IEA Heat Pump CENTRE
NEWSLETTER

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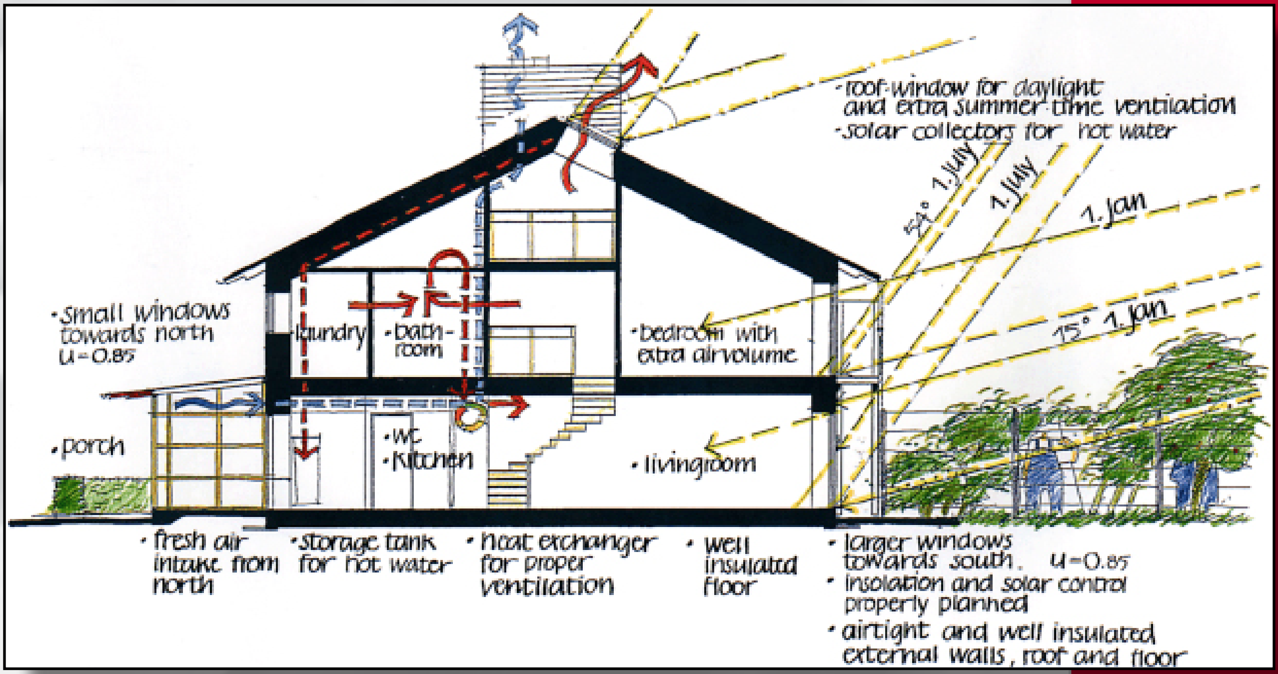
No. 2/2008

Heat pumps for low energy buildings

A low-energy commercial building with ground-source heat pumps

Performance of a Ground Source Heat Pump System in a Near-Zero Energy Home

Integrated CO_2 heat pump systems for low-energy and passive houses



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In this issue

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Energy efficiency is one of the main means of curbing global CO2 emissions. In its Energy Technology Perspectives 2008, IEA has shown that many energy-saving measures in the building stock can actually be accomplished at negative cost.

Low-energy and passive houses are one way of reducing the building energy demand by improvements in the building envelope, and using efficient technologies to maintain a good indoor climate. Have heat pumps a role to play in low-energy houses? Will they become obsolete?

Research has shown that, on the contrary, heat pumps can play a significant part in delivering the additional space heating needed, as well as the hot water supply in low-energy houses.

In this issue, some examples are presented on cost-efficient use of heat pumps for low-energy houses.

In the very successful IEA Heat Pump Conference in Zurich, a workshop on the ongoing Annex32, Heat Pumps in Low-Energy Buildings, presented a number of new and innovative ways of using heat pumps. There will be a detailed report from the conference in the next issue of HP News, but you can read about the Ritter von Rittinger prize recipients in this issue.

I wish all readers a well-deserved summer vacation, and hope to hear from you again in August!

Roger Nordman
Editor, HPC Newsletter

Heat pump news

Features

Topical article

COLOPHON

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Heat pumps for low energy buildings

Antonio Bouza
U. S. Department of Energy

The theme for this edition of the Newsletter is Heat pumps for low energy buildings. It is also the topic of the HPP Annex 32 – Economical heating and cooling systems for low energy homes. The U.S. Department of Energy's Energy Efficiency and Renewable Energy (EERE) Building Technologies Program (BT) is collaborating with researchers in eight other HPP member countries (Austria, Canada, Germany, Japan, the Netherlands, Norway, Sweden, and Switzerland) in this important Annex. Included in this issue is a summary of Annex 32 provided by the Operating Agent (Wemhöner) along with a number of relevant topical articles from several countries covering heat pump applications in low energy buildings. DOE/BT's primary focus with respect to Heating, Ventilation, Air Conditioning (HVAC) and Water Heating (WH) system R&D is to address the critical needs to achieve net-zero energy performance in homes (ZEH) by 2020 and commercial zero energy buildings (ZEB) by 2025.

DOE/BT's HVAC/WH R&D efforts will focus on system energy consumption, rather than simply EER or SEER, which do not capture the impacts of the entire system. HVAC/WH equipment also need to be designed specifically to meet anticipated ZEH building loads (e.g. cooling, heating, dehumidification and domestic hot water), which will be quite different in magnitude and relative proportions than those of current homes. Achieving the ZEH/ZEB goals will require the development of cost-effective, highly efficient heat pump systems that reduce energy consumption by over 50% relative to existing systems. Current activities with respect to heat pumps center around three main areas: Integrated Heat Pumps (IHP), Ground Source Heat Pumps (GSHP), and Heat Pump Water Heaters (HPWH). Both air and ground source IHPs are being explored that can combine heating, cooling, ventilation, humidity control, and water heating into one unit. This effort comprises the primary US input to Annex 32. With respect to GSHP, research focuses on means to address the market barrier of high installation cost. HPWH research focuses on development and deployment of high efficiency water heaters leading to significant energy savings. Additional information can be found in the BT Program Multi-Year Plan, at http://www1.eere.energy.gov/buildings/mypp.html

I am pleased to introduce this Newsletter issue, which includes several interesting articles on heat pump applications to low energy residential and commercial buildings in Canada (Genest and Minea), Japan (Nagano, Kohei), Norway (Stene) and the U.S. (Liu). These articles show clearly the interest and activity around the world.

I look forward to productive collaboration with my IEA Heat Pump Program colleagues to make low-energy-use buildings a market reality in the coming years.

Antonio Bouza

Heat pumps and low energy buildings win the palm

Carsten Wemhöner
Operating Agent, Annex 32

In many countries, the building sector accounts for up to 40 % of the country's total energy consump¬tion and CO_2 emissions. Building regulations have therefore increasingly been tightened up since the middle of the 1990s, in order to reduce the space-heating energy requirements of buildings.

To construct a low-energy house requires good thermal insulation, a compact, thermal bridge-free and airtight building envelope, and high-quality double or triple glazing. The use of passive solar gains and a mechanical ventilation system with heat recovery further reduce the energy requirement. Typical advantages of low-energy houses are high building quality, lower energy consumption and better indoor comfort with limited additional investment costs.

The proportion of low-energy houses is increasing in many countries In Switzer¬land, about 30 % of new buildings comply with the Swiss MINERGIE label, defining a good low-energy house. Germany, meanwhile, has about 5000 passive houses with a space heating energy requirement of less than 15 kWh/(m^{2}a), and about 68000 energy-saving houses with a primary energy requirement of 40 or 60 kWh/(m^{2}a), which are supported by subsidies of the government. In Austria, about 1700 passive houses have been built by 2006, and in Norway, the number of low-energy houses being designed or built increased from 2000 in 2006 to 10000 in 2007.

Summarising, low-energy buildings have growing markets and are considered as a major strategy to reach Kyoto targets, in particular by retrofitting the existing large building stock to low-energy standard.

However, to gain full benefits from low-energy buildings, building techno¬logy must also be adapted to the specific needs. Heat pumps have parti¬cular advan¬tages in terms of energy-efficiency, environmentally sound operation, independence of fossil fuels and market-available capacity range, and have already considerable market shares in low-energy buildings.

Heat pumps specifically designed for low-energy houses have already been introduced in the market, and development continues. Annex 32 of the IEA Heat Pump Programme is dedicated to evaluation of systems on the market and further development of heat pump systems for application in residential low-energy buildings. Some of the national contributions are presented in this issue of the HPC Newsletter.

One part of the work of IEA HPP Annex 32 is concerned with new system concepts and layouts in combination with a prototyping of the units and laboratory testing, while the other is concerned with field testing of marketable units and new systems. Development is concentrated on heat pumps in the 3 5 kW capacity range, and include the use of natural refrigerants.

System integration to multifunctional heat pumps seems a particular promising solution, since ventilation and (increasingly) space cooling function are often requested by the occupants. A compact integrated design could cover the different building needs with the benefit of internal heat recovery and a minimum of installation costs and space. The integration of further functions is therefore a further issue, and one project is dedicated to a highly integrated unit covering all building services, including humidification and de¬humidification.

The results to be expected from Annex 32 are lab-tested new system concepts as well as field-tested best practice systems. In due course, an evaluation of system design will be carried out, resulting in design recommendations for a robust and reliable system of this type. Information on monitoring techniques and energy balancing are further results of the field testing. Interim results and information can be found on the Annex 32 website at http://www.annex32.net.

Building and heat pump markets both show the same tendencies: Heat pumps in low-energy buildings are one step towards future sustainable energy use in the built environment.

Carsten Wemhöner

IEA Executive Director, Mr. Nobuo Tanaka speak at G8 meeting in Aomori, Japan

Distinguished Ministers, it is a great honour to have been invited to participate in this event, and I would like to thank the Japanese Government for the opportunity.

In recent years attention has been focused on negotiations to set a greenhouse gas emissions reductions target. But a target alone will not miraculously solve the problem. What is needed is practical action to transform our energy system. With this in mind, during the Gleneagles Summit in 2005 the G8 asked the IEA to "advise on alternative energy scenarios and strategies aimed at a clean, clever, competitive, energy future". Today I will share with you the key findings of the 3-year work program we launched in response to this request.

Let's start with our work on energy scenarios and strategies. The Energy Technology Perspectives 2008 publication describes how we can address our energy challenges using today's technology and tomorrow's innovation. It demonstrates that cutting emissions by 50% by 2050 is achievable but tough. We would need to achieve very large improvements in efficiency. We would need to substantially de-carbonise power generation. And we would need to make an eightfold reduction in the carbon intensity of transport. Of course, if we can succeed in this we could also make a big contribution to energy security.

In terms of energy efficiency, we have developed a set of 25 recommendations across seven priority areas. If implemented globally, they could save around 8.2 Gt of CO_2 per year by 2030. This is greater than the current energy related CO_2 emissions from the USA and Japan combined. They would also reduce global energy demand by an amount comparable to the total current energy consumption of the USA.

The triple-win potential of energy efficiency -- higher economic performance, higher energy security and less climate change -- leads to three recommendations: implement, implement, implement. With this in mind, in time for the Summit, the IEA will prepare scorecards to monitor the progress that countries are making against the efficiency recommendations. It is already clear that everyone has areas for improvement.

We have also developed energy indicators which are used in setting efficiency standards and to identify policy best-practices. This work has shown that significant energy efficiency improvements have already been made but a lot of potential remains. For example, if all newly built coal-fired units were state of the art it would be possible to reduce up to 1.7 billion tonnes per year of CO_2 emissions. This slide gives another example, this time for the iron and steel industry, where the global adoption of best practices could save up to 3.2 Gt of CO_2 per year.

To continue this work on energy indicators we need to improve data quality and availability. I am therefore calling upon all countries gathered here to commit to improving and sharing the necessary energy efficiency data with the IEA.

As I mentioned, decarbonising the power sector will also be essential. This can be achieved through renewables, nuclear power, and the capture and storage of CO_2 emissions from coal or gas plants. There is a degree of choice, for each country, as to the balance of these technologies that you chose. But action is needed urgently, and the costs are substantial. For instance, just as part of efforts to meet a 50% cut in emissions, we would need to build 14,000 large wind turbines and 32 nuclear power plants every year between now and 2050.

Some of the technologies that will be needed are not yet available, and others require further refinement and cost reductions. A huge effort of research, development, and demonstration will therefore be needed.

To guide this process, we have made a first attempt on 17 energy technology roadmaps which outline the steps needed to bring the technologies through to commercialisation. This slide shows the example of the Carbon Capture and Storage. It calls for the construction of at least 20 demonstration plants over the course of the next twelve years, at a cost of US$1.5 billion per plant. Such a program should be seen as one 'litmus test' of our seriousness of combating global warming. Commitment to fund CCS, including through the clean development mechanism, could serve as a trigger for the deployment of this critical new technology. Continuing this work on technology roadmaps must be viewed as a priority. lease allow me to conclude by emphasising that the IEA was extremely proud to have been involved in the Gleneagles Plan of Action.

Our work has demonstrated that we must treat energy security and climate policy as two sides of the same coin. To solve these challenges we will need a global energy revolution to transform the way we produce and use energy. Policy makers must set the policy framework within which industry can respond to the climate change challenge without detriment to their competitive position. We will therefore need to put an appropriate cost on carbon and draw upon the full range of mechanisms including sectoral approaches. Decisions have to be taken now and implementation has to begin now. The primary scarcity facing the planet is not of natural resources nor money, but time. Thank you.

Nobuo Tanaka

IIR 100th anniversary conference in Paris

The 1st International Congress of Refrigeration took place in Paris in 1908. It was followed by the creation of the International Institute of Refrigeration (IIR), the French Refrigeration Association (AFF) and several other national associations (The Netherlands, Serbia,..).

The IIR and the AFF thus decided to organize a 1-day conference, in Paris, in order to celebrate their 100th anniversaries and a new century of new technologies to come: “Hundred years at the service of the development of refrigeration and its applications”.

This conference took place on June 12, 2008 at UNESCO and there were 437 attendees, with about 100 people from countries other than France, from all continents. The conference was bilingual (English-French). The speakers came from all over the world, thanks to the IIR member network.

After an introduction on the history of refrigeration in general, four refrigeration applications were presented, with several speakers from the industry and universities explaining the history, the state of the art and the future of these uses: cryogenics, health, air conditioning and food.

In the afternoon, a video produced by the IIR and showing the economic and technical challenges of refrigeration and its uses introduced two round tables.

The first one, introduced by the head of the ozone unit at the United Nations Environmental Programme, focused on sustainable development: how to continue to develop refrigeration (necessary, particularly for developing countries) and to mitigate global warming, with various solutions proposed by various private companies.

The second one was a debate on technological perspectives (new technologies for refrigeration, new refrigerants) involving scientists from all over the world. The debate, presenting various competing solutions, was lively.

Afterwards, several medals were awarded and a dinner on the top floor of UNESCO concluded this prestigious but really interesting event, presenting such a comprehensive overview of refrigeration technologies and their future.

For more information, please consult the site of the IIR where you will find the video and the various presentations: www.iifiir.org

General

Current condition "Renewable Energy and Heating Act"

In Germany, the Renewable Energy and Heating Act, EEWärmeG, should come into force in 2009. The Federal Government wants to increase the percentage of heat supplied from renewable energy from 6 % to 14 % by 2020. Owners of new buildings will be compelled to meet their buildings' energy requirements with renewable energy. This requirement should not only reduce the use of fossil-fired cogeneration, but also increase the use of thermal insulation. Around 400.000 radiators are changed annually in old buildings, due to the improvement incentives offered by MAP. The Federal Government had agreed to most of the changes suggested to the draft bill put forward by the Federal Council of Germany on 15th February 2008. These concerned a simplification of procedures for the legal liberation possibilities. Suggestions which lead to the slowing down of requirements will not be complied with.
Source: energy-server newsletter Issue 86

EIA: U.S. carbon dioxide emissions increased 1.6 % in 2007

A growing U.S. economy, more extreme weather conditions and a drop in hydro power production pushed up U.S. carbon dioxide emissions from energy use by 1.6 % in 2007, according to preliminary estimates by DOE's Energy Information Administration (EIA). The agency notes that the U.S. gross domestic product (GDP) increased by 2.2 % in 2007, while more energy was needed for both heating and cooling relative to 2006. In addition, electricity generation increased by 2.5 % and carbon dioxide emissions from the power sector increased even more, at 3 %, indicating that U.S. utilities shifted towards energy sources that emitted more carbon. That shift was partially caused by a 40 TWh decrease in hydro power production, causing a greater reliance on natural gas and coal. Carbon dioxide emissions from power plants fuelled with natural gas increased by 10.5 %, while coal-burning power plants increased their emissions by 1.8 %.
Source: EERE Network News

Refrigerants and replacements top commercial contractors' lists

Considering the changing climate and evolving technology, rooftop units and their components present interesting challenges to the commercial contractors who install and maintain these systems. After talking to some commercial contractors, new refrigerants and the replacement market are two concerns populating a commercial contractor's weekly checklist. The 2010 R-22 phase-out deadline is an inevitability that the industry is preparing to embrace. With the changing refrigerant requirements, the rooftop replacement market is the next area to address.
Source: ACHR News

Coca-Cola announces commitment to CO2 refrigeration

Neville Isdell, chairman and CEO of the Coca-Cola Co., in remarks made at the Greenpeace China Business Lecture Series, announced that Coca-Cola and its bottlers will purchase and deploy 100,000 CO2 coolers by the end of 2010. According to the company, this will be the largest deployment of CO2 technology by any firm.
Source: ACHR News

'Ambitious' EU eco standards in the making

Current standards and labelling schemes for appliances and office equipment are insufficient in the light of the EU's climate change agenda, and need to be expanded to a range of non energy-consuming products.
Brussels wants to expand the scope of the EU's Eco-Design Requirements for Energy-Using Products (EuP) Directive to include non energy-using products as a central part of a new action plan. Brussels laments that existing rules for 'energy-using products only account for 35/40 % of the environmental impacts of products', and that there is a lack of coordination between regulatory instruments and voluntary initiatives, as well as a disconnect between different national and regional schemes.

In addition, current EU standards regulations and labellings schemes - notably the Ecolabel Regulation, the Energy Efficiency Labelling Directive, and the Energy Star Programme - have had only limited successes in reducing EU CO_2 emissions while lessening the environmental impact of production and consumption patterns, according to the Commission.
Source: Euractiv newsletter

Working Fluids

A carbon dioxide refrigeration training facility has been unveiled by WR Refrigeration.

The facility, baseed at the company's newly-opened Birmingham branch, will be used to train WR's UK network of more than 300 installation and service engineers in carbon dioxide-based refrigeration technology. Hugh Cole, managing director of WR Refrigeration, said: "Natural refrigerants, and carbon dioxide in particular, have an important role to play in the future. They may not take over from traditional technology in all applications, but it is going to be a significant part of the overall mix."
Source: http://www.acr-news.com/news/news.asp?id=887i

Refrigerant metering system from Emerson climate technologies

Emerson Climate Technologies introduces the Refrigerant Metering System, which enables users to monitor and track refrigerant usage. This helps users to maintain compliance with the Environmental Protection Agency's reporting and record-keeping requirements for Class I and Class II refrigerants. With meters and valves, the system measures the amount of refrigerant a service provider adds to a refrigeration system over time. The system's integrated computer then stores this data, making it available locally and remotely.
Source: The HVAC&R Industry

Natural alternatives to HCFCs explored in Montreal

As countries discuss whether to adopt a speedy phase-out of HCFCs within the frame of the Montreal Protocol, to avoid further ozone depletion effect from these refrigerants, the European Commission held a specialized workshop on 5-6 April to explore alternatives for refrigeration and foam-blowing applications. Next to minimizing ozone depletion, alternatives were evaluated for their global warming impact. Therefore, several applications based on CO2 and other natural refrigerants attracted high interest from experts from private and public institutions.

This meeting, according the European Commission, is the first in a series of events that will serve thoroughly to evaluate different alternatives and help countries decide the best options to suit their specific situations.
Introducing the workshop, the Technology and Economic Assessment Panel (TEAP), a specialized body within the UN Environment Programme, gave an overview of the current use and impact of HCFCs. Figures show that the actual use of this ozone-depleting substance in 2005 and 2006 was much higher than the highest estimates from industry and public sources. TEAP recommended focusing on significant markets to minimize the emissions, and looking carefully into low-GWP alternatives.
Source: www.r744.com

Technology & Applications

ASHRAE Technical Program focuses on benchmarking

The 2008 ASHRAE Annual Meeting technical program focuses on establishing a basis for measuring performance of buildings. The program features more than 100 sessions covering topics such as failed moisture management, water conservation in systems and the recently published Advanced Energy Design Guide for K–12 Schools.
Source: www.ashrae.org

DOE initiates rulemaking for air conditioners, heat pumps

The U.S. Department of Energy (DOE) has begun a three-year rulemaking and data collection process for establishing amended energy conservation standards for residential central air conditioners and heat pumps.
A final rule is expected to be published in 2011, and the new standards will become effective in June 2016.
Source: www.ahrinet.org

Field test electro-heat pumps. Geothermal energy system.

The local agenda-group 21 environment/energy in Lahr and the Ortenauer energy agency examined the efficiency and profitability of 33 heat pumps and five domestic hot water heat pumps (German) in a two- year field test. The plants (with a maximum age of four years) from different producers use air, ground and groundwater as heating sources. The annual working hours sometimes differ quite significantly from the manufacturer's data. The best results were obtained from geothermal energy systems combined with underfloor heating, with an average SPF of 3.4, followed by air heat pumps at 2.8, and domestic hot water heat pumps at only 1.9. The efficiency is clearly downgraded by buffer storage, if panel heating is used.
Source: energy-server newsletter,Issue 84
Read the German report here:
http://www.erdwaerme-zeitung.de/Feldtest%20WP-Bericht-2006-07.pdf

Bock has developed a piston compressor range for CO_2 applications

Based on its current semi-hermetic product range and building on extensive experience in the transport sector, Bock has developed a piston compressor range to fit all CO_2 (R744) applications of up to 40 bar in supermarket and industrial refrigeration. Through modification of existing technology and an extensive use of tried-and-trusted standard parts, Bock's compressors permit the greatest possible level of operational safety and an economic spare part storage. Their solid construction with low friction sleeve bearings, aluminium piston with two-ring assembly, and high-resistance piston bolt bearings, ensures a wear-resistant durable driving gear, which leads to substantial life cycle cost reductions. Moreover, a valve plate construction using impact-resistant spring steel parts, tested thoroughly all over the world, ensure that the compressors operate safely.

Through a continuously variable speed control system installed on the compressor – the Bock EFC-System, available as a plug & play accessory for models HG12P, HG22P, and HG34P, Bock's models consume up to 25 % less energy than do compressors using a conventional capacity regulator, while operating at low vibration and noise levels. All types use with a special oil to allow good mixing solubility with CO_2 while protecting the compressora gainst wear even at extreme loads.

Source: www.r744.com

New energy-saving label for heat pumps

Danish Electricity Saving Trust has prepared the introduction of a new energy-saving label for air-to-air heat pumps installed in second and holiday homes in Denmark. This segment accounts for more than 200,000, properties and the purpose is to reduce electricity consumption.

The suggested criteria are based on product descriptions and test methods from the Danish Institute of Technology. Producers and distributors of air-to-air heat pumps are asked for their comments before May 20th to Per Henrik Pedersen, Danish Institute of Technology.

The full report will be published in the September issue of ScanRef.
Suggested criteria (all of which must be fulfilled) to qualify for the Danish Electricity Saving Trust's recommended energy-saving label for air-to-air heat pumps (hereinafter referred to as "the device") are as follows:

1. The device must be energy efficient and must be classified as "A" in heating mode in accordance with the "European Commission Directive 2002/31/EC implementing Council Directive 92/75/EEC with regard to energy labelling of household air-conditioners", which specifies that reverse cycle systems must also be energy-labelled in the heating mode. This requirement must be verifiable by random testing and the standard accreditation test based on EN-14511 at +7/+20 C, specified humidity and the "rated capacity" as stated by the producer.
2. Based on supplementary tests carried out in accordance with EN-14511, COP must also conform to the following: A) ≥ 2.8 at +2/+20 C at full load with humidity per the defined standard; B) ≥ 2.5 at -7/+20 C at full load with humidity per the defined standard. Energy efficiency must be verifiable by random testing.
3. The device must be capable of being adjusted down to an indoor temperature of max. +10 C. This should be achievable by the integrated control unit fitted to the heat pump.
4. The device must be fit for purpose in the Nordic climate, and should be capable of defrosting in low room temperature conditions. This feature must be verifiable by random testing.
5. The device must be installed by professional refrigeration or heat pump installers, and all accompanying literature pertaining to the device should state that the device must be installed by an authorised professional installer. The relevant recommend list on the Trust's website will provide a link to the websites of professional installers in Denmark at www.koeleteknik.dk and www.vp-ordning.dk.
6. Any device sold on the Danish markets must be supported by a stock of spare parts, service network, etc. This can be achieved by offering a 3-year extended warranty.

Criteria 1-4 above will normally be covered in the documentation in support of the application, which must contain test reports covering the relevant operating modes, together with a written declaration on minimum room temperature and fitness for purpose in relation to the Nordic climate, including the appropriate defrosting function.

Criteria 5-6 will be deemed to be satisfied where the device appears on the Danish Technological Institute's list of approved devices, or on the basis of written documentation, including the offer of a 3-year extended warranty.

The Danish Electricity Saving Trust draws attention to the fact that this is a voluntary scheme, and that inclusion on the list is free of charge. Applicants are required to sign a contract with the Trust, which will indicate amongst other things that the distributor in Denmark is committed to making a device available for random testing.

Source: ScanRef Newsletter May 21 2008

Humidity control thermostat from emerson climate technologies

Emerson Climate Technologies introduces the Big Blue™ humidity-control touchscreen thermostat. The universal thermostat controls single-stage, multistage, and heat pump systems with up to four stages of heating and two stages of cooling. It offers two selectable program schedules or can be

dedicated non-programmable. It has up to four time and temperature settings per program.
Source: The HVAC&R Industry

IBM introduces energy-efficient water-cooled computer

IBM introduced a new supercomputer on April 8 powered by one of the world's fastest microprocessors and cooled by an innovative water system. The Power 575 supercomputer uses water-cooled copper plates located above each microprocessor to remove heat from the electronics. According to the company, the computer can reduce typical energy consumption used to cool the data center by 40 %. IBM scientists estimate that water can be up to 4000-times more effective than air in cooling computer systems.
Source: The HVAC&R Industry Newsletter

DOE & national laboratories project targets commercial viability for enhanced geothermal systems

Ormat Desert Peak Aims to be First U.S. Commercial Power Project Using EGS
Work has begun on the first application of an Enhanced Geothermal System (EGS) utilizing a production well at a commercial geothermal site. This project will demonstrate the viability of EGS and the technology's potential to generate clean, renewable baseload geothermal electricity in many areas throughout the country.

"Ormat anticipates Desert Peak will be the country's first commercial project to tap into an EGS resource and produce substantial levels of electricity providing a rebirth for certain geothermal prospects in the U.S.," said Ormat Chairman and Chief Technology Officer Lucien Bronicki. "Our objective in the Desert Peak EGS project is to demonstrate that EGS technology can achieve its potential of providing 100,000 MW of clean, baseload power, as identified in last year's DOE study by Massachusetts Institute of Technology, and show that this technology will enable geothermal electricity to be produced in regions where it is not currently economically viable," he added.

Bronicki noted that the participants in this R&D project, include in addition to DOE and GeothermEx, also Idaho National Laboratory, Lawrence Berkeley National Laboratory, Sandia National Laboratory, University of Utah EGI, TerraTek, Pinnacle Technologies and US Geological Survey.

Commenting on the potential of the Desert Peak Resource, Subir Sanyal, President of GeothermEx said: "The Desert Peak resource, which currently supports 11 MW of electricity production from a conventional geothermal resource, is likely to have the potential to support 50 MW or more from an EGS development."
Source: The HVAC&R Industry Newsletter

Efficiency benchmark for German computing centres

At present there are approximately 50,000 computing centres in Germany, and their energy use is enormous. Even though 'green IT' is the hot topic, until now there have not been any widespread measures of energy use by the sector. The eco association of the German internet sector is therefore planning a unique appraisal of the efficiency of German computer centres to establish a benchmark and to create more transparency of market problems. The focus of the appraisal should above all show the energy efficiency.
Source: energy-server newsletter, Issue 85

MIT researchers achieve dramatic increase in thermoelectric efficiency

Nanotech advance heralds new era in heating, cooling and power generation. Researchers at Boston College and MIT have used nanotechnology to achieve a major increase in thermoelectric efficiency, a milestone that paves the way for a new generation of products - from semiconductors and air conditioners to car exhaust systems and solar power technology - that run more cleanly. Using nanotechnology, the researchers at BC and MIT produced a big increase in the thermoelectric efficiency of bismuth antimony telluride - a semiconductor alloy that has been commonly used in commercial devices since the 1950s - in bulk form. Specifically, the team realised a 40 % increase in the alloy's figure of merit, a term scientists use to measure a material's relative performance.
Source: MIT news, http://web.mit.edu/newsoffice/2008/thermoelectric-0320.html

Skanska installs Europe's largest geothermal lake loop

Skanska is close to completing Europe's largest geothermal lake loop to service a new hospital in Mansfield, Nottinghamshire. The company, in conjunction with Geothermal International, is installing a ground source cooling and heating system that will offer Mansfield Hospital 5.4MW of cooling and 5MW of heating.
The system will use a network of heat exchangers submerged in nearby Kings Mill Reservoir, and which are connected to the heat pumps in the hospital buildings. As necessary, the reseroir will provide either a source of, or a sink for, heat to or from the heat pumps.
Skanska spokesman Gerry McNabb said the technology used was popular overseas because it was environmentally friendly and cheap.
He added: "The technology that Skanska and Geothermal International offers makes sense to homeowners and businesses, especially with government emission reduction and renewable energy targets on the horizon."
Source: rewenergy

Markets

Review of the world air conditioning market 2007

In 2007, the world market for air conditioning was valued at US$62 billion, up from US$55 billion in 2006. Asia Pacific is the largest market, with total sales amounting to US$28 billion in 2007. The Chinese market alone was valued at US$12 billion in 2007. Sales of air conditioners in the Total Americas region were valued at US$15 billion, followed closely by Europe with US$13 billion in 2007. The Middle East, Africa and India market was valued at US$5 billion.

The global residential/light commercial market, which includes windows, portables and moveables, was valued at US$39 billion, representing approximately a 14 % increase from the previous year. Minisplits continued to be the largest market segment in terms of value.

In our 2008 report, figures for VRF are presented separately due to the increasing importance of this product group: in 2007 the VRF segment was valued at US$5 billion. The total value of the chiller market (excluding air side products) was estimated at US$7 billion in 2007.

China has become the world largest market for air conditioning. China and the US were almost equal in market value in 2007, but the Chinese market is expected to grow further in 2008 and widen the gap between the two countries.

A growing awareness of green technologies and energy efficiency will continue to have a significant impact on air-conditioning applications in saturated markets, and will support a trend for more advanced products such as inverters, heat recovery and VRFs.

Growth prospects by region

In 2007, the most rapidly growing market (among countries researched in 2007/08) was Ukraine, as the market value increased by over 45 % compared with 2006: this was closely followed by Greece. The growth came from an unexpected surge in minisplit sales due to a long and hot summer in both countries.

Growth prospects by product

- VRF has continued to be the best performing segment, and is expected to grow by around 15 % in value during 2006-2011. Minisplit units of over 5 kW will also show strong growth of over 10 % in value during the same period.
- Centrifugal chillers are expected to perform slightly better than other chiller types, reflecting the strong growth in large construction projects, mostly in the Middle East, Brazil, Russia, China and India.
- Indoor packaged is the flattest market with an annual growth in value of less than 2 %.

Window/through the wall units

Currently, in 25 out of the 46 observed countries, the market for window units continues to decrease. The US is still the largest world market for windows, but sales dropped in 2007 compared with the previous period.

India, the second largest market in the world, will continue its sustained slow growth mostly due to strong demand from customers with low disposable income. However, at the moment, the Indian windows market is experiencing strong competition from minisplits.

Moveables

In 2007, half of the world sales in the moveables market were made in Europe. A hot summer, combined with lack of minisplits stock and, in some countries, installers' availability, prompted the market to double in volume compared with its performance in 2006. However, the market in France plummeted by 75 % and the markets in Spain, UK and Germany also experienced a decline. This was partially caused by customers switching to permanent cooling solutions such as minisplits in anticipation of changes in global weather.

Minisplits

China continues to be the world leader in the minisplits market. The chart shows that the Chinese market for minisplits will grow by 11 million units by 2011. China is the biggest manufacturer in the world, and also the largest minisplit market. With 24 million units sold in 2007, China accounted for nearly half of the world minisplit sales.

Unitary products

The US market for unitary products decreased by US$0.5 million in 2007 compared with 2006, producing an overall decline in the world market value for unitary products. The market for large ducted splits less than 17.58 kW in the US fell by approximately 13 % in 2007, due primarily to the ailing US housing market. Approximately 80 % per cent of all ducted split systems are sold to the residential sector. Overall in the world, total sales of rooftops and indoor packaged remained flat compared with 2006.

Chillers

China, the biggest world chiller market, reached US$1.6 billion by value in 2007. Growing rapidly at 19 % per year, the market value of the Middle East and Africa region is expected to equal that of the total Americas region by 2010. India was ranked as the sixth largest market by value in 2007, but was the second most attractive market in terms of growth " by 2011, this market's value is expected to increase by around US$360 million.

Reciprocating chillers continue to disappear from the majority of markets and are expected to remain a niche, mostly process cooling application.

Centrifugal chillers boomed in the fastest emerging world construction markets - Brazil, Russia, India, China and the Middle East - all of which have a strong potential for further growth.
Source: www.bsria.co.uk

AHRI commends new ENERGY STAR® water heater program

The U.S. Department of Energy (DOE) will launch a new ENERGY STAR® program for residential water heaters, effective Jan. 1, 2009. It covers gas-fired storage, gas-fired tankless, heat pump and solar water heaters.
The program for gas-fired storage water heaters will take effect in two phases. For the first 19 months of the program, these water heaters must achieve an Energy Factor of .62 to qualify for the ENERGY STAR label, but on Sept. 1, 2010, the program criteria requirement changes to require an Energy Factor of 0.67 to qualify. Learn more about the program requirements and performance criteria on AHRI's Web site.
AHRI will continue to work with DOE to expand the scope of the ENERGY STAR program for water heaters to include other technologies and energy sources such as electric water heaters with resistance elements and oil-fired water heaters.

Residential heat recovery in Europe

The European market for heat recovery is set for continued growth. It is estimated that sales reached approximately 207,316 units in 2007, which is a 12 % increase from 2006. Germany is the most dominant country in the heat recovery market, with approximate sales of 51,400 units in 2007, closely followed by Finland, UK and Netherlands.

One of the main drivers for this the growth is the change in legislation and construction. New legislation has guaranteed that building standards across Europe place a high emphasis on minimising energy consumption and rising energy prices have made consumers more receptive towards alternative energy resources.

Sweden is a key driver for renewable energy policies and energy saving measures in Europe, therefore encouraging the use of heat recovery systems. At the moment, Swedish renewable energy use stands at 28 %, but the Swedish government has set a target of 49 % of the country's energy use to be supplied from renewable sources by 2020. Heat recovery units are not a new concept to the Swedish consumer, as they have had units installed since the 1980s. The Netherlands is the most developed European country in terms of heat recovery installations, with slightly less than half of all new residential buildings now being equipped with heat recovery systems. Legislation is a key driver of this growth, the European Performance of Building Directive (EPBD) has resulted in a review of the Dutch Building Code, which now states that there must be a minimum level requirement of energy performance in new builds or major renovations.

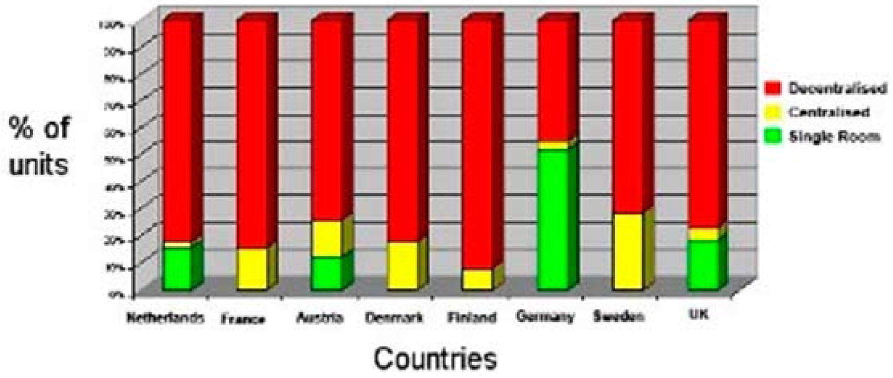
Dedicated heat recovery units are the most common type in the European market. Integrated heat recovery systems, such as heat pumps, are new to the market and therefore do not have a substantial market share, but gradual growth is expected in the future.

Decentralised units are the most common type of product in the European heat recovery market. In Denmark, they accounted for over 80 % of the market by volume in 2007. In terms of heat exchangers, the trend is away from cross-flow and towards counter-flow, although cross-flow is still popular in the UK and Austria. Counter-flow heat exchangers are by far the most popular type in the European market. However, the cross-counter flow type is evident solely in the Austrian market and is most dominant. accounting for 90 % of the market. At nearly 63 %, rotating heat exchangers hold the greatest market share in Sweden, because of their greater efficiency.

The market is driven to a great extent by the residential new-build sector. This is a clear trend in nearly all of Europe, with the exception of Sweden, where there is a slight increase in the residential replacement sector over the residential new-build sector.

Single room units are not popular in the majority of the European countries studied, and the market is almost non-existent in Sweden and France, because of their low capacity of air flow and energy efficiency. In terms of product type, dedicated heat recovery units, mainly single room and decentralised units, are the most popular type in the German market, accounting for more than 80 % of the total market. The vast majority of heat recovery units in Finland are dedicated units, and the larger share of heat recovery units

Figure 1. European market volume by dedicated heat recovery product type 2007E



are made up of decentralised systems that serve a single flat or single dwelling. The most common units are in the 151-400 m^3/h range, because it is the most widespread type used for single dwelling housing.

Distribution channels for heat recovery units vary from country to country. For example, in Sweden, the distribution channel is relatively fragmented and each player's distribution channel varies depending on its end users. Furthermore, in Denmark, the distribution channel differs greatly for centralised and decentralised units. However, in general, the most common route to the market is through specialist installers and wholesalers.

The majority of the European heat recovery market is made up of local players, with the exception of Austria (40-50 players) and Germany, where there are over 100 different brands available. The Danish market is made up of local players, such as Exhausto, Genvex A/S, Nilan A/S, land Villaventilation A/S and Vent-Axia. Stricter legislation is a major obstacle for imported brands in the Danish market, which states that heat recovery units must, at the very minimum, recover 65 % of the lost heat. Many imported brands cannot meet this requirement, and therefore have either left the market or are currently undergoing product development.

OEM activity is increasingly popular in the UK, Germany, and Austria. In Austria, OEM systems account for more than half of the entire market volume, and it is common practice in Germany, accounting for more than two-thirds of the market. The largest OEM supplier is the Dutch company, Brink. In the rest of the European countries studied there was very little or no OEM activity.
Source: www.bsria.co.uk

Cooling equipment shipments accelerate to meet seasonal demand

With the cooling season fast approaching, shipments of central air conditioners and heat pumps for March jumped 75 % compared with last month, according to the Air-Conditioning, Heating, and Refrigeration Institute.

Central air conditioners and air-source heat pumps

Combined U.S. factory shipments of central air conditioners and air-source heat pumps for March totaled 590,192, a 7 % drop compared with the same month a year ago. For the year-to-date, combined shipments totaled 1.2 million, a 7 % drop compared with the same period last year.

Heat pump shipments for March totaled 186,720, a 4.5 % drop from the same month a year ago. For the year-to-date, heat pump shipments totaled 435,331, a 3 % drop compared with the same period last year.

Warm air furnaces

U.S. factory shipments of gas warm air furnaces in March totaled 200,544, a 26 % drop compared with the same month a year ago. Oil warm air furnaces for the same month totaled 4,185, a 26 % drop compared with March 2007 totals. For the year-to-date, gas furnace shipments totaled 528,153, a 17 % drop compared with the same period last year. Oil furnace shipments for the year-to-date totaled 13,710, a 27 % drop compared with the same period last year.

Room heaters

A total of 2,603 unvented room heaters were shipped in March 2008, an 11 % drop compared with the same month last year. For the year-to-date, 12,429 units have been shipped, an 11 % drop compared with the same 3-month period last year.

Storage water heaters

Residential electric water heater shipments for March totaled 380,074, a 14 % drop from the same month a year ago. Residential gas water heater shipments totaled 385,448, a 15 % drop compared with shipments for the same month last year. For the year-to date, 2.1 million residential gas and electric storage water heaters have been shipped, a 9 % drop compared with the same period a year ago.

Commercial gas water heater shipments for March totaled 8,655, dropping 9 % compared with the same month last year, while commercial electric water heater shipments totaled 6,772, jumping 9 % compared with the same month a year ago. For the year-to-date, electric water heaters shipments are 4 % ahead of total shipments of this product during the same period last year. Commercial gas water heater shipments for the year-to-date are down 2 percent, compared with the same period a year ago.
Source: www.ahrinet.org

Air conditioning - UK market review

The UK air-conditioning market is changing. No longer is it a straight fight between fan coils and chilled beams. Variable-flow refrigerant systems are developing into various different guises, with roof-top units showing strong potential for growth. David Garwood presents the headline statistics.

Everybody, it seems, wants air conditioning. In 2006, BSRIA estimates that the total value of the UK air-conditioning market was a little over £692 million. The market is thought to have risen further in 2007. But where are the trends heading?

The market in 2007

There was strong growth in demand during 2007 for new-build and refurbishment of offices. Property developers took advantage of lower borrowing costs. Many manufacturers reported the growth in the market for central plant and packaged products to be positive, as their clients were accelerating construction and refurbishment programmes.
However, with the rises in interest rates and the recent turmoil in the financial markets this is expected to change. It is now more difficult to fund the projects through loans.

BSRIA expects a decline in new orders into 2008. There may be a swing towards refurbishment as opposed to new-build, as budgets will be tighter.

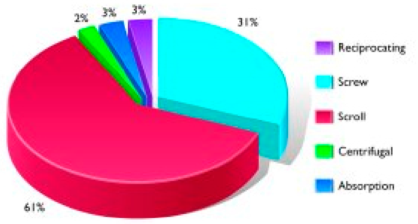


Figure 1: The chiller market by type of compressor, expressed in volume of units (2006)

Rooftop systems

The rooftop market experienced an increase in volume and value in 2006. The market has recovered to levels last seen in 2004. The increase is largely due to investment from the retail sector such as cinemas and fast-food restaurants, which is bucking the trend in consumer spending.

In 2006, rooftop products became available above 200 kW. Together with other recent technology developments, this has allowed rooftop systems to start to penetrate the traditional chiller/air handling unit market. The rooftop product can perform all the requirements of these conventional systems in one box, so it will benefit from applications of low capacity and where plant space is limited.

Air handling units

The total market size for air handling units recovered in 2006 to the level last seen in 2004. The market grew by 13 % in volume and 14 % in value in 2006 over 2005. Modest growth is expected in 2007, as a number of manufacturers reported significant sales on the back of further growth in the UK construction industry, particularly in the office sector and the chiller market as a whole.

Close-control air-conditioning

Manufacturers and suppliers are currently experiencing high demand for close-control equipment, enabling companies to place a price premium on their products. The growth is being driven by a number of factors including:

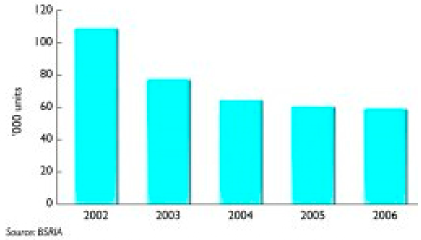
- USA and European accounting Directives
- Development of virtualisation software
- Online broadcasting and videostreaming
- High-density blade servers.

Growth is expected to decline after 2008, as there is only a limited number of merchant banks and other end-users requiring data centres to be built. This will also affect increases in the average price in 2008 and beyond, when pressure on price is expected to be down.

Compressor technology

The market will continue to experience shifts in compressor type, refrigerant and size. There has also been growth in recent technologies such as the Turbocor and inverter screw compressors.

Scroll compressors are continuing to erode the market share of screw and reciprocating chillers through further developments of larger capacity units with R410A refrigerant. But as with screw compressors, scroll compressors are facing increasing competition from VRF systems, especially in refurbishment projects.



Source: BSRIA

Figure 2: Fan-coils have lost share to VRF and chilled ceilings

Reciprocating chillers have lost significant market share. Many manufacturers are no longer including them in their portfolio, and they now account for less than 3 % of the market.

Source: www.bsria.co.uk

Canada's Budget 2008 proposes to include ground-source systems

The Canadian GeoExchange Coalition (CGC) welcomed yesterday's announcement that the Federal Government intends to broaden Class 43.2. Budget Plan 2008 includes GSHP systems used in applications other than industrial processes or greenhouses, for the first time. The Budget will extend Class 43.2 to include applications such as space and water heating in industrial, commercial and residential buildings used for an income-earning purpose.

This announcement is directly in line with CGC Government relations efforts. In September 2007, CGC staff presented a submission to the House of Commons Finance Committee during the Pre-Budget Consultation 2007 entitled "For a Fair & Equitable Tax Treatment of All Renewable and Traditional Energy Sources in Canada". The arguments set forth by the CGC were heard and the Government responded favourably to CGC's expressed concerns. "This is another example of what a national industry association can do to promote a technology and advance the growth of an industry. CGC will continue its Government relations efforts to maintain a level playing field within the energy sector," said Denis Tanguay, CGC President and CEO.

One important element of the announcement requires ground source heat pump installations to meet requirements under CAN/CSA Standard C-448-02. "This is a very intelligent move by the Government, as it reinforces the efforts deployed by the CGC over the past three years to raise the bar in geoexchange design and installation practice," added Denis Tanguay.

Source : The Canadian GeoExchange™ Coalition, www.geo-exchange.ca

IEA Heat Pump Programme

Press release from the IEA Heat Pump Programme 2008-06-19

IEA international heat pump conference a great success

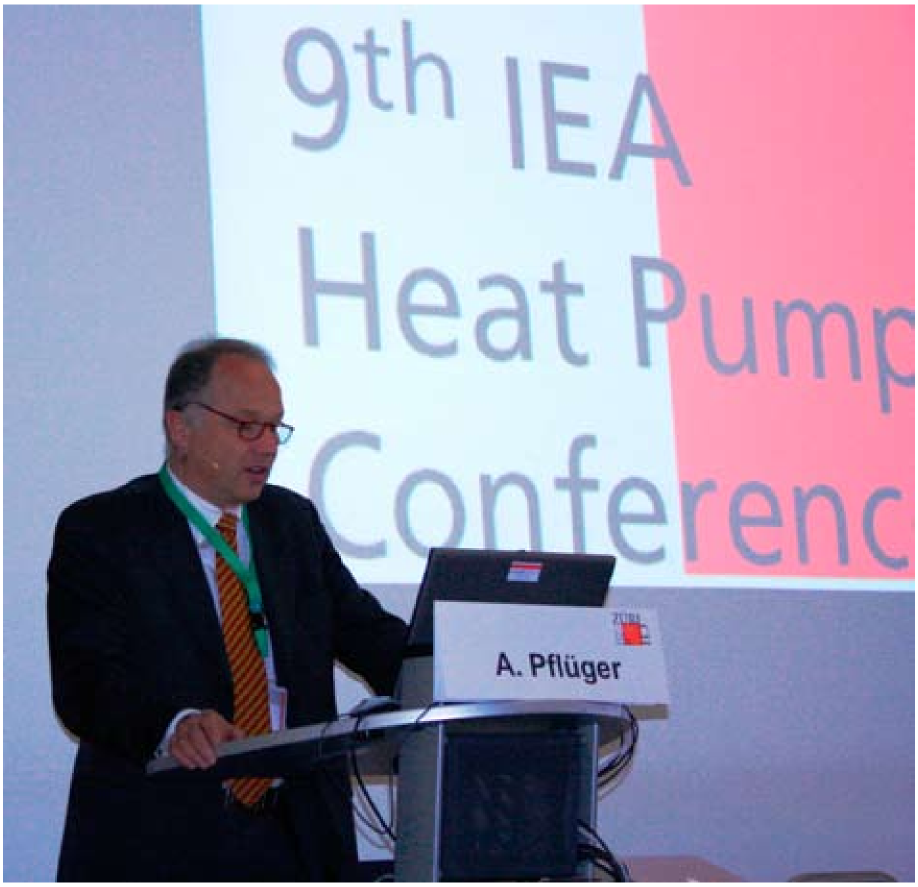
More than 450 people from 36 countries spent some interesting days in Zurich discussing the latest news in research, development, market and policies related to heat pumping technologies. The successful 9th International Energy Agency Heat Pump Conference, held on May 20 - 22 2008, provided a unique international meeting place for experts in the field.

The participants included representatives from governments, utilities, industry, research organizations and other organizations concerned with energy-efficient technologies. The conference program included 71 presentations by plenary, keynote and technical authors in nine sessions covering the theme "Advances and Prospects in Technology, Application and Markets". In addition there were 150 poster presentations related to the field.

The conference has been held every three years since 1984, and is organized by the IEA Heat Pump Programme Executive Committee to provide a status review of progress in the introduction of heat pumping technologies.

All ongoing international projects within the IEA Heat Pump Programme held workshops with presentations of the latest news related to ground source heat pumps, low-energy buildings, heat pumps for the retrofit market, compact heat exchangers and thermally driven heat pumps.

The Best Poster Award was made for the first time at the conference. The two poster award recipients were "Performance characterisation of a reversible water-to-water heat pump" from Spain, and "System performance of HVAC in a low-energy house in the cold region of Japan" from Japan.



At the conference banquet the second Peter Ritter von Rittinger International Heat Pump Awards were presented to three individuals in recognition of their contributions to international collaboration in advancing heat pump technologies: M. Sc. Gerald C. Groff of the U.S., Professor Eric Granryd of Sweden, and Professor Predrag S. Hrnjak of the U.S.

The conference partners were:
The International Institute of Refrigeration (IIR)
The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
The Swiss Association for the Promotion of Heat Pumps (FWS)
The European Heat Pump Association (EHPA)

Press release from the IEA Heat Pump Programme 2008-06-19

Researcher from the University of Illinois awarded with international heat pump medal

Professor Predrag S. Hrnjak from the University of Illinois at Urbana-Champaign, was awarded the 2008 Rittinger Medal at the International Energy Agency Heat Pump Conference held on May 20-22 in Zurich, Switzerland.

Predrag S. Hrnjak

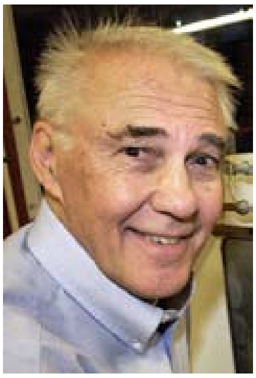
Predrag S. Hrnjak obtained his Master's degree and Doctorate at the University of Belgrade. He broadened his international experience with visiting professorships at the Danish Technical University and the University of Missouri-Rolla. In 1992 he joined the Air Conditioning and Refrigeration Center at the University of Illinois at Urbana-Champaign, where he has served as co-director since 2001.

"Pega", as he is known to colleagues throughout the world, was chosen to lead a multi-year programme to compare alternative refrigerants by a consortium bringing together all main global automobile manufacturing and supplying companies. The programme produced the first widely accepted comparison between conventional HFC systems, transcritical carbon dioxide systems and hydrocarbons systems with secondary loops. But the most significant result was that the carefully managed competitive nature of the projects stimulated development of new components, new refrigerants and new systems that are twice as efficient as those that were available at the start of the program.

Professor Hrnjak's contributions to the international automotive air conditioning industry represent only a small sample of his overall impact on heat pumping technologies. He is a widely recognized expert on microchannel heat exchangers and ammonia refrigeration, serving on the board of the International Institute of Ammonia Refrigeration. He also serves as CEO and Board Chairman of Creative Technology Solutions Inc., which develops heat pumping technologies.

Swedish researcher awarded with international heat pump medal

Professor Eric Granryd from the Royal Institute of Technology in Stockholm, was awarded the 2008 Rittinger Medal at the International Energy Agency Heat Pump Conference held on May 20-22 in Zurich, Switzerland.



Eric Granryd

Eric Granryd has graduated from the Royal Institute of Technology in Stockholm and has served as Professor from 1984 until 1999 at the Department of Applied Thermodynamics and Refrigeration. He was successful in continuing the work started by Matts Bäckström and later Bo Pierre, to build up an internationally well known department in the field of applied thermodynamics and refrigeration. He has always attached considerable importance to international collaboration and networking.

Professor Granryd has worked part-time as a guest researcher at several different universities and research institutes abroad, including the Cemagref in France, the Oak Ridge National Laboratory, the University of Illinois and the University of Valencia. His most outstanding contributions to research and development of heat pumping technologies are his calculation method for air coils and optimization of heat pump systems. The calculation method has been widely used by the industry, especially for further improvements in the heat transfer on the air side.

Professor Granryd has worked internationally within the International Institute of Refrigeration (IIR), first as Chairman of the Scientific and Technical Commission E2 (heat pumps, energy recovery), later as President of the Executive Committee and finally as President of the General Conference. He is now President of the board of Effsys2, a programme for research and innovation funded by the Swedish Energy Agency and the Swedish industry.

American expert awarded with international heat pump medal

M. Sc. Gerald C. Groff of Cazenovia, New York was awarded the 2008 Rittinger Medal at the International Energy Agency Heat Pump Conference held on May 20-22 in Zurich, Switzerland.

Gerald C. Groff

Mr. Groff was awarded advanced degrees in Mechanical Engineering from the University of Minnesota and in Engineering Administration from Syracuse University. He has written more than 50 technical papers, articles and reports on air conditioning, building energy systems and office workstation ergonomics.

Mr Groff served as President of Marquardt Switches from 1988 to 1999, and has also served as Director of Carrier's Corporate Research Laboratories and as Director of Solar Heat Research at the U.S. Solar Energy Research Laboratory (NREL). He was Chairman of the IEA Heat Pump Programme Advisory Board from 1990 to 2002, representing the U.S. and Canada, and was a keynote speaker at the 2002, 2005 and 2008 International Heat Pump Conferences. Mr Groff is a Fellow and Life Member of the American Society of Heating, Refrigerating and Air Conditioning Engineers, a Life Member of the American Society of Mechanical Engineers and a Life Member of Sigma Xi Scientific Research Society. He has served in the International Institute of Refrigeration (IIR), both as Vice-Chairman of the Scientific Council and as President of the section working with activities regarding air conditioning and heat pumps. In 1999 Gerald C. Groff was awarded the W.L. Pentzer Award by the U.S. National Committee for IIR. Currently Mr. Groff is a consultant to the U.S. Department of Energy, to Oak Ridge National Laboratory and to several industrial clients. American expert awarded with international heat pump medal. M. Sc. Gerald C. Groff of Cazenovia, New York was awarded the 2008 Rittinger Medal at the International Energy Agency Heat Pump Conference held on May 20-22 in Zurich, Switzerland.

Mr. Groff was awarded advanced degrees in Mechanical Engineering from the University of Minnesota and in Engineering Administration from Syracuse University. He has written more than 50 technical papers, articles and reports on air conditioning, building energy systems and office workstation ergonomics. Mr Groff served as President of Marquardt Switches from 1988 to 1999, and has also served as Director of Carrier's Corporate Research Laboratories and as Director of Solar Heat Research at the U.S. Solar Energy Research Laboratory (NREL). He was Chairman of the IEA Heat Pump Programme Advisory Board from 1990 to 2002, representing the U.S. and Canada, and was a keynote speaker at the 2002, 2005 and 2008 International Heat Pump Conferences. Mr Groff is a Fellow and Life Member of the American Society of Heating, Refrigerating and Air Conditioning Engineers, a Life Member of the American Society of Mechanical Engineers and a Life Member of Sigma Xi Scientific Research Society. He has served in the International Institute of Refrigeration (IIR), both as Vice-Chairman of the Scientific Council and as President of the section working with activities regarding air conditioning and heat pumps.

In 1999 Gerald C. Groff was awarded the W.L. Pentzer Award by the U.S. National Committee for IIR. Currently Mr. Groff is a consultant to the U.S. Department of Energy, to Oak Ridge National Laboratory and to several industrial clients.

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
Annex 30 Retrofit heat pumps for buildings	30	**DE**, FR, NL
Annex 31 Advanced modelling and tools for analysis of energy use in supermarkets.	31	CA, DE, **SE,** UK, US
Annex 32 Economical heating and cooling systems for low-energy houses.	32	CA, **CH**, DE, NL, SE, US, JP, AT, NO
Annex 33 Compact Heat Exchangers In Heat Pumping Equipment	33	**UK**, SE, US, JP
Annex 34 Thermally Driven Heat Pumps for Heating and Cooling	34	AT, **DE**, NL, US

IEA Heat Pump Programme participating countries: Austria (AT), Canada (CA), France (FR), Germany (DE), Japan (JP), The Netherlands (NL), Italy (IT), Norway (NO), South Korea (KR), 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.

A low-energy commercial building with ground-source heat pumps

Frédéric Genest and Vasile Minea, Canada

The Canadian low-energy building presented in this article integrates ground-source heat pumps with floor heating for space heating and free cooling. Featuring also a two-stage outdoor make-up air preheating unit with exhaust air and geothermal heat recovery, and hybrid ventilation, optimized natural lighting and improved envelope, the annual electrical energy consumption was reduced by 71.4 % compared to the reference cold climate building. This ranks this building among the highest performance structures in North America.

Introduction

Reducing the energy consumption and minimizing the environmental impact of HVAC systems are significant goals for building designers. Combining ground-source heat pumps heating with exhaust air heat recovery and geothermal free cooling, active and passive solar energy, and natural ventilation and lighting lead to a cold-climate high-performance building. The concept described here has received the ASHRAE 2005 Award of Engineering Excellence (ASHRAE Insights 2005) and Quebec's AQME 2004 ENERGIA GALA Award.

Building characteristics

The 4180 m^2 commercial building, including 19 % storage and offices areas, meets the Canadian C 2000 standard for high-performance buildings (Genest, Charneux 2005). It is located in a cold-climate city (Montreal) with design temperatures of -21.7 °C in the winter, and 28.3 °C (dry-bulb) and 21.1 °C (wet-bulb) temperatures in the summer. The building walls and roof R-values are 6.2 m^{2}K/W and 7 m^{2}K/W respectively, more than twice as good as the local code requirements. The windows are made with double-glazed low-e glass with a U-factor of 1.87 W/m^{2}K, and the overall building U-factor averages 0.54 W/m^{2}K. The window system has been designed to provide about 325 lux of daylight, while the artificial lighting requires 14 W/m^2, a power density 48 % lower than the Canadian National Energy Code for Buildings' requirement. As a special feature, the HVAC system includes a large (1.2 m x 1.2 m) underground tunnel running along the building's perimeter for ventilation purposes. At maximum capacity, it supplies 5.6 L/s.m^2 of outdoor air, which is about four times the ASHRAE standard minimum requirement. This system operates when the outdoor dry-bulb temperature is between 12.8 °C and 26.7 °C, but only if the dewpoint is below 18.3 °C in order to prevent condensation on the cool concrete slabs. When the outdoor temperature is outside this range, the roof-mounted outdoor make-up air unit (Figure 1), with variable-speed fans controlled by CO_2 sensors, is activated. This unit preheats (in the winter) and dehumidifies (in the summer) the outdoor fresh air, and is used at all times in order to keep the indoor CO_2 level at 900 ppm. In heating mode, the circulating pump P4 runs and the 3-way valve D modulates to maintain the supply air temperature between 22 °C and 13 °C, while in free cooling mode, the supply air setpoint is set at 12 °C to provide dehumidification.

Ground-source heat pump system

The geothermal system contains two sections of vertical ground heat exchangers (zone 1) totaling twelve 175 m deep boreholes (Figure 1). Section #1 supplies most of the building heated floors located in the sales and office areas (zone 2), and the peripheral areas (zone 3) including air heating units (cash registers, coffee shop, stairs) and a few heated floors. The indoor temperatures of these zones are corrected according to the weather forecasts automatically retrieved from the Internet. This strategy accelerates the slab energy loading in advance on cold winter and hot summer days, because of their slow time response to the heating and cooling demands. Section #2 supplies the outdoor air make-up unit (zone 4), including an enthalpy rotary wheel (75 % thermal efficiency) and a geothermal direct heat recovery coil. Propylene glycol/water mixture (50 % by volume) is used as the geothermal heat transfer fluid in both the indoor building and the heat recovery closed loops. Even though propylene glycol is more viscous than other fluids, and more difficult to handle in cold weather, it is recommended in Canada because it is a non-toxic, non-flammable and non-corrosive antifreeze. Eight 28-kWC (nominal cooling capacity) water-to-water heat pumps with HFC-407C refrigerant are connected to the ground heat exchanger sections. Small pumps (P) circulate the geothermal fluid through the heat source side of each heat pump, thus eliminating the conventional unique, large geothermal circulating pumps. The first 4-heat pump group, "a", is assigned to the

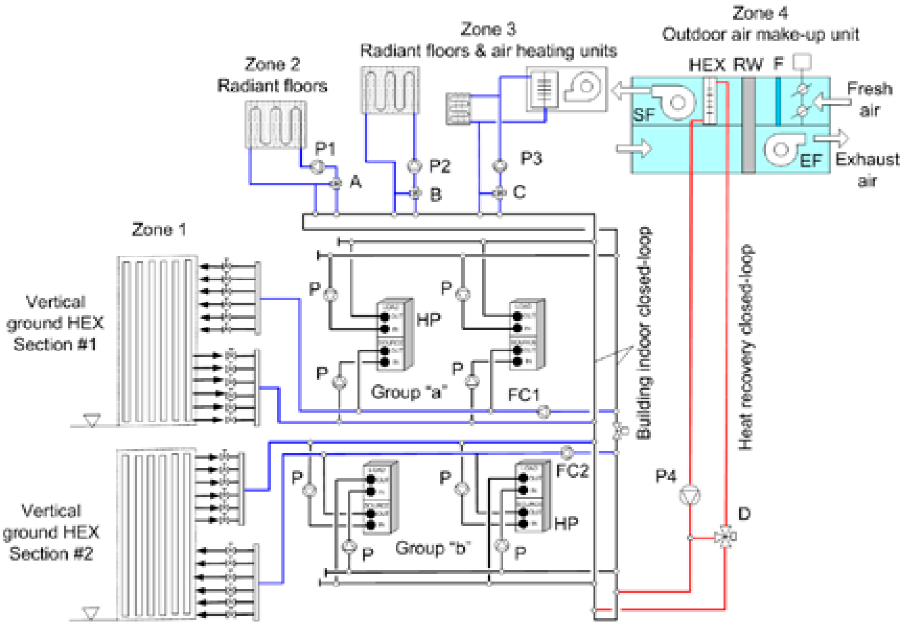


Figure 1 – Configuration of the building ground-source heat pump system. "a" and "b": groups of four liquid-to-liquid heat pumps; HP: heat pump; HEX: heat exchanger; P: loop circulating pump; A, B, C, D: 3-way control valves; FC: free cooling circulating pump; SF: supply fan; RW: heat recovery wheel; EF: exhaust fan; F: filter

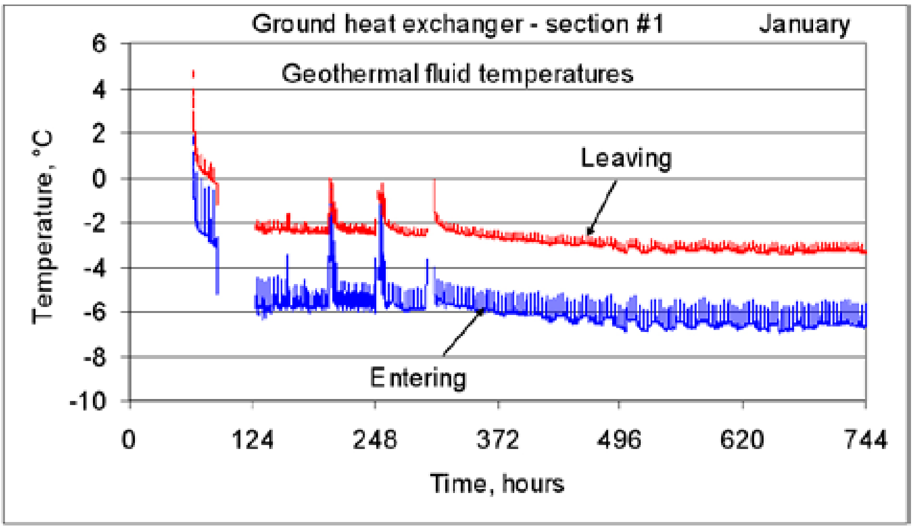


Figure 2 – Geothermal fluid temperatures entering and leaving the ground heat exchanger – section #1 (January)

building heated floors and air heating units, while the second 4-heat pump group, "b", supplies the rooftop make-up air unit. In the geothermal sensible (free) cooling mode, the dedicated circulating pumps FC1 and FC2 operate to delay using the heat pumps in this mode for as long as possible. In order to avoid the high energy consumption of the fans, the building space heating and cooling system contains radiant concrete slabs on both floors, with flexible cross-linked polyethylene piping (PEX). PEX pipes are durable, don't become brittle over time, are not affected by aggressive concrete additives and are expected to last more than 50 years. The hydronic radiant slabs allow extending the usual range of indoor comfort temperatures from as low as 18.3 °C in the winter to as high as 26.7 °C in the summer. This extended range further reduces the heat losses and gains through the building envelope, and the required capacity of the GSHP system.

Geothermal heating

In heating mode, the energy source for the concrete slabs is section #1 of the ground heat exchanger. Since radiant floor heating has low operating temperatures, the ground-source heat pumps are appropriate energy sources for such a concept. The radiant floors provide comfortable indoor conditions, as there is less air movement without air drafts, and the thermal mass avoids large temperature fluctuations. The indoor temperatures may be set, for example, at 20 °C rather than the usual 22 °C as required by other conventional systems. In this mode, when the outdoor temperature is lower than 12 °C, water pumps P1, P2 and P3 are running, and zones 1, 2 and 3 are operating. 3-way valves A, B and C modulate the flow in order to keep the return temperature of each zone at its setting point, following a ramp from 36 °C to 20 °C according to the outdoor temperature from –25 °C to 15 °C. Starting in mid-afternoon and until midnight, the weather forecast software overrides the outdoor temperature reading with the following night's low temperature forecast, thus adjusting the water supply setpoint accordingly. During a typical very cold winter month (January), the geothermal fluid entered the heat pumps at temperatures varying around -3 °C, while the average temperature drop through the ground heat exchanger was about 4 °C (Figure 2) (Minea 2005). Both parameters show that, in this example, the actual flow rate of the geothermal fluid was about 40 % lower than the design value. Consequently, the heat pump average COPs varied around 3.3, but this situation was fixed a few times after being discovered by cleaning and balancing the ground secondary fluid circuits (Genest, Minea 2006).

The geothermal fluid was supplied to the radiant floors and air heating units (zones 2 and 3) at temperatures varying from 35 °C to 38 °C, while the average temperature difference through the heating zones has generally been kept at around 10 °C (Figure 3). Such a relatively low temperature range of the geothermal heat source was ideal for radiant floor heating, because the slab surface temperature has generally to range between 26 °C and a maximum of 29 °C.

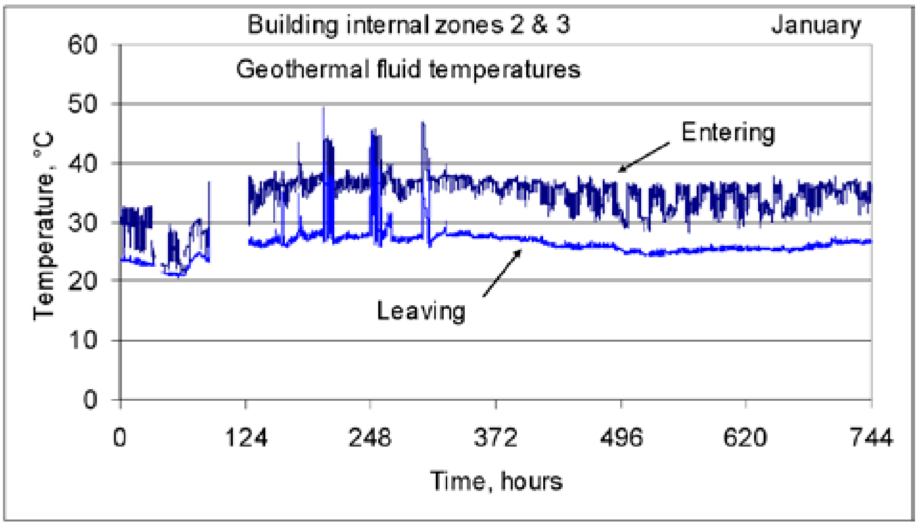


Figure 3 - Geothermal fluid temperatures entering and leaving the building internal zones 2 & 3 (January)

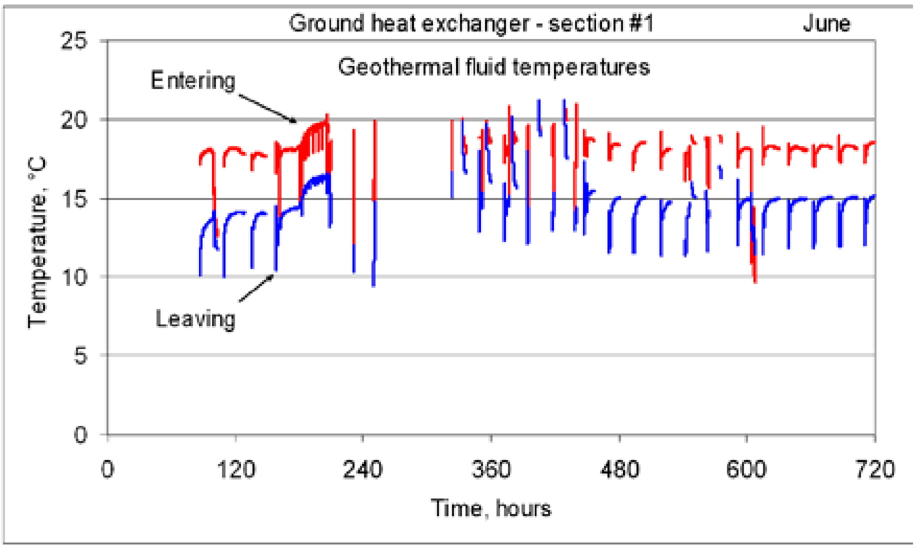


Figure 4 – Geothermal fluid temperatures entering and leaving the ground heat exchanger – section #1(June)

Natural and geothermal cooling

All-air systems achieve building cooling by convection only. An alternative solution was to provide cooling through a combination of radiation and convection inside the building, where approximately 60% of the heat transfer is due to radiation. By providing cooling to the space surfaces rather than directly to the air, such a system allowed separation of the ventilation and thermal space conditioning tasks. While primary air distribution is used to meet the ventilation requirements for a high level of air quality, the secondary geothermal fluid distribution system provides thermal conditioning to the building. Consequently, this concept significantly reduced the amount of air transported through the building. Furthermore, space needs for ventilation system and the ductwork were reduced to about 20 % of the conventional space requirement. Due to the physical properties of the geothermal fluid, the system used less than 5 % of the otherwise necessary fan energy, while the slab thermal storage capacity helps to shift the peak cooling loads to later hours.

In the natural ventilation mode, the underground tunnel supplies outside air to maintain indoor temperature at about 22 °C, and operates for about 47 % of the annual store opening time. The role of the geothermal free cooling mode is to supplement natural ventilation if the outdoor temperature is higher than 24 °C. In this mode, zones 1, 2 and 3 are operating, all heat pumps and zone 4 are shut off, and the section #1 acts as a heat sink. If the temperature of the geothermal fluid returning from section #1 is higher than 15 °C, circulating pump FC1 runs until this temperature falls below 12 °C. When this temperature is attained, pumps P1, P2, P3 start and run continuously, and valves A, B and C modulate in order to maintain the return temperature from each zone at 18 °C. It can be seen that during a typical warm summer month (June), the geothermal fluid entered the ground heat exchanger at 18 °C and left it at 12–15 °C (Figure 4). These parameters allowed the provision of sufficient free (sensible) cooling capacity to the radiant floors by using the ground as a heat sink (Minea 2005). In fact , the cold geothermal fluid entered zones 2 and 3 at average temperatures of 12 °C to 15 °C and left them at 23 °C before being mixed with the incoming fluid and returning to the ground heat exchanger (Figure 5). The geothermal mechanical cooling mode using the heat pumps operates when the outdoor temperature and the indoor air dewpoint are higher than prescribed. In this case, valves A, B and C modulate in order to prevent the return water temperatures dropping below the indoor air dewpoint (13 °C) in order to prevent indoor air moisture condensation.

Energy savings

The annual energy consumption of the building was 556.4 MWh (or 133.1 kWh/m2/year), representing more than US$100 000 in energy cost savings (2005). Compared to conventional systems, the additional costs of the new HVAC system was US$475 000 (Genest, Charneux 2005), and consequently the simple pay-back period has been estimated at 4.75 years. From the building annual energy consumption, the geothermal system represented 40 kWh/m2/year or 30.09 %. During the winter, the GSHP system (i.e. all heat pumps and their small circulating pumps) represented between 35 % (March) and 44 % (January) of the building's total energy consumption. During the summer, the GSHP consumption dropped to 28 % (August) and 31 % (July) of the store total energy consumption (Figure 6).

The highest energy consumer was the artificial lighting with about 71 kWh/m2/year or 53.31 % of the total building annual energy consumption. Compared to the geothermal and the artificial lighting systems, the peripheral foundation electrical heating (2.77 %) and the outdoor make-up air unit (4.29 %) were almost marginal energy consumers (Figure 7). The simulated energy consumption of an all-electric reference building designed according to Canadian standards and codes (electric boiler with air-cooled chiller supplying distributed fan coils, a lighting density of 26.9 W/m2 and total building U factor of 0.64 W/m2•K) was 466 kWh/m2/year. Compared to this specific reference energy consumption, the new building has reduced the annual specific energy consumption by 71.4 % (Table 1), representing about 1.4 GWh/year in electrical energy savings.

Compared to three other well-documented high-performance North American buildings (a secondary school, a retail store and an office building), the specific energy use of the new Canadian building was of the same order of magnitude (Table

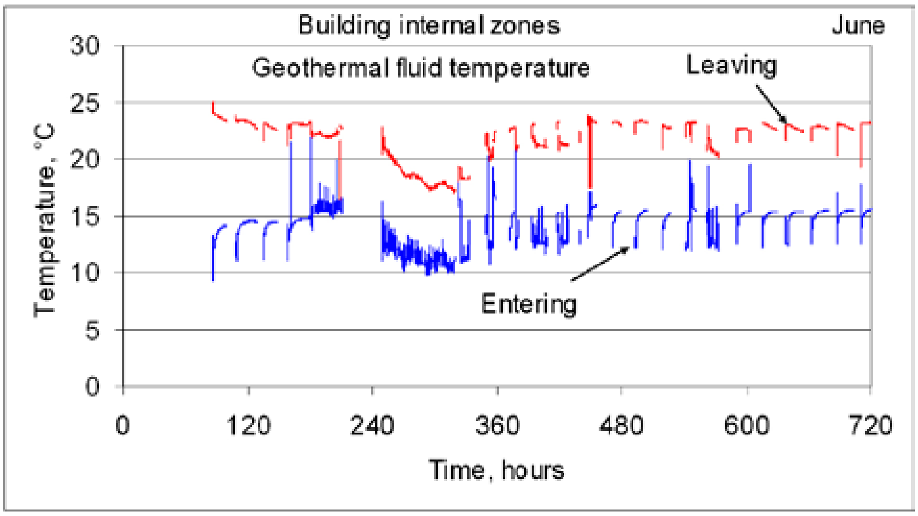


Figure 5 – Geothermal fluid temperatures entering and leaving the building internal zones (June)

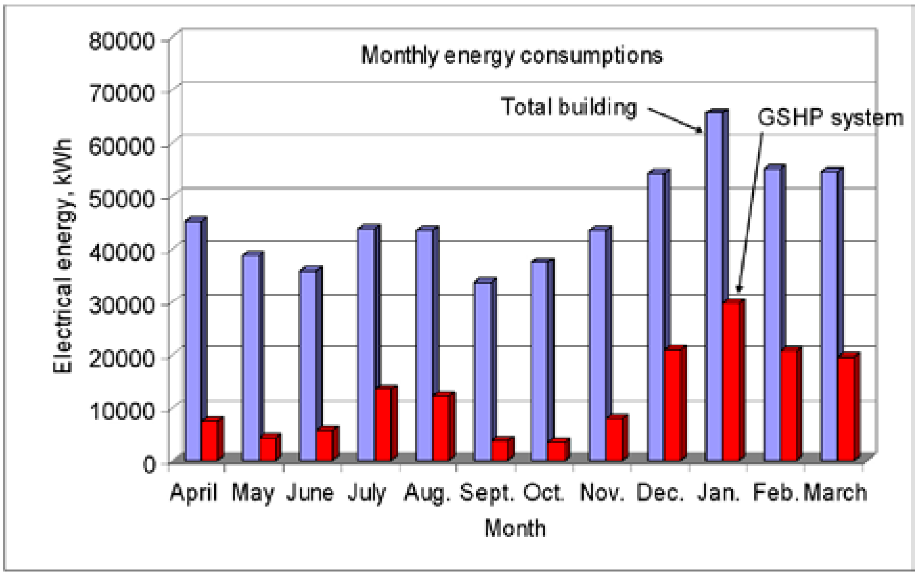


Figure 6 – Share of the building and GSHP system monthly energy consumptions

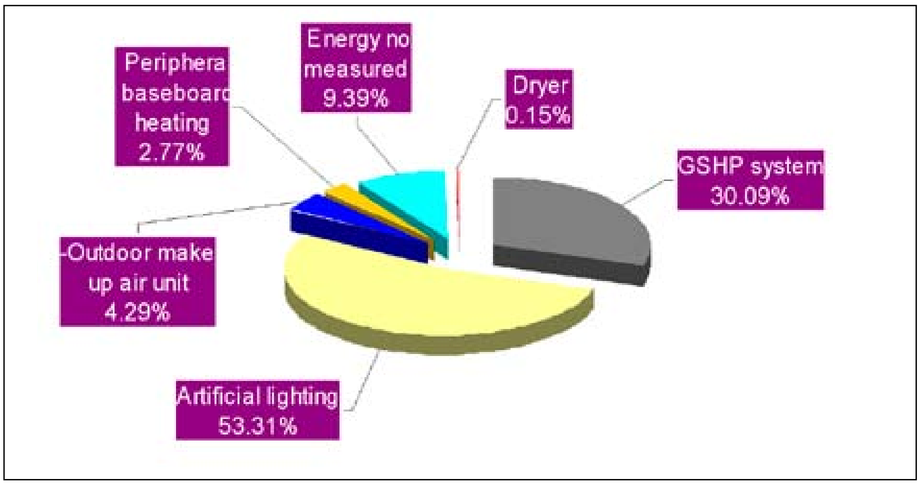


Figure 7 – Share of the building annual electrical energy consumptions

Table 1 – Comparison of annual energy consumptions of three high-performance buildings

Low-energy building (source)	Main characteristics	Specific annual energy consumption		Annual energy savings
-	-	Actual building	Reference building	-
-	-	kWh/m^2.year	kWh/m^2.year	%
High McGivney School, Ontario, Canada (ASHRAE 1998)	17 657 m^2. 1435-kW_C GSHP (20 heat pumps). 360 wells (62.6 m deep each). 517 kW exhaust air heat recovery with heat pipe HEX.	139 (130 electric; 9 natural gas)	352	42
BigHorn Center, Colorado, USA (Torcellini et al)	Hardware retail store and warehouse. 3,940 m^2. Photovoltaic and passive solar panels. Hydronic radiant floor and natural gas heaters.	124.3	296	42
Cambria Office Building, Pa, USA (Torcellini et al).	3 205 m^2. GSHP system. Heat recovery ventilators. 18 kW photovoltaic system. High-performance windows	115.8	322	36
New commercial building, Montreal, Canada (Genest, Minea 2006).	4 180 m^2. 280 kW_C GSHP system. 12 vertical wells (175 m deep each). Hybrid ventilation system. Exhaust air heat recovery wheel. Space heating and sensible cooling by radiant floor. Solar panels for DHW preheating.	133.1	466	71.4

1 and Figure 8). However, the global energy savings compared to the respective reference buildings were twice as much, mainly because of the colder climate location of the new Montreal low-energy commercial building.

CO_2 emissions reductions

The indirect emission factor for the electrical energy distributed in Québec (97 % hydroelectricity) is 0.00122 kg of CO_2 per kWh. Consequently, for the 1.4 GWh saved, the greenhouse gas emissions have been reduced by 1 698 kg of CO_2 per year. However, if located – for example - in a Canadian region where the electricity is produced with 75 %-efficient natural gas plants, the reduction of greenhouse gas emissions may amount 371 000 kg of CO_2 per year because the indirect emission factor of natural gas is 0.2 kg of CO_2 per kWh saved.

Conclusions

The new Canadian low-energy commercial building comprises an original ground-source heat pump system combined with radiant floors for space heating and sensible cooling. Other innovative features, such as hybrid ventilation, exhaust air and geothermal heat recovery, and outdoor weather forecasts, allowed high-energy performance in a cold climate. The building annual electrical energy consumption (133.1 kWh/m^2/year) was of the same order of magnitude when compared to three of the most efficient North American buildings. The ground-source system represented 30.09 %, and the artificial lighting 53.3 % of the annual energy consumption. During the coldest winter month (January), the geothermal system delivered 44 % of the total store energy consumption as the main building heating system. The annual electrical energy savings allow reducing the greenhouse gas emissions by about 1.7 metric ton of CO_2 per year.

Acknowledgments

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Residential heat pump systems in Japan

Hasegawa Kohei, Japan

Mitsubishi Electric Corporation has been developing various heat-pump systems for commercial and residential use. This article introduces two of them. One is a residential central heating system that uses a heat pump to produce hot water efficiently, while the other is a duct-type air conditioning system designed to heat a whole house. It can also provide ventilation. Both can provide better comfort and safety than normal air conditioners, and the market for systems such as this is expected to expand.
The article presents their specifications and technology.

Introduction

Mitsubishi Electric Corporation's Nakatsugawa works has developed two residential heat pump air conditioning systems. "Econucool" is a central heating system that uses a heat pump to produce hot water efficiently. "Air Resort" is a duct-type air conditioning system which also provides ventilation for a whole house.

The products have been developed in response to the following and other factors: environmental concern about CO_2 emissions, changes in the housing market, and improvement in thermal insulation in houses.

Heat pumps have advantages in energy consumption over electric heaters, and also emit less CO_2 than heaters using fossil fuel.

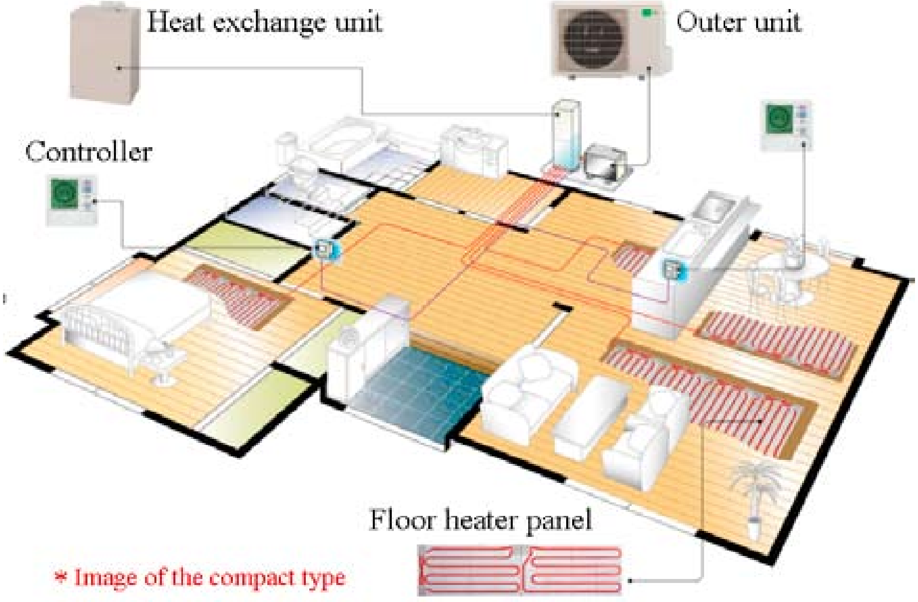

Figure 1

Background to development

According to Mitsubishi's calculations, heating accounts for over 50 % of household energy consumption in northern Japan. Even in a comparatively mild climate region such as Tokyo, over 20 % of energy is used for heating. Reducing domestic energy consumption is one of the most important factors in reducing CO_2 emissions.

About 1.2 million houses are built in Japan every year, with single-family houses accounting for 40 to 50 % of new construction. These trends have existed for the last several years.
One new and rapidly increasing trend in new home construction is that of all-electric houses. Currently, over 40 % of houses are of this type. One of reasons for this expansion is the development of high-efficiency heat pump systems such as air conditioners and hot-water supply devices using CO_2 as the refrigerant. The other factor is the progress in heat insulation of houses. The recent sudden rise in the price of kerosene will also accelerate this increase.
The number of new houses in which floor heating systems are installed is also increasing. In single-family houses and in condominiums the proportion of houses with floor heating systems is increasing by about 10 % every year, and is now over 30 %.
Apart from the cold areas of the country, air conditioning in Japan is usually non-integrated and intermittent. But central air conditioning systems, which are popular in Europe and America, are gradually becoming accepted as the number of well-insulated houses increases.

System outline of "Econucool"

"Econucool" is a central heating system that uses heat pumps to produce hot water efficiently.
Figure 1 is a diagram of a system of this type.
There is a single heat-producing unit, consisting of a heat exchange unit and an outdoor unit. Heat can be delivered by wall-mounted heaters or floor heating.
Controllers can individually control each room in which they are installed.
Traditional hot water heating systems burn fossil fuel, such as gas or kerosene, but our product uses only electricity, so it can be adopted as the

air conditioning system of all-electric houses.

The system has been developed with four years of vigorous testing and field trials in extremely cold areas. The "Eco-nucool" is able to operate in temperatures as low as –25 °C.

Hot water production

Figure 2 is a diagram of the system.

The outdoor unit absorbs heat from the outside air. The heat exchange unit, which is of high-efficiency plate type, heats the domestic hot water. Hot water from the circulation pump passes through wall and/or floor radiators, heat exchanger and the collecting tank.

Unlike hot water supply devices which store up hot water late at night using low-priced night tariff electricity, this system keeps the outer unit running.

Other hot water supply devices producing very hot water utilize CO2 as the refrigerant, however the refrigerant used in this product is R410A. The temperature difference between outgoing and incoming water for floor heating applications is less than 10 °C, with a water temperature normally in the range 25 °C to 55 °C. R410A is therefore the most suitable refrigerant for generating low-temperature water and low-intensity heating.

Line-up

We offer two models.

"Econucool-Leo", the most powerful model, has an 11.5 kW heating capacity, and can heat an area up to 130 m^2. It is mainly used in cold regions of Japan to heat a whole house.

"Econucool-Picco", the compact model, has a 6 kW heating capacity, and can heat up to 65 m2. It is mainly used in mild climate regions. (The heating capacities shown are with an outdoor air temperature of 7 °C)

We offer 11 varieties of floor panels, employing copper pipes that are installed on joists, and three varieties employing polyethylene pipe, which are installed between joists. Depending on uses and dimensions of the room, a suitable floor heater can therefore be provided.

Energy-saving technology

"Econucool" has several energy-saving technologies. In addition to its heat pump inverter control; it can save much more energy by:

(1) Automatic control of the supply water temperature

As the temperature of the heated water is reduced, the COP improves. For this reason, low-temperature water supply is useful in saving energy.

Our products produce hot water from 25 °C to 55 °C to suit heat load of houses.

The heat pump inverter makes a low-temperature water supply possible, which conventional kerosene boilers cannot do.

As shown in Figure 3,"Econucool" regulates the supply water temperature according to the information of desired and actual temperature. When the room temperature is much lower than the desired temperature, "Econucool" supplies high-temperature water. As the room temperature approaches the desired temperature, the supply water temperature is reduced. In this way, this heat pump delivers low-temperature water and saves energy without sacrificing comfort and convenience.

(2) Efficient defrosting

The outer unit reverses the flow of the refrigerant and melts frost on it by transferring indoor heat to itself. Because it regulates the timing and length of defrosting according to the amount of frost, defrosting is efficient.

(3) Antifreeze heater

The outer unit has a heater that prevents condensation water from freezing and accumulating ice, which is particularly a risk in cold regions. Electricity consumption is reduced by controlling the heater in response to the ambient temperature and the amount of defrosting required.

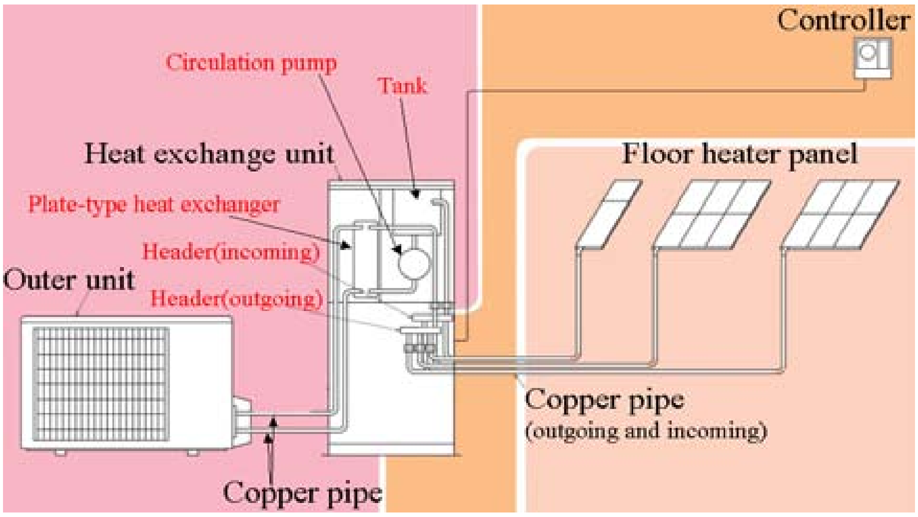

Figure 2

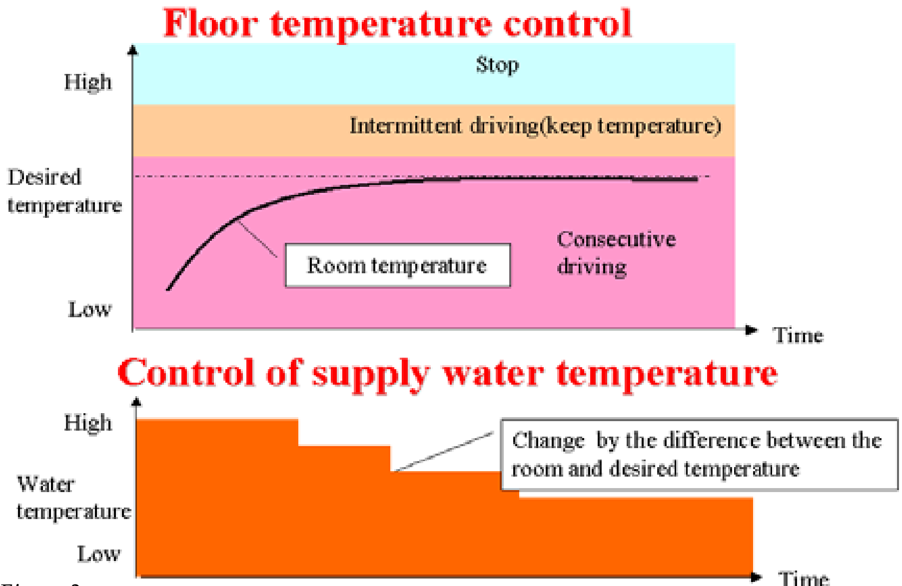

Figure 3

Running cost and CO_2 emissions

"Econucool" cuts running cost and CO_2 emissions compared with traditional floor heating systems which use kerosene or gas boilers or an electric heater. The running cost is half that of kerosene boilers, and one-third that of gas or electric boilers. CO_2 emissions are one-third that of kerosene or electric heaters, and half that of gas.

System outline of "Air resort"

Figure 4 is a description of a single-family house in which "Air-resort" is installed. There are two outer units, and one floor-type inner unit in the indoor space.

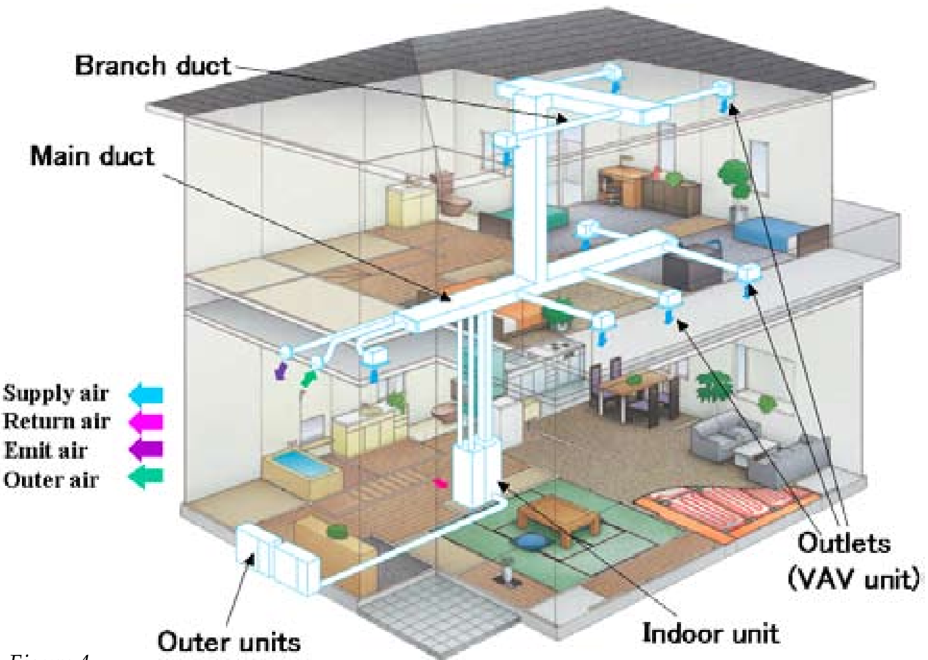

Figure 4

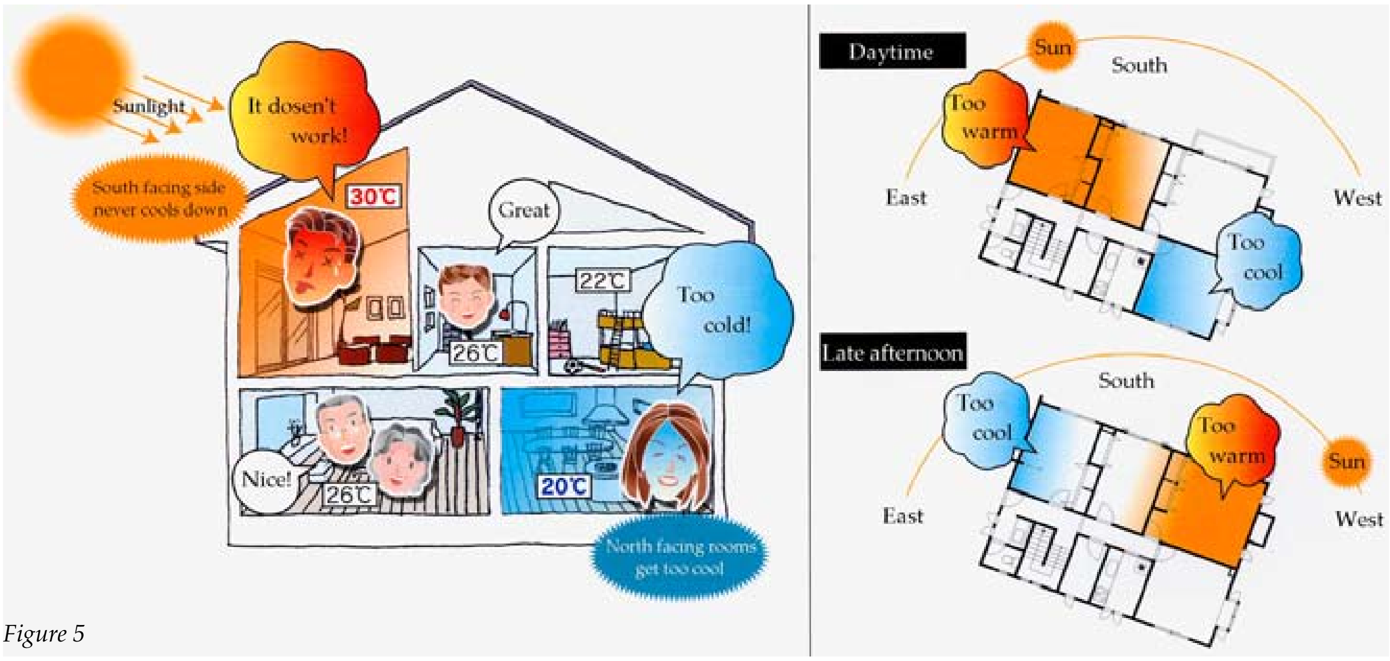

Figure 5

The indoor unit supplies cool or hot air to each room through insulated ducts which are run in the ceiling or between joists. The air is delivered via outlets and returns to the indoor unit via gaps below doors. Part of the indoor air goes through the air-to-air heat exchanger before discharge to the outside by the ventilating device which is connected to the inner unit.

The floor-type unit can provide 8 kW of cooling and 9.6 kW of heating. The space-saving ceiling-type unit has 5 kW cooling capacity and 5.6 kW heating capacity.

Features of "Air resort"

With this system, fresh air at a comfortable temperature circulates slowly through the whole house. The temperature can be kept constant, not only in rooms where an outlet is installed but also in other areas.

Our products can control the individual temperatures in a maximum of eight zones. control is by VAV (variable air volume). It is difficult for traditional whole-house air conditioners to maintain every room comfortable, as shown in Figure 5, because there are sunny rooms and sunless rooms. If capacity is sufficient for sunny rooms, sunless rooms become too cool and waste energy. Our products regulate air volume into rooms according to the desired temperature, which means that everyone in the house can set his or her desired room temperature individually.

VAV control

Figure 6 is an explanation of VAV.

VAV has two programs: one for trial running, and the other for air volume control.

(1) Trial running

The resistance of the ducts, in other words the pressure drop in the ducts, is automatically calculated by the trial running. These results are the used when "Air resort" regulates air volume.

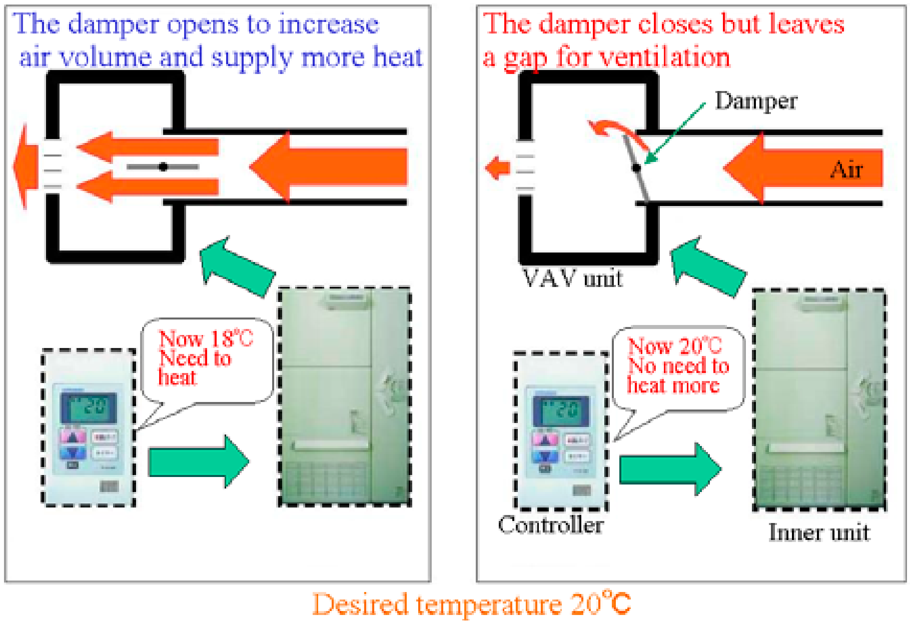

Figure 6

(2) Air volume regulation
When the system is running, the indoor unit controls the angle of each VAV unit's damper.
Each unit's angle is calculated based on two factors that control the minimum air volume flow. One factor is the difference between the actual and the desired temperature, and the other is the duct resistance. The indoor unit regulates its fan power to control the total air volume to the sum of air volume required by all the rooms.

As the actual temperature becomes closer to the desired temperature, the indoor unit changes the angle of the VAV unit's damper and decreases air volume and so also the fan power.

Low energy consumption

Our products have a high COP, and save energy when they are installed in well-insulated and airtight houses. In addition, "Air resort", with its VAV technology, can reduce energy consumption by 5 % compared with other traditional duct-type whole-house air conditioners.

Conclusion

The development of efficient products is expected to become more important for energy saving in addition to the improvement of insulation and airtightness of houses.

Heat pumps are one of the most necessary technologies in developing efficient systems. In addition, as insulation and airtightness of houses are improved, central air conditioning systems, which have not been popular in mild climate regions of Japan, will gradually become accepted.

These two different heat pump systems, that MITSUBISHI ELECTRIC Nakatsugawa Works has developed, are suitable for the current social situation, and can provide comfort with a low running price.
We naturally intend to continue improving our products further.

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Integrated CO_2 heat pump systems for low-energy and passive houses

Jørn Stene, Norway

Introduction

Low-energy and passive houses are superinsulated and airtight buildings where the space heating demand is much lower than that of buildings constructed in accordance with current building codes. Due to the low space heating demand, the annual heating demand for domestic hot water (DHW) typically constitutes 50 to 85 % of the total annual heating demand for the residence.

A heat pump system can be used to cover the entire heating demand in a low-energy or passive house. It can be designed as a stand-alone system, i.e. a heat pump water heater in combination with a separate unit for space heating, or can be an integrated unit for combined space heating and hot water heating. Due to the more compact design, the latter system is most likely to achieve the lowest investment and installation costs and therefore the best profitability.

Integrated residential heat pump systems using carbon dioxide (CO_2, R744) as the working fluid can achieve a particularly high Seasonal Performance Factor (SPF) in low-energy and passive houses due to the unique characteristics of the CO_2 heat pump cycle. However, the energy efficiency is very dependent on the design and operation of the heat pump unit and the secondary systems.

Heating demands in low-energy and passive houses

The space heating demand and ventilation loss in low-energy houses and passive houses have been greatly reduced compared to houses constructed in accordance with current building codes. This has been made possible by better insulated and more airtight building envelopes, balanced ventilation systems with high-efficiency heat recovery and utilization of passive solar heating.

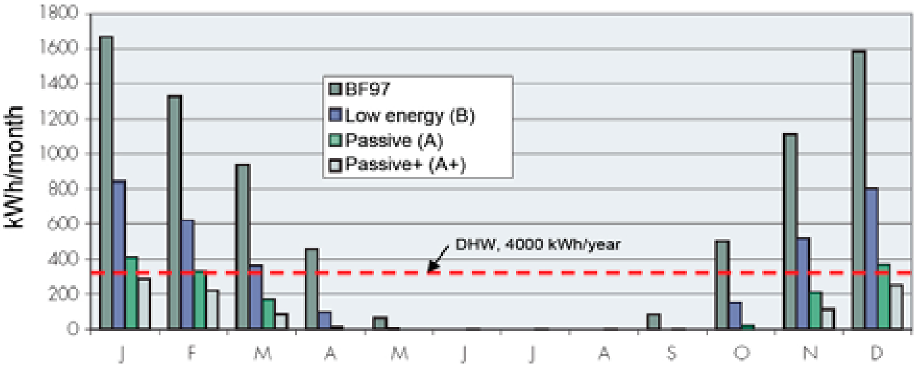

Figure 1 Calculated monthly space heating demand and DHW heating demand for a 105 m2 semi-detached house in Oslo, Norway (Dokka and Hermstad, 2006).

Figure 1 shows, as an example, the calculated monthly space heating demand and DHW heating demand [kWh/month] for 105 m2 semi-detached house of different standards in Oslo, Norway (Dokka and Hermstad, 2006). The different standards for the building envelope correspond to a house constructed according to the 1997 Norwegian building codes (BF97), a low-energy house (Energy rating B), a passive house (Energy rating A) and a passive house+ (Energy rating A+). The average monthly DHW heating demand is about 335 kWh/month (4000 kWh/year), which is a typical average value for Norwegian homes. In the example, the annual heating demand for DHW constitutes about 75 % of the total annual heating demand.

Analysis of integrated residential CO2 heat pump systems

There exists many different designs for integrated heat pump systems with R407C, R410A, R134a or R290 (propane) as working fluids, and the main differences are related to the design and operation of the DHW system. The most common systems are “double-shell storage tank systems” for preheating of DHW, “desuperheater systems”, “shuttle-valve systems” with alternate operation between DHW heating and space heating, and “two-stage DHW systems” where the DHW is preheated by the water in the buffer tank for the space heating system and heated to the final temperature by means of a desuperheater. The latter system achieves the highest seasonal perfor¬mance factor (SPF) of state-of-the-art heat pump systems.

Main characteristics of CO_2 heat pumps

Carbon dioxide (CO_2, R744) is one of the few non-toxic, non-flammable working fluids that neither contributes to ozone depletion nor global warming, and therefore represents an interesting long-term alter¬native to the commonly used HFC working fluids. CO_2 has excellent thermo¬physical properties, and by utilizing these proper¬ties by means of optimised com¬ponent and system design for the heat pump unit, the DHW system and the heat distribution system, high energy efficiency can be achieved.

CO_2 has an especially low critical temperature (31.1 ºC) and high critical pressure (73.8 bar). As a consequence, the operating pressure in CO_2 heat pump systems will typically be 5 to 10 times higher than that of standard heat pumps, i.e. 20 to 40 bar in the evaporator and 80 to 130 bar in the gas cooler. Due to the low critical temperature, most CO_2 heat pumps operate in what is known as a transcritical cycle with evaporation at subcritical pressure and heat rejection at supercritical pressure (>73.8 bar). Unlike a subcritical heat pump cycle, heat is not given off by means of condensation of the working fluid in a condenser but by cooling of high-pressure CO_2 gas in a heat exchanger (gas cooler). The temperature drop for the CO_2 gas during heat rejection is denoted the temperature glide. Figure 2 shows the principle of the transcritical CO_2 heat pump cycle in a Temperature-Enthalpy (T-h) diagram.

The main factors that determine the Coefficient of Performance (COP) for a single-stage CO_2 heat pump unit are the evaporation temperature, the overall isentropic efficiency of the compressor, the optimum gas cooler pressure, the CO_2 outlet temperature in the gas cooler, and possible recovery of expansion energy by means of an ejector or an expander.

Since the discharge gas temperature from the compressor in a CO_2 heat pump cycle is relatively high (>80ºC), a CO_2 heat pump can meet high-temperature heating demands. However, in order to achieve a high COP for a CO_2 heat pump system, it is essential that useful heat is rejected over a large temperature range, resulting in a large enthalpy difference for the CO_2 in the gas cooler (h2-h3) and a relatively low CO_2 temperature (t3) before the expansion/throttling valve. This in turn presupposes a relatively low inlet water temperature in the gas cooler, i.e. a low return temperature in the (hydronic) heat distribution system and/or a low inlet water temperature from the DHW tank.

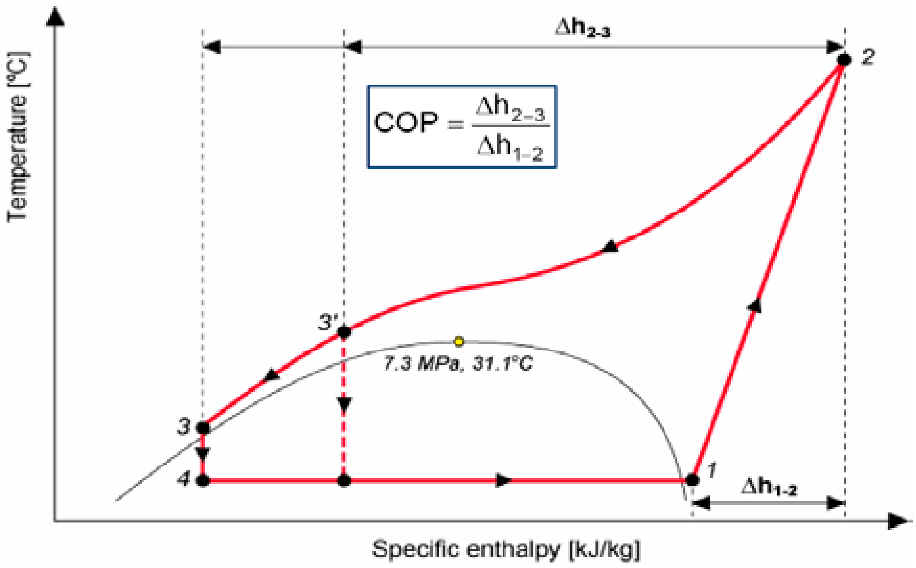

Figure 2 The transcritical CO_2 heat pump cycle in a T-h diagram. 1-2: Compression, 2-3: Heat rejection in a gas cooler, 3-4: Expansion/throttling, 4-1: Evaporation.

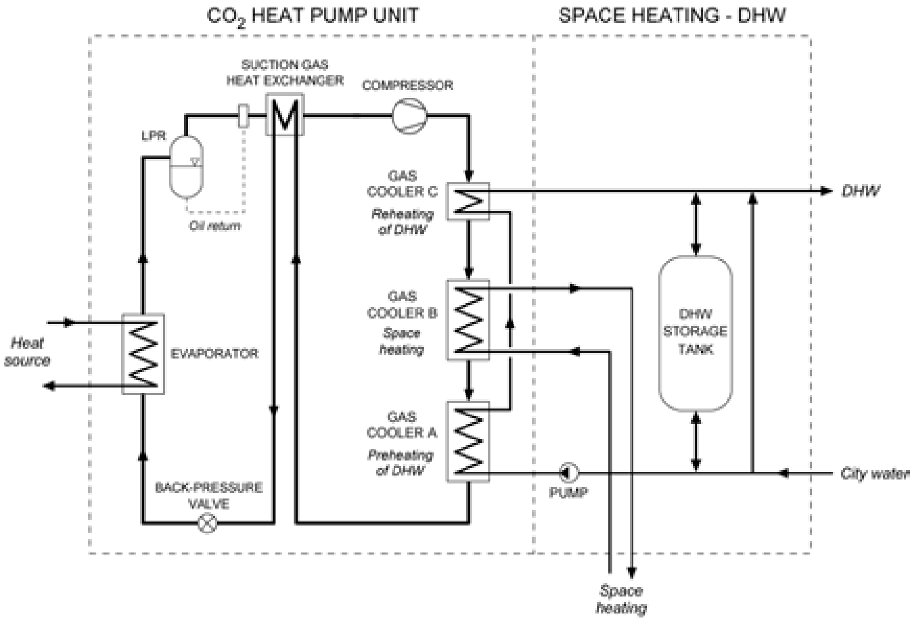

Figure 3 Main design features of the prototype brine-to-water integrated CO_2 heat pump system.

The input power to the compressor is more or less proportional to the gas cooler pressure, i.e. the higher the gas cooler pressure, the lower the COP. Consequently, CO_2 heat pumps should preferably be designed for a moderate gas cooler pressure.

Testing and evaluation of a prototype CO_2 heat pump system

A 6.5 kW prototype brine-to-water CO_2 heat pump system for space heating and DHW heating has been extensively tested and analysed (Stene, 2004/2006). A large number of different gas cooler configurations were evaluated, and it was found that an external counter-flow tripartite gas cooler for preheating of DHW, low-temperature space heating and reheating of DHW, would enable production of DHW in the required temperature range from 60 to 85 ºC, and contribute to the highest possible COP for the heat pump unit. Figure 3 shows the principle of the integrated CO_2 heat pump system.

The prototype CO_2 heat pump unit was equipped with a hermetic rolling piston compressor (Sanyo), a tripartite counter-flow tube-in-tube gas cooler, a counter-flow tube-in-tube suction gas heat exchanger and a tube-in-tube evaporator. An expansion valve (back-pressure valve) and a low-pressure liquid receiver (LPR) were used to control the CO_2 pressure in the tripartite gas cooler and thereby maximize the COP of the system. Gas cooler units A and C were connected to an unvented single-shell DHW storage tank and an inverter-controlled pump by means of a closed water loop. Gas cooler unit B was connected to a low-tempera¬ture hydronic heat distrib¬ution system.

The integrated CO_2 heat pump unit was tested in:

- DHW mode – heating of domestic hot water (DHW)
- SH mode – space heating
- Combined mode – simultaneous space heating and DHW heating

During draw-off of DHW, hot water was delivered at the draw-off site, while cold city water entered the bottom of the DHW tank. During charging of the DHW tank in the Combined and DHW modes, the cold city water from the bottom of the DHW tank was pumped through gas cooler units A and C, heated to the setpoint tempe¬rature, and returned at the top of the tank. The CO_2 system was tested at 40/35ºC, 35/30ºC or 33/28ºC supply/return temperature for the SH system, and 60ºC, 70ºC or 80ºC for the DHW system.

The heat rejection processes in the three different operating modes are illustrated in temperature-enthalpy diagrams in Figure 4. In the example, the supply/return temperatures for the floor heating system were 35/30ºC, while the city water temperature and the setpoint for the DHW were 6.5 and 70 ºC respectively. In the Combined mode, the DHW heating capacity ratio was about 45 %, which means that 45 % of the total heating capacity of the tripartite gas cooler was used for hot water heating.

The COP in the Combined mode was about 2-10 % higher than that of DHW mode, due to the moderate optimum gas cooler pressure (85-95 bar) and the relatively low CO_2 outlet temperature from the tripartite gas cooler as a result of the excellent temperature fit be-

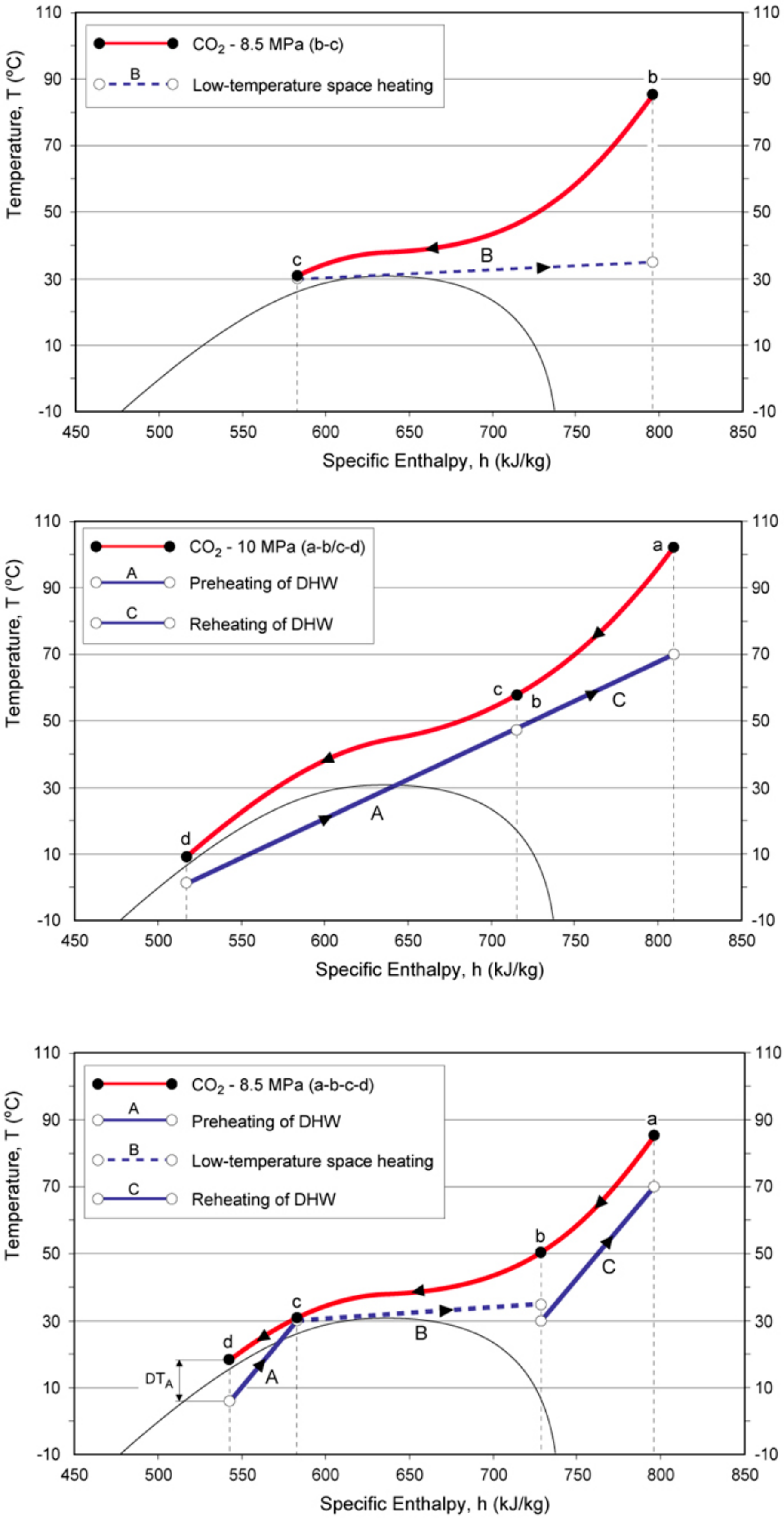

Figure 4 Example – Illustration of the heat rejection process for an integrated CO_2 heat pump in Space Heating (SH) mode (35/30ºC), DHW mode (70ºC) and Combined mode (35/30ºC, 70ºC). The optimum gas cooler pressures were 85 and 100 bar.

tween the CO_2 and the water. The COP in the SH mode was 20-30 % lower than that of the Combined mode. This was a result of the poor temperature fit between the CO_2 and the water, and the fact that the CO_2 outlet temperature from the gas cooler was limited by the relatively high return temperature in the space heating system: i.e. the lower the return temperature in the space heating system, the higher the COP for the CO_2 heat pump.

Comparison of seasonal energy efficiency

The Seasonal Performance Factor (SPF) for the prototype CO_2 heat pump unit and a state-of-the-art high-efficiency brine-to-water heat pump with HFC working fluid was calculated, assuming constant inlet brine temperature for the evaporator (0 ºC) and constant temperature levels in the low-temperature space heating system (35/30 ºC) and in the DHW system (10/60 ºC). An improved CO_2 heat pump unit with 10 % higher COP than the prototype system was also investigated in order to demonstrate the future potential of the CO_2 system. The COP can be increased by using a more energy-efficient compressor, optimising the tripartite gas cooler or replacing the throttling valve by an ejector. The latter is capable of increasing the COP by typically 10 to 20 % (Stene, 2004). For the CO_2 heat pump systems, the thermodynamic losses in the DHW tank due to mixing and internal conductive heat transfer were not included when calculating the SPF. Table 1 shows the measured COPs for the heat pump systems at the selected operating conditions.

Table 1 demonstrates that the integrated CO_2 heat pumps and the state-of-the-art HFC heat pump had reversed COP characteristics, i.e. the CO_2 units achieved the highest COP during operation in the DHW mode and the Combined mode, whereas the state-of-the-art unit achieved the highest COP in the SH mode.

Figure 5 shows the calculated SPFs for the three residential heat pump systems during mono¬valent operation, presented as a function of the seasonal DHW heating demand ratio.

Table 1 Measured COPs for the brine-to-water heat pump systems – boundary conditions

Prototype CO2 heat pump	COP = 3.0 – SH mode at 35/30ºC COP = 3.8 – DHW mode at 10/60ºC – no electric reheating COP = 3.9 – Combined mode at 35/30ºC and 10/60ºC
Improved CO2 heat pump	COP = 3.3 – SH mode at 35/30ºC COP = 4.2 – DHW mode at 10/60ºC – no electric reheating COP = 4.3 – Combined mode at 35/30ºC and 10/60ºC
State-of-the-art heat pump	COP = 4.8 – SH mode at 35/30ºC COP = 3.0 – DHW mode at 10/60ºC – no electric reheating

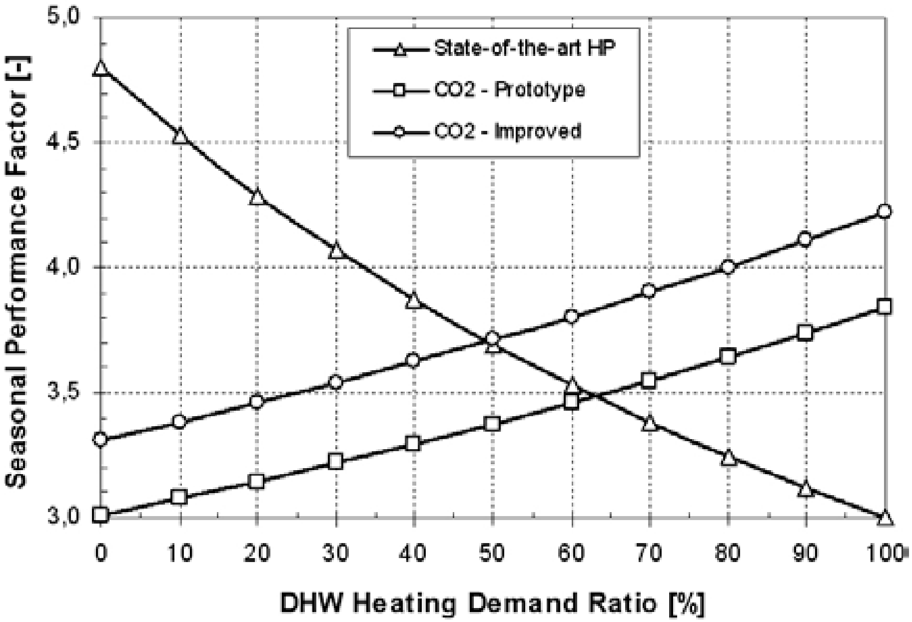

Figure 5 Calculated SPF during monovalent operation for a high-efficiency state-of-the-art heat pump, the prototype CO_2 heat pump and an improved CO_2 heat pump

At low DHW heating demand ratios, the state-of-the-art heat pump was more efficient than the CO_2 systems due to their poor COP during operation in the SH mode. At increasing DHW heating demand ratios, the SPF of the CO_2 systems gradually improved, since an increasing part of the heating demand was covered by operation in the Combined mode and the DHW mode. On the other hand, the SPF for the state-of-the-art heat pump dropped quite rapidly with increasing DHW heating demand, since the COP during operation in the DHW mode was about 35 % lower than that of the SH mode.

At the actual operating conditions, the break-even for the prototype CO_2 system occurred at a DHW heating demand ratio around 60 %, whereas the break-even for the improved CO_2 system was about 10 percentage points lower.

At 70 % DHW heating demand ratio, the SPF for the improved CO_2 heat pump was about 3.9. This corresponds to an annual energy saving of about 70-75 % compared to a direct electric heating system, and is 20-35 percentage points higher that that of Scandinavian DHW systems based on solar collectors and electric immersion heaters for supplementary heating.

In existing houses where the DHW heating demand ratio typically ranges from 10 to 30 %, a state-of-the-art high-efficiency heat pump system will be more energy-efficient than an integrated singe-stage CO_2 heat pump system. However, in low-energy houses and passive houses, where the DHW heating demand ratio typically ranges from 50 to 85 %, an integrated CO_2 heat pump system with a tripartite gas cooler will outperform the most energy-efficient heat pump systems on the market.

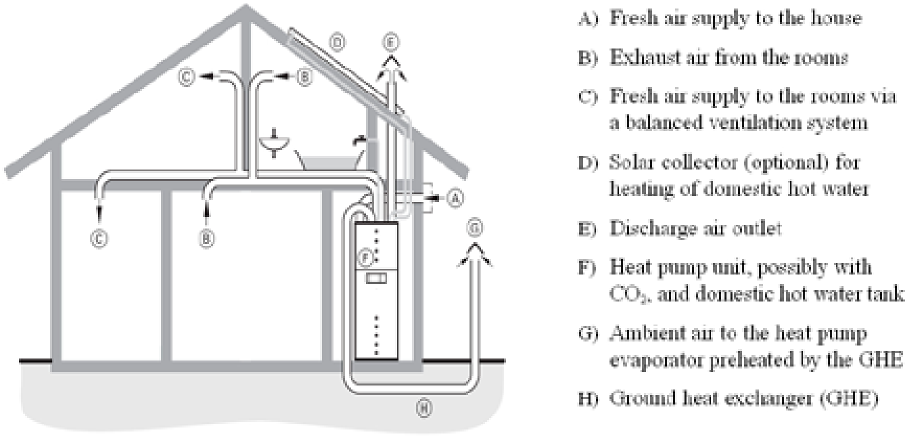

Figure 6 Example – heat pump installation in a passive house (Viessmann, 2008).

CO_2 heat pumps in passive houses – application example

A CO_2 heat pump system with a tripartite gas cooler for heating of low-energy houses and passive houses can be designed to utilize different heat sources. In Germany, 40-50 % of all passive houses use an integrated heat pump system for space heating and hot water heating (Bühring, 2005). The most common heat source is ventilation air, often in combination with outdoor air that is preheated in a ground heat exchanger. Figure 6 shows a schematic diagram of a residential heat pump system for a passive house using ventilation air and ambient air as heat sources (Viessmann, 2008). This is an excellent application area for integrated CO_2 heat pumps.

Ground (soil) is also a heat source of current interest for CO_2 heat pumps in low-energy and passive houses. In these systems, the evaporator tubes (direct expansion system) or 40 mm or 32 mm (external diameter) PE tubes with circulating anti-freeze fluid (indirect system) are installed horizontally in the ground about 0.8-1.5 metres below the surface of the ground. Due to the relatively low heating capacity of the heat pump unit in a passive house (2-3 kW), a relatively small ground space is required for the ground-heat exchanger.

Summary and conclusions

An integrated CO_2 heat pump system equipped with a tripartite gas cooler represents a promising, high-efficiency system for combined space heating and DHW heating in low-energy houses and passive houses. This is mainly due to fact that a major part of the total annual heating demand of such buildings is for DHW heating – an operating mode where a CO_2 heat pump will outperform heat pump systems using conventional working fluids. In low-energy and passive houses, the most interesting heat sources for a heat pump include ground (direct expansion system), ventilation air or a combination of ventilation air and outdoor air.

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Performance of a Ground Source Heat Pump System in a Near-Zero Energy Home

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Due to its high energy efficiency, ground source heat pump (GSHP) systems have been applied in many zero or near-zero energy buildings, which use renewable power generated on-site to offset partially, or completely, the energy consumed in the building on an annual basis. How does the GSHP system perform in these buildings? How much does it contribute to reaching the goal of zero or near-zero energy? In this article, the real performance of a near-zero energy home and its GSHP system will be presented.

Introduction

Limited resource of fossil fuels, increased demand for energy, and accelerated global warming are some serious challenges of our society. According to the official energy statistics from the U.S. government, buildings consume 39% of all the primary energy used in the U.S. Clearly, improving the energy efficiency of buildings is of great importance in lessening our reliance on fossil fuels, meeting the growing demand for energy, and reducing the emissions with global warming potential.

The concept of zero or near-zero energy building is to offset the energy consumed in a building with renewable energy generated on site on an annual basis. Given the expensive cost of on-site renewable energy generation, the building has to be highly energy efficient so that the required capacity of on-site renewable energy generation can be minimized and the building is economically feasible.

Due to its high energy efficiency, ground source heat pump (GSHP) systems have been applied in the design of many zero or near-zero energy buildings. How does the GSHP system perform in these buildings? How much does it contribute to reaching the goal of zero or near-zero energy building? Through year-round monitored data, the real performance of a near-zero energy home and its GSHP system will be presented in this article. At the end, suggestions will be given on how to further reduce the energy consumption of the house so that it could be a true zero-energy home.

Figure 1. Illustration of Ideal Homes ZEH with indication of integrated EEMs

Ideal Homes' Zero Energy Home (ZEH)

The house presented in this paper was built in Edmond, Oklahoma, in the U.S. by Ideal Homes, a local home builder. It was part of a Building America research project to demonstrate high efficiency technologies that help reach the goal of zero-energy at an affordable cost to average home buyers. National Renewable Energy Laboratory (NREL) installed a data acquisition system and has been continuously monitoring the energy performance of the house under occupied conditions since February 2006.

This house (we call it ZEH hereafter) is a 147 m^2, three bedroom, single-story, slab-on-grade, single family house with attached garage. The house was designed to have a tight, well-insulated envelope, and includes an energy recovery ventilator (ERV), high-performance windows, tank-less gas water heater, energy efficient lights and appliances, and a closed-loop ground source heat pump (GSHP) for space conditioning. A photovoltaic (PV) array is installed on the south-facing roof of the house. An image of the ZEH that illustrates the integrated energy efficiency measures (EEM) is shown in Fig. 1. A brief description of each of the EEMs is given in Table 1.

Monitored Performance

Energy consumed in the Ideal Homes ZEH includes both electricity used for HVAC, lighting, and appliances; and natural gas used for domestic hot water (DHW). Fig. 2 shows a comparison between the measured total electricity generated by the PV and all the energy consumed in the house during the whole year of 2007. In this figure, the natural gas consumption has been converted to equivalent kWh. Since the air

Table 1 Energy Efficiency Measures Integrated in Ideal Homes Zero Energy Home

Building envelope	Orientation	North
	Ceiling	Blown cellulose at ceiling, R value = 6.7 K·m²/W
	Walls	Blown cellulose (R value = 3.3 K·m²/W) + insulating sheathing (R value = 0.5 K·m²/W)
	Foundation	Slab perimeter insulation (R value = 0.7 K·m²/W)
	Windows	Double-glazed vinyl-frame Low-e; U = 2.2 W/K·m², SHGC = 0.31; Mostly south-facing with overhang
	Infiltration	0.19 ACH
Mechanical systems	Space heating	Split GSHP, 3.5 COP, 2-ton capacity[1]
	Space Cooling	Split GSHP, 4.9 COP, 2-ton capacity[1]
	Domestic hot water (DHW)	Gas-fired tank-less water heater, 0.82 Energy Factor
	Air-handler location	In conditioned space (utility room)
	Ducts	In vented attic, insulation (R value = 1 K·m²/W), 5% or less leakage to the outside
	Ventilation	ERV with 70% sensible recovery
	Lighting	90% compact fluorescent lighting
	Appliances and miscellaneous	ENERGY STAR refrigerator, clothes washer, dishwasher, TV, computer
	PV System	5.3-kW DC maximum under standard test conditions, 5.1-kW inverter

[1] The COP and capacity are measured at the ARI rating conditions. The entering air conditions are 26.7 ºC dry bulb and 19.4 ºC wet bulb in cooling and 21.1 ºC dry bulb in heating; the entering fluid temperatures are 25 ºC in cooling and 0 ºC in heating.

conditioning system was shut down from 7/3/2007 through 7/27/2007 due to a mechanical problem and the house was not occupied in March and July, the measured energy consumption may be slightly less than it would have been if the house was fully occupied and normally operated for the whole year.

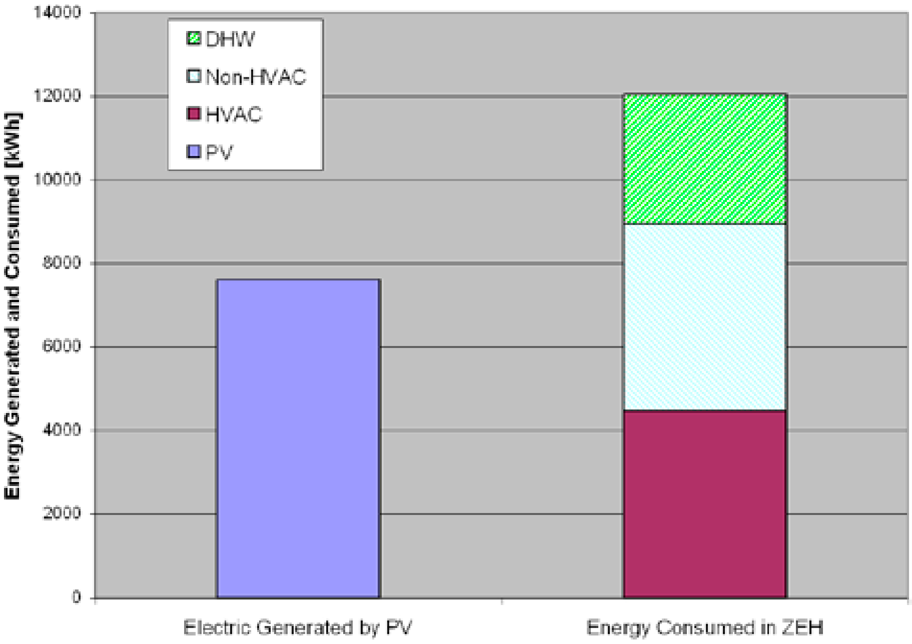

Figure 2. Energy generated and consumed in Ideal Homes ZEH in 2007

Table 2 Energy Savings Achieved by ZEH without Accounting for PV

		Site Energy		**Source Energy**	
		Electric [kWh]	Gas [kWh]	MWh	Saving %
Building America Benchmark		20018	8556	76.9	
ZEH	Predicted	9640	5128	38.2	50.3%
	Measured	8947	3077	33.5	56.4%

Although this house has not achieved zero-energy performance to date, it does consume significantly less energy than typical houses built in the U.S. Table 2 gives a comparison between the energy consumed in the ZEH and the Building America Benchmark, which is determined by NREL [1]. To give a broader view of the energy consumption, both the site energy (electricity and natural gas consumed in the house) and the source energy (the primary energy used to generate and distribute the consumed site energy) are compared in Table 2. The source to site energy ratio for electricity and natural gas are estimated to be 3.365 and 1.116, respectively [2]. To account for the energy consumption in the period when the house was not occupied or the air conditioning system was shut down, a computer simulation of the ZEH has been conducted using the enhanced eQUEST program [3] to predict the total energy consumption of the house assuming it is occupied and conditioned all year long. As shown in Table 2, the measured energy consumption of the ZEH is 56.4% less than the Building America Benchmark. With the adjustment for the energy consumption during the unoccupied or unconditioned periods, the predicted energy saving is 50.4%.

Fig. 3 shows the measured Coefficient of Performance (COP) of the GSHP system during 2007. The COP is calculated as the ratio of the delivered cooling/heating capacity to the associated power consumption for running compressor, fan, pump, and control devices. As shown in Fig. 3, most data of COP in cooling mode are within the range of 3-4 and most data of COP in heating mode are within the range of 4-5. The difference between the measured COP and the COP at rating conditions is due to the different entering air and fluid temperatures as well as the different fan and pump power consumption[2]. Heating COP is shown as negative to more clearly delineate heating and cooling performance.

Fig. 4 shows the measured leaving fluid temperature (LFT) of the ground loop heat exchanger (GLHE), which is also the entering fluid temperature to the heat pump, and the predicted LFT from the eQUEST simulation. As can be seen from Fig. 4, the measured LFT was within the range of 20-35 °C in summer when the system was running in cooling mode, and it varied between 10-20 °C in winter when the system was running in heating mode. Comparing Fig. 3 and 4, we can see clearly that the variation of COP is consistent with the variation of the GLHE's LFT. It can also be observed from this figure that the eQUEST predicted LFT matches the measured data fairly well. Differences between the predicted and measured maximum and minimum LFT are less than 2.5 °C.

Fig. 5 shows the measured master bedroom (MBR) temperature and the coincident outdoor air temperature. The monitored data showed that the MBR temperature is usually 1-2 °C lower than the temperature at the corridor where the thermostat is located. As shown in Fig. 5, the MBR temperature was maintained around 20 °C in winter months. However, in summer months, the MBR tem-

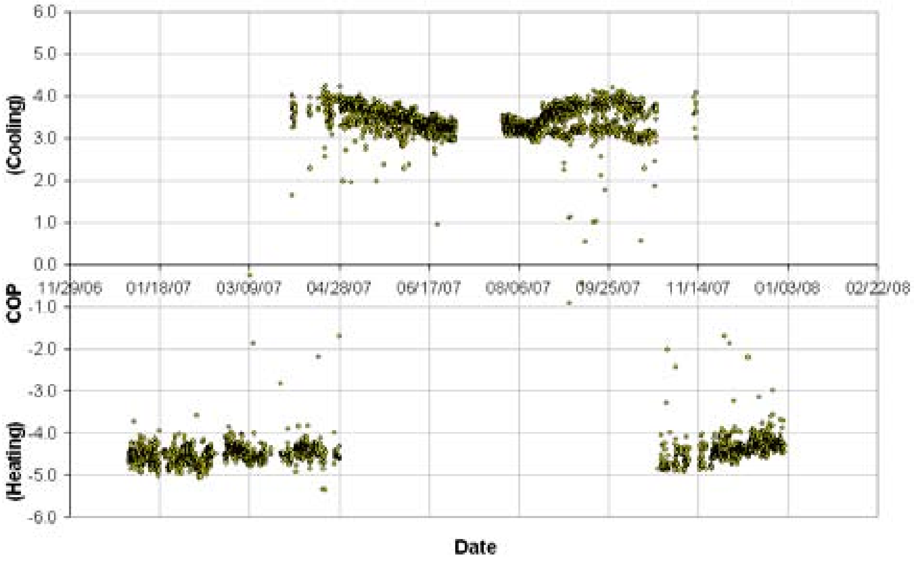

Figure 3. Measured GSHP system COP at heating and cooling modes

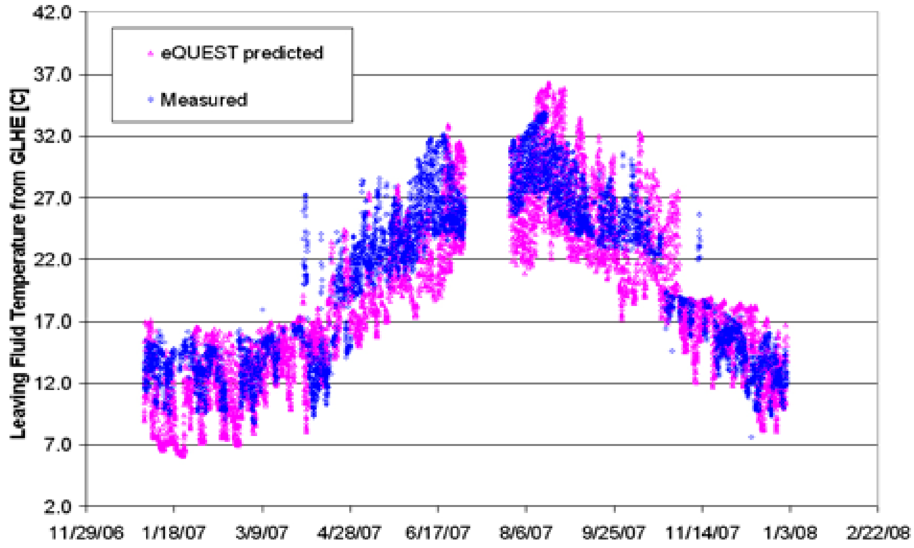

Figure 4. Measured and eQUEST predicted leaving fluid temperature of GLHE

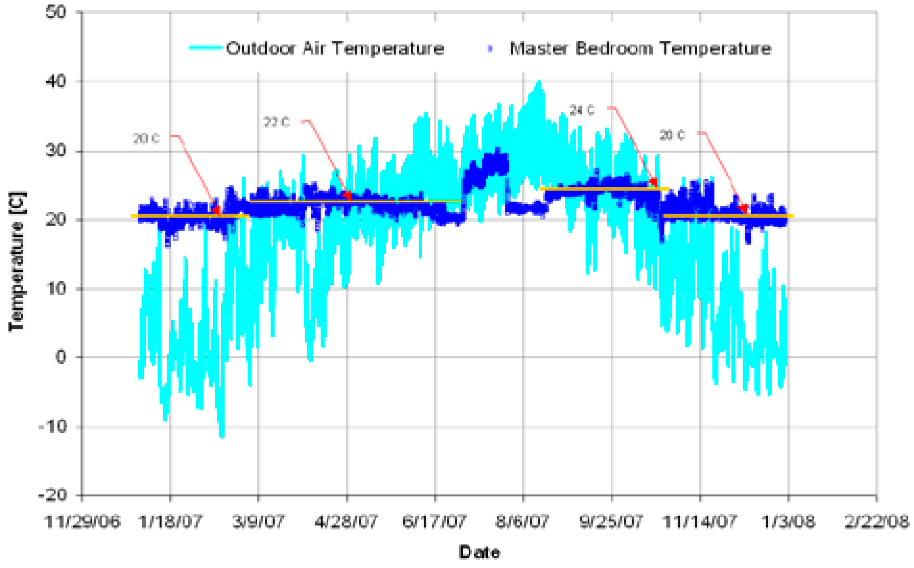

Figure 5. Measured outdoor air temperature and the master bedroom temperature

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[2] The power consumption of fan and pump for overcoming the resistance outside the heat pump unit is not accounted for in the ARI COP calculations.

perature was maintained at different levels: from March through June, it was around 22 ºC; from mid August though October, it was around 24 ºC. Both 22 ºC and 24 ºC are acceptable temperature in terms of thermal comfort, but the associated energy for space cooling may be significantly different [1].

Further Enhancements

In order to reach the goal of zero-energy, we need to either increase the capacity of the PV panel, or reduce the house energy consumption by further improving energy efficiency. Due to the expensive cost of PV panels, improving energy efficiency may be more economically feasible. Based on the monitored performance, the following energy efficiency measures are recommended to further reduce the house energy consumption.

- Improve energy efficiency for DHW heating by adopting solar thermal, GSHP de-superheat, or combination of these two measures;
- Use natural ventilation in spring and fall for space cooling instead of running GSHP;
- Increase thermostat set point in summer while retaining acceptable thermal comfort;
- Replace the heat pump unit with one that has higher cooling COP.

Conclusions

Monitored data from a near-zero energy home shows that the GSHP system satisfactorily conditioned the home with high energy efficiency, especially for space heating. To further reduce the home energy consumption and reach the zero-energy goal, additional energy efficiency measures should be implemented, including more energy efficient DHW heating technologies, natural ventilation for free cooling, optimal thermostat set point control, and a more energy efficient heat pump unit.

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Low-energy house integrated with heat pump system in Japan

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Due to its high energy efficiency, ground source heat pump (GSHP) systems have been applied in many zero or near-zero energy buildings, which use renewable power generated on-site to offset partially, or completely, the energy consumed in the building on an annual basis. How does the GSHP system perform in these buildings? How much does it contribute to reaching the goal of zero or near-zero energy? In this article, the real performance of a near-zero energy home and its GSHP system will be presented.

Background to low-energy houses in Japan

The Japanese climate [1]

Japan consists of five main islands: Hokkaido, Honshu, Shikoku, Kyushu, Okinawa and other smaller islands. The country extends from the sub-frigid zones in the north to the subtropics in the south, with average annual temperatures varying from 6.4 °C in Wakkanai-city (Hokkaido) to 22.4 °C in Naha-city (Okinawa) as shown in Figure 1. Corresponding temperatures for Sapporo, Sendai, Tokyo, Osaka, Kagoshima are 8.2, 11.9, 15.6, 16.3 and 17.6 °C respectively. Therefore, the number of heating degree-days ΣQ_{h14-10} varies widely from 3218 in Asahikawa to 0 in Naha. Values in Sapporo, Sendai, Tokyo, Osaka and Kagoshima are 2638, 1594, 900, 850 and 515 respectively. On the other hand, cooling degree-days ΣQ_{c24-24} vary from 0 in Asahikawa to 424 in Naha. In Sapporo, Sendai, Tokyo, Osaka and Kagoshima they are 0, 10, 130, 250 and 515 degree-days respectively. Climate conditions in Hokkaido island are similar those of northern European cities and Canadian cities and Chicago in USA.

The average daily insolation does not differ much among cities: in Sapporo, Sendai, Tokyo, Osaka and Kagoshima, it is 12.0 to 13.3 MJ/m^2/day. This suggested that typical passive solar techniques for heating can be effective even in the northern part of Japan.

1.2 Energy consumption in the dwelling sector in Japan [2], [3]

Japan's total primary energy supply and final energy consumption in a year 2006 were 23.8 x 10^{18}J and 16.0 x 10^{18}J, respectively. This is the world's 5th largest consumption. The fraction of energy consumption in both the commercial building sector and the residential sector occupies 32.3 %. Japan has signed the Kyoto protocol and a 6% reduction of CO_2 emission has to be achieved by the end of 2012 compared to that in 1990. However, CO_2 emission levels are still increasing. Especially, increasing energy consumption in both the commercial building and the residential sector has been over 30% compared to 1990. A reason for this trend is increased cooling and heating demand and use of electricity for multiple number of household equipment, and increased total floor area in commercial buildings.

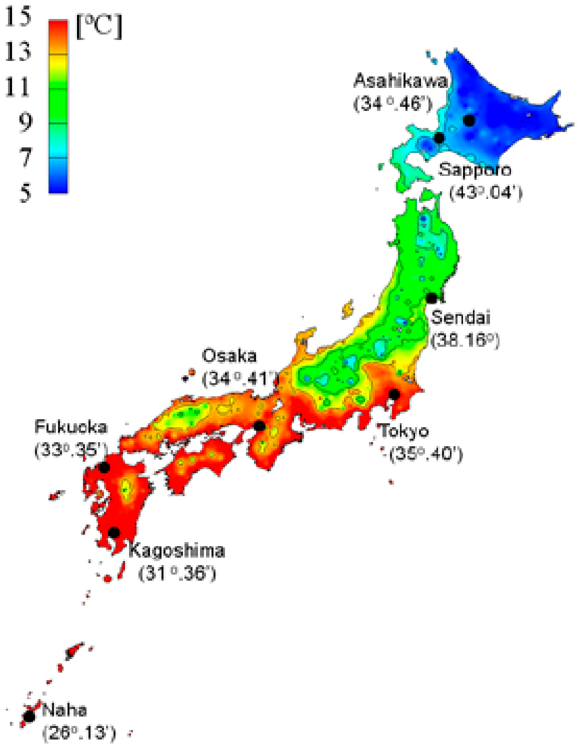


Figure 1 Distribution of annual average air temperature in Japan

The Japanese government has taken a variety of policies to reduce energy consumption in these sectors. They can be classified into two categories. One targets energy conservation and the other one is related to use of renewable energy. Enhanced thermal insulation of the buildings and use of energy efficient equipments are primary measures. For residences, so-called "Next-Generation Energy Conservation Standard" was established in 1997 and has presented a clear guideline for the required thermal performance of residential building in defined six climatic zones as shown in Figure 1. Table 1 describes representative climatic conditions in winter and summer in each zone, with the required overall heat transfer rate (Q-value) [W/m^2/K] and air leakage equivalent area ratio (C-value) [cm^2/m^2] in accordance with the next-generation energy conservation standard for single-family houses. The required Q-value in Hokkaido is 1.6 W/m^2/K, which is almost the same as that in the US and France, and even slightly higher than that in Germany. In this report, the authors concentrate on the development of low-energy houses in Hokkaido in Japan.

Table 1 Climatic features and required building performances

Zone	Color	Climatic feature		Required building performance		
		Summer	Winter	Q-value $[\mathrm{W/m^2/K}]$	C-value $[\mathrm{cm^2/m^2}]$	Annual heating and cooling load $[\mathrm{MJ/m^2}]$
I	🟦	Cool	Very cold much snow	1.6	2.0	390
II	🟦	Slightly hot	Cold much snow	2.4	2.0	390
III	🟩	Slightly hot	Slightly cold snow	2.7	5.0	460
IV	🟨	Hot	Moderate	2.7	5.0	460
V	🟧	Hot	Moderate	2.7	5.0	350
VI	🟥	Hot	Warm	3.7	5.0	290

The first full-scale low-energy experimental house at Hokkaido University [4]

The first full-scale low-energy experimental house was built in March 1997 at Hokkaido University. The author joined this project as a project manager under the leadership of Emeritus Prof. Ochifuji. The exterior appearance is shown in Photo 1. Residential floor area was 128 m2, and total floor area was 192 m2.

Photo 1 Low-energy experimental house at Hokkaido University

Passive system

Typical passive solar techniques were adopted in this house.

(1) High thermal performance and low air leakage: The thermally insulated wooden panel construction method was adopted. Ten inches thick foamed polystyrene beads board was sandwiched in this panel. High-performance windows, with a K-value of 1.38 $W/m^2/K$, were fitted mainly on the southern wall (21 m2). The overall heat loss coefficient was estimated as 0.97 $W/m^2/K$, and measured air leakage equivalent area ratio was 0.81 cm^2/m^2.

(2) High internal heat capacity: The ground floor consisted of a 150 mm thick concrete slab, covered by 100 mm thick cement mortar finish. The first floor consisted of 60 mm mortar concrete covering on the wooden floor, with 450 kg of PCM capsules having a phase change temperature around 20 -21 °C for the second floor construction.

(3) Natural ventilation system with earth tubes: Outside fresh air is supplied to the basement space, which acts as a large plenum chamber, through two 20 m long earth tubes which pre-heat or pre-cool the air passing through them. Natural ventilation through the ventilation shaft was powered by chimney effect of the ventilation tower at the centre of the house. In addition to above, small fans were installed in the side wall of the ventilation shaft in order to distribute fresh air to rooms in each floor.

Active system

A GSHP system and two types of active solar systems were installed as shown in Figure 2.

(1) Heating system; Low-temperature floor heating system heated by a small ground heat source heat pump unit with three buffer tanks of each 310 l volume. A heat pump was specially developed for this project. Compressor capacity was 1.0 kW, with R-134A refrigerant. COP at 0 °C – 30 °C was about 3.8. Floor heating tubes were laid in both the concrete slab of the first floor and on the wooden floor of the second floor, and covered by a mortar finish.

(2) Domestic hot water supply; An exhaust air heat pump (compressor capacity 0.4 kW, R-22) integrated with a 300 l storage tank, with four flat-panel type thermal solar collectors of 8 m^2 on the centre of the roof was used for hot water supply. A simple finned-tube type heat exchanger of 1 m^2 as an evaporator for heat recovery was installed at the exit of the ventilation tower. On a clear day, the solar thermal panels collect heat and can produce hot water during the daytime. However, on cloudy or rainy days, a heat pump unit operates from 3 PM

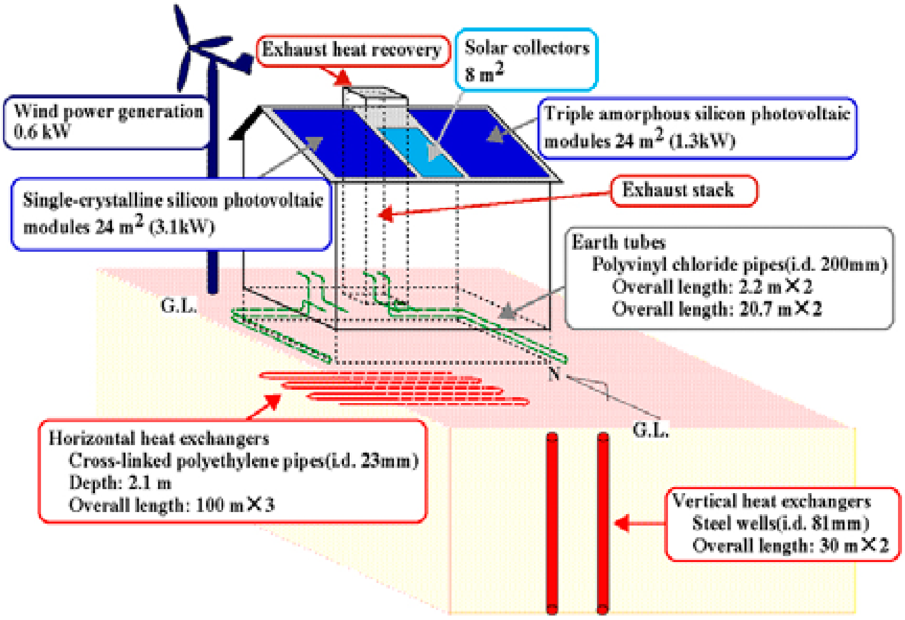


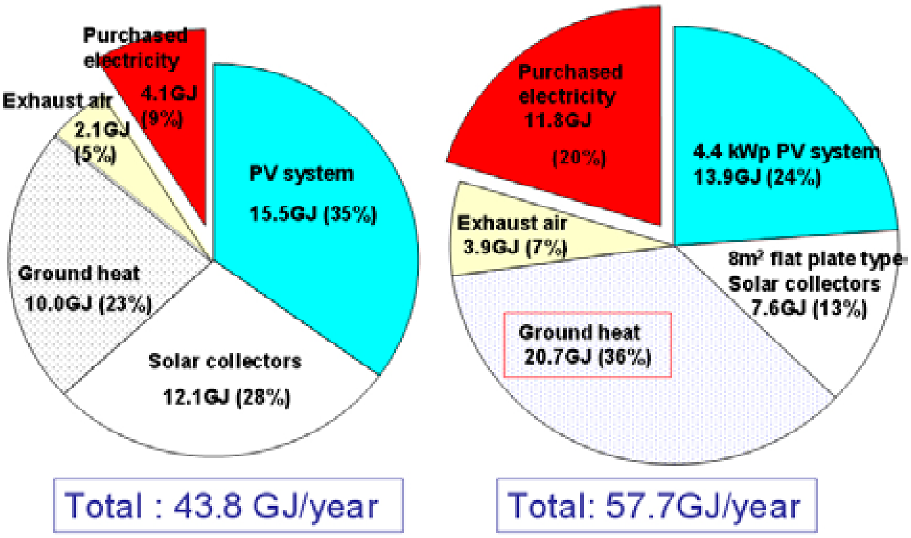
Figure 2 Active and passive energy systems and features

according to the stored hot water and heats up the water up to 65 ^{o}C.

(3) Electric power generation; Glass-covered monocrystalline silicon solar photovoltaic modules, with a peak generating capacity of 3.0 kW, were fitted on the left side of the roof. The right-hand side of the roof carried three layered amorphous silicon-coated on metal roof materials, covered by fluorine-resin sheets, to produce 1.4 kW of the peak generating capacity. These cells also provided the roofing cover material. It was expected that the total amount of generation power would be approximately 4200 kWh per year.

Annual energy balance

Figure 3 shows the estimated and actual secondary energy quantities used in 1998. It is estimated that annual energy consumption is 43.8 GJ/year, with 91 % of consumption being covered by the PV system, solar thermal collectors and ground heat for the heat source of the heat pump. Only 9 % is supplied from utility. On the other hand, 57.7 GJ was actually used, and the house purchased 11.8 GJ from the utility. This was because power generation and the amount of collected heat were smaller than expected, due to snow covering on the devices and heating demand and energy consumption for pumping to drive the heating system being larger. The final balance was that 80 % of the consumed energy was supplied by natural energy resources.



(a) Estimated

(b) Actual measured

Figure 3 Estimated and actual energy supply

Photo 2 External appearance

3. An actual modern low-energy house in Hokkaido [5]

Characteristics of the building

The actual modern low-energy house has been constructed in Naganuma, 30 km east of Sapporo, Hokkaido in November, 2005. Photo 2 shows an external appearance. An externally insulated timber-framed construction method with a concrete basement was adopted. The total residential floor area is 200 m^2 and the house has two occupants. Overall heat loss coefficient is estimated as 0.96 W/m^2/K including the effect of heat recovery from mechanical ventilation (0.5 times/h, temperature efficiency is 0.9). The structure has a high thermal capacity from its 300 mm thick concrete slab and 50 mm thick cement mortar finish, in which polyethylene tubes have been laid for the floor radiative heating. Large, south-facing triple-glazed low-E argon gas-filled windows (K=1.3 W/m^2/K for the standard size) provide significant passive solar input. The air leakage equivalent area ratio C-value was measured at 0.4 cm^2/m^2.

System configuration

Figure 4 shows a system configuration of the house.

Heating and cooling: a standard ground source heat pump (GSHP) system from SUNPOT Co Ltd. is used for heating and cooling. Two 100 m deep boreholes each contain a single U-tube. The natural ground temperature is 10.8 ºC. The geological layer mainly consists of mudstone under the water level. The effective thermal conductivity of the ground is evaluated as 1.4 W/(m^2·K) by a thermal response test.

The heat pump uses R-410A as the refrigerant and it has an inverter-controlled rotary compressor. Measured partial load efficiencies for the heating operation are shown in Figure 5. It can be seen, for example, that maximum heat output of 10 kW can be obtained with the highest power supply frequency and an inlet temperature on the primary side (T_{1in}) of 0 ºC and an outlet temperature on the secondary side (T_{2out}) of 35 ºC. This gives a COP of 3.7. Heating output can be varied by varying the compressor drive frequency, with the COP increasing to (for example) 4.5 at a moderate heating output of 4 kW. The diagram also shows lines calculated by a multi-regression analysis, which are useful for calculation of performance predictions. The heat pump provides a constant supply temperature T_{2out}, which is set by the house owner according to preference.

Ventilation system: The outside fresh air for the ventilation is taken in and preheated through a 50 meter long earth tube, which is buried 1.55 m below the ground. Condensate during the summer season can drain from the lowest point of the slightly sloping tube. The fresh air is introduced to a mechanical ventilation unit with 90 % efficient heat recovery and is supplied to the room.

Hot water supply: An EcoCute CO$_2$ heat pump water heater, designed for use in the cold areas of Japan, has been installed. The hot water generated by the heat pump during the night is stored in a 460 l tank at a temperature from 65 ^{o}C up to 90 ^{o}C.

Power generation: Glass covered polycrystalline silicon PV modules integrated with a steel roofing material are fitted on the roof. Total maximum output power is 6.8 kW with 1000 W/m^2 insolation.

Results of performances

Temperature variations and heating output: Measurements were mainly made during the winter season from 2006 to 2007. Figure 6 indicates seasonal variations of temperatures and daily average heating output of the heat pump. The temperatures are the daily average ones during operation period: weather conditions were relatively mild during this winter season. The observed minimum outdoor air temperature was -6.8 ºC. The supply temperature to the floor heating T2out was adjusted by the inhabitants depending on their thermal sensation. The highest value was around 40 ºC for only a few days in the beginning, but was generally between 30 ºC and 35 ºC.

The return temperature from the ground T1in was relatively stable above 0 ºC in mid-winter, and it recovered again in March as the demand for heating decreased. T1in was mostly higher than the outdoor air temperature.

The figure also indicates a variation of average room air temperature, which is the temperature of the return air to the ventilation unit. The room temperature varied from 16 ºC to 25 ºC, but was generally around 22ºC as a daily average.

Figure 7 shows indoor temperature differences with height on January 17th in 2007. T$_{2out}$ was set at 30 ºC in the day. In the early morning, room temperature was around 20 ºC when the outdoor air temperature was -4.1 ºC. However, the room temperature increased to 28 ºC due to the solar heat gain in

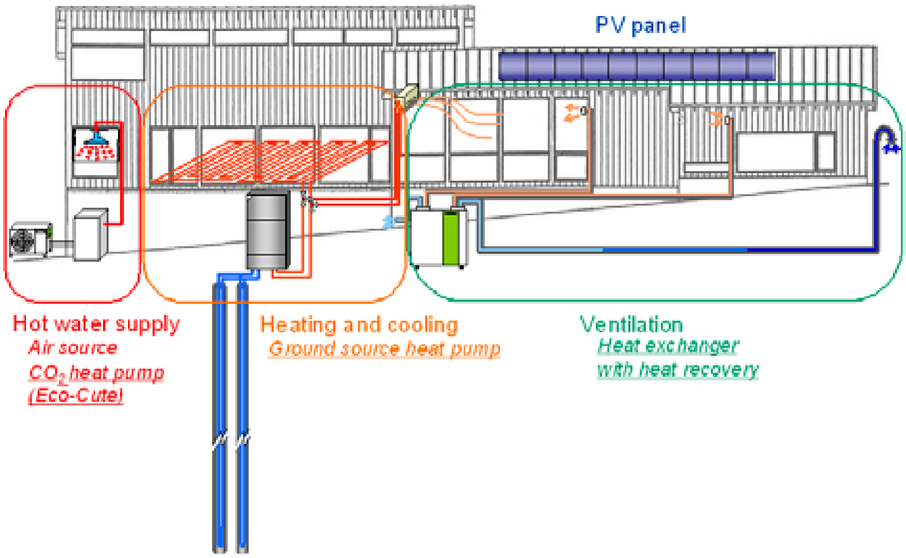


Figure 4 System configuration

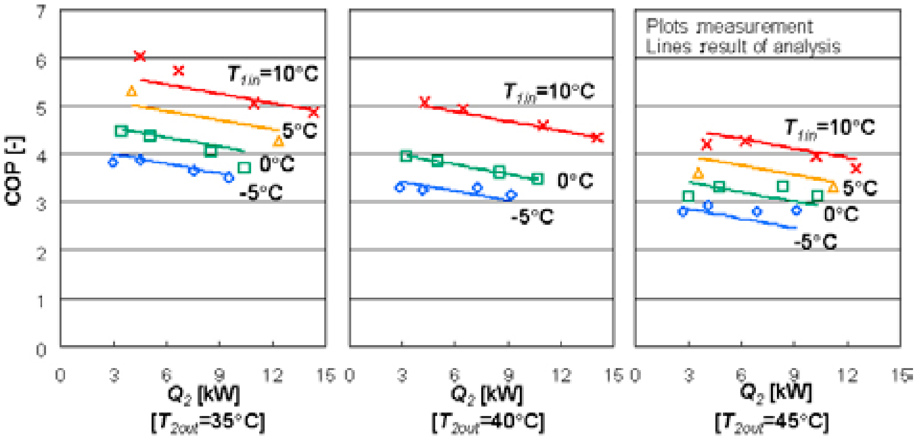


Figure 5 Partial load efficiency of the GSHP unit

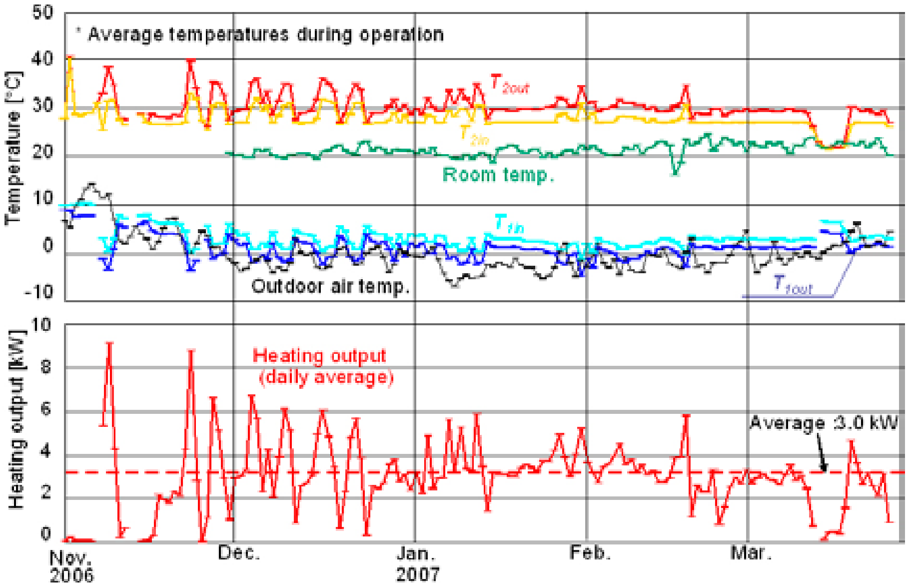


Figure 6 Seasonal variations of temperatures (upper) and daily average heating output (lower) (Nov 2006-March 2007)

the daytime. Air circulation from the living space to the northern part of the house or to the basement space helps to modify and stabilize the temperature distribution.

Performance of the GSHP system: The daily average heating output ranges from nearly 0 to 9 kW, as shown in Figure 6. It can be seen that output was generally in the range 2 6 kW. The seasonal average is calculated as 3.0 kW, which is less than one-third of the maximum heating capacity. Since this unit has an inverter-driven compressor, such partial load operation can give higher performance, as indicated in figure 5.

Figure 8 shows the monthly integrated heating output and the monthly average COP and $SCOP_1$. The seasonal heat balance of the GSHP system is also shown in Figure 9. $SCOP_1$ is an index of system performance of the GSHP, which includes the power consumption of the circulation pump in the primary side.

The monthly heating output varied depending on the outdoor air temperature. Maximum output was 2,591 kWh and was observed in January. Supposing that the system is operated every day for 24 hours in the period, this would give a daily average heating output of 3.5 kW, where the heat pump can work with higher efficiency due to the partial load operation even in the coldest season. The monthly average COP lies in the range from 4.66 to 5.72. For the winter heating season as a whole, the electrical power consumption was 2,455 kWh, the heating output was 12,624 kWh and the average COP was calculated as 5.14. This high performance can be attributed to the following reasons;

1) Low secondary temperature condition: The supply temperature can be set quite low around 30 ºC even in the coldest period, since the house is well insulated and has a large area of radiant floor heating.
2) Part-load operation: The heat pump can be operated at a lower speed, for higher COP as shown in Figure 5.
3) High primary temperature condition: The temperatures in the primary side can be mostly kept higher than 0 ºC.

The seasonal $SCOP_1$ reaches 4.45. The high system performance may be brought by the use of the adequate circulation pumps. It should be noted that excess designs of the circulation system

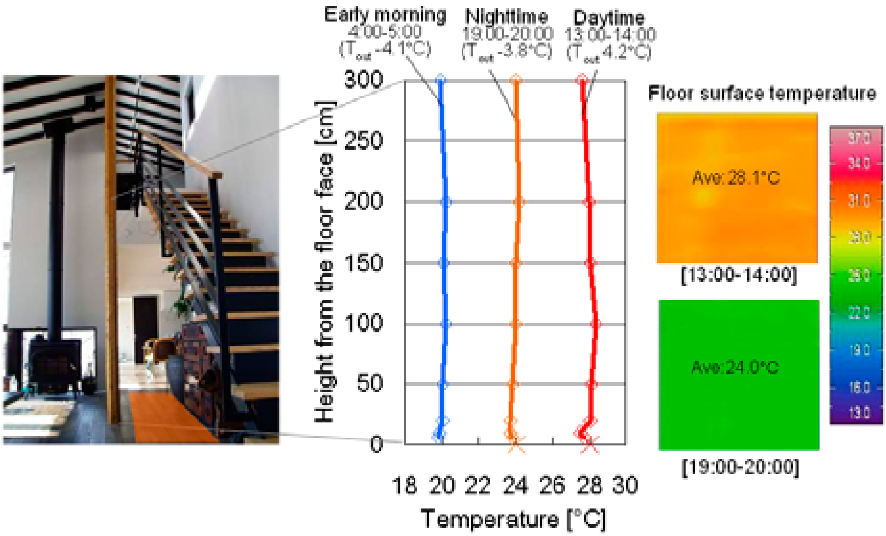


Figure 7 Vertical distributions of room temperature and floor surface temperatures measured by an infrared camera (17th Jan 2007)

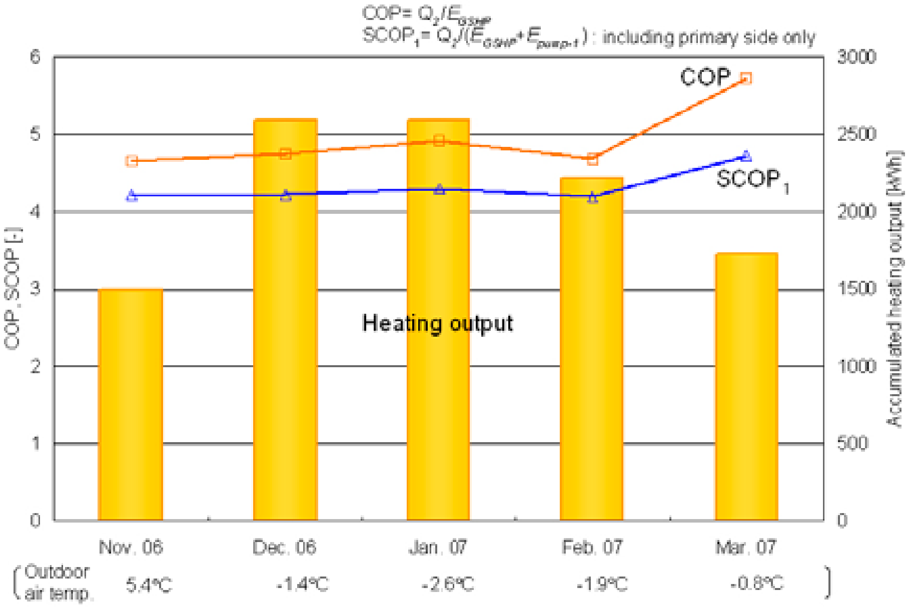


Figure 8 Monthly integrated heating output and monthly average COP and SCOP1 of the GSHP system, (Nov 2006-March 2007)

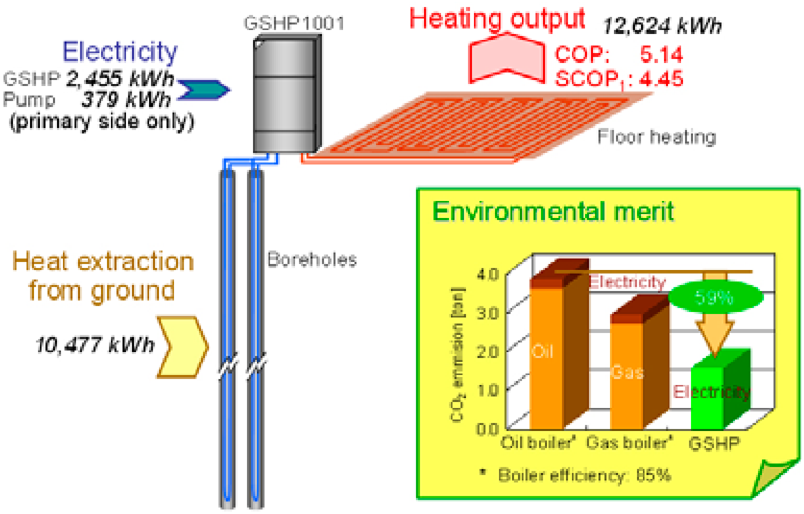


Figure 9 Seasonal heat balance of the GSHP system, (Nov 2006-March 2007)

may reduce the system performance.

Figure 9 also shows comparisons of CO_2 emissions from different heat source systems. The thermal efficiencies of the boiler systems are assumed to be 0.85. Calculations indicate that the GSHP system provides a CO_2 reduction effect of 58 % compared to the oil boiler system.

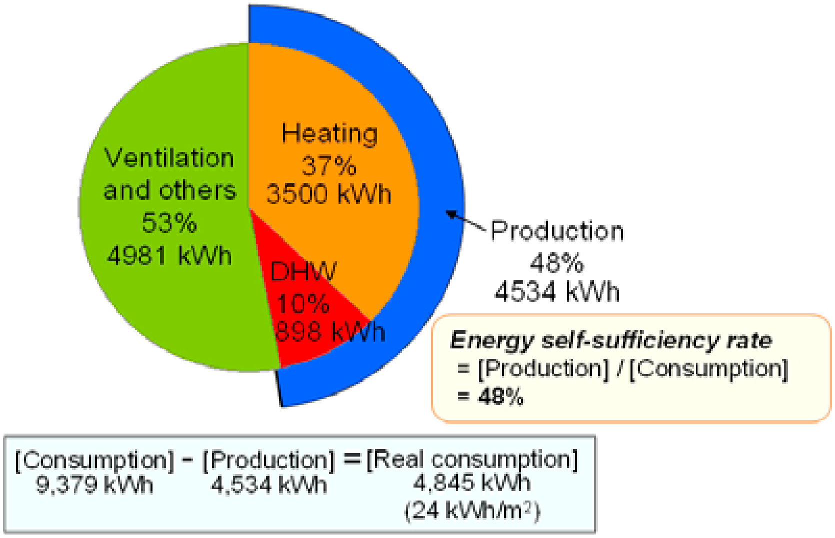


Figure 10 Monthly and annual energy balances in the low-energy house (June 2007-May 2007)

Annual energy balance: The monthly and annual energy balances in the actual low-energy house are analysed in Figure 10. Electricity consumption consists of that for heating, hot water supply and other purposes, including ventilation. Power is supplied by the PV system. The total annual consumption is 9,379 kWh, consisting of 37 % for heating, 10% for hot water supply and 53% for other purposes. The total produced power is 4,534 kWh and the energy self-sufficiency rate, which is shown as the ratio of production to consumption, can be 48 %. The real electric power consumption for all purposes, which is obtained by calculating the difference between consumption and production, is 4,845 kWh (24 kWh/m^2).

Real power consumption can be reduced in a number of ways. For heating purposes, automatic outlet temperature control according to heating demand will increase the COP of the heat pump unit and therefore reduce power consumption. Additional heat recovery from the exhaust air of a ventilation unit to the primary side of the heat pump unit can be effective in reducing the necessary borehole length and helping to recharge the ground in the autumn. Snow cleaning on the PV modules and pre-heating of supply water for the DHW are also effective. Introduction of a short-term thermal energy storage device such as a phase-change material will reduce overshoot of indoor air temperature.

Conclusions and future development

This report describes two examples of a traditional and a modern low-energy house with two heat pumps for space heating and hot water supply in Hokkaido, Japan. From the heat source point of view, it has been confirmed that ground heat source and exhaust air play very important parts, and are very effective in the cold region. Design of an integrated heat pump system for space heating, hot water supply and ventilation, with a heat recovery unit and also a humidity control device, is expected shortly. An advanced low-energy house can have an air system for heat distribution including ventilation. In this case direct expansion for the secondary side can be acceptable and the system will be very light. It must be very high performance.

Advances in the design of large high-performance windows enables very modern design of the low-energy house, but we have to pay much attention to prevent overshoot of the room temperature even in the winter season. Appropriate eaves are required for outside. The provision of air circulation between the southern part of the building and the northern part or the basement space is very easy and very effective.
In addition to the above, evaluation and publication of the the results of measurement is only one method to promote the reduction of CO_2 emissions through dissemination of low-energy houses integrated with heat pump systems.

Acknowledgement

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Heat pump water heaters for apartment buildings and blocks of flats of low-energy/passive house standard

Jørn Stene and Tore Hjerkinn, Norway

In apartment buildings and block of flats of such buildings of low-energy and passive house standard, the annual energy demand for heating of domestic hot water (DHW) typically constitutes 60 to 85 % of the total annual heating demand of the building. Since the DHW heating is the dominating heat load, a centralized DHW system that meets the entire demand can be a very profitable installation. Possible heating systems include electric immersion heaters, solar collectors in combination with electric immersion heaters for supplementary heating, gas- or pellet-fired boilers and heat pump water heaters (HPWH) utilizing e.g. outdoor air, exhaust ventilation air, groundwater, boreholes in crystalline rock or grey water as a heat source.

A HPWH using carbon dioxide (CO_2, R744) as the working fluid will typically achieve 20 % higher COP than the most energy-efficient HPWH system on the market using HFC or propane as working fluid. Air-to-water and water-to-water CO_2 HPWHs in the capacity range from about 5 to 60 kW have now become commercially available in Japan and Europe from a number of Japanese manufacturers (www.R744.com).

Evaluation of different heat pump water heater systems

Heat exchanger configuration and system design

The COP for a heat pump unit is very dependent on the condensation temperature/pressure, and typically increases by 3-4 % per K reduction in the condensation temperature. In order to enable production of domestic hot water (DHW) in the required temperature range (60-80 °C) and still achieve a relatively high COP for a heat pump, state-of-the-art heat pump water heater (HPWH) systems are normally equipped with a desuperheater and possibly a subcooler. A desuper¬heater is a heat exchanger that cools down the hot exhaust gas from the compressor for final heating of DHW, while a subcooler is a heat exchanger that cools down the working fluid after the condenser (condensate) for preheating of DHW. Many HPWH systems also use a combination of a desuperheater and a suction gas heat exchanger. The latter heat exchanger transfers heat from the condensate to the suction gas at the compressor inlet, and increases the exhaust gas temperature and the superheating enthalpy for the HPWH.

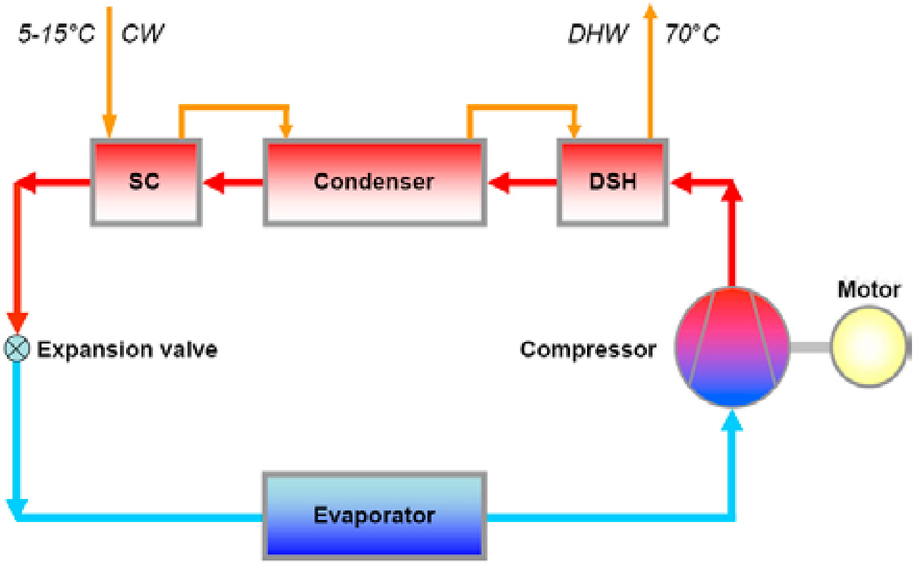

Figure 1 A heat pump water heater equipped with three separate heat exchangers in series.

Figure 1 shows, as an example, a schematic diagram of an HPWH system equipped with a subcooler (SC), condenser and desuperheater (DSH), while Figure 2 shows the cooling curve of the working fluid and the heating curve of the water in a Temperature-Enthalpy diagram (T-h diagram) when the city water (CW) is heated from 5 to 70 °C.

Heat pump systems using carbon dioxide (CO_2, R744) as the working fluid represent a new and promising technology, e.g. for HPWH systems. CO_2 is a non-flammable and non-toxic fluid that does not contribute to global warming as the HFC working fluids, i.e. GWP=1. Due to the unique thermophysical properties of CO_2, high energy efficiency can be achieved if the heat pump system is correctly designed and operated in order to utilize the properties of the fluid.

Due to the low critical temperature of CO_2 (31.1°C), a CO_2 HPWH will operate in what is known as a transcritical heat pump cycle, where heat is rejected by cooling of CO_2 vapour at supercritical pressure in a counter-flow gas cooler. Figure 3 shows an example of temperature profiles for CO_2 and water in a CO_2 gas cooler for DHW heating.

COP comparison

Four different HPWH designs have been analysed in order to identify the system with the highest COP at varying evaporation temperature (-10 to +10 °C), varying inlet city water temperature (5 to 30 °C) and varying outlet water temperature (60 to 85 °C). The HPWH systems were as follows (Hjerkinn, 2007):

- **System 1** – Heat pump with condenser and desuperheater
- **System 2** – Heat pump with subcooler, condenser and desuperheater
- **System 3** – Heat pump with suction gas heat exchanger, condenser and desuperheater
- **System 4** – CO_2 (R744) heat pump with a single gas cooler

HPWH systems no. 1, 2 and 3 were simulated with both R134a and R290 (propane), since these working fluids have a sufficiently high condensation temperature (60-70 °C) when using standard components with 25 bar pressure rating.

In order to ensure equal boundary conditions for the four different heat pump units, the various heat exchanger combinations were simulated with equal UA-values, which limited the size and heat transfer efficiency for the heat exchangers. The UA-value ranged from 1800 to 2400 W/K, and the higher the UA-value the lower the condensation temperature.

Figure 4 shows the COP for the different HPWH systems as a function of the evaporation temperature, t0 (Hjerkinn, 2007). The calculations assumed a total UA-value of 2100 W/K for both the condenser combinations and the CO_2 gas cooler, 5 K superheated vapour from the evaporator, 5 °C inlet city water temperature and 70 °C DHW temperature. The overall isentropic efficiencies for the compressors were calculated on the basis of typical efficiency curves from laboratory measurements.

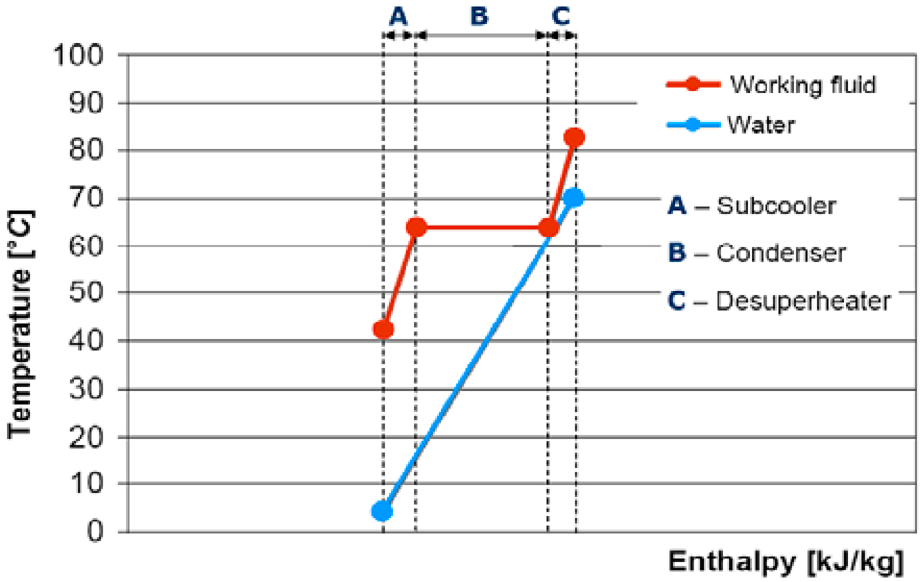

Figure 2 A heat pump water heater with heat rejection in a subcooler (A), condenser (B) and desuper¬heater (C) for heating of city water from 5 to 70°C.

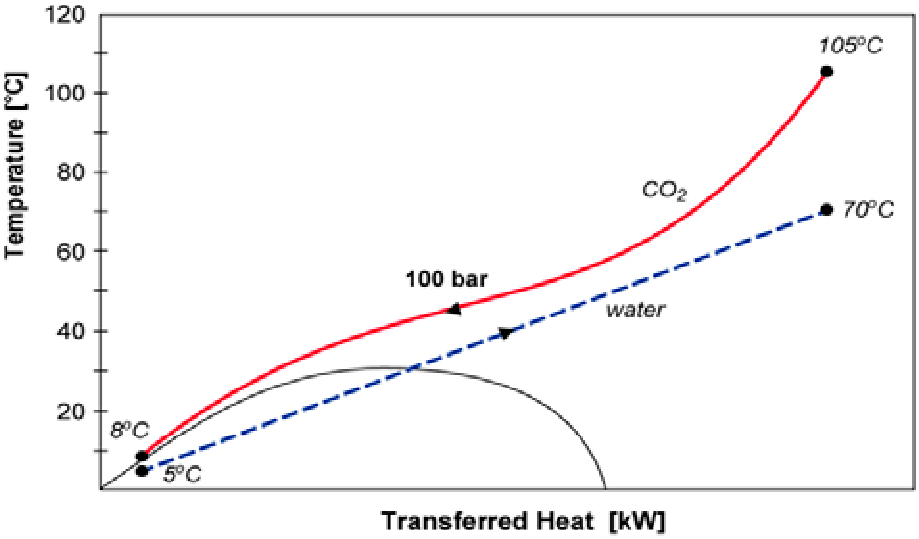

Figure 3 Example of temperature profiles in a CO2 gas cooler for DHW heating.

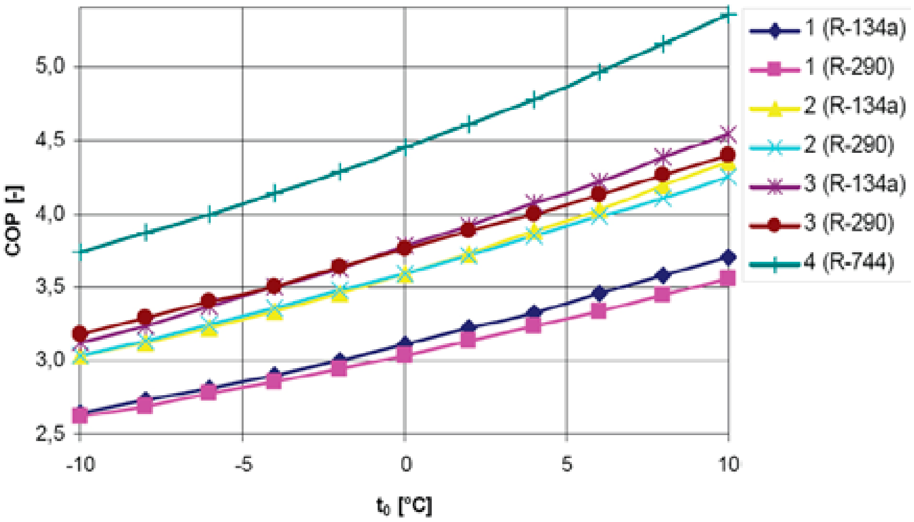

Figure 4 Calculated COP as a function of the evaporation temperature t0 (Hjerkinn, 2007).

For the state-of-the-art HPWH systems with R134a or R290 as the working fluid, System 2 (subcooler, condenser and desuperheater) and System 3 (suction gas heat exchanger, condenser and desuperheater) achieved more or less the same COP at varying operating conditions. System 1 (condenser and desuperheater) achieved roughly 15 % lower COP than System 2 and 3. The main reason for the lower COP was that System 1 operated at a higher condensation temperature due to poorer temperature fit between the water the working fluid.

The most energy-efficient HPWH was System 4, the CO_2 system, which on average achieved about 20 % higher COP than Systems 2 or 3. This was mainly due to higher compressor efficiency and the excellent temperature fit in the gas cooler between the CO_2 and the water, which minimized the average CO_2 temperature during heat rejection. In addition to the high energy efficiency for the CO_2 HPWH, CO_2 has the advantage of being a non-flammable, non-toxic and environmentally friendly fluid with a GWP factor of one.

Case study – design and evaluation of a CO_2 HPWH

“Bergen og Omegn Boligbyggelag” is about to construct a number of apartment buildings of passive-house standard at Damsgårdssundet in Bergen, Norway, with about 300 flats. An in-depth analysis has been carried out for one of the buildings with 40 flats, in order to develop a centralized CO_2 HPWH system (Hjerkinn, 2007).

Design of the HPHW and the storage tanks

The energy demand for DHW heating in the apartment building was estimated to be approx. 170,000 kWh/year, i.e. about 4,250 kWh/year for each flat. This included DHW to washing machines and dishwashers (600 kWh/year).

The CO_2 HPWH was designed for a heating capacity of 26 kW at 12 ºC inlet city water tempera¬ture, 70 ºC DHW temperature and 3 K difference between the outlet CO_2 and the inlet city water in the gas cooler. The isentropic and volumetric efficiencies of the compressor were 0.70 and 0.75 respectively. The HPWH capacity was calculated assuming 18 hours operating period per 24 hours for the heat pump unit and the application of four 1000 litres DHW storage tanks to cover large momentary DHW demands (Hjerkinn, 2007). Figure 5 shows the estimated 24 hour DHW consumption diagram for the apartment building, with the maximum DHW demand between 16:00 and 19:00 in the evening (approx. 3 hours maximum).

Component and system design

The 26 kW CO_2 HPWH system was simulated in CSIM (Skaugen, 2002), which is an advanced computer programme developed at NTNU-SINTEF for optimisation of CO_2 heat pump systems. CSIM calculates, among other things, real evaporator, gas cooler, suction gas heat exchanger and compressor performance based on laboratory measurements.

The CO_2 HPWH was equipped with a 60 bar plate heat exchanger as evaporator (SWEP), a reciprocating compressor with 150 bar pressure rating (Bitzer), a 140 bar counter-flow plate heat exchanger as gas cooler (SWEP), a counter-flow tube-in-tube suction gas heat exchanger, an automatic back-pressure valve (expansion valve) and a low-pressure receiver (LPR). The expansion valve and the LPR were used for optimisation of the pressure in the gas cooler at varying operating conditions in order to maximize the COP.

The inlet water temperature in the gas cooler has a considerable impact on the COP of a CO_2 HPWH, and the lower the temperature the higher the COP. A low inlet water temperature leads to a low CO_2 outlet temperature from the gas cooler and therefore a large enthalpy difference during heat rejection. Figure 6 shows simulated relative COP values for a CO2 HPWH unit at varying inlet water temperature and 60 and 80 ºC DHW temperature. Example – by increasing the inlet water temperature from 5 ºC to 15 and 25 ºC at 60 ºC DHW temperature, the COP is reduced by approximately 10 and 25 % respectively (Stene, 2004).

From Figure 6 it can be concluded that the DHW storage system for a CO_2 HPWH should use relatively small diameter storage tanks connected in series in order to minimize conductive heat transfer between the DHW and the city water in the tanks (exergy loss). Efficient diffusers at the tank inlets should also be installed in order to minimize the water velocity and consequent mixing of water at different temperature levels (exergy loss).

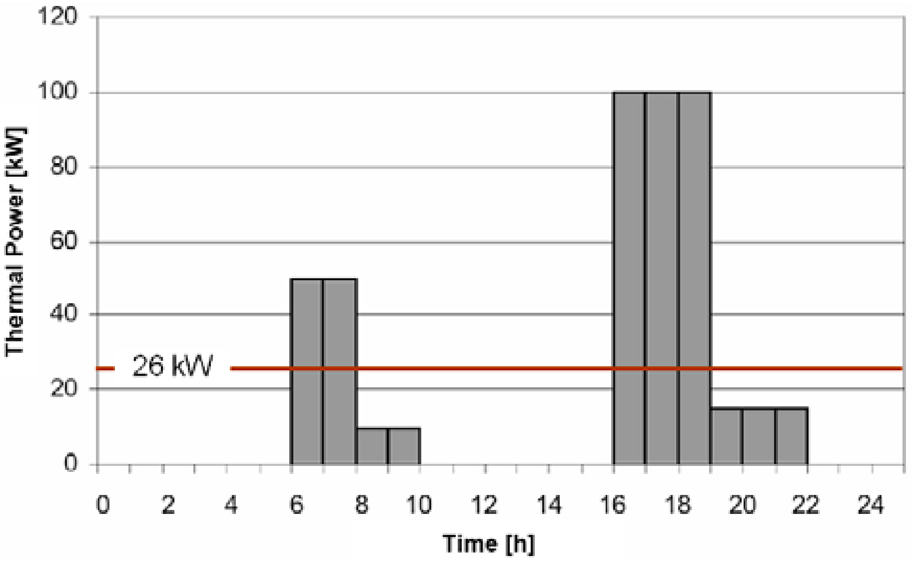

Figure 5 24 hours DHW consumption diagram for the apartment building (Hjerkinn, 2007).

Figure 7 shows a schematic diagram of the CO_2 HPWH system including four 1000 litres single-shell storage tanks connected in series and an inverter-controlled pump, Pump 1 (Hjerkinn, 2007).

Control strategy

The DHW system was designed as a closed unvented (pressurized) system, where DHW tank 4 was connected to the city water supply and DHW tank 1 was connected to the taps.

During the draw-off periods, cold city water will enter the bottom of DHW tank 4 and the same amount of hot water will flow from the top of DHW tank 1 to the taps. The CO_2 HPWH will normally run during the draw-off periods. An inverter-controlled pump (Pump 1) circulates the cold city water to the gas cooler, where the water is heated to the setpoint temperature (T1) before it enters DHW tank 1. When the tapping period has ceased, the CO_2 heat pump will run as long as the water temperature (T2) at the bottom of DHW tank 4 is lower than the setpoint temperature (e.g. 70ºC). The gas cooler pressure for the CO_2 heat pump unit is optimised in order to maximize the COP for the heat pump at varying operating condition.

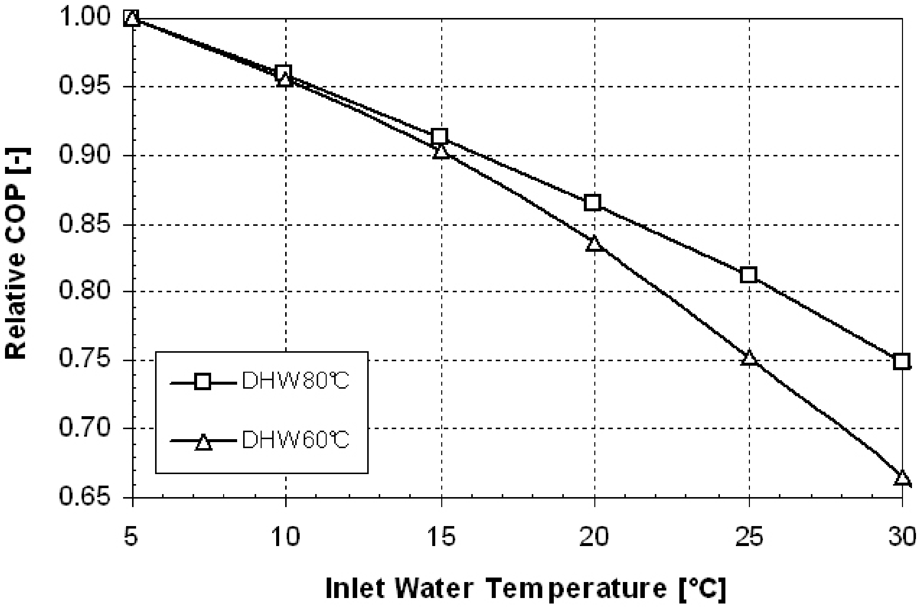

Figure 6 Simulated relative COPs for a CO2 HPWH as a function of the inlet water temp. to the gas cooler at 60 and 80 ºC setpoint temperature for the DHW (Stene, 2004).

Simulation results – COP and profitability

When using groundwater at 7 ºC as the heat source, the calculated COP for the CO_2 HPWH was approximately 3.8 (Hjerkinn, 2008). This corresponds to an annual energy saving of about 70-75 % compared to a conventional DHW system with electric immersion heaters, and is 20-35 percentage points higher that that of Scandinavian DHW systems based on solar collectors and electric immersion heaters for supplementary heating. Figure 8 shows the energy saving (i.e. the utilization of renewable heat – green bars) for the CO_2 HPWH compared to electric immersion heaters and a solar heating system.

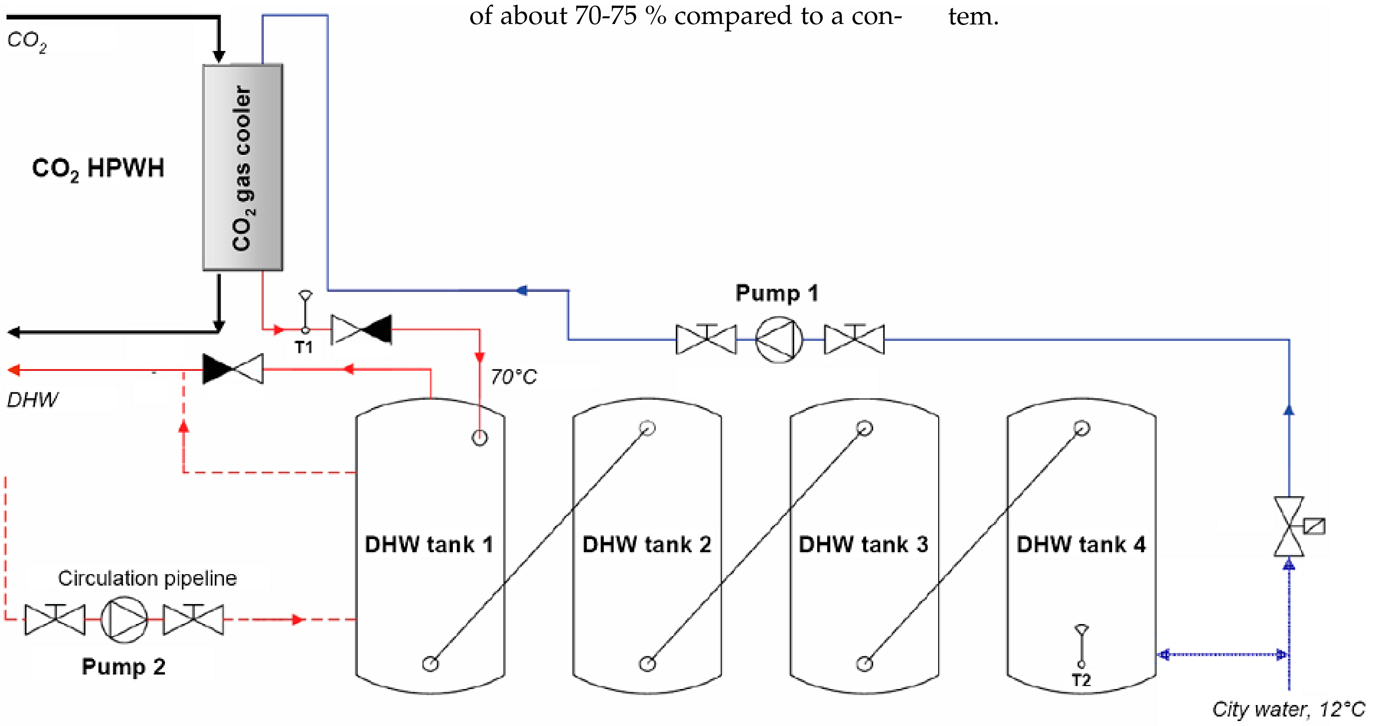

Figure 7 Schematic diagram of the DHW system connected to the CO2 HPWH (Hjerkinn, 2007)

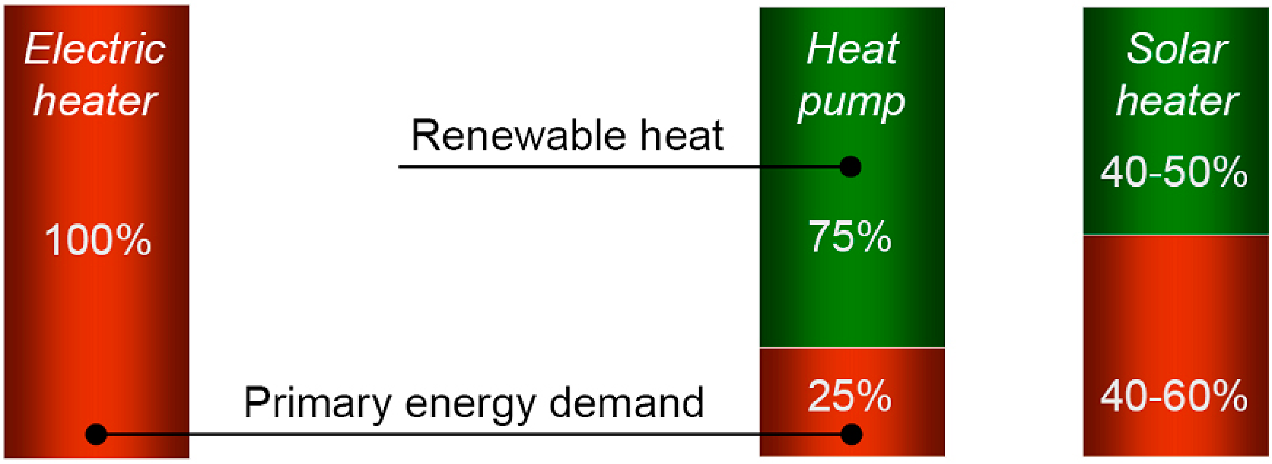

Figure 8 Primary energy demand and utilization of renewable heat for different hot water heating systems (electric immersion heater, heat pump, solar heater)

The maximum (permissible) investment cost for the CO_2 HPWH system was about €125,000 or 4800 €/kW (i.e. excellent profitability) with the following boundary conditions:

- Annual heating demand: 170,000 kWh/year
- Heat pump average COP: 3.5 – conservative value
- Real interest rate: 6%
- Economic lifetime: 15 years
- Electricity price: 0.1 €/kWh (0.80 NOK/kWh)
- Reference DHW system: Electric immersion heaters

Conclusion

Due to the high energy efficiency, the excellent profitability and the favourable environmental properties of CO_2, CO_2 heat pump water heater (HPWH) systems are regarded a promising technology for centralized DHW heating in apartment buildings and blocks of flats of low-energy and passive-house standard. In terms of energy efficiency and utilization of renewable heat, they even outperform state-of-the-art solar heating systems. Air-to-water and water-to-water CO_2 heat pump water heaters in the capacity range from about 5 to 60 kW are now available in Japan and Europe from a number of Japanese manufacturers (www.R744.com).

References

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Energy Technology Perspectives 2008 -- Scenarios and Strategies to 2050

The world needs ever-increasing energy supplies to sustain economic growth and development. But energy resources are under pressure, and CO_2 emissions from today's energy use already threaten our climate. What options do we have for switching to a cleaner and more efficient energy future? How much will it cost? And what policies do we need?

This second edition of Energy Technology Perspectives addresses these questions, drawing on the renowned expertise of the International Energy Agency and its energy technology network. It responds to the G8 call on the IEA to provide guidance for decision-makers on how to bridge the gap between what is happening and what needs to be done in order to build a clean, clever and competitive energy future.
Source: www.iea.org

Energy Policies of IEA Countries – Japan -- 2008 Review

Declaring climate change and environment as a top priority of the 2008 G8 Summit in Hokkaido, host country Japan has demonstrated its commitment to pressing ahead in these domains. Already a world leader in advancing energy technology transfer and environmental policy, the country is determined further to improve its domestic policies, moving it towards a more sustainable and secure energy pathway for the long term. Along with other accomplishments, government support for energy R&D is very strong, and policies to enhance the efficiency of appliances – both for domestic consumption and export – are models for other countries.
Source: www.iea.org

Energy Policies of IEA Countries – Sweden -- 2008 Review

Sweden is one of the leading IEA countries in the use of renewable energy and has a long tradition of ambitious and successful policies to improve energy efficiency. Compared to the other IEA countries, Sweden's CO_2 emissions per-capita and per unit of GDP are low, partly owing to efficient and low-carbon space heating, and virtually carbon-free electricity generation. The country also remains a forerunner in electricity market liberalisation. Still, even if Sweden has continued to make progress in most areas of its energy policy since the IEA last conducted an in-depth review in 2004, there is room for improvement
Source: www.iea.org

New ASHRAE book presents data center cooling case studies

A new book from ASHRAE provides guidance on cooling data centers and presents case studies. The book provides case studies of high-density data centers and a range of ventilation schemes that demonstrate how loads can be cooled using a number of different approaches. High Density Data Centers — Case Studies and Best Practices is part of the ASHRAE Datacom Series, developed to provide a comprehensive treatment of datacom cooling and related subjects.
Source: The HVAC&R Industry

Sustainability reporting software from autodesk

Autodesk has launched a Sustainable Materials Assistant for its Inventor program. Users of Inventor, a program for making 3D prototypes, can input data on toxicity, carbon footprint, recyclability and regulatory information for materials, and later analyse the sustainability information of components or entire projects. The program creates a report that highlights data on materials in the project regarding environmental subjects, allowing designers to check if the project contains toxic materials or has what could be too large a carbon footprint.
Source: The HVAC&R Industry

Promoting Energy Efficiency Investments -- Case Studies in the Residential Sector

Type: Studies
Existing buildings are responsible for over 40 % of the world's total primary energy consumption. An impressive amount of energy could be saved simply by applying energy-efficient technologies.

Yet various market barriers inhibit energy efficiency improvements in existing buildings and result in energy savings that are significantly lower than potentials. Financial barriers -- including the initial cost barrier, risk exposure, discount-factor issues and the inadequacy of traditional financing mechanisms for energy-efficient projects -- play a major role. Policies that may help to overcome financial barriers to improving energy efficiency in existing residential buildings are the focus of this study.

The publication provides illustrations of policies and measures implemented in five IEA member countries and the European Union. Each case includes relevant background and contextual information, as well as a detailed evaluation of each policy according to five pre-defined criteria: relevance, effectiveness, flexibility, clarity and sustainability.

Promoting Energy Efficiency Investments aims to inform policy makers and offers ideas on the most effective policies, programmes and measures available to improve energy efficiency in existing residential buildings.
source: www.iea.org

2008

Purdue International Compressor Conference
14 - 18 July, W. Lafayette, IN, USA

nternational Refrigeration Conference
14 - 18 July, W. Lafayette, IN, USA

11th International Conference on Indoor Air Quality and Climate
17 - 22 August, Technical University of Denmark
E-mail: info @ indoorair2008.org
http://www.indoorair2008.org/

8th IIF/IIR Gustav Lorentzen Conference on Natural Working Fluids Refrigeration and Energy - The Natural Choice
7 - 10 September, Copenhagen, Denmark
Tel: +45 72 20 12 67
E-mail: poul.jeremiassen @ teknologisk.dk
www.iir-gl-conference-2008.dk

7th Minsk International Seminar ”Heat Pipes, Heat Pumps, Refrigerators, Power Sources”
8 - 11 September
First Announcement ›››
www.minskheatpipes.org

International Conference on Compressors and their Systems
10 - 12 September London, UK
www.imeche.org/events/compressors

HVAC Energy Efficiency Best Practice Conference
IIR Commissions E1 with E2
18 - 19 September, Melbourne, Australia
Information coming up on www.airah.org.au

GSHP Scotland
22 September
Edinburgh, Scotland
www.gshpscotlandevent.org

International Sorption Heat Pump Conference 2008 - ISHPC08
23 - 26 September Seoul, South Korea
http://www.iifiir.org or http://web.khu.ac.kr/

RENEXPO® 2008
9 - 12 October
International trade fair and conference for renewable energies and energy efficient building and renovation.
Augsburg, Germany
E-mail: redaktion @ energie-server.de
www.renexpo.com

Chillventa 2008
15 - 17 October
International Trade Fair for Refrigeration, Air Conditioning and Ventilation, and Heat Pumps
Nürnberg, Germany
http://www.chillventa.de

Integrated design and operation problems of refrigeration and AC systems
15 - 17 October
Poznan, Poland
Contact: Marek Michniewicz, m.michniewicz @ clch.pl

SMACNA Annual Convention
21 - 25 October
Maui, HI, USA
http://www.smacna.org/

HARDI Annual Fall Conference
25 - 28 October
Phoenix, AZ, USA
http://www.hardinet.org/

For more events, check out the Heat Pump Centre website, www.heatpumpcentre.org

In the next Issue

9th IEA heat pump conference

Volume 26 - No. 3/2008

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 worldwide source of independent information and expertise on environmental and energy conservation benefits of heat pumping technologies (including refrigeration and air conditioning).

The Programme conducts high value international collaborative activities to improve energy efficiency and minimise adverse environmental impact.

Mission

The Programme strives to achieve widespread deployment of appropriate high quality heat pumping technologies to obtain energy conservation and environmental benefits from these technologies. It serves policy makers, national and international energy and environmental agencies, utilities, manufacturers, designers and researchers.

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.

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