IEA Heat Pump CENTRE NEWSLETTER

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ATES/BTES systems for commercial buildings

Ground-source heat pumps for commercial buildings

Underground systems are becoming more common in the Netherlands

Energy pile systems in Japan

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IEA **Heat Pump** CENTRE
NEWSLETTER

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In this issue

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Energy storage + heat pumps = sustainable heating and cooling

In many cases, heat pumps for official and commercial buildings are a very efficient means of both heating and cooling. Despite this, the technology of energy storage combined with heat pumps is relatively unknown. This issue therefore focuses on the application of ATES and BTES systems for buildings with demands for both heating and cooling (and air conditioning), to review some of the recent developments and to show examples of successful, efficient installations that save a lot of energy and CO_2 emissions.

Enjoy your reading!

Roger Nordman
Editor, HPC Newsletter

COLOPHON

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Underground Thermal Energy Storage (UTES) – more than 40 years of experience

Dr. Burkhard Sanner
President, European Geothermal Energy Council (EGEC)

Dear Readers
In the mid 1960s, the first practical use of "aquifer storage" was made in the Shanghai region in China, storing cold from winter for cooling purposes in the textile industry in shallow groundwater-bearing layers (aquifers). The first application destined exclusively for UTES in Europe dates back to 1987, when an aquifer storage system for cooling newsletter printing shops in Amsterdam became operational. Since then we have seen numerous plants commissioned, with a variety of technologies and purposes:

- Storage in the ground using closed borehole heat exchangers ("BTES"), storage in groundwater (aquifers) using wells ("ATES"), and even some projects with storage in caverns or abandoned mines ("CTES");
- storage of cold or heat at various levels (in practice up to about 70–90 °C), or both heat and cold;
- the retrieval of heat or cold directly, or via heat pumps;
- applications in industry, offices, hotels, residential areas, etc.

In Europe, the main areas of application are Sweden, The Netherlands, Belgium and Germany. One of the most prominent installations can be found in Berlin, where since 1999 the German Parliament complex comprises two ATES at different levels, both in depth and in temperature – one shallow for cooling purposes, and one deep for storing waste heat from co-generation in summertime to assist heating in winter. A large absorption heat pump is part of the heat retrieval system.

It is difficult to give a number for UTES plants world-wide, as there is a continuous range from large, ground-source heat pump systems (GSHP) to pure storage. Large fields of borehole heat exchangers and large groundwater heat pumps require balanced heat extraction and injection on the ground side in order to operate effectively over time. The same operational strategy applies to UTES, so a definition in IEA ECES Annex 8 called for a UTES system to have less than 25% of the annual heat turnover of the storage exchanged with the ground outside the storage volume.

The IEA Heat Pump Newsletter devoted an issue on UTES back in 1998 (issue 16/2). UTES applications have been built in substantial numbers since then – an ATES for Stockholm Arlanda airport, Sweden, and another ATES for a campus with office buildings and a 5-star-hotel in Bonn, Germany, both operational since 2009, and a BTES for storing heat from a foundry in Emmaboda, Sweden, currently under construction, to name a few recent examples.

Having been part of the UTES and GSHP scene for some 25 years, I am very optimistic that another UTES issue of the IEA Heat Pump Newsletter in 10 years from now would bring news from further successes in utilising underground storage for thermal purposes.
I hope you enjoy this interesting issue about the 2010 status!

Column

Moving energy through time and space – a new movement

Signhild Gehlin
Secretary General
Swedvac – The Swedish HVAC Society

The world does not lack energy. Plenty of thermal energy would be available were it not for one annoying little snag – heat and cold occur in abundance when we need them the least. Imagine applying winter cold during warm summer days and how useful summer heat would be in wintertime. By moving energy through time and space we can get around this mismatch to achieve energy efficiency and sustainability. The heat pump plays a key role in making use of the thermal energy available. It enables us to collect the seemingly useless thermal energy in air, water and ground, and to refine it into highly useful thermal energy, with only a relatively small driving energy penalty. In seasonal energy storage installations, heat pumps help us move energy through time and space.

Seasonal energy storage systems must be large in order to minimise diffusion losses. The large volumes required make underground storage a suitable medium as material and construction costs are low. The heat and cold may be stored in soil or rock, or in underground water. Sweden has more than 30 years of experience from underground seasonal thermal energy storage. The bedrock, mainly hard crystalline rock, is highly suitable for borehole thermal energy storage. More than 300,000 Swedish family dwellings are heated by ground source heat pumps (7,500 GWh/year) and around 300 borehole thermal energy storage systems provide roughly 100 GWh/year of heat and cold for larger buildings. In addition to this, there are today about 100 aquifer thermal energy storages in Sweden, providing a total of around 300 GWh/year of heat and cold. One of the most recent aquifer storages was built at Arlanda Airport in Stockholm. This storage, with a capacity of 10 MW, provides 15–20 GWh/year of heat and cold.

Borehole storage systems have a typical capacity of 50 to 500 kW and a COP of 4.5 to 5.5, while aquifer storages typically reach 0.5 to 5 MW capacity with a COP of 5 to 8. Aquifer storage systems generally have a payback time of less than three years, whereas large borehole storage systems need five to six years. The necessary aquifers are however not available everywhere and only 10% of Sweden has geology suitable for aquifer storage. In the Netherlands, where aquifer systems are most common, the situation is quite the opposite. The entire country is more or less one large aquifer, and there are today around 1,000 aquifer systems in operation in the Netherlands.
Geothermal energy is a renewable energy source that can be put to use in most countries. Previously dormant countries are beginning to realise that underground heat sources may play an important role in a sustainable energy system. The British Environment Agency recently reported a 100% increase in ground source installations since 2007, and is counting on today's 8,000 installations growing to a potential of 1.2 million installations in 2020, to generate 78 TWh/year of renewable energy for the British energy consumption.

Heat pumps are becoming the new global movement – by moving energy through time and space.

The 10th IEA Heat Pump Conference

Early Notice – Call for Papers
May 16 – 19, 2011, Tokyo, Japan

The Conference program will cover the following topics:

- **Environment-friendly Technology**
  Advances in equipment design and development
- **Systems and Components**
  Advanced electrically and thermally operated systems, and ground source systems
- **Applications**
  Demonstrated energy efficiency and environmental advantages
- **Research and Development**
  New developments and new refrigerants in heat pumping technologies
- **Policy, Standards, and Market Strategies**
  Government, utility and professional society activities related to heat pumps
- **Markets**
  Market status, trends and future opportunities
- **International Activities**
  Discussion of actions in response to climate change initiatives

Papers: Papers will be presented both orally and as posters. Abstracts (200 - 300 words) should be submitted through our website, www.hpc2011.org by 30 June 2010.

The abstracts will be screened by an appropriate Regional Coordinator, authors will then be advised of acceptance by 31 August 2010. Full papers will be required by 31 January 2011.

Workshops: There will be opportunities for organization of workshops during the Conference. Interested organizations should contact one of the Regional Coordinators.

Exhibition: There will be an exhibition in connection with the Conference. For those interested in exhibiting, please contact your Regional Coordinator.

Web: For more information, please log on to the Conference website at: www.hpc2011.org

Regional Coordinators
For information on papers and workshops, conference program, etc., please contact the Regional Coordinator for your area:

- Asia and Oceania: Mr. Makoto Tono, tono.makoto@hptcj.or.jp
- North and South America: Mr. Gerald Groff, ggroff2@twcny.rr.com
- Europe and Africa: Mrs. Monica Axell, monica.axell@sp.se

General

The Paul Anderson Award to Gerald Groff

Gerald Groff was honoured with the Paul Anderson Award at ASHRAE's 2010 Winter Conference, held in Orlando, Florida, in January 2010. The award, ASHRAE's highest award for technical achievement, is named in memory of Presidential Member F. Paul Anderson, who was a pioneer in the study of environmental conditions for comfort. The Heat Pump Centre congratulates Mr. Groff on this award.
Sources: http://www.nxtbook.com/nxtbooks/ashrae/ashraeinsights_201002/#/2 , (see p. 3); http://www.heatpumpcentre.org/Home/anderson%20-%20insights.pdf

Implementation of the EU Buildings Directive in different countries

An EU-funded project has cast light over the status of implementation of the Energy Performance of Buildings Directive in twelve EU countries (Czech Republic, Finland, Italy, the Netherlands, Norway, Poland, Spain, Greece, Belgium, Denmark, France and Germany) as part of the ASIEPI project. The project is funded by the European Community's Intelligent Energy Europe programme.
Source: http://www.ammonia21.com/content/articles/2010-01-25-implementing-the-eu-buildings-directive-in-different-countries-.php

EPEE commitment to improve the energy efficiency of refrigeration and air conditioning equipment

EPEE, the European Partnership for Energy and the Environment has, as its key priorities, the improvement of energy efficiency of refrigeration, air conditioning and heat pump equipment, in addition to the use of renewable energy technologies. EPEE's members manufacture, design and install heating, cooling and refrigeration technologies.
With these priorities, EPEE and its members intend to:
- Promote the European Directive on Renewable Energies at EU member state level, to make sure that all heat pump types, whether aerothermal or geothermal, are recognised as renewable energies and, as such, are included in national subsidy schemes;
- Foster the responsible handling of refrigerants and their careful selection in order to achieve energy-efficient systems;
- Help to implement the European Ecodesign Directive by providing technical information on refrigeration and air conditioning equipment.
Source: http://www.fluorocarbons.org/templates/_NewsDetail/index.php?page=65f4c7c703c51d71d1a31d4d0f87d921&detail=f491c21cd9255654cde8b21723afb99f&lang=en&category=[in

AHRI hosts the IEA Heat Pump U.S. National Team

AHRI hosted the International Energy Agency Heat Pump U.S. National Team on Oct. 13. The U.S. National Team is organised by the U.S. Department of Energy - Energy Efficiency and Renewable Energy, and consists of representatives from the Oak Ridge National Laboratory, AHRI, and other HVACR-related associations, several universities, and numerous AHRI member companies.
Source: http://www.ahrinet.org/Pages/ShowMeMore.aspx?src=single&lpk=1147

New ASHRAE Standards available

The following revised standards are now available from ASHRAE, and can be purchased via the ASHRAE website at http://www.ashrae.org/bookstore:
- ANSI/ASHRAE Standard 16-1983 (RA2009), Method of Testing for Rating Room Air Conditioners and Packaged Terminal Air Conditioners
- ANSI/ASHRAE Standard 24-2009, Methods of Testing for Rating Liquid Coolers
- ANSI/ASHRAE Standard 37-2009, Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment

Source: http://www.ahrinet.org/Pages/ShowMeMore.aspx?src=single&lpk=1140

AHRI publishes standard for walk-in coolers and freezers

AHRI's Commercial Refrigerator Manufacturers' Section has approved AHRI Standard 1250-2009, "Performance Rating of Walk-In Coolers and Freezers" for publication. The standard, which is available for free download at http://www.ahrinet.org, establishes definitions, test requirements, rating requirements, minimum data requirements for published ratings, operating requirements, marking and nameplate data, and conformance conditions for walk-in coolers and freezers.
Source: http://www.ahrinet.org/Pages/ShowMeMore.aspx?src=single&lpk=1181

ICC, ASHRAE, USGBC and IES announce nation's first set of Model Codes and Standards for Green Building in the U.S.

What do organisations representing building safety professionals, energy and lighting engineers, green building practitioners, architects, and technical standards developers have in common? They have all come together to green the nation's built environment by establishing a comprehensive model green building code designed rapidly to advance green building practice across the U.S.
The International Code Council (ICC), the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), the U.S. Green Building Council (USGBC), and the Illuminating Engineering Society of North America (IES), announced the launch of the International Green Construction Code (IGCC) in March, representing the merger of two national efforts to develop adoptable and enforceable green building codes. The IGCC provides the building industry with language that both broadens and strengthens building codes in a way that will accelerate the construction of high-performance green buildings across the U.S.
Source: http://www.ashrae.org/pressroom/detail/17468

Energy Star specification for geothermal heat pumps

EPA recently issued a draft revised Energy Star specification for geothermal heat pumps. The draft specification is largely based on a proposal submitted by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI). Key changes proposed by EPA include:
- New requirements for water-to-water heat pumps
- More stringent efficiency levels for water-to-air and direct exchange systems
- Third-party certification (by an organisation approved by EPA) for all Energy Star qualified products, effective from August 1, 2010
- Requirement to offer, rather than automatically include, a means of providing domestic water heating through the use of a desuperheater, integrated demand water heater, or stand-alone demand water heating system.
Source: http://www.ahrinet.org/Pages/ShowMeMore.aspx?src=single&lpk=1102

Working Fluids

Honeywell gets European patent for HFO-1234yf

Honeywell announced in January that it has received a patent from the European Patent Office covering the use of its new low global-warming refrigerant, HFO-1234yf, in automobile air conditioning systems.
Honeywell has worked jointly with DuPont to commercialise Hydrofluoro-olefin (HFO)-1234yf, for use in automotive air conditioning systems in response to the EU's Mobile Air Conditioning Directive, which requires that all new vehicles produced in 2011 and thereafter use a refrigerant with a global warming potential (GWP) below 150. Current mobile aircon systems use R134a, a refrigerant with a GWP of 1,300. HFO-1234yf has a GWP of only 4.
Source: http://www.acr-news.com/news/news.asp?id=1851&title=Honeywell+gets+European+patent+for+HFO%2D1234yf

EPA lists HFO-1234yf for mobile air conditioning

The US EPA has proposed listing HFO-1234yf as an acceptable alternative refrigerant in mobile air-conditioning (MAC) systems. The proposed decision applies only to new MAC systems in passenger cars and trucks, since EPA has previously determined that the use of flammable refrigerants in existing equipment as a retrofit was unacceptable.
Source: https://www.iifiir.org/en/news.php?rub=2&page=2&id=2068#2

Global Business Directory for the hydrocarbon community goes live

Recently, Hydrocarbons21.com launched the world's first online "Yellow Pages" for hydrocarbon refrigerant and component suppliers, system manufacturers, trade associations and research institutes. More than 100 companies are already listed.
Source: http://www.hydrocarbons21.com/content/articles/2010-01-22-global-business-directory-for-the-hc-community-goes-live.php

Hydrocarbon blends as HFC replacements

A recent presentation by Earthcare Products at the Transforming Technologies Conference in London described the potential opportunities that hydrocarbon refrigerant blends offer as HFC replacements in a wide range of applications. The conference was organised by ACR News, and focused on low-carbon cooling and heating solutions, such as hydrocarbon blend refrigerants.
Source: http://www.hydrocarbons21.com/content/articles/2010-03-05-hydrocarbon-blends-as-hfc-replacements-.php

The world's largest natural refrigerant heat pump

Star Refrigeration is in process of designing and manufacturing a large heat pump that will deliver over 14 MW of heat at over 90 °C. The system components are specifically designed for ammonia at pressures up to 65 bar.
Source: http://www.ammonia21.com/content/articles/2010-03-09-star-refrigeration-supplies-world%E2%80%99s-largest-natural-heat-pump.php

Waitrose adds Bakewell tart scent to sniff out refrigerant leaks

The smell of Bakewell tarts is to be added to Waitrose's refrigeration gases to sniff out refrigerant leaks. The Bakewell tart scent of cherries and almonds will be added to the HFC gases in the retailer's fridges. Waitrose hopes that the new initiative will help it achieve its target of cutting refrigerant leaks by 50 % in the next three years.
Source: http://www.acr-news.com/news/news.asp?id=1897&title=Waitrose+adds+Bakewell+tart+scent+to+sniff+out+leaks+++

Tesco uses CO_2 refrigeration in zero-carbon store

CO_2 refrigeration is one of several green measures adopted in Tesco's new zero-carbon store. The retail giant describes its newly-opened store in Ramsey, Cambridgeshire, as the world's first zero carbon supermarket.
Source: http://www.acr-news.com/news/news.asp?id=1934&title=Tesco+uses+C02+refrigeration+in+zero+carbon+store+

Technology

Copper tube makers launch heat transfer venture

A US and a German copper tube manufacturer have launched a joint venture to develop new heat transfer technologies. German manufacturer Wieland and its US counterpart, Wolverine Tube, have formed Wolverine/Wieland Heat Transfer Technologies (WWHTT). WWHTT will develop new heat transfer technologies, processes and products that will be licensed to Wolverine, Wieland and third parties.

"WWHTT will develop technologies that allow engineers to create air conditioning and refrigeration systems with higher efficiency, lower end-user operating cost, and reduced refrigerant use," said Harold Karp, president and chief operating officer of Wolverine.
Source: http://www.acr-news.com/news/news.asp?id=1885&title=Copper+tube+makers+launch+heat+transfer+venture+

An automotive first: the heat pump

Audi is showing a compact sports car with all-electric drive at the first major auto show of 2010. The two-seater Detroit show car is the second electric concept vehicle from Audi.

Unlike a combustion engine, the electric drive system does not generally produce enough waste heat to heat the interior effectively. Other electric vehicles have electric supplemental heaters, which consume a relatively large amount of energy. The car uses a heat pump, using mechanical work to provide heat with a minimum input of energy.
Source: http://www.audi.com/com/brand/en/tools/news/pool/2010/01/detroit-showcar_audi.html

Markets

German subsidy scheme refers to EHPA quality label for innovation bonus on heat pumps.

The German "Marktanreizprogram" (MAP) subsidy scheme is constantly being adjusted to accomodate a changing market environment. In its most recent revision, it requires an independent third party test for the

COP value. The EHPA Quality label is a sufficient proof of efficiency. The new rules came into effect on 22.2.2010.
Source: http://www.ehpa.org/news/article/german-subsidy-scheme-refers-to-ehpa-quality-label-for-innovation-bonus-on-heat-pumps/

More stringent specifications for China's air-conditioners

CHINA is to implement a new energy efficiency standard for air conditioners, which will see COP levels raised by an average of 23 %. From June 1 2010, the lowest COP for market entry will be raised to 3.2 from the current 2.6 for air conditioners with a rated power output of up to 4.5 kW.
Source: http://www.acr-news.com/news/news.asp?id=1959&title=It%27s+a+fair+COP+for+China%27s+air%2Dconditioners+++

Denmark incentivises heat pump take-up

The Danish authorities have allocated DKK 400 million (about €54 million) for scrapping old oil-fired boilers and replacing them with energy-efficient heating systems such as heat pumps. The scheme will provide grants of up to €2,700 for the installation of heat pumps.
Source: http://www.hydrocarbons21.com/content/articles/2010-01-15-denmark-incentivises-heat-pump-take-up.php

Daikin, Mitsubishi and TEV share £3.75m heat pump deal in UK

Daikin, TEV (Heat King), and Mitsubishi have secured contracts to provide some 2500 air-to-water heat pumps over the next two years to UK homes that do not have a gas supply. Non-profit organisations Community Energy Solutions (CES) and Renewables East called for tenders for heat pump suppliers to heat 2500 off-gas homes. The contracts, for the supply and distribution of the heat pumps, are worth an estimated £3.75m.
Source: http://www.acr-news.com/news/news.asp?id=1884&title=Daikin%2C+Mitsubishi+and+TEV+share+%A33%2E75m+heat+pump+deal++++

'The State of Renewable Energies in Europe' published

EurObserv'ER has released its annual publication 'The State of Renewable Energies in Europe' (February 2010). It is a synthesis of the technology barometers published during 2009. The publication gives detailed capacity and energy performance data for all 27 member states of the European Union (for wind power, photovoltaics, solar thermal energy and solar thermal electricity, small hydropower, geothermal energy, ground source heat pumps, biogas, biofuels, municipal solid waste, solid biomass and ocean energy). Unfortunately, the use of aerothermal energy is not covered.

Also included in 'The State of Renewable Energies in Europe' is a chapter on socio-economic indicators (employment, turnover) for most technologies in a selection of member states. The publication concludes with seven country case studies, where specific regions are particularly strong in renewable energy industry.
Source: http://www.ehpa.org/news/article/the-state-of-renewable-energies-in-europe-published/

Publication of Geothermal Heating and Cooling Vision 2020 – 2030 for Europe

The Geothermal Panel of the European Technology Platform on Renewable Heating and Cooling (ETP-RHC) published its "Vision 2020 – 2030" at the end of December 2009. It foresees a steady decrease in costs, and an increase in the total heat and cold production from 2,6 Mtoe (2007) to 10,5 Mtoe in 2020, and possibly 60 Mtoe in 2030 in the case of an enhanced market.
Source: http://www.egec.org/index.html (see "News", scroll down to 04.01.2010)

Annexes, ongoing

Final working meeting of IEA HPP Annex 32

The topic of IEA HPP Annex 32 is the investigation and further development of multi-functional heat pump (HP) systems for application in residential low and ultra-low energy buildings, covering the different building services of space heating (SH), domestic hot water (DHW) and partly the ventilation (V) and space cooling (SC) functions, including dehumidification and humidification (DH/H).

The 7th Annex 32 working meeting was held in Montreal, Canada on Sep. 14–16, 2009. The meeting agenda included a two-day expert meeting and a one-day technical tour to visit two field monitoring objects, so-called EQuilibrium houses, which are Canadian Net Zero Energy Buildings (NZEB) with integrated solar technologies.

The aim of the expert meeting was to exchange current results from the national projects and to discuss deliverables from Annex 32. The national contributions can be mainly separated into system analysis, prototype developments and field testing of new and existing system solutions. In the following some of the results from the national project are presented.
Within the framework of the prototype developments an integrated brine-to-water CO_2 heat pump for space heating (SH), domestic hot water (DHW) and space cooling (SC) was developed and is currently being lab-tested as part of the Austrian contribution at the Institute of Thermal Engineering at TU Graz. After the finalisation of lab-tests, system simulations to evaluate seasonal performance and control issues will be performed.

The USA has developed prototype systems of an air-source (AS) and ground-source (GS) integrated heat pump (IHP) for net zero energy building application which cover all building functions including dehumidification. Net zero energy building simulations showed a reduction of system energy consumption of above 50% compared to DOE minimum-requirement, state-of-the-art technology. Field tests of the AS and GS-IHP prototypes are currently in preparation and are planned to start in 2010.

Norway performed different feasibility studies for the application of CO2 heat pumps in low energy buildings. An SPF of 3.8 was calculated for DHW applications in particular, resulting in savings potentials of about 75% compared to common direct electric water heating in Norway.

Within the framework of the field monitoring projects the Austrian Institute of Technology (AIT) completed field monitoring of 10 SH and combined SH&DHW heat pumps with different source and emission systems. Seasonal performance factors (SPF generator based on energy produced by the heat pump and electrical back-up divided by the electrical expense for the generator(s) and the source system) for ground water-coupled systems and SH mode are above 4, and for A/W systems above 3. DHW performance ranges between 2.2 and 3.5 and overall performance is in the range of 3 to 4.2.

In the Swiss project, preliminary field monitoring results from the two-year measurements of a ground-coupled heat pump with passive cooling function in a multi-family building, according to the Swiss MINERGIE-P® standard, were completed. In the second winter period, an optimisation of the heating curve led to an improvement in the overall SPF generator (based on produced energy) for space heating, DHW and space cooling from 3.8 to 3.9 and of the SPF system (based on delivered energy) from 3.3 to 3.5.

Germany is carrying out two large field tests of around 100 heat pumps in low energy buildings and around 75 heat pumps in existing buildings as replacements for boilers. Table 1 gives the resulting overall seasonal performance values (system boundary SPF generator) for the different system configurations.

Table 1: Seasonal performance generator in the two German field tests.
** Average of 17 systems, **average of 61 systems*

Field monitoring	HP Efficiency (low energy buildings)			HP existing buildings (high flow temperatures)	
Period	7/2007-7/2009		1-12/2008	1-12/2008	
HP-Type	A/W	B/W	W/W	A/W	B/W
SPF SH&DHW	2.9*	3.8**	3.5	2.6	3.3

In Japan a new design and calculation method for heat pump air conditioners (HPAC) developed in the framework of Annex 32 has been adopted in the Act Concerning the Rational Use of Energy in 2009. The method enables a better design of HPAC for low energy buildings, since the old method led to oversized systems. In the Hokkaido area, two field tests with ground-coupled heat pumps confirmed that low energy buildings with the respective heat pump systems can reduce primary energy consumption by more than 50% compared to oil boiler heating in conventional buildings in the region. A design tool for this typical system solution for broad introduction in cold climate zones has been developed and work continues on the design of a compact integrated heat pump including ventilation function.

Sweden is starting field monitoring in low energy buildings with heat pumps, where measurements of the winter period can be included in the Annex 32 results. As a consequence of new requirements regarding energy use in new Swedish buildings, improved inverter-controlled exhaust air heat pumps will be introduced on the Swedish market. These heat pumps will have a size and price that make them ideal as an economic heating system for low energy buildings. Results from completed field tests of ground source heat pumps and exhaust air heat pumps in existing and new-built standard Swedish single-family houses will be translated and made available to Annex 32.

Work in most of the national projects was concluded by the end of 2009. Main Annex 32 deliverables will refer to system solutions and designs, new system developments in the prototype state, documentation and best practices in field test activities in the different countries. Final results will be presented to the ExCo in June 2010 and made available in autumn 2010. It is intended to present the final results at a workshop on the 10th IEA Heat Pump Conference in Tokyo in May 2011. Updated information on the IEA HPP Annex 32 project and the national contributions, publications and links are provided on the Annex 32 website at http://www.annex32.net.

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Fig. 1: Participants at the 7th working meeting of IEA HPP Annex 32 in the centre of Montreal

ANNEX 33: COMPACT HEAT EXCHANGERS IN HEAT PUMPING EQUIPMENT

The Final Report is being checked by Participants at present, but the provisional conclusions may be of interest to readers:

"The outcomes of Annex 33, which was concerned with compact heat exchangers (CHEs) in heat pumping equipment have been many, quite diverse in their nature and comprehensive.

The objective of this Annex was to present a compilation of possible options for compact heat exchangers, used as evaporators, condensers and in other roles in heat pumping equipment. The aim of the work was to highlight technologies and techniques to minimise the direct and indirect effect on the local and global environment due to operation of, and ultimate disposal of, the equipment.

The Annex involved five countries – Austria, Japan, Sweden, the United States and the United Kingdom, the latter acting additionally as Operating Agent. The Annex ran for three years, the final Annex meeting being held in the UK in September 2009.

The Annex deliverables consist of a wide variety of data ranging from fundamental research on boiling in narrow channels to guidelines for selecting and using CHEs in heat pumping systems. There are considerable market data available within the Report and the cited references, and a number of novel heat exchanger concepts, including the use of new materials and the application of process intensification methods, should allow equipment manufacturers in the future to achieve the Annex aim.

Particular aspects that it is considered worth highlighting in the Conclusions are:

1. The increasing interest in, and use of, CO_2 as a working fluid. This has interesting implications in terms of the equipment used and the concepts for heat pumping that might be applied – see particularly the inputs from Austria and Japan.
2. The growing market for domestic heat pumps, where efficiency, arising in part out of the increased use of CHEs, is critical to further sustained market growth, particularly in countries where heat pump use has been slow to materialize.
3. The vast portfolio of research on heat transfer and fluid dynamics in narrow channels in CHEs. The research highlighted in Sweden, Japan and the USA are of particular note.
4. The role heat pumps could play in industry, where reduced payback times could be aided by CHEs. The UK study highlights the market possibilities.
5. There is a need to educate the heat pump industry in the use of CHEs, their merits and limitations, and the types that are available. The use of new materials, as indicated in some of the research in the USA, could reveal new opportunities.

The project has brought together many experts in the heat pump/CHE field and the Annex Report will, it is believed, be a major and constructive source of data for those interested in using CHEs in heat pumping equipment."

Recently the industrial heat pump aspects have received support from the UK EPSRC with a project linking Brunel, Newcastle and Northumbria Universities to optimize the selection and placement of process heat recovery equipment (including heat exchangers and open and closed cycle heat pumps). CHEs will have a major role to play here.

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IEA Annex 34: Thermally Driven Heat Pumps for Heating and Cooling

Most heat pumps and chillers, providing the building sector with heating or cooling, are electrically driven. However, the substitution of the electrically driven compressor by the use of a thermally driven one could lead to significant primary energy savings, especially if the thermal energy is provided via solar or waste heat (cf. Figure 1).

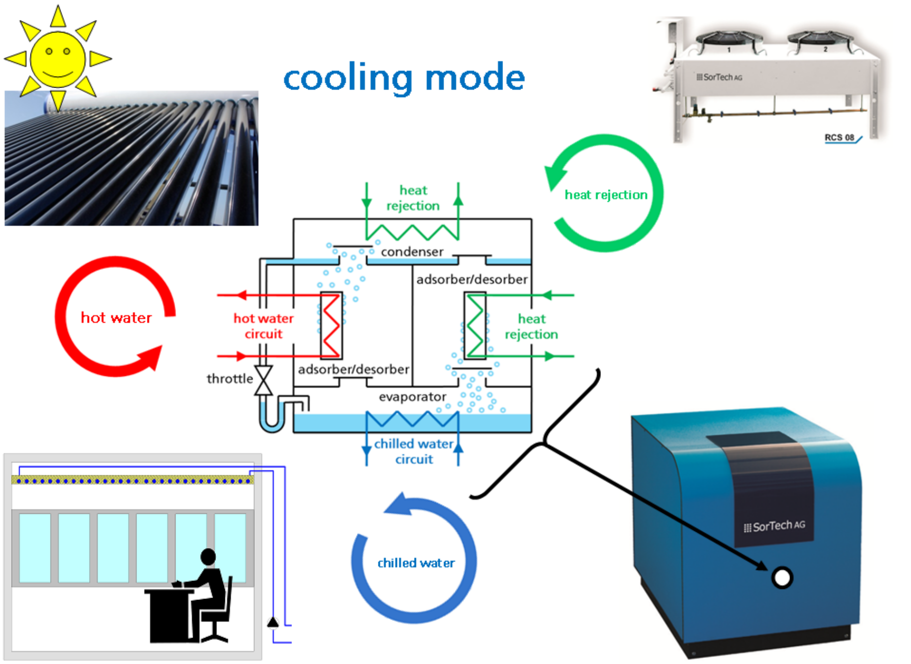

Figure 1: Scheme of a thermally driven adsorption machine in cooling mode using solar energy as driving force. Internal action in the machine (bubbles indicate the motion of the water vapour) and hydraulic connections are shown

Therefore the objective of this Annex is to reduce the environmental impact of heating and cooling by the use of thermally driven heat pumps (absorption and adsorption machines). It is based on the results of Annex 24, "Absorption Machines for Heating and Cooling in Future Energy Systems", and cooperates with Task 38, "Solar Air-Conditioning and Refrigeration" of the IEA Implementing Agreement "Solar Heating and Cooling" (SHC).

One of the main objectives is to quantify the economic, environmental and energy performance of integrated, thermally driven heat pumps in cooling and heating systems in a range of climates, countries and applications. From this, those areas and applications with the greatest environmental benefit, the most favourable economics and the greatest market potential will be identified.

Annex 34 is subdivided into the following tasks (progress included):

Task A
Market overview and state-of-the-art report – More and more country reports are coming in, showing a widespread use of thermally driven heat pumps and their different consideration in national funding schemes/ building codes. These country reports, based on the template developed at the ECN Energy Research Centre of the Netherlands, will be compiled to form a state-of-the-art report in 2010.

Task B
Performance evaluation – The Austrian Institute of Technology AIT presented a proposal for the evaluation of performance standards for thermally driven heat pumps which will be discussed and tested for viability within the annex 34 group. In Germany a directive (VDI-Richtlinie) is expected to be published in 2010.

Task C
Apparatus technology – The sorption material database on the internal web-pages has been completed with the first material data followed by the proposed measurement procedures. The round robin test was extended to heat conductivity since this is important for the power density of thermally driven heat pumps. Several national projects on component developments are under way and producing their first results.

Task D
System technology – A test lab to carry out tests on whole systems was set up at EURAC (Bolzano, Italy) and the first tests have already been conducted. A methodology of how to describe the systems, i.e. solar cooling/thermally driven heat pumps, was developed and agreed on with SHC-Task 38, "Solar Air-Conditioning and Refrigeration".

Task E
Implementation – The first demonstration projects have been collected. The Technical University of Berlin has developed the first outline for the planned handbook. The basic idea is to split the content into two parts, the first being a textbook dealing with the thermodynamic background for teaching and less frequent updates, with the second providing more up-to-date information on the state-of-the-art, best practice guides and case studies for planners, which can be updated more frequently. Both will be harmonized with the SHC-Task 38 Handbook.

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Annexes, planned

Solar + Heat Pumps

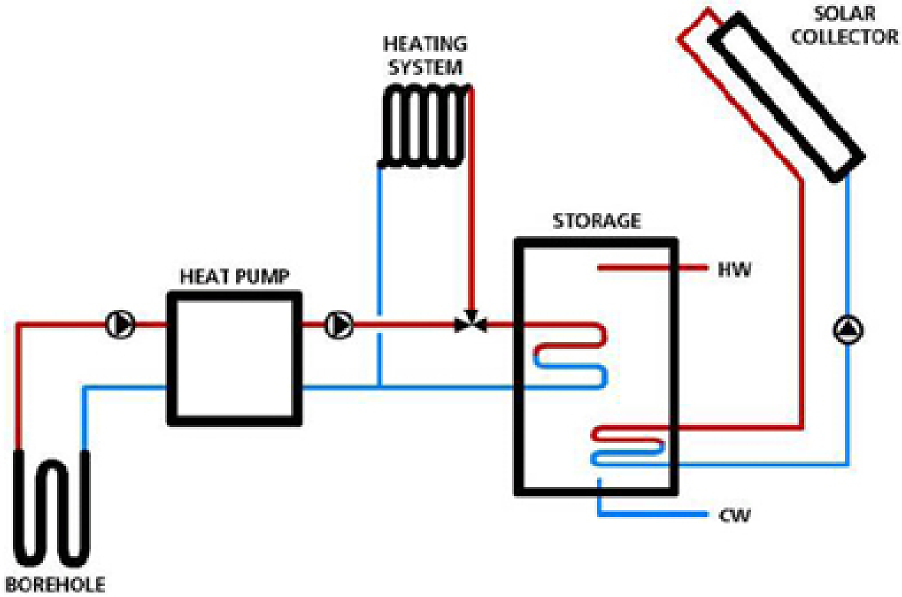
A new IEA SHC Task focusing on systems using solar thermal energy in combination with heat pumps will begin in 2010. This is planned to be a joint annex with the IEA Heat Pump Programme (the annex number in HPP has not yet been decided). Be a part of Task 44.

Over the past few years, systems that combine solar thermal technology and heat pumps have been marketed to heat buildings and produce domestic hot water. This new combination of technologies is a welcome advancement, but standards and norms are still required for its long-term successful commercialisation. At this time, most of the manufacturers are developing systems without a clear framework of what would be the best combinations of the two worlds, and customers are lacking comparative approaches. The result is that systems reaching the market today are far from being optimized and simple enough to guarantee a problem-free service life and efficient operation, both technically and economically.

What is needed is a systematic analysis of the different feasible systems and their potential for application in various climates and under various boundary conditions. To begin tackling this, the SHC Programme has initiated Task 44, Systems using solar thermal energy in combination with heat pumps (HP + Solar).

The scope of this new Task, which will begin in 2010, will encompass the following:

- Small-scale residential heating and hot water systems that use heat pumps and any type of solar thermal collectors as the main components.
- Systems offered as a single product from a system supplier/manufacturer and that are installed by a contractor.



One system of ten... Is this a good enough or can we do better?

- Electrically powered heat pumps, but during the development of performance assessment methods thermally powered heat pumps will not be excluded.
- Market available solutions and advanced solutions (produced during the course of Task 44).

In order to better focus on current market demand, large-scale systems (i.e. systems using any type of district network or systems for large buildings) are not included, nor is comfort cooling of buildings. However a heat pump can also be used for cooling, and the performance assessment methodology should not overlook this "optional" feature.

Task project participants plan to divide their work into four Subtasks:

- Overview of solutions (existing, new) and generic systems
- Performance figures and performance assessment
- Modelling and simulation
- Dissemination and market-supporting measures

Why participate ?

- The combination of heat pumps and solar pumps will represent a large market share in future decades. In some regions, systems are already installed in 80% of new homes.
- An IEA framework provides a unique opportunity to meet and to share ideas and information with experts from universities and industries working with thermal solar and heat pumps.
- We are attracting top engineers and manufacturers to the Task.
- Future systems will be sketched out and new ideas will emerge from the exchange of practice, knowledge and experience.
- The pre-normative work will produce materials to assess performances of combined systems, the definitions of which are currently lacking.

For more information about this new Task, contact the Operating Agent, Jean-Christophe Hadorn, jchadorn@baseconsultants.com, from Switzerland.

SPF project on the launch pad

The proposed SPF annex is getting closer to a start. In March, a meeting was held in Paris to further develop the draft legal text (project description) of the project, and the revised version is now being circulated among the interested parties. We believe that the Executive Committee will approve this draft at the meeting in June, at the latest.

A kick-off meeting for the project will be held in conjunction with the ASHRAE annual conference in Albuquerque, New Mexico, on June 30th and July 1st. For those who would like to participate in the annex, please contact roger.nordman@sp.se and your national ExCo delegate. See www.heatpumpcentre.org for contact points.

Overview on USA-proposed IEA Annex:

Quality Installation/Quality Maintenance Sensitivity Studies (Avoiding Efficiency Degradation due to Poor Installations and Maintenance)

It is widely recognized that residential and commercial heat pump equipment suffers significant performance loss (i.e., capacity and efficiency) depending on how the components are sized, matched, installed, and subsequently field-maintained. Some commonly noted problems caused by incorrect installation and maintenance practices include improper refrigerant charges (up to 15% off), incorrect airflow/water-flow over the coil (up to 50% off design), oversized equipment (routinely, 50% oversized), leaky ducts (up to 50% of airflow), and dirty coils or blowers.

This proposed Annex will evaluate how installation/maintenance deficiencies cause heat pumps to perform inefficiently and waste considerable energy. Specifically to be investigated is the extent to which small operational deviations are significant, whether the deviations (when combined) have an additive effect on heat pump performance, and whether the deviations (by various equipment applications and country-specific locations) have a larger impact than others. The desired objectives arising from this proposed Annex include:

- Developing information for use by key stakeholders in industry (HVACR and construction trades), government (policy makers), and building sector (owners/operators).
- Providing reliable data to position each participating Annex country to evaluate its pertinent industry standards and practices for the heat pump system types of primary interest to ensure optimum heat pump performance.
- Assisting building owners/operators and consumers to better understand the links between comfort (temperature, humidity levels & drafts), utility bills (energy usage and/or its cost – which varies with dynamic energy pricing), and indoor air quality resultant from proper HVAC system design (equipment sizing, selection, and component matching), installation and maintenance practices.
- Reducing usage of energy and emissions of greenhouse gases by encouraging use of quality heat pump installation and maintenance practices.

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Ongoing Annexes

Bold text indicates Operating Agent.

Annex	No.	Countries
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), Finland (FI) Germany (DE), Japan (JP), The Netherlands (NL), Italy (IT), Norway (NO), South Korea (KR), Sweden (SE), Switzerland (CH), United States (US). All countries are members of the IEA Heat Pump Centre (HPC). Sweden is Operating Agent of the HPC.

Ground-Source Heat Pumps for Commercial Buildings

Hermann Halozan, Austria

Installations of ground-source heat pumps are increasing world-wide. Small systems for both heating and cooling are state of the art. Large ground-source systems for commercial buildings using the ground as a heat store, which is charged by heat abstracted from the building when in cooling mode, and discharged when heat is needed for heating mode, are presently the systems with the highest efficiency. Hygienic conditions, thermal comfort and low operating costs are the result of sophisticated design of such systems, which can also contribute to reducing the effects of climate change.

Introduction

Heat pumps offer the possibility of reducing energy consumption significantly, mainly in the building sector, and also in industry. The Second Law of Thermodynamics shows the advantages: while a condensing boiler can reach a primary energy ratio of at best 105 % (i.e. the theoretical maximum would be 110 %, based on the lower calorific value), heat pumps achieve 200 % and more [1].

It should be noted that the heat pump, which in most cases upgrades free heat from the environment (air, water, ground) and from waste heat, is a major provider of renewable energy. The renewable heat collected by the heat pump makes up the difference between the thermal output and the drive energy, if the source is renewable.

After World War II, small heat pump units for air conditioning of homes and individual rooms became common. They were followed by the "reversible" units for cooling/dehumidifying as well as heating, and then, after the oil price crisis of 1973, heat-only heat pumps for heating in moderate and cold climates were accepted by the market.

Since the 1980s, heat pump units and the components used, such as advanced compressors and flat-plate heat exchangers, have been improved significantly. Other developments occurred in the building sector. The building envelope has been improved significantly and, with its improvement, specific heat loads have been reduced significantly.

Development of heat source systems and heat sink systems on the one hand, and the overall system approach on the other hand, has not been as rapid, and development in the direction of highly efficient systems is still going on.

Ground-Source Heat Pumps

Ground-source heat pumps are gaining importance world-wide with respect to energy efficiency in heating and cooling operation. Using the ground as a seasonal heat store offers the possibility of reducing the effects of outside air temperature fluctuations, while in colder climates it also enables monovalent heating operation of the heat pump. For utilities it is - in comparison with air-heat-source heat pumps - a means of applying demand-side management measures.

For heat pumping, ground-source systems offer stable operating conditions. In small systems heat recovery occurs by natural mechanisms: in the case of horizontally installed coils, by heat from the surface; and in the case of vertical pipes, by geothermal effects.

Ground-source heat pumps at present dominate the heat-only heat pump market in Europe. Direct-exchange ground-source heat pumps already achieve SPFs between 4 and 6. They have been identified as an interesting and energy-efficient solution for the heating and cooling market in North America, and there is also considerable interest from Japan and China.

Large systems

The design of large commercial buildings has changed significantly over the last decades. In addition to their original task of providing space for offices, stores or shopping centres, they are now also expected to add form to function. After other facades, glass became the main material for the envelope of large commercial buildings. Although glass has excellent properties in respect of corrosion resistance and cleaning, using it as the sole or main cladding means that the whole building becomes transparent. The result of such designs are large cold surfaces in the winter and problems with overheating in the summer, especially on west-facing facades. Such buildings require cooling on the side facing the sun, and heating on the opposite side – without sunshine – even when ambient temperatures are significantly below 0 °C. The common way of doing this is through the use of air-based air conditioning systems with a cooling tower, and an additional heating system. The disadvantage of air-based systems is that peaks of heating and cooling loads result in increasing temperature lifts in the heat pump, which means a significant loss in capacity and efficiency.

If the heating and cooling demands are of similar order of magnitude, it is possible to store the "waste" heat from summer cooling in the ground, and to recover it for heating in the winter (Fig. 1). Using the same system for both heating and cooling results in reduced investments costs and a short pay-back time, followed by significant annual savings. These savings are the result of avoiding peaks caused by outside temperature fluctuation and by avoiding the need for a cooling tower.

With this type of utilisation of the ground, the ground becomes a heat store, with the temperature changes in this store being the result of heat extraction from the store in winter and heat removal from the building in summer. Such a store offers at least improved conditions at the beginning of both the heating and the cooling season. At the beginning of the cooling season, direct cooling - without heat pump operation - is possible.

Thermal stores

Thermal energy can be stored through the use of a number of mechanisms: sensible heat stores using temperature changes, latent heat stores using phase change effects, and chemical stores using chemical effects. For large buildings, it is sensible heat stores, and one latent heat store - using ice storage for cooling and dehumidification - that are used.

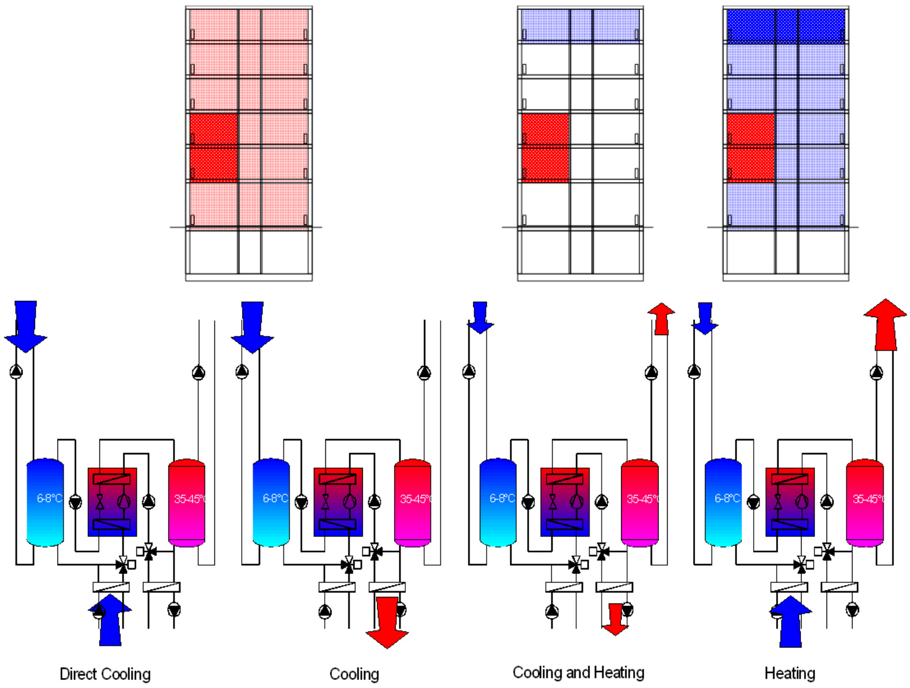

Fig. 1: Ground-Source HVAC System

All these stores have thermal losses. As losses are proportional to the square of the size of the store, while the capacity increases with the cube of the size, it is much easier to construct a large store than a small one.

There are mainly three types of stores used in the building sector: aquifer heat stores, borehole stores, and stores using the building foundation, mainly piles, the foundation itself as well as the pile walls.

Aquifer thermal stores

An aquifer is an underground layer of permeable rock, sediment (usually sand or gravel), or soil that yields water. The pore spaces in aquifers

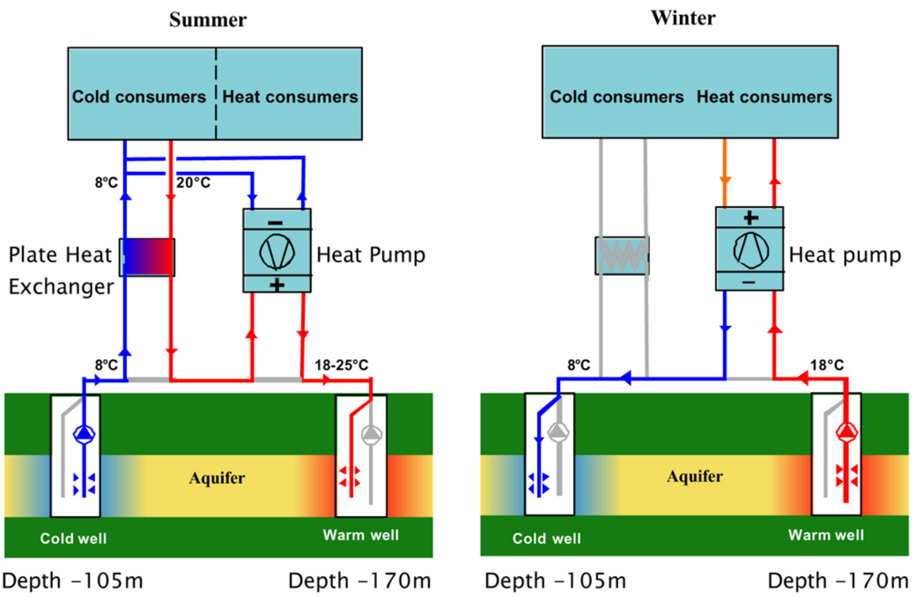

Fig 2: Aquifer Energy Store

are filled with water and are interconnected, so that water can flow through them (Fig. 2). Sandstones, unconsolidated gravels, and porous limestone make the best aquifers.

To utilise such an aquifer as a thermal energy store, there should be no natural water flow. The aquifer is accessed by two wells (typically) on either side with a hydraulic connection between them. One well is for the warm water and the other one is for the cold.

In the winter, cooled water from the heat pump is pumped into the cold well, while warmed water from the aquifer is abstracted from the other well and provides a heat source for the heat pump. In summer, the process is reversed and cold water is abstracted for cooling. The warm water from the heat pump is returned to the warm well.

The advantage of this system is that it is environmentally safe; the water which circulates from underground to the heat exchangers and back cannot be contaminated as it remains in the system. In addition, there is no net loss of underground water. The only problem is that this system can be used only in areas that are above aquifers with no or negligible natural water flow.

Borehole energy stores

Borehole heat stores deliver heat in the winter, with a fluid (usually water or a water–antifreeze mixture) as the heat transfer medium to the evaporator of the heat pump, thus utilising geothermal energy. In cooling mode, the store is used as a heat sink.

With Borehole Heat Exchangers (BHE), ground-source heat pumps can offer both heating and cooling at virtually any location, with great flexibility to meet any demands.

More than 20 years of R&D focusing on BHE in Europe have resulted in a well-established concept of sustainability for this technology, as well as sound design and installation criteria. Recent developments are the Thermal Response Test, which allows in-situ-determination of ground thermal properties for design purposes, and thermally enhanced grouting materials to reduce borehole thermal resistance.

Fig. 3: Building foundation heat store

The building foundation as an energy store

High-rise buildings require substantial foundations, often consisting of a slab plate and piles. The piles can form a store similar to a borehole store, but at more or less for no additional cost: the piles simply have to be equipped with coils. Additionally, the slab can be also used as a coil (Fig. 3).

All these stores work well if heat extraction and heat removal are more or less balanced. If not, the store temperature will gradually increase or decrease over the years, to the detriment of heating or cooling performance. In such case, what is known as a hybrid system has to be designed.

If the store temperature is gradually rising, a cooling tower will be needed in the system. If it is falling, an additional system for keeping the temperature level of the store at the design value will be required. This can be a solar thermal system.

Improvement of systems

The choice of an air conditioning system for a commercial building depends on the climatic conditions, on the building and on its utilisation. However, it is the design of the building that is the main factor determining energy consumption.

An air conditioning system ventilates the building, filters and humidifies the air, provides the necessary heating in the winter, dehumidifies the air in the summer and removes heat to compensate external and internal loads, and maintains hygienic conditions and year-round comfort for the occupants.

Furthermore, the air conditioning system provides a means of doing all this with a minimum of energy by shifting heat from areas which have to be cooled, to those which have to be heated at the same time. Additionally, using the ground as a heat store, heat and cold can be stored to a certain extent and used for providing cooling without additional energy input, i.e. for direct cooling, and for increasing the heat source temperature for heating.

Other possibilities include low-ex systems, i.e. high-temperature cooling and low-temperature heating systems. Providing heating and cooling can be delivered by radiant systems such as floor heating systems and ceiling cooling systems - both of which can be used for both heating and cooling - and by storing heat in, or removing it from, the building structure.

For these tasks, the temperature required for heating purposes is in the range of maximum 35 °C, for cooling in the range of minimum 17 °C, both of which reduce the temperature lift in the heat pump. Additionally, part of the cooling can be provided by direct cooling without heat pump operation. Dehumidification can be carried out with a separate heat pump operated at about 6 °C, or with a DEC (desiccant evaporative cooling) system [2].

Conclusion

Large ground-source systems using the ground as a heat store are at present those that have the highest efficiency for large commercial buildings. Hygienic conditions, thermal comfort and low operating costs are the result of sophisticated design of such systems. Considering the expected world-wide increase of such buildings, ground source systems can contribute significantly to energy saving and reducing CO_2 emissions.

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Underground systems are becoming more common in the Netherlands

Wilko Planje, the Netherlands

Since the late 90s, use of geothermal systems has become increasingly common in the Netherlands for sustainable cooling in offices by means of aquifer thermal energy storage (ATES) systems. Besides this form of low-energy cooling, ATES systems are increasingly equipped with a heat pump system, mainly for space heating. More than 1,200 ATES systems with a total thermal capacity of more than 900 MWth are currently in operation. Approximately 60% are linked to a heat pump system. The ambition of the Dutch government is to continue this process of sustainable heating and cooling. Interference in this context becomes a real danger. Development of new regulations facilitates maximum usage of underground energy systems without adverse effects. In the case of smaller utility buildings, the borehole thermal energy storage (BTES) systems are a good alternative. These do not thermally exceed property boundaries. Besides the simplicity in maintaining closed systems, their robustness and low-profile of licensing and inspection procedures are also advantageous.

Introduction

Currently the Netherlands has 180 million m^2 of gross floor space in the utility sector which annually requires 13 PJ of electricity and 3 PJ of gas for cooling [1]. This is just a small part of the 10% of total electricity consumption in the utility sector. For heating in this sector, more than 150 PJ of energy is involved, mainly from natural gas.

Looking at the full range of the utility sector, cooling has only a modest role. In addition, cooling is still not standard in the utility sector. About 81% of the hospitals, 58% of the offices, 33% of the care/nursing homes and 22% of the schools utilise cooling units.

ATES systems have expanded enormously in these sectors, which also have fairly large cooling demands. Where previously energy-guzzling chillers handled cooling of the outside air, the ATES system with temperatures < 12 ^oC was the ideal answer for low-energy cooling. Deployment of this technique results in a reduction of energy costs for cooling by a factor of 4 to 12. Payback times of 4 to 7 years have proved to be feasible.

With the advent of the first aquifer systems in the 90s, the Dutch Association of Underground Energy Storage (NVOE) was established in 1999 [2].

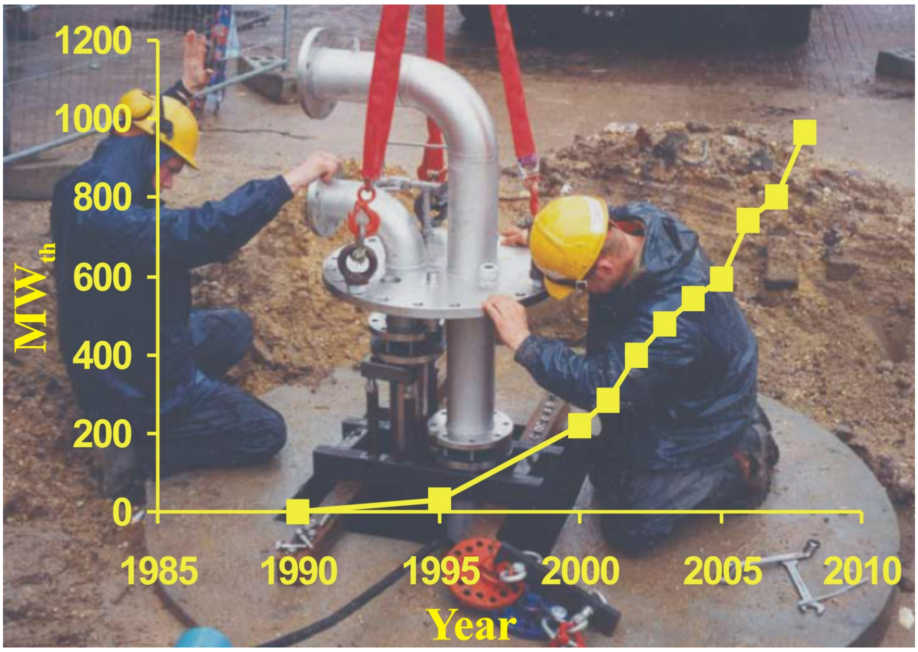

Figure 1 Installed ATES systems (MWth) in the Netherlands over the years. Overview of realised ATES systems in the Netherlands. About 69% of the systems are currently used for office buildings, 9% for homes, 11% in agriculture, 9% for greenhouse farming and 2% in industry.

The association represents the interests of the construction parties, develops regulatory and quality guidelines and holds courses and conferences.

Another important factor of the relative success of ATES in the utility sector is the soft surface of the ground in the Netherlands, with its alternating layers of aqueous sand layers and water-impermeable clay layers, which makes drilling easy. This permits water-permeable sand layers (10^{o}C - 12^{o}C) with a thickness of 10–80 meters to be accessed at depths of 50 to 500 meters. Mono- as well as doublet-source variants are used for ATES. The radius of the thermal influence around the sources varies from 20 to 100 meters, depending on maximum flow rate, thickness of the aquifer, groundwater flow and heating and cooling demands.

Consequently, the aquifer systems often exceed the property boundaries beneath the surface and can interfere with adjacent systems. A distortion of 1 K can result in an increase of 2–3% of the energy bill for heating. For the cooling portion, the relative figure is even larger and may increase to 5–7%. Until now, newly planned projects have had to demonstrate that the construction of the ATES will not negatively affect existing systems.

Due to the new Crisis and Recovery Act, adopted by the Upper House of the Dutch Parliament 17 March 2010, more direction will be provided by central and local authorities to (re)optimize the underground with respect to thermal storage. This act, worked out during the summer of 2009, will speed up new building projects by, e.g., overruling environmental legislation and simplifying expropriation procedures. The act was initiated to counteract unemployment in the building sector. It also includes the stimulation of ATES systems in which large-scale projects are preferred. The intention is to have about 18,000 ATES systems by 2020. This goal requires new regulations and legislation for optimal underground planning.

Heat pumps and ATES

The Dutch Central Bureau of Statistics has estimated that approximately 60% of the ATES systems in 2009 included a heat pump system. These are mainly used in office buildings, care homes, schools and hospitals. In general, the related heating and cooling capacities are of the same order of magnitude. As an example, new offices require capacities for cooling of 40–60 W/m^2 and heating of 20–40 W/m^2. In these cases, the yearly balance of extracted and injected heat from the underground can be made without too much extra loading/unloading via dry coolers or cooling towers.

The effect of heat pump systems with ATES on the reduction of total primary energy performance usage (including lighting, ventilation, etc.) is about 15–25% [4]. This is derived from the calculation methodology as described in the Dutch Standard NEN2916 [5].

The NEN2916 standard describes the protocol in which the total yearly primary energy demand of a newly constructed utility is expressed in an energy performance coefficient (EPC). It not only includes calculation methods for heating and cooling, but also for ventilation/air circulation, (de)humidification, lighting, combined heat-power units, photovoltaic, etc. For each function within the utility sector, building-specific standards are related to the usable floor and envelope area. In this way, an area-independent performance factor is attained, which is a dimensionless figure. Roughly, it makes comparisons possible between buildings with respect to their energy performance. When a building decreases from an EPC of 2 to 1, the net energy consumption is approximately halved; the lower the EPC value, the better the energy performance.

In the Dutch Building Code, the standards for EPC values are set for each sector of the utility. Over the years, the government has tightened the required EPC values. Since 2009, an EPC of 1.3 applies to schools and 2.6 to shops and hospitals. New offices must have a low EPC value of 1.1. Before 2009, an EPC of 1.5 was required. The ground-coupled heat pump system in offices might provide sufficient primary energy savings for heating to meet this new standard when accompanied by extra insulation measures.

But what are the typical financial implications for the Dutch situation? The cost for an ATES is about €500–1000/kW_{th}. The extra investment for usage of heat pump systems is about €350–450/kW_{th}, resulting in a total cost of €850–1450/kW_{th} for an ATES and heat pump system.

As stated above, cooling becomes 4–12 times more efficient. But when heating is included with a heat pump system, the yearly heating costs are reduced 'only' by 10–40% (calculated in relation to gas-fired boilers with an efficiency of 75%). This takes into consideration the state-of-the art seasonal performance factors (SPF) for heating of 3.0 up to 4.5. The high SPF values may result in acceptable payback times of less than 10 years.

Heat pumps and BTES

For smaller systems, a good alternative is available. In the lower capacity region, the borehole costs per kW_{th} are comparable or even less than for ATES systems. The costs of a borehole are about €800/kW_{th} up to €1400/kW_{th}, strongly dependent on the conditions of the underground (sand or clay). The low maintenance costs, robustness and the low entry costs make the loops excellent for smaller systems. In addition, the systems can be used in cases in which no aquifer is present or usable. A disadvantage is the lower temperature of the source, around 0^{o}C during the heating season. As a result, the seasonal performance factor for heating is, on the average, 0.5 points lower.

A phenomenon that is slowly appearing in the market is loops in the construction piles (10–25 m); see Figure 2. There are a few dozens projects realized in the Netherlands where both loops in the pile and loops along the pile are used to provide sustainable heat and cooling. But it is still not a mainstream market.

Direct expansion (DX) heat pump-systems are still in their infancy in the Netherlands. In the case of DX heat pumps, copper evaporator loops of 10–30 meters are inserted in the underground with a refrigerant. As of this writing, only a few contractors install these systems.

Concrete core activation

The compressor in the heat pump systems is still the weakest link for heating with a heat pump system. This weak link is strengthened when temperature lifts are lower. In this respect, the (prefab) reinforcement mats are used with loops for concrete core activation in the construction of new office buildings (Figure 3). Heating with supply/return temperatures of 24^{o}C/22^{o}C are sufficient and allow the COPs to rise by one point, resulting in an overall increase of the seasonal performance factor of 0.7, i.e. a reduction of the electricity costs of about 15%. In addition, the construction of integrated loops results

Figure 2 Piles with heat exchangers (left: Betonson, right: Voorbij). So-called 'energy-piles' are slowly gaining popularity in the Netherlands [6].

in 10–15% lower prices than is the case with conventional installation of heating elements. Concrete core activation is increasingly becoming standard for new office buildings and in the case of thorough renovations.

Conclusions

The ATES system, based on cost savings for cooling, has experienced strong expansion in the utility sector. The ATES technology has thus been strongly improved with respect to quality, directives and legislation. In parallel with this development, heat pump technology has been further optimized. This makes coupling between aquifers and heat-pump systems economically feasible. For smaller systems, BTES is another good option with low maintenance costs. But large-scale BTES projects are also becoming more popular because of robustness and short permit procedures.

The use of the minimum required energy performance coefficient (EPC) for the utility sector, according to the Dutch standard NEN2916, stimulates the application of heat pumps in the sector. This is in line with the national subsidy strategy for heat pump systems.

For both ATES and BTES, there are still concerns regarding the control strategy, design and maintenance of the sources and the heat pump systems to achieve optimum seasonal performance of heating. Consequently, spatial underground planning is an important issue for the coming years with respect to large-scale application.

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Figure 3 Prefabricated reinforcement mats for low-temperature floor loops.

Energy Pile Systems in Japan

Katsunori Nagano, Japan

Use of building foundation piles as ground heat exchangers, "Energy Pile System"

Foundation piles of a building can be applied as ground heat exchangers. This will lead to a reduction of the installation cost of the heat exchangers, which is one of the market barriers of the ground source heat pump (GSHP). At the same time multiple building foundation piles are suitable for the underground thermal storage as the well field. This technique has been called "Energy Pile System" in European countries, and the market is growing constantly. For example, an Austrian engineering company, Enercret GmbH [1], constructed over 5,000 piles with tubes in 2004. However, when we look at the past, the first idea had already been presented by Takashi in 1962 in the Journal of Japanese Association of Refrigeration [2]. At that time, he described the principle of energy pile systems, in which building foundation piles 2.5 times as long as the building height can release all of the waste heat from air conditioners to the ground under Japanese climate conditions, and also suggested that this may effectively avoid the overheating of the urban area which would occur in the near future.

In this article, the types of foundation piles are classified broadly into three categories as shown in Table 1. The first is the cast-in-place concrete pile. This is the major construction method in Japan for large buildings and is very popular for all types of buildings in the European countries.

Table 1. Classification of building foundation piles used as energy piles in Japan

	Circulation principle	Examples of pile works on the ground	Examples of U-tube installation
Cast-in-place concrete pile	- Closed system (4 ~ 10 U-tubes)		
Pre-cast concrete pile	- Open system - Closed system (2 U-tubes)		
Steel foundation pile	- Open system - Closed system (2 U-tubes)		

Generally, two to ten high density polyethylene tubes, according to the diameter of the pile, are tied off on the reinforced frame on the ground. The reinforced frame with plastic tubes is then inserted into the drilled hole by an earth drilling machine. Finally, the drilled hole is filled with freshly mixed concrete, and the cast-in-place concrete pile is created.

The second method is the pre-cast concrete pile. This is a hollow pile, but the end is closed conically. There are also two methods of using the concrete pile as the heat exchanger as indicated in Figure 1. One is the direct heat exchange method, in which water in the hollow is circulated directly to the heat pump or the secondary side, called the open

Open system
(Direct water circulation system)

(b) Closed system
(Indirect heat exchanging system)

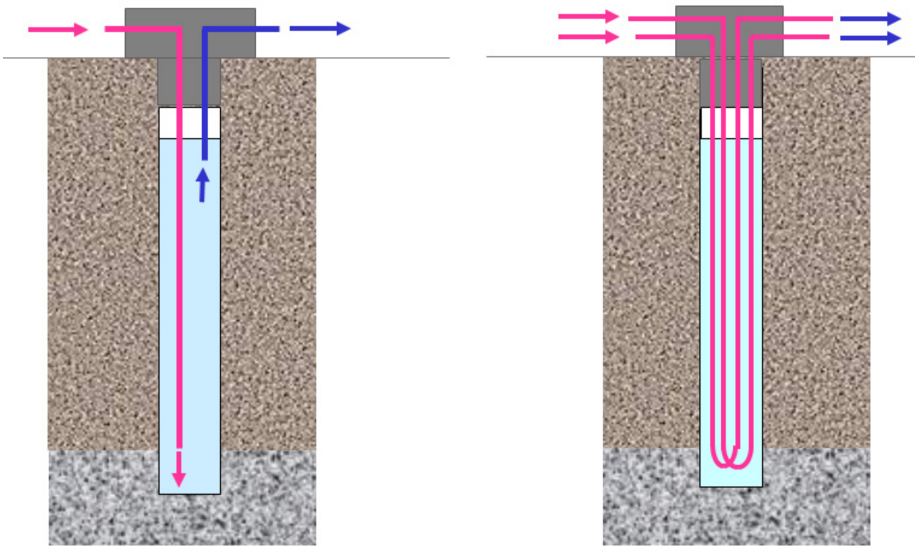

Figure 1. Use of a building foundation pile as energy pile

system. The other one is the indirect heat exchange method, in which heat is exchanged through inserted sets of U-tubes in the hollow (almost the same as the normal borehole system). This is called the closed system. In some cases cement mortar mixture is filled instead of water to minimize the risk of leakage of filled water due to the change of the natural ground water level around the piles, in the long term. The direct system has an advantage from a heat transfer point of view, but still some risks exist, such as air leakage due to the differences in the distribution. On the other hand, the indirect method using U-tubes in water filled piles uses a closed circulating system, which is better in terms of maintenance over many years.

The last type of foundation pile is the steel foundation pile. The steel pile has a blade on the tip of the pile and is buried into the ground by the swivelling press-in pile driver. This construction method, known as the "rotating press-in steel pile foundation method", was approved in 1999 in Japan. When the steel foundation piles are used as ground heat exchangers, the methodology is the same as that for the pre-cast concrete pile, but the former has some advantages. When steel piles are utilized as indirect ground heat exchangers, the thermal resistance of the steel wall is very low due to high thermal conductivity. It is easily understandable that the performance of the heat transfer is enhanced due to the natural ground water flow. Also, the huge amount of heat capacity of the water filled in piles plays the role of a buffer tank for the heat source system. From a full scale experiment, the author has confirmed that the amount of heat extracted by the indirect heat exchanger with more than two U-tubes in the steel pile is almost equal to that extracted by one using direct heat exchange a few weeks after the continuous heat extraction has started [3].

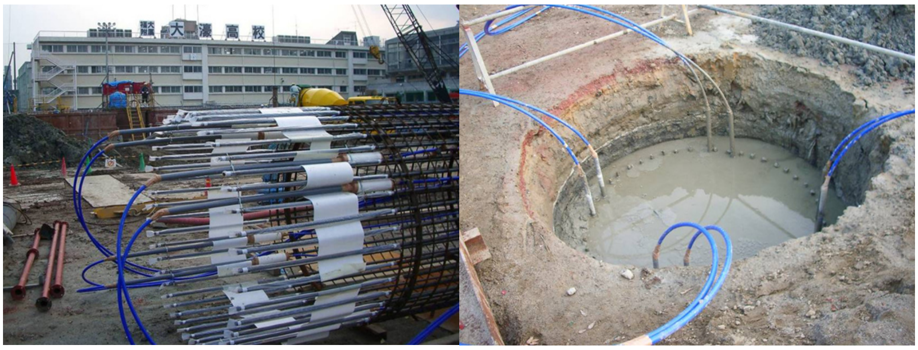

Photo 1. Energy pile system with cast-in-place concrete piles. Left: Four U-tubes tied onto the reinforced frame Right: Installation of four U-tubes in a concrete pile

Some Energy Pile Projects in Japan

The cast-in-place concrete pile

There are two construction methods used to fix the U-tubes in the cast-in-place concrete pile in Japan. One is the common method in which U-tubes are tied onto the reinforced frame on the ground. Photo 1(a) presents the construction site of a new private high school building in Fukuoka city designed by Nihon Sekkei Inc. [4]. A total of 65 piles, each of which are 8.0 m long and have a diameter of 1,000 mm – 1,200 mm, were cast. Four U-tubes of 20 mm in diameter were tied onto the piles on the ground (Photo 1(b)). A heat pump unit with an output of 60 kW was connected to these energy piles for the floor heating and cooling of the entrance hall. This new building is in operation from April, 2009.

Another method is that multiple U-tubes are inserted when the reinforced frame is set into the drilled hole from the ground. This method was developed by Taisei Corp. The largest example of this was applied to the new head office of Maekawa Manufacturing Industry, Co., Ltd. in the central area of Tokyo in 2008 [5]. The total floor area is 9,304 m^2. 20 piles whose average length is 37 m and average diameter is 2,000 mm are used as ground heat exchangers by using eight U-tubes fixed by using special spacers which are tied on each reinforced frame to maintain the correct distance from the outside of the reinforced frame. The piles are installed at 6.4 m intervals in the horizontal direction and 13.7 m intervals in the vertical direction. This system uses a unique ammonia screw type heat pump unit which has a heating capacity of 140 kW. It can supply heat corresponding to 14 % of the peak demand and 31 % of the daily demand.

The pre-cast concrete pile

Open systems have been developed by the snow and construction technology institute of Fukui prefecture [6]. This system is named "Pipe in Pile" [7]. The first system was applied in the snow melting system of the car parking spaces of the public apartment houses without a heat pump unit [6]. Water filled in the concrete pile is circulated directly by using a circulation pump to the buried tubes in the parking spaces. After this installation, there have been several actual energy pile systems applied to the HVAC system. One of the larger systems is a GSHP HVAC system of the Fukui prefecture library and public record office which has been in operation since 2002 [6]. The total floor area is 18,486 m^2. A heat pump of 170 kW for cooling and 205 kW heating capacity is connected to 210 piles whose average length is 16 m and diameters are from 450 mm to 600 mm. It produces part of the total heat demand of 1,480 kW and is integrated with a 1,000 m^3 water thermal storage tank. This system also supplies heat to the snow melting tubes buried in the pavement in front of this facility. Pictures in Photo 2 show how the two tubes run from the top of the concrete pile and pass through the reinforced frame for the column footing of the system of Fukui prefecture education center building.

Photo 2. Tubing of the open system using the pre-cast concrete pile and a pile cap of the system in Fukui prefecture education center building. Left: Two tubes come from a reinforced frame of the footing. Right: A used pile cap.

Closed systems using pre-cast concrete piles are increasing in popularity. A representative example is a GSHP system for floor heating and cooling of the main lobby of the Funabashi city rehabilitation hospital which has been in operation since 2008 (Photo 3(top)) [8]. The total floor area is 14,158 m^2. For the energy pile system, 39 pre-cast concrete piles, whose average length is 25 m and average diameter is 800 mm, are used as ground heat exchangers by means of inserting two U-tubes in the hollow of the piles (Photo 3 (bottom, left and right). In this case the hollow space of the concrete pile was filled with cement mortar mixture. A heat pump unit which has 57 kW of cooling and 66 kW heating capacity was equipped for the energy pile system. This is 3 and 4 % of the total cooling and heating capacity of the whole HVAC system, respectively.

Photo 3. A closed system using pre-cast concrete piles in the Funabashi city rehabilitation hospital. Top: Exterior of hospital building. Left: Inserting two U-tubes in the hollow of a pre-cast concrete pile. Right: U-tubes from pre-cast concrete piles under construction.

The steel foundation pile

The largest open-type steel foundation energy pile system was applied to the snow melting system of a bridge of the prefectural highway in Sakai city, Fukui prefecture in 2006 (Figure 2) [9]. The length of the bridge is 240 m and road area is 1,810 m^2. 36 steel foundation piles of both bridge bases are used as ground heat exchangers. The average pile length and the average pile diameter is 38 m and 550 mm, respectively. They were buried 2.0 m apart. Steel tubes for snow melting in the concrete roadbed can work as a kind of solar collector during the summer. Absorbed heat from the tubes is transferred to the water in the piles by small circulation pumps. The heat is then released to the surrounding soil and stored seasonally. In the winter, the stored heat in the ground is recovered and transferred to the bridge roadbed and used for the snow melting of the bridge using just small circulation pumps without any heat pump.

Steel companies are interested in the development of the energy pile systems using steel foundation piles. One example is a system adopted in a new school building, operated by Sapporo City University Sapporo (Photo 4) [10]. The author joined this project in 2005, as responsible for design and commissioning of the system. This energy pile system has been in operation since 2006.

Photo 4. Sapporo City University

Design and performance prediction tool for the energy pile system

Nagano and Katsura have developed a design and performance prediction tool for the energy pile system [11], [12] and it has been commercially available through the web site (Figure 3, left) [13]. The advantages of this tool are that it can calculate the temperature of the heat carrier fluid in a large diameter energy pile system employing a random layout of the building foundation piles (Figure 3, right). The layout of the building foundation pile depends on the

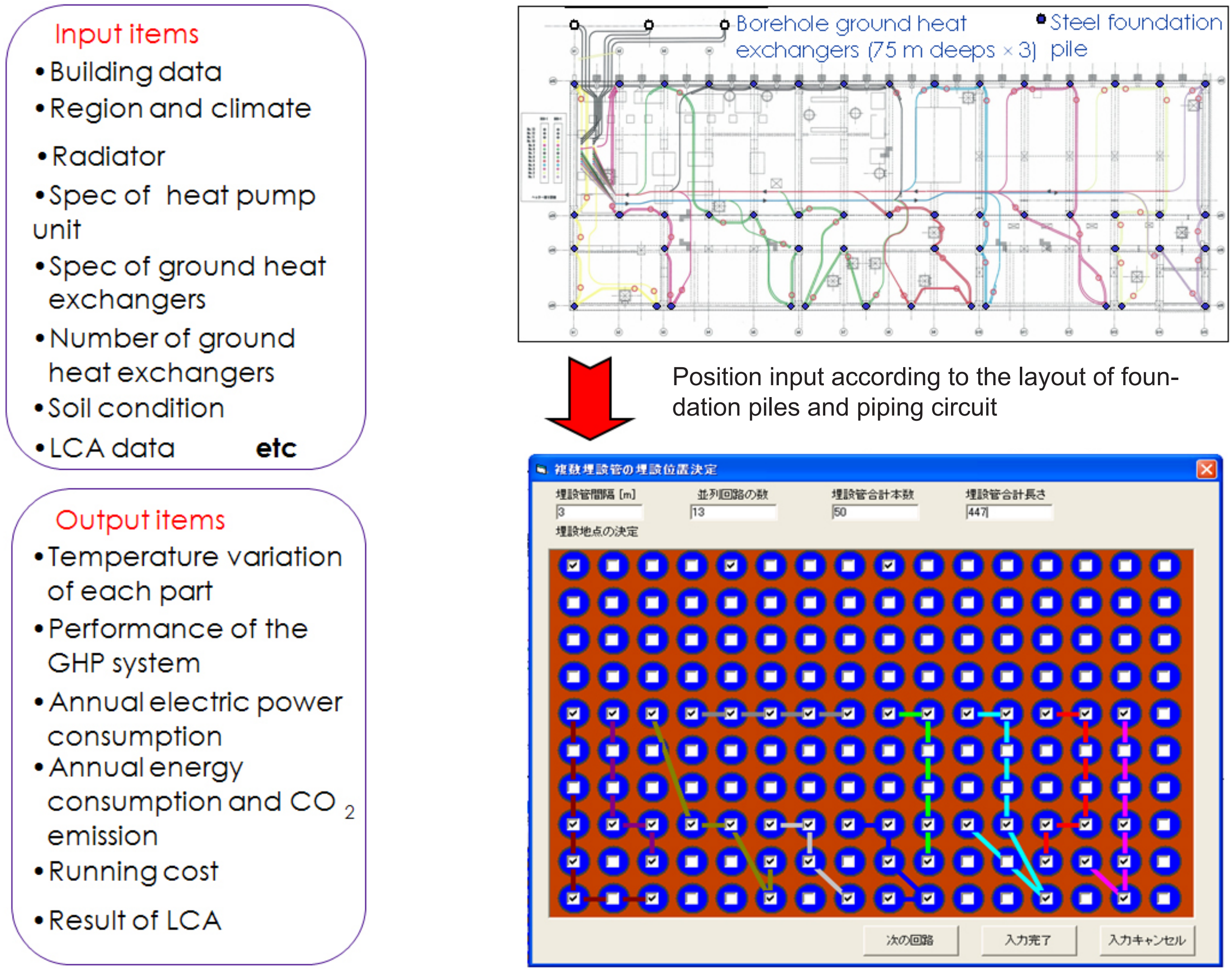

Figure 3. A design and performance prediction tool for the energy pile system developed by authors

building structure and geological condition. This means that the layout in most cases does not have a regular lattice pattern. Many existing designing softwares utilize what is known as a "G-function". However, they cannot support the irregular layout. The author's group has developed a novel GSHP designing and performance prediction tool which is able to treat the random layout of ground heat exchangers with a high speed calculation algorithm. It can also take into account the effect of a large heat capacity in the ground heat exchanger. The thermal response of a short ground heat exchanger with a big diameter is calculated using the cylindrical heat source theory modified by the similar method by Eskilson [14]. A convolution integral is calculated for the hourly heating and cooling loads. In addition, this tool includes databases of performance curves of heat pumps according to both outlet temperature of the primary side and inlet temperature of the secondary side, energy prices and specific CO_2 emissions. Consequently, this tool can calculate hourly energy consumption and energy cost. Then life cycle energy (LCE) and life cycle CO_2 emissions ($LCCO_2$) are evaluated in addition to life cycle cost (LCC). Graphical input and output screens provide a user-friendly interface. As an example, it takes only a few minutes to get results for multiple ground heat exchangers running for two years.

Energy Pile System in Sapporo City University

Designing of Energy Pile System in Sapporo City University

The new building of the nursing school of Sapporo City University has adopted a closed type energy pile system in the HVAC system in 2006. It is the world's first application using steel foundation piles filled with water. The floor area is 2,800 m^2. The layout of the steel foundation piles and piping for ground heat exchangers is shown in Figure 3 (right). The principle of construction of the steel foundation piles and the installation of U-tubes has been presented recently in the HPC Newsletter (issue 1/2009, p 47, Figure 13). In total, 51 piles were screwed into the ground under the base plates at 4.0 m depth from the ground level. The diameters of the steel piles range from 600 mm to 800 mm. As shown in Figure 4, a layer of hard gravel and pebble appears under 10 m depth in this area. Consequently, the lengths of the piles were 6.2 m on average. After subtracting the necessary head space of 1.0 m for footing and a bottom space of 0.5 m, the average effective length for each ground heat exchanger will be 4.7 m, and the total effective heat exchanging length will be 240 m. The total volume of filled water is 115 m^3. The indirect closed circulating system was adopted, and two sets of U-tubes were inserted into each steel pile, determined from results of actual experiments. Steel caps with four holes were used in order to prevent the concrete for the footing from dropping. U-tubes were protected by sheathed plastic covers during the construction work.

Prediction of performance of the energy pile system

The maximal feasible heat supply from the energy pile system was evaluated by using the developed GSHP designing tool according to hourly heating loads including the ventilation. Here, the authors used the constraint condition that the minimum allowable outlet temperature of the heat pump unit was -1°C.

The average effective thermal conductivity input into the calculation was 2.2 W/(m·K), which was measured by an on-site thermal response test. The results showed that these energy piles with an additional three boreholes of 75 m length can supply the daily base heating load of 50 kW for heating and cooling of the outside fresh air in the air conditioning unit equipped on each floor. Recovered heat by natural cooling is released into the ground during summer.

Calculated results of the time variations of the outlet temperatures, in both the primary-side and the secondary-side of the heat pump unit, for the fifth year's operation are shown in Figure 5. The minimum outlet temperature of the primary side is -0.8 °C. It is clear that the brine temperature after the summer season returns to the initial temperature at the beginning of the fifth year's operation. This means that sustainable operation can be established in this energy pile system.

Figure 6 shows comparisons of estimated annual CO_2 emission and annual operating cost of the GSHP system with those of a gas system, which has a gas boiler without a chiller or a gas cooling and heating machine. The annual operating cost of the GSHP is 3,500 USD. This is only half the cost of the gas boiler system and 42 % of the gas cooling and heating system. Annual CO_2 emissions from

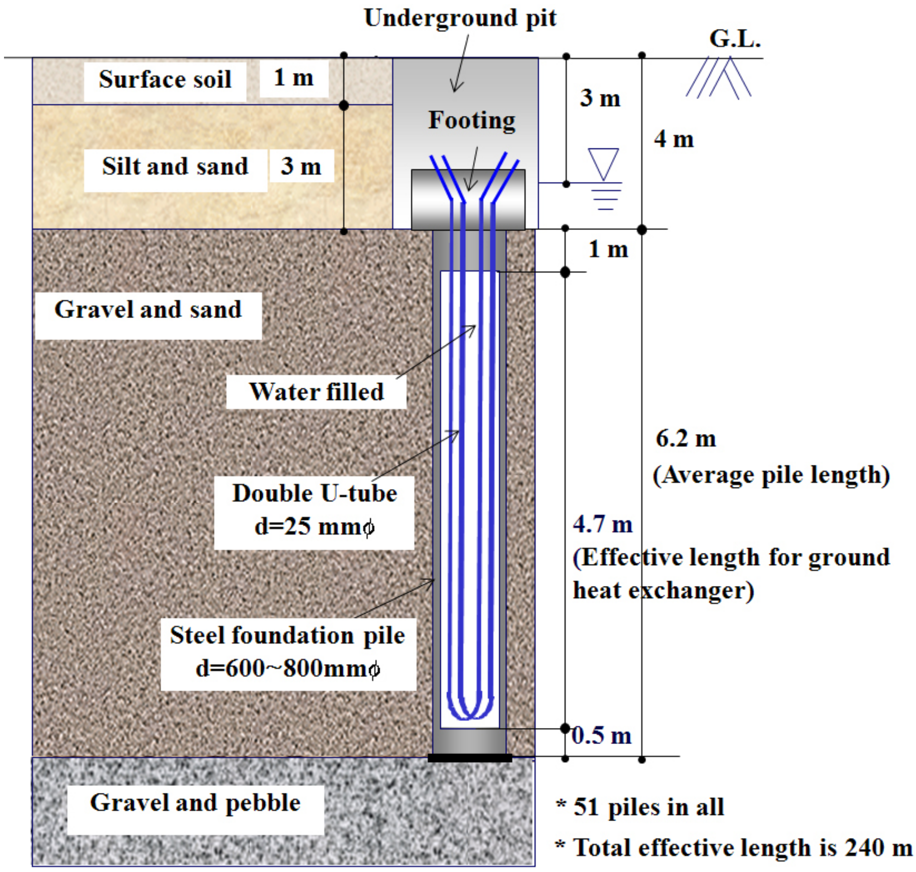

Figure 4. A detail of the energy pile and the geological conditions

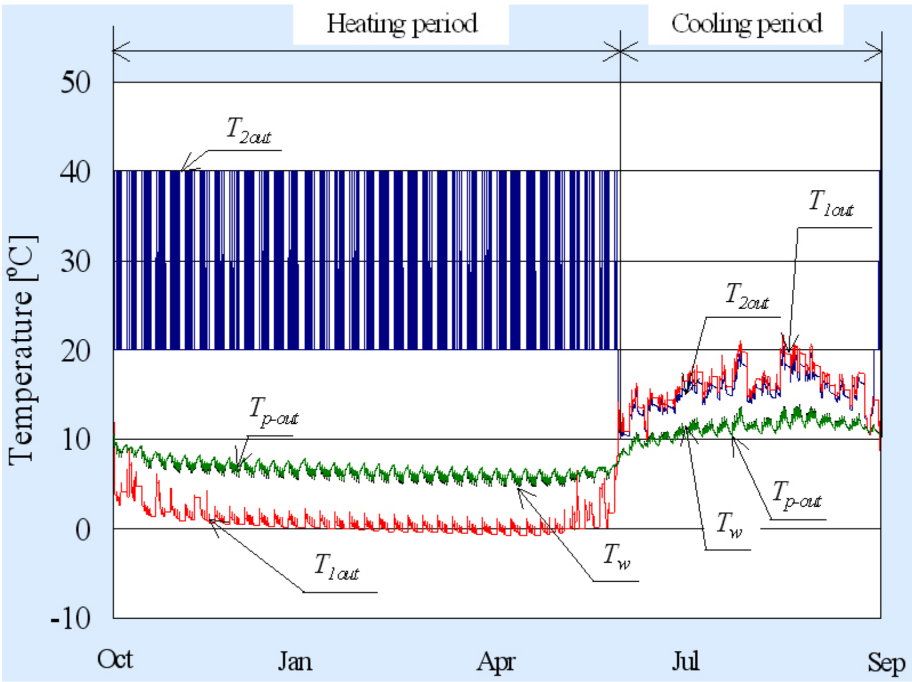

Figure 5. Calculation results of annual temperature variations for 5th year's operation
T1out: Primary-side outlet temperature of heat pump unit (Inlet temperature of piles)
T2out: Secondary-side outlet temperature of heat pump unit (Inlet temperature of ventilation unit) Tw: Average water temperature in piles, Tp-out: Average outside wall temperature of piles

the GSHP are 12 tons. Compared to the gas boiler and the gas cooling and heating system, this is a reduction of 3.8 tons and 7.4 tons of CO_2, respectively.

Results from two years' operation

A heat pump unit, which has a heating capacity of 50 kW and COP of 4.0 under the condition of 5ºC for the inlet of the primary side and 40ºC for the outlet of the secondary side, has been installed. Commissioning was performed in summer 2006. Figure 7 and Figure 8 summarize heat balances and system performances during the summer and winter of the first year (2006) and the second year (2007). In addition, the variation of the average filled water temperature in the steel foundation pile for the first and the second year are indicated in Figure 9.

In the first summer (Figure 7) free cooling was tried, but the fraction of energy consumption from circulation pumps compared to the cooling effect was relatively high because the pump capacities were determined by the peak demand of heating. Thus, they were unnecessarily large for the free cooling so that SPFc of the free cooling, which is defined as the amount of cooling demand of the air conditioner Qc divided by energy consumption of circulation pumps Epump, was as low as 2.36. In the second year (2007), chilled water produced from a heat pump unit was supplied to the outside air conditioner from June to September. In this case the waste heat from the heat pump unit was released into the ground and the average filled water temperature in the steel foundation pile rose above 26 ºC. However, the temperature returned to the same level as the previous year by the beginning of October. This fact suggested that the buffering effect by the natural ground water flow affected the temperature response of the filled water in the energy piles after the cooling period.

On the other hand, the expected COP of the heat pump (Figure 8) unit was as expected from the performance test value. Here, SPFh of the second year was drastically improved compared to that of the first year by the adjustment of the start-stop control logic of circulation pumps according to the commissioning results. This shows that commissioning is important in order to improve the performance and reduce the energy consumption and the energy charge, even though it requires extra effort and expense.

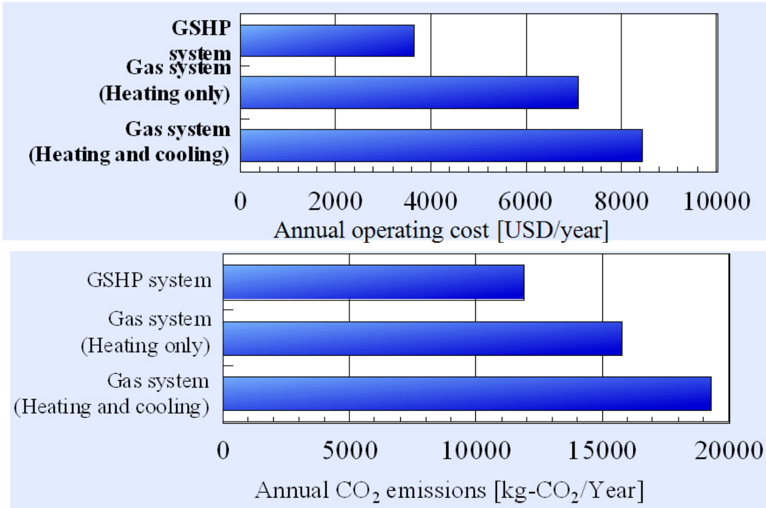

Figure 6 Comparisons of annual operating cost and annual CO_2 emissions. Top: Annual operating cost. Bottom: Annual CO_2 emissions.

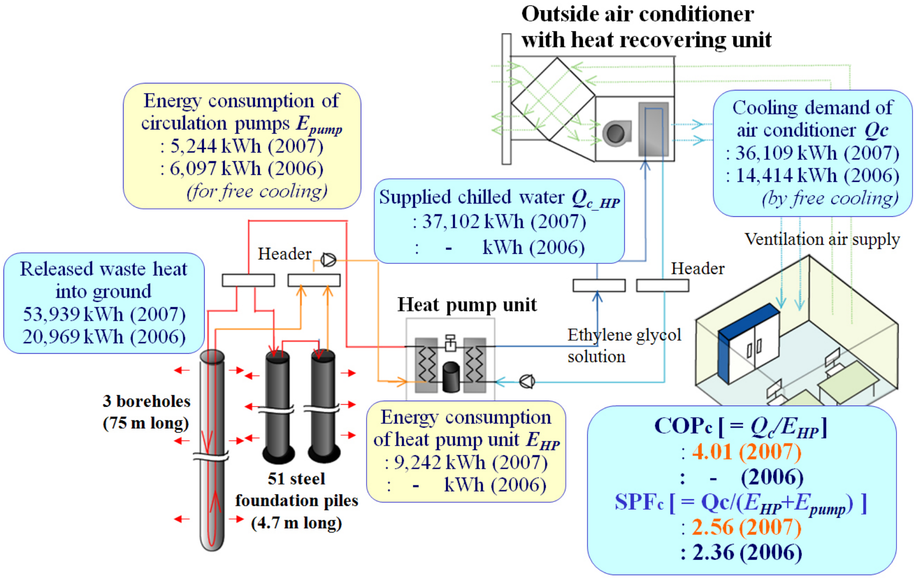

Figure 7. Heat balance and system performance during summer of the first year (2006) and the second year (2007)

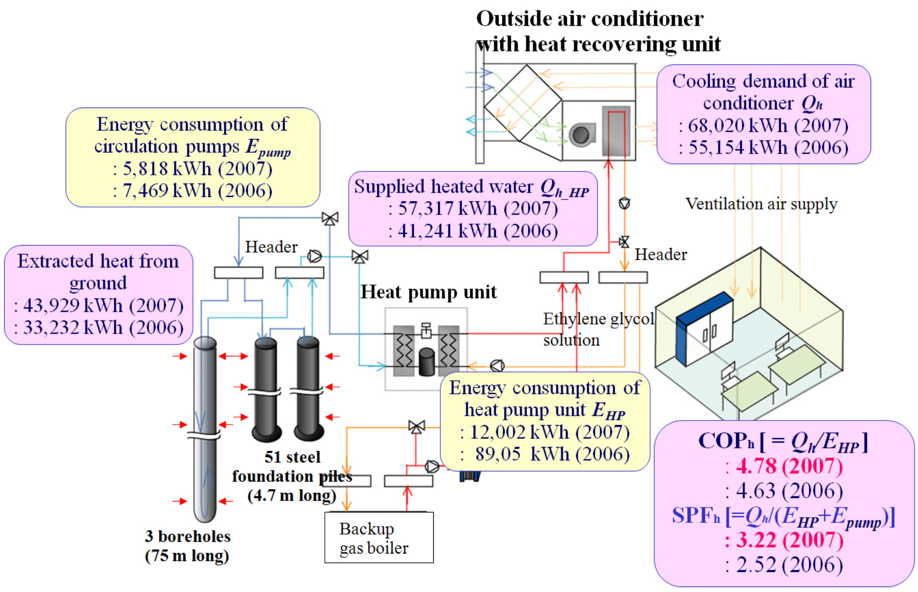

Figure 8. Heat balance and system performance during winter of the first year (2006) and the second year (2007)

The complete temperature recovery to the initial condition by the start of the heating season assures us of the sustainable operation for many years of this energy pile system (Figure 9), although the amount of released heat is 25 % larger that that of extracted heat from the ground.

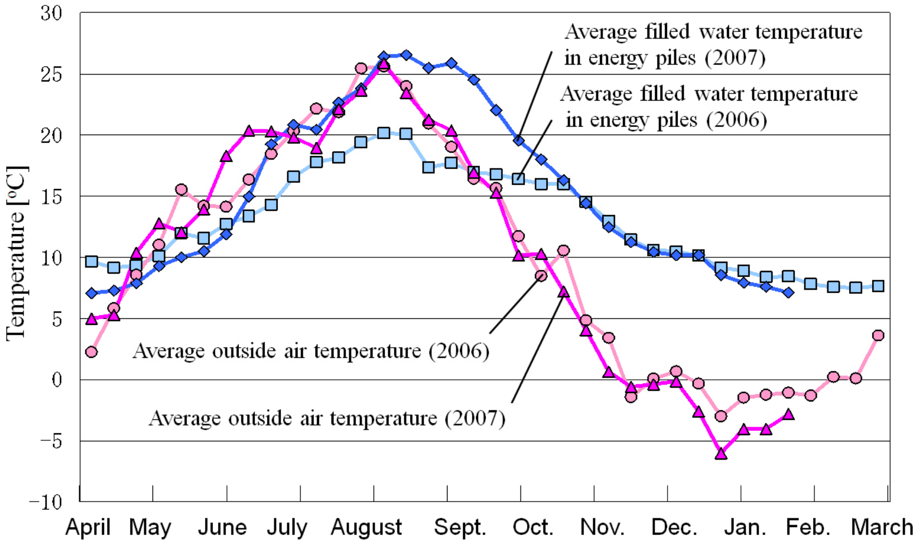

Figure 9. Average temperature variation of the filled water in the energy pile with average air temperature changes.

Conclusions

The energy pile system is getting popular in Japan, especially in school buildings and other public buildings and facilities. Recently, several national famous facilities such as the new Tokyo international airport terminal building and the new Tokyo TV tower known as "Tokyo Sky Tree" have adopted the energy pile system [16]. This fact proves that developers and engineers in the central area of Japan have gradually understood its great potential for reducing primary energy consumption and CO_2 emissions from HVAC systems. To overcome several barriers and to spread this technology widely, we have to collect success stories and show the evidence of the energy conservation effects and reduction of environmental impacts both to installers, architects and policy makers. In addition, reducing the installation cost is important, especially in the distribution and piping works after the installation of tubes in the foundation piles. It may be very effective to establish a standard engineering procedure for the installation by using prefabricated tubing systems including the headers to maintain an even distribution. On the other hand, designing flexibility for hybrid systems integrated with small cooling towers and air source heat pumps is required in the large systems of Japan. Training and engineering education will be necessary for engineers and designers in order to spread this technology in the right way.

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Development of heat pump air-conditioning system using Aquifer Thermal Energy Storage (ATES): Snow Melting System without sprinkling groundwater

Masahiko Katsuragi, Japan

System development background

A large part of Japan is subject to severe winter weather. Currently, 22% of the population (approximately 28 million people) live in such regions, which have a total area of 230,000 km2. This is about 60% of the area of Japan. In April 1957, the *Act on Special Measures concerning Maintenance of Road Traffic in Specified Snow Coverage and Cold Districts* was introduced in Japan, which made it possible to allocate means to solve snow-related problems in these regions. However, traffic accidents and the isolation of cities due to heavy snow fall and icy roads continued to be serious problems here.

In 1961, as a result of the abovementioned act, a new snow melting system was introduced. It used groundwater sprinkled from pipes installed on the roads directly over the snow to help melt it. This became the main snow melting technology system, and was widely installed in cold regions to support the daily life of people during the winter.

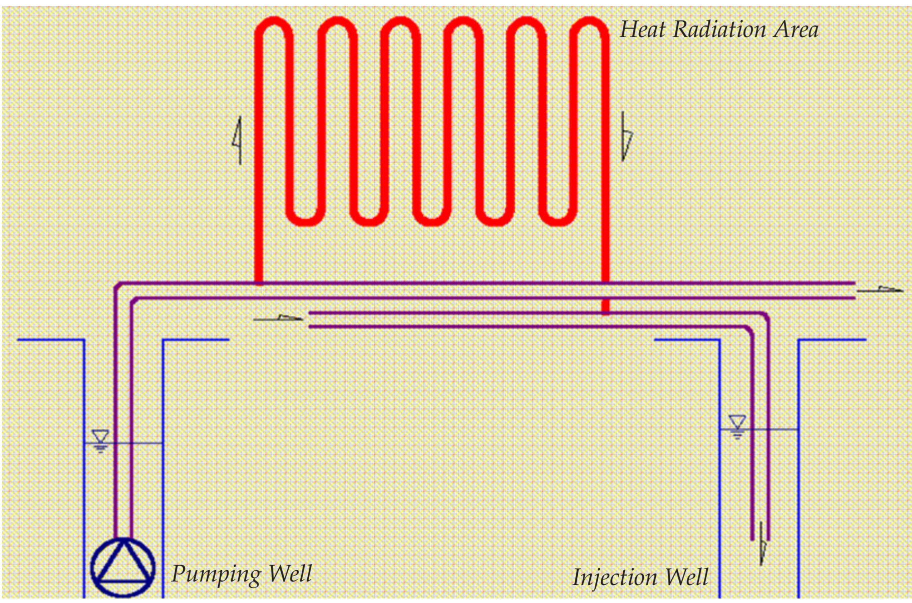
It soon became obvious that this system had serious flaws. The use of excessive amounts of groundwater resulted in lowered groundwater levels, which ultimately led to ground subsidence. However, a new, better solution was developed even before this problem became apparent. The Japan Groundwater Development Co., Ltd. (JGD), developed the *Snow melting system without groundwater sprinkling*.

Overview of the Snow melting system without groundwater sprinkling

The system melts snow and prevents roads from freezing by using heat radiation pipes installed under the pavement, with groundwater as the heat source. Since it does not directly spray water, it provides for smoother, more convenient traffic, and less damage to the pavement. After releasing heat energy, groundwater is led back into the aquifer, so that it neither affects the water supply nor causes land subsidence.

This system consists of a pumping well, a heat radiation area, and an injection well. The pumping well extracts groundwater and pipes it to the heat radiation areas. Heat radiation areas have pipes under the pavement that transfer heat energy from groundwater. They melt snow and prevent roads from freezing. The injection well is used to lead the groundwater back into the aquifer without making contact with the atmosphere.

In Yamagata City we drill wells to a depth of 100 m where the groundwater temperature is between 14ºC to 15ºC, which is almost equal to



the average annual air temperature. Moreover, as we do not use fossil fuels for this system, running costs are very economical and the system emits less carbon dioxide than boiler and electrical snow melting systems.

In 1981, we introduced this new system under the main street in front of Yamagata City Hall and it produced excellent results. In October 1981, we installed it in Asahikawa City, Hokkaido, to study system capacity. Asahikawa City can be very cold, it registered record cold (–41.0°C) on January 25, 1902. The system demonstrated satisfactory performance and proved its usefulness in the coldest city in Japan. By December 2009, we had installed this system in well over 1,330,000 m^2 in Japan.

Development of heat pump air-conditioning system using ATES

The following serves as an example of the snow melting system combined with indoor climate control. Our company, JGD, is in Yamagata City, Yamagata, located in the north eastern part of Japan. The July to August air temperature in Yamagata is 23.9°C and –3.5°C January to February (averages for 1971 to 2000). The groundwater temperature from the company well is 16°C, and it is almost constant year round. As will be seen, it is higher than the atmospheric temperature in winter and lower in summer.

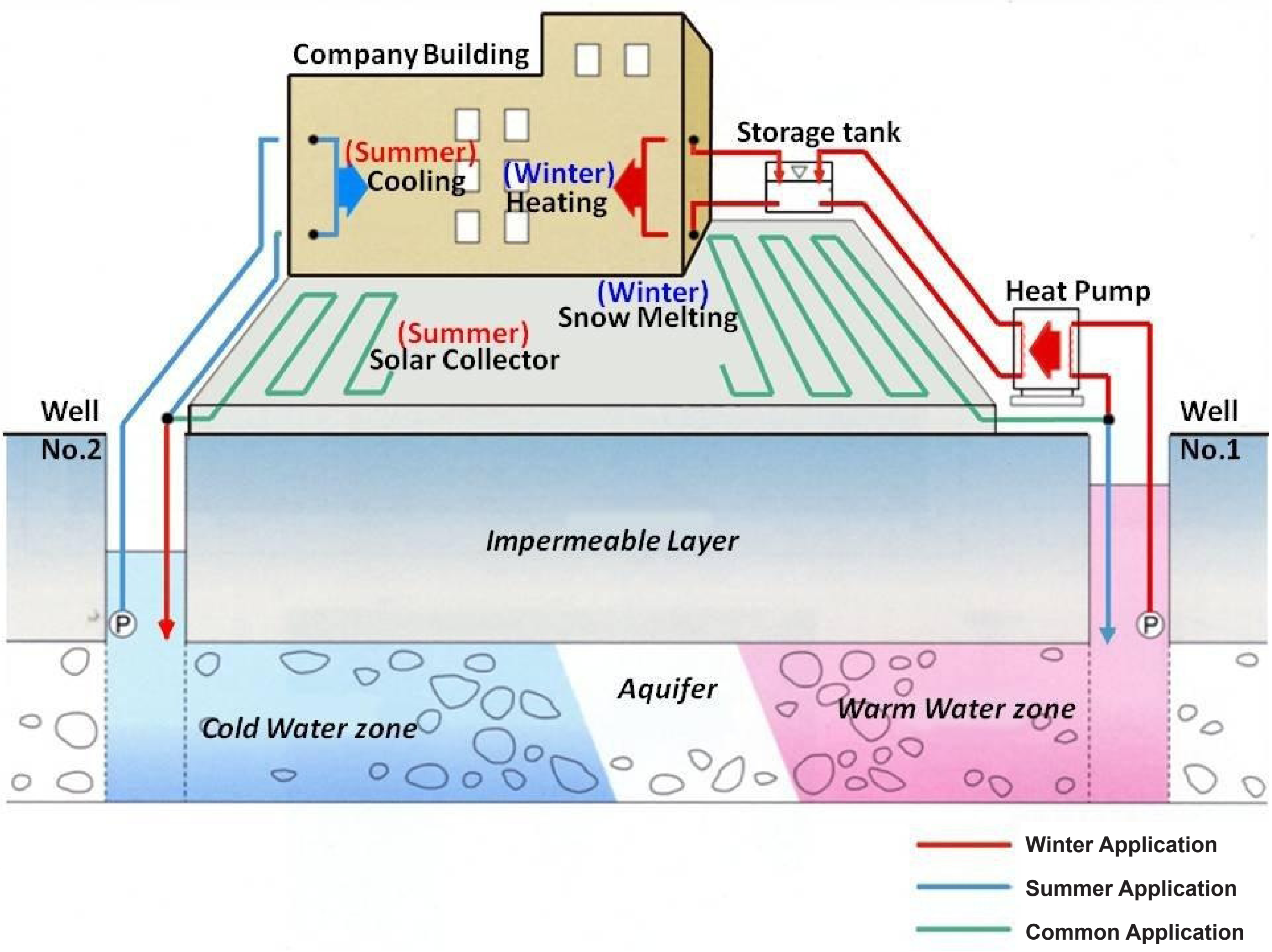
In 1983, JGD began looking at the possibility of utilizing ATES not only for melting snow and de-icing, but also for air-conditioning buildings.

Construction site of Snow Melting System.

Snow Melting System in operation.

In winter, groundwater is pumped from well No. 1, and fed into a heat pump to produce hot water at 50°C. This hot water circulates throughout the office building for heating. After the groundwater has transferred its heat to a heat pump, it is led through the pipes under the parking zone to melt snow. The water temperature drops to approximately 8°C during the process, and it is injected back into the aquifer through well No. 2 to form a cold groundwater zone. By the end of winter, the cold groundwater zone temperature is 12°C.

In summer, groundwater is pumped from well No. 2 (cold groundwater zone) and piped to the office building for cooling and to the parking zone to collect solar heat from the pavement, which functions as a solar collector. Groundwater heated by the solar collector is then injected into the aquifer again at well No. 1, which forms the warm groundwater zone, where the temperature is around 30°C. At the end of summer, the tem-



perature of the warm groundwater zone is 20°C.

This system can achieve year-round heat energy utilization by adopting the solar collector. This is an excellent system for both cooling in summer and heating and snow melting in winter, with reasonable operating and maintenance costs. It is certainly cheaper than the cost of electricity for ordinary furnaces/air conditioning systems.

It achieves both energy savings and a reduction in carbon dioxide emissions.

We continue to study this system for further improvements. Running costs come from the use of a submersible pump, circulating pump and heat pump, and are roughly 33% of the annual running costs of a standard air-conditioning system including fuel boiler in winter. CO_2 emissions are also around 33% of that of a conventional air-conditioning system, as would be expected.

If hot water temperature is set to 50°C and groundwater temperature is 16°C, heat pump COP is 3.9. However, if we use a solar collector during the summer, when groundwater temperature is 20°C, COP becomes 4.7. This is an 18% improvement. A similar evaluation has been made for cooling and we came to the conclusion that were this system the only source of cooling then it might not be quite enough for summer comfort.

Although the ATES system is still not widely known in Japan, it is obvious that groundwater and ground source energy is more stable than other natural energy sources such as solar and wind. ATES has a large potential and is not yet fully exploited.

In 2009, the JGD ATES system was adopted by the Cool City Project of the Japanese Ministry of Environment.

We are committed to collecting more data and carrying out further studies to show how well the ATES system can contribute to the prevention of the heat-island effect and global warming.

Development and Planned Operation of a Ground Source Heat Pump Test Facility

Saqib Javed, Per Fahlén , Sweden

A new heating, ventilation and air-conditioning laboratory has been established at Chalmers University of Technology, Sweden. The new laboratory provides test facilities for experimental studies of various HVAC systems including borehole thermal energy storage and heat pump systems. The test facility can be used to test operation and control strategies, to develop and validate models for ground source heat pump systems and to conduct thermal response tests. This paper reports on the design and development of the laboratory's ground storage and heat pump system and its planned operation.

Introduction

The division of Building Services Engineering at Chalmers University of Technology, Sweden, has recently built a new heating, ventilation and air-conditioning (HVAC) laboratory [1]. The test facility was developed with an aim to conduct experimental studies on system solutions for space conditioning, integrated control-on-demand and optimized control of HVAC systems. An integral part of the laboratory's HVAC system is its ground source heat pump (GSHP) system, which was primarily developed to study the performance of a wide range of GSHP system configurations. The GSHP test facility consists of a borehole thermal energy storage system (BTES), heat pumps, thermal storage tanks and multiple heat exchangers. The test facility can be used, among other things, to develop, test and optimize control strategies for different GSHP system configurations, to develop and validate component and system models and to perform thermal response tests (TRTs) under different experimental conditions. The following sections describe the design and development and the planned operation of the test facility.

Design and development

The GSHP system consists of a BTES, made up of nine boreholes, connected to three water-to-water heat

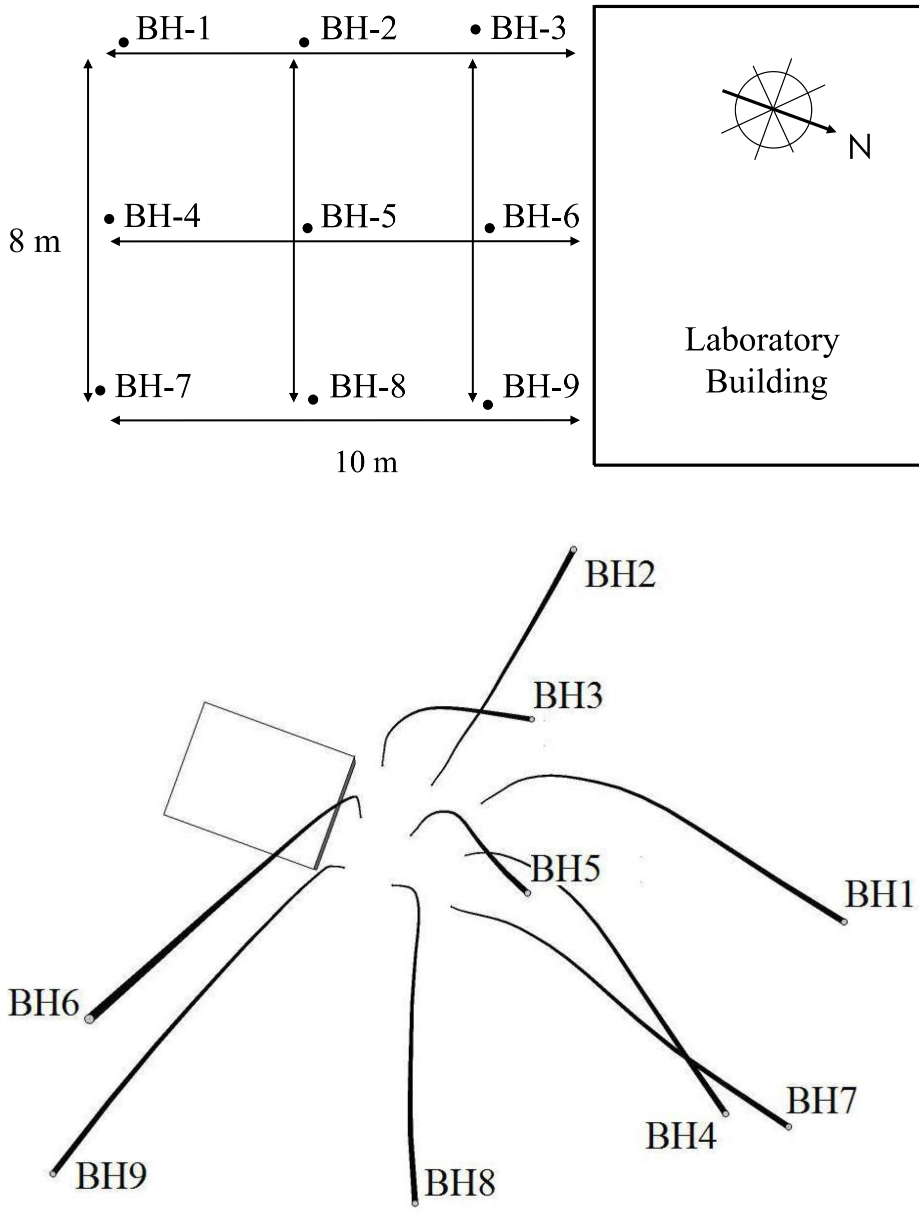


Figure 1 Layout and geometry of the borehole system.

pumps. The boreholes are drilled in a 3x3 rectangular configuration. All the boreholes are groundwater filled and have single U-tubes as ground loop heat exchangers. The distance between adjacent boreholes is around 4 m and each borehole has an active depth of around 80 meters. The inclination of all nine boreholes in the ground has been measured and the horizontal deviation between the two ends of the boreholes varies between 1.7 to 7.2 meters. Figure 1 further illustrates the borehole system layout and the geometry of the nine boreholes.

All nine boreholes have dedicated variable speed pumps and flow control valves to monitor and control brine flow in individual boreholes. Brine exiting the borehole system is stored and distributed through the accumulator tank AT1. From AT1, brine can either be supplied to the evaporator of heat pump HP1 or directly pumped to the heat exchanger HX1 to provide free cooling. The effects of long-term heat injections or heat extractions on the boreholes can be minimized by balancing borehole loads or by recharging the boreholes using direct heat transfer between the brine and the ambient air by means of dry cooler DC1.

The accumulator tank AT2 stores low temperature water (5-15 °C). This water may be cooled directly by heat pumps HP2 and HP3 or indirectly by the ground storage or by outdoor air (DC1) via heat exchanger HX1. AT2 is also used to cool the condenser of heat pump HP1. The low temperature water is used for various laboratory operations. It is supplied to the air handling unit to produce cooling in summer, it is pumped to heat pump HP2 and HP3 evaporators as a low temperature heat source to produce heating and it is used in other laboratory operations requiring process cooling. The HW1 hot water (20-55 °C) produced by HP2 and HP3 can either be directly supplied for heating and process heating applications or can be stored in accumulator tanks AT3 and AT4 and used when required. In case of additional heating requirements or high-temperature water demand, HW2 hot water (20-80 °C) produced by the EP1 electric storage water heater and stored in accumulator tank AT5 can be utilized. Any excess heat in the hot water storage system can be rejected to ambient air using heat exchanger HX2 and dry cooler DC2.

A state-of-the-art building management system has been installed to monitor and control the test facility and for data acquisition and storage. Temperature measurements in the system are made at the inlet and outlet of all the installed components using electronic immersion temperature transmitters. Flow measurements in the system are taken for all the flow circuits using vortex flow meters. Electric power measurements in the system are made for all major components by means of meters that also provide the possibility of waveform analysis. Ambient air temperature and indoor air temperature in each room are measured using electronic temperature transmitters.

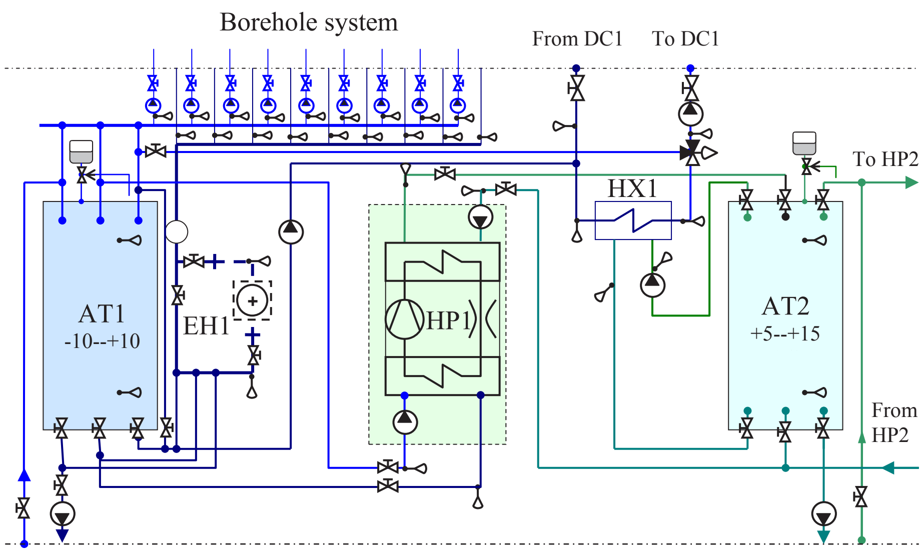


Figure 2 Brine and process cooling water system.

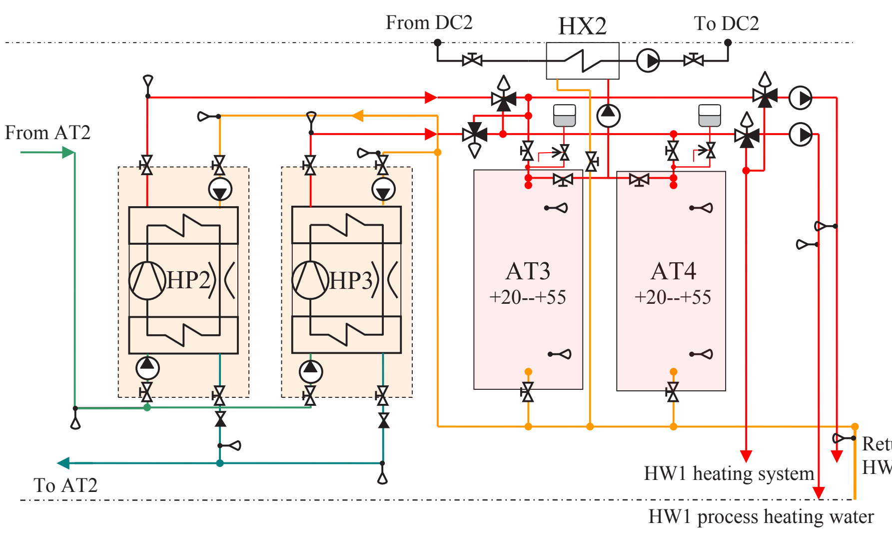


Figure 3 The HW1 heating and process heating system.

Planned operation

The test facility can be used to investigate the effects of various control strategies on the operation and performance of GSHP systems. Traditionally, controlling the heat pump entering fluid temperature has been the most common control strategy as a higher entering fluid temperature in winter and a lower entering fluid temperature in summer increase the heat transfer and positively influence the performance of the heat pump. However, requirements for heating and cooling in buildings have changed considerably in recent years. Today, many commercial and office buildings have a cooling demand during the day, even in a climate as cold as Sweden's, and a heating requirement during the night. Other commercial buildings, like shopping centres and supermarkets, have simultaneous heating and cooling demands. These changing heating and cooling demands require new control strategies that need to be investigated and adapted to optimize the performance and operation of GSHP systems [2]. Such strategies may be based on actual and predicted system loads, forecasted and historical energy use etc.

The new test facility will be used to study existing and new control strategies for different configurations of GSHP systems. The flexible design of the test facility permits components to be included or excluded from the system as per test requirements. The GSHP system to be investigated can be designed using various configurations of the borehole system, heat pumps, accumulator tanks and supplementary heat exchangers. Depending on the application, the borehole system can be used in heat storage or heat dissipation modes. When used in the rectangular configuration, the borehole system acts as a heat storage system to store thermal energy in the ground at a time of energy surplus for extraction later. When used in a line, a U or an open rectangular configuration, the borehole system acts as a heat dissipation system. Any number or configurations of boreholes can be chosen for a particular test. Dry cooler DC1 can be used to moderate borehole system temperature but it can also be used as a standalone alternative for free cooling during periods of low outdoor temperature.

The size and augmented thermal mass of the system can be altered as it is possible to use either of heat pumps HP2 and HP3 with either of the accumulator tanks AT3 and AT4. Alternatively, it is also possible to operate HP2 and HP3 together with either or both of AT3 and AT4. Dry cooler DC2 can be used to reject any excess heat present in the hot water storage systems. Electric resistance heaters installed in all the accumulator tanks and electric storage water heater EP1 can be utilized to provide additional heating or to meet high-temperature water requirements. All of these possibilities allow a wide range of GSHP system configurations with flexible levels of temperature, thermal loads and thermal mass in the system. The test facility will be used to investigate control strategies for different GSHP system designs and to study the effects of system design on the operation and the performance of the GSHP system.

The test facility will also be used to develop new component and system models, to experimentally validate existing and new models and to conduct experimental studies. At a component level, models for the borehole system, heat pumps, storage tanks and auxiliary equipment can be developed, tested and validated. At the system level, investigations regarding operation, control and optimization of simple and hybrid GSHP systems can be carried out. The test facility can be used to test borehole system models both for heat storage and heat dissipation modes. Investigations regarding short-term borehole response, long-term borehole performance deterioration and thermal interaction between boreholes are of particular interest.

Other examples of possible experimental investigations which can be conducted using the test facility include studying the differences between the thermal response of peripheral and central boreholes, attainable free cooling in relation to ground heat injection and the trade-off between heat pump and the circulation pump energy consumption in free cooling modes. The laboratory system makes possible the testing of both brine-to-water and the

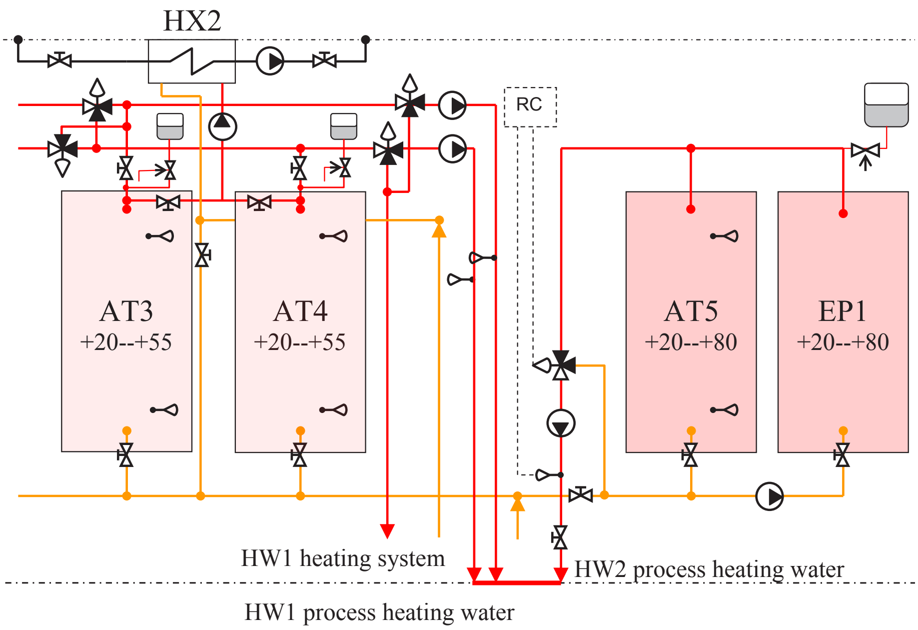


Figure 4 The HW1 and HW2 process heating system.

water-to-water heat pump systems. Simultaneous testing of heat pumps at similar or different temperature levels is also possible using the test facility.

Another feature of the test facility is its flexibility in conducting TRTs. The laboratory borehole system provides a unique opportunity to study ground thermal properties such as undisturbed ground temperature, thermal conductivity and the borehole resistance of nine boreholes in close proximity. Such an investigation has rarely been conducted on an academic level in controlled laboratory conditions. Issues like repeatability and reproducibility of TRTs can be comprehensively studied using various alternative approaches. The installed electric resistance heater EH1 can be used to conduct the thermal response testing in the heat injection mode. It is also possible to conduct TRTs in heat extraction mode using heat pump HP1. Another possibility is to conduct TRTs using brine at constant input temperature to the boreholes.

When conducting a TRT, the brine accumulator tank, AT1, can either be included or excluded from the flow circuit. The storage tank is bypassed if the conventional constant heating flux approach is used for the thermal response testing. Alternatively, the storage tank is included in the flow circuit and is used to provide brine at a constant input temperature to the borehole for constant heating temperature approach. The installation of nine variable speed pumps, one for each borehole, and an adjustable electric heater for heat input allow investigations regarding effects of different flow and heat injection rates when conducting TRTs. The results from TRTs of the laboratory borehole field can be used to simulate the long-term response of the individual boreholes. The differences between the long-term responses of the different boreholes can then be used to underline the uncertainties related to the borehole system design process.

Additional testing facilities

In addition to the GSHP system, the laboratory building houses a conference room and two test rooms for specific test applications. The first test room is designed as a 'clean room' with stainless steel interior and a dedicated air conditioning system. This test room is used to perform experiments which require precisely controlled temperature and air quality. It can also be used to test components like sensors and air cleaners and to study emissions from different materials.

The second test room is made of clear glass and has a dedicated ventilation system. Special filming equipment has been installed to study the room-air and ventilation-air movement under specific conditions, e.g. that of an operating theatre etc.

The conference room was purpose built to investigate issues related to thermal climate and indoor air quality, lighting and noise, the control and positioning of room sensors and the operation and control of decentralized pumps and fans etc. The temperature in the room can be maintained using supply air from the centralized air handling unit or by using radiators, fan coil units, or under-floor heating and cooling as alternate systems. Supply and exhaust air flow rates, indoor air quality and noise levels in the conference room can all be precisely monitored and controlled. The use of four sets of supply and return ducts to the conference room also permits the division of the room into four cell-type offices to study the effects of indoor climate on the performance and behaviour of people.

Conclusion

This paper reports on the design and the development of a GSHP laboratory. The laboratory setup includes a BTES, three heat pumps, five accumulator and storage tanks, two dry coolers and several additional auxiliary components. The laboratory offers facilities to test different GSHP system configurations in controlled laboratory conditions. The planned operation of the laboratory was also reported. The laboratory will be used to test operation and control strategies for GSHP systems, to develop and validate system and component models and to conduct thermal response tests.

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The following article is based on a presentation given by Mr. Katakura at the ASHRAE meeting in Orlando, Florida, in January 2010.

The Role of Refrigerant for Wider Deployment of Heat Pumps

Momoki Katakura, Japan

Given the global implications at stake in the prevention of climate change, drastic reduction of CO_2 emissions should be implemented via the speedy expansion of renewable energy usage.
In pursuit of this target, as a highly efficient energy appliance, the widespread dissemination of heat pumps to potential customers all over the world is absolutely imperative. In order to fully make use of the advantages inherent in this unique product, strongly needed is establishing a refrigerant management system which is consistently applied from production to recovering and destroying process with international cooperation.

Introduction

The Japan Society of Refrigerating and Air Conditioning Engineers (JSRAE) is making great effort to contribute to the preservation of our planet's environment through the promotion of highly efficient heat pumps which yield the following three benefits; the drastic reduction of fossil fuels consumption, the drastic reduction of CO_2 emissions and the expansion of renewable energy usage.

It is necessary to minimize the volume of leakage presently associated with the refrigerant, the primary ingredient essential to the operation of heat pumps, given its harmful global warming effects. Therefore, establishing an effective management system is crucial to the further development of heat pumps.

Accordingly, this article intends to clearly articulate JSRAE's concept of pursuing the compatibility of promoting heat pumps while effectively managing the refrigerant in order to accelerate present efforts towards the prevention of climate change.

Expectations for Heat Pumps

In order to stabilize the atmospheric concentration of CO_2, the following "Kaya Identity," which analyzes the three contributing factors responsible for CO_2, gives us an idea of leverage for reducing CO_2 emissions.

CO_2 emissions
= GDP
×Energy intensity(Energy/GDP)
×CO_2 intensity (CO_2/Energy)

The success in mitigating CO_2 depends heavily on the twin efforts of maximizing the low carbon energy sources on the supply side and improving energy efficiency on the demand side. Hence, one method that will meet such synergetic requirements is the utilization of the high-efficiency heat pump which meets the demands that have up until now primarily been satisfied by fossil fuel combustion, which is now regarded as primitive by current technological standards.

Recent energy scenarios that depict the building of a low carbon society strongly believe that the role played via the dual application of energy-efficient technology on the demand side with low carbon power is the key to simultaneously solving existing energy and environmental problems, which are both sides of one coin.

The results of the cost-benefit analyses of various CO_2 mitigation measures, including McKinsey's GHG abatement cost curve and IEA's analysis, reveal that investing in end-use energy efficiency is less costly and is sometimes negative in cost compared with other new technologies on the supply side and renewable energies. Thus, the decisive conclusion reached regarding end-use energy efficiency, which includes heat pumps, is that it is the fastest, cleanest and cheapest energy resource currently available and the most effective short-term technological option to reduce GHG emissions in the world.

Current Situations of Heat Pumps in Japan

The Coefficient of Performance (COP) for residential air-conditioners in Japan has doubled in the past 10 years and now exceeds 6. This rapid improvement has established heat pumps as the most efficient in terms of low CO_2 emissions and cost per space heating equipment among other similar appliances in the market. Such an accomplishment was realized via the accumulation of incremental progress made in elemental technology stimulated by the regulation. The inverter-controlled air-conditioner also remarkably improves the efficiency of partial load operations.

The world's first CO_2 refrigerant air-source heat pump water heater named Eco Cute is expected to consume 30% less primary energy and reduce CO_2 emissions by 50% in comparison to a conventional combustion boiler. By 2010, a total of more than two million units of Eco Cute have come into use in Japan bolstered by strong government support.

Newly developed air-source heat pump water heaters for residential space heating that are designed to work efficiently under cold climate conditions are becoming commonplace as superior alternatives to conventional boilers in Europe and North America as these nations grapple with the influence of fuel prices, the quest for CO_2 reduction and the reconsideration of their dependence on foreign energy.

In industrial sectors, heat pumps are also being substituted for combustion steam boiler systems. Newly developed heat pumps efficiently supply hot water at 80 degrees Celsius or are used during the industrial drying process and steam generating operations.

The potentially achievable CO_2 reduction amount via heat pumps utilization in Japan totals 130 million tons per year, equivalent to about 10% of the nation's total CO_2 emissions at present. (Fig.1) This fact is a strong indicator that the widespread use of heat pumps from regional to global levels is a most feasible and effective measure to combat climate change.

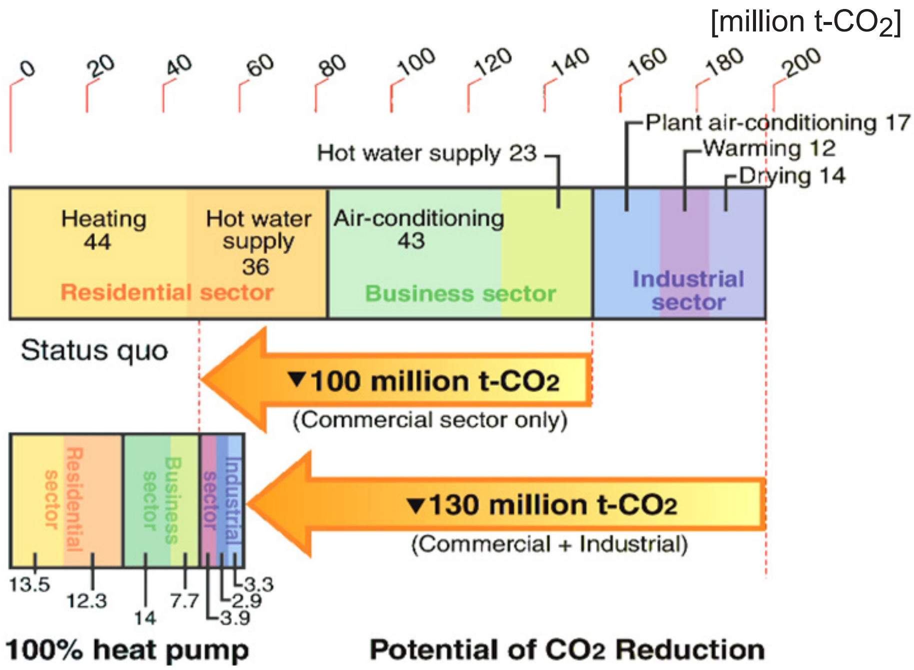

Figure 1: Potential of CO_2 reduction by Heat Pumps in Japan

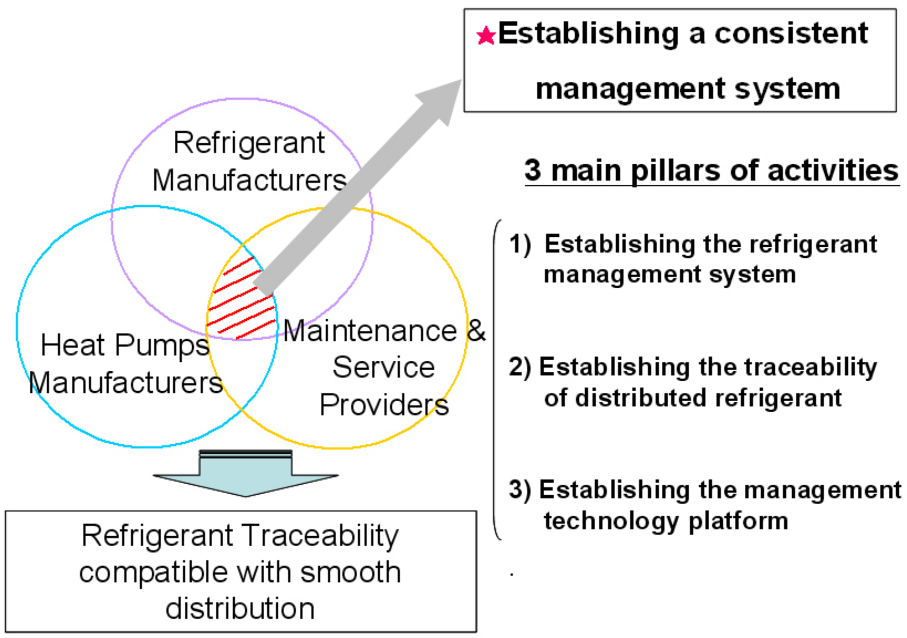

Figure 2: Concept of the Refrigerant Management System

Current Situations of Refrigerant in Japan

In compliance with the Montreal Protocol concerning the prevention of ozone depletion, Japan has made efforts to convert its refrigerant from CFC to HFC and now almost all new commercial air-conditioners are designed to use this refrigerant. Today, HFC is the most widely used refrigerant and is incorporated into every residential, commercial and industrial heat pump application in Japan. Admittedly, its considerable harmful contributions to global warming when directly exhausted into the atmosphere is unfortunate. However, the potential benefits of HFC far outweigh the disadvantages when properly managed.

In 2001 in Japan, the "Fluorocarbons Recovery and Destruction Law" for both the protection of the ozone layer and prevention of climate change was adopted. This law sets down the rules concerning the proper treatment of disposed commercial freezing and air-conditioning units, recovery of fluorocarbons, operator licenses, and the obligations of each participant which include users and owners of units, maintenance operators and contractors for specified demolition operations.

This law, however, lacks a set of comprehensive regulations governing the distributive flow of refrigerant from its production to its charging, maintenance, recovery and destruction when disposing of heat pump units. Since the processes of this flow are complicated and its participants are numerous, the challenge is how we can best create a consistent management system to govern this refrigerant.

Concept of Further Use of Refrigerant

JSRAE's fundamental position on refrigerant issues is to "Overcome the barriers that affect the dissemination of heat pumps." To realize this principle, we have two targets: "Establishing a Refrigerant Management System" and "Developing a low-GWP System."

HFC, which is highly efficient and widely applicable, shall and should be the indispensable major refrigerant for the mid term range. Therefore, we are pleased in making every effort to establish a refrigerant management system through the cooperation of manufacturers, installers and operators.

To minimize the enhanced global warming effects that result from using this refrigerant, the acceleration of R&D for low-GWP refrigerant and its heat pumps is required. In order to reach this target, we are presently developing natural refrigerants and new heat pump systems that suit low-GWP refrigerants.
Since the expectations towards heat pumps to become the indispensable and feasible answer to combat global warming is growing, it is incumbent upon us to proactively contribute to the development and dissemination of this technology in our society. Utilization of natural refrigerant (or a new low-GWP refrigerant) is one potential solution. However, from an engineering perspective, more time is needed in order to establish its market feasibility for general usage. Until then, we have to depend on HFC as the main pillar undergirding heat pump technology.

In dealing with this refrigerant, at present there are three layers of participants; refrigerant manufacturers, heat pump manufacturers and maintenance and service providers. The biggest problem with this structure is the lack of existing management consistency between them. Further, the most important problem that needs to be rectified in building the new management system is establishing an accurate method of the traceability of the distributed refrigerant.
The chart shows the target of the refrigerant management system that JSRAE are moving towards. (Fig.2) We are planning to establish a management organization which manages refrigerant flow consistently by implementing the following three main activities.

First, we must establish a refrigerant management system which not only operates consistently, but also allows for smooth commercial management of stock and flow of the refrigerant.
Second is securing the traceability of distributed refrigerant by a physical tracking method as it makes its way from point to point along its designated distribution route with ICT devices like IC Tags. One idea is to adopt a similar existing self-automated management system currently used in Japan by which the whereabouts of several industrial and medical gases contained in high pressure cylinders are meticulously auto-managed utilizing ICT devices.
Third is establishing a management technology platform, including the improvement of anti-leakage technologies and the establishment of an inspection and certification system.

Conclusions

Serious consideration regarding the possibility of both expanding HFC use and supporting environmental policies is well worth the effort.

There is no question that HFC is an indispensable refrigerant when it comes to the deployment of heat pumps. Further, for the mid-term, in terms of its dependability, no other refrigerant come close in effectiveness.

Hence, in order to establish HFC as a refrigerant that plays an important role in our society, we need a common roadmap that will bring all countries together to sustain, rather than phase-out, this precious resource.

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Development of a new 2.5 kW adsorption chiller for heat-driven cooling

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In addition to (better) utilisation of available solar heat or waste heat, and thereby reduction of fossil fuel consumption, sorption cooling offers several other advantages compared to conventional compression cooling: examples include reduction of summer peaks on the electricity grid, the use of natural refrigerants, and less noise & maintenance. Sorption cooling in itself is not a new development, but the development of small-scale sorption chillers (2-20 kW) is new. This development allows sorption cooling to enter the markets for individual homes, small collective systems and small commercial applications. A second trend is gradual reduction of the necessary driving temperatures of the sorption cycles, allowing more solar and waste heat to be used. This article describes the design and performance of a new, innovative 2.5 kW adsorption chiller, developed by ECN. ECN is currently searching for suitable commercial parties for production and commercialisation of this chiller.

Introduction

Sorption cooling is a technology that uses heat to generate cooling. Compared to conventional compression cooling, sorption cooling offers several advantages, e.g.:

- Using heat instead of electricity reduces peaks on the electricity grids in the summer.
- Many sorption cycles are based on natural refrigerants.
- Using thermal compression reduces noise levels and maintenance requirements.

In recent years, several companies have started development of small-capacity sorption chillers, with cooling powers below 20 kW, as was shown at the IEA Heat Pump Conference 2008 in Zürich. Some of these efforts have already led to commercial products. These new developments open up the market for thermally driven cooling in single-family homes and small commercial applications. A second trend is a gradual reduction of the driving temperatures of sorption cycles to well under 100 °C (typically 80-90 °C). This allows for an increase in the use of such heat sources as solar heat or industrial waste heat (via district heating systems).

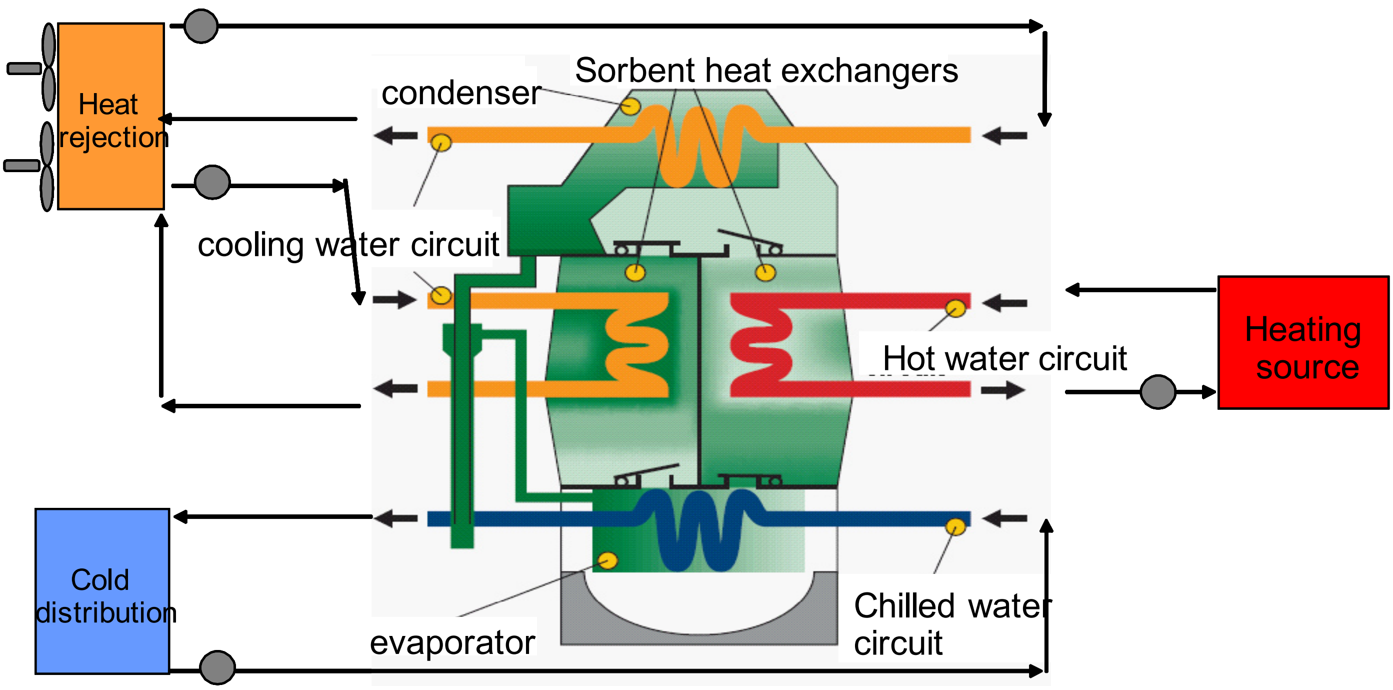

Figure 1: Schematic of adsorption chiller lay-out

Triggered by the national potential of waste heat (e.g. from industry) and renewable heat (e.g. from the sun), the Energy research Centre of the Netherlands (ECN) initiated development of sorption cooling technology several years ago. Silica gel – water were chosen as a working pair: a choice that has proven successful so far.

Working principle of adsorption cooling

Just like a conventional compression chiller, an adsorption chiller uses a cycle where a refrigerant condenses at high pressure/temperature and evaporates at low pressure/temperature. However, this cycle is not driven by a mechanical compressor but by a thermal compressor, based on the sorption reaction of silica gel and water, using heat as the driving force. Dry silica gel (a porous, glass-like solid) attracts and adsorbs water vapour until it is saturated, and must then to be regenerated. Heating the silica gel releases the water vapour at a pressure that allows it to condense at ambient temperatures, after which the cycle of adsorption and desorption can be repeated.

This cycle is not unlike absorption cycles (with e.g. LiBr-solution), but there are two important differences: 1. the silica gel can be regenerated efficiently at lower driving temperatures, and 2. the silica gel is a solid that cannot be pumped from generator to absorber. The silica gel is applied to the surfaces of heat exchangers, which are supplied intermittently with hot and cooling water. The adsorption cycle is therefore a batch process, and for quasi-continuous cooling at least two silica gel beds (reactors) are needed, operating in counter-phase.

The lowest possible chilled water temperature of this adsorption cycle is about 4 °C, making it perfectly suited for air-conditioning and chilled water systems in the built environment and in industry.

Design of a 2.5 kW adsorption chiller

As part of the European PolySMART project (www.polysmart.org), ECN has developed a small-scale adsorption chiller using silica gel - water as working pair, which will be tested and demonstrated. The starting point for this chiller is to supply sufficient cooling power (2.5 kW) for a modern single-family house. A common (challenging!) standard for household appliances is used to determine the physical size limits: a 60 x 60 cm footprint, and a height of about 100 cm.

Compact light-weight aluminium heat exchangers from the automotive industry have been used to carry the silica gel, creating a large surface while maintaining low weight and volume. For the same reason, this type of heat exchanger has also been used for the condenser and for the evaporator. Figure 2 shows the layout of the new chiller: the evaporator at the bottom, two silica gel reactors above the evaporator, and the condenser on top.

Water vapour flows at low pressure from the evaporator (creating a cooling effect) and is adsorbed in one of the two silica gel reactors (adsorption phase). At the same time, water vapour flows from the other reactor to the condenser (desorption phase) at a higher pressure. Special check valves have been placed between these components to prevent the water vapour from flowing back. This (low pressure) process requires that the system does not contain any gases or vapours other than water vapour, and that all components are hermetically sealed. The water from the condenser flows back to the evaporator via a condensate return line. The flow for heating and cooling of the silica gel is controlled by eight valves, which intermittently supply both reactors. A PLC unit is included in the chiller to control these valves and to monitor temperatures and pressures.

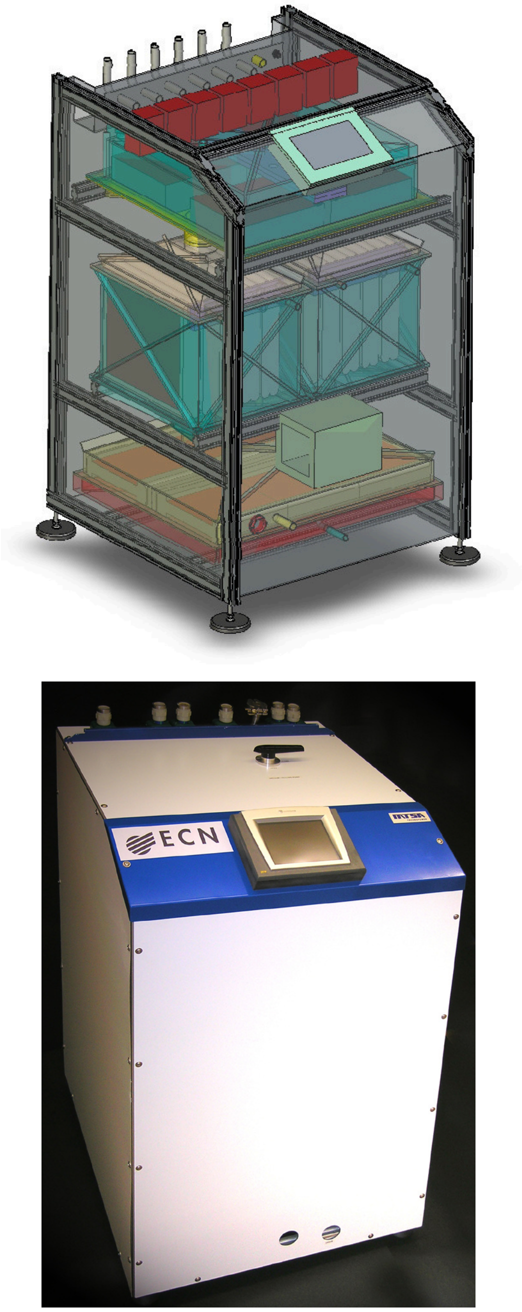

Figure 2: Design drawing and picture of the ECN 2.5 kW adsorption chiller

Adsorption chiller performance

The adsorption chiller has been tested in an ECN laboratory, with the facilities to control flows and temperatures for hot, cooling and chilled water. Hot, cooling and chilled water temperatures strongly influence the chillers' performance. The following inlet temperatures are used as nominal operating conditions: 80 °C, 30 °

and 15 °C respectively. The influence of cycle time on thermal performance has been determined for these operating conditions. The cycle time is the duration of a complete cycle of heating up and cooling down of one reactor. Figure 3 shows the cooling power (left axis) and Coefficient of Performance (right axis, ratio of cooling power and driving heat). For this application, the coefficient of Performance is defined as:

$$COP = \frac{Q_{evaporator}}{Q_{heatsource}}$$

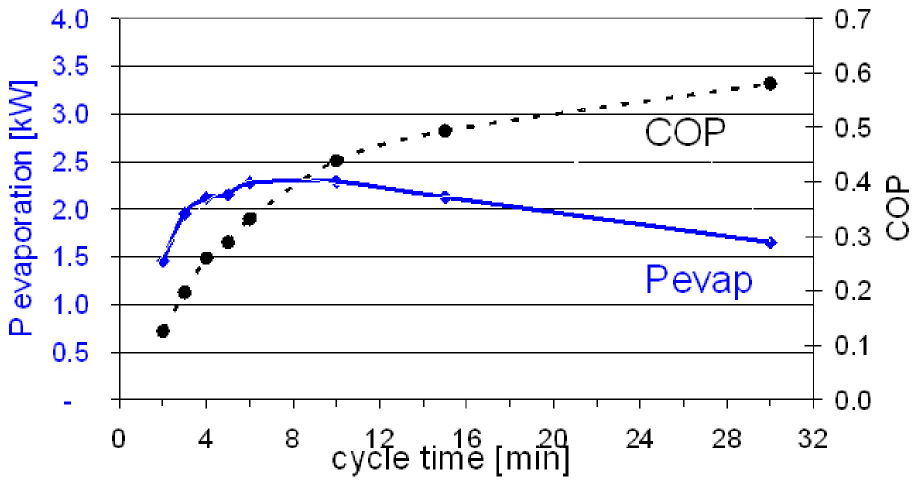

Figure 3: Influence of cycle time on thermal performance of the adsorption chiller

Figure 3 shows that cycle times under six minutes are not useful, because both cooling power and COP show a decrease (because this short cycle time does not allow all the silica gel to go through the complete temperature cycle). With increasing cycle times (>10 minutes), a decrease in cooling power is compensated for by an increase in efficiency (because fewer changes between heating and cooling of a reactor mean less thermal losses).

Figure 4 shows the influence of the cooling water and chilled water inlet temperature on the chiller's performance. Chiller performance clearly benefits from "high-temperature cooling" and relatively low cooling water temperatures. When designing a complete (solar) cooling system, these aspects must be taken into consideration.

The laboratory tests show that the ambitious design specifications for this prototype have been achieved. Nearly 2.5 kW cooling power can be produced with a very compact chiller (power density of about 7 kW/m3) at a very respectable COP.

Outlook

This 2.5 kW chiller has recently been installed in one of the research houses at the ECN premises in Petten, The Netherlands. These research houses are not inhabited, but nearly

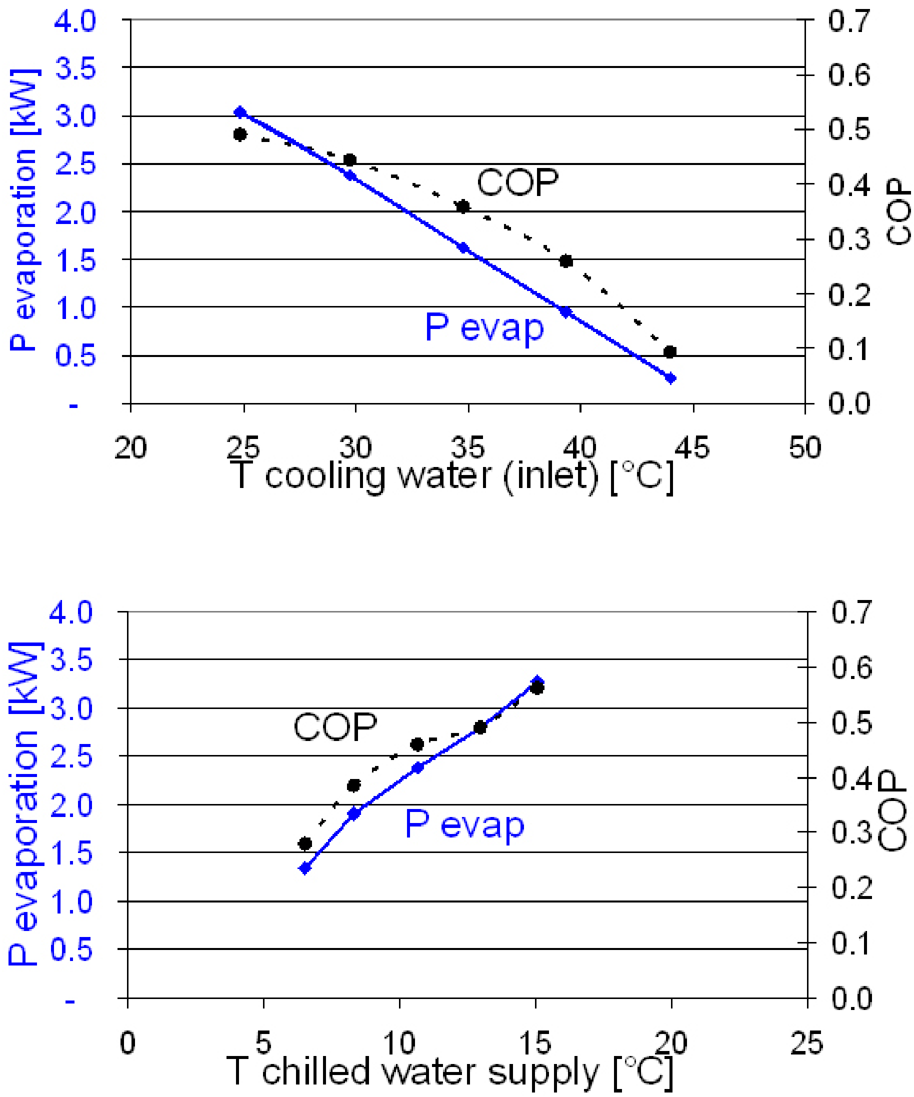

Figure 4: Influence of cooling water (top) and chilled water (bottom) inlet temperature

all aspects of user behaviour are simulated (such as domestic hot water use, internal heat production, and humidity and CO_2 production), offering a realistic but controlled test environment.

Within the framework of the PolySMART project, this chiller will be driven by a small cogeneration unit (micro-CHP), creating a unique micro-trigeneration system. A standard dry cooler is used for heat rejection. This configuration will be tested until the summer of 2010, after which the intention is to create a follow-up demo project with a solar cooling configuration. The thermal power of this chiller fits well with Stirling-based micro-CHP (or small-scale solar collector systems) for individual residences. When applied in combination with measures to reduce "overheating" in summer (e.g. solar shading, night ventilation), it is expected that 2.5 kW cooling will be sufficient to provide a comfortable indoor temperature, especially if this cooling power can be used completely, when necessary, to tackle a commonly reported comfort problem (in Dutch residences): that of overheating of bedrooms.

Development of the 2.5 kW sorption chiller continues in parallel with this field test, with the aim of turning it into a commercial product. Current emphasis is on redesign for manufacturability. ECN is currently looking for interested and suitable commercial companies for both production and commercialisation, to form a consortium that will transform the current prototype into a commercial product.

Energy Policies of IEA Countries - Italy 2009 Review

The Italian government has made substantial progress in a number of sectors since the last IEA in-depth energy policy review in 2003. The success of the green certificate and white certificate schemes, and continued reform of the electricity and natural gas supply markets, are just a few examples and build on the recommendations contained in the previous review. Nonetheless, many challenges remain. This review analyses the energy challenges facing Italy, and provides sectoral critiques and recommendations for further policy improvements.
Source: http://www.iea.org/w/bookshop/add.aspx?id=385

Energy Policies of IEA Countries - Canada 2009 Review

Canada, with its diverse and balanced portfolio of energy resources, is one of the largest producers and exporters of energy among IEA member countries. The energy sector plays an increasingly important role for the Canadian economy and for global energy security, as its abundant resource base has the potential to deliver even greater volumes of energy. This review analyses the energy challenges facing Canada and provides sectoral critiques and recommendations for further policy improvements.
Source: http://www.iea.org/w/bookshop/add.aspx?id=395

CO_2 Emissions from Fuel Combustion 2009

In recognition of fundamental changes in the way governments approach energy-related environmental issues, the IEA has prepared this publication on CO_2 emissions from fuel combustion. The data in the book are designed to assist in understanding the evolution of CO_2 emissions from 1971 to 2007 for more than 140 countries and regions by sector and by fuel. Emissions were calculated using IEA energy databases, and the default methods and emission factors from the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.
Source: http://www.iea.org/w/bookshop/add.aspx?id=36

Projected Costs Of Generating Electricity - 2010 Edition

This joint report by the International Energy Agency (IEA) and the OECD Nuclear Energy Agency (NEA) presents the latest data available for a wide variety of fuels and technologies, including coal and gas (with and without carbon capture), nuclear, hydro, onshore and offshore wind, biomass, solar, wave and tidal as well as combined heat and power (CHP). It provides levelised costs of electricity (LCOE) per MWh for almost 200 plants, based on data covering 21 countries (including four major non-OECD countries), and several industrial companies and organisations. The study shows that the cost competitiveness of electricity generating technologies depends on a number of factors which may vary nationally and regionally.
Source: http://www.iea.org/w/bookshop/add.aspx?id=403

2010

9-12 May
Clima 2010
Antalya, Turkey
www.clima2010.org/default.asp

10 – 12 May
Energy Efficiency Global Forum and Exposition (EE Global) 2010
Washington, D.C., USA
http://eeglobalforum.org/

16-19 May
ASME-ATI-UIT 2010 Conference on Thermal and Environmental Issues in Energy Systems
Sorrento, Italy
http://www.ichmt.org/asme-ati-uit-10/

19-20 May
6th International Geothermal Conference
Freiburg, Germany
http://www.egec.org/index.html

25-26 May
18th National Conference on Building Commissioning
Chicago, Illinois, USA
http://www.peci.org/ncbc/2010/index.html

7-9 June
ACRA 2010, The 5th Asian Conference on Refrigeration and Air-Conditioning
Tokyo, Japan
http://www.jsrae.or.jp/acra2010/index.html

8-10 June
Renewable Energy World Europe 2010
Amsterdam, the Netherlands
http://ree09.events.pennnet.com/fl//index.cfm

8-10 June
IEPEC - Counting on energy efficiency - It's why evaluation matters!
Paris, France
http://www.iepec.org/

13-16 June
Sustainable Refrigeration and Heat Pump Technology
Stockholm, Sweden
http://www.sustainablerefrigeration.org

14-17 June
23rd International Conference on Efficiency, Cost, Optimization, Simulation & Environmental Impact Of Energy Systems (ECOS2010)
Lausanne, Switzerland
http://www.ecos2010.ch

26-30 June
ASHRAE 2010 Annual Conference
Albuquerque, New Mexico, USA
http://www.ashrae.org

10-15 July
Purdue Compressor Engineering and Refrigeration and Air Conditioning Conferences and Short Courses
West Lafayette, USA
https://engineering.purdue.edu/Herrick/Events

12-15 July
20th International Compressor Engineering Conference at Purdue
IIR-co-sponsored, Commissions B1, B2, E1
West Lafayette, USA
https://engineering.purdue.edu/Herrick/Events

19-21 July
7th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics (HEFAT2010)
Antalya, Turkey
http://www.hefat.net

In the next Issue

Retrofit heat pumps for buildings

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International Energy Agency

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

IEA Heat Pump Programme

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

Vision

The Programme is the foremost 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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