IEA Heat Pump CENTRE
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Ground Source Heat Pumps

Improvements of large institutional ground-source heat pump systems

Installing Heat Pumps to Reduce Energy Consumption

GSHP in Japan

New member country

IEA
OECD
heat pump centre

IEA **Heat Pump** CENTRE
NEWSLETTER

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In this issue

COLOPHON

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In this issue

Ground-Source Heat Pumps (GSHP) utilise the most stable heat source of all heat pumps, but are relatively costly to install. Overcoming barriers to a wider uptake of GSHP thus requires lower first costs, in the form of cheaper boreholes and improved installation procedures. The interest in GSHP is therefore very strong, as the articles in this issue show.

Roger Nordman
Editor, HPC Newsletter

Heat pump news

Features

Topical article

Non-Topical article

Foreword

An important contribution of the GSHP system to the environment and our life in Japan

Katsunori Nagano, Hokkaido University, Japan

Japan has ratified the Kyoto protocol in 2005. The rates of greenhouse gas emissions reduction relative to 1990 to be achieved during the first commitment period were set at 6 % for Japan. However, the amount of greenhouse gas emissions in 2007 increased by 8.7 % relative to the 1990 figure, which means that Japan has to achieve a 14 % reduction by 2012. In particular, energy consumption in the consumer sector (which accounts for 27 % of total energy consumption in Japan) has been steadily increasing, so that it was 36 % higher in 2006 than in 1990. The amount of CO_2 emissions per Japanese citizen is 4.7 t- CO_2 in 2005. Although this is still approximately 20 % less than the average among OECD countries, we have to promote the introduction of high-efficiency systems and modify building thermal performances, in addition to using renewable energy sources and waste heat sources.

It is clear that utilizing a high-efficiency heat pump system is the most reliable and realistic way of reducing energy consumption for HVAC and hot water supply. At the same time, high-efficiency heat pumps and thermal energy storage (TES) systems are very useful and very effective for improving the balance of heat demand and heat sources, smoothing out heat demand over the day and night and reducing machine size. Although the heat pump technology is rather traditional, effort is needed in order to inform users that the efficiency of the modern heat pumps is becoming much higher, and that there must be a drastic increase in the used of renewable energy sources and waste heat sources in order to reduce CO_2 emissions and running costs. The heat pump and thermal storage technology centre of Japan has reported that if the total demand for heating, cooling, air conditioning and hot water supply in Japan was covered by the current high-efficiency heat pump systems, there would an estimated reduction of 0.985 million t–CO_2 [1] in CO_2 emissions: almost equivalent to the 1.18 million t– CO_2 which is the Japanese target for CO_2 reduction under the country's Kyoto protocol commitments decided in 2005.

The Japanese government has two policies for the reduction of CO_2 emissions through the use of heat pump systems. One is the "New Energy" policy and the other is the "Energy Conservation" policy. The new energy policy sees the use of river water, sea water or treated/untreated sewage water as heat sources and heat sinks for heat pump systems. The energy conservation policy, on the other hand, uses groundwater, geothermal energy and thermal energy in the ground, extracted by a ground heat exchanger (the author refers to them as ground thermal energy systems [GTES]). The Ministry of Economy, Trade and Industry of Japan (METI) has applied some policy measures to promote GTES according to the second policies. In addition, the Ministry of the Environment (MOE) has its own measures for the reduction of CO_2 emissions and reduction of heat island phenomena through the GTES.

The use of ground thermal energy has been gradually recognized as a green energy source, and it has been realized that the GTES, including ground-coupled heat pump systems, has a considerable potential for reducing CO_2 emissions, although the GSHP market in Japan is still tiny. This wave has occurred from the north, but now is spreading to the whole of Japan. For example, GSHPs have been included in the DHC system of "Tokyo Sky Tree" area shown in February [2].

Current technologies related to GTES in Japan are almost equivalent, and the costs of construction and the heat pump unit are getting closer to those in GSHP's advanced countries. In addition, we have a substantial advantage in the availability of reasonable electricity tariffs for GSHP systems. This has meant that GSHP systems have already become one of a few economically realistic green technologies. The author believes that the biggest market barrier is just the lack of the recognition of GSHP systems now in Japan. With greater awareness of such systems, and a track record of successful installations and use, take-up of GSHP systems should spread quickly and a strong contribution to the environment and our life will emerge.

[1] http://www.hptcj.or.jp/about_e/index.html
[2] "Tokyo Sky Tree" is a TV tower for digital broadcasting with a height of about 610 m. The tower is expected to be completed in 2011 and will be one of the world's tallest. http://www.tokyo-skytree.jp/english/
http://www.rising-east.jp/news/pdf/090217.pdf

Column

Increasing deployment of heat pumps

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What industry and government have in common, and what industry expects from government in order to increase the deployment of heat pumps, especially GSHPs

Generally speaking – and not only for Switzerland - industry and administration have a common interest in increasing the use of renewable energy in the heating sector. For industry, there are many suitable heating systems - and not just heat pumps - for the different needs of different climates, buildings, consumer's needs. Seeing heat pumps as a leading product is not as obvious as it might seem for a company in the heating market. The ranking of products for large companies is determined mainly by economic considerations, consumers' needs, and the legal framework too.

The administrative side can influence the market through its actions, which can be divided into two main categories: enforcement and motivation.

To the enforcement group belong:
- laws that prescribe or ban systems
- regulations on values for buildings and/or consumption
- regulations on heating systems (type, performance)
- subsidies of any kind (one-way financial help, loans, taxes on undesirable systems or materials

To the motivation group belong:
- A favourable framework, e.g. harmonized and easy procedures for installation of heat pumps, especially when using heat from the ground
- Financing or supporting or encouraging information and advice to potential customers and professionals
- The same for the training of installers and engineers
- Setting a comprehensive quality system with clear labelling or certification schemes.
- Encouraging research & development of the technology.

These two groups of actions may be combined. But the best ways of increasing deployment differ, depending on whether the heat pump is an emerging application, a mature application, or is established on the market. The role of the state must respond to the maturity of the market if it is to be successful. The key issue is the ability of the state to adjust to the changing needs of the market's players.

Industry needs clear statements from the state at any stage of the market's development. These must remain the same over many years. Stop-and-go actions, such as subsidies in an electoral year, are politically attractive but the effect on the market is slight and might even be negative. Statements on heat pumps must be simple and clear. The position of the technology in the political strategy of the state should be clear. The role of the technology in policy must be defined and communicated, unconditionally and without disturbing comparison with other systems.

Ground-source heat pumps are still not always well accepted by the environment ministries of the HPP-countries. Well-intentioned overprotection can hinder their deployment. The use of geothermal energy must be achieved with respect of the environment. Poor experience has a strong impact on the behaviour of the authorities, so industry must demonstrate high quality standards and skills of the drilling contractors to build up confidence. Negotiation of simple procedures for authorization and controls can only become reality with a reliable partner. Successful collaboration between state and industry is based on confidence.

Industry can play an active role to help energy and environment ministries to increase the deployment of GSHPs, especially through a national or international association.

General

We welcome Finland as a member of the HPP!

Finland has now joined the Heat Pump Programme and we are glad to welcome them as our newest member. The picture shows HPP ExCo Chairman Dr Sophie Hosatte, the Finnish representatives Dr Arto Kotipelto and Mr Jussi Hirvonen, and the HPC Manager Dr Monica Axell.
In a forthcoming issue of the newsletter, an interview with one of the Finnish delegates will be presented.

German agency predicts 'green power' surge

Wind, biomass, water, solar and geothermal energies will together represent a 47 % share of Germany's total electricity supply by 2020, according to the country's renewable energy agency. The amount of electricity produced from renewable sources will grow three-fold in the next decade, according to a study predicting the industry's development presented 28 January by the German Renewable Energy Federation (BEE) and the Renewable Energies Agency.

The industry says renewables can provide a secure power source even at times of peak demand, allowing Germany to avoid having to import additional natural gas and even to diminish its use for electricity generation by up to 12 %. This could save the country €22.6 billion in 2020 alone, it says.

Moreover, developing green electricity will have a wider positive impact on the economy, the study argues. It estimates that the number of jobs in the renewables sectors in Germany will double to 500 000 by 2020, while society will simultaneously avoid having to spend millions recovering from climate-related damage. The overall savings resulting from greater renewables capacity will thus far exceed the investment needed to build the additional production capacity, the report concludes.

EPEE supports new EU demands

On April 23. the European Parliament supported an ambitious revision of the law on energy performance of buildings. This revised law has a real impact on building design and consumer awareness of efficiency of buildings, and pushes for more uniform rules across the EU so that real comparisons can be made.

EPEE, the voice of the heating, cooling and refrigeration industry in Europe, welcomes the strong stance taken by the Parliament, which is critical for the environment when it is realised that buildings account for 40 % of EU energy consumption.

The introduction of a common calculation and assessment methodology for the energy performance of buildings should make it easier to calculate the performance of different buildings in different climatic zones.

The Parliament also makes a strong case for increased use of efficient renewable technologies, such as heat pumps. This will also be a powerful contributor towards the European renewable energy use targets of 20 % by 2020.

Friedrich Busch, Director-General of EPEE, commented "This vote by the European Parliament is a clear indication of the political willingness in the EU to achieve its efficiency targets and increased use of renewable technologies such as heat pumps. We hope that national governments will follow the lead set by the European Parliament".

It is hoped that the revised law will be finalised by the end of the year.
Source: ScanRef Newsletter

EU Parliament paves way for wider eco-design product list

On 17 February, MEPs backed European Commission proposals to extend the scope of the Eco-design Directive and the Ecolabel, but rejected proposals to include food products in the plans.

The European Parliament's environment committee voted on a report to cover all products with an impact on energy use, such as windows, insulation materials and water-using devices, in the EU's Eco-design Directive. Currently, only devices that directly use energy are part of the scheme.

However, MEPs rejected a proposal from the rapporteur, Romanian MEP Magor Imre Csibi (ALDE), to go as far as including all products except means of transport. This would have effectively mandated the Commission to set minimum energy requirements for food and clothes, for example.

The committee consequently requested the Commission to come up with a proposal by 2012, extending the scope only to "non-energy-related products" with "significant potential for reducing their environmental impacts throughout their whole life cycle".

Backing on traditional light bulb ban

At the same time, MEPs also voted on whether to block the Commission's implementing measure to phase out incandescent and inefficient halogen light bulbs by 2012. The EU executive proposed the measure under the Eco-design Directive in December 2008. German MEPs Holger Krahmer (ALDE) and Anja Weisgerber (EPP-ED) had drafted a resolution arguing that the regulatory committee's procedure, which excludes Parliament from decision-making, was not justified for the banning of a product such as light bulbs. An overwhelming majority of MEPs nevertheless voted against it, effectively endorsing the Commission's proposal.

Cutting red tape on Ecolabel scheme

MEPs also backed the Commission's proposal of July 2008 to make the voluntary EU Ecolabel less bureaucratic and less expensive. The Parliament wants to ensure that the Commission and member states provide proper funding for awareness-raising campaigns, and that particularly small and medium-sized enterprises have better access to the flower label.

Although the Committee voted in favour of bringing new goods within the scope of the directive, which currently covers more than 3000 products, such as detergents and paper, it decided to omit processed food and products containing dangerous chemicals.
Source: Euroactiv newsletter

President Obama orders swift action on appliance efficiency standards

President Barack Obama issued a memorandum that instructs DOE to take all necessary steps to finalize new appliance efficiency standards as quickly as possible. As noted by the president, the Energy Policy and Conservation Act of 1975 (EPCA) set certain deadlines for DOE to set energy efficiency standards for a broad class of residential and commercial products, and in 2005 DOE was sued for allegedly failing to meet the deadlines and other requirements of the EPCA. In November 2006, DOE entered a consent decree, under which DOE agreed to publish the final rules for 22 product categories by specific deadlines, the latest of which is June 30, 2011. In addition, the Energy Independence and Security Act of 2007 (EISA) directed DOE to establish energy standards for additional product categories.

President Barack Obama has directed DOE to expedite its energy efficiency standards for appliances. Credit: DOE

Although DOE has made progress on meeting its consent decree, the agency remains subject to deadlines on 15 of the 22 product categories, as well as a number of additional product categories added by the EISA. President Obama directed DOE to focus its efforts on the five energy efficiency rules with deadlines prior to August 8, and then to prioritise its efforts, tackling first the standards that will result in the greatest savings, while still meeting all applicable deadlines. The president announced the new memorandum on a visit to DOE, during which he spoke primarily about his economic stimulus plan. Regarding the efficiency standards, he noted that they will avoid the use of "tremendous amounts" of energy. "We'll save through these simple steps, over the next thirty years, the amount of energy produced over a two-year period by all the coal-fired power plants in America," said the president.
Source: EERE Network News

Working Fluids

US draft Act maintains HFC phase down

The draft American Clean Energy and security Act 2009 maintains that all HFCs, including 134a, 32 and HFO-1234yf, will be scheduled for tighter production, exports/imports controls as well as a gradual phase-down to 15 % of current levels by 2038. Additional energy efficiency measures may enhance uptake of natural refrigerants such as hydrocarbons.

Presented recently by the US House Energy and Commerce Committee, the draft American Clean Energy and Security Act 2009 is the first set of concrete nationwide measures to help the US position as a key world player in fighting climate change. Though weak, it does include provisions regarding the phase-down of HFCs.

According to the draft Act, the regulation and phase-down of all HFCs would now fall under the scope of the US Environmental Protection Agency (EPA), in the same way as the case of substances that deplete the ozone layer.

All HFCs, including 134a, 32 and HFO-1234yf, will now be treated as Class II, Group II substances, which are scheduled for a gradual phase-down, tighter production and exports/imports controls. More specifically, as of 1 January 2012, it will be forbidden to produce, export or import any Class II, Group II substance without holding one consumption allowance unit or offset credit for every CO_2 equivalent tonne of the substance. The base line reduction percentage will be calculated on the basis of calendar years 2004, 2005 and 2006 consumption and import averages. According to the phase-down schedule, about half of the amount

of such substances compared to the base line levels will be allowed in 2027, while eventually only 15 % of base line level will be allowed for consumption in 2038.
Source: www.hydrocarbons21.com

First B2B platform for ammonia sees the light

The world's first online platform exclusively to promote the natural refrigerant ammonia (R717) is available at www.ammonia21.com. The website will offer daily news, products and knowledge for the industry, as well as raise awareness of its benefits worldwide.
Source: www.ammonia21.com

US may propose HFC phase-out through Montreal Protocol

The US administration is seriously considering proposing an amendment to the Montreal Protocol to include the phase-out of HFCs, reports the Associated Press, and cites natural refrigerants as a viable alternative. An EPA spokeswoman has called this potential proposal the administration's "preferred option".

News released by the Associated Press (AP) state that the Obama administration, in a major environmental policy shift, is leaning toward asking 195 nations that ratified the U.N. Montreal Protocol ozone treaty also to enact mandatory reductions in hydrofluorocarbons. This option would expand the scope of the ozone treaty to cover global warming concerns as well. An EPA technical expert said that the Montreal Protocol created virtually the entire market for hydrofluorocarbons and, therefore, including them in the treaty would resolve a problem of its own making.

AP reports that scientists say that eliminating the use of HFCs would spare the world an amount of greenhouse gases up to about a third of all CO2 emissions about two to four decades from now. Manufacturers in Europe and the U.S. have begun to replace HFCs with natural refrigerants such as ammonia, hydrocarbons or carbon dioxide.

Although a final decision is still pending, Environmental Protection Agency spokeswoman Adora Andy described the inclusion of HFC mandatory cuts within the scope of the Montreal Protocol as the Obama administration's preferred option.

While the US is considering putting forward such a proposal, two island nations, namely the Federated States of Micronesia and Mauritius, did actually file a proposed amendment to regulate HFCs under the Montreal Protocol Ozone Treaty on 30 April, urging the 195 nations that signed the U.N. Ozone Treaty to reduce consumption of HFCs by 90 % by 2030.
Source: www.ammonia21.com & www.hydrocarbons21.com

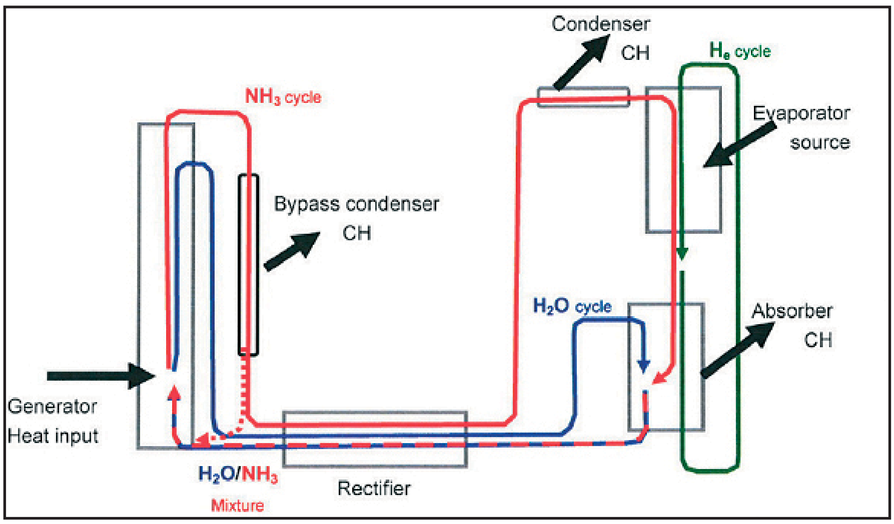
Technology

Online tool evaluates free cooling for data centres

The Green Grid has released an online tool for data centres to determine how much free cooling and free evaporative cooling is available to augment their traditional air-conditioning systems. The tool allows users in the United States and Canada to input specific variables such as local energy costs, IT load and facility load to determine the energy savings for individual facilities. http://cooling.thegreengrid.org/calc_index.html
Source: The HVAC&R Industry newsletter

New generation of gas heat pumps

The new generation of gas heat pumps from Bosch Thermotechnology has been awarded the IGU Gas Efficiency Award 2008 thanks to their trendsetting technology with extremely high potential for energy savings. In modulated operation (4-10 kW), the awarded gas heat pumps (GHP) control heating and domestic hot water heating, including the large heating burden in the area of one/two-family houses. Compared to condensing boilers, it saves around 20 % in gas, and investment costs are lower. It works according to a diffusion-absorption principle. An ammonia-water mix as a processing substance is used as a carrier gas. The circuits inside the heat pumps set themselves in motion when heat is applied. That means that the GHP does not need moving parts such as compressors and is therefore silent, with low maintenance costs. The feasibility studies have been completed, and the pump is now starting to be developed as a mass-produced product.
Source: energy-server Newslette, Issue 100



Markets

IIAR partners with Global Alliance

The International Institute of Ammonia Refrigeration has formed a partnership with the Global Cold Chain Alliance “designed to enhance IIAR’s ability to be the world’s leading technical resource and advocate for the safe, reliable and efficient use of natural refrigerants for industrial applications,” according to officials involved in developing the accord.
A Memorandum of Understanding was signed during the recent IIAR Annual Conference and Exhibition in Dallas.
GCCA was described as “an umbrella organization that unites partners to be innovative leaders in the temperature-controlled products industry.”
IIAR President Bruce Badger said the alliance was particularly beneficial to end users. “The partnership with GCCA is a way for the end users of the cold storage warehouse community to get closer to the technical expertise of the IIAR. Conversely, it enables IIAR members to get closer to more end users. ”
Source: www.iiar.org

AHRI announces implementation schedule for transitioning to new mark

The Air-Conditioning, Heating, and Refrigeration Institute announced today that it will begin using a new unified mark to identify heating, ventilation, air conditioning and commercial refrigeration products that have achieved third-party certification of their performance ratings. The new mark will replace the ARI Performance Certified, GAMA Efficiency Rating Certified and I=B=R marks, but these changes will be made over an implementation period that provides enough time to bring all certification programs into compliance with internationally recognized accreditations.
Contact: Colleen Hughes, chughes@ahrinet.org
Source: AHRI News

No crisis for high technology

Aluminium heat exchanger growth in HVACR, predicted for 15 %, was almost fulfilled in the first quarter of 2009, despite the downturn in total heat exchanger sales. The use of copper declined, while that of aluminium grew substantially. This gives good hope for the rest of 2009. Since January 2009, LME copper price has risen by 40 % while LME aluminium fell by 10 %
Source: International. Association for Aluminium Technology in Air conditioning & Refrigeration related Industry

Stimulus Act expands clean energy tax credits for homes and businesses

The American Recovery and Reinvestment Act of 2009 provides greater tax credits for clean energy projects at homes and businesses and for the manufacturers of clean energy technologies. For homeowners, the act increases a 10 % tax credit for energy efficiency improvements to a 30 % tax credit, eliminates caps for specific improvements (such as windows and furnaces), and instead establishes an aggregate cap of $ 1500 for all improvements placed in service in 2009 and 2010 (except biomass systems, which must be placed in service after the act is enacted). The act also tightens the energy efficiency requirements to meet current standards. For residential renewable energy systems, the act removes all caps on the tax credits, which equal 30 % of the cost of qualified solar energy systems, geothermal heat pumps, small wind turbines, and fuel cell systems. The act also eliminates a reduction in credits for installations with subsidized financing.
Source: EERE Network News

Heat pump market growing fast

The worldwide market for heat pumps is growing fast, new research by BSRIA shows. European and national legislation that promotes renewable energy, coupled with regulation for energy-efficient buildings and financial incentives, have continued to be the main drivers of the heat pump growth.

The growth of the heat pump market comes against a backdrop of sluggish or negative growth of the market for conventional heating products such as boilers. The French heat pump market alone increased by 30 % in 2007, with generous tax credits being the main driver.

Overall, ground/water to water heat pumps systems dominate the global heat pump market. The air-to-water type holds the largest share in France, Japan, Switzerland and Norway. Despite ground/water to water heat pump holding the largest share of the German market, in fact, growth was mainly driven by air-to-water heat pumps, accounting for 16 % growth, whilst ground source and water-to-water heat pump sales decreased by 6 %.

Indoor air to water cylinder-integrated heat pump water heaters remain a relatively small market. Their largest share, by volume, is in China, with 64 400 units sold in 2007. Small domestic heat pumps less than 5 kW is the most popular system type in this segment. Compared with other water heaters, high prices and low levels of customer awareness prevent the indoor-air-sourced heat pumps moving away from anything but a niche market in China. In Slovenia, this type of system is preferred to ground/water to water or air-to-water heat pumps.

Despite its double-digit growth in 2006, the German heat pump market experienced only a small increase in 2007 in the region of 1.5 %. However, since the conventional heat generator market such as gas, oil and solid fuel boilers dropped drastically by 25 % in 2007, heat pumps continue to gain market share in an overall deteriorating market and are expected to see healthy growth of 9-10 % in 2008.

Stemming from their growing popularity, several new players have entered the market. Previously, in many countries, it was mainly specialist companies that offered heat pumps. In Germany, some large air conditioning suppliers have started to offer inverter-controlled air-to-water heat pumps for space heating and hot water heating.

The UK’s small heat pump market

grew sharply, with sales of around 3000 units in 2007. Rising energy prices are said to be the main reason of this growth. Ground/water source heat pumps continue to be the global market leader, as they are supported by government grants, although air-to-water heat pumps have for the first time been approved for £ 900 subsidy for the last quarter of 2008.

Switzerland maintains its position as one of the most developed heat pump markets in Europe with a high penetration rate. The market has been growing continuously since the 1990s, with an average yearly growth of 13 %.

BSRIA predicts the period from 2008 and up to 2010 will see a sustained growth of renewable technologies, particularly in Western Europe, Japan and China. While energy scarcity is becoming an issue in several countries, other factors such as changes in building regulations and legislation that aims to reduce greenhouse gases will play a major role in shifting the focus towards adopting energy-efficient products in both the residential and commercial sector. Although financial subsidies remain limited to very few markets, they have proved to be very effective in promoting the take-up of renewables. In France, for example, tax credits of 50 % have led to all boiler and air conditioning manufacturers supplying heat pumps. However, suppliers will increasingly face ever-changing technical and legal requirements before their products can be distributed or approved for subsidies.

As fossil fuel prices are expected to remain at high levels in the years to come, an increasing number of countries around the world are showing greater interest in electricity power generation projects from a mix of renewables sources. While wind turbines projects are attracting most funding, together with solar thermal and biomass CHP plants, upgrading or constructing new nuclear power stations is seen by many governments as a way of safeguarding energy security in the future.

In global terms, sales to installers are the leading distribution channel, followed by wholesalers. In the Netherlands, sales to installers account for 84 % of the market. The Japanese market is dominated by direct sales to end users through retail shops. The residential new build sector is the driving factor of the global heat pump market. However, the first-time installation sector leads the way in the Japanese market, and is a close second in the Norwegian market. Heat pumps for residential applications are mainly used for providing space heating. In contrast, in Japan, China, Slovenia and the US, heat pumps are predominantly used for water heating only.
Source: www.bsria.co.uk

IEA HPP

Annex 29: Ground-Source Heat Pumps –Overcoming Market and Technical Barriers

Final Report, Spring 2009
Annex 29 is investigating the present status of ground-source heat pump systems (GSHP), which varies widely all over the world, and identifying systems – depending on climate and application – that could improve the performance and market attractiveness of ground-source heat pump systems. The objective is to demonstrate the economic and environmental benefits of ground-coupled heat pump systems.

The final step in the work of Annex 29 was overcoming economic barriers. Economic barriers are based mainly on lack of awareness of this highly efficient technology, an inadequate infrastructure and - for the consumer - the high first cost. To overcome these barriers it is important to reduce first-cost barriers by lowering maintenance costs, by using life cycle analysis, and by moving along the learning curve of ground source technology. Different contracting models can be used in this context, covering the ground heat source/heat sink system, the total heating system or the total heat generation system (as in the case of district heating systems). Examples are Loop Leasing, Chauffage, Integrated Community Systems, Loop Guarantee and Performance Contracting.

The final report of Annex 29 will be presented at the next ExCo Meeting in Amersfoort, Netherlands, May 2009.

IEA HPP Annex 30 Retrofit Heat Pumps for Buildings

From the beginning of the International Energy Agency's (IEA) Heat Pump Programme (HPP) the markets in most of the member countries have been mainly concerned with the development and application of heat pumps for new buildings. Recognising the potential of the retrofit market, the IEA-HPP initiated Annex 30, an international collaboration on "Retrofit Heat Pumps for Buildings".

The primary focus of this annex has been on domestic buildings. In order to reach the goals of the annex, solutions have been studied and experience gained on:

- The application of available heat pumps in standard buildings that have been renovated, resulting in a reduced heat demand.
- The development and market introduction of new high-temperature heat pumps that use a compact heat source, for application in existing buildings.
- The use of reversible (heating-cooling) heat pumps (air-to-air), in buildings without centralized heat distribution systems

Active participants are Germany, with the operating agent IZW e.V.,and six companies, France and the Netherlands. Sweden is represented by a German company. The annex started in spring 2005, and was concluded at the end of 2008.

The February 2008 meeting, held in Utrecht / The Netherlands, was therefore concentrated on final discussions

of the results achieved and the preparation of the annex report and related appendices, in particular presenting case studies and R&D, D projects.
Two workshop for the open public were organised in 2008, presenting the major findings of the annex as well as new developments related to the items of the annex in Germany, France, The Netherlands and Sweden, in connection with the 9th IEA Heat Pump Conference on 19. May 2008, Zürich / Switzerland and the DKV International Heat Pump Conference, 14. October 2008 at the Chillventa Nürnberg

As result of this work, it is clear today that in many cases heat pumps already can or will soon be suitable for use as a recommended retrofit choice. The use of heat pumps is leading to substantially improved efficiency of heat generation, reduction in the use of fossil energy and, at the same time, facilitating the use of geothermal, hydrothermal and aerothermal renewable energy sources

The final results of the annex will be published in three reports for the different target groups:
- Executive Summary,
- Full report with all details for internal use of the participating organisations / companies
  Special reports for information to defined target groups, e.g.:
  - Politicians
  - The heat pump industry
  - R&D organisations and sponsors

Annex 31: Advanced Modelling and Tools for Analysis of Energy Use in Supermarkets

Supermarkets are the most energy-intensive buildings in the commercial sector. It has been estimated that 3-5 % of the total use of electricity stems from supermarkets in industrialised countries. In addition, it is estimated that the annual refrigerant losses may be as high as 15 - 30 % of the total charge, thus making supermarkets the second largest emission source after mobile air conditioning, according to the most recent report from the UN Intergovernmental Panel on Climate Change. The supermarket sector has therefore a significant role to play, not only from an energy consumption point of view, but also from the point of view of the impact of refrigerant leakage.

The overall objective of Annex 31 is to provide new knowledge, methods and tools for enhanced energy efficiency of, and therefore reduced environmental impact from, supermarkets. The aim is also to share ideas and best practices among participating countries, as well as information on available tools for modelling and analysis, in order further to improve supermarket refrigeration systems. The annex builds on experience and findings from Annex 26, Advanced Supermarket Refrigeration/ Heat Recovery Systems. Participating countries in Annex 31 are: Sweden (operating agent), Germany, USA and Canada. The project started at the beginning of 2006 and will continue until the end of 2009.
In order to achieve the objectives of the annex, the following task-sharing activities are planned:

Task 1 Collection of available data from different supermarkets (benchmarking)
Task 2 Development of performance indices for supermarkets
Task 3 Development and validation of a model library for specific supermarket equipment
Task 4 Development of whole-building simulation models.
Task 5 Comparison of the results obtained with the different whole-building simulation models for selected case studies
Task 6 Future perspectives and possibilities
Task 7 Deployment of the knowledge developed (indices, guidelines, papers, fact sheets)

Annex members have been active in the second half of 2008 in performing Tasks 3-5. A template to report sub-models (Task 3) and whole supermarket systems (Task 4) has been distributed and information on several whole-system supermarket models has been delivered to the operating agent. Task 5 will develop input data for a generic model or a case study in order to compare the different simulation models for supermarkets.

The results of the annex are presented in workshops attached to international conferences. The most recent workshop was at the IEA HP conference in Switzerland, in May, 2008. A working meeting was held in Chicago in conjunction with the ASHRAE winter meeting in January 2009.

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IEA HPP Annex 32 working meeting held in Graz, Austria

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

The 6th Annex 32 working meeting has been held in Graz, Austria on March 2-4, 2009. The meeting schedule comprised a one and a half-day expert meeting, and a technical tour to a highly integrated compact system, which is being monitored by Arsenal Research. The expert meeting was to present the current results of the national projects and discuss deliverables of Annex 32.

The national contributions can be mainly classified as system analysis, prototype developments and field testing of new and existing system solutions.

The **Austrian contribution** at the Institute of Thermal Engineering at TU Graz is dedicated to the prototype development of a brine-to-water CO_2 heat pump for SH, DHW and SC. Based on a system comparison, a test rig for the prototype layout has been built and first tests have been accomplished. Currently, a new CO_2 com-

Tab. 1: Seasonal performance of year-round measurement data in 2008 in the two German field tests

Field monitoring	HP efficiency (low energy buildings)			HP existing buildings (high flow temperatures)	
HP type	A/W	B/W	W/W	A/W	B/W
SPF SH&DHW	3.0	3.8	3.5	2.6	3.3

pressor is awaited, which seems better suited for the application. Arsenal Research has several field monitoring systems for combined SH&DHW, as well as two compact units for SH, DHW, V and a passive SC option. The first winter results of the latter systems show an overall performance factor of 3.6. The combined systems are mainly ground-coupled (both horizontal and vertical ground collectors) and have an overall seasonal per¬formance factor in the range of 3.5-4.

The **contribution of Canada** refers to the design and monitoring of two EQuilibrium houses as part of a demonstration programme of 13 houses by the Canadian Mortgage and Housing Corporation. The two houses incorporate both solar (e.g. building-integrated PV/thermal combination) and heat pump technology. Field measurements of the first house were gathered for an unoccupied house, showing the functionality and interaction of the single system components. The second house is currently instrumented.

Switzerland's project is dedicated to the derivation of HP standard system solutions with an integrated energy-efficient space cooling function. Design recommendations for a system layout with vertical borehole heat exchanger for passive and active cooling operation have been modelled by simulations. Two field tests of respective systems are currently ongoing. The year-round results of the system installed in a multi-family ultra-low energy house acc. to MINERGIE-P® was an overall seasonal performance for SH&DHW of 3.8, and 8.8 for the passive cooling operation in summer. The monitoring of a ground-coupled heat pump in a single-family house acc. to MINERGIE® started in Dec. 2008.

Germany is carrying out two large field tests of about 100 heat pumps in low-energy houses, and about 75 heat pumps in existing buildings as replacement for boilers. Tab. 1 shows the resulting overall seasonal performance values for the different system configurations for the 2008 monitoring period.

France joined Annex 32 in Sept. 2008. Low-energy houses in France are still at the market introduction phase, but will be required by the French Building Regulations in 2012. In particular, France will investigate A/A heat pump solutions for low-energy houses including laboratory and field testing.

Japan is investigating the design of heat pump systems for low-energy houses in the moderate (Tokyo, Osaka) and cold climate zone (Hokkaido). Heat pump air conditioners are being investigated for the moderate climate zone. It was found that conventional design methods lead to oversized units with restricted efficiency. A better design method for low-energy houses has been derived and will be implemented in a design tool. In the Hokkaido area, two field tests with ground-coupled heat pumps confirmed that low-energy houses with the appropriate heat pump systems can reduce primary energy consumption by more than 50 % compared to an oil boiler heating conventional houses in the region. A design tool for this standard system solution has been developed.

As in France, low energy houses in **The Netherlands** are still at the market introduction stage, but by 2015 all new buildings must be climate-neutral in cities such as Amsterdam, which means that much effort will be needed with regard to standardised system designs. A demonstration program will be started in 2010 to obtain experience of the different system solutions.

Norway has performed several case studies for the application of heat pumps with natural refrigerants, in particular propane and CO_2, showing high performance values for buildings with a high share of DHW energy. Currently, a field test of a propane W/W HP prototype is in progress.

Sweden will mainly contribute to the system comparison. Calculations for different system configurations for the Swedish climate have been made, and will be extended to other European sites.

The USA has developed prototype systems of an air and ground-source integrated heat pump (IHP) for net-zero-energy house applications which covers all building functions, including de-/humidification. Simulation showed reductions of energy consumptions of over 50 % compared with state-of-the-art technology. Field tests of the prototype systems are in preparation.
Work in most of the national projects is to be concluded by the end of 2009. The main results of Annex 32 will refer to standard system solutions and design, new system developments in the prototype state and best practice systems from the various field test activities in the different countries.
Updated information on the IEA HPP Annex 32 project and the national contributions, publications and links are available on the Annex 32 website at http://www.annex32.net.

IEA HPP Annex 32 participants at the 6th working meeting at the Graz Technical University

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Annex 34 Thermally driven heat pumps for heating and cooling

Participating countries: Germany (Operating Agent), Italy, USA, Austria, Canada, The Netherlands, Switzerland, Norway (tbc)

Objectives

Most heat pumps are driven by electricity. However, the use of heat as the driving force of a heat pumping device used for heating or cooling buildings might lead to significant primary energy savings, especially if the heat source is solar or waste heat.

The objective of this annex is therefore to reduce the environmental impact of heating and cooling by the use of thermally driven heat pumps. It will continue from the results from Annex 24, "Absorption Machines for Heating and Cooling in Future Energy Systems", and cooperate with Task 38, "Solar Air-Conditioning and Refrigeration" of the IEA Solar Heating and Cooling Implementing Agreement.

Past events

Several work group meetings have been held in the last period. As an outcome of the Task C meeting, held in July in Messina, Italy, standard conditions for measurements of adsorption characteristics and a format of a data base have been defined and will be tested in a round-robin test with several partners.

In addition, as a major outcome of the Task B meeting, held in Vienna, rules for the characterisation of an apparatus and possible system performance definitions have been proposed, and a test apparatus data base has been initiated. With regard to current efforts for standardisation of thermally driven heat pumps in different organisations, the work done within Annex 34 will help to create and consolidate measurement criteria.

The third Annex 34 full meeting was held in October and, in addition, an Austrian national workshop was successfully held at Arsenal Research.

The workshop started with an overview of current available technologies and applications, given by Christian Schweigler ZAE Bayern.

Possibilities for cooling with district heating were described in a presentation by Olivier Pol (Arsenal Research). A presentation of the concept of district cooling was also given by Alexander Wallisch (Fernwärme Wien), who demonstrated impressive possible larger-scale applications. Coming back to small-scale cooling applications, another presentation with commercial relevance was given by Werner Pink (Pink GmbH) and Harald Dummer (Helioplus Energy Systems GmbH).

With regard to cooling and heating applications by biomass, a presentation of the BioAWP project was given by Rene Rieberer and Harald Moser (IWT TU Graz). Finally, new ways were demonstrated in the presentation of the CoolPlate project by Ivan Malenkovic (Arsenal Research).

Future events

The fourth Annex 34 full meeting will be held on April 28th – 30th at Fraunhofer ISE Freiburg as a back-to-back meeting with the IEA-SHC Task 38 meeting in order to exchange experiences, results and working topics which might result in synergic effects for both working groups.

All presentations of the meetings and information of upcoming events can be found on the Annex website www.annex34.org, which will be updated regularly.

Ongoing Annexes

Bold text indicates Operating Agent.

Annex 29 Ground-Source Heat Pumps - Overcoming Market and Technical Barriers	29	AT, CA, JP, NO, SE, US
Annex 30 Retrofit heat pumps for buildings	30	DE, FR, NL
Annex 31 Advanced modelling and tools for analysis of energy use in supermarkets.	31	CA, DE, SE, UK, US
Annex 32 Economical heating and cooling systems for low-energy houses.	32	CA, CH, DE, NL, SE, US, JP, AT, NO
Annex 33 Compact Heat Exchangers In Heat Pumping Equipment	33	UK, SE, US, JP
Annex 34 Thermally Driven Heat Pumps for Heating and Cooling	34	AT, **DE**, NL, US

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

Installing Heat Pumps to Reduce Energy Consumption

Mark Smith
Strategic Planning Manager, British Waterways Scotland

Introduction

British Waterways manage the 137 miles of canals in Scotland: the Caledonian, Crinan, Forth & Clyde, Union and Monkland canals. These waterways were originally built in the 1790's and early 1800's for commercial use and were once vital transport networks across Scotland. However, reduction in commercial usage and lack of investment resulted in the Forth & Clyde, Union and Monkland Canals becoming derelict. The Caledonian and Crinan Canals remained operational as these routes were and continue to be popular with leisure boaters. In recent years this decline has been reversed and with substantial investment these waterways are being regenerated and are now recognised as national assets.

These canals run through stunning scenery, provide important wildlife corridors and habitats and many parts of these canals are Scheduled Ancient Monuments (Industrial). It is therefore important that development is managed sensitively and sustainably, in line with the Water Framework Directive promoting sustainable management of all waters.

British Waterways have therefore adopted a sustainable approach to all their developments along the canal network. One major approach has been the investment in heat pump technology to provide heating and hot water. As part of their commitment to reduce their energy consumption by 5% per year for five years, they have now installed water source heat pumps, using canal water to provide heat and hot water for toilet/shower block facilities at:

Falkirk Wheel, Forth & Clyde Canal

1st Auchinstarry (Forth & Clyde canal),
2nd Bowling (Forth & Clyde canal) and
3rd Gairlochy (Caledonian Canal)
4th Falkirk visitor centre (Forth & Clyde Canal)
5th Crinan Canal

Installing a Heat Pump at Auchinstarry Marina

The Millennium Link, a three year project started in 1999, restored the 68 miles of the Forth & Clyde and the Union canals, and included the construction of the Falkirk Wheel, the only rotating boat lift in the world. As part of this regeneration a new mooring basin was developed at Auchinstarry, with 64 moorings and hard standing for 40 boats. This marina was carefully developed to be a benchmark for future sustainble marinas and basins.

Considerations included using local recycled materials for all parts of the construction process, from recycled aggregates for road surfacing to surplus steel and concrete from Rosyth for slipways and crane pads. The bank sides were developed as 'soft edges' and surface runoff was minimised by using permeable car park and hard standing surfaces. A reed bed has also been established to provide a green sewerage system.
In addition to these measures the decision was made to explore the feasibility of using heat pump technology to supply all the heating and hot water requirements for the toilet/shower block, using the canal water as a heat source for the system.

Heat pump technology has developed over the last 50 years and now represents a proven and cost effective, environmentally friendly option compared to coal, gas or oil heating. The benefits of this technology are

Auchinstarry Basin, Forth & Clyde Canal

that it is designed to provide heat/hot water for entire buildings and does not require an external supply of fuel. It is therefore ideal in remote locations.

How Does a Heat Pump Work?

Heat pumps work in a similar way to a refrigerator, where the inside is cooled down using a heat exchanger and heat is emitted to the outside. In a heat pump this process works in reverse.

Effectively heat pumps have three separate components:

i) Heat recovery from the air, ground, or water
ii) Heat exchange
iii) Heat transfer

Heat Recovery using canal loops

Polyethylene loops are sunk into the water and refrigerant circulated through them. It is recommended that there be a least depth of 2m and approximately 9m^2 surface area is required per kW energy output required. These pipes absorb heat from the water and the temperature of the circulating fluid is raised a few degrees, typically in the range of 5 to +2ºC.

Heat Exchange

The loop containing the refrigerant then passes through a heat exchanger, where the temperature is raised further by a compression pump. This raises the temperature typically from +2ºC to the usable temperature 65ºC.

Heat Transfer

It is then circulated through a further heat exchanger where the heat is transferred to the domestic heating and hot water system. The cooled refrigerant is then returned to the canal loops and the process begins again.

Feasibility Study and Energy Efficiency

Geothermal Ltd were engaged as consultants and provided feasibility studies, comparing designs, with cost analyses and savings tables. These assessments included factors such as site and building requirements, design, installation procedures and maintenance schedules.

Using the canal water as the heat source proved an attractive option. Water heat pumps are efficient and by placing the heat recovery loops into the water there was no need for the expensive costs of digging trenches and burying the loops. The feasibility study, was based on a typical set up using convection panel heaters (with no switch) with a total load of 6.12kW and five 10.5 kW electric showers. On this basis, the anticipated return on investment in heat pump technology was within five to six years, with annual savings in operating costs of £574.38. These figures represent real cost savings in terms of energy costs and the decision was made to go ahead with this technology. The benefit in environmental terms is 4.69 tonnes less CO_2 emitted.

Heat pump technology is energy efficient. For an average heat pump, for every one kW of electricity used to drive the heat pump, 3.5 – 4.5 units of heating/cooling energy are produced. This Coefficient of Performance (COP) is essentially the sum of the heat extracted from source and the energy needed to drive the pump. The closer the temperature between the heat source and the output temperature, the more efficient the system will be. Heat pumps are therefore ideal for running low temperature heating systems such as underfloor heating and low surface temperature radiators. The toilet block was therefore designed with low temperature radiators and a pressurised hot water tank to run the showers.

Installation

All plumbing, installation and commissioning of the heat pump technology was carried out by Geothermal Ltd. The heat pump system designed for the toilet block facilities required four 100m heat recovery loops. It took half a day to build the coils and then only a further hour to drop them into location in the canal. Further plumbing was required to connect to the heat pump and compressor, housed within the toilet block. The heat pump provides the heating and hot water for three showers, toilets, eight washhand basins and one washing machine. A thermostatic valve was installed at source, to ensure that all the showers and basins were supplied with water at the same temperature. A specialised water cylinder, essentially a tank within a tank rather than the usual coils, was installed. This provides a greater surface area and therefore transfers the heat to the domestic water quicker. In the event of heat pump failure, an electric panel heater provides heating if required.

Grants and Funding

Total Cost: approximately £10,000 for supply and installation. British Waterways received 50% match funding through the Scottish Community and Households Renewables Initiative (SCHRI Energy Savings Trust) of £4095.25 and is now reaping the benefit of lower running, maintenance and servicing costs.

Environmental Education

British Waterways intend to provide information panels on the sustainable technology used, showing live readings of kW/Hrs generated and details of savings per tonne of coal.

Lessons Learnt

The installation of the heat pump technology at Auchinstarry marina was the first such project for British Waterways. One specialist contractor was therefore used for the whole installation process. With experience of further heat pump installations, a general plumber is now employed to undertake the plumbing and the specialist contractor only brought in to install and commission the heat pump system. This has advantages in terms of cost savings.

Auchinstarry marina has proved very popular and is now at full berthing capacity, with some liveaboard residents. This has meant that in the winter months, with the current water tank capacity, all the hot water is being used and the recovery time (how quickly the heat pump system can replenish the hot water) is too long. British Waterways are therefore looking into doubling the hot water storage capacity.

Due to the success of the facilities at Auchinstarry, British Waterways has utilised heat pump technology in other toilet blocks at Bowling, Gairlochy, Falkirk and most recently on the Crinan canal. The sustainably built timber building at Gairlochy uses an 8.8kW heat pump to provide hot water and underfloor heating for the toilet/shower block facilities and laundry there. It is estimated that 10,000 boaters/walkers will use these facilities annually. Again, 50% match funding was granted by SCHRI through the Highland and Islands Community Energy Company (HICEC).

On a larger scale

The New Lanark Conservation Trust installed similar technology at New Lanark on the River Clyde costing £144,000. The fast flowing water of the Mill Lade drives a turbine and there was the risk that a heat pump system using conventional polyethylene pipe loops could be drawn into the turbine, shredded and released into the river. Three stainless steel heat exchangers ('Slim Jim's') 3.6m x 1.2m were submerged into the water instead of looped pipes. The 90kW heat pump provides the heating for the visitor attraction 'The Institute for Correction of Character' and Mill levels 1, 2 and 3 and has reduced the heating costs by 40%. Another heat pump system installed in the tail race provides heating for the new leisure facility there.

Conclusion

Heat pump technology offers a green alternative to conventional heating systems using gas or oil and has the added benefit of financial savings in the long term. The systems are capable of heating entire buildings and are suited to remote locations. Marinas have the potential to use the surrounding grounds or water for heat recovery and there are a variety of systems available to match the requirements of any site. This technology deserves consideration for use in future marina and centre developments. British Waterways Building Surveyor commented '*It is a real eye opener*'. So, let us all open our eyes.

Acknowledgements

Many thanks to David James and Ewan Kerr (British Waterways) and Neil Phillips, Development Officer (SCHRI) for supplying the information and photographs of the Auchinstarry heat pump study.

Further Information

Find out about *British Waterway* canals in Scotland at www.britishwaterways.co.uk/scotland

For information on *geothermal heat pumps*, how they work, the types of system available and for a list of installers in your area visit: www.geothermalint.co.uk

Grants are available in Scotland through the *Scottish Community and Householder Renewables initiative (SCHRI)* to communities and householders. Visit: www.energysavingstrust.org.uk/schri/

For impartial, free and independent advice on energy efficiency, renewable energy, sustainable transport, recycling and waste management contact *Strathclyde & central energy efficiency advice (Strathclyde and central EEACs)*: www.eeac.co.uk
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Energy Efficiency: VRF vs. GSHP Systems

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With the current movement toward more energy efficient buildings, many technologies are promoted with emphasis on their superior energy efficiency. The variable refrigerant flow (VRF) and ground source heat pump (GSHP) systems are probably the most competitive technologies among these. However, there is few, if any, published literature comparing the energy efficiency between VRF and GSHP systems. This article presents preliminary results of a simulation-based investigation on the energy efficiencies of VRF and GSHP systems. The results show that, for conditioning a small office building, GSHP system can save up to 36% electricity compared with VRF system.

Introduction

The movement towards more energy efficient buildings gives tremendous challenges and opportunities to the Heating, Ventilation, Air-Conditioning, and Refrigeration (HVAC&R) industry. Many HVAC&R technologies are promoted with emphasis on their superior energy efficiency. Among these, the variable refrigerant flow (VRF) and ground source heat pump (GSHP) systems are probably the most competitive technologies. They have many similar advantages, including flexibility for design and installation, capability for individual climate control, and significant potential for energy savings. However, while GSHP systems have been used in the US for decades, VRF systems were just introduced into the US in recent years and it is relatively new to many practitioners in the HVAC&R industry [1].

The VRF system is an outgrowth of the "multi-split" systems used in residential applications. The major difference between VRF systems and conventional HVAC systems is that they adjust cooling/heating output by modulating the refrigerant flow continuously with variable speed compressor. VRF systems enable a single outdoor unit to be connected to dozens of indoor units of varying capacity and configuration throughout a building. It typically comprises of one or more centralized outdoor unit(s), which contains 2 or more air-cooled compressors, one of which is of variable speed. The indoor units contain electronic expansion valve, direct expansion coil, and fan. The outdoor and indoor units are connected with relatively long refrigerant line and require sophisticated control and refrigerant management. There are two types of VRF systems available: the "heat pump" (HP) type VRF, which provides either heating or cooling to the space, and the "heat recovery" (HR) type VRF, which provides heating and cooling simultaneously to different zones within a building.

VRF system incorporates several energy efficiency technologies, including variable speed compressor and fan, pumping free heat from ambient air to conditioned spaces, and recovering heat between zones demanding heating and cooling simultaneously, but it has some unique characteristics that may result in additional energy consumptions. First, as with any air source heat pumps, VRF systems must defrost the air-refrigerant heat exchanger in the outdoor unit when in heating mode. Second, the long refrigerant line may result in significant heat/cool loss and increased compressor power consumption. Third, some VRF systems require special "oil return" operation to get the lubricant oil back to the compressor, which consumes extra energy compared with conventional packaged air source heat pumps.

Currently, there is few, if any, published literature comparing the energy efficiency between VRF and GSHP systems. No ARI-certified rating system exists for VRF systems at present time. Furthermore, VRF systems cannot at present be modelled with non-proprietary building energy simulation tools like Energy Plus or DOE-2, widely used for comparing energy efficiency of various HVAC systems. Nevertheless, there are a few proprietary tools available for simulating VRF systems, such as Trace 700 and Energy Pro.

The best way to compare the energy efficiency of VRF and GSHP systems may be monitoring two identical buildings at the same location but use VRF and GSHP systems, respectively. However, these kind of monitored data are not currently available yet to the best knowledge of the author. Computer simulation with credible software tools is perhaps the only way to get quantitative comparison of the energy efficiency between the two systems. In this paper, a recent effort of such simulation-based investigation is reported. The algorithm, simulation tools, performance data, and results of this investigation are presented in the following sections.

Simulation-based Comparison between VRF and GSHP Systems

The comparative result of energy efficiency between VRF and GSHP systems depends on not only the difference of the technologies themselves, but also many other factors, of which the most dominant is the building and its location. In this investigation, a small office building with conditioned area of 360 m^2 is selected. As shown in Figure 1, this one story office building has four perimeter zones (with 4 m depth and one at each orientation) and one core zone. It has potential needs for simultaneous heating and cooling for different zones within the building. Three US cities are selected to cover the hot, mild, and cold climates: Miami, San Francisco, and Chicago.

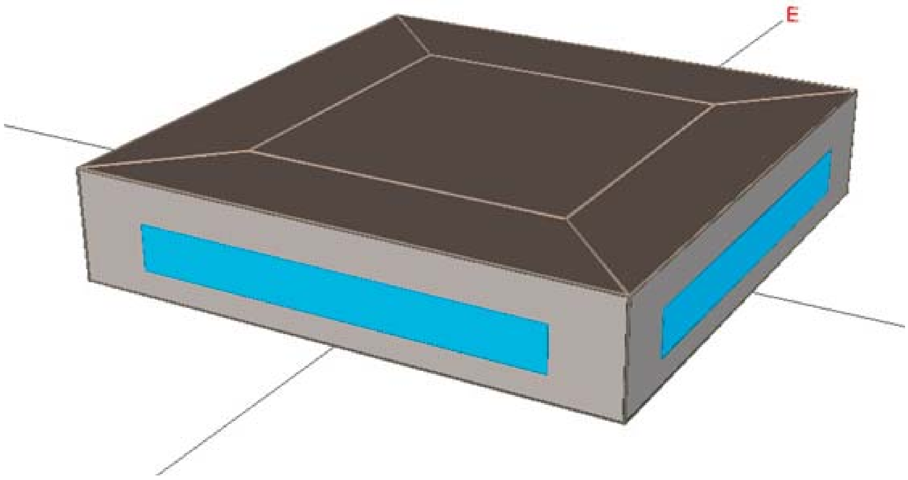

Figure 1. 3-D image of the simulated small office building

Table 1 Nominal Capacity and Efficiency of the Simulated VRF and GSHP Systems.

Location	VRF					GSHP				
	Cooling Capacity[1] [kW]	Heating Capacity[1] [kW]	Cooling COP[1]	Heating COP[1]	Outdoor air temp. range[2] [C]	Cooling Capacity[3] [kW]	Heating Capacity[3] [kW]	Cooling COP[3]	Heating COP[3]	EFT range[4] [C]
Miami	31.6	35.2	3.3	3.5	3.3 - 33.9	38.2	24.9	5.9	4.2	24.7 – 32.8
San Francisco	28.1	31.6	3.2	3.7	0 – 35	34.3	22.4	5.9	4.2	8.2 – 28.3
Chicago	36.9	41.0	3.3	3.5	-22.8 – 35.5	54.7	35.8	5.9	4.2	2 – 25

Note:

1. For the VRF system, according to the performance data provided by the VRF manufacturer, cooling capacity and COP are measured when the outdoor dry bulb temperature is 33°C and the heating capacity and COP are measured when the outdoor wet bulb temperature is 3°C.
2. Outdoor air temperature range is obtained from TMY2 weather data used in the simulation.
3. For GSHP units, per industry standard (ARI/ASHRAE/ISO 13256-1), the cooling capacity and COP are measured at 25°C EFT; the heating capacity and COP are measured at 0°C EFT.
4. Entering fluid temperature is from eQUEST GSHP system simulation results.

For each location, a HR type VRF system of a major VRF manufacturer and a GSHP system that uses single-stage heat pump made by a major GSHP manufacturer and vertical ground loop heat exchanger (VGLHE) are designed for the same building. Both systems use R410a refrigerant. The nominal cooling and heating capacities as well as the associated coefficient of performance (COP), and the outdoor conditions, at which the two systems are operated, are summarized in the following table. The outdoor conditions affecting the VRF and GSHP system are the outdoor ambient air condition and the entering fluid temperature (EFT) to the GSHP units, respectively. The differences in nominal capacities of the two systems are mainly due to two reasons: one is the different rating conditions for the nominal capacities, and the other is GSHP units are sized to cover both heating and cooling loads and thus no supplemental heating is needed, but electric heater is used in the VRF system for supplemental heating.

In the simulations, outdoor ventilation air is assumed going directly from outdoor ambient into the building, and the fan of GSHP units and the indoor units of the VRF system is assumed running continuously (to provide air circulation) when the building is occupied. Variable speed pump is assumed being used in the GSHP system. There is no air-economizer integrated with the VRF system.

In order to investigate how variations of the VRF system affect its efficiency, two additional scenarios are investigated for the building in Chicago: HP type VRF system with 25 ft (7.62 m) refrigerant line (standard length given in manufacturers' catalog), and a HR type VRF system with 574 ft (175 m) refrigerant line (longest allowed by the VRF manufacturer).

Simulation Tools

Among the available simulation tools for VRF systems, Energy Pro is perhaps the only one accepted by major VRF manufacturers. Energy Pro is a comprehensive energy analysis program that uses DOE-2.1E as simulation engine. Since DOE-2 cannot directly model VRF systems, a "post-processing" procedure was developed for DOE-2.1E to calculate the cooling, heating, and fan energy use of a VRF system based on the simulation results of a water loop heat pump system. Major VRF manufacturers supported the development of the "post-processing" procedure and provided performance data/curves of VRF systems for use with Energy Pro.

Simulation of GSHP systems is conducted with eQUEST, a building energy analysis program powered by DOE-2.2, the latest development of DOE-2. In the current version of eQUEST/DOE-2.2, a model based upon the widely accepted g-function algorithm [2] has been implemented to simulate the performance of VGLHE [3]. The performance data/curves of GSHP units used in the eQUEST simulation are from a major GSHP manufacturer.

Performance Curves

Performance (i.e. heating/cooling capacity and efficiency) of the VRF system and GSHP units at various operating conditions can be associated with their performances at certain "reference condition" with a set of correction factors in the form of data table or curves. These data/curves are provided by major manufacturers of the VRF and GSHP equipment. They may be different from those provided by other manufacturers.

Figure 2(a) and 2(b) shows performance curves of heating/cooling capacity and efficiency of the simulated VRF system in response to various outdoor air temperatures, respectively. The performance curves of cooling capacity and efficiency are normalized at 33°C outdoor dry bulb temperature (ODBT). The performance curves of heating capacity and efficiency are normalized at 3°C outdoor wet bulb temperature (OWBT).

Two performance curves are used for heating capacity. The first accounts for the impact of OWBT and the second represents the effect of defrosting operation. As shown in these curves, heating capacity of the VRF system decreases almost linearly down to only 50% of its nominal heating capacity when OWBT goes down to –18 °C, the minimum allowed. Defrosting operation further degrades the heating capacity when OWBT is below 5 °C. On the other hand, the cooling capacity of the VRF system seems not very sensitive to ODBT. For a ± 10 °C variation from the referencing temperature (33 °C), the change of cooling capacity is about 10% of its nominal value.

Energy efficiency is represented with the ratio of electric input to heating/cooling capacity and abbreviated as "EIR" in Figure 2(b). As shown in the figure, the heating EIR of the VRF system has a peak around 3 °C OWBT when defrosting operation most adversely affected the heating capacity as shown in Figure 2(a). Clearly, the defrosting operation significantly degrades the heating performance of the VRF system. Same as for the cooling capacity, the performance curve shows almost linear relationship between cooling EIR and ODBT. For the same ± 10 °C variation from the referencing temperature (33 °C), the change of cooling EIR is about 20% of its nominal value.

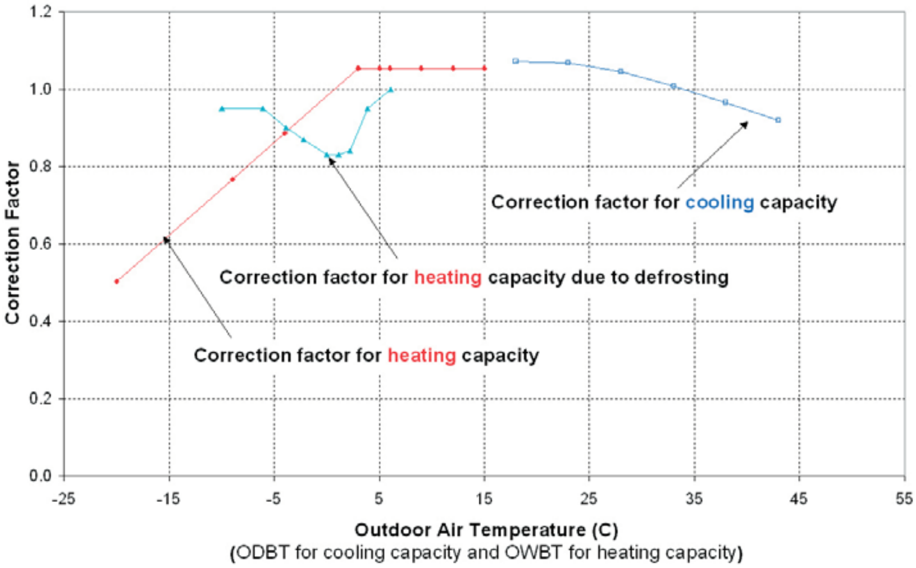

Figure 2(a). Performance curves of heating and cooling capacities of the simulated VRF system in response to various outdoor air temperatures

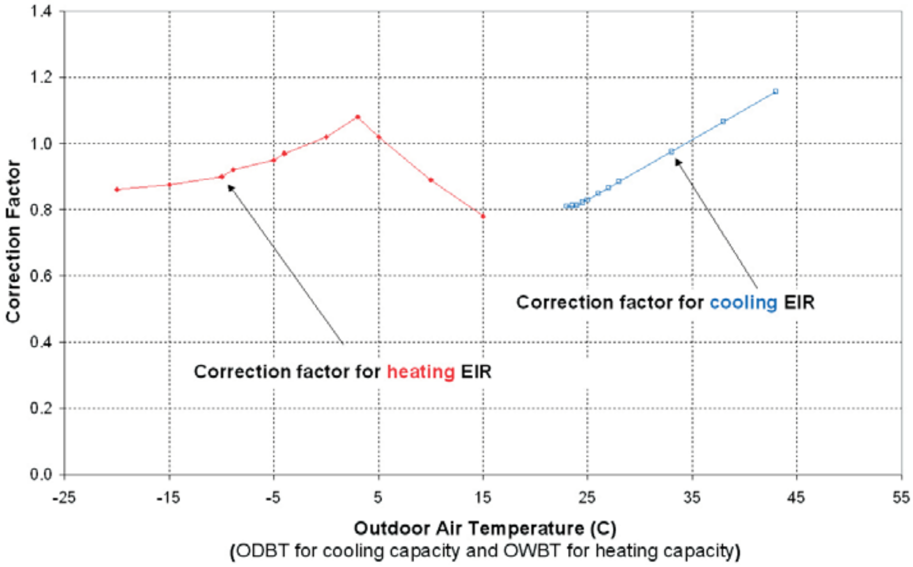

Figure 2(b). Performance curves of heating and cooling efficiencies of the simulated VRF system in response to various outdoor air temperatures

Figure 3(a) and 3(b) shows performance curves of heating/cooling capacity and EIR of the simulated GSHP units in response to various entering fluid temperatures, respectively. Per the industry standard previously stated, the performance curves for cooling capacity and EIR are normalized at 25°C EFT and the performance curves for heating capacity and EIR are normalized at 0°C EFT. As shown in Figures 3(a) and 3(b), increasing EFT results in higher capacity and lower electric consumption for heating, but lower capacity and higher electric consumption for cooling. Therefore, actual performance of a GSHP system strongly depends on EFT, which is affected by local ground temperature and thermal conductivity, VGLHE design and installation quality, and building loads (cooling dominated vs. heating dominated).

The energy efficiency of VRF and GSHP systems is also affected by the capability of adjusting heating/cooling output to meet the varying building heating/cooling load. This capability is usually characterized by "Part Load Factor" (PLF) in response to various "Part Load Ratio" (PLR), which is the ratio of building heating/cooling load to the available heating/cooling capacity of a HVAC system. If PLF is less than PLR, it indicates that the system has better energy efficiency at part load condition than an ideal single-stage heat pump without any cycling loss and vice-versa.

Figure 4(a) and 4(b) show the part load performance of the simulated VRF system and GSHP units. The diagonal line in each figure shows the performance of the ideal single-stage heat pump. As shown in Figure 4(a), the PLF of the simulated VRF system is below the diagonal line when it runs in cooling mode and PLR is bigger than 0.4, but it is slightly above the diagonal line when the VRF system runs in heating mode. It implies that the VRF system has better energy efficiency than the ideal single-stage heat pump in cooling mode but not in heating mode. The defrosting operation could be responsible for the lower energy efficiency in heating mode. Contrastingly, as shown in Figure 4(b), the simulated GSHP units have part load performance very close to the ideal system.

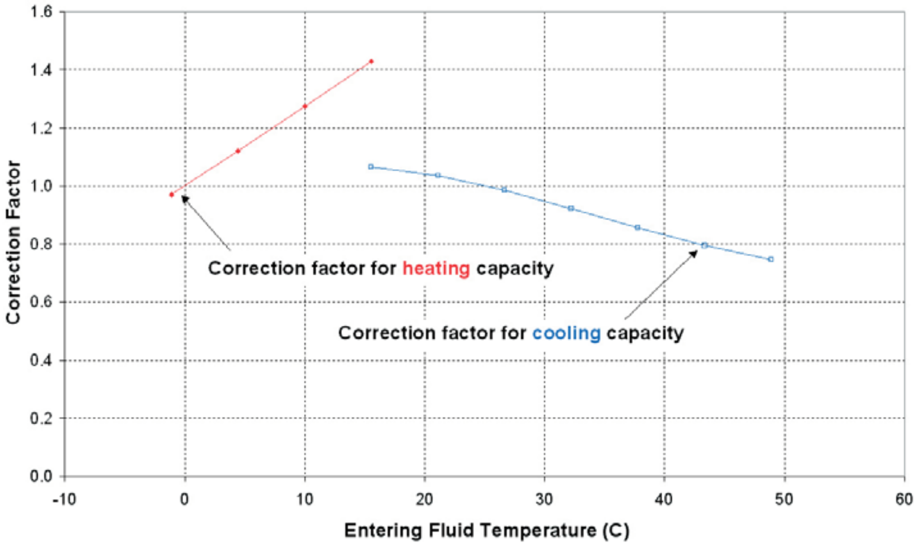

Figure 3(a). Performance curves of heating and cooling capacities of the simulated GSHP units in response to various entering fluid temperatures

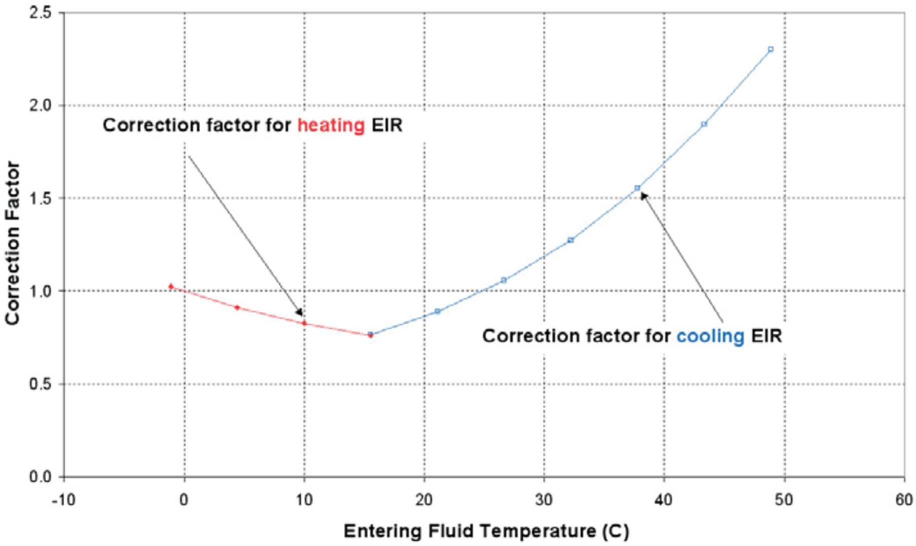

Figure 3(b). Performance curves of heating and cooling efficiencies of the simulated GSHP units in response to various entering fluid temperatures

Compared with typical packaged GSHP units, VRF system usually has much longer refrigerant lines. The longer lines not only require larger system refrigerant charge, but also results in loss of heating/cooling capacity as well as increased compressor power consumption. Energy Pro uses a set of manufacturer provided correction factors to account for the impact of line length on the heating/cooling capacity of VRF systems. However, there is no correction for the increased compressor power consumption resulting from longer line in the VRF system simulation.

As shown in Figure 5, length of refrigerant line significantly affects both the heating and cooling capacity of the simulated VRF system. It appears that the cooling capacity is more sensitive to this factor than the heating capacity. It may indicate that, in cooling mode, some refrigerant has been evaporated while transporting through the refrigerant line before entering into the indoor units.

Though there is no long refrigerant line in the GSHP system, it does have a two-pipe water loop that connects the VGLHE with the multiple GSHP units installed in the building. It thus consumes additional pumping energy to move water through the water loop, VGLHE, and all the GSHP units.

Results

Simulations of the VRF and GSHP systems are conducted with Energy Pro and eQUEST, respectively. Due to differences between the two programs, the calculated building heating and cooling loads of the VRF and GSHP systems are not identical to each other. To get a fair comparison between the two systems, the eQUEST calculated energy consumption of the GSHP system is adjusted to account for the difference in the heating and cooling loads. Since both the VRF and GSHP systems circulate same amount of air in each zone, assuming the fans have same performance, the fan electricity consumptions of the two systems are set equal.

Table 2 summarizes the annual total electricity consumption by each end use of the HR type VRF and GSHP systems at each location. The GSHP system saves 14%, 17%, and 29% electricity compared with the VRF system in Miami, San Francisco, and Chicago, respectively. The results show clearly that the electricity savings increase with increasing heating demands. While the GSHP system is more energy efficient than the VRF system in all of the three locations, it performs better in places like Chicago where substantial heating and cooling are needed.

Figure 6 shows comparison results between the GSHP system and three variations of the VRF system in Chicago. The HP type VRF system consumes more electricity than the HR type VRF, but the difference is not significant in the case being investigated. Electricity savings from the GSHP system is increased by 2% when the HP type VRF system with 25ft (7.62 m) refrigerant line is used in the comparison. The electricity savings from the GSHP system goes up to 36% compared with the HR type VRF system using 574ft (175m) long refrigerant line.

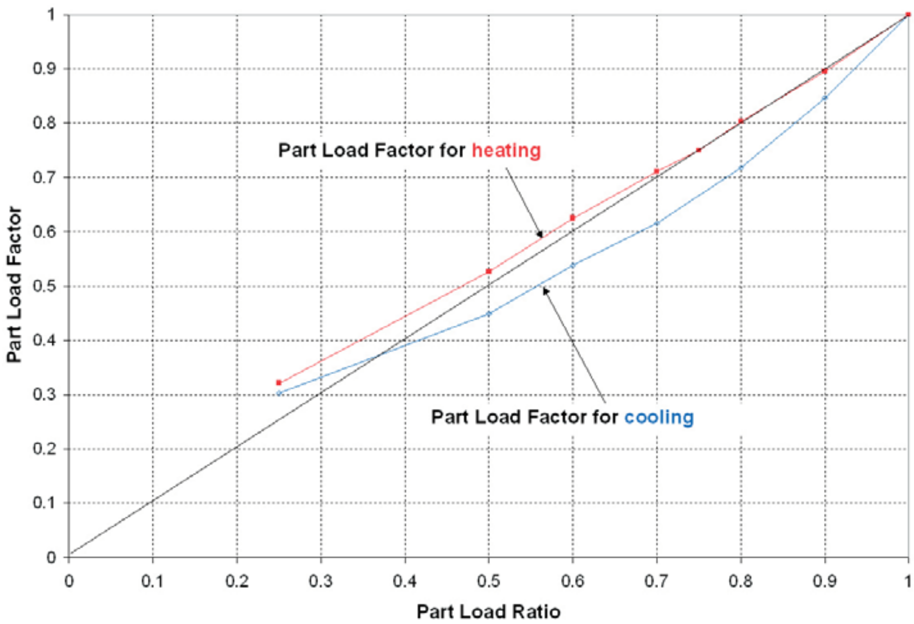

Figure 4(a). Part load performance of the simulated VRF system

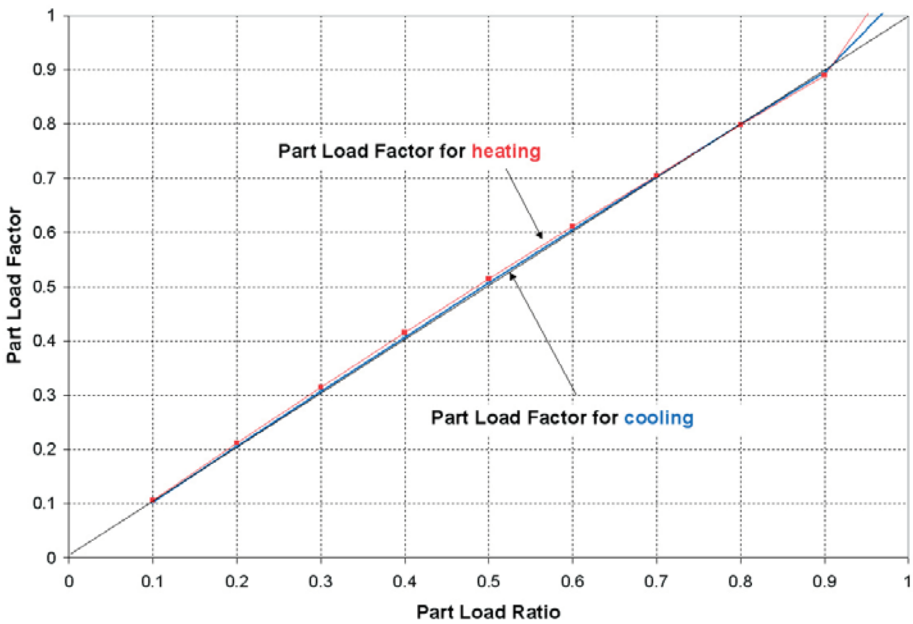

Figure 4(b). Part load performance of the simulated GSHP units

Conclusions and Discussion

A preliminary comparison of energy efficiency between VRF and GSHP systems has been conducted using available building energy analysis software and the performance data/curves from VRF and GSHP equipment manufacturers. The results show that, for conditioning a same small office building, GSHP system is more energy efficient than VRF system. At three locations that represent hot, mild, and cold climates, GSHP system saves 14% to 29% electricity compared with the "heat recovery" type VRF system with standard refrigerant line. More energy savings from GSHP system could be expected if the "heat pump" type VRF system is compared and/or longer refrigerant line is used in the VRF system.

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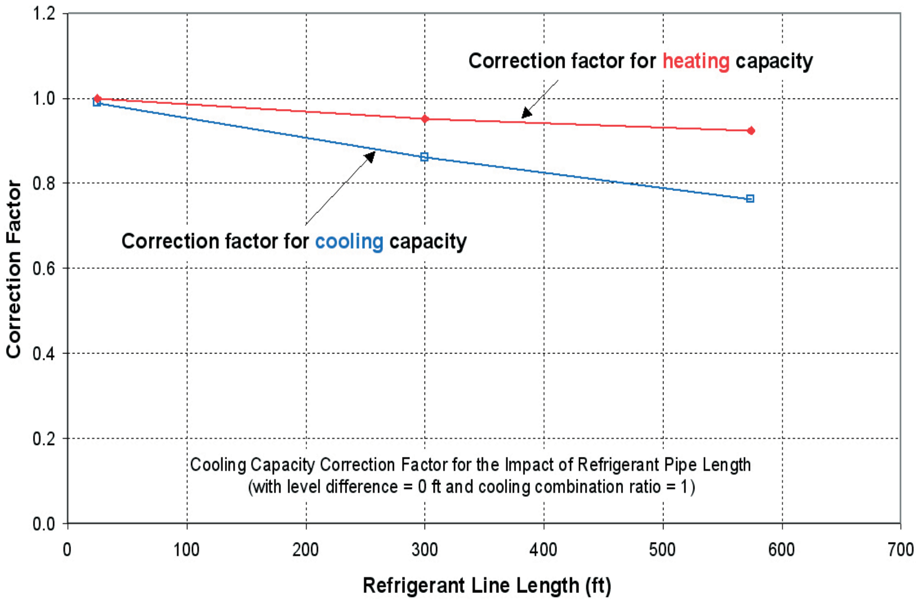

Figure 5. Impact of refrigerant line on heating and cooling capacity of the simulated VRF system

Table 2 Annual Total Electric Consumption by End Use.

System / Location		Miami	San Francisco	Chicago
VRF Annual electricity Use [kWh]	Cooling	18,612	6,974	7,396
	Heating	128	2,502	9,287
	Fan	4,740	3,940	5,080
	Total	23,480	13,416	21,763
GSHP Annual electricity Use [kWh]	Cooling	13,388	3,882	3,829
	Heating	82	1,514	4,454
	Fan	4,740	3,940	5,080
	Pump	1,924	1,744	2,177
	Total	20,134	11,080	15,539
Electricity Saving		14%	17%	29%

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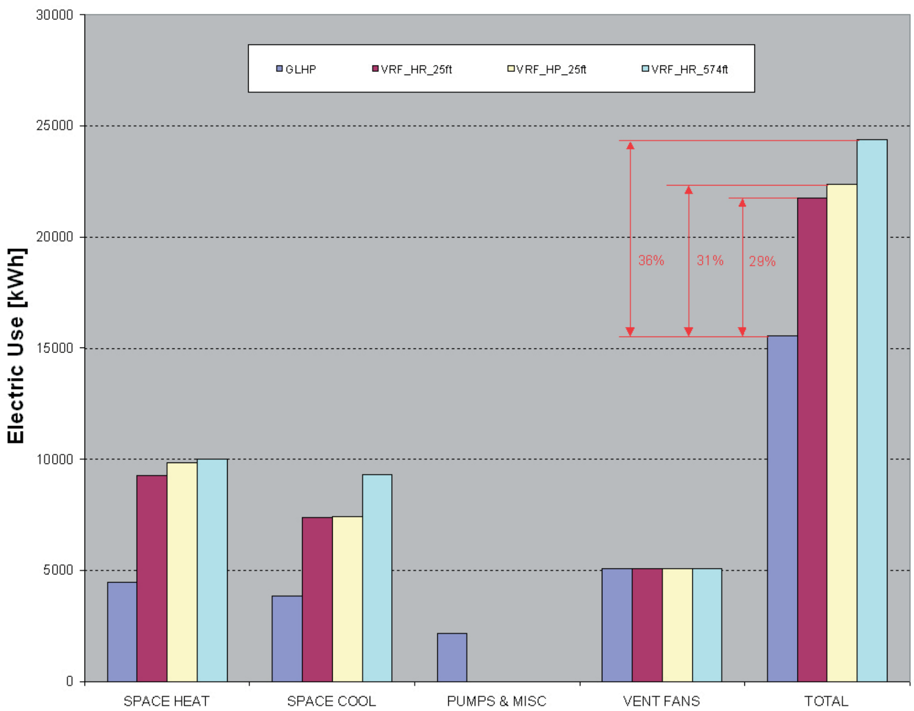

Figure 6. Annual electricity consumptions of the VRF and GSHP systems

Foundation Heat Exchangers: Reducing the First Cost of Ground Source Heat Pumps

John Shonder, Jeffrey D. Spitler, USA

Despite their high efficiency and low operating costs, the use of ground source heat pumps in residential applications is limited by the cost of installing ground heat exchangers. A collaborative research project between Oak Ridge National Laboratory (ORNL), Oklahoma State University and De Montfort University is examining potential solutions to this problem and developing design tools that will allow broader use of ground source heat pump technology in tomorrow's homes.

Introduction

Geothermal or ground source heat pumps (GSHP) are one of the most efficient technologies available for space conditioning of buildings. Their main disadvantage is their higher first cost compared with conventional HVAC technologies, due to the cost of the drilling and/or excavation required to install ground heat exchanger piping.

In general, the length of the ground heat exchanger piping required for a given building is a function of the building's heating and cooling loads; minimizing those loads minimizes the heat exchanger length, which in turn minimizes installation costs. In the case of zero energy homes, space conditioning loads are so low that the excavations made for the basement/foundation – along with other excavations such as those required for water and sewer lines – may be sufficient to contain all of the ground heat exchanger piping necessary. Where existing excavations are insufficient, auxiliary heat sources and/or sinks such as mechanical ventilation could satisfy the remainder of the requirement. In either case, such foundation heat exchangers can eliminate the need for separate drilling or trenching for ground heat exchangers, thereby significantly reducing or eliminating the cost premium associated with ground source heat pumps.

Experimental Work and Modeling

ORNL has previously demonstrated the feasibility of foundation heat exchangers in a 2,600 square foot residence in Lenoir City, Tennessee. However, before the technology can be applied on a large scale, much more must be learned about the interaction between the basement/foundation, the soil, the ground loops, and ambient conditions at the ground surface. Currently there are no design tools available to size foundation heat exchangers or the supplemental heat sources/sinks that may be required. Building simulation programs such as EnergyPlus cannot model them.

As part of an alliance between ORNL, the US Department of Energy, the Tennessee Valley Authority, a Knoxville, TN construction company and various equipment and building material manufacturers, four research homes are being constructed in the Oak Ridge, Tennessee area. The houses incorporate a number of energy-efficient technologies, and will be extensively monitored to assess their performance.

One of the technologies being incorporated is the foundation heat exchanger. As shown schematically in Figure 1, the mass of soil around the foundation is subject to heat transfer from the foundation itself and from the heat exchanger pipes by way of

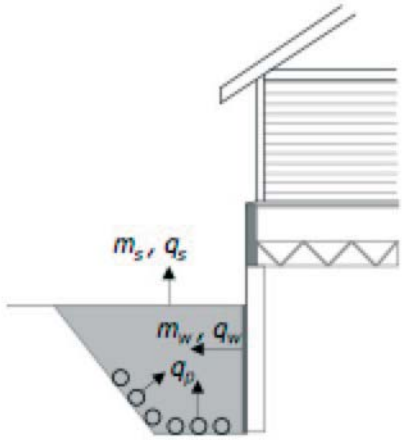

Figure 1: Schematic of foundation heat exchanger.

conduction within the soil. Moisture flow takes place within the soil as well. At the surface, heat is transferred through convection, radiation and evapotranspiration.

Figure 2 is a photograph of the foundation heat exchanger for one of the houses during construction, prior to being backfilled. This installation consists of three parallel loops located in the basement/foundation overcut; trenching for water and sewer connections is also utilized. ORNL has instrumented the system and is collecting data on water inlet and outlet temperatures, pipe surface temperatures at various points along the length, soil temperatures both within the trenches and at undisturbed locations, heat flux across the foundation walls, and other variables of interest.

Figure 2: Foundation heat exchanger in basement overcut.

Conclusions

Foundation heat exchangers have the potential to reduce the cost of using ground source heat pumps in zero energy homes and other low-energy buildings. With calibrated design tools and simulation models available, engineers and architects will be able to specify the use of foundation heat exchangers in buildings, leading to reductions in energy consumption and carbon emissions.

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In parallel with the data collection effort, the team from Oklahoma State University and De Montfort University is developing a series of 2-dimensional and 3-dimensional analytical and finite volume heat transfer models that will serve as the basis for both a stand-alone design tool and a simulation model to be incorporated into building energy analysis programs such as EnergyPlus. Preliminary results of temperature distribution in the ground surrounding a foundation heat exchanger, calculated with an analytical model are shown in Figure 3. The models will be validated against data collected at the site.

The stand-alone design tool will allow determination of whether or not a foundation heat exchanger will be sufficient to meet the heat rejection/extraction needs of the ground source heat pump system over the life of the system. If it will not be sufficient, the design tool will support the sizing of an alternative supplementary heat source or sink. The simulation model will be capable of predicting entering fluid temperature to the heat pump, from the foundation heat exchanger, on hourly or shorter time steps.

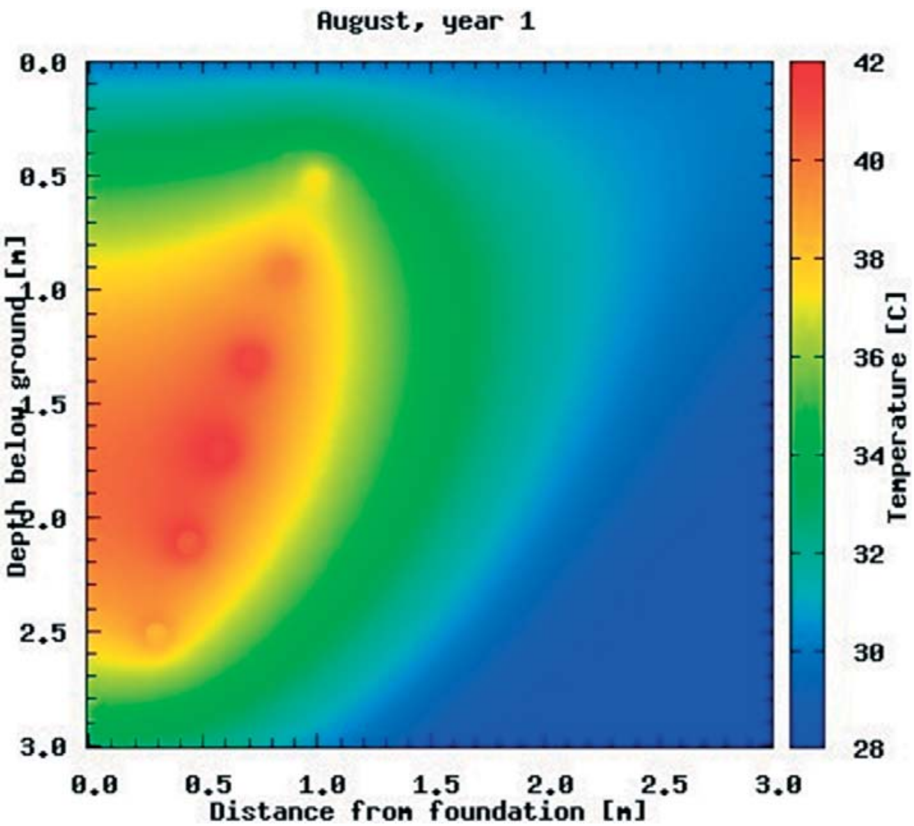


Figure 3: Temperature distribution in the ground surrounding a foundation heat exchanger.

Improvements of large institutional ground-source heat pump systems

Vasile Minea, Canada

A number of design control improvements of large commercial and institutional ground-source heat pump (GSHP) systems have been implemented in Canada during the last 20 years. The majority of these improvements aimed at reducing the energy consumption of the geothermal fluid pumps and at optimizing the integration of various functions as solar energy recovery, thermal storage, direct geothermal heating and cooling with radiant floors and exhaust air heat reclaim. Such improvements generally reduce the system energy consumption and overall efficiency, but their initial costs and technical feasibility have to be established for each particular application. Other improvements are still possible and necessary today to overcome technical barriers and increase the market accessibility of GSHP systems.

Geothermal fluid pumping

Optimizing the geothermal fluid pumping power inputs and flow rates, as well as the running schedules result in less pumping energy consumption. Conventional large GSHP systems generally consist in reverse primary loops with single large circulating pumps P (Figure 1, A). In Canada, the recommended flow rates vary from 0.16 to 0.19 L/s per 3.5 kW of installed cooling capacity. When not correctly sized and controlled, the energy consumption of such brine pumps may represent up to 25% of the total annual energy consumption of the GSHP system. However, up to 30% of the annual energy consumption could be saved by optimizing the geothermal fluid flow rates. An optimum sizing of circulating pumps corresponds to about 5.6 electric kW per 3.5 kW of nominal cooling capacity. High-efficiency motors also can save energy with interesting pay-back periods. For example, increasing by 4.5% the circulating pump motor efficiency may result in 5% energy savings and peak demand reduction of about 0.85 kW. It is well known that in large GSHP systems, most of the time, a number of heat pumps do not operate due to diversity of loads, occupancy and other factors. For buildings with varying occupancy patterns and different internal loads, such as schools and hotels, buildings that require space heating and cooling in different zones at different times of the day, is advantageous to incorporate a primary and several secondary pumping loops (Figure 1, B). In this case, secondary circulating pumps provide brine flow in zones with similar load profiles. Other method reducing the total flow rate uses variable speed pumps (Figure 1, C). In this case, when several heat pumps are not operating, the geothermal fluid connexions are closed with solenoid valves and the circulating pump modulates to provide only the flow required by the operating heat pumps. A variable-speed drive (VSD), two loop pressure sensors and one solenoid valve (SV) at each heat pump are required. The pressure differential sensor (PD) continuously reads the difference between the supply and return sections of the loop and then activate the VSD in order to modulate the fluid flow rate. The solenoid valve installed on the return side of each heat pump opens when the compressor starts and closes when the compressor shuts-down. The compressor is not operating when the solenoid valve is closed. Such variable speed systems may save up to 85% in pump energy, but the addition of solenoid valves, pressure sensors and VSD increase the initial costs (ASHRAE, 1995). Therefore, sometimes a single-speed pump seems the better economical choice.

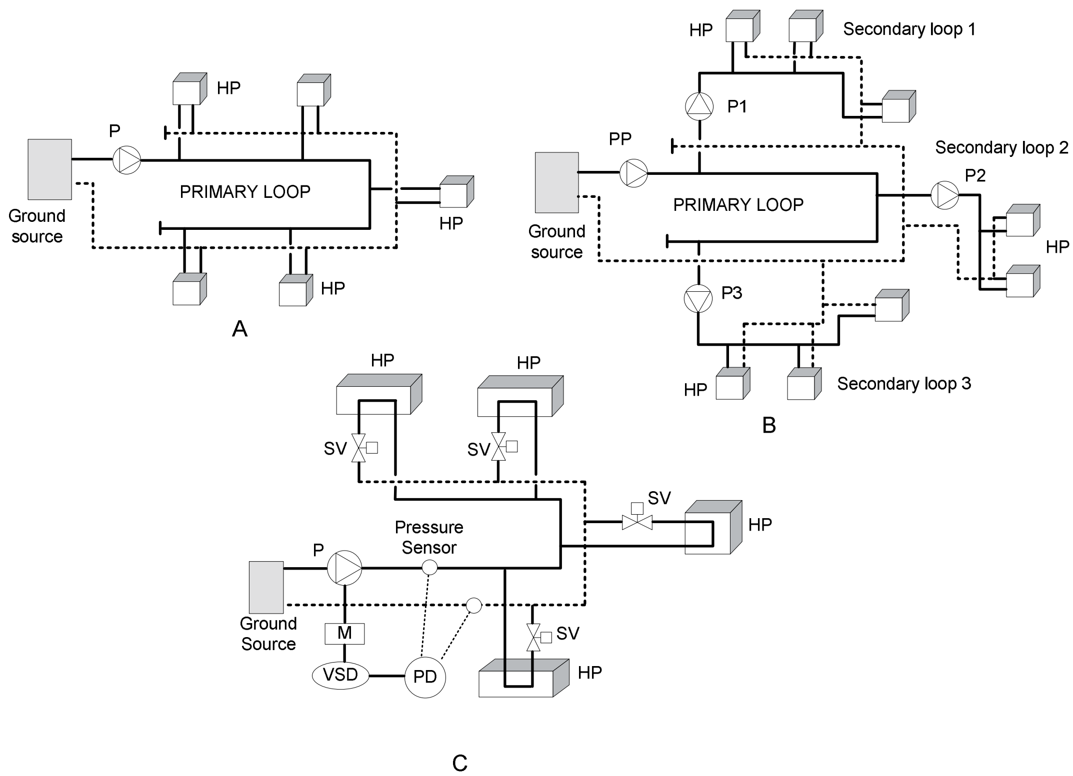


Figure 1 – GSHP systems with primary (A) and secondary (B) loops, and variable speed circulating pump (C). HP: heat pump; P: circulating pump; SV: solenoid valve; VSD: variable speed drive; PD: pressure differential sensor

Multiple energy sources

Multiple energy sources and thermal storage may improve energy performances of large GSHP systems. Such concepts (Figure 2) allow combining and managing several energies, as primary (electrical, fossil) and renewable (solar, geothermal, internal gains) sources. The ground heat exchanger (vertical, horizontal or under surface water) recovers geothermal energy. A passive solar wall recovers solar energy for make-up air preheating. A back-up heater using a fossil energy (natural gas or propane) is necessary when the solar energy is insufficient. An oil-fired generator supplies power to the GSHP system during the winter peak demand periods or in emergency situations. A waste heat recovery loop recovers heat from both exhaust gases and engine cooling fluid. It is stored into a water thermal storage tank and used, when necessary, for space heating through the building brine closed-loop. A three-way valve alternates the geothermal fluid flow through the ground heat exchanger or the thermal storage tank.

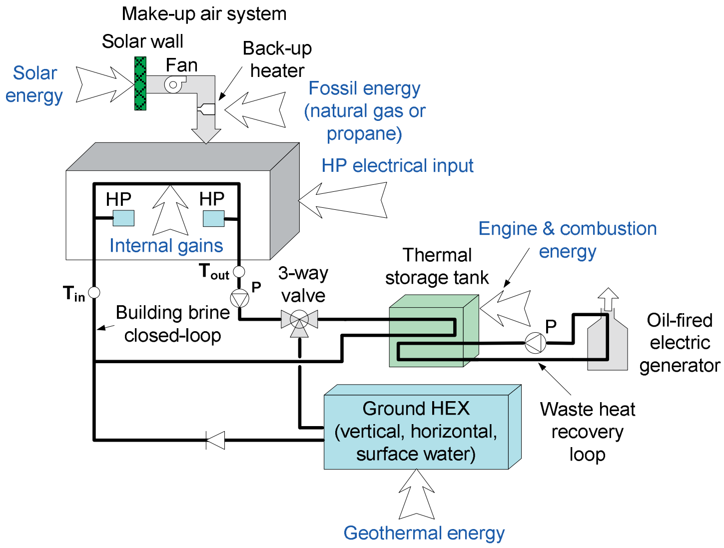
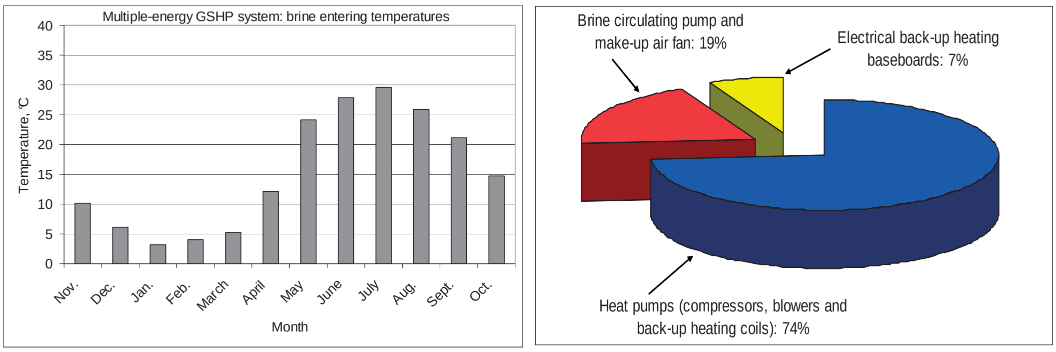


Figure 2 - Multiple-energy large GSHP system with thermal storage. HP: heat pump; P: circulating pump; T: temperature; in: inlet; out: outlet

Such a system with horizontal ground heat exchanger buried at 4 feet (50% of the total length), and the rest buried at 6 feet depth, already was tested in Canada. The total initial cost this system was 26% lower compared to equivalent conventional systems with central water chillers, induction heating/cooling terminals and cooling tower (Minea, 1996). The brine average temperatures entering the building closed-loop (T_{in}) have never dropped below 3°C during the winter, and never exceeded 30°C during the summer (Figure 3, A). Moreover, by alternating the brine flow through the ground heat exchanger and the thermal storage tank, the thermal capacity of the ground horizontal coils has been increased by 20% by the second heating season of operation. This performance was performed by avoiding unnecessary heat rejection to the ground by controlling the three-way valve according to the brine return temperature T_{out}. In such a system, the energy stored in the heating transfer medium (brine) is provided by the soil, internal gains, heat pumps' compressors, the brine circulation pump and the waste heat recovery loop. The rest of the heating energy is supplied by other sources as ventilation fans, passive solar wall, natural gas-fired boiler, and the building peripheral electrical back-up baseboards. Between November and March, the heat transferred from the ground horizontal coils represented 39% of the building total peak heating demand, and the seasonal coefficient of performance (SCOP) of the heat pumps averaged 3.5. During this period, a number of heat pumps located in the building core areas have operated in the cooling mode about 7.5% of the time, with a seasonal energy efficiency ratio (SEER) of 19.2. Most part of the total annual electrical energy consumption of the GSHP system (Figure 3, B) was assumed by the heat pumps' compressors, blowers and electrical back-up heating coils (74%). The brine circulating pump and the outdoor air make-up fan consumed together 19%, and the peripheral electrical back-up baseboards, 7%. The building energy consumption, including electricity and natural gas, was about 0.69 GJ/m^2/year (192 kWh/m^2), about 8% lower than the average consumption of all provincial schools (Minea, 1997)



A. B

Figure 3 – Multiple-energy large GSHP system with thermal storage. A) Brine entering temperatures; B) Share of GSHP system annual energy consumption

Artificial cooling charge

In large open-loop GSHP systems, creating so-called *artificial* cooling charges may improve the system global energy efficiency. Figure 4 represents such a system containing two water-to-water heat pumps connected in series on the building hot and cold water closed-loops. The following design and control strategies may simultaneously recover building internal gains and geothermal energy by the aid of a groundwater heat recovery heat exchanger. The heat pump #1 has two condensers, respectively for heat recovery (REC-CD1) and heat rejection (REJ-CD1) purposes, while the heat pump #2 contains only a heat recovery condenser (HR-CD2) connected to the building hot water loop with circulating pump P1. Both water-to-water heat pumps recover excess heat (internal gains) from the building. In addition, the heat pump #1 is able to recover additional energy from the groundwater during the heating season. For that, during the winter, the water in the building cold loop (with circulating pump P2) is cooled in two steps. Inside the evaporator EVAP2, the temperature drops from 12°C to 7°C and in the evaporator EVAP1, from 7°C to minimum 1.6°C. Thus, the temperature difference between the groundwater (8.3°C) and the cold water entering the intermediate coil is of about 6°C. This process creates an *artificial* cooling charge allowing efficiently recovering heat from the groundwater. After the groundwater heat recovery heat exchanger, the cold water enters the building closed loop. During the summer, the valves V1 (close) and V2 (open) allow by-passing the groundwater heat recovery coil and rejecting the excess heat directly to the ground. Figure 5, A shows the monthly share of internal gains and groundwater energy recovered by the heat pump #1 during the winter heating mode. In Figure 5, B it can see that the average temperature of the groundwater coming from the supply well was practically constant at approximately 8.3 °C, the temperature of the water entering the building cold water loop, varied between 0.4 °C (in April) and 5.3 °C (in October, and the monthly average temperature of the water entering the building loop varied between 44.5 °C (in November) and 55.6 °C (in January).

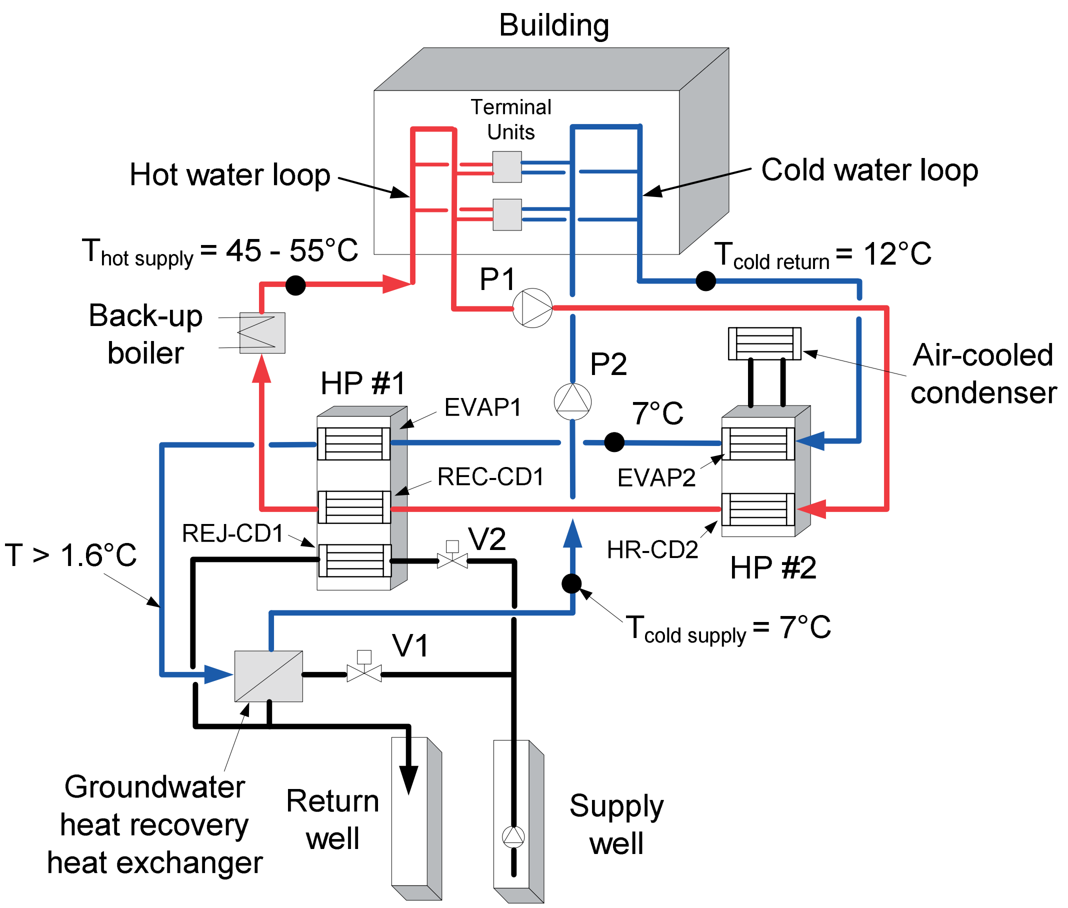


Figure 4 – Open-loop GSHP system with *artificial* cooling charge. HP: heat pump; HR: heat recovery; EVAP: evaporator; CD: condenser; HR-CD: heat recovery condenser; V: motorized valve; T: temperature

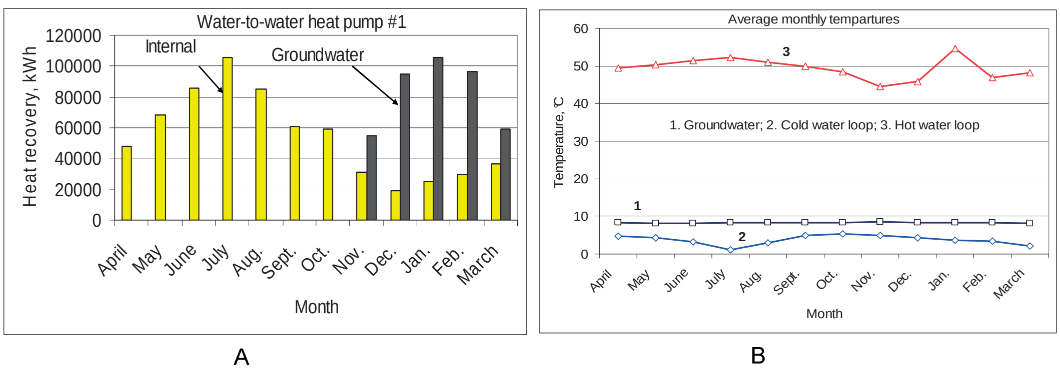


Figure 5 – Open-loop GSHP system with "artificial" cooling charge. A) Monthly share of internal gains and groundwater energy; B) Average monthly temperatures of groundwater, cold and hot water

Such a large open-loop groundwater GSHP system provides high energy performances in heating and cooling modes, while operating issues related to the groundwater chemical properties, to quality of underground piping and submersible pump materials, and to the periodical maintenance of the heat recovery heat exchanger are relatively easy to fix (Minea, 1997).

Domestic hot water heating

Domestic hot water is frequently prepared with air-to-air heat pumps providing heating, cooling and hot water preheating with desuperheaters (Figure 6, option A). In the case of water-to-water loop-connected heat pumps (Figure 6, option B), hot water is prepared in condensers linked to storage tanks by the aid of small circulating pumps (P). Depending on the brine entering temperatures, domestic hot water temperatures up to 70°C with COP in the range of 3 to 5, may be provided.

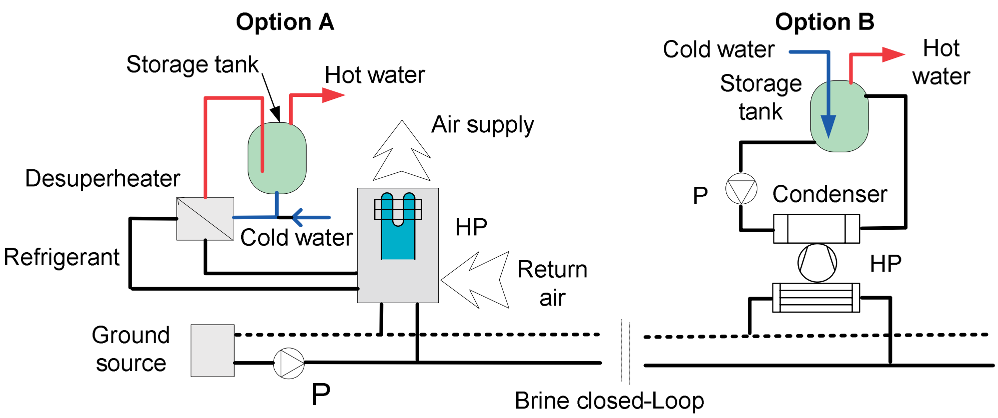


Figure 6 – Domestic hot water heating systems. Option A: air-to-air heat pump with desuperheater; Option B: water-to-water loop connected heat pump; HP: heat pump; P: circulating pump

Figure 7 represents a mono-fluid, multi-function 8.7-kW (heating capacity) ground source heat pump prototype with desuperheater (GEOPAC-LTE). Its main operating functions are the space heating by direct condensing radiant floor, space heating and cooling/dehumidification with refrigerant-to-air coil, and simultaneous domestic hot water preheating with refrigerant-to-water desuperhester and thermal storage tank (Minea, 2005).

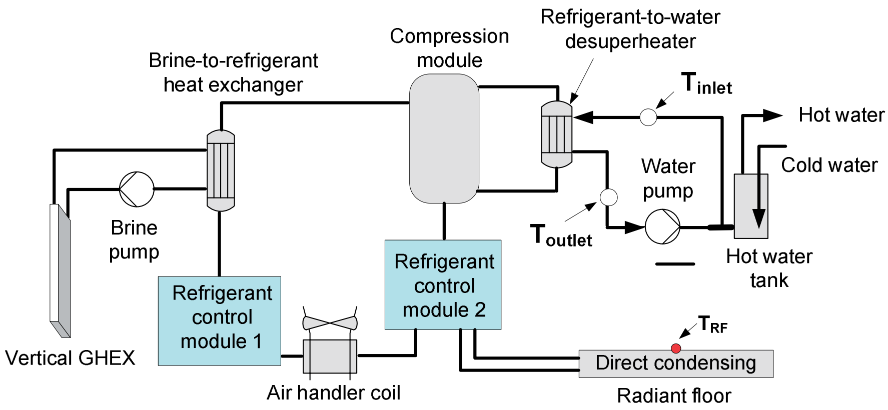


Figure 7 – Multi-function ground source heat pump GEOPAC-LTE: principle of refrigerating circuits and controls

In the heating mode with direct condensing radiant floor, the temperature of the concrete radiant floor surface (T_{RF}), up to 35°C, ensures homogeneous vertical air temperature distribution and acceptable indoor thermal comfort (Figure 8, A). In addition, the refrigerant (R-410A) discharge superheated vapour entering the desuperheater at temperatures as high as 100°C, provides domestic hot water up to 50°C with constant flow rate of 3 L/min (Figure 8, B).

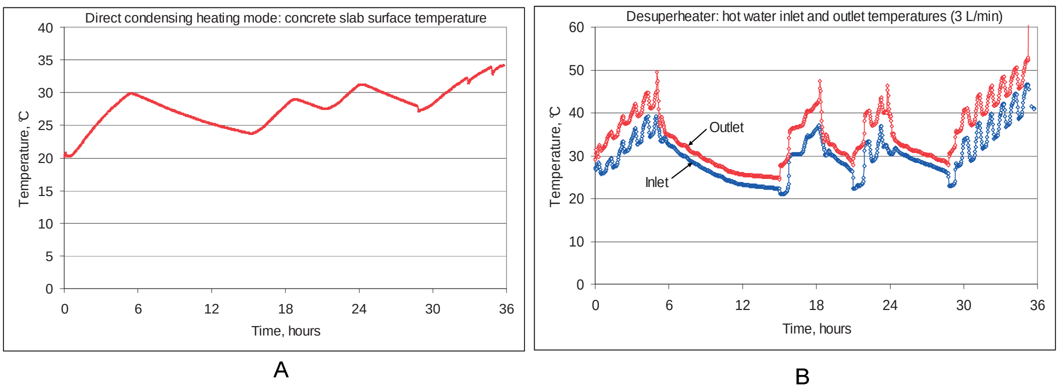


Figure 8 – Multi-function ground source heat pump GEOPAC-LTE. A: surface temperature of the concrete slab; B: domestic hot water temperatures entering and leaving the heat pump desuperheater

Make-up air preheating

In cold climates, the outside make-air heating charges are very high in large buildings. They can be substantially reduced by using efficient heat recovery devices. Figure 9 represents an improved make-up air conditioning system including passive solar walls, exhaust air heat recovery heat exchanger, back-up heating coil and geothermal brine-to-air heat pump (Harouni, 2002). The solar walls, simple, efficient and cost effective devices, use perforated-plate absorbers and are relatively easy to install or retrofit. They are incorporated in large buildings within minimum additional capital costs, and can take as little as 2 years to pay back the initial investment. The exhaust air heat recovery devices generally are enthalpy rotary wheels or heat pipes heat exchangers. Rotary wheels are available in Canada with typically effectiveness of 65% to 85% at 3 m/s face air velocity. Their effectiveness is modulated by varying the rotational speed from about 6 to 12 RPM. The back-up heating devices generally are electric or natural gas-fired boilers.

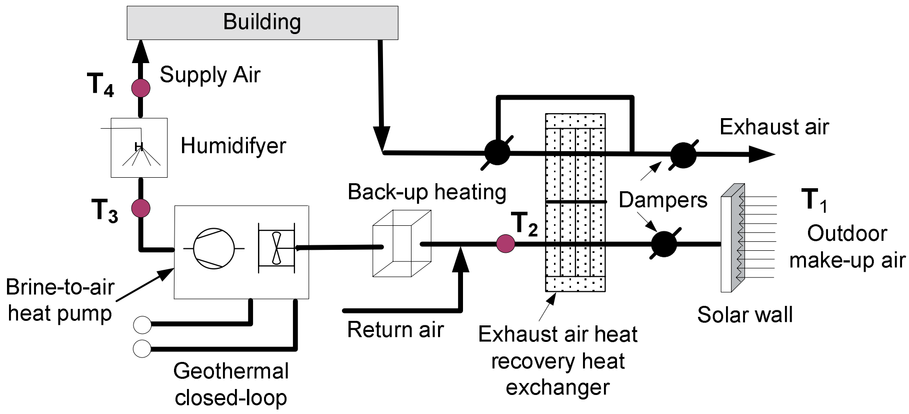


Figure 9 – Make-up air preheating/air-conditioning system. T: temperature

The brine-to-air heat pump may contain single-stage, double-stage, two parallel or variable speed compressors in order to modulate the heating/cooling capacity. Such a GSHP system with vertical ground heat exchanger and make-up air preheating system was implemented (Gastaldy, 2004) and experienced in Canada (Minea, 2006). Figure 10 represents the variation of air temperatures through the air preheating system during a typical cold climate winter week. It can see that, even when the outdoor temperature drops below -25°C, the air temperatures reaches 30°C prior being supplied to the return ducts. During the weekend, i.e. the last two days in Figure 10 when the building is unoccupied, the make-air system is shut-down. The specific annual consumption of the building (school) attained 0.251 GJ/m^2/year, which is 67% lower than the provincial (Québec) educational sector average consumption. The simple pay-back period of the entire geothermal system with vertical ground heat exchanger was estimated at 7.4 years, and the building has been classified as the most energy efficient school in Canada (Minea, 2005).

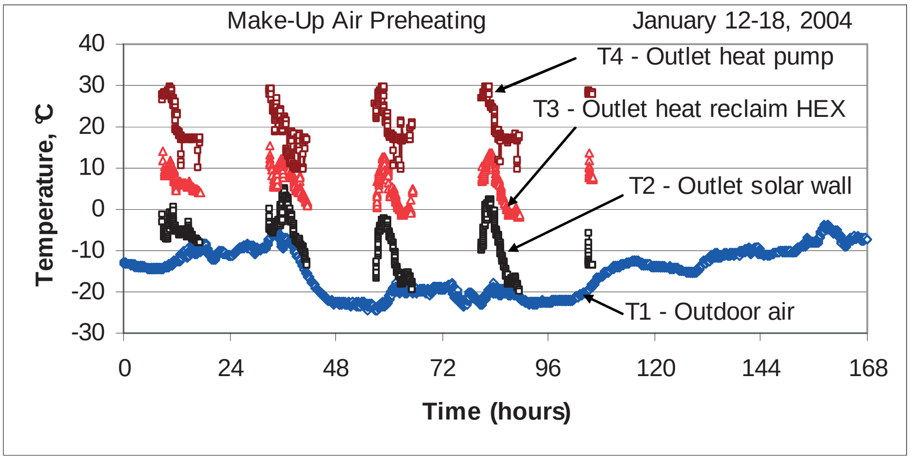


Figure 10 – Make-up air preheating/air conditioning system. NOTE: for temperatures T_1, T_2, T_3 and T_4 – see **Figure 9**

Solar energy

In regions with average annual solar gains of 1 000 kWh/m^2 or more, passive solar collectors may contribute at preheating the geothermal fluid. Moreover, the soil could be used as a seasonal storage mass with high thermal inertia. The example #1 in Figure 11 integrates low temperature solar captors, a thermally-driven (Diesel motor) heat pump, a vertical ground heat exchanger and an oil-fired back-up boiler. The scope of the solar collectors is to recover solar energy when the temperature of the geothermal brine is lower than the solar panel surface temperature.

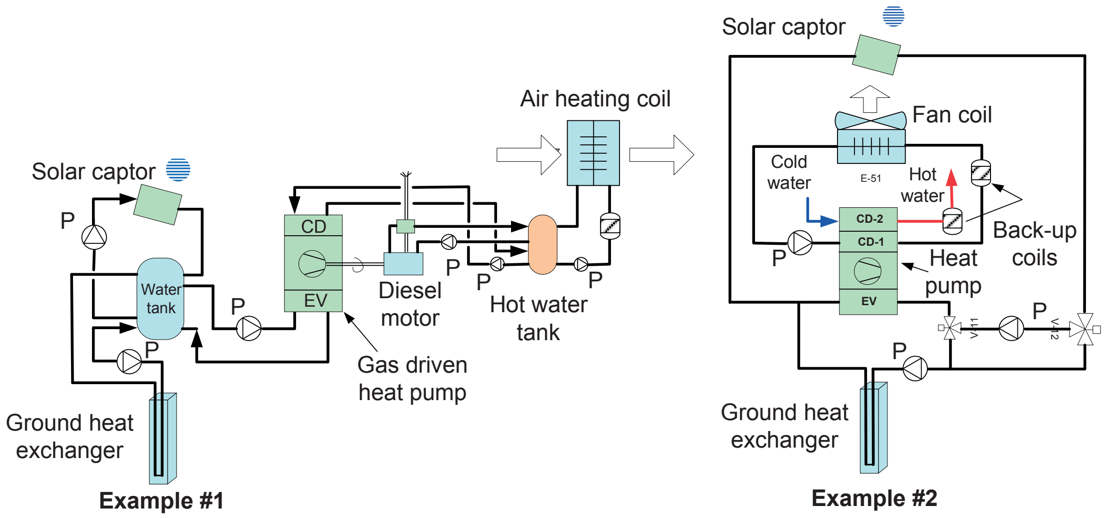


Figure 11 – Combining ground and solar energies in large GSGP systems. P: circulation pump; EV: evaporator; CD: condenser

By combining the ground and solar energy and heat recovery from the engine and combustion gases, it is possible to cover a high percentage of the building annual heating demand. The cost of the solar panels and of the heat pump may attain up to 55% of the system total cost, and the water storage tank with accessories – up to 20%. The average thermal efficiency of the solar collectors may reach 42% when the panel surface temperature is of 25°C or higher. The seasonal coefficient of performance of the heat humps generally is high, between 3.5 and 4.0. Other large GSHP systems (Figure 11, example #2) may differently combine geothermal and solar energies for space and domestic hot water heating purposes. In this case, the electrically-driven heat pump contains two condensers for heat recovery purposes. When solar energy is available, the 3-way valves allow operating the system with this renewable energy source. When the solar energy is insufficient, geothermal energy system is activated alone or in combination with the solar collectors. The space heating system is a low temperature distribution water system (fan coils) with temperatures varying between 30°C and 35°C. Electrical boilers may be used as back-up heaters for domestic hot water and space heating water. The seasonal energy performance factors may vary from 2.5 to 3.0 depending on considered components (heat pump alone or heat pump with brine circulating pump and/or back-up heating coils).

Geothermal direct cooling

Another efficient use of the ground as heat sink is the direct (free) cooling. When the temperature of the geothermal fluid coming from the ground coils or from the groundwater wells is less than 10°C, an opportunity exists to stop the heat pumps in cooling mode and directly cool and dehumidify the building. At temperatures higher than 10°C, effective dehumidification is not possible and the brine or groundwater can be used only to pre-cool the return air. Such energy improvements may be realized by using brine-to-air free cooling heat exchangers on the outside air main duct or by installing additional free cooling brine-to-air coils upstream of each heat pump interior condenser/evaporator coil (Figure 12). It was be estimated that in Canada the increased cost for the brine-to-air (or groundwater-to-air) free cooling coil, three-way motorized valve and necessary controls is in the range of 100 to 150 US$ per 3.5 kW of cooling capacity (2008) (ASHRAE, 2004).

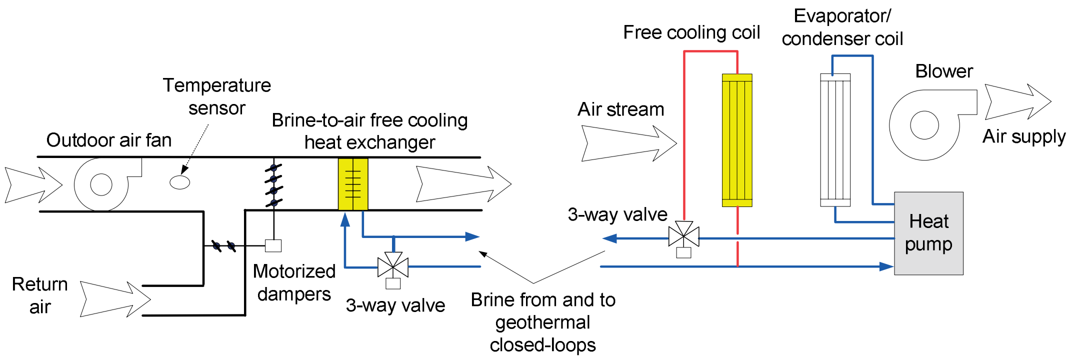


Figure 12 – Direct (free) geothermal cooling systems

Radiant floor heating and cooling

In some applications (retails stores, offices) direct radiant floor heating and cooling with geothermal fluid is possible. In this case, brine-to-water heat pumps are connected on a reverse building brine closed-loop and to the ground heat source/sink heat exchanger (Figure 13). The system can operate in both geothermal heating and cooling by using radiant floors. The direct cooling circulation pump (DC-P) is operating in geothermal cooling mode only, while the heat pump small circulating pumps (**P**) are running in geothermal heating mode.

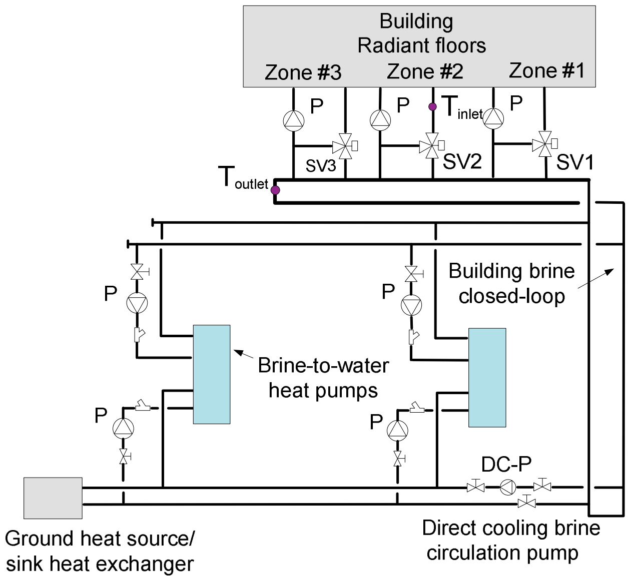
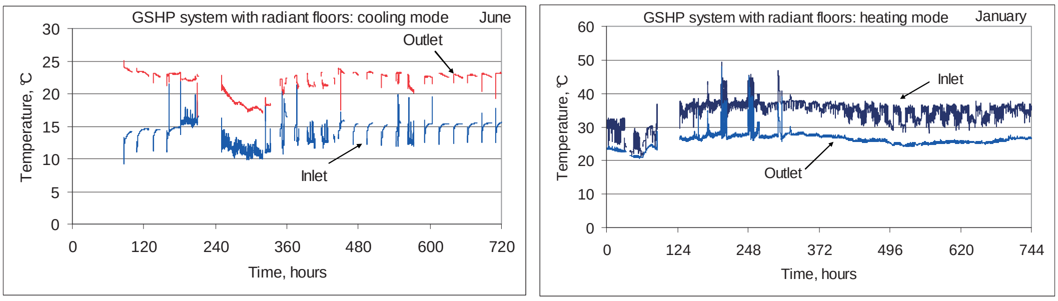


Figure 13 – Large GSHP system with radiant floor geothermal heating and cooling. P: heat pump's circulation pump; DC-P: geothermal direct cooling circulation pump; SV: solenoid valve; T: temperature sensor

Such a GSHP system was designed and implemented in a new Canadian retail store (Genest and Minea, 2006). In this application, rigorous temperature and humidity controls were provided in order to prevent water vapour condensation on the floor surfaces. As a result, in geothermal cooling mode, the brine temperatures entering the building radiant floor zones (T_{inlet}) never dropped below 10°C (Figure 14, A). In the heating mode, by modulating the zone solenoid valves (SV), the brine has entered the zone radiant floors at around 38°C and provided normal indoor comfort (Figure 14, B).



A B

Figure 14 – Large GSHP system with radiant floor geothermal heating and cooling – brine temperature. A) cooling mode; B) heating mode

The specific energy consumption (133.1kWh/m^2.year) of the new Canadian retail store (Figure 15) was of the same order of magnitude compared to three other high-performance North-American commercial and institutional buildings (Torcellini, 2004). Compared to an all-electric reference building designed according to current Canadian norms, which would have a simulated energy consumption of 466kWh/m^2.year, this performance represents 71.4% reduction in store annual specific energy consumption (Genest, Minea 2006).

Cost reduction by design

One of the most significant barrier to market penetration of large GSHP systems in Canada is still the cost of installing the vertical ground heat exchangers. It varies with the drilling conditions and the experience of the contractor and equipment capability. Typical ground loop installation costs for clay, sand and soft rock, vary in the range of 46 to 59 US$/m (2006). This includes 78.1-m borehole depth with 150-mm diameter boreholes, 11/4” vertical U-tube, backfilling, bentonite grout, 12.5-m casing and the ground-loop purge. The upper cost limit may be exceeded if the contractor has high travel cost and/or is inexperienced, if entire boreholes must be grouted, and if labour rates are higher than average rates.

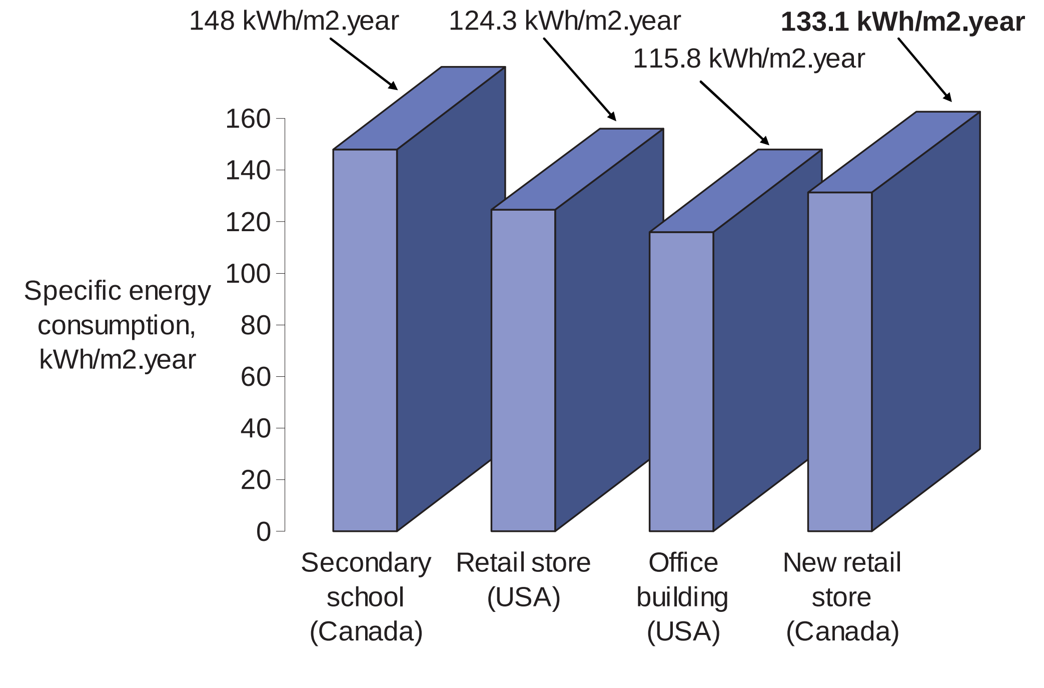


Figure 15 – New Canadian retail store: comparison of specific annual energy consumption with three high-performance North American large buildings

In addition to presented design improvements, several other suggestions may be formulated for reducing the costs of large systems by design. For example, the configuration of large GSHP systems has to not be complicated by multiplying the number of zones, motorized valves, circulating pumps, storage tanks or sophisticated control strategies. It is also indicated to specify several smaller high-efficiency single-stage heat pumps because the economy scale normally associated with larger units seems not provided with large commercial/institutional GSHP systems. Reducing the ground heat exchanger and the indoor distribution system costs may result in more substantial global cost reductions. For reducing the ground coil cost, it is important to determine the ground type, moisture content and thermal conductivity, static groundwater level and difficulty of drilling, as well as calculating the necessary ground heat exchanger length with efficient design programs. For example, if there is a high rate of groundwater movement on the site, it is appropriate to reduce the minimum distance between boreholes up to 4.6 meters. Finally, even if the use of concrete pile foundations of large buildings as heat exchangers is at the beginning, this alternative has to be more and more considered in the future.

Conclusions

From a technology standpoint, the ground-source heat pump industry has matured in Canada, but improvements of large GSHP pump system by design are still possible and necessary. This paper presents a number of design improvements as applied or intended to apply in Canada, aiming at reducing the GSHP systems initial costs and annual energy consumptions. The present dynamism and the future growth rates of Canadian geothermal industry have to be supported by more research efforts especially involving the development of advanced ground heat exchangers, efficient design criteria and lower cost techniques for boreholes drilling and ground heat exchangers construction.

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Application of ground source heat pumps for air conditioning of greenhouses

Hikari Fujii, Kunio Ohyama, Japan

High energy costs for heating greenhouses have been a serious problem in Japan due to increased oil prices. Field tests have been carried out in a greenhouse since 2007 in order to evaluate the applicability of ground source heat pump (GSHP) systems to greenhouses. The system consists of two heat pumps of 10 kW heating/cooling capacity and four vertical ground heat exchangers of total 240 m. COPs of heating and cooling operations ranged between 4-6 and 4-5 respectively, demonstrating that the systems could significantly reduce CO_2 emission and energy costs.

Introduction

Due to the recent high crude oil prices, fuel costs for heating greenhouses are becoming a serious problem among the greenhouse farmers of Japan. GSHP systems, which are known to be highly energy-efficient and environmentally-friendly, could be one of the most promising replacements of conventional fossil-fuel based heating systems, if the payback period of the relatively high initial cost is short enough. The importance of the agricultural use of GSHP systems has been recognized in the past few years, but the number of field applications is still limited due to the lack of field operational data.

To evaluate the performances of GSHP systems in greenhouse applications, a GSHP system was installed in a 105 m2 greenhouse in Fukuoka, Japan in 2007. Before the air conditioning tests, a thermal response test (TRT) was carried out to evaluate the vertical distribution of ground thermal conductivities. Long-term air-conditioning tests were then performed, based on the actual growing schedule of the plants. Finally, the reduction of energy costs and CO_2 emissions was evaluated using the obtained field test data.

Information of GSHP system

In June 2007, a GSHP system was installed in a 105 m2 greenhouse in

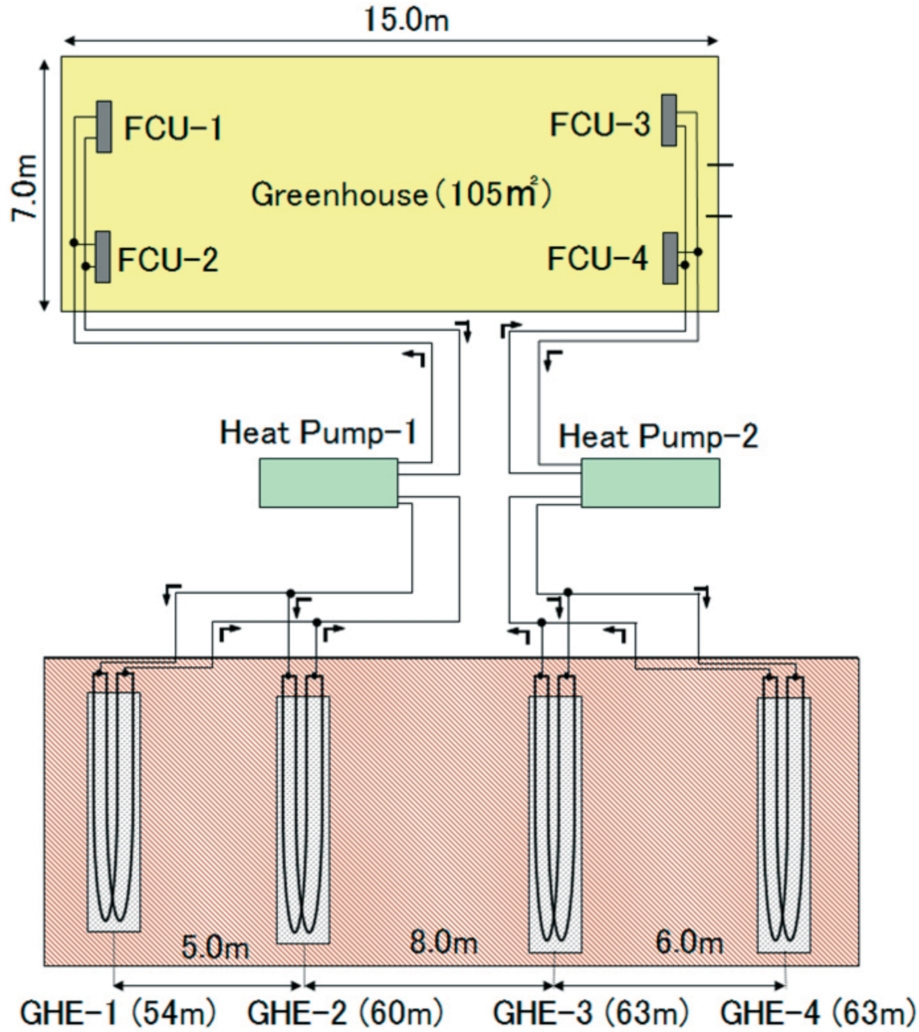

Figure 1: Schematic of GSHP system

Maebaru City, about 20 km west of Fukuoka City, Japan. Maebaru City is located in a relatively warm region of Japan; having an average temperature from 2003 to 2007 of 16.6 °C. The geological structure at the location consists of a thin surface layer of soil, 8 m thick, overlying solid granite. Past groundwater surveys in a neighbouring well showed the existence of an active groundwater flow at 30 m to 40 m depth. A schematic and a photo of the GSHP system are shown in Figures 1 and 2 respectively. Two water/water heat pumps of 10 kW heating/cooling capacity (Sunpot Co., Ltd., GSHP-1001) were installed, each of which was connected to two ground heat exchangers (GHEs) and two fan coil units (FCUs). The ground heat exchangers consisted of two sets of high-density polyethylene U-tube (double U-tube) of 25 mm ID, were grouted with silica sand of 20-65 mesh/inch. Bearing in mind the mild climate at the location and the low heating loads of greenhouses, water was used as the heat transfer medium on both sides of the heat pumps. Approximately 300 pots of orchids, which need both cooling and heating to control the timing of blooming for meeting market demands, were raised in the greenhouse.

Figure 2: Photo of GSHP system under construction

Thermal response tests

In June 2007, we carried out a thermal response test on GHE-3. During the test, we measured the vertical profile of ground temperatures using an optical fibber thermometer to determine the vertical distribution of thermal conductivities. Heat medium (water) was circulated through one of the two U-tubes for three days with a heat load of 64.0 W/m, followed by an observation period of five days. The average water circulation rate was 20.9 l/min. Using a conventional semi-log plot (time vs. average fluid temperature), the thermal conductivity of the ground was estimated as 2.74 W/(mK), which is within the common range of the thermal conductivity of granite. Figure 3 shows the vertical distribution of ground thermal conductivities, calculated using the measurement of the optical fibber thermometer. Since soils generally show lower thermal conductivities than rocks, the low thermal conductivity (less than 2.0 W/[mK]) of the soil layer above 8 m depth is considered reasonable. Higher thermal conductivities were observed in the granite body, especially between the depths of 30 m and 40 m, where groundwater flow was estimated to exist. The average thermal conductivity was calculated as 2.56 W/(mK), which well agrees with the result of conventional plot (2.74 W/(mK)).

System performance and cost evaluation

The GSHP system started operation in August 2007 and has been running without major problems. The system performances in the cooling and heating modes, and cost evaluation of the GSHP system using the actual operation records, are discussed below.

In the cooling mode, greenhouse temperatures were controlled as 25 °C and 18 °C during the day and night respectively. The temperature of cold water supplied to the fan coil units was fixed at 10 °C. Figure 4 shows the COPs of heat pump no. 2 (HP-2), average heat exchange rates at GHEs and the ambient temperatures during cooling operations. COP ranged mostly between 4 and 6, while SCOP was lower than the COP by 0.5-1.0. When ambient temperatures were high and the cooling load was high, the COP tended to decrease due to the increase in ground temperatures. Before September 15, 2007, when maximum daily temperature frequently exceeded 35 °C,

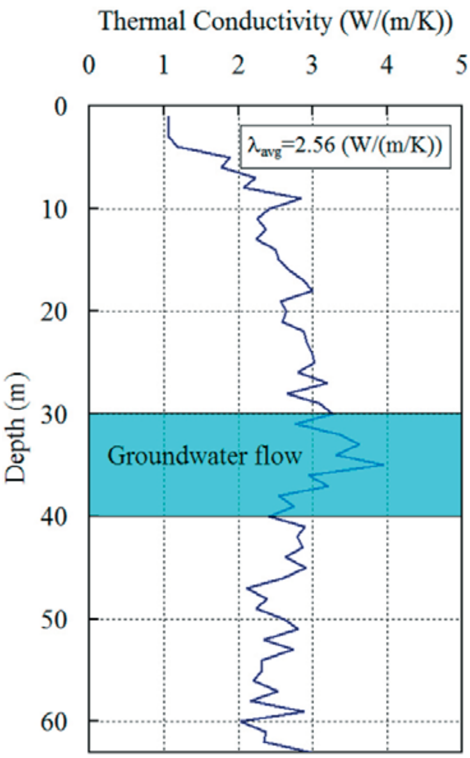

Figure 3: Estimated distribution of thermal conductivities

the average of operating hours of the system and heat disposal rates were 16.9 hours/day and 60 W/m respectively. Though the heat exchange rates were quite large due to the high cooling load of the greenhouse, the high thermal conductivities of the granite and the thermal advection effect of groundwater flow maintained high COPs throughout the cooling operations.

In heating operation, temperatures in the greenhouse were set as 25 °C and 20 °C during the day and night respectively. The temperature of heated water to the fan coil units was set at 40 °C. Figure 5 shows the COPs of HP-2, average heat exchange rates at the ground heat exchangers and ambient temperatures during the heating operations. In January and February, 2008, the average operating hours of the system was 20.6 hours/day, which is much longer than that in residential use, since plants need to be cared for all the time. As ambient temperatures decreased, heat exchange rates increased due to the increase of heat loss from the greenhouse to the atmosphere. Though a high heat exchange rate, around 40 W/m, was required of each ground heat exchanger for long operation hours, the temperatures of the heat transfer medium to heat exchangers remained above 2 °C because of the favourable thermal properties of the ground. High COPs of 4-5 were obtained throughout the heating period due to the use of water as heat medium, which has a better heat transfer coefficient than anti-freeze, and the choice of low temperature (40 °C) for the heating water to fan coils.

On the basis of the measured COP of the GSHP system, the emission of CO_2 and energy costs were compared with the case of using air-source heat pumps and kerosene boilers. The size of the greenhouse (105 m2) and other operational conditions, were set as equal to the field tests. The COPs of an air-source heat pump were set as 2.8 in cooling mode and 3.2 in heating mode, assuming ambient temperatures of 35 °C and 5 °C respectively. The prices of kerosene and electricity were set as 1.0 USD/litre and 0.14 USD/kWh (1 USD = 90 JPY) respectively. Figure 6 shows that CO_2 emissions and energy costs were less than half those of using air-source heat pumps in the summer and kerosene boilers in the winter.

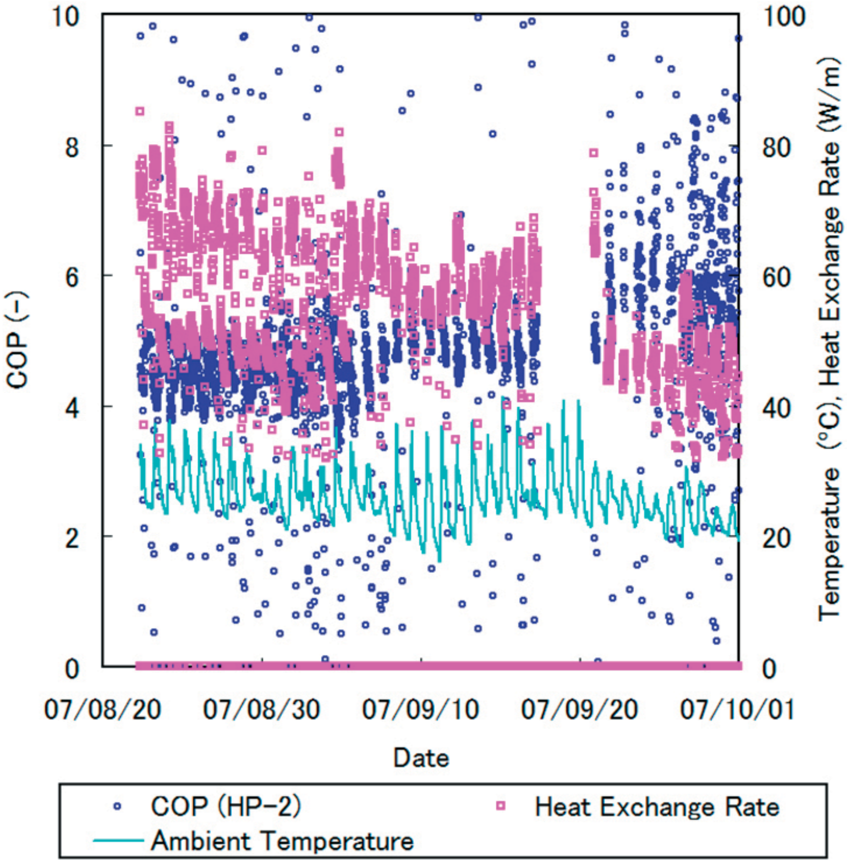

Figure 4: COP, heat exchange rate and ambient temperature in cooling mode

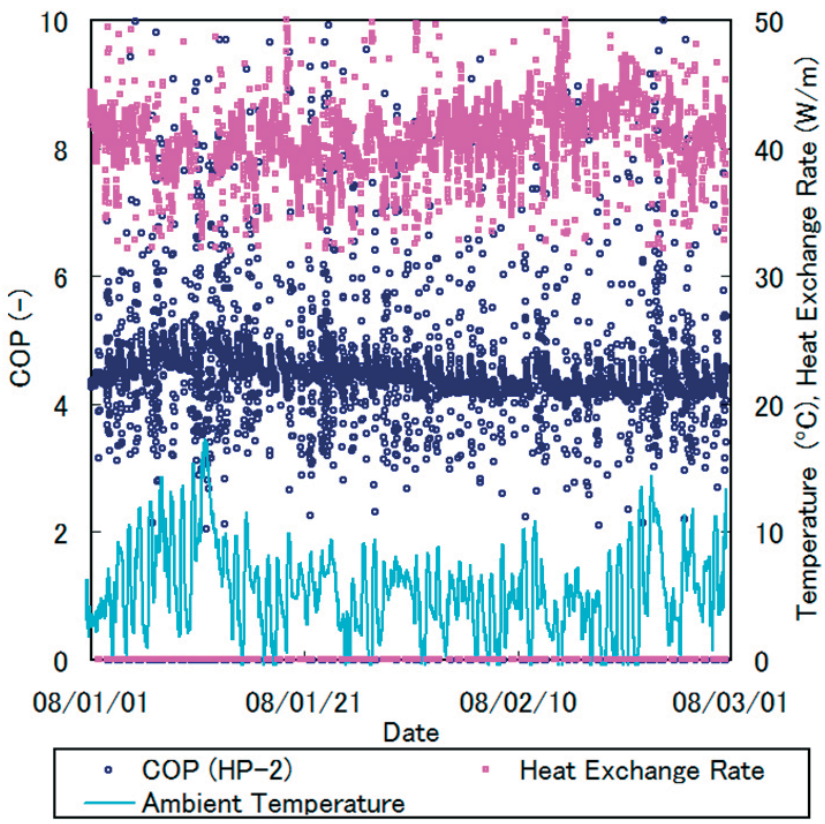

Figure 5: COP, heat exchange rate and ambient temperature in heating mode

The cost payback period of GSHP systems was estimated as 7.8 years, based on the actual installation cost of the system and the prices of heat pumps and boilers. The cost payback period was relatively short due to the high COP of GSHP systems and the high oil prices, though drilling costs of ground heat exchangers in Japan are among the highest in the world.

Conclusions

For evaluating the applicability of ground source heat pump (GSHP) systems in greenhouses, field tests were carried out in a GSHP system in Kyushu, Japan from 2007 to 2008. The system consists of two heat pumps of 10 kW capacity and four ground heat exchangers of a total of 240 m deep. A thermal response test was carried out using optical fibber thermometers to estimate the vertical distribution of ground thermal conductivities. The interpretation results agreed reasonably well with the local geological and groundwater information.

Through the summer of 2007 and the winter of 2008, the measured COPs of the GSHP system ranged between 4-6 and 4-5 respectively. Evaluations of the field test results showed that GSHP systems can reduce both CO2 emissions and energy costs by 50 % in comparison with conventional heating/cooling systems. Similarly, the cost payback period, in comparison with conventional systems, was estimated as relatively short, at 7.8 years, because of the high COP of the GSHP system and high oil prices.

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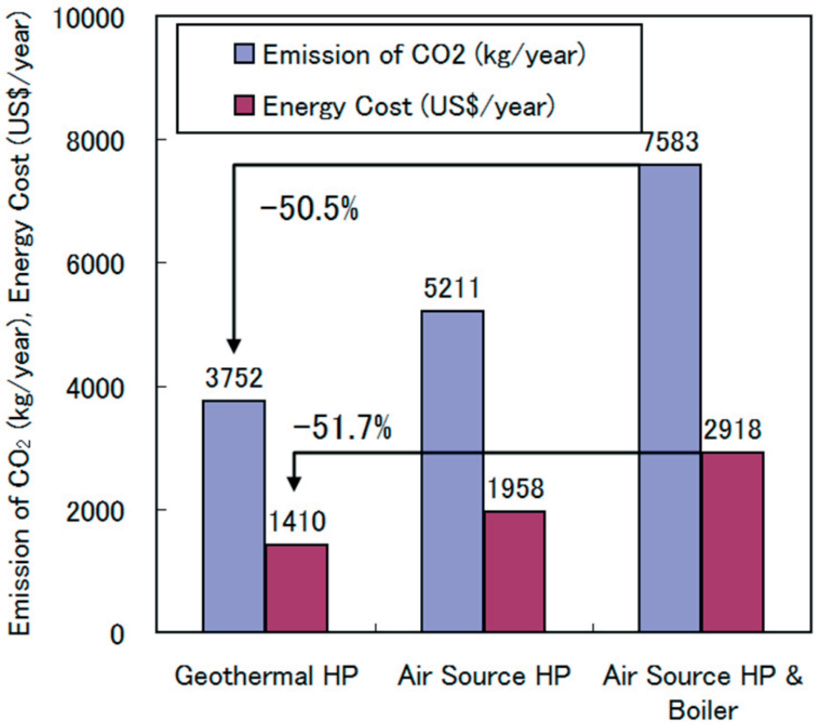


Figure 6: Evaluation of CO2 emission and energy cost

GSHP in Japan

Katsunori Nagano, Professor of Hokkaido University, Japan

1. Introduction

It is undoubted that utilizing high efficient heat pump systems is the most reliable and the most realistic method in order to reduce the energy consumption for the HVAC and hot water supply in not only the consumer sector but also the agriculture and the industrial sector which needs both heating and cooling. The high performance heat pump utilizes renewable energy sources and waste heat sources, with considerable potential for reduction of CO_2 emissions and running costs. Particularly, when we use the ground as heat source for the heat pump, the ground works not only as the heat source/ heat sink but also as a thermal energy storage medium, and an increase of SPF due to the storage effect can be expected. This is the great advantage of the ground thermal energy storage (GTES) system.

The Japanese government has two policies on the reduction of CO_2 emissions related to uses of the heat pump system. One is "New Energy" policy and the other one is "Energy Conservation" policy. The use of ground water, geothermal energy and thermal energy in the ground extracted by the ground heat exchanger are categorized in the energy conservation policy. The ministry of Economy, Trade and Industry of Japan (METI) operates a number of measures to promote GTES according to this policy [1], [2]. On the other side, the ministry of the environment (MOE) has own measures related to reduce CO_2 emissions and reduce heat island phenomena through the GTES [3]. In addition, many institutes and organization have continued to conduct the research works, development of the innovative GTES and education activities of the GTES according to their conviction that the GSHP system can make the great contribute to the environment and our life in Japan.

Through the above mentioned measures and activities, the use of ground thermal energy has been gradually recognized as green energy and have been realized the GTES including the ground source heat pump system has the large potential to reduce CO_2 emissions. This wave has occurred from the north, but now is spreading to the whole of Japan.

In this paper, the outline of current technologies and measures related to GSHP are explained and the future prospect of GSHPs contributions in Japan is described.

2. The GSHP's Market in Japan

Figure 1 shows the market trends of sold GSHP units in Japan [4]. After the compact heat pump unit was developed and released to the market in 2004, the number of sold heat pump units has risen dramatically. In 2006, it reached 120 including the snow melting system. However, the current GSHP market in Japan is still at an early stage.

The first research activities in Japan from the late 1950's until the early 1960's followed the pattern of those in the USA, because no air source heat pump existed and ground water was the only heat source for heat pumps at that time. However, research stopped as a result of low-price fuel oil for heating purposes, and the development and penetration of split-type air conditioners. After the second oil crisis, a small private enterprise, was established in Hokkaido in the early 1980s, developed the ground source heat pump system that could provide space heating, cooling and domestic hot water. The company installed about a dozen GSHP systems, using coaxial-type ground heat exchangers, and supplying heat to a condominium, a hospital, some small hotels and some detached houses some years after the oil crisis. (Figure 2). In addition, research into UTES was carried out at some universities and research institutes. This was the first success story in Japan, but the work was again discontinued due to the drastic drop of the oil price. However, only Prof.

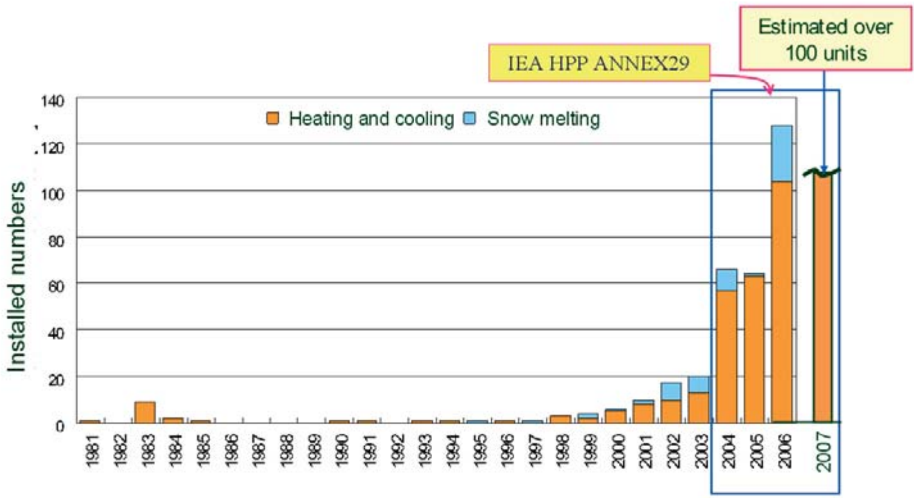


Figure 1 The market trends of sold GSHP units in Japan

Ochifuji's research group at Hokkaido University and Hokkaido Electric Power Company, Inc. (HEPCO) had continued research activities, joining IEA HPP ANNEX 15 in connection with direct expansion systems [5]. The author was involved in these projects. Then, in the middle of 1990s, a private company in Hiroshima province started in the business of GSHP in cooperation with a heat pump manufacturing company in Switzerland [6]. The company has been successful in introducing GSHP systems in public spas and public indoor swimming pool facilities (Figure 3). The GSHP system met the Mayor's requirement that heat source equipment must not emit any air pollutant. This was the second success story. At the same time in Tohoku area, the first GSHP snow melting system was installed under a public road. Since then, a few dozen GSHP snow melting systems have been installed in Japan. However, installed numbers in a year were still low, due mainly to high initial cost.

The breakthrough occurred in 2004, when the first domestic mass-produced compact heat pump unit was developed and released by SUNPOT Co. Ltd. [7] in collaboration with Nagano's research group at Hokkaido University. Following this machine, a new reversible GSHP unit developed by the same company was the big trigger of the second breakthrough in 2006. As mentioned above, GSHPs have been gradually recognised as a renewable energy system, not only by engineers and architects, but also by administrative officers concerned with energy conservation policy. GSHPs have been installed in various fields, such as school buildings, hotels, a library, museums, hospitals, shopping centres, an airport terminal, a district heating and cooling system and greenhouses.

Figure 2 A condominium provided space heating, cooling and hot water supply by the GSHP operated from 1981 in Sapporo

Figure 3 The Spa and pool facility operated by GSHP in Miyoshi city, Hiroshima prefecture [6]

Figure 4 A compact inverter controlled GSHP unit of the maximum heating capacity of 6.2 kW with a free cooling circuit from 2004 (SUNPOT Co. ltd. cooperated with Nagano's laboratory, Hokkaido University)

3. GSHP technologies in Japan

3.1 Heat pump unit

(1) ~10 kW for domestic purposes

There are a few small companies and some workshops which provide conventional On-Off type heat pumps. They have helped to cultivate the GSHP market in Japan from about 30 years ago, and still produce heat pumps to special order. But they were not enough seriously to develop the GSHP market. In 2004, SUNPOT Co. Ltd. [7], which has a countrywide business network in Japan for small heating systems, developed a compact heat pump unit with an inverter-controlled variable-speed compressor and two brushless DC circulating pumps inside the body of the unit (Figure 4). There is therefore no need for a buffer tank or external circulation pumps, and installation is very fast and straightforward. In addition, the unit has a free cooling circuit mode which can be selected electrically. Following this machine, a new reversible GSHP unit developed by the same company was the big trigger of the second breakthrough in 2006 (Figure 5). The heating and cooling output capacity can be varied from almost 3 kW to 10 kW. The unit can also be installed outdoors. This is a commercially important requirement in Japanese market. This unit is available in sizes suitable for a small house up to a commercial building, when multiple units are used. Nowadays, these SUNPOT's GSHP units have captured almost the entire GSHP domestic housing market in Japan.

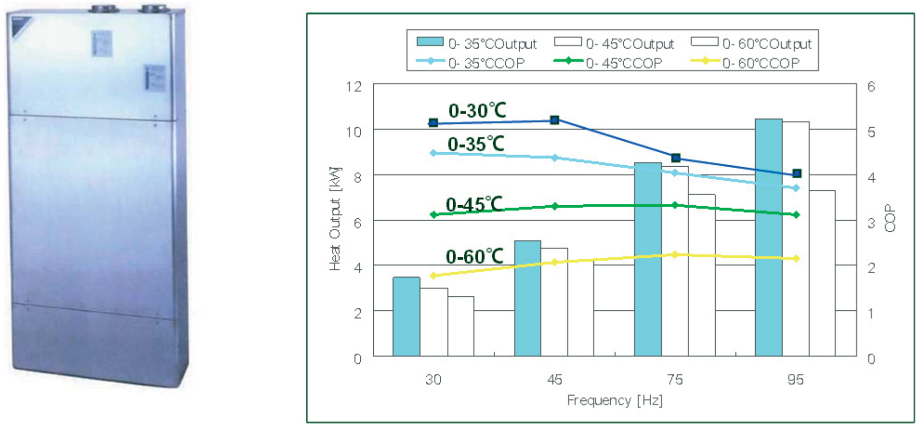


Figure 5 A compact inverter controlled reversible GSHP unit of the maximum heating and cooling capacity of 10.0 kW from 2006 (SUNPOT Co. ltd. cooperated with Nagano's laboratory, Hokkaido University)

(2) 10kW ~ 350 kW for small buildings

When a low supply temperature (less than 35 °C) can be used for space heating, the general water-cooled brine chiller can be used. Many kinds of chillers in this class are made by major electrical appliance manufacturers in Japan, such as Mitsubishi Electric, Hitachi, Toshiba-Carrier and others [8], [9], [10], [11]. Multiple units can be linked by quantity control. On the other hand, Daikin industries has a water-source air conditioner unit for commercial buildings, which can be used with ground heat sources. In addition, Zeneral Heat Pump Industries has been one the pioneer companies in this field, and has produced high performance and multifunctional heat pump units [12]. This company also provides unique products, such as a hybrid heat source heat pump which has two heat exchangers: one for a water heat source, and one for an air heat source. The machine can automatically select whichever heat source that provides the better performance (Figure 6).

Figure 6 A hybrid heat source heat pump which has two heat exchangers for water heat source and for the air heat source (Zeneral heat pump industries, co., ltd.)

(3) 330 kW ~ for commercial building purpose and other large systems

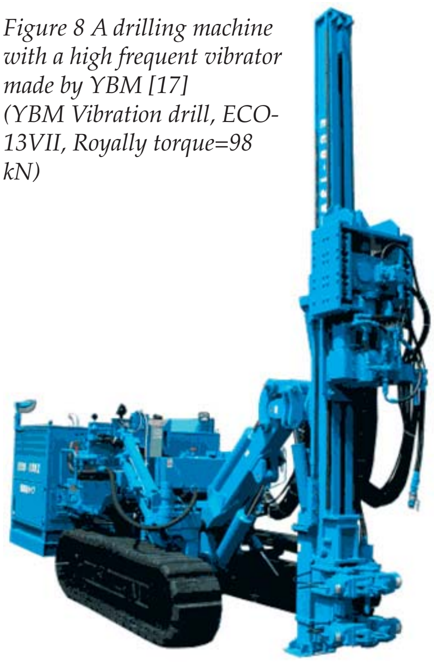
An ultra-high-efficiency water-cooled semi-hermetic screw heat pump chiller made by KOBELOCO is popular, and has been available in Japan since 2003 (330 kW ~ 3200 kW outputs available) [13]. It uses HFC 407E as the refrigerant, uses the Lorenz cycle, and can deliver a very high COP. Below 30 % load, COPs of around 7.0 are possible, with a 30 °C return temperature on the secondary side and 7 °C supply temperature of the chilled water. Recently, the company has released a new model of this series which can deliver a water output temperature of up to 70°C on the secondary side (Figure 7).

For larger systems, several inverter-driven centrifugal compressor type chillers, with very high efficiencies under part load, have recently become available in Japan up to 7,500 kW. manufacturers include Mitsubishi Heavy Industries [14], KOBELCO [13], Hitachi [9], Toshiba Carrier [10], Ebara Corp. [15], Train [16] and others.

3.2 Drilling machines and drilling costs

There are several drilling machinery companies in Japan, such as YBM [17], TOA-TONE BORING [18], KOKEN BORING MACHINE [19] and others. Recently, high-speed low-noise drilling machines, using high-frequency vibrators on the drilling head, have become popular in Japan (Figure 8). These machines can drill a 150 m deep borehole in two days,

Figure 8 A drilling machine with a high frequent vibrator made by YBM [17] (YBM Vibration drill, ECO-13VII, Royally torque=98 kN)



including the setting up and dismantling times, even with the complex geological conditions of Japan.
The drilling cost of boreholes depends on the number of holes at a given site, and on the province of Japan. In Hokkaido, the cost is approximately 100 USD per meter for a single borehole, reducing to less than 80 USD per meter for multiple boreholes, including the cost of inserting a single U-tube and for the back filling. This construction cost is much lower than that in Tokyo and other areas [20].

3.3 U-tubes

Two domestic companies can supply their own high-density polyethylene U-tubes in Japan now (Figure 9). INOAC Corp. produces U-tubes according to the Japanese Industrial Standards [21], and Nisshin Techno supplies U-tubes according to ISO standards [20].

Figure 9 U-tubes made by Nisshin Techno, Japan [20]

3.4 Design tool and design guideline

There is a commercial GSHP design and performance prediction tool in Japan, which was originally developed by Prof. Nagano and Dr. Katsura, of Hokkaido University [22]. It has been licensed from Hokkaido University to ZENERAL Heat Pump Industry [12], and the modified version for commercial use is now available through the company's web site(Figure 10) [23]. The main calculating engine used in the program is the convolution method of the temperature responses of a cylindrical heat source theory in an infinite solid, which is modified by a unique coefficient function depending on the depth of the borehole and the elapsed time. The major advantages of this tool are that any arbitrary borehole layouts are possible, requiring just a mouse click on the input screen, while hourly evaluation is calculated from the hourly heating and cooling demands and the selected heat pump performance, which is included in the program. The program calculates annual hourly temperature variations on the primary and the secondary side, COP, SCOP, electric power consumption and other parameters, which are displayed on the screen and stored on the hard desk as digital data. Consequently, the life cycle cost and the life cycle CO_2 emission compared with conventional systems can be calculated, and the designer and building owner can realise both the environmental and economic benefits of planned GSHP system. Up to now, about 40 sets of software have been sold in Japan. On the other hand, there is no proper official guideline for design and construction of GSHP systems in Japan. Only one published guide book, ("Ground source heat pump systems"), written by the author's group in Hokkaido University in 2007, exists in Japan [24], and is available in any book store (Figure 11).. It provides excellent descriptions of GSHP systems, not only for designers and engineers but also for

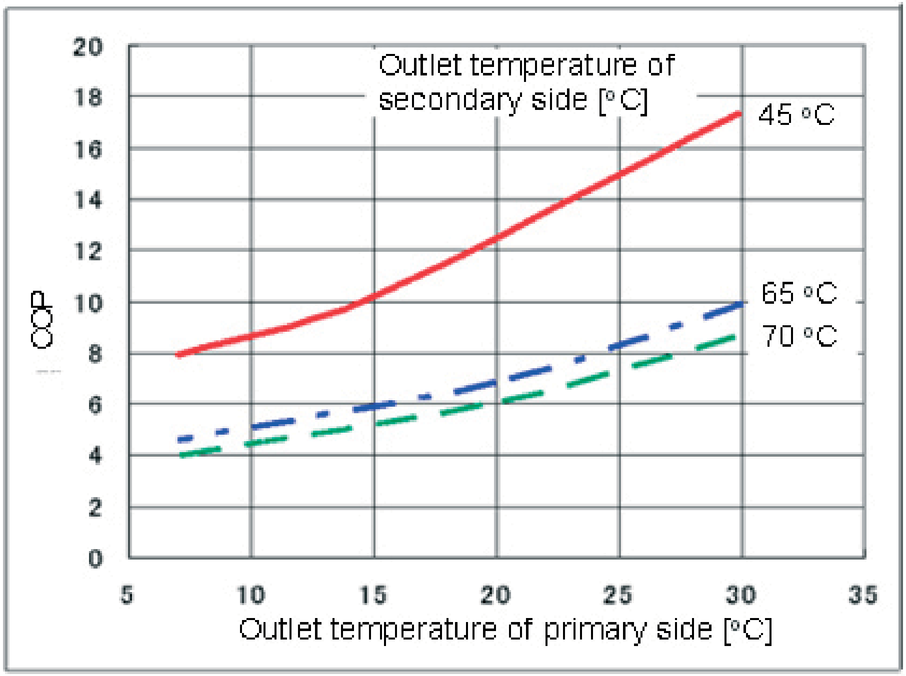


Figure 7 Performance curves of an ultra high efficiency water cooled semi-hermetic screw heat pump chiller made by KOBELOCO (http://www.kobelco.co.jp/topics/2008/01/1179343_5996.html)

Figure 10 The GSHP design and performance prediction tool, "Ground Club" originally developed by Prof. Nagano and Dr, Katsura, Hokkaido University and sold from ZENERAL heat pump industries (US Patent: US7,113,888B2, Under submission of Japanese patent No.2004-276099)

Figure 11 A book named "Ground source heat pump systems" prepared Nagano's group in Hokkaido University and published from Ohmsha (2007), [24]

building owners. On the other hand, of course, the general construction of boring, piping and electrical works should be performed in accordance with general construction regulations and rules in Japan. Small systems usually have a borehole depth as determined by an empirical maximum heat abstraction rate of about 50 – 75 W/m, as calculated from the peak demand and the predicted performance of the heat pump. However, in the case of larger systems such as "energy pile systems", the above-mentioned design tool has generally been used in Japan.

3.5 Energy piles

In Japan, there are mainly three types of building foundation piles. The first is the cast-in-place concrete pile, the second is the precast concrete pile and the last is the closed end steel pipe pile. Each pile can be applied to the energy pile system. In the case of the cast-in-place concrete pile several pairs of U-tubes are bundled on a reinforced frame on the ground (Figure 12) and then inserted in the drilled hole and backfilled with concrete. The same method is used in the European countries. In the case of the precast concrete pile, two or tree U-tubes are inserted in the opening of the precast concrete pile and then backfilled by mortal concrete. The construction procedure of the energy pile system using steel pile is shown in Figure 13. Water is filled in the steel pile and then normally two U-tubes are inserted. This has been applied in the new building of Sapporo City University and a reversible GSHP system has operated from 2006 (Figure 14).

Figure 12 Four U-tubes are bundled on the reinforced frame for the cast-in-place concrete pile

3.6 Thermal response test (TRT)

There are about 15 TRT machines in Japan and TRT is popular in the case of large GSHP system with multiple boreholes. The Japanese TRT ma-

Figure 13 The construction procedure of "Energy Pile System" using steel piles

chine is rather compact compared to the European one. For example, a TRT machine of Nagano's laboratory, Hokkaido University is very small and light weight as shown in Figure 15. It can be lifted by two men-and can be carried in a small van. The maximum heating is 5 kW (AC 220V) and it is applicable up to a 150 m long borehole. The constant temperature difference control has been added.

Figure 14 A new building of Sapporo City University installed "Energy Pile System" using 51 steel pile foundations and operated from 2006

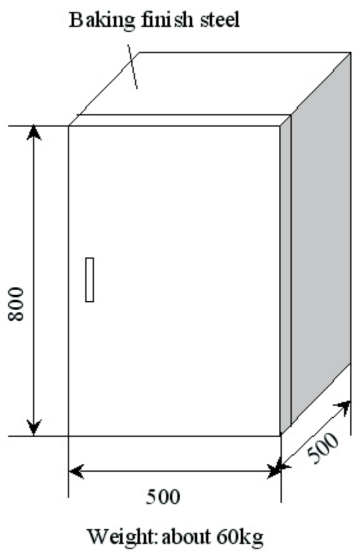
4. Electricity price for heat pumps

There are ten electric power companies in Japan which are approved by the government as public utilities for power generation, transmission and distribution of electric power. They are guaranteed regional monopolies by the government. Each utility company can set its own tariffs individually through the permission procedure by METI. This means that utility companies can offer strategic electricity rates to promote heat pumps and other electric appliances, and to help to balance day and night electricity demand.

Electricity tariffs basically consist of a demand charge and an energy charge. The monthly energy charge can be adjusted under a fuel cost adjustment factor. The demand charge is determined by the contracted ampere or power rating, while the energy charge is calculated as the product of the energy charge rate and energy consumption. There are a number of electricity tariffs available, from which consumers can choose. For example, recently a tariff menu in which the energy charge rate is varies according to the time of day has recently become popular. In the daytime, the energy charge rate is higher, but is quite low during the night (Table 1, [23]). This tariff is favourable for all-electric houses and those with heat pump systems with thermal energy storage not only for domestic hot water but also for the space heating and cooling system. On the other hand, some utility companies have special rates for snow melting systems, which are cheaper than the regular rates. TEPCO, in particular, offers these rates for electric heating systems, including heat pump users [25]. This helps the growth in GSHP heating installations in houses and for other purposes.

5. Support measures for GSHP

The new energy and industrial technology development organization (NEDO), which was established by the Japanese government in 1980, has grants available for house owners and building owners who install high energy-efficient equipment or high-performance windows and high thermal insulation in their houses or buildings, sufficient to achieve energy savings of at least 15 % of the estimated energy conservation of conventional systems. GSHP systems



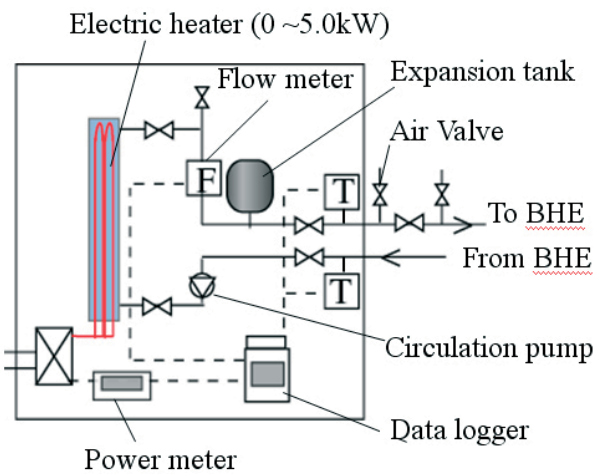


Figure 15 A compact TRT machine of Nagano's laboratory, Hokkaido University

Table 1 A tariff menu in which the rate is varying according to time in a day in Tokyo Electric Power Company, Inc. (2009), [25]

Season-and time-specific lighting ("Denka Jozu")

Recommended for residential customers who use "Eco Cute," an electric water heater, and other kinds of overnight thermal storage equipment, as well as an electric kitchen. A discount for customers with all-electric homes is also available.

			Unit	Rate(JPY)
Demand charge	Under 6kVA		(per contract)	1,260.00
	7kVA – 10kVA		(per contract)	2,100.00
	Over 11kVA		(per contract)	2,100.00 +273.00×(Demand – 10kVA)
Energy charge	Daytime	Summer	1kWh	33.37
		Other seasons	1kWh	28.28
	Morning and evening hours		1kWh	23.13
	Nighttime hours		1kWh	9.17
Discount rate	When using appliance turned on for 5 hours		1kVA	241.50
	When using nighttime heat storage devices with controlled electricity use		1kVA	136.50
	For all-electric homes, power volume fee discounted by 5% (except summer daytime hours)			
Minimum monthly charge			(per contract)	306.60

are approved as appropriate high energy-efficient equipment. If the owner's application for a grant is approved, the owner receives the grant, amounting to one third of the total investment cost, including the construction cost [25]. On the other hand, MOE has a programme to encourage the use of the ground heat sources in order to reduce CO_2 emissions and decrease the heat island phenomenon of the big cities. This assists actual measures such as subsidies for the installation of GSHP systems in public buildings and facilities, and also assists promotional activities for GSHP systems [3]. The programme provides grants to local governments who invest in GSHP system of over 50 kW heat output, amounting to half the total investment costs of the GSHP system, including secondary equipment. In addition, there is another subsidizing measure to the non-governmental local consultative meetings, which consist from multiple constitutors and can play a coordinating role in the installation of renewable energy systems including GSHPs into small buildings and private houses in the particular local community. In this case, a third of the construction costs will be covered by this program through above meetings to the building owners. The Sapporo city government has its own policy for supporting GSHP installations in private houses and buildings, and also for the installation of renewable energy systems such as solar photovoltaic systems in order to reduce CO_2 emissions [26]. Up to about 2,000 USD per application can be subsidized by this programme.

6. Promotion organizations

The Heat Pump and Thermal Energy Storage Technology Center of Japan, which was established in 1980, is the national centre of heat pump technologies and promotion, including GSHP and UTES [14]. The Centre's Research Group for Heat Pump Systems and Use of Ground Thermal Energy has conducted promotional activities for information and new technologies since 2003. Over forty private enterprises and ten public organisations are now members of this research group. Three seminars, including study tour visits and an annual conference, which is open, are held every year. The research group has been the parent of the Japanese national team of IEA HPP ANNEX 29 and IEA ECES ANNEX 21 [27].

There is also an NPO for the promotion of GTES, named "Geothermal Promotion Association of Japan". Members of this NPO were originally mainly geothermal energy and drilling companies, but now more 81 private companies and 45 organisations have joined [28].

Japan has a number of scientific associations covering GTES, such as SASHE, AIJ and others. They present GTES in their magazines, and invite GTES specialists as keynote speakers at their annual conferences.

In addition, the Ministry of Environment, the Ministry of Trade and Industries, NEDO, local governments, and Tokyo metropolitan and Sapporo city promote GTES as a green technology that can help to reduce CO_2 emissions and heat island phenomena.

7. Summary and future prospects

As described here, the GSHP market in Japan is still tiny, but can be seen to be starting to expand, particularly in the small GSHP market for housing purposes in the northern part of Japan. Current GTES technologies are almost equivalent to those of, and costs of the construction and heat pump units are approaching those in, GSHP advanced countries such as Sweden, Switzerland, Austria and Germany. On the other hand, GSHP systems in Japan are greatly assisted by favourable electricity tariffs, which mean that GSHPs are one of few realistic green technologies that c an have payback times of less than a decade. The author believes that the biggest market barrier now in Japan is just the lack of the recognition of GSHP.

The next issue in Japan is competition with air source heat pump systems. Recent air conditioners sold in Japan incorporate inverter control and can therefore operate with high efficiency in the moderate climate zone of Japan. In addition, air/water heat pump units have appeared and gradually penetrated the domestic market. Actual measured values of SPF during the heating season of units installed in houses with typical thermal insulation standards were reported above 2.0 even in the Hokkaido region. The designing ability of GSHP systems which use the ground thermal energy storage effect obtain higher SPF of the whole system than most ASHP.

Spreading the message that the GSHP can make a large contribution to the environment and our life is now a task of pressing urgency, because few people know what GSHP systems are and how they work in Japan. In addition, it is necessary to prove and to demonstrate that GSHP systems can operate without requiring significant maintenance, and with ultra-low running costs in comparison with those of conventional systems or air source heat pump systems. Environmental benefit is becoming attractive for consumers, but it is nevertheless the satisfaction of GSHP system owners that will be the most help to widespread market take-up. This means that the reliability and economic benefits of the system are essential.

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Sustainable Energy systems in New buildings – market inTROduction of feasibility studies under the Energy Performance of Buildings Directive

Svein H. Ruud, Sweden

The buildings sector accounts for 40 % of the EU's energy requirements. An estimated potential of one-fifth of the present energy consumption in this sector could be saved by 2020. To translate this potential into reduced energy consumption, the Energy Performance of Buildings Directive 2002/91/EC (EPBD) is intended to promote the improvement of energy performance of buildings. An important aspect (Art. 5) of the EPBD is that all member states are obliged to ensure that the feasibility of alternative energy systems is considered in national building codes for new buildings over 1000 m^2.

> Feasibility studies in Article 5 of the EPBD (2002/91/EC)
> [..] For new buildings with a total useful floor area over 1000 m2, member states shall ensure that the technical, environmental and economic feasibility of alternative energy systems, such as:
> - decentralised energy supply systems based on renewable energy,
> - CHP,
> - district or block heating or cooling, if available,
> - heat pumps, under certain conditions,
>
> are considered and are taken into account before construction starts

Article 5 of the Directive (EPBD) imposes obligatory consideration of the technical, environmental and economic feasibility of alternative energy systems (AES) for large new buildings. Most countries have incorporated the requirements into their national legislation. However, operational legislation, technical guidelines and support tools are not yet usually in place. At present, barriers such as higher cost, lack of knowledge, experience and confidence are hindering alternative energy systems. If Article 5 is to have a substantial impact, feasibility studies of alternative energy need to become a common part of the planning process.

The SENTRO project, recently concluded, has aimed at developing and promoting an "optimal" approach in order effectively to incorporate feasibility studies of alternative energy systems (Art. 5 EPBD) in the common building practice.

The project started with an survey on how European member states comply with the requirements of conducting a feasibility study for alternative energy systems for new buildings. The survey also asked about which policy they pursue actively to introduce this requirement. Subsequently, in the seven SENTRO countries (Denmark, France, Lithuania, Poland, Slovenia, Sweden and The Netherlands), a further survey was made of specific building practices as possible barriers for the implementation of alternative energy systems (AES). After this survey phase, tools were developed to ensure that assessment of alternative energy systems will become an integral part of the common planning process of new buildings. These tools, such as universal checklists for requirements, handbooks and flow charts, cover technical, financial and organizational aspects. The core of the project has been the testing of these tools in a field trial in the participating countries. Towards the end of the project, the experience has been disseminated to policy-makers and key actors in the building process through courses, workshops and conferences.

Results (deliverables) from the SENTRO project are:

- Information concerning the status of the feasibility study part of the EPBD in all EU-27 member states
- Insight into the barriers which are hindering the use of alternative systems and insight into possible solutions to overcome these barriers
- Supporting methods, handbook and checklist for embedding feasibility studies in common building practice
- Lessons learned from the field trial of these tools and evaluation of this element of the EPBD.

A general conclusion from the SENTRO project is that there is a common lack of knowledge of Article 5 of the EPBD and of the potential of alternative energy systems throughout the EU. In most countries, the main focus up to now has been on other parts of the EPBD, such as energy performance certificates, setting of energy performance requirements, calculation of energy performance etc. The field trials show that heat pumps are, in many cases, the best solution. Depending on local conditions, this might even be the case when other alternative sustainable solutions such as district heating are available. This is particularly the case for larger commercial buildings having a need for both heating and cooling. Finally, it should be pointed out that, to achieve an optimum solution at the lowest cost, the feasibility study should be performed early and as an integrated part of the planning process of a new building.

It should also be mentioned that the ongoing review of the EPBD is proposing to delete the present starting point of Article 5 of covering only buildings larger than 1000 m^2, i.e. in the future, a feasibility study may be needed for all new buildings, including single-family houses.

Further information on the EIE SENTRO-project can be found at (http://www.sentro.eu/), where also the "Handbook for Performing Feasibility Studies of Alternative Energy Systems" can be downloaded (in pdf-format).

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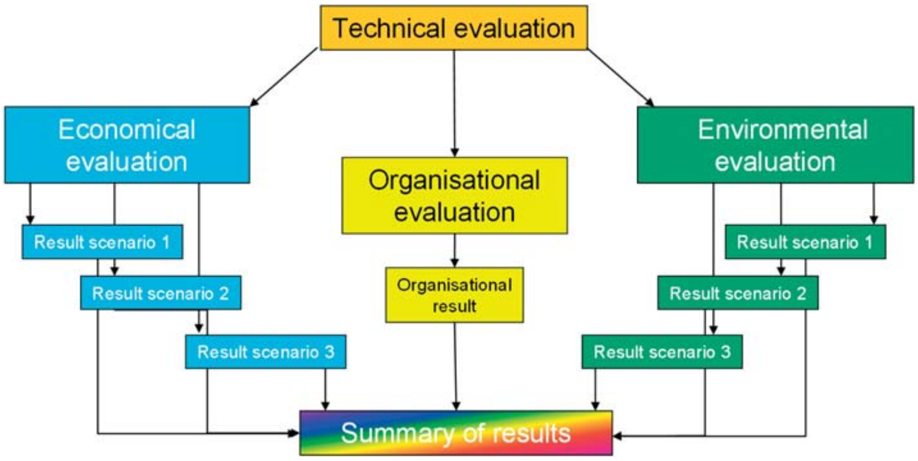


Figure 1 Flow chart overview of different evaluations in a feasibility study.

Table 1 Activities to incorporate the feasibility study in the building process, including supporting tools.

Building process	Activities feasibility study (AES)
Planning*	- Agreement on starting points - Raise awareness of AES - Gain insight into the potential of AES at district level or at building level - Request for feasibility study
Program	- Formulate energy requirements - Filter out unrealistic options
Proposal	- Towards two or more energy concepts - Identify building concepts for the chosen energy systems - Detailed feasibility study - Choice of building concept and energy system(s)
Project	- Specifications, energy concept(s) - Qualification, builder, installer
Construction	- Compliance, selected energy concept
Operation	- Monitoring performance, energy concept

SENTRO Awareness
Shining examples
FAQ

SENTRO Handbook – Specifications request feasibility study

SENTRO Checklist

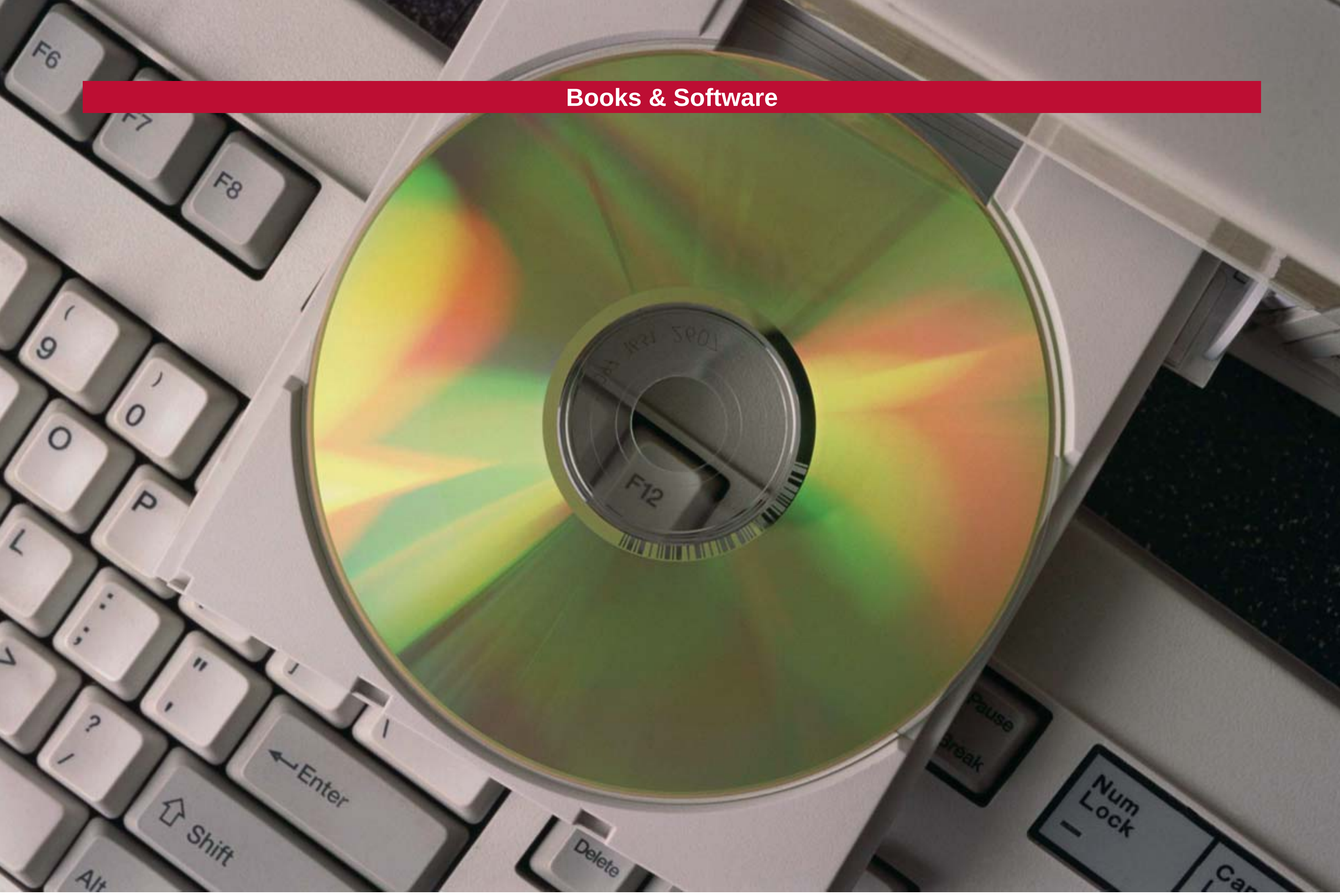
SENTRO Handbook – how to perform the feasibility study and references to existing software tools

Calculation methods – different national and international software tools

Building permit

*In case of an individual building, the activities of the planning phase are applicable during the programming phase

Space to find suitable solutions to realize a high quality building including an optimal energy concept within acceptable costs



ASHRAE publishes load calculations manual

Guidance to help designers improve the performance and efficiency of design as it relates to load calculations is contained in a new book from ASHRAE.

Load Calculation Applications Manual focuses on two methods for calculating cooling loads in non-residential buildings – the heat balance method and the radiant time series method (RTSM).

Author Jeffrey Spitler noted that understanding these methods is crucial when answering three primary design questions – what is the required equipment size; how do the heating/cooling requirements vary spatially within the building; and what are the relative sizes of the various contributors to the heating/cooling load?

"Cooling load calculations are performed primarily to answer the first and second questions, providing a basis for specifying the required airflow to individual spaces within the building," Spitler said. "Answers to the third question help designers make choices to improve the performance or efficiency of the design."

The new manual features in-depth examples, as well as bringing together the latest data for building materials, windows, weather and internal heat gains, according to Spitler. The accompanying CD contains spreadsheets that compute the factors needed by the RSTM and compute cooling loads with the RSTM.

The manual is the fourth in a series of load calculation manuals published by ASHRAE, including the first and second editions of Cooling and Heating Load Calculation Manual as well as Cooling and Heating Load Calculation Principles.

The cost of the Load Calculations Applications Manual is $119 ($97, ASHRAE members).
To order, contact ASHRAE Customer Service at 1-800-527-4723 (United States and Canada) or 404-636-8400 (worldwide), fax 404-321-5478, or visit www.ashrae.org/bookstore.

2009

12 - 13 June XIII European Conference
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www.centrogalileo.it/milano/CONGRESSODIMILANO-2009english

14 - 17 June EFFSTOCK 2009
Thermal Energy Storage for Efficiency and Sustainability
Stockholm, Sweden
www.effstock2009.com

23 - 26 June 3rd Conference on Thermophysical Properties and Transfer Processes of Refrigerants
Boulder, United States
www.iirboulder2009.org

9 - 10 September European Heat Pump Summit 2009 Powered by Chillventa
Nürnberg, Germany
www.chillventa.de/de/heatpumpsummit

24 - 27 September RENEXPO® 2009
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Casta Papiernicka, Slovak (Republic)
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3 - 5 October ASHRAE Region-At-Large
Chapters Regional Conference
Movenpick Hotel & Resorts, Kuwait
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26 - 28 November RENEXPO®
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Orlando, USA
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In the next Issue

Heat pumps in year-round space conditioning system

Volume 27 - No. 2/2009

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 effi ciency 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 benefi ts 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.

The IEA Heat Pump Centre is operated by

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