in shipments of ECO CUTE water heaters, indicating that the market for ECO CUTE has been growing rapidly. In fiscal year

2005 alone, about 225 000 units were shipped [4]. Although this is far less than total water heater shipments (4.2 million per year), it is an excellent result.

There are many reasons for the rapid uptake of ECO CUTE water heaters, such as:

- Good concept and good performance
- Many manufacturers and suppliers in the market (Fig. 9 [3]). There are six manufacturers: Denso, Daikin, Sanyo, Matsushita Electric Industrial, Hitachi Appliances and Mitsubishi Electric. These may increase in future.
- Government subsidy program
- Electric power companies have been promoting all-electric homes (IH cooking heater for cooking and ECO CUTE for hot water supply)
- The government has set a specific target for installation (5.2 million units by 2010).

Technical progress of heat pump water heaters

Manufacturers have been competing to be the market leader of ECO CUTE water heaters, and therefore have made the following improvements independently.

- Size reduction
  The unit footprint has been reduced in order to install ECO CUTE water heaters in confined spaces, such as housing complexes in urban areas.
- For cold regions
  In order to encourage installation of ECO CUTE water heaters in cold climate regions of Japan (Hokkaido, Tohoku and Hokuriku areas), a certain heating capacity and efficiency must be available at a very low ambient temperature, and steps taken to prevent freezing in pipes etc. Some manufacturers are already marketing ECO CUTE water heaters for cold regions, and others are developing such heaters.
- Multiple functions
  New features (floor heating and bathroom heating) have been added.
- Silent operation
  Because ECO CUTE water heaters run during the night, quietness is very important. The noise level has now been reduced to 37 dB from 45 dB in 2001.
- High efficiency
  Efficiency is a very important factor in the success of ECO CUTE technology. The highest COP is now 4.9 (latest model in 2006), an increase from 3.5 (first model in 2001) under intermediate conditions. Each manufacturer is developing technology independently, using compressors and heat exchangers with different designs. Measures used to improve efficiency are different too. For example, Denso's ECO CUTE water heater is equipped with an ejector to recover the expansion energy.
- Optimum operation control
  When stored hot water is not used up, cooled remaining hot water (not so hot, about 40 °C) must be reheated to over 65 °C. This is a loss. Moreover, the COP is reduced when inlet water temperature rises higher than the usual water temperature. This is also a loss. An optimum operating control method (studying daily demand and controlling the optimum hot water amount) needs to be developed as soon as possible.

Figure 5: Photograph of capillary tube heat exchanger.

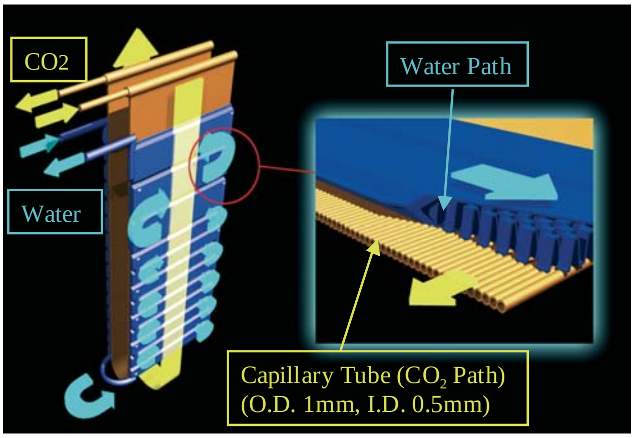
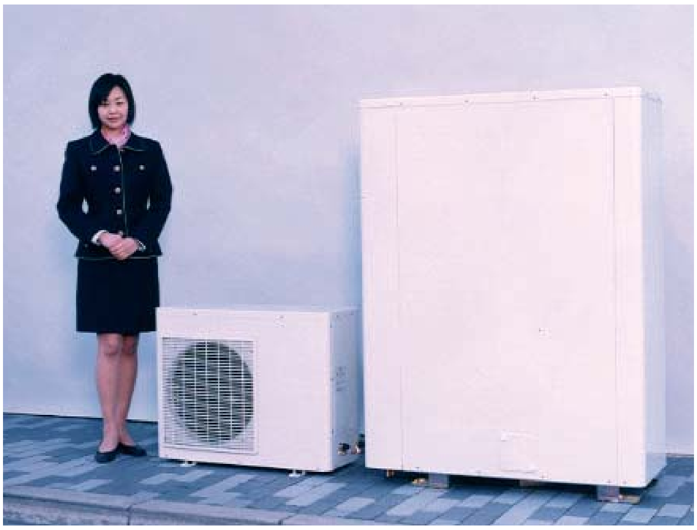
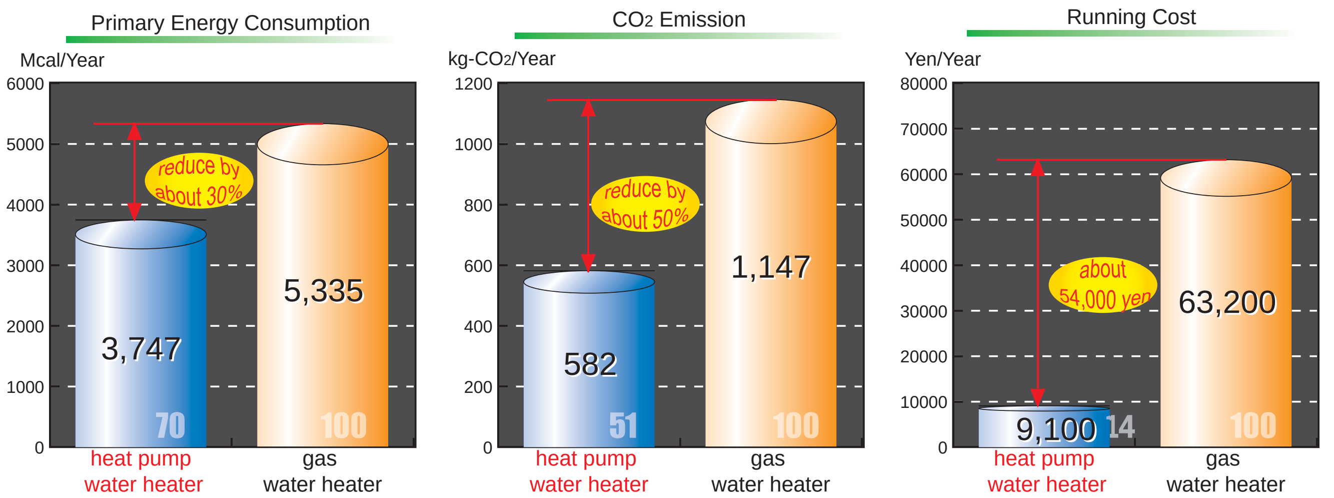


Figure 6: Photograph of the first CO_2 heat pump water heater for residential use.



Left: Heat Pump Unit (81 x 32 x 65cm), Heating Capacity: 4.5 kW
Right: Hot Water Tank(109 x 45 x 152cm), Capacity: 300 liters

Figure 7: Energy conservation, greenhouse gas reduction and cost saving performance.



Primary Energy Consumption:

1. The equivalent hot water amount at the temperature of 43 °C on the L mode of IBEC*1 is used for the standard water heater load.
2. The ambient air temperature and the tap water temperature are based on JRA4050:2005*2.
3. The primary energy intensity for electricity is 2.3 Mcal/kWh(night), one for city gas is 11 Mcal/m³.
4. COP is assumed to be 3. Defrosting and boiling out loss are included.

CO2 Emission:

1. The equivalent hot water amount at the temperature of 43 °C on the L mode of IBEC*1 is used for the standard water heater load.
2. The ambient air temperature and the tap water temperature are based on JRA4050:2005*2.
3. The CO_2 emission intensity for electricity is 0.357 kg-CO2/kWh, one for city gas is 2.364 kg-CO2/m³.
4. COP is assumed to be 3. Defrosting and boiling out loss are included.

Running Cost:

1. The equivalent hot water amount at the temperature of 43 °C on the L mode of IBEC*1 is used for the standard water heater load.
2. The ambient air temperature and the tap water temperature are based on JRA4050:2005*2.
3. COP is assumed to be 3. Defrosting and boiling out loss are included.
4. The electricity rate: TEPCO's "Season and Time-Specific Lighting (Denka-Jozyu)" (the discount for fully-electrified homes and the discount for energization-controlled nighttime thermal storage type appliances are applied. In this case, an amount due to the fuel cost adjustment is not applied) [3]. The electricity cost required for heat retension of bathtub water is not included.
   The gas rate: Tokyo gas's cost table B (In this case, an amount due to the fuel cost adjustment is not applied.)

*1: Institute for Building Environment and Energy Conservation
*2: the standard of The Japan Refrigeration and Air conditioning Industry Association

New moves surrounding ECO CUTE

The government has a strong interest in ECO CUTE because of its potential to save energy and reduce greenhouse gas emissions. The government announced a target of 5.2 million units to be installed by 2010, and has been providing subsidies to purchasers of ECO CUTE heaters since fiscal year 2002.

A number of technical development projects have also been launched since 2005 on the initiative of NEDO. Development items in the projects include downsizing and improving performance in cold regions. Denso, Daikin, Sanyo and Matsushita have been working to reduce the size of the units. Hitachi, Mitsubishi Electric and Corona meanwhile have been working to improve COP in cold climate regions. The results of these projects will be published by NEDO.

Figure 8: Shipment of ECO CUTE.

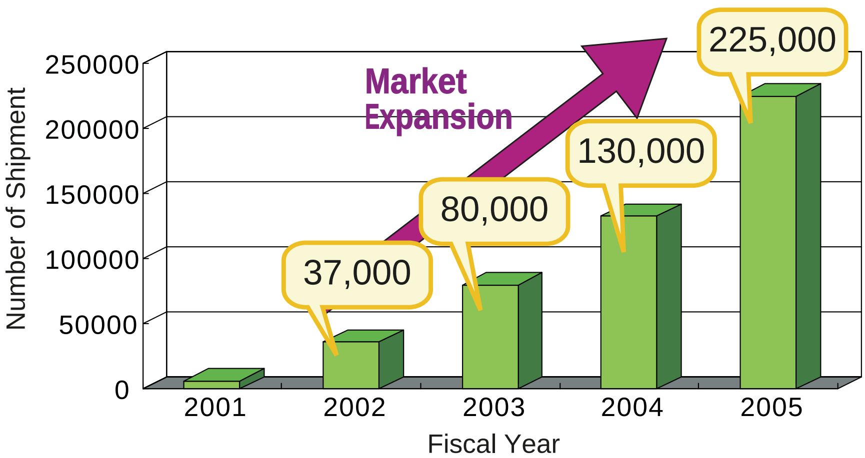


Figure 9: Photographs of various ECO CUTEs.

Conclusions

There are high expectations of technological developments by the NEDO projects and manufacturers. Once these technologies are incorporated in new ECO CUTE models, shipments are expected to grow. Further widespread use of ECO CUTE water heaters may reveal new problems. It is hoped that all the interested parties will cooperate to address any such problems and facilitate further uptake of the technology.

Finally, CRIEPI will cooperate with electric power companies on these issues and offer positive support. We also intend to conduct our own basic research on heat transfer phenomena in the evaporating and gas cooling processes, and methods for evaluating CO2 heat pump water heater technology.

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	Winter (Dec.-Mar.)	Intermediary (Others)	Summer (Jun.-Sep.)	Yearly
Ambient air temperature (°C)*1	4.6	13.8	22.5	-
Tap water temperature (°C)	8.3	15.9	23.2	-
Hot tap water temperature (°C)*2	65	65	65	-
Estimated system COP (-)*3	3.1	3.5	3.9	-
Hot tap water demand (MJ)	7369	5828	4291	17488
Energy consumption (MJ)	2378	1679	1115	5172
Estimated yearly average COP				3.4

*1 Temperatures are the average for each season.
*2 Heating capacity / power input to inverter of compressor motor
*3 Heating capacity / power input to heat pump unit (including input to air fan and water pump)

Table 1: Estimation of yearly average COP of the final prototype for a family living in Tokyo

Development of automatic drink vending machines with CO_2 refrigerant

Toshiaki Tsuchiya, Kouji Takiguchi, Japan

The authors have developed a technology for applying carbon dioxide as refrigerant to refrigerating system (unit) of vending machines of cold(and hot) drinks in order to reduce greenhouse gas emissions and power consumption. In the refrigeration system carbon dioxide becomes supercritical at high ambient temperatures, resulting in lower operation efficiency. The authors therefore optimized the refrigerating cycle by employing two stage compressor, and developed a new fin-shaped evaporator, thus increasing operation efficiency and reducing power consumption by 9%. Moreover, the authors have confirmed that simultaneous heating and cooling of cans and bottles with heat pump mode can significantly reduce power consumption.

Introduction

Automatic drink vending machines for cans and bottles are placed on the streets and in offices, thus offering widely acknowledged convenience specifically in Japan. Conversely, public welfare concerns make it necessary to use ecofriendly vending machines for cans and bottles in order to reduce greenhouse gas emissions.

The mainstream refrigerant currently used in the refrigerating system(unit) of vending machines for cans and bottles is hydrofluorocarbons (HFC). For reducing the use of greenhouse gas, there is growing demand for the use of natural refrigerants that have low global warming factors.
The authors have therefore developed non-Freon vending machine based on a refrigerator using carbon dioxide as refrigerant.
Moreover, to combat with global warming, efforts to save energy are becoming increasingly important. As a new energy-saving technology, the authors have developed a technology for applying a heat pump that conducts cooling and heating simultaneously in the vending machines for cans and bottles

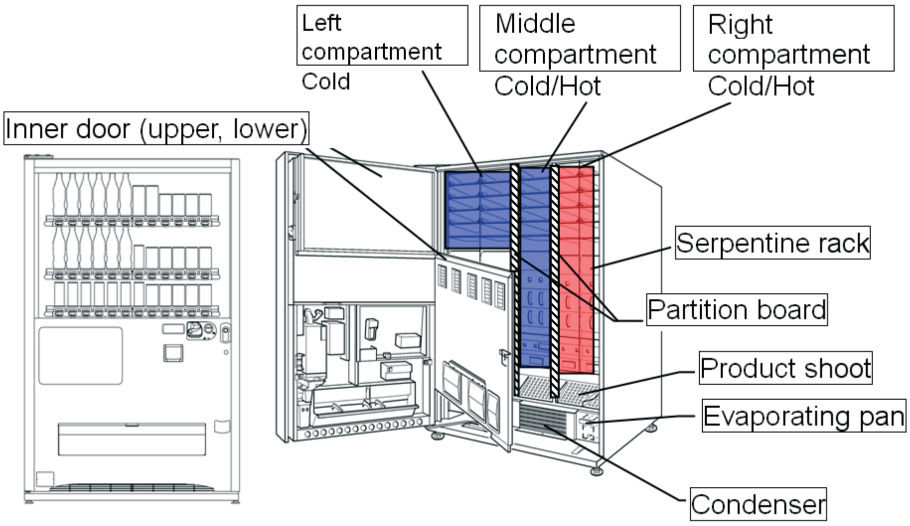

Fig.1 Structure of Vending machine

Structure of vending machine for cans and bottles

Fig. 1 shows the external view of a typical vending machine for cans and bottles. Cans and bottles to be contained in the machine are stored as cold or hot drinks depending on the season. Consequently, the vending machine is internally divided into several compartments by using partitions, with each compartment equipped with separate evaporator and heater. Moreover, stored products are cooled and heated by using an internal fan to circulate air. Inside the machine, all compartments are cooled in summer; one compartment is heated in spring and fall in winter. Other cooling/heating patterns also are employed depending on the season. Thus, each compartment can be switched to cooling or heating independently.

Freon-free vending machines for cans and bottles

Selecting a refrigerant

Hydrocarbon and carbon dioxide is an alternative refrigerant candidate for the vending machines for cans and bottles. The authors selected a refrigerant in view of the following considerations:

1) It must be safe even when it leaks out of the machine.
2) It must be safe and easy (inexpensive) to scrap.
3) It must cover cooling-capacity range for small and large machines.

Since hydrocarbon, an alternative refrigerant candidate is highly flammable, it may explode when it leaks or vending machine is scrapped. Moreover, scrapping is highly likely to be expensive due to the introduction of new equipment and additional work steps to ensure safety. Furthermore, since there are limits to the amount of refrigerant that can be sealed, it is unknown whether hydrocarbon is applicable to large units having large cooling loads. We have, therefore, selected carbon dioxide as the refrigerant, because it is very safe, easy to scrap, and offers large refrigerating capacity.

Refrigeration cycle refrigerators based on carbon dioxide
Fig. 2 shows the refrigeration cycle refrigerators based on carbon dioxide. The developed carbon dioxide refrigerating system employs an inverter driven two-stage compressor to reduce the compression ratio per step, thus increasing energy efficiency.

Moreover, the external heat exchanger has been designed as an integral configuration of an Inter Cooler for cooling the first-stage discharge refrigerant with a gas cooler for cooling the second-stage discharge refrigerant, thus saving space. Furthermore, an electronic expansion valve is employed as the expansion mechanism, thus increasing adaptability to changes in refrigeration load.

Challenges and solutions for carbon dioxide refrigerators
Since carbon dioxide has low critical temperature, high ambient temperatures cause the high-pressure side to become supercritical. Since the refrigerant is not liquefied in the

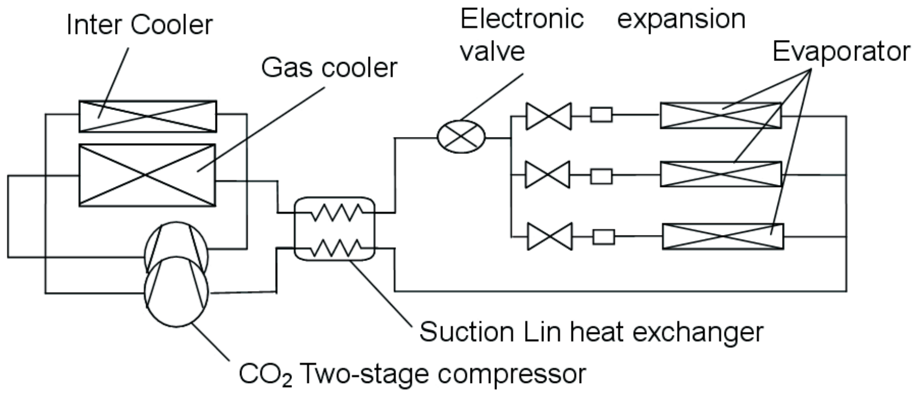

Fig. 2 Configuration of refrigeration system based on carbon dioxide

Gas cooler, the high pressure undergoes great changes depending on the operating conditions, thus causing unstable operation. Moreover, higher efficiency in the heat exchanger and higher operation efficiency are required to save energy. The main challenge to applying carbon dioxide, therefore, is to reduce the high-pressure changes at high ambient temperatures and increase operation efficiency in the heat exchanger.

the return piping and the hot refrigerant on the high-pressure side, thus cooling down the high-pressure refrigerant and increasing its density, thus inhibiting rise in pressure.[1]

High Efficient heat exchanger
As illustrated in Fig. 4,the evaporator used in the Vending machines for cans and bottles employs fin-and-tube heat exchanger consisting of refrigerant piping and fin that efficiently conveys heat in the piping to air.[2]

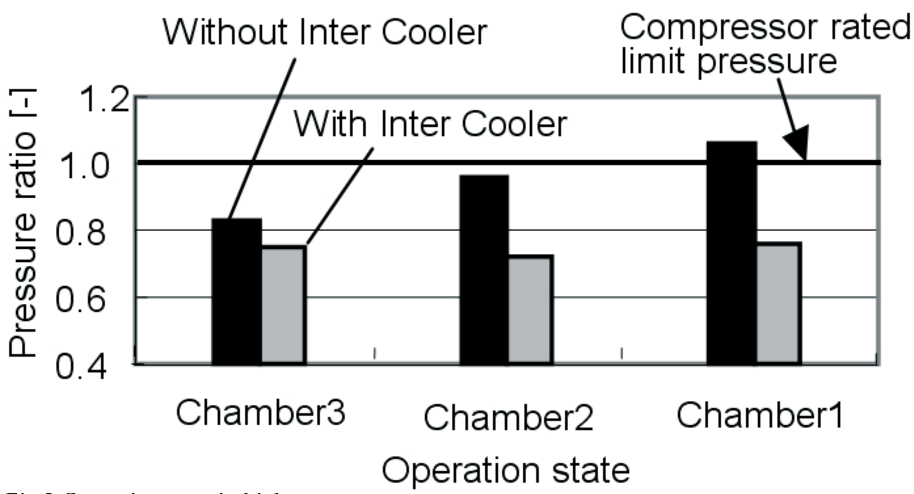

Fig.3 Operation state in high pressure

Preventing over pressure
As shown in Fig. 3, refrigerators based on carbon dioxide undergo great changes in high pressure depending on the operating conditions in a critical state. For instance, cooling only one compartment in particular will exceed the specification limits of the compressor. Thus, to prevent over pressure, the Suction pipe heat exchanger was utilized to exchange heat between the cold refrigerant in

As shown in Fig. 4a, the authors devised evaporator fin consisting of delta wing in front of the tube, and two kinds of vortex generators defined as a delta winglet pair. Fig. 4b shows the principles of the heat convection promotion based on the delta wing of the vortex generator.
The delta wing generates vertical vortexes on the fins, thus promoting the transport of heat between the fins. The delta winglet pair, on the

other hand, leads upstream streams of the piping to the dead water region generated in the rear portion of the piping. As a result, as shown in Fig. 5, the developed evaporator exchanges 40% more heat than the current models in the wind velocity region used for the vending machines for cans and bottles.
Moreover, the external heat exchanger has been made 3% more efficient by optimizing the capacity ratio of the gas cooler to the intermediate heat exchanger in a limited installation space.

Evaluation
This refrigerating unit was mounted in the Vending machine 30 selected kinds of cans and bottles at the beginning of 2004 and later for conducting a field test. The refrigerator was demonstrated to run stably under all environmental conditions, including the initial cooling of products and thermostatic running to maintain product temperature. The drink temperature was also kept at 4.0°C or less, thus demonstrating that the machines had sufficient cooling performance as vending machines for cans and bottles.

Moreover, upon measuring power consumption based on JIS standards, the refrigeration unit saved energy by 9% from conventional models based on R407C as refrigerant.

Based on these technologies, the company of the authors began mass-producing vending machines for can sand bottles based on carbon dioxide refrigerators in 2005.

Development of Vending machines with heat pump function (mode)

Energy-saving by heat pump
Of the annual power consumption of the standard machines "30 selection", with heating and cooling function, which are common models of vending machines for cans and bottles, the electric energy consumed for heating accounts for about 50% of the total. Therefore, to effectively save energy, it is imperative to reduce the power consumption of heaters.
Since refrigerant temperature at the compressor discharge becomes as hot as 90 to 100°C, this can be effectively used for heating cans and bottles. The authors therefore developed vending machines with carbon dioxide heat pump, as an energy-saving technology for the future, where heat pump is used to cool and heat drink cans and bottles simultaneously.

Principles of the heat pump and the refrigerant circuit
Fig. 6 shows how heat is generated and taken in a typical vending machine for cans and bottles when run with a heat pump. Conventional refrigerators discharge heat energy externally that has been suctioned inside the units. Conversely, in a heat pump operation, heat energy suc-

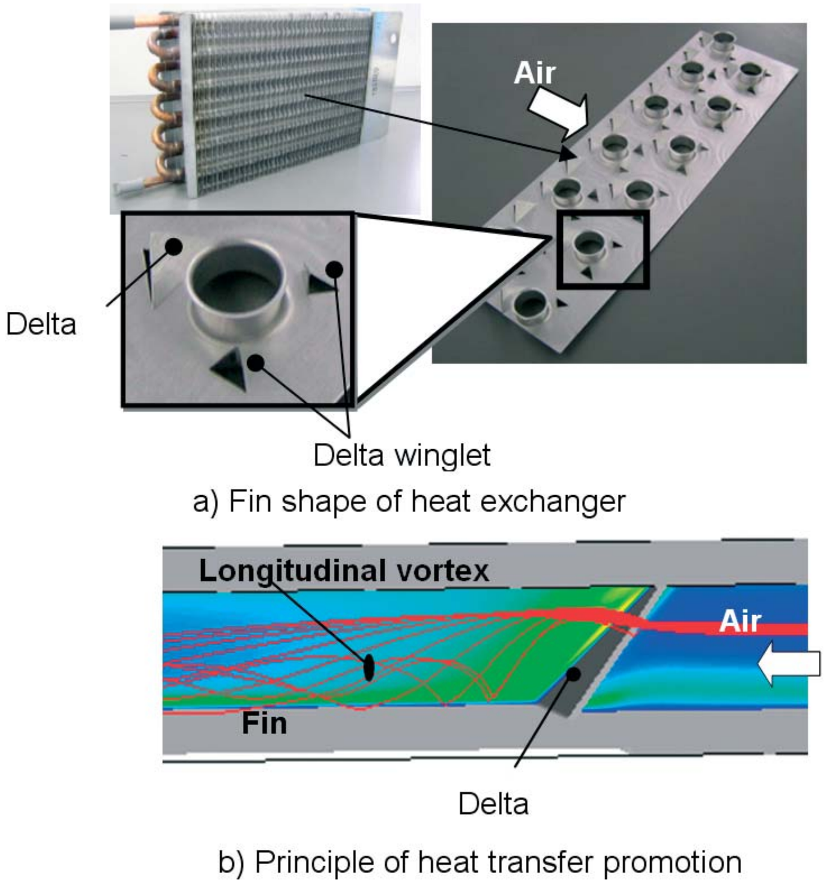

Fig.4 Structure and principle of Delta fin

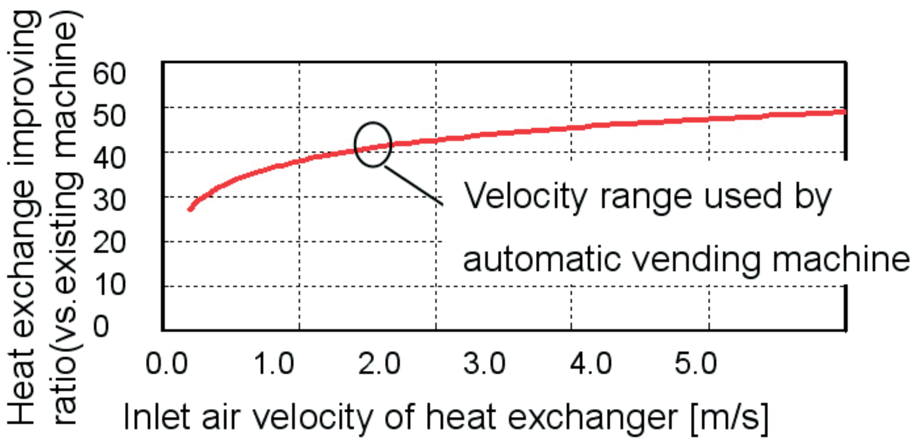

Fig.5 Evaluation result of evaporator performance

tioned into the refrigerator is transported (heat-pumped) into the heating unit for heating the products. In so doing, while switching between the refrigerant circuits by turning on and off the solenoid valve, a highly efficient run with low heat loss can be conducted in order to generate and transport heat within the same system.

Challenges and solutions for Vending machines with carbon dioxide heat pump

In the heat pump operation, heating requires temperatures higher than those specified for drink products, while cooling requires a supply of cold air. This entails control of the compressor's discharge temperature and evaporation temperature. To save energy, it is important to balance the cooling load with the heating load to minimize heat emissions. The authors consequently developed a technology for adjusting the compressor's operating speed, the aperture of the electronic expansion valve, and airflow of the fan used to control the compressor's discharge temperature and evaporation temperature to the specified respective temperatures. The authors then confirmed that by using heat pump system, reinforcing heat insulation, and increasing heat exchange efficiency, along with other measures, an energy savings of at least 35% was achieved.

Conclusions

In the application of carbon dioxide as refrigerant to vending machines, the authors succeeded in optimizing refrigerating system and employed new fin configuration of the heat exchange and reducing power consumption by 9%. The authors have also confirmed that, power consumption can be reduced by more than 35% by heating cans and bottles with heat pump operations and reinforcing heat insulation operations, along with other measures.

The Kyoto Protocol regarded fluorocarbons, now being used as refrigerants in many areas of refrigeration, as requiring reduced emission levels.

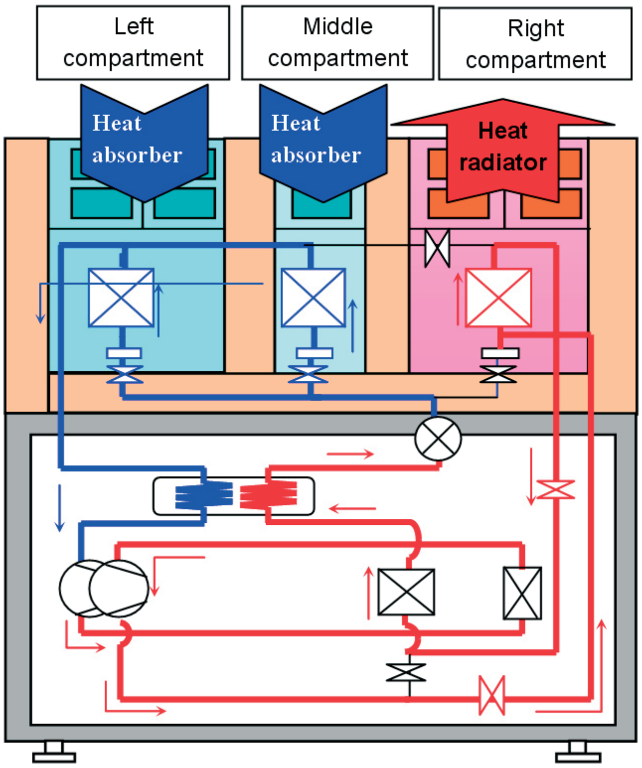

Fig.6 Architecture of heat pump automatic vending machine

Consequently, the emissions and consumption of HFCs are highly likely to be limited, while carbon dioxide and other natural refrigerants will presumably become more important.

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Performance test of a carbon dioxide heat pump for combined domestic hot water and floor heating

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Introduction

Japanese companies were the first to succeed in the commercialisation of a heat pump for domestic hot water heating, in which carbon dioxide is used as a refrigerant. As shown in Figure 1, sales of heat pumps have been steadily rising. In recent years, several types of multi-functional heat pumps that provide hot water, floor heating, or bathroom heating have been introduced on the Japanese market. However, no method for testing these multi-functional heat pumps has yet been established. It is difficult to decide a suitable test standard for these heat pumps in a reasonable and easy manner because of the diversities in their use by family members and household structures. In order to establish a new standard for measuring annual energy consumption of multi-functional heat pumps, they were subjected to several tests for combined domestic hot water and floor heating. This research was carried out as part of Annex 28 of the IEA Heat Pump Program.

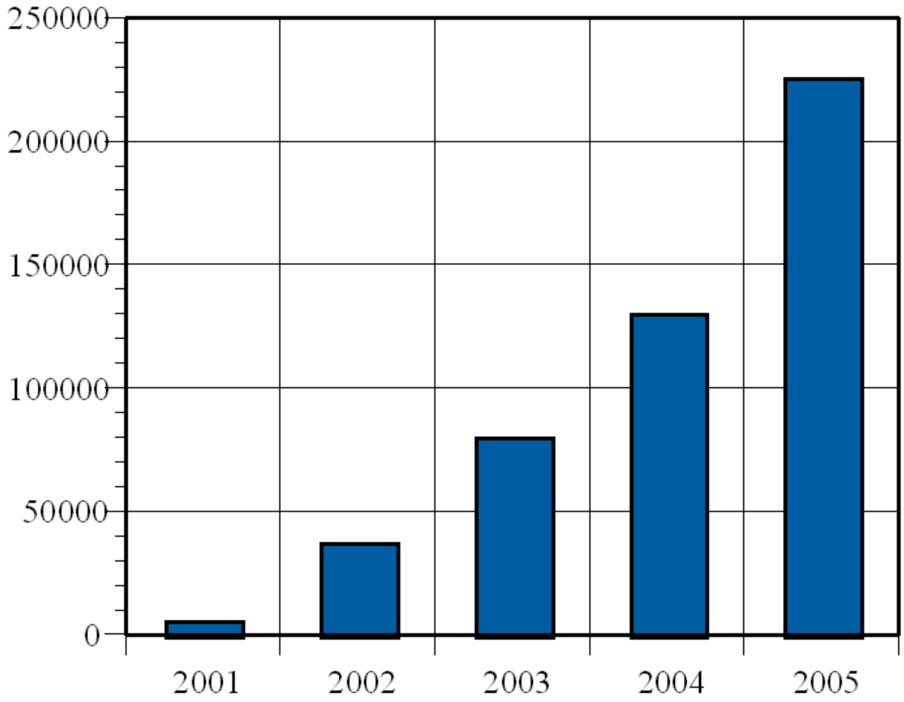

Fig.1 Shipment of CO_2 heat pump water heaters in Japan

Testing facility and the heat pump

The calorimetric chambers of the artificial environment laboratory at the R&D centre of the Tokyo Electric Power Company were used for the testing. The heat transferred by the heat pump being tested was measured by employing the air-enthalpy method, which measures the temperature and humidity of outdoor and indoor air and the air flow rates.

In order to measure the performance of the heat pump for combined domestic hot water and floor heating, the testing apparatus shown in Figure 2 was set up in the calorimetric chambers. The tap water was controlled at a prescribed temperature by the flow-control unit, and its pressure was maintained at 200 kPa. The outflow of hot water from the hot water tank was regulated by a solenoid valve using a sequence timer. Cold water was supplied to a plate-type heat exchanger to simulate the floor heating load, which was regulated by measuring the flow rate and temperature change of cold water.

The heat pump tested for combined space heating and domestic hot water heating was manufactured by Denso Corporation and was available on the market. Its specifications are shown in Table 1. The heat pump system consists of a heat pump unit and hot water storage unit. The heat pump runs during the night, and the hot water produced is stored in the tank.

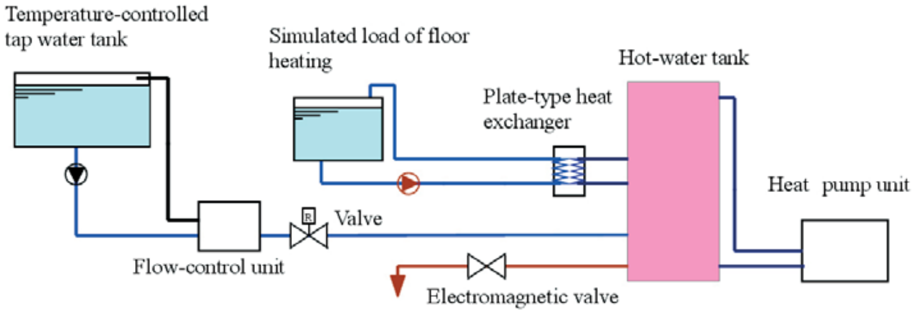

Fig.2 Schematic diagram of the testing apparatus

The heat pump seldom needs to run during the day since the cost of electricity is less during the night.

Testing method

The method employed for testing the heat pump unit excluding the hot-water storage unit is described in JRAIA Standard JRA4050:2005. The temperature conditions of outdoor air and cold water supply are summarized in Table 2. The compressor was operated at a constant speed during the test according to the test conditions, except during the defrosting test.

The typical draw-off profile for the house of a standard family is proposed by the Institute for Building Environment and Energy Conservation in Japan, and is shown in Table 3. Based on the meteorological data for Tokyo district, the number of days that witnessed an increased heating load during summer, winter, and the intermediate season were 92, 120, and 153, respectively.

No standard for the floor heating load for Japanese houses or apartments has yet been established. In this study, assuming a typical family house, the heat demand for floor heating in houses was calculated using a heat-load calculation program. The Architectural Institute of Japan considers a standard house for discussing thermal environmental problems. In Japanese houses, central air conditioning systems are not popular; instead, each room is individually air-conditioned. We assumed that the living and dining rooms are equipped with floor-heating panels, with an area of 20.49 m2. The remaining areas of the house are not air-conditioned by this heat pump system. The temperature of the floor surface is maintained at 30 °C by the hot water, which is equivalent to an indoor temperature of 20 °C. The patterns of the heating load during an average day, cold day, and warm day are assumed. Figure 3 shows the pattern for an average day.

Table 1 Specifications of the tested heat pump

Working fluid in the heat pump	Carbon dioxide
Tank capacity	460 l
Heating power	6.0 kW
Electric power input	1.4 kW
Hot-water temperature in the tank	Approximately between 65 °C and 90 °C (automatically controlled in response to hot water consumption)
Compressor	Variable-speed hermetic compressor
Size of the heat pump unit	640 mm(H), 820 mm(W), 300 mm(D)
Size of the hot-water storage unit	1890 mm(H), 720 mm(W), 800 mm(D)

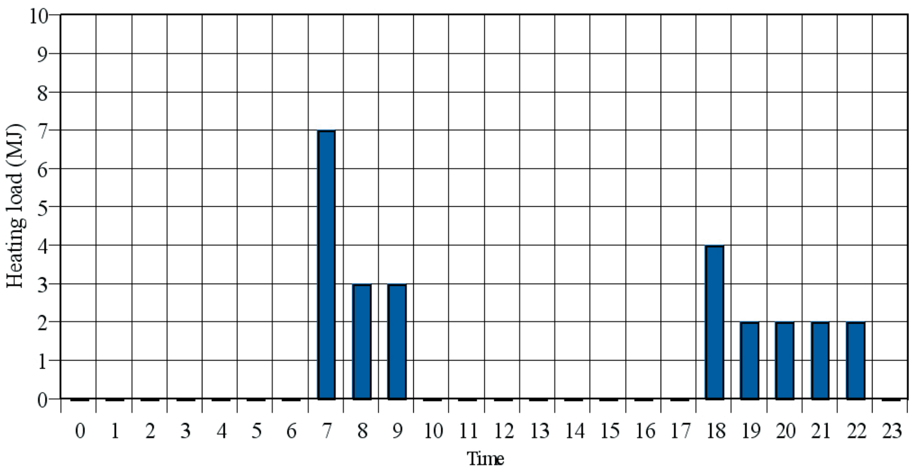

Fig.3 Floor heating demand pattern on an average day

Table 2 Temperature conditions

	Outdoor temperature		Temperature of the cold water supplied	Temperature of the outgoing hot water
	DB	WB		
	°C	°C	°C	°C
Rated heating condition	16	12	17	65
Heating condition during winter	7	6	9	90
Defrosting condition during winter	2	1	5	90
Heating condition during summer	25	21	24	65

Table 3 Draw-off profile

Time	Usage	Temperature of hot water	Temperature of tap water	Amount of hot-water supply
				L
600	Kitchen and lavatory	42°C	24°C in summer 17°C in intermediate seasons 9°C in winter	15.9
630				15.9
700				15.9
730				15.9
800				15.9
1200				15.9
1800				15.9
1830				15.9
1900				15.9
1930				15.9
2100	Bath			180
2130	Shower			40
2200	Additional use for bath	60°C		22

Table 4 Heat load and electrical energy input

Season	Mode	Type of day	Number of days	Heat produced	Electrical energy input to the HP	Heat load	Total electrical energy input
				MJ/day	kWh/day	MJ/day	kWh/day
Summer	WH	-	92	39.81	2.33	33.04	2.64
Intermediate seasons	WH	-	123	54.83	3.61	45.66	3.93
	WH & FH	Warm day	30	78.14	5.81	59.58	6.12
Winter	WH & FH	Average day	108	112.46	10.24	90.23	10.56
	WH & FH	Cold day	12	128.86	13.15	103.55	14.68

Test results

The results of the seasonal performance test of the combined hot water and floor heating operation are shown in Tables 4 and 5. The difference between the heat produced by the heat pump unit and the heat load is 18.9 % of the total heat produced. The reason why the heat loss from the hot water storage unit is large is that all the water in the tank is heated at 70 °C in the combined water heating (WH) and floor heating (FH) mode. The result on the overall seasonal efficiency of this combined mode is lower than that of the hot-water-heating-only mode. This efficiency can be improved by modifying the management of hot water in the tank.

Table 5 Seasonal performance of the combined hot water and floor heating mode

Heat produced by the HP, GJ/year	26.4
Electrical energy input to the HP, MWh/year	2.10
Heat load, GJ/year	21.4
Total electrical energy input, MWh/year	2.23
Seasonal efficiency of the HP unit	3.5
Seasonal efficiency of the overall system	2.7

Conclusion

A brand new heat pump for combined water and floor heating was tested to investigate the method for testing its seasonal performance. Depending on the system configuration, the heat pump operates in various ways. Further, a wide variety of floor heating panels are available. Therefore, the method for testing the efficiency of floor and water heating pumps should be specified by the parameters at the system boundary. The draw-off profile and patterns of the floor-heating demand for each season should be determined and the test operation should be performed in accordance with these profiles.

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Brine-to-water CO_2 heat pump systems for heating and cooling of non-residential buildings

Jørn Stene, Norway

Carbon dioxide (CO_2) has been identified as an interesting working fluid in brine-to-water heat pumps for heating and cooling of non-residential buildings. Connecting such a heat pump in series with a hydronic radiator and ventilation heater system provides a relatively low return temperature in the system, and thus favourable operating conditions for a CO_2 heat pump. Preheating and reheating of domestic hot water will lead to a further increase in the COP of the CO_2 heat pump system. Computer simulations have demonstrated that a CO_2 heat pump system in non-residential buildings can achieve the same or higher seasonal performance factor (SPF) than heat pumps using conventional working fluids, as long as the heat distribution system is designed for a low return temperature. The operational time of the ventilation system will have a major impact on the SPF of the CO_2 heat pump, since the return temperature in the heat distribution system is considerably lower when the ventilation system is in operation.

Introduction

In Norway, R407C, R134a and ammonia are the most commonly used working fluids in heat pumps for heating and cooling of office buildings, commercial buildings, hotels, schools, nursing homes and hospitals. Although the working fluid leakages from HFC heat pump plants are relatively small, it is regarded as a better long-term solution to utilize working fluids that do not have any negative impact on the global environment, such as the non-synthetic working fluids ammonia, hydrocarbons and carbon dioxide (CO_2). CO_2 is one of the few non-toxic and non-flammable working fluids that contributes neither to ozone depletion nor global warming, and therefore represents an interesting long-term alternative to the HFCs.

Concept Description

In addition to the heat source temperature and the isentropic efficiency of the compressor, it is mainly the mean temperature during heat rejection that determines the COP of a heat pump. Due to the low critical temperature of CO_2 (31.1ºC), a CO_2 heat pump will reject heat by cooling of single-phase CO_2-gas at supercritical pressure in a gas cooler. Since the CO_2 outlet temperature from the compressor is relatively high (>90ºC), a CO_2 heat pump can easily meet high-temperature heating demands. However, in order to achieve a high COP for the heat pump, it is essential that useful heat is rejected over a large temperature range, resulting in a high enthalpy difference for the CO_2 in the gas cooler and a relatively low CO_2 temperature before throttling.

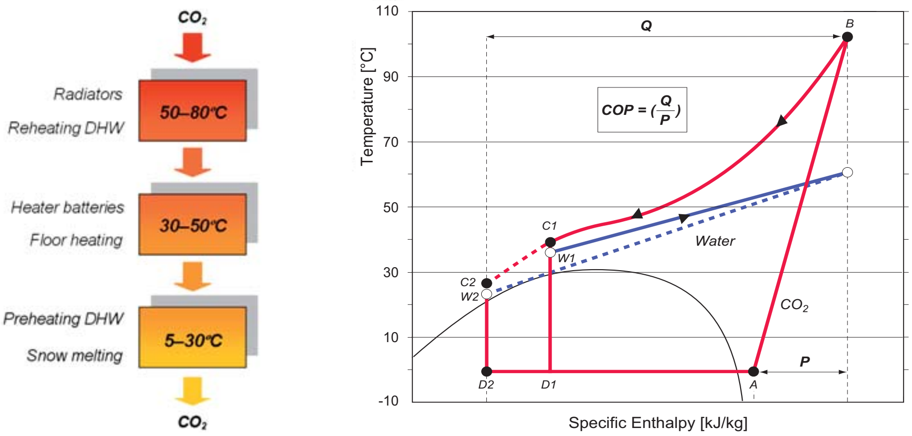

Figure 1. Illustration of how serial connection of heat loads with diminishing temperature requirements affects the CO2 outlet temperature from the gas cooler.

In European non-residential buildings, high-temperature radiators are commonly used to cover the space heating demand, which means that CO_2 heat pumps rejecting heat only to radiators will have a relatively low COP due to the high return temperature. However, in many non-residential buildings, the demand for heating of ventilation air after the heat recovery unit constitutes a relatively large share of the total heating demand. Consequently, by connecting the radiator system and the ventilation heater batteries in series, it is possible to obtain a relatively low return temperature. Preheating and reheating of domestic hot water will lead to a further increase in the system COP.

Figure 1 illustrates how a serial connection of heat loads with diminishing temperature requirement leads to a relatively low CO_2 outlet temperature from the gas cooler.

The return temperature in the heat distribution system is determined by the heating effect and the temperature requirement for the different heating demands. The ratio of the heating effects for space heating and heating of ventilation air depends on, for example, the insulation standard and airtightness of the building, air flow rates and type of ventilation system (CAV, VAV, hybrid), period of use of the ventilation system during the day/week and the design of the hydronic heat distribution system.

Figure 2 shows examples of measured heating effects (relative values) for space heating and heating of ventilation air for two Norwegian office buildings during a three-day period (Thursday to Sunday) in February (Mathisen, 2006).

Figure 3 shows a schematic diagram of a CO_2 heat pump unit supplying heat to a hydronic heat distri¬bution system, where the radiator circuits, heater batteries (ventilation), floor heating system, hot water system (preheating) and snow melting system are connected in series. By employing inverter-controlled circulation pumps operating at constant differential pressure, i.e. volume flow control of the primary circuit in the heat distribution system, a low return temperature can be achieved under all operational conditions (Tengesdal, 2003).

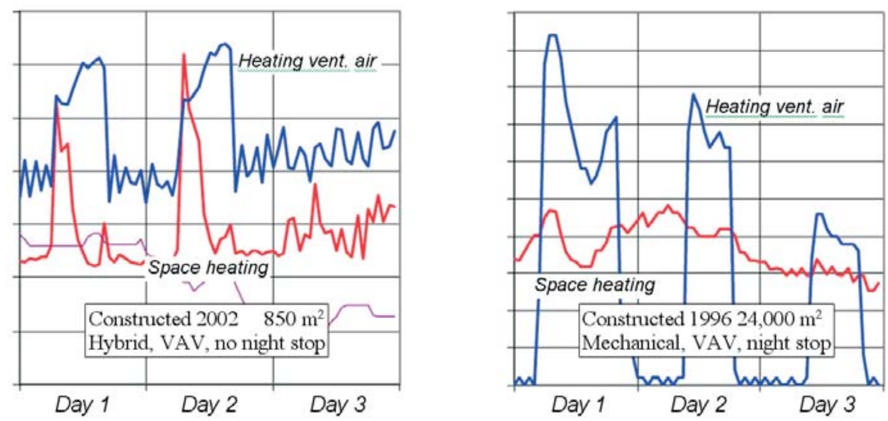

Figure 2. Measured heating effects (relative values) for space heating and heating of ventilation air for two Norwegian office buildings during a three-day period in February, Thurs¬day to Sunday (Mathisen, 2006)

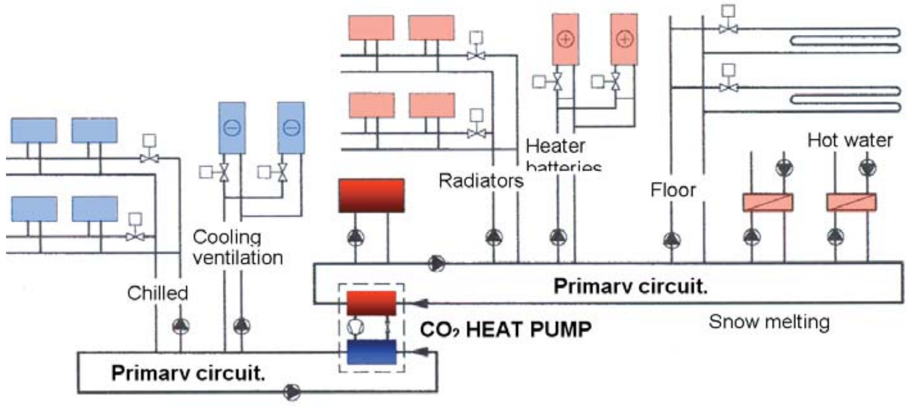

Figure 3. Schematic arrangement of a CO2 heat pump system with serial connection of radiators, heater batteries, floor heating system and hot water system (Tengesdal, 2003).

Calculation of SPF

In order to evaluate the potential for CO2 heat pumps for heating and cooling of non-residential buildings, the Seasonal Perform¬ance Factor (SPF) has been calculated for single-stage CO_2 and R134a air-to-water heat pumps for heating and cooling of a 7000 m2 office building located in Oslo (Andresen and Stene, 2004). The heat pump units supplied heating and cooling to hydronic distribution systems, where the radiator circuits and the circuits for the ventilation heater batteries were connected in series. The supply water temperature from the CO_2 heat pump unit was controlled to respond to an outdoor temperature compensation curve. Ambient air was used as the heat source in the heating mode and as the heat sink in the cooling mode. The design loads for space heating, heating of ventilation air and space cooling were 250, 300 and 400 kW respectively. The overall isentropic efficiency for the CO_2 compressor was assumed to be 5%-points higher than that of the R134a compressor. For both systems, the necessary peak load in heating mode was covered by an electric boiler (bivalent heating system). Figure 4 shows the calculated SPF in heating mode for the heat pumps at different design sup-

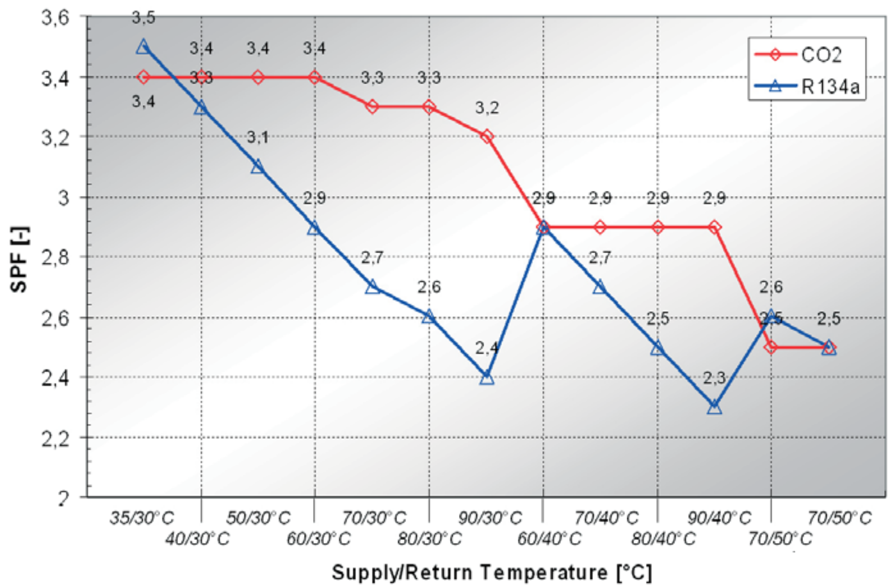

Figure 4. Calculated SPF in heating mode for the heat pump systems at different supply/ ¬return temp. (design conditions) for the heat distribution systems (Andresen, Stene, 2004)

ply and return temperatures for the heat distribution system.

The CO_2 heat pump system achieved the highest SPF under most operating conditions. The SPF for the CO_2 system was primarily governed by the return temperature in the heat distribution system, while the SPF for the R134a heat pump system was mainly governed by the supply temperature.

The simulation results clearly indicate that a single-stage CO_2 heat pump for heating and cooling of an office building may achieve the same or higher SPF than a single-stage R134a heat pump as long as the temperature level in the heat distri¬bution system is adapted to the characteristics of the CO_2 heat pump system. The CO_2 heat pump system will achieve an even higher SPF if the heating of ventilation air dominates the total heating demand of the building, if there is a considerable hot water demand or if the CO_2 heat pump is equipped with an expander, an ejector or a heat exchanger that cools the CO_2 after the gas cooler and transfers the heat to the heat source (water or brine).

Construction of brine-to-water CO2 heat pump systems

Due to the availability of components in the required capacity ranges, it is now possible to construct high-quality brine-to-water CO_2 heat pumps for heating and cooling of non-residential buildings.

- ***Compressor*** – Reciprocating CO_2 compressors for non-residential applications are available from several manufacturers including Dorin (Italy), Bock (Germany), Mycom (Japan) and Bitzer (Germany). The swept volume for the compressors ranges from 3 to 17 m3/h, which corres¬ponds to a heating capacity of approximately 15 to 60 kW at -10 to 0 ºC evaporation tempera¬ture, 10 K suction gas super¬heating, 85 % volu¬metric efficiency, 70 % overall isen¬tropic efficiency, 10 % heat loss from the compressor shell, 90 bar gas cooler (high-side) pressure and 30 ºC outlet CO_2 temperature from the gas cooler.
- ***Evaporator*** – SWEP (Sweden) has recently developed a brazed plate heat exchanger (PHE) with a maximum operating pressure of 64 bar, which corresponds to a CO_2 saturation tempe¬rature of about 25 ºC. The maximum capacity per unit is roughly 100 kW when assuming an LMTD of 5 K and a U-value of 2,500 W/(m2K).
- ***Gas cooler*** – SWEP has recently developed a brazed plate heat exchanger with a maxi¬mum operating pressure of 140 bar. The maximum capacity is about 75 kW at 70/30 ºC supply and return tempe¬ra¬ture in the space heating system, 75 % overall isentropic efficiency and 10 % heat loss for the compressor, 105 bar high-side pressure and 2 K temperature approach at the gas cooler outlet. A tube-in-tube gas cooler unit is also a viable option, but this heat exchanger type has lower heat transfer efficiency on the water side than a PHE.
- ***Other components*** – Expansion valves, low-pressure receivers and high-pressure control valves, safety valves, drying filers and tube fittings are commercially available.

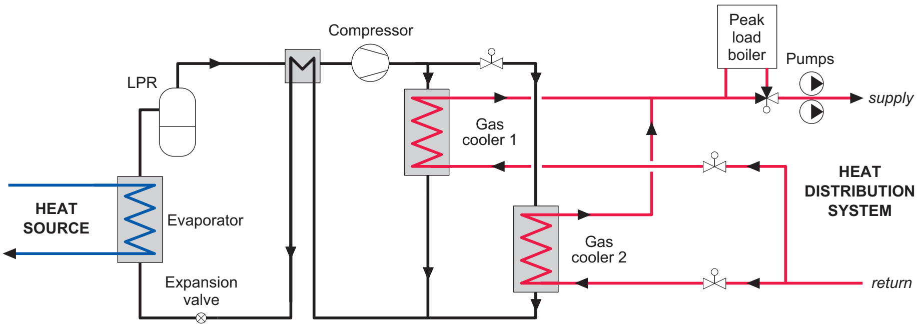

Figure 5. Schematic diagram of a single-stage brine-to-water CO2 heat pump system

Figure 5 shows a schematic diagram of a single-stage brine-to-water CO_2heat pump system, where the high-side pressure is controlled by means of a low-pressure receiver (LPR) and a back-pressure valve (Shecco Cycle). The heat pump unit is equipped with an inverter-controlled reciprocating compressor and two parallel gas cooler units for maximum performance at part load conditions, i.e. at reduced heating capacity and reduced water flow in the heat distribution system.

Conclusions

Computer simulations have demonstrated that CO_2 heat pumps for heating and cooling of non-residential buildings can achieve the same or higher seasonal performance factor (SPF) than heat pumps using conven¬tional working fluids, as long as the heat distribution system is designed for a low return temperature. The opera¬tional time of the ventilation system will have a major impact on the SPF of the CO_2 heat pump, since the return temperature in the heat distri¬bution system is considerably lower when the venti¬lation system is in use. As opposed to conventional working fluids, CO_2 has practically no tempera¬ture limitations in respect of heat rejection. Hence, in buildings with a dominating cooling demand, a CO_2 heat pump installed in a bivalent heating system will be able to cover the entire heating demand with high energy efficiency.

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Development of reversible residential air conditioners and heat pumps using CO_2 as working fluid

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Since 1997, SINTEF Energy Research and The Norwegian University of Science and Technology (NTNU) have been investigating and developing reversible residential air conditioners and heat pumps (RAC split-type units) using carbon dioxide (CO_2) as their working fluid. A third-generation prototype CO_2 RAC split-type unit has recently been constructed and extensively tested in heating and cooling modes. The test results have been used for calculating the seasonal heating and cooling performance (SPF) for two different climates; Greece (Athens) and Norway (Oslo). The results have been compared with manufacturer's data with verified rating points for the most energy-efficient Japanese R410A split-type unit available on the market.

In both the heating mode and the cooling mode, the calculated SPF for the CO_2 and R410A units in the Oslo climate were more or less identical. However, in the cooling mode in the Athens climate, the SPF of the CO_2 unit was about 17 % lower than that of the R410A unit. Further development and optimization of the CO_2 unit, e.g. by utilizing microchannel heat exchanger technology, increasing the isentropic efficiency of the compressor and/or using an ejector or expander for expansion work recovery, will be necessary before the CO_2 unit will be able to match or outperform the market-leading R410A unit in terms of energy efficiency. However, since the CO_2 unit already matches many of the better R410A units on the market, CO_2 must be regarded as a promising working fluid in reversible air-conditioning and heat pump units for residential use.

Introduction

The current world market for RAC split-type units is roughly 30 million units per year. Virtually all of them use HCFC-22, R407C or R410A, which are powerful greenhouse gases with relatively high global warming potentials. This is also the main reason why the European Union has introduced legislation regarding better containment of HFCs for all kinds of applications, as well as clear phase-out targets for mobile air conditioning systems.

Carbon dioxide (CO_2) is a non-toxic and non-flammable working fluid that does not contribute to ozone depletion (ODP = 0) and has negligible global warming (GWP = 1). Due to its favourable thermophysical properties, CO_2 is regarded an interesting alternative to the HCFCs and HFCs in many heat pumping applications, including RAC split-type units.

Testing of a prototype CO_2 RAC split-type unit

A prototype CO_2 RAC split-type unit and a state-of-the-art R410A unit have been tested in a two-chamber calorimetric test rig, described by Jakobsen et al. (2004, 2006). According to Eurovent (2005), the selected R410A reference unit had the highest cooling COP at the rating point of all the tested R410A reversible split-type units (Unit 1, Table 1). The measured COP was about 11 % higher than that of the second most energy-efficient unit.

The prototype CO_2 RAC split-type unit was equipped with an inverter-controlled two-stage rolling piston compressor, finned tube heat exchangers (HX), and a tube-in-tube internal heat exchanger. The compressor was connected to an intercooler to enable cooling of the CO_2 gas between the compression stages. In order to simplify the experiments, the heat exchanger was water cooled. However, in a real sys-

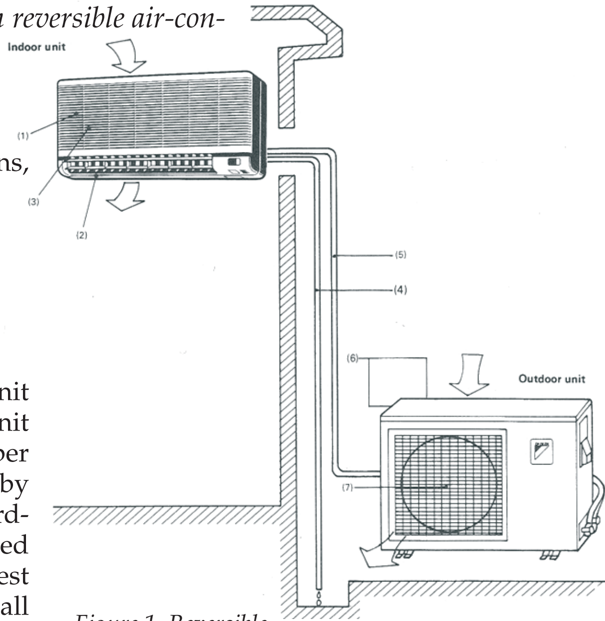

Figure 1. Reversible residential air conditioner and heat pump unit (RAC split-type unit)

Table 1. Relative rating point COPs for different R410A RAC split-type units (Eurovent, 2005)

Unit	***1***	2	3	4	5	6	7	8	9	10	11	12	13	14
COP [%]	***100***	89	83	73	69	62	64	79	77	83	92	78	75	71

tem, the heat exchanger would have been an integral part of the outdoor heat exchanger and would be cooled with ambient air. The CO_2 pressure in the gas cooler was controlled and optimised by means of a manual expansion valve and a low-pressure receiver (Shecco Cycle, http://www.shecco.com). Figure 2 shows a schematic diagram of the prototype CO_2 unit.

The maximum compressor power consumptions of the CO_2 unit and the R410A unit were about 2.0 kW and 1.7 kW respectively. Microchannel (MPE) heat exchangers for CO_2 in, for example, mobile air conditioning applications have shown excellent performance. However, round tube heat exchangers were selected for the CO_2 prototype unit due to the limited availability of MPE heat exchangers, and concern about water retention and frosting issues.

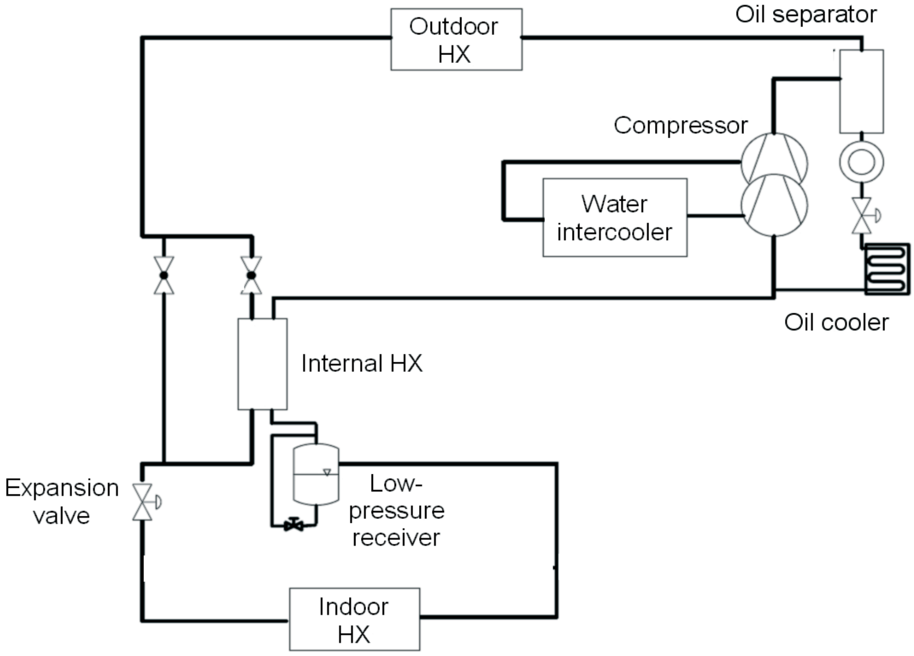

Figure 2. Schematic diagram of the prototype CO2 RAC split-type unit, AC operation

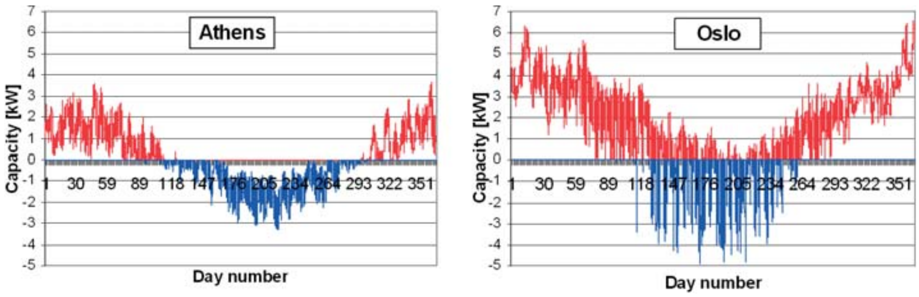

Figure 3. Predicted heating and cooling loads in the Norwegian and Greek dwellings

Calculation of Seasonal Heating and Cooling Performance

In order to estimate the heating and cooling demands in typical residential dwellings, simulation models representing conditions for a dwelling in Athens, Greece (hot, dry climate) and one in Oslo, Norway (cold, dry climate) were created using the integrated ESP-r (ESRU, 1999) building simulation tool. The models were based on a reference dwelling established through the IEA District Heating and Cooling project. The reference two-floor dwelling was located in a terrace block with four similar dwellings of 112 m2. Identical dimensions were assumed for the Greek and the Norwegian dwellings, and the mass of the structure was chosen to reflect thermo-physical qualities in accordance with building traditions in the two countries. The windows of the Greek dwelling were assumed to be equipped with external shading systems. Ventilation of the dwellings was assumed to be solely by exhaust fans placed in the laundry and the bathroom.

Simulations for a whole year were carried out for one hour time steps, using climate data for a reference year. Figure 3 shows the predicted heating and cooling loads during the year.

The set-point for the indoor air temperature was 25 ºC in cooling mode, and 21 ºC in heating mode. The indoor relative humidity was calculated using the same absolute humidity as in the ambient. Cooling in Athens and Oslo started at 23 °C and 18 °C respectively. The difference was mainly due to different practice in the application of solar shading systems and exposure of thermal mass, as a result of different building traditions in the two countries.

The measured COPs for the CO_2 unit, and the manufacturer's data with verified rating point for the R410A unit, together with the heating and cooling loads at different ambient temperatures, were used for calculating the seasonal performance factors (SPF) in the heating and cooling modes in the two different climates. Table 2 shows the results. The SPF in heating mode included the electric peak load (bivalent heating system), while the SPF for the CO_2 unit in cooling mode included intercooling between the compressor stages, which increased the SPF by 5 to 7 %.

Table 2. The calculated seasonal performance factors (SPF) for the RAC split-type units based on measured data in heating and cooling mode in two different climates

RAC unit	Heating Mode		Cooling Mode	
	Athens	Oslo	Athens	Oslo
CO2 prototype – measured data	4.3	2.7	4.4	6.7
R410A-unit – manufacturer data	4.0	2.6	5.3	6.7

The calculated SPF in heating mode for the CO_2 unit was about 7 % higher than that of the R410A unit in the Athens climate, and about 3 % higher in the Oslo climate. In cooling mode, the CO_2 unit achieved the same SPF as the R410A unit in the Oslo climate, but about 17 % lower SPF in the Athens climate. The results demonstrate that it is possible for a CO_2 RAC split-type unit to match the energy efficiency of the best R410A unit on the market in heating mode and in cooling mode in colder climates, but that further development is required in order to achieve the same energy efficiency in cooling mode in warmer climates.

Sakamoto (2001) indicated that the overall isentropic efficiency for hermetic R410A compressors for RAC split-type units is up to 0.65. The measured isentropic efficiency of the CO_2 compressor was about 0.54 (Jakobsen et al., 2006), with the relatively low efficiency probably being due to the fact that the compressor was from an early stage of development. Owing to the favourable charac¬teristics of the CO_2 compression process, a CO_2 compressor should be able to reach at least the same efficiency level (Fagerli, 1997). Postulating an isentropic efficiency of 0.65 for the CO_2 compressor, and using intercooling, the SPF for the CO_2 unit in cooling mode in the Athens climate would have equalled the SPF of the R410A unit.

Conclusions

Extensive testing of a prototype CO_2 RAC split-type unit has shown promising results when comparing the unit with the most energy-efficient R410A unit on the market. However, the CO_2 system is still at an early stage of the development process, and improvements are required to achieve the same energy efficiency as the best R410A units under certain operating conditions. The next development steps for the CO_2unit will be to optimize the heat exchangers, use a compressor with higher isentropic efficiency and possibly use an ejector or expander for expansion work recovery.

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Use of CO_2 in heat pump systems – practical experience with transcritical systems

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Abstract

The use of CO_2 as refrigerant in heat pump and refrigeration systems has increased over the past few years in Denmark, especially in the Danish commercial refrigeration market (e.g. in supermarkets). The Danish environmental authorities have implemented a plan for phasing out HFC refrigerants, and the plan has initiated a lot of activities within the field of alternative refrigerants. An essential part of the work has focused on the use of transcritical CO_2 in heat pump systems.

This presentation concentrates on four projects concerning the use of CO2 as refrigerant in small, medium-sized and large heat pump systems:

- CO_2 used in domestic hot water heat pumps
- CO_2 used in heat pumps for commercial applications
- CO_2 used in HVAC systems (air conditioning and heat pump systems)
- CO_2 used in large heat pump systems for district heating.

It also presents project results obtained through a combination of traditional R&D projects and field test measurements. Finally, the discussion considers the future of CO_2in refrigeration and heat pump systems

1. Introduction

Over the past few years, the use of CO_2 as a refrigerant in heat pumps has been the focus of attention for many development projects in Denmark. The reason is of course the many immediate advantages of CO_2 as refrigerant in this type of system, and also because the Danish environmental authorities have implemented a phase-out plan for HFC refrigerants. From 1 January 2007 it will no longer be legal to use HFC in various applications. However, a number of amendments have been made to the basic legislation which have meant, for example, that systems containing less than 10 kg of HFC are exempt from the phase-out plan. Nevertheless, work is being carried out nationally to develop the phase-out plan, and several sources have shown an increasing interest in heat pumps with CO_2 as the refrigerant. In addition, the Danish Environmental Protection Agency has started a Knowledge Centre for HFC-free refrigeration, from which the refrigeration industry can obtain technical support in connection with the transition to natural refrigerants.

Many of the projects that were carried out in Denmark in the past years have received support from the Danish Environmental Protection Agency, and their main objective has been to disseminate knowledge about alternative solutions when only environmentally friendly refrigerants are used. In the following, four cases will be examined in which either HFC refrigerants or other alternative solutions with considerable environmental importance are used

2. Domestic hot water heat pump

Through the 80s and the 90s, quite a few heat pumps for heating domestic hot water have been produced in Denmark, typically using R134a. At the beginning of this decade, the Danish refrigeration industry experienced a continually increasing demand for environmentally benign alternatives, especially from Central European export markets. The demand has resulted in a number of activities where CO_2 has played an important part. Just as the Danish refrigeration industry made a great effort within this area, Sanyo marketed their CO_2-based heat pump, which forced the Danish refrigeration industry to give development work high priority.

In 2001, the first major development project concerning the use of CO_2 as refrigerant in domestic hot water heat pumps was finalised. The project subsequently continued in a project where a prototype was built and tested in the laboratory (in 2003). The results were very promising, but at the time it was not possible to procure a compressor of the right size. Therefore the gain was somewhat smaller than expected.

As follow-up on this project, yet another development project was carried out with support from the Danish Environmental Protection Agency. A starting point was taken in a specific product – namely a Vesttherm/Nilan domestic hot water heat pump using R134a. A prototype was designed and tested, built from components that were commercially available:

- Danfoss TN 1416 compressor and Danfoss TBR expansion valve (thermal back-pressure regulator)
- Nilan CTS 600 regulator
- Standard evaporator 440 bar and gas cooler coil placed in water tank
- 135 bar Saginomiya safety pressure control

The gas cooler is designed on the basis of a number of CFD calculations carried out on the tank equipped with a heating coil. The calculations show that the placing of the gas cooler is very important for the performance of the system. Figure 2 gives an example of the results of the CFD calculations on a tank with and without baffles. The thin lines show the movement of the water during heating, while the pillar in the middle of the tank shows the general temperature distribution.

3. Heat pump in a commercial clothes drier

In 2004, Danish Technological Institute developed a completely new commercial clothes drier (to be used in small laundromats and housing associations) in co-operation with Electrolux Laundry System. The starting point of the project was an ever-increasing desire to phase out electrically heated appliances without prolonging the drying time. This is not immediately possible with HFC-based heat pumps, as the temperature in the appliance cannot become high enough. Therefore, it was decided to develop a CO_2 heat pump with a heating capacity of about 10 kW, where the heat is recovered from the hot exhaust air from the chamber in the tumbler.

Two standard HP expansion valves from Danfoss were used, as the capacity of each valve is not sufficient for the desired plant capacity. The following components have been used in the heat pump system in the tumble drier:

- Dorin compressor TCS 110 (400 V, 87 Hz motor)
- Danfoss HP expansion valve
- ECO gas cooler and evaporator (special design)
- Tube-in-tube internal heat exchanger.

There are quite a few challenges connected with using a heat pump in a semi-industrial tumble drier. Maintenance, for example, must be minimised, and therefore it has to be possible to avoid a need for clean-

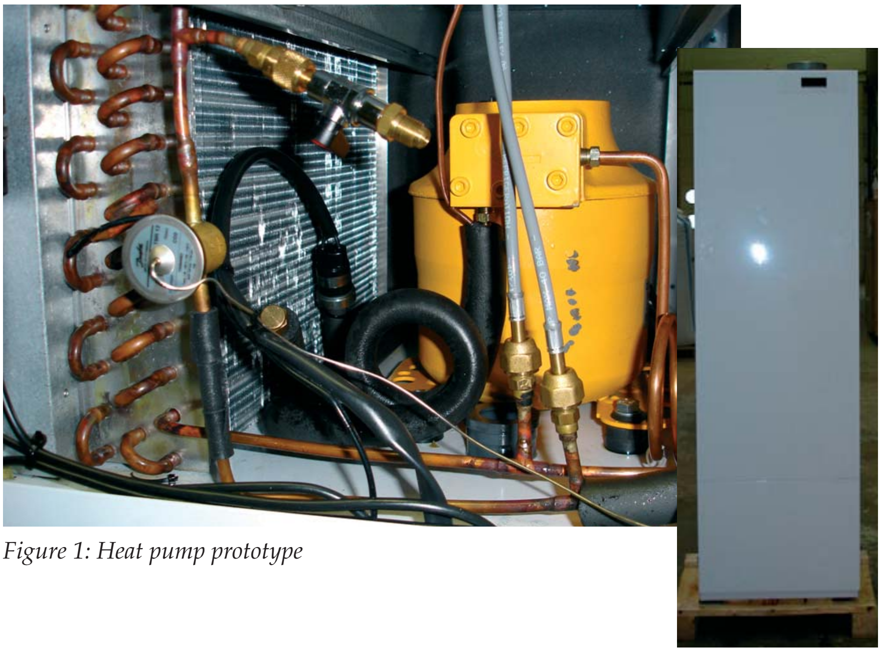

Figure 1: Heat pump prototype

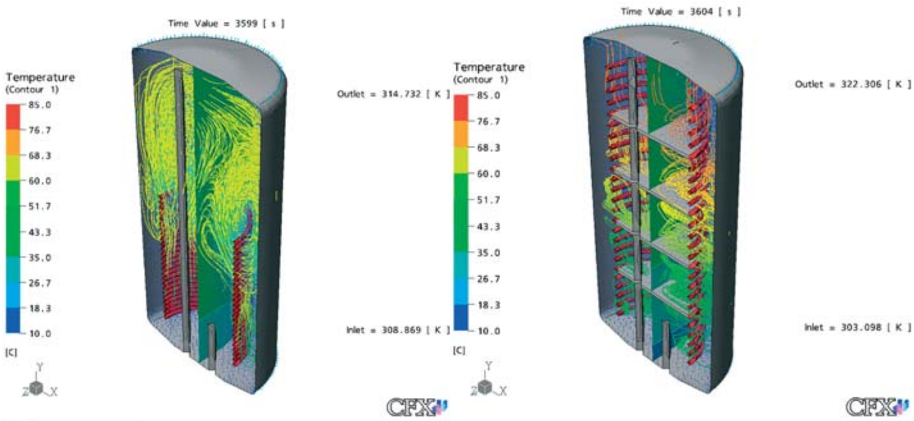

Figure 2: Results of the CFD calculations on water tank and gas cooler

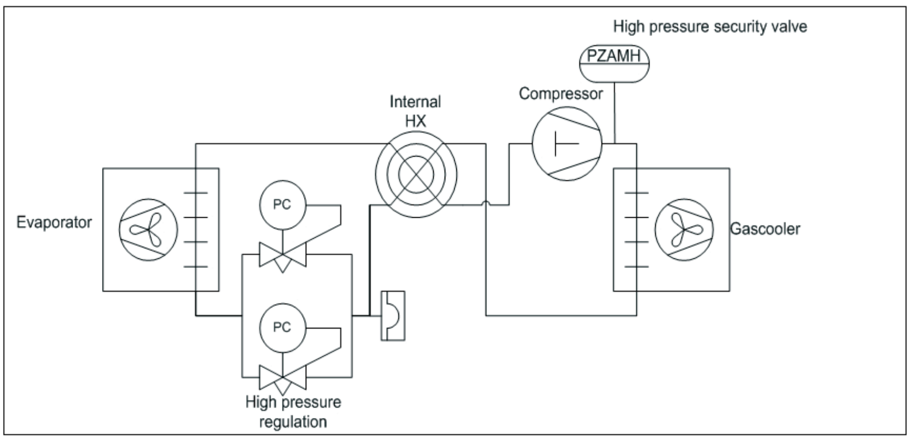

Figure 3: Heat pump system in commercial clothes drier

ing the evaporator and gas cooler. In practice, it has turned out that a large amount of water condenses on the evaporator. Therefore, dust and pieces of material can easily run off the evaporator and extra cleaning is unnecessary. In addition, the system design is of course important as the operating conditions in a tumble drier are somewhat different from those in other systems – e.g. during some periods the evaporator is exposed to air that is more than 45°C which places heavy demands on the compressor, motor and other parts. A Dorin TCS 110 compressor was therefore chosen, powered by a 400 V, 87 Hz motor to ensure sufficient capacity even during the most extreme operating conditions.

In addition, the gas cooler has to be designed so it can function at very low inlet temperatures on the air side, e.g. if the appliance is installed in Sweden with direct air intake from the outside.

A number of analyses have been carried out on the system, including the efficiency of the heat pump as a function of the gas cooler pressure, the swept volume of the compressor and the efficiency as a function of the inlet temperature of the air to the system (inlet gas cooler). The results in Figure 5 show that the efficiency of the system to a high degree depends on the pressure in the gas cooler, while the swept volume of the compressor influences the efficiency of the system to only a small degree. It should be stressed that the shown results include electricity consumption in the electric heating element of the system that boosts the air temperature from the approximately 100 °C that exists after the gas cooler to about 130 °C that is necessary in the air inlet to the drum of the tumbler.

4. HVAC system in restaurant

In 2002-2003, Nilan A/S and Danish Technological Institute jointly carried out a project where they converted an HVAC system from HFC refrigerants to CO_2 in a McDonalds

Figure 4: Heat pump in commercial clothes drier (front and back)

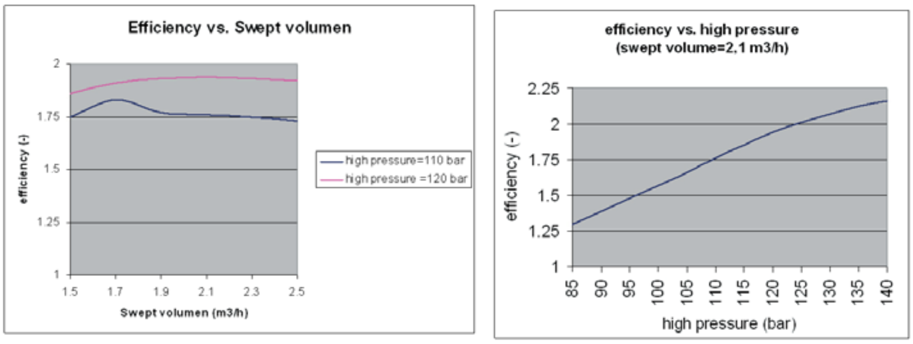

Figure 5: Efficiency of drier (incl. heating element)

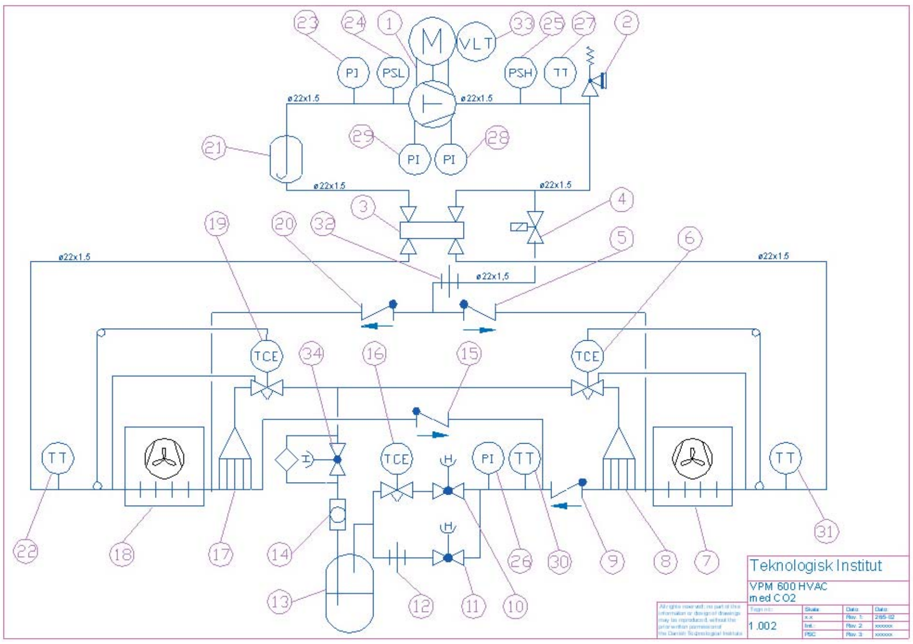

Figure 6: HVAC system – McDonald's restaurant

restaurant in Vejle, Jutland. This is an example of a conventional reversible HVAC system (Nilan VPM 600 with R407C) with a performance of 25 kW refrigeration and 30 kW heating. The system is equipped with a heat pipe for heat recovery (originally with R407C and converted to CO_2). Two HVAC appliances are installed in the restaurant – one in the lobby and one in the kitchen.

A challenge facing the construction of a reversible HVAC system is how to ensure the change between cooling and heating function. This is arranged through a four-way valve, with the system design itself in accordance with the superior strategy shown in figure 7.

Measurements on the installed system show that in connection with warm operation a minor saving has been obtained, while the CO_2 system during cold operation uses a little more energy than the traditional R407C system. The system has now been in operation since the beginning of 2003.

5. CO_2 heat pump in district heating system

A major Danish development project started in 2003, with financial support from the Danish Energy Authority. The objective of the project was to develop a combined compressor/expander machine ("expressor") to be used in decentralised CHP plants. The project took its starting point in the quite large number of decentralised CHP plants in Denmark, as well as in the problems that a large part of the plants face today - mainly due to steeply rising fuel prices. Today, there are about 750 decentralised CHP plants in Denmark, selling electricity produced in connection with heat production. The plants normally have a size of 1-4 MW (shaft output).

Originally, the idea was to operate the heat pump with electricity produced at the CHP plant, with the heat source of the heat pump consisting of

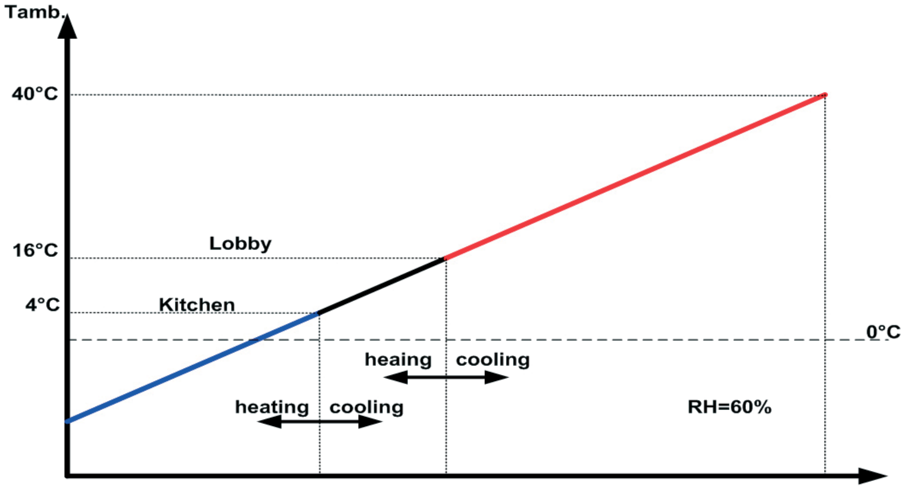

Figure 7: Regulation strategy - HVAC unit

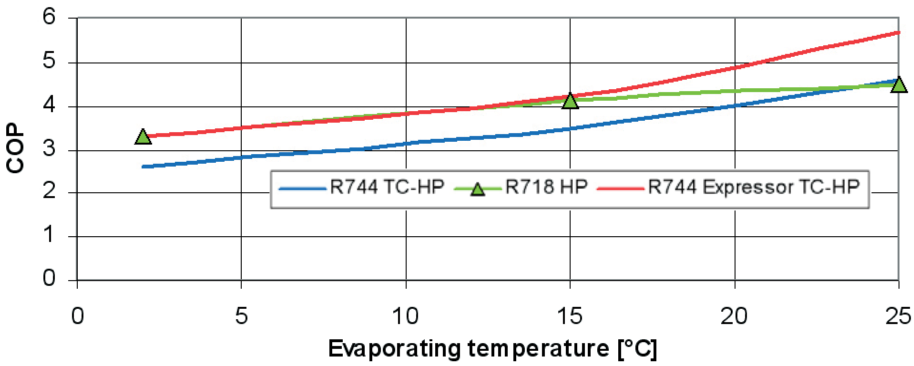

Figure 8: Comparison – CO2 HP system with and without expander and water.

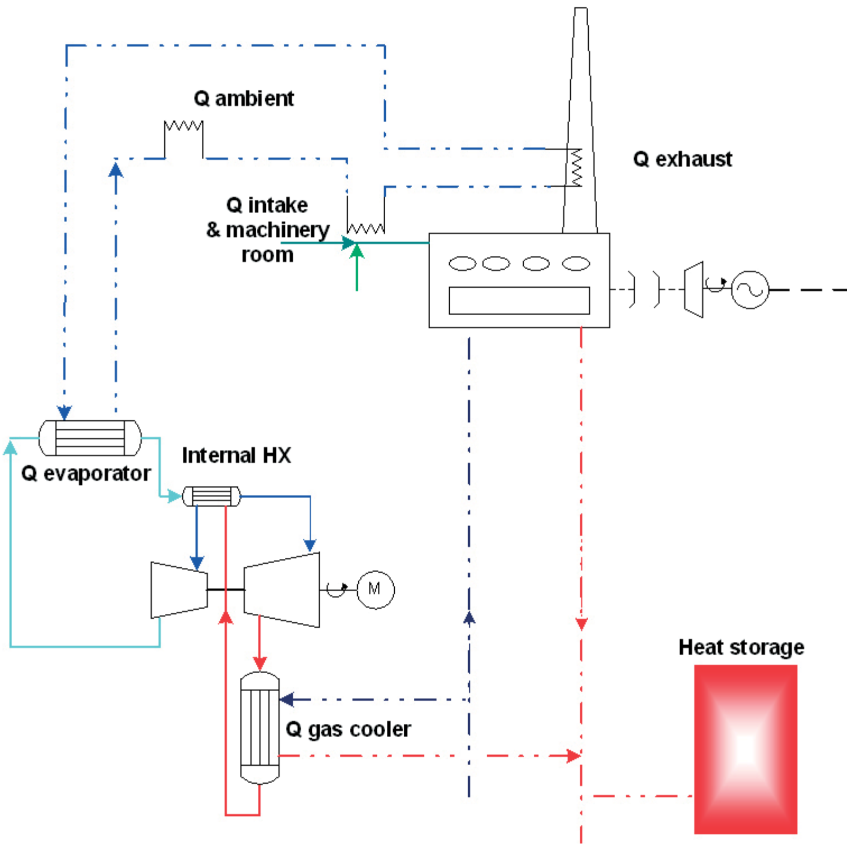

Figure 9: HP system with expander integrated in district heating system

an exhaust gas cooler, oil cooler and, if possible, a heat exchanger to recover heat from the engine and generator coolant systems. In that way, the heat pump could reduce the load on the natural-gas fuelled engine, minimising gas consumption and service and maintenance costs for the plant.

Unfortunately, several measures related to changes in legislation within the specific area have resulted in a varying level of interest at the different plants. However, the plant operators' views on electricity sold and the possibility of using their own generated electricity for the heat pump are the cardinal points in this discussion.

The project has analysed the various system arrangements, including alternative heat pump arrangements. Normal supply temperatures from Danish CHP plants are 76-80 °C (depending on seasonal variations), while the return temperature is normally around 39-44 °C.

The transcritical heat pump operates in the super-critical area of CO_2 with a pressure of 105 bar in the gas cooler that absorbs waste heat from low-temperature exhaust gas (60-30°C), engine room ventilation and the second stage of the intercooler in the decentralised CHP plant. As something completely new, the traditional expansion valve of the heat pump can be replaced with an expansion machine that utilises and supplies the expansion work as a contribution to operating the compressor of the heat pump. The share from the expansion machine improves the coefficient of performance of the heat pump by about 20 %. This can be seen in Figure 8, which also shows the efficiency of a three-stage water vapour process with intercooler.

Figure 9 shows how the entire system with heat pump could be designed. The heat pump should be equipped with an adjustable internal heat exchanger to be used when the efficiency is increased, and also for the purpose of adjustment, meaning that a bypass contributes to determine the supply temperature from the heat pump.

Discussion

Undoubtedly, coming years will also focus on the use of CO_2 as refrigerant in transcritical as well as in sub-critical refrigeration systems. Development in Denmark is to a great extent controlled by legislation, but it is probably doubtful if the trend will spread to other EU countries and then internationally. However, when the market at some time in future demands CO_2 as an alternative to HFCs, development will take place quickly.

As it appears from the cases stated in this paper, CO_2 in transcritical systems is very interesting in certain applications. In the long term, small systems (such as those used to heat domestic hot water) will no doubt be based on CO2, and if a number of the existing barriers (mainly legislative) are removed when heat pumps in CHP systems are used, it will also be possible for large transcritical CO_2heat pumps to gain a foothold in the market.

The supply of components for transcritical CO_2 is still rather limited, but as it appears from this paper it is today possible to build systems with components that must be considered as almost commercially available. Of course, the price is high compared with systems using traditional refrigerants, but in the long run when demand and supply increase the price level will fall and it is expected that the component price will end up about 10-20 % higher than for traditional refrigerants.

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Topical article

Measurement of the performance of an air/water heat pump using CO_2 or R744 for the production of hot water for use in a hospital

Patrice Anstett, Switzerland

The main objective of this project is to explore the capacities of a 60 kW air/water heat pump using CO_2 (or R744) as refrigerant for the production of hot water at the Le Locle hospital (canton of Neuchâtel, Switzerland). The goal is to produce hot water with a temperature of 60 ° to 80 °C from cold water at a temperature of 10 °C. The project will permit real-time measurement of the coefficient of performance of the heat pump under differing conditions of use (e.g. changes in the temperature of the cold water), as well as its verification over an extended period of time in order to evaluate its performance under changing seasonal conditions.

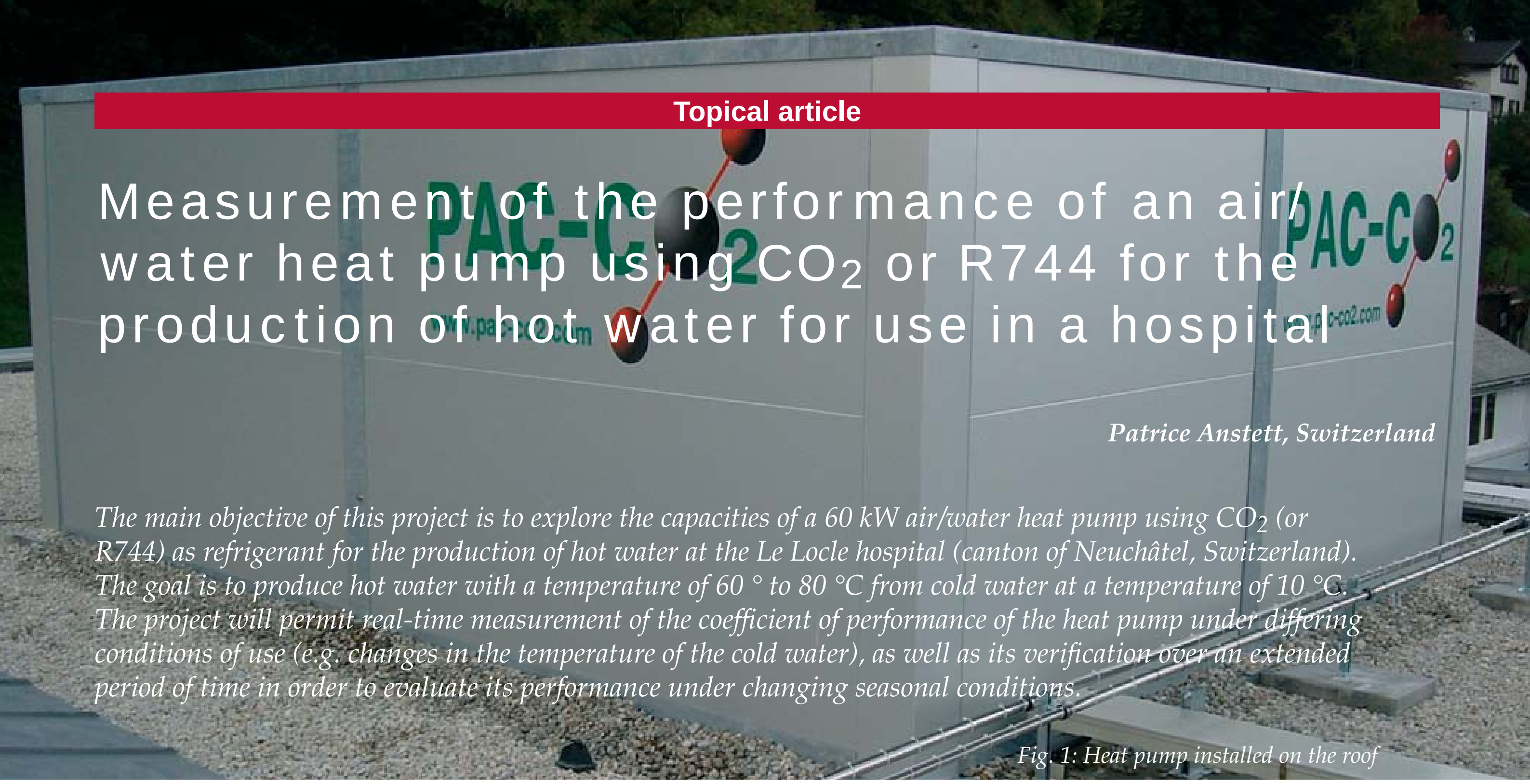

Fig. 1: Heat pump installed on the roof

Description of project

We used the renovation and expansion of the Le Locle hospital (canton of Neuchâtel, Switzerland), as an opportunity to install a 60 kW air/water heat pump to replace the existing gas-fired system for the production of hot water.

The heat pump concerned is a prototype that uses CO_2 (also known as R744) as the refrigerant and permits the production of water with a temperature of 80 °C, which is an essential requirement for a hospital in order to prevent the occurrence of salmonella.

The system was specially designed for optimum use at the Le Locle hospital, as well as to permit real-time measurement of a wide range of data:

- The lengthy measurement period will enable us to obtain seasonal data (i.e. with external air temperatures ranging from –20 to + 30/40 °C)
- Thanks to the special design of the hydronic circuit, it will also be possible for us to adjust the temperature of the cold water in order to measure the performance of the heat pump under extreme conditions.

A web server connected directly to the heat pump functions as a link between the boiler room and the Internet. In this way:

- Readings obtained from different sections of the system can be viewed in real time
- Information is fed into two data bases, so that all measurement data are stored redundantly throughout the duration of the project.

The personnel involved will thus be able to view both the stored results and real-time data (e.g. in the form of graphs) via the pac-co2 web site (http://www.pac-co2.com).

The following data will be available:

- Thermal output (kW) of the heat pump
- Coefficients of performance of the heat pump

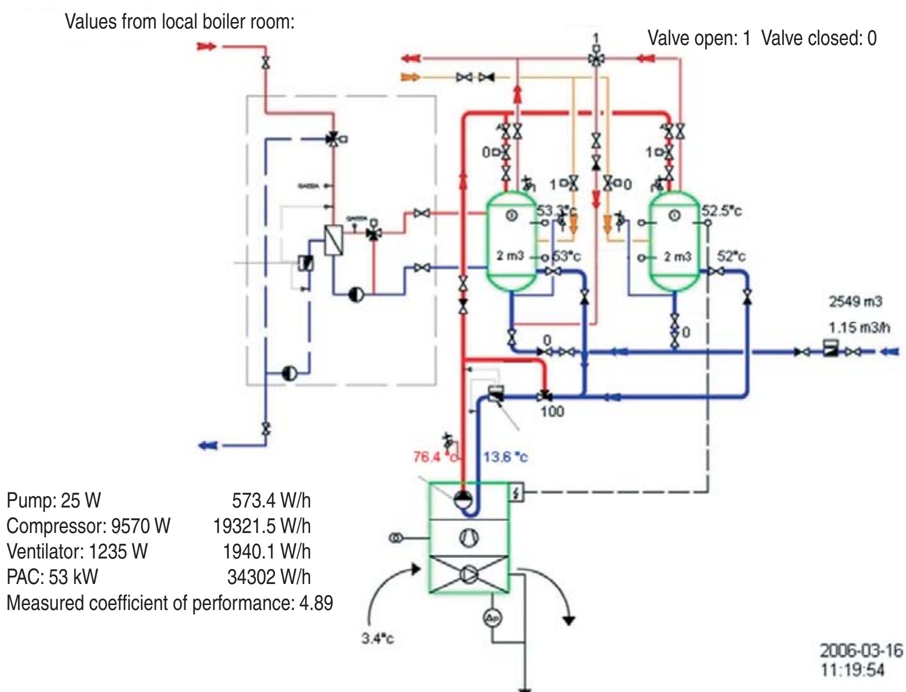

Fig. 2: Diagram of overall system

The technical specifications of the heat pump, which is supplied by Axair Kobra, and other specifications provided by Siemens Building Technologies, have been stored by Axair Kobra on the web site so that it is possible to verify the relation between the different readings, since these are all available in real time via the same media.

Anticipated results:

Figures 5, 6 and 7 show the theoretical performances of such a heat pump in the form of graphs in fig 5 to 7.

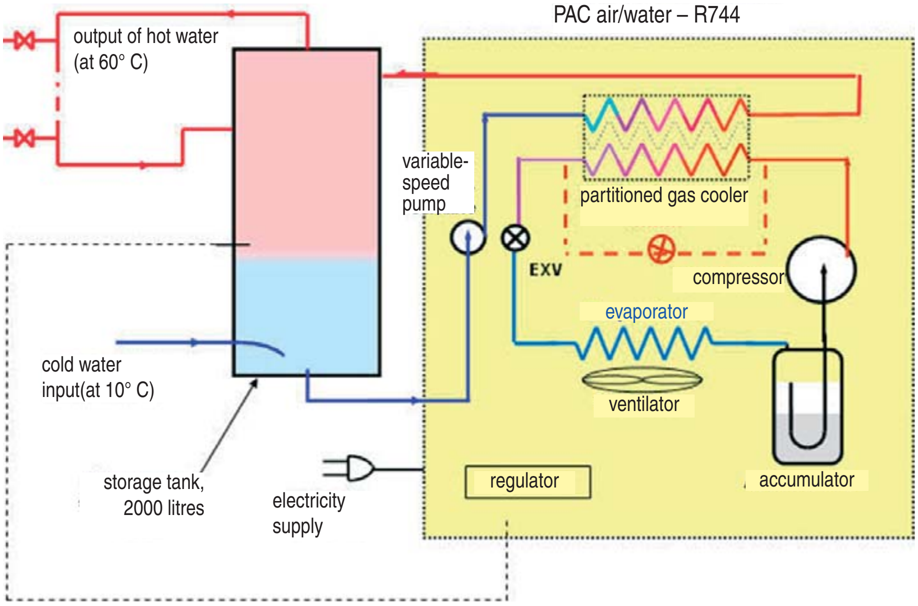

Fig. 3: Diagram of PAC

Fig. 4: Exchanger of PAC

Technical specifications of PAC air/water heat pump:

- Calorific capacity:	60 kW
- Mass of CO2 coolant:	6 kg
- Piston compressor	
- Absorbed capacity (compressor, ventilator and pump):	21 kW
- Air flow (high speed):	3700 litres per second

Temperature ranges:

Water exchanger (condenser)	Minimum ° C	Maximum ° C
Water input (at startup)	3	70
Water ouput (in operation)	50	80
Water input (when off)	3	70
Air exchanger (evaporator)		
Air input temperature	-15	46

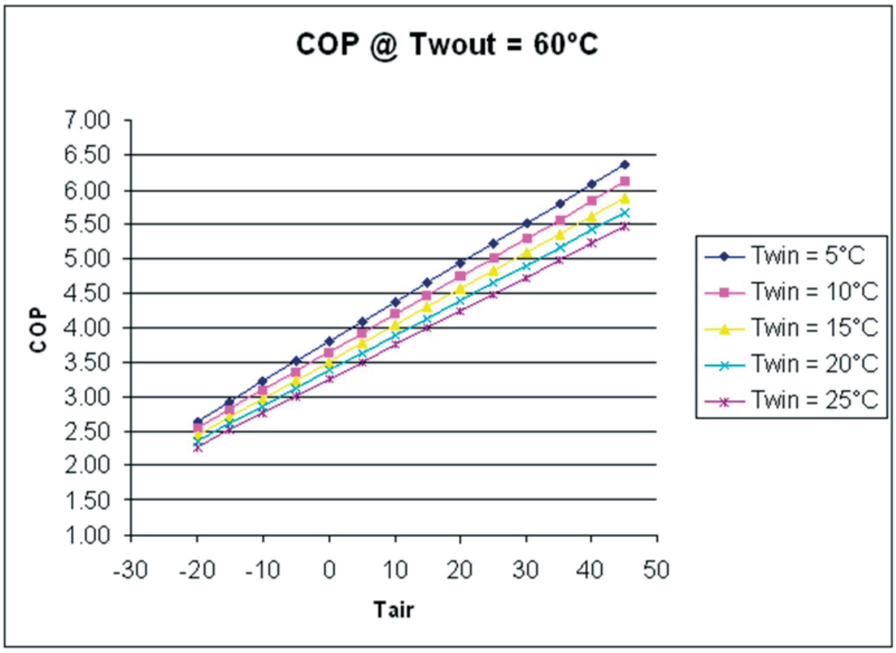

Fig. 5: Coefficient of performance for a water temperature of 60° C

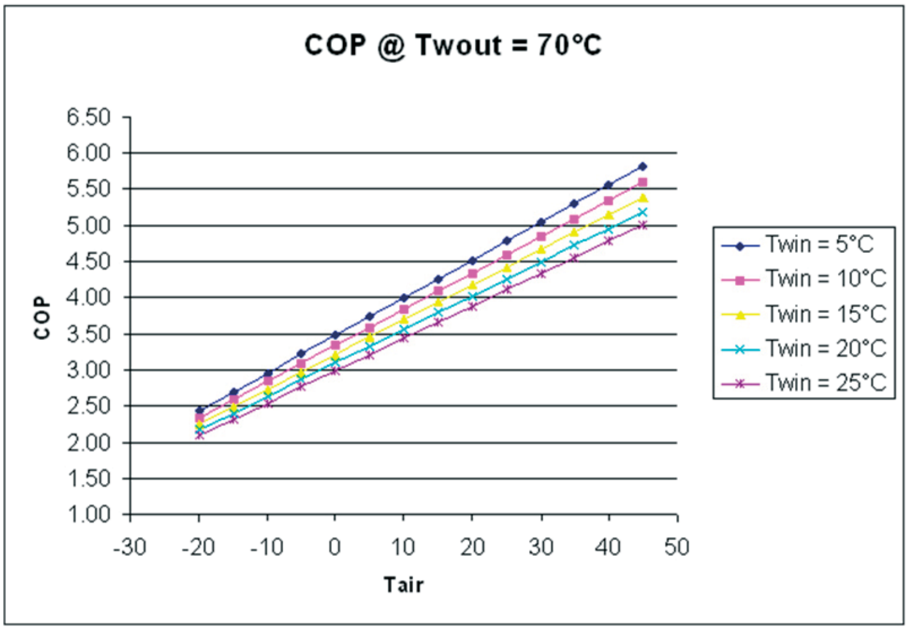

Fig. 6: Coefficient of performance for a water temperature of 70° C

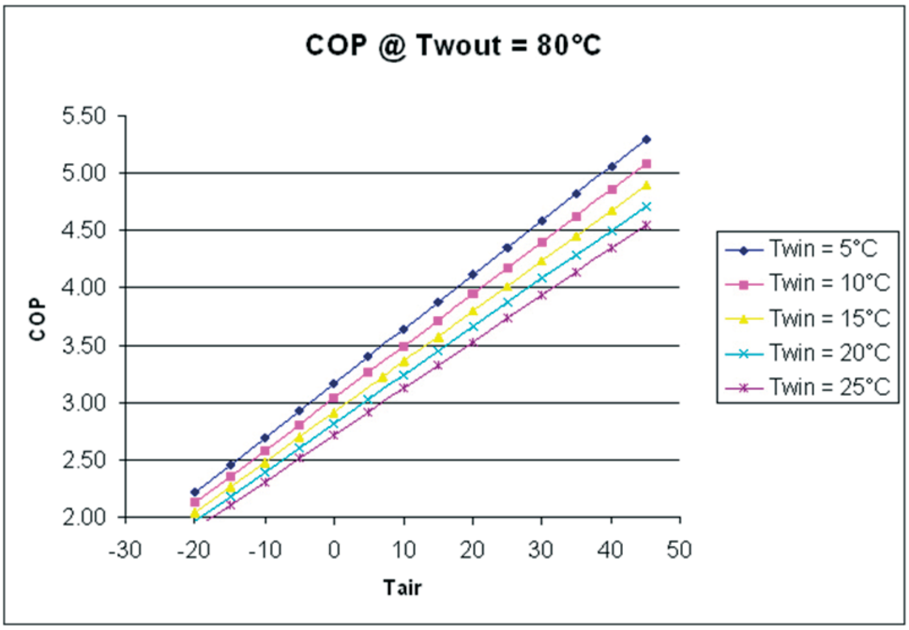

Fig. 7: Coefficient of performance for a water temperature of 80° C

Obtained results

The table below presents some the most encouraging results obtained to date:

Table 1: Readings obtained from the system installed at Le Locle hospital (selection)

t_{in} [°c]	t_{out} [°c]	t_{air_ext} [°c]	$P_{thermal}$ measured [kW]	COP	$p_{aspiration}$ [bar]	$p_{refoulement}$ [bar]	date	hour
46.5	76.7	-3.6	29	2.61	29.9	97.8	2006-03-01	16:16:46
47.7	77.7	-5.4	26	2.40	29.1	94.6	2006-03-01	18:24:06
27.8	78.7	0.9	28	2.64	31.8	97	2006-03-04	07:02:45
36.8	76.7	1.5	27	2.48	33.2	95	2006-03-15	17:29:34
21.4	79.4	-7.5	39	3.67	26.2	95.8	2006-03-16	07:01:08
13.6	76.4	3.4	53	4.89	31.4	93.3	2006-03-16	11:19:54

Figures 8, 9 and 10 depict samples of obtained results in the form of graphs.

The cold water temperature should not be above 25°C because the efficiency drops near the critical point. The best absolute values and trends are with cold water at 20°C. Interesting is the COP at very low ambient air temperatures: the COP for hot water at 70°C remains around 2.5 below -5°C. This is quite remarkable, when compared with heat pumps using HFCs. The anticipated results are achieved, but it is noticeable that they are very sensitive to the cold water temperature and to its variations.

The hospital did not notice the heat pump, which means that it fulfilled its required performance. Running costs are low, due to the good COPs.

The machine was not yet a standard product: it was noisy and large due to the need for easy access during the tests. The final version will be much quieter and smaller in size.

This project was realized with the financial support of the Swiss Federal Office of Energy.

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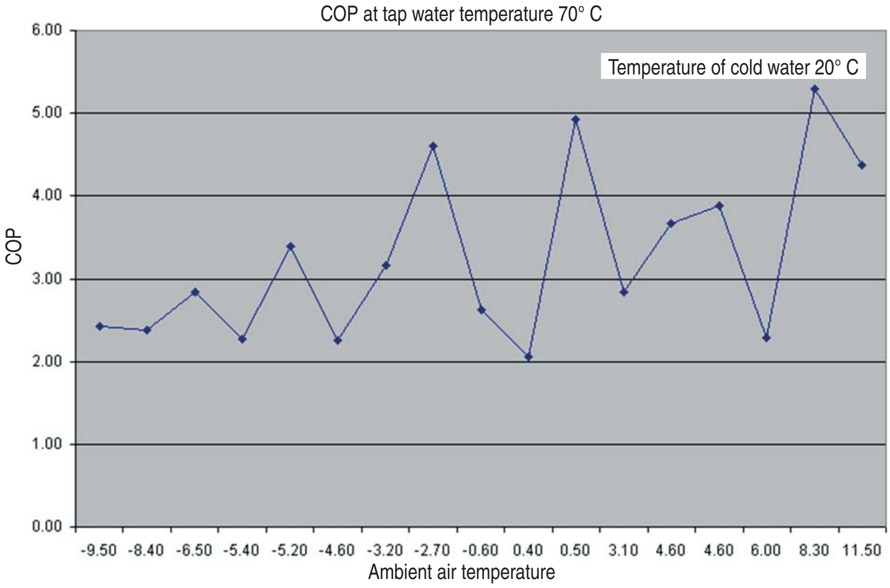

Fig. 8: Coefficient of performance with hot water temperature 70° C for cold water 20° C

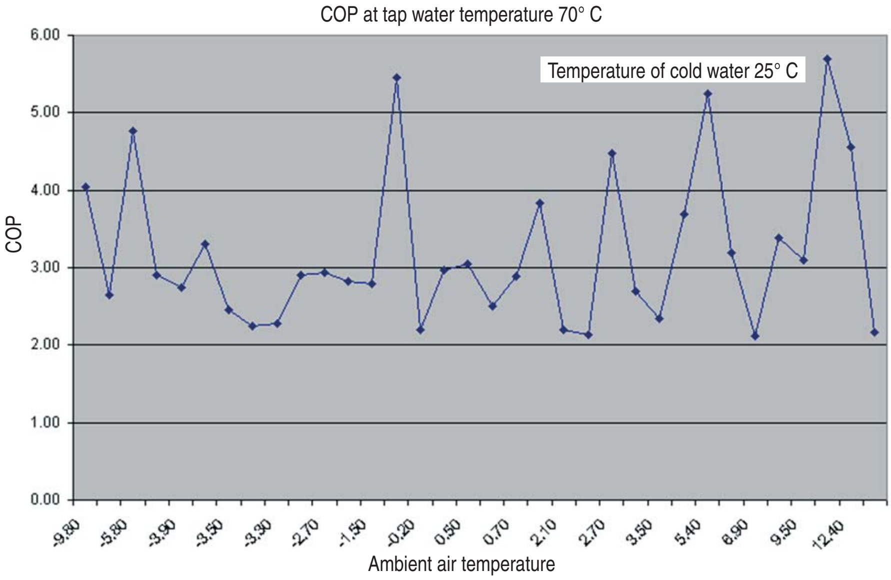

Fig. 9: Coefficient of performance with hot water temperature 70° C for cold water 25° C

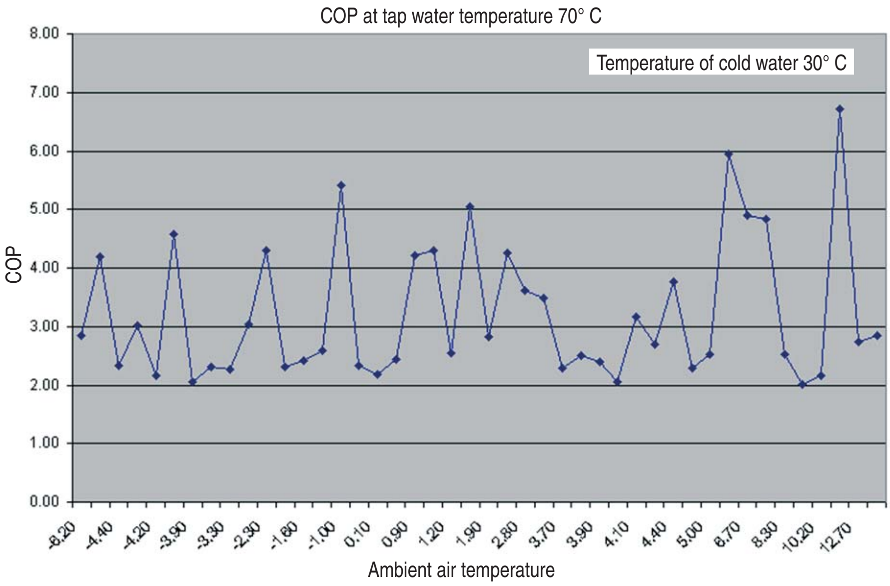

Fig. 10: Coefficient of performance with hot water temperature 70° C for cold water 30° C

The latest developments on the use of CO_2 as refrigerant

Tobias Sienel, USA

CO_2 heat pump water heaters have been studied extensively in the last decade in universities and research labs. Although much research has been conducted, few systems have been commercialized outside of Japan. This situation is likely to change in the next few years, as compressor manufacturers release reliable CO_2 compressors and other CO_2 system components become commonly available. Inside Japan, CO_2 heat pump development continues at a furious pace, with efficiency improvements common.

Introduction

Heat pump water heating (HPWH) systems have been known almost since the inception of the use of reverse rankine vapor compression systems. The advantages of these systems compared to the traditional gas and electric water heating systems are mainly in efficiency and operating cost. Since these systems are considerably more complex than traditional water heating systems, there has always been a challenge in terms of first cost and operational reliability. In addition, many of these systems are not able to produce truly hot water (above 60C). CO_2 systems overcome some of these challenges with a low or zero global warming potential working fluid, but face large challenges in others.

CO_2 History and Development

In the last 15 years, there has been a reemergence in the use of Carbon Dioxide (CO_2) as a working fluid in vapor compression systems. One of the earliest working fluids used, 80% of marine refrigeration systems used CO_2 up through the 1930s. CO_2 suffered from very high operating pressures (over 60 Bars) requiring heavy walled equipment, and also was not typically used with high condensing temperatures due to its low critical temperature of 31C. In the 1930s, new fluids called CFCs were developed which had much better operational characteristics than CO_2 and in a relatively short period of time replaced most applications of CO_2. It was not until the 1970s that the adverse affect these fluids had on our global environment were more fully understood. In the 1980s, Prof. Gustav Lorentzen at NTNU/SINTEF in Norway developed a number of prototype systems showcasing the potential of CO_2 to reemerge as a viable working fluid.

Table 1 presents some commonly used working fluids as well as CO_2. The challenges of CO_2 as a working fluid remain high pressure and operation above its critical point. The traditional reverse rankine vapor compression system compresses a relatively low pressure, low temperature vapor to a relatively high pressure, high temperature vapor, after which it rejects heat and condenses in a constant temperature process back to a liquid, is throttled to a two phase low pressure, low temperature fluid, and finally absorbs heat and evaporates in a constant temperature process back to a vapor and the entrance to the compressor. In this process, the temperatures in the heat exchangers set the pressures in these components. When operating above the critical point, however, there is no distinction between liquid and vapor, and the temperature does not remain constant through the heat rejection process. The pressure in this part of the cycle is now no longer only a function of temperature, but also of density. This causes an additional degree of freedom in the selection of the high pressure in the system. This high pressure has a large influence on the efficiency of the system, and there is typically an ‘optimum’ high pressure which maximizes the efficiency of the system. Operation at supercritical pressures is be very advantageous for HPWH systems due to the temperature glide experienced by the fluid as it cooled in the heat rejecting heat exchanger. This glide can be matched in a counterflow heat exchanger to the fluid to be heated, resulting in a highly efficient process. These characteristics are shown in Figure 1. In addition, although the pressures in the system can be high (over 100 Bar), the pressure ratio is actually low compared to conventional working fluids. For well designed compressors, this can result in higher compressor efficiencies. Finally, CO_2 has a very low viscosity,

Table 1

	R22	R134a	R410A	Propane	Ammonia	CO2
Global Warming Potential (100 year)	1700	1300	1730	20	2	(1)
Critical Temperature (C)	96	101	71	97	132	31
Pressure at 20 C (kPa)	910	570	1440	840	860	5700
Flammable	No	No	No	Yes	Yes	No
Toxic	No	No	No	No	Yes	No

which considerably enhances its heat transfer potential when compared to traditional working fluids, which results in lower heat exchanger losses and higher system efficiencies.

Japanese CO_2 HPWH Development

Serious development of commercialized CO_2 heat pump systems started in Japan in the mid 1990s by Denso. This development was focused on residential systems and was financed in part by electric utilities (TEPCO and others). These systems use a duct-free split type condensing unit as a unitary system containing the entire CO_2 system (heat exchangers, compressor and expansion device). Coupled with the condensing unit is a storage tank which stores the heated water at relatively high temperatures (up to 90C) until ready for use. The systems are designed to work at night utilizing reduced nighttime energy rates to heat the water. During the day, the water is drawn from the tank and mixed to a safe temperature for use. Since space is at a premium in Japan, where most of these systems reside on apartment balconies, it was found that storing water at high temperatures reduces the size of the storage tank. To achieve water delivery temperatures of 50C, a storage tank with 90C water only needs to be 40% of the size of a storage tank with 50C water. Denso was first on the market with their system in 2001, followed by Sanyo and Daikin in 2002, and Mitsubishi in 2003. Over 17 companies now sell these systems.

System efficiencies were originally in the range of 3.2 – 3.7 COP (amount of heat produced by the system divided by the energy supplied to the system), but have rapidly increased due to fierce competition in the market. These systems now all boast system efficiencies of greater than 4.0 COP [1]. Recently, Mitsubishi electric company reported the development of a system with a COP of 4.9, due in part to a highly efficient rotary compressor [2]. Coatings on the inside of the storage tank also contribute to overall energy efficiency by decreasing the heat transfer from the tank to ambient while the water is waiting to be used. In addition to efficiency

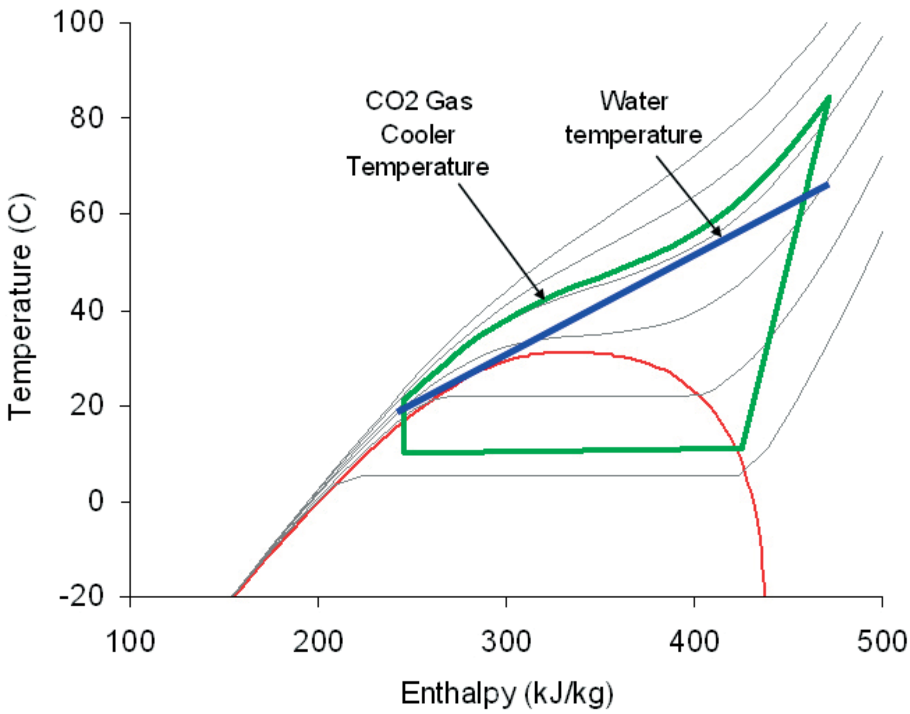

Figure 1 – Temperature glide effect of transcritical cycle

improvement, noise has also been considerably improved for this very sensitive market. The first units on the market had operating noise of 45dB or higher, which has now been improved to 38dB. The early systems were designed to produce sanitary hot water only, while more recent systems also have a provision for space heating.

Figure 2 – Hitachi 23kW instantaneous CO_2 HPWH

These residential systems have system capacities of about 6kW and less, which when combined with a large enough storage tank, is appropriate for a storage water heating system run at night only. Recently, Hitachi introduced a semi-instantaneous residential CO_2 HPWH with a capacity of 23kW [3] and a COP of 4.6, shown in Figure 2. The large capacity of the system allows the storage tank size to be dramatically reduced and integrated into the condensing unit, which installs in one piece without additional connections to a separate tank. Hitachi has developed a horizontal scroll compressor for this unit, which lays flat in the fan coil section of the unit, allowing the storage tank to occupy the space where the compressor normally is. Hitachi claims this unit eliminates any potential for running out of hot water during normal operation.

A commercially sized CO_2 heat pump was also developed by Nishiyodo which is currently being sold through Itomic. This unit also consists of two separate modules, one of which houses the heat pump and associated controls, and the other of which contains the storage tanks, which are available from 500-3000 liters in size. The modular nature of the storage tanks allows the overflow from one tank to enter the next tank, which reduces the heat transfer from mixing of the cold and hot layers in the tanks. These units have system capacities of up to 26kW and a COP of 3.8. Hitachi has also started to sell their larger ECO-cute systems into the commercial market, offering modular 15kW units with a COP of 4.1 along with 500-3000 liter storage tanks.

The success of the CO_2 HPWH market penetration in Japan can be traced to the high cost of existing water heating products, the high cost of energy, as well as the existence of a rebate program for purchasers of these units. The residential CO_2 HPWH systems with a 300 liter storage tank in Japan cost approximately $6000, as compared to $4000 for a similarly sized electric resistance water heater. Half of the cost differential is covered by the rebate program. As of 2005, over 200,000 CO_2 heat pumps have been installed in Japan. The Japanese government has estimated that the total number of installed units will exceed 5 million by 2010 [4].

Development of CO_2 HPWH systems in Japan continues, most notably with the application of ejector systems by Denso, and the development of expander technology by the other manufacturers of CO_2 HPWHs. These devices recover some of the energy of expansion and thereby increase the overall efficiency of the system.

European CO_2 HPWH Development

From the mid 1990s through 2002, the EU sponsored a series of projects under the name COHEPS with the intent of developing and demonstrating CO_2 heat pumps for both sanitary hot water and hydronic heating. These efforts culminated in the production of a number of prototype systems, but did not lead to commercialization of any products. Since the COHEPS project, another effort under the name SHERHPA has continued, although with a more commercial focus. This effort is intended to develop the next generation of natural refrigerant heat pumps, including CO_2. The effort has resulted in the development of a small 3kW capacity prototype [5]. It should be noted that numerous universities and research centers have developed prototype CO_2 HP systems. None have moved beyond the prototype stage into series production, however.

Since 2002, Carrier in France has developed a commercially sized 60kW CO_2 HPWH and has developed extensive field test experience [6], but not entered the market with a product to date. Similarly, Stiebel Eltron in collaboration with Awtec have developed a CO2 heat pump [7] for single family homes and displayed it at the 2006 Hannover Messe. This system currently uses a small Danfoss CO2 compressor, resulting in a heating capacity of less than 2kW. This system has also not yet been commercialized.

As of today, the only CO_2 heat pump system available on the market in Europe is an imported 4.5kW Sanyo, offered through Ahlsell in Sweden [8].

North American CO2 HPWH Development

As in Europe, numerous prototype CO_2 heat pump systems have been built at universities and research centers. None of these systems have been commercialized.

Carrier and United Technologies Research Center, in collaboration with the US Department of Energy (DOE), modified the Carrier France 60kW CO_2 heat pump units for US application (to meet UL and 60Hz requirements). Eight field trial units have been installed in a range of applications from hospitals to hotels and have accumulated considerable operating time, as shown in Table 2 [9]. Figure 3 shows a picture of one of these units installed on a restaurant roof.

Conclusions

In spite of over a decade of research into CO_2 heat pump water heating systems, the only commercially available systems are manufactured by Japanese companies, who by now have considerable experience in the design, manufacture, operation, and servicing of high pressure CO_2 systems. The Japanese systems have, for the most part, not found application outside of their home market due to their high first cost in comparison to water heating systems outside of Japan. It is interesting to note that all of the commercially available system manufacturers, with the exception of the commercially sized system sold by Itomic, use compressors developed within their respective companies. There continues to be a high level of interest in these systems outside of Japan, however. All of the major compressor companies have efforts underway to evaluate and/or develop CO_2 compressors as of this date [10]. As these efforts mature, this key component will allow the development of cost effective, reliable, and efficient CO_2 heat pump systems. It is clear that the overall trend points toward the development and

Table 2 (through June, 2006)*

Application	US Location	Accumulated hours of operation*	Projected run hours/year	Projected Energy Cost Savings ($/yr)
Cafeteria	CT	2500	2200	1800
Industrial – process water	AL	600	2200	2800
Hospital Laundry	AL	4000	4400	7000
Food Processing	MS	3200	4400	10400
University Gymnasium	CT	1200	6600	4200
Hospital	AL	1300	4400	8500
Restaurant	OR	1300	5800	6200
Hotel	CT	100	2900	2100

Figure 3 – Carrier 60kW CO2 Heat Pump installed on restaurant roof in Oregon

commercialization of these systems in the near future. The market is eagerly waiting for these products.

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Using Refrigerants Responsibly

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United States manufacturers of heating, ventilation, air conditioning, and refrigeration (HVACR) equipment have played a leadership role in making sure refrigerants are used and handled responsibly. For instance, in 1994, the Air-Conditioning and Refrigeration Institute (ARI), the trade association of North American HVACR equipment manufacturers, published the *Industry Recycling Guide*, a guide to recovering, recycling, and reclaiming refrigerants. This guide established the authoritative rules for those activities and was referenced in the regulations of the U.S. Environmental Protection Agency. Recently, ARI and the industry have embarked on an ambitious program to increase their efforts to keep refrigerants contained and to properly dispose of refrigerants at the end of their useful life. ARI's Refrigerant Responsible Use Initiative involves all sectors of the refrigeration and air-conditioning industry. This article outlines the main initiatives of the program.

The use of refrigerants in the U.S. extends from CFCs, still used in thousands of older chillers; to HCFCs, now used mainly in split air conditioning units, packaged equipment, commercial refrigeration and chillers; to HFCs, which are being used at a growing rate in all types of refrigeration and air-conditioning equipment as a replacement for CFCs and HCFCs. HFCs are the recognized permanent replacement for CFCs and HCFCs and have an environmental advantage – they do not contribute to stratospheric ozone depletion. But they like the CFCs and HCFCs they replace, are global warming gasses and need to be handled responsibly.

In spite of the hard work and diligence of the HVACR industry, atmospheric analysis shows that significant amount of refrigerant is escaping to the atmosphere. For HFCs to remain a viable long term refrigerant, the HVACR industry will have to demonstrate that they can be contained and handled properly.

The first responsible use initiative deals with the regulations pertaining to refrigerants. The U.S. is a signatory of the Montreal Protocol and the U.S. government regulates the use of ozone depleting substances, including CFCs and HCFCs through the U.S. Clean Air Act. That Act states that intentional emissions of these refrigerants are illegal. Regulations specify in great detail how refrigerants are to be monitored, handled, how leaks are to be fixed (in large systems) and how refrigerants are to be disposed. These regulations specify the level of expertise a technician must achieve before handling refrigerants, how much vacuum must be maintained when evacuating a system, and when a leak must be repaired. For CFCs and HCFCs the rules are detailed and are numerous.

The rules are a bit different for HFCs. Because the U.S. is not a signatory to the Kyoto Protocol on Climate Change, and the U.S. Clean Air Act primarily focuses on ozone depleting chemicals like CFCs and HCFCs, the authorizing language in the statute is not as clear about HFCs. The Clean Air Act states that HFCs cannot be vented/released to the atmosphere; therefore, these refrigerants need to be responsibly cared for. However, the U.S. Environmental Protection Agency, the regulating authority, has not taken a strong position on enforcement of HFCs even though the rules covering CFCs and HCFCs mention that similar enforcement folds over onto the alternative refrigerants. The first goal of the Responsible Use Initiative is to encourage the EPA to aggressively enforce the no venting rules! The next step will be to strengthen and enhance the Clean Air Act to proactively promote the responsible use of HFCs. ARI is encouraging Congress and the U.S. EPA to treat the handling and use of HFCs in the same manner that they treat other refrigerants.

Another project of the Responsible Use Initiative is to demonstrate that manufacturers are proactive within their manufacturing facilities to contain refrigerants. ARI surveyed manufacturers to learn about their practices to contain refrigerants as they use them to charge the millions of units manufactured every year. The results of this survey were reviewed by industry experts and compiled into a list and published as the **Responsible Use Guide for Minimizing Fluorocarbon Emissions in Manufacturing Facilities**. This guide has been co-signed by the U.S. EPA and has been distributed to all ARI manufacturers. It has been printed in a format that makes it easy for facility managers to carry it with them as they inspect their plants to assure proactive measures are being taken to contain refrigerant during manufacturing. This guide is available to other industry associations and to HVACR equipment manufacturers around the world from the ARI website [http://www.ari.org/_documents/RUI-guide.pdf].

An important development in the responsible use of refrigerants is

ASHRAE Standard 147, Reducing the Release of Halogenated Refrigerants from Refrigerating and Air Conditioning Equipment and Systems. This standard has the potential of demonstrating the industry's leadership in promoting responsible use. ASHRAE has provided a valuable service in promulgating this standard and with some revisions; it can be embraced by manufacturers. These revisions might include a repeatable method of measuring small leaks, as well as a leak rate design standard acceptable for varying types of equipment. ASHRAE has established a standards committee to consider improvements to the standard.

It is clear that technicians who are properly trained tend to be more responsible in refrigerant handling. In the U.S., technicians must pass a government test in order to be able to purchase ozone-depleting refrigerants and service equipment containing them. While that is good, U. S. industry is encouraging a higher level of competence. It has instituted a technician certification program, called the North American Technician Excellence Program (NATE). NATE administers a series of tests that measure a technician's competence. Industry feels that NATE certification should be required for technicians that work on refrigerant containing equipment. As a first step, industry would like the U.S. federal government to require NATE certification in order to work on federal projects.

The most ambitious project in ARI's responsible use portfolio is called Refrigerant Management USA (RM USA). Some would claim that every bit of refrigerant that is manufactured will eventually wind up in the atmosphere, because there is currently little economic incentive to destroy refrigerants. RM USA will provide incentives for technicians to return used refrigerants, for wholesalers to process them and for reclaimers to either clean or destroy used refrigerants. Planning is in the formative stages and more information should be available later this year.

The Responsible Use Initiative is a wide ranging and ambitious effort to improve the containment of refrigerants, improve refrigerant handling practices, and make refrigerants benign at their end of life. It will take the cooperation of the entire HVACR industry: engineers, manufacturers, installers, and service and maintenance technicians to make this effort a success. It is imperative that we succeed, if we are to have a variety of safe, efficient and reliable refrigerants available in the years to come.

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F-gas Regulation is now published

Lars Nordell, Sweden

14 July 2006 saw publication of the new EU F-gas Regulation in the Official Journal of the European Union: 20 days later it came into force.
This new EU Regulation governs requirements for the use of greenhouse gases. For the European refrigeration and heat pump industry, it means requirements for the use of all the HFC refrigerants, such as R134a, R407C and R410A as just a few examples.
At the same time, the EU Directive for the Use of Greenhouse Gases in Air Conditioning in Motor Vehicles – the MAC-Directive – was adopted. See table "EU regulation for HFC products in Europe".
This article will focus on the F- gas Regulation.

Introduction

This new F-gas Regulation for HFC products in Europe for refrigeration, air conditioning and heat pump applications is applicable to all the sizes and also for all use in both industry and domestic applications.
In general, the Regulation gives mandatory requirements for…

- Leakage checking for all applications containing more than 3 kg of HFCs, and with a frequency of at least once a year to once every three months
- After repairing a detected leak, a further follow-up leak check must be carried out within one month repair
- Records shall be maintained by the operator having the main legal responsibility for prevention of leakage of these gases
- All personnel performing leakage checking must be individually certified, as must also companies performing installation, maintenance or servicing, including repair and recovery of HFC.
- Disposable cylinders containing HFC will be prohibited from 4 July 2007.

EU regulation for HFC products in Europe [http://eur-lex.europa.eu and search for Official Journal L161]	
Stationary equipment **Refrigeration, air conditioning and heat pumps**	**Mobile air conditioning equipment**
Regulation (EC) No 842/2006 of the European Parliament and of the Council of 17 May 2006 on certain fluorinated greenhouse gases (F- gas regulation)	Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 relating to emissions from air-conditioning systems in motor vehicles and amending Council Directive 70/156/EEC (MAC-Directive)

F-gas Regulation imposes mandatory responsibility of operators

The whole ethos of the Regulation is the containment that the European HFC products industry uses today. Keeping those products from leaking, leaching or deliberate release into environment is prescribed and provided for within its clauses. The Regulation therefore applies to **refrigeration, air conditioning** and **heat pump** plant in all stationary applications.

The main legal responsibility, which will be a new situation for many owners/end users, is that they, being operators of HFC-containing plants, equipment or systems, of no matter what size, large or small, **shall** using all measures which are technically feasible and do not entail disproportionate cost: a) prevent leakage of these gases and b) as soon as possible, repair any detected leakage. To do this, the operator who is defined as *the natural or legal person exercising actual power over the technical functioning of the equipment and systems covered by this Regulation*, must ensure that the systems are checked for leakage by certified persons.

Leakage checking

Referring to Article 3, the leakage checks will vary in frequency depending on the charge size per circuit (See table for information on Article 3).

Systems containing 3 kg and over will be checked every twelve months; 30 kg and over every six months, and 300 kg and over once every three months. If a leak is found, a follow-up leak check must be carried out within one month after a leak repair to ensure that the repair has been effective. Hermetically sealed systems*, which are labelled as such, and which contain less than 6

F- gas **Article 3** **Containment**
Operators of the following stationary applications: refrigeration, air conditioning and heat pump equipment, including their circuits, as well as fire protection systems, which contain fluorinated greenhouse gases listed in Annex I, shall using all measures which are technically feasible and do not entail disproportionate cost;
a) prevent leakage of the gases: and b) as soon as possible, repair any detected leakage

kg of refrigerant, fall into the once in twelve months group.

Leakage detection systems

Operators of the different applications, for example heat pumps containing 300 kg pr more, must install leakage detection system. These leakage detection systems shall be checked at least once every twelve months to ensure their proper functioning.

The F-gas Regulation also says "where a properly functioning appropriate leakage detection system is in place, the frequency of the checks under paragraph 2(b) (mentioned above) shall be halved".

Just a short example, for a heat pump system containing 35 kg R410A, where a properly functioning (!) and appropriate leakage detection system is installed, this means a mandatory leakage checking once every twelve month instead of every six months.

Records

Records shall be maintained by the operator on the quantity and type of HFC installed, any quantities added and the quantity recovered during servicing, maintenance or final disposal. The operator must also keep records of the identification of the company or technician performing servicing or maintenance, as well as the results of the leaks checks. The records shall be made available on request to the competent authority and to the Commission.

The Commission itself shall define and describe the procedures for minimum standard leak detection requirements.

The regulation demands that log books are filled in for all works carried out on any plant containing 3 kg or more.

* Article 2 definitions gives the following wording for a hermetically sealed system; a system in which all refrigerant-containing parts are made tight by welding, brazing or a similar permanent connection, which may include capped valves and capped service ports that allow proper repair or disposal and which have a tested leakage rate of less than 3 grams per year under a pressure of at least a quarter of the maximum allowable pressure.

Mandatory recovery of HFC

Recovery of HFCs contained in any sort of equipment, stationary or mobile, is now mandatory and will encompass all refrigeration, air conditioning and heat pump systems, car, bus and train air conditioning as well as transport refrigeration.

The operator is also responsible for ensuring that any refrigerant needing to be recovered shall only be recovered by certified persons/companies.

Competency

F-gas gives strict requirements that, for leakage checking and recovery of HFCs, personnel performing such work must be proven to be competent to a standard which shall have mutual recognition through all the member states of the EU.

Article 5 on Training and Certification specifies that training programmes and certification must be established by 4 July 2007 for both the companies and the relevant personnel involved in installation, maintenance or servicing, as well as for personnel involved in leakage checking activities (article 3).

Disposable gas cylinders and restriction for delivery

The first sign of the Regulation beginning to bite will be the disappearance of disposable cylinders containing HFC. These cylinders will now be prohibited from 4 July 2007, giving industry just twelve months to use up their stocks.

The restriction on taking delivery of HFCs will include HFCs precharged in cylinders, condensing units and other split system equipment, and installation will be permitted to be carried out only by certified competent companies. For the installer, this also means "a licence to trade".

Labelling

Article 7 about labelling says that the products and equipment listed in paragraph 2 (see below) containing fluorinated gases shall not be placed on the market unless the chemical name (using the accepted industry nomenclature) and the quantity are clearly and indelibly stated on the product or equipment. The label shall be placed adjacent to the service points for charging or recovering, or on that part of the product which contains the gas. Paragraph 2(b) in Article 7 listed the equipment as; refrigeration, air conditioning products and heat pumps.

Timetable for the F-gas Regulation

The F-gas Regulation came into force on the 20th day after its publication in the Official Journal of the European Union. It shall apply with full effect from 4 July 2007, with the exception of Article 9 and Annex II, which shall apply from 4 July 2006.

The date of publication in the Official Journal was 14 June 2006.

Very briefly and generally, the timetable is as follows;

One year after the F-gas Regulation came into force (4 July 2007);

- The Commission shall define the minimum requirements for training programmes and certification
- The Commission shall establish the standard leakage checking programmes for different applications.
- Mandatory leakage inspection and records of equipments will be required.

Two years after the F-gas Regulation entered into force (4 July 2008);

- Member states shall establish or adapt their training programmes and certification procedures.
- No member state can restrict the freedom to provide services or the freedom of establishment on the basis of the certification having been issued in another member state.

Three years after the F-gas Regulation entered into force (4 July 2009);

- Only companies involved in carrying out the activities provided for in Articles 3 and 4 shall take delivery of fluorinated gases. (Taking delivery of HFCs will include HFCs precharged in cylinders, condensing units and other split system equipment).

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Annex 28 Final report now available

IEA HPP Annex 28 entitled "Test procedure and seasonal performance calculation for residential heat pumps with combined space and domestic hot water heating" has been started to develop a calculation method for the Seasonal Performance Factor (SPF) of combined operating heat pump systems.

Since a calculation requires a characteristic of the component efficiency (COP) and the heating capacity, an adapted test procedure has been developed in parallel to enable performing the calculation. Consequently, IEA HPP Annex 28 had the objective to deliver

- An easy-to-use calculation method ("hand calculation") to calculate the Seasonal Performance Factor of combined operating heat pump systems without extensive computational expense
- An adequate test procedure to provide the required input data of the heat pump system with a minimum of testing expense

Following these objectives the final report of the IEA HPP Annex 28 is structured in two parts:

Part 1) Proposals for calculation method and test procedure
The first part comprises an executive summary of the IEA HPP Annex 28 project and the two essential results, namely the proposal for the calculation method and the proposal for the test procedure formatted in the layout of the template for draft standards of the European standardisation organisation CEN.

Part 2) Project description and standard documentation
The second part comprises the background on the project, the national contributions, and introduction to the present situation in standardisation and systems on the markets, performed evaluations and the discussion and decision of the approached, which led to the calculation and test procedure in part 1. further in-depth information can be found in the country reports on Task 1 and Task 2 and 3 of the participating countries which are referenced in the report.

The report can be ordered from the Heat Pump Centre website at www.heatpumpcentre.org
Price (60 € non-members, 20 € members)
Order no.: HPP-AN28-1

ASHRAE Updates Existing Building Energy Conservation Standard

ASHRAE has updated Standard 100-2006, Energy Conservation in Existing Buildings, to bring it in line with ASHRAE Standard 90.1-2004 and the 2003 ASHRAE Handbook. Other changes allow for newer technology, such as more efficient lighting.

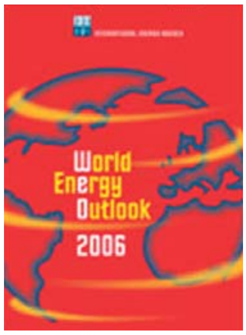
The report can be ordered from the ASHRAE website at www.ashrae.org
Price (33 $ non-members, 26 $ members)

World Energy Outlook 2006

IEA Ministers, meeting in May 2005, recognised that current trends in energy consumption are not sustainable economically, environmentally or socially. At the 2005 Gleneagles Summit and again this year in St. Petersburg, G8 leaders reaffirmed this conclusion. These political leaders called upon the IEA to propose alternative energy scenarios and strategies for achieving a "clean, clever and competitive energy future". The World Energy Outlook 2006 offers a response. Going beyond previous WEO scenarios it projects the impact that targeted policies and more robust deployment of energy technologies could have on sustainability through to 2030.

It also provides in-depth analysis of:

- Economic sensitivity to high energy prices – delayed reaction or new rules?
- Tracking energy investment – is spending appropriate? If not, why not?
- Nuclear energy – investment, adequacy of uranium supply and prospects for new reactors?
- The full economics of biofuels – how far can they take us?
- What impact will Brazil have on global energy markets?
- How can cleaner cooking and heating fuels help to meet the Millenium Development Goals?
- Beyond 2030 – what can technologies offer in the much longer-term?



The World Energy Outlook 2006 provides an objective basis for understanding the drivers of energy markets and is essential reading for decision makers in both government and industry. The World Energy Outlook series has received a number of awards for analytical excellence. For more information about the WEO please see www.worldenergyoutlook.org.

Pre-order now from the IEA Online Bookshop
Benefit from a 10% discount on orders placed before 3 November 2006.
A 30% discount is granted to students and non-profit organisations, a 50% discount to clients from developing countries.

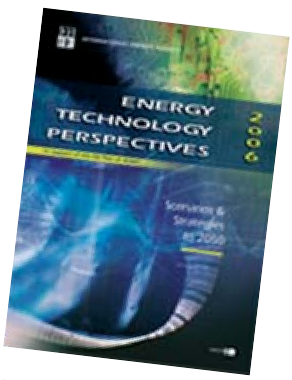
The report can be ordered from the IEA website at www.iea.org

Energy Technology Perspectives: Scenarios and Strategies to 2050

A more secure and sustainable global energy future is certainly within reach. That is the main message in this newly published IEA study. Energy Technology Perspectives: Scenarios & Strategies to 2050 charts pathways for transitioning to a sustainable energy sector by mid-century.

Bringing together the technical expertise of IEA's international energy technology network and IEA's modelling and analytical muscle, this new publication puts forward strategies for attaining energy scenarios unimaginable under current trends. It offers rich detail on the status and prospects of all key energy technologies in power generation, buildings, industry and transport to 2050. Five Accelerated Technology scenarios model differing assumptions about speed of energy efficiency gains and technology market penetration.
Energy Technology Perspectives offers compelling messages for policy makers, notably on the need for a portfolio of technologies to spread risk and costs. A sustainable, secure energy future will hinge on dynamic financial and policy efforts, within both public and private sectors, to streamline and deploy existing or emerging energy technologies and to boost energy efficiency in transport, industry and buildings. Urgent action is needed now to prevent current investment decisions from locking inefficient, high-carbon energy infrastructure into the world's economies.

The report can be ordered from the IEA website at www.iea.org



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2005 ASHRAE Handbook - Fundamentals
2004 ASHRAE Handbook - HVAC Systems and Equipment
2003 ASHRAE Handbook - HVAC Applications

The report can be ordered from the ASHRAE website at www.ashrae.org
Price (499 $ non-members, 249 $ members)

Building Ventilation - The State of the Art

Edited by Mat Santamouris and Peter Wouters

Ensuring optimum ventilation performance is a vital part of building design. This book reviews the main research and industrial achievements in the field of building ventilation, offering professionals an up-to-date framework for further development. Selecting the most appropriate ventilation strategy is made especially difficult by the complexities of airflow behaviour, climatic influences, occupancy patterns and pollutant emission characteristics. Recognizing such complexities, the editors bring together expertise on each key issue, providing an authoritative reference work relevant for all those interested in energy-efficient building design. From components to computer tools, this book offers detailed coverage on design, analysis and performance, and is an important and comprehensive publication in this field.

Contents:
Natural Ventilation in the Urban Environment • Successful Ventilation Case Studies • Analytical Methods and Computing Tools for Ventilation • Ductwork, Hygiene and Energy • Building Airtightness • Ventilation Performance Indicators and Targets • Heat Recovery • Hybrid Ventilation • Ventilation for Comfort and Cooling • Effect of Ventilation on Health and Other Human Responses • Advanced Components for Ventilation • Ventilation Standards and Regulations • References, Index

The report can be ordered from the earthscan website at http://shop.earthscan.co.uk/ProductDetails/mcs/productID/48
Price: £72

2006

Workshop: "Reducing Europe's consumption of fossil fuels for heating and cooling"
10 October
Hotel Silken Berlaymont, Brussels
dusan.jakovljevic@euroheat.org

IKK 2006 Nürnberg - 27. International Trade Fair
18 - 20 October
Nürnberg, Germany
Refrigeration, Air Conditioning, Ventilation
E-mail: http://www.ikk-online.com/main/

ASME International Mechanical Engineering Congress and Expo
5 - 10 November
Chicago, Illinois, USA
Contact: Dr Ahmad Fakheri
E-mail: ahmad@bradley.edu http://www.asmeconferences.org/Congress06

EPIC 2006 AIVC
29 November - 1 December
Lyon, France
The 4th European Conference on Energy Performance & Indoor Climate in Buildings
The 27th Conference of the Air Infiltration & Ventilation Centre
Conference of the IEA Programme on energy conservation in buildings & community systems
Conference Secretariat:
Tel: + 33 (0)4 72 04 70 27
Fax : + 33 (0)4 72 04 70 41
E-mail: epic2006aivc@entpe.fr
http://epic.entpe.org

5th International Conference on Fluid and Thermal Energy Conversion 2006
10 - 14 December
Jakarta, Indonesia
E-mail: nathan@termo.pauir.itb.ac.id
http://www.uic.edu/labs/trl/ftec.home/

7th International Conference on System Simulation in Buildings (SSB)
11-13 December
Liège, Belgium
SSB'2006 Secretariat: Vincent Lemort
Tel: +32 (0)4 366 48 00
Fax : +32 (0)4 366 48 12
E-mail: thermoap@ulg.ac.be
http://www.ulg.ac.be/labothap/ (Go to: Meetings/SSB'2006) Second announcement and call for papers

2007

The 4th International Workshop on Energy and Environment of Residential Buildings (IWEERB2007)
15 - 16 January
Harbin, China
Contact: PhD Jianing Zhao
School of Municipal & Environmental Engineering
Harbin Insistute of Technology
Tel: 86-0451-88776496
Fax: 86-0451-6282123
E-mail: iweerb2007@hit.edu.cn or sky-lcy@163.com
http://indoorair.hit.edu.cn

Natural Refrigerant Heat Pumps Theory and design of CO2 systems
25 - 26 January
Lyon, France
E-mail: info@greth.fr
www.greth.fr

ASHRAE Winter Meeting
27 - 31 January
Dallas, USA
E-mail: jyoung@ashrae.org
www.ashrae.org

2007 European Renewable Energy Policy Conference
29 - 31 January
Brussels, Belgium
conference@erec-renewables.org
http://www.erec-renewables.org/events/2007PolicyConference/default.htm

2nd International Conference on Magnetic Refrigeration at Room Temperature
11 - 13 April
Portoroz, Slovenia
info@thermag2007.si
http://www.thermag2007.si/

HEAT - SET 2007 Heat transfer in components and systems for sustainable energy technologies
18 - 20 April
Chambery, France
E-mail: info@greth.fr
www.greth.fr/heatset

Ammonia Refrigeration Technology for Today and Tomorrow
19 – 21 April
Ohrid, Republic of Macedonia
Contact: Risto Cikonkov
Tel.: +389 2 3064 762
Fax: +389 2 3099 298
E-mail: ristoci@ukim.edu.mk
www.mf.ukim.edu.mk/web_ohrid2007/ohrid-2007.html

8e Colloque Interuniversitaire Franco-Québécois
sur la thermique des systèmes
28 - 30 May
Montréal, Canada
Contact : Stanislaw Kajl
Tel : 1-514-396-8517
Fax : 1-514-396-8530
Stanislaw.Kajl@etsmtl.ca
http://www.cifq2007.etsmtl.ca/
The colloquium is held in French but open to everybody

CLIMA 2007
9th REHVA World Congress, endorsed by ASHRAE
10-14 June
Helsinki, Finland
E-mail: info@clima2007.org
http://www.ashrae.org/clima2007

Energy Efficiency in Motor Driven Systems
10-13 June
Beijing, China
eemods07@copper.org.cn
http://www.eemods.cn/

22nd IIR International Congress of Refrigeration (ICR2007)
21 – 26 August
Beijing, China
Contact: Qiu Zhongyue
Tel: +86 10 6843 4683
Fax: +86 10 6843 4679
E-mail: icr2007@car.org.cn
http://www.icr2007.org

10th International Building Performance Simulation Association Conference and Exhibition
3 – 6 September
E-mail: bs2007@tsinghua.edu.cn
http://www.bs2007.org.cn/

Fan Noise 2007
17 – 19 September
E-mail: info@fannoise2007.org.
http://www.fannoise2007.org/

2nd International Conference SOLAR AIR-CONDITIONING
18 - 19 October
Tarragona, Costa Dorada, Spain
Organisation Commitee:
Das Ostbayerische Technologie-Transfer-Institut (OTTI e.V.)
Regensburg, Germany
Tel: +49 941 29688-29/-37
Fax +49 941 29688-17
E-mail: gabriele.struthoff-mueller@otti.de
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For further publications and events, visit the HPC internet site at http://www.heatpumpcentre.org.

In the next Issue

Retrofit heat pumps for buildings

Volume 24 - No. 4/2006

International Energy Agency

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

IEA Heat Pump Programme

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

Vision

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

Mission

The Programme serves the needs of policy makers, national and international energy & environmental agencies, utilities, manufacturers, designers & researchers. It also works through national agencies to influence installers and end-users.
The Programme develops and disseminates factual, balanced information to achieve environmental and energy efficiency benefit through deployment of appropriate high quality heat pump, refrigeration & air-conditioning technologies.

IEA Heat Pump Centre

A central role within the programme is played by the IEA Heat Pump Centre (HPC). The HPC contributes to the general aim of the IEA Heat Pump Programme, through information exchange and promotion. In the member countries (see right), activities are coordinated by National Teams. For further information on HPC products and activities, or for general enquiries on heat pumps and the IEA Heat Pump Programme, contact your National Team or the address below.

The IEA Heat Pump Centre is operated by

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IEA OECD heat pump centre

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