IEA Heat Pump CENTRE
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Systems & Applications

How to choose a heat pump system

Exergy method takes root

Geothermal Heat Pump Consortium

IEA
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heat pump
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In this Issue

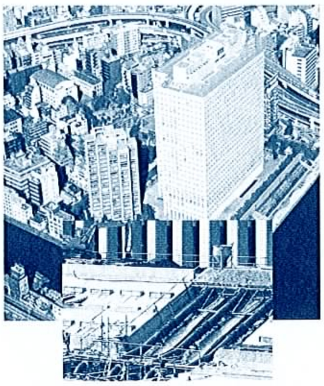
Systems and applications

Heat pumps must never be considered in isolation. Whether their use is planned for a building, industrial plant or a large community, heat pumps must integrate with all elements of the energy system, from the generation of power to the distribution of heating and cooling. This issue examines some of the methodologies and tools available to designers and includes some examples of applications that illustrate the systems approach to heat pump design.

TOPICAL ARTICLES

HEAT PUMP NEWS

FEATURES



Front cover: *River-water source heat pump serving the Waterfront District of Hakozaki in Tokyo. A methodology known as the "Analytic Hierarchy Process" helped designers choose the right system. The article on page 20 explains further.*

NOTE

The HPC has a new telephone number

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The information revolution

When historians look back on the late 20th century they may well label it the era of the information revolution. For the production of printed and electronic documentation has risen to overwhelming levels in the past decade.

So when you have an important message to tell, extra efforts are needed to avoid being lost in the information "noise". Introducing a new, and I hope you agree, more attractive style to our Newsletter, is one way by which the IEA Heat Pump Centre (HPC) is helping to make its voice heard.

This new face also reflects the beginning of a new three-year period of operation for the HPC. A period when we will continue to offer the services and products that Newsletter readers have come to expect. But also a time when new activities will be introduced.

Our already popular Internet site will continue to grow and to act as the world's central access point for heat pump information. And we will be expanding our activities to promote heat pump technology and strengthening links with utilities and manufacturers.

A central strategy will be to highlight the benefits of taking a "systems approach" to energy systems design. Such an approach is a recurring theme in this issue of the Newsletter. Examples are given of the integration of heat pumps with district heating, cogeneration and conventional heating technologies, and of the application of the "exergy" concept in energy system design.

But the success of the HPC, past and future, lies in the strength of our network. So it is my great pleasure to say "bienvenida", or welcome, to all our new readers in Spain, who now receive this Newsletter thanks to their country becoming our latest member. As for all our readers, your subscription is highly valued. For the wider our network for information exchange, the more we can do to enhance the prospects for the heat pump market. Surely this is an excellent way to profit from the information revolution.

Jos Bouma

General Manager of the IEA Heat Pump Centre

Utilities sign promotion plan

Netherlands - The Dutch Heat Pump Programme took a significant step last December, when agreement was reached for cooperation among the government and utility organizations on the stimulation of heat pump implementation in the Netherlands.

Three major Dutch energy distribution companies (NUON, REMU and ENECO), the Dutch Association of energy distribution companies, EnergieNed, the Dutch Electricity Generating Board, NV Sep signed the agreement along with the Netherlands Agency for Energy and the Environment, Novem, who did so on behalf of the Ministry of Economic Affairs.

The agreement aims at the development and deployment of *integrated* heating systems based upon readily available, high-efficiency electric heat pumps for both space heating and hot water production. Each of the participating energy distribution companies will organize a demonstration site for at least one hundred houses with heat pumps.

The agreement focuses on the implementation of electric heat pumps in the so-called new urban "VINEX-areas" where around 85,000 new houses will be built annually during the next decade (see article on page 24). The initial duration of the agreement is two years and more utilities are expected to join.

To help find the best heat pump systems, the Dutch Heat Pump Programme is holding a *heat pump heating systems competition*, to be launched in April 1996. The competition is intended to encourage heat pump suppliers, installers and advisors to form strategic clusters to co-operate in the design, production and installation of heat pump heating systems for Dutch houses. The competition follows the recent success of similar activities in Scandinavia and Switzerland.

Systems entered for the competition will be tested and modelled using the facilities of TNO (the Netherlands Organization for Applied Scientific Research) described in *IEA Heat Pump Centre Newsletter* Vol.13 No.3. The winner, or winners, will be awarded with a demonstration project of at least one hundred houses in the new urban areas, and some free publicity.

Source: Mr Krijn Braber, Dutch Heat Pump Programme coordinator, Novem, Fax: +31-30-2316-491.

Rating procedure for integrated systems

USA - The Department of Energy has granted an interim waiver to allow the use of a novel rating procedure to measure the performance of the Nordyne "Powermiser" - an innovative heat pump that integrates domestic water heating with space heating and cooling. US heat pumps must normally be rated by the Seasonal Energy Efficiency Ratio (SEER) for cooling and the Heating Seasonal Performance Factor (HSPF) for heating. These ratings typically provide the basis for utility rebates, but fail to address water heating.

The new rating procedure, developed by Nordyne, arrives at a "combined cooling performance factor" and a "combined heating performance factor." These reflect the energy required to meet the combined space conditioning and water heating loads during the heating and cooling seasons.

The new rating procedure can be expected to improve the market prospects for the Powermiser. Developed with support from the Electric Power Research Institute (EPRI), the Powermiser is reported to be attracting increasing interest, both for residential use and for light commercial applications such as restaurant kitchens.

Source: EPRI News Exchange, Fall 1995.

Spain becomes newest HPC member

HPC - The IEA Heat Pump Centre (HPC) is pleased to announce that Spain has become a new member country. Meeting at the Ministry of Industry and Energy in Madrid, on 29 February 1996, representatives of the sponsoring organizations agreed on the necessary financial arrangements and formed a Spanish National Team. The contact person for the National Team is Mr Gabriel Carrasco of AEDIA (Asociación para la Investigación y Diagnosis de la Energía) who is based in Madrid. His full contact details are given on the back cover of this Newsletter.

Like all people in member countries, Spaniards can now obtain the *IEA Heat Pump Centre Newsletter* free-of-charge. They can also benefit from easier access to the HPC network and can obtain HPC publications at a lower price. The HPC looks forward to learning more about the heat pump situation in Spain and in providing information services to support the market and to assist in the development of heat pumping technology.

Source: IEA Heat Pump Centre

Detecting defects

Switzerland - A methodology for defect detection in heat pumps promises to save maintenance costs by giving advance warning of a fault. With this methodology, a range of performance indicators, such as exergetic efficiency or the number of transfer units (NTUs) of a heat exchanger, are compared with recorded laboratory measurements made under normal and faulty conditions. If the indicators begin to look like the fault conditions, an early warning of a defect can be given.

At the Energy Systems Laboratory in Zürich, techniques, such as the fast fourier transform (FFT) algorithm, are used to represent these dynamic parameters as state patterns, or points in "property space" as shown in **Figure 1** (top). During heat pump operation, the point representing the current state can move due to changes in ambient conditions or because of a fault. If, as with the red point in Figure 1, the current state is moving towards faulty states, there is an increasing probability of these faults occurring.

Applying such defect detection in heat pumps would lead to early fault recognition and a reduction in operation and maintenance costs. The methodology is currently being validated on a laboratory heat pump and will be the subject of a PhD thesis to be finished by end of 1996.

Source: Mr Roger Raeber, Energy Systems Laboratory, ETH Zentrum, Zurich, Switzerland. Fax: +41-1-632 6008; E-Mail: raeber@iet.mavt.ethz.ch

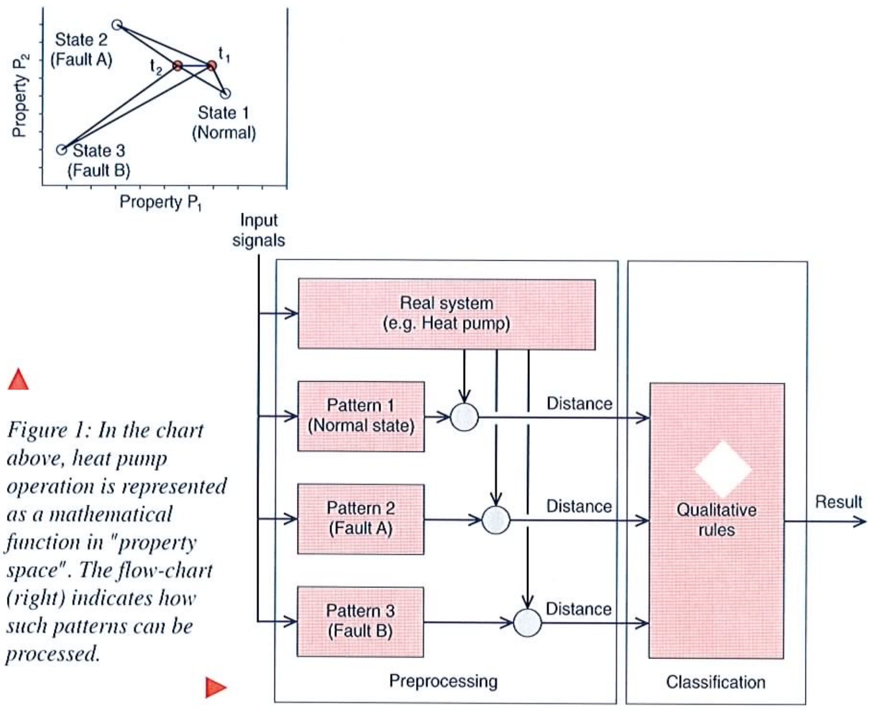


Figure 1: In the chart above, heat pump operation is represented as a mathematical function in "property space". The flow-chart (right) indicates how such patterns can be processed.

Olympic heat pumps

USA - The 1996 Summer Olympic Games in Atlanta serve as an important opportunity to demonstrate advanced energy technologies. During the Games, the Education and Training Centre, a 700 m² building in downtown Atlanta, will offer information on energy saving. Visitors will be able to witness at first hand the benefits of heat pumping since ground-source (or geothermal) heat pumps will be providing space heating and cooling and hot water for this Olympic building.

Source: CADDET Energy Efficiency Newsletter, March 1996.

Study finds satisfied users

Netherlands - A study of eight heat pump applications in the Netherlands found widespread satisfaction amongst the users. The study looked at the use of heat pumps in a plastics factory, a chicken factory, a crematorium and an underground museum, and four applications in the well-known Dutch flower-bulb industry.

The use of heat pumps in the handling of flower-bulbs was found to be especially advantageous. After harvest, flower bulbs must be kept in climate-controlled containers which may require heating or cooling - ideal conditions for heat pumping.

In the applications studied, it was often the advice of the installer that led to the installation of a heat pump. All users were satisfied with the heat pump performance and found the maintenance requirements to be no more than those for conventional heating and cooling systems. The largest energy savings were reported from the systems that supplied simultaneous heating and cooling.

The study was executed by the engineering and advisory bureau KEMA, under the earlier (1993) Dutch Heat Pump Programme executed by TNO (the Netherlands Organization for Applied Scientific Research). A full report, entitled "Evaluatie Acht Warmtepompen" (Evaluation of Eight Heat Pumps) is available from the KEMA library (Tel: +31-26-356-2204).

Source: Mr Paul Juffermans, NV Kema, Arnhem, The Netherlands. Fax: +31-26-351-7362

Compact chiller

Japan - A newly developed, ammonia filled, absorption chiller uses 20% of the working fluid required in conventional equipment. Developed by Osaka Gas, in collaboration with Hitachi Zosen Corp. and Sumitomo Precision Products, the new system has been made more compact by using stainless-steel plate-fin heat exchangers. Three models ranging from 16 RT (56 kW) to 100 RT (350 kW) cooling capacity will be launched this spring.

Source: JARN, January 1996

Air-cycle refrigerators ready for market

Japan - The Japanese trading company Kanematsu has announced that it plans to market commercial refrigerators and freezers using air as refrigerant. The system has been developed by a consortium of Japanese firms and is awaiting patents. Kanematsu believes the system should sell well in North America and Europe. The company will also work with Kajima Corporation on marketing air-conditioning systems using the same technology.

Source: OzonAction from UNEP IE, January '96.

Replace your CFCs by June '98!

Germany - Owners of equipment using CFC-12 have until June 1998 to either replace the refrigerant with one more favourable to the environment, or to install new equipment. Announced by the government at the end of 1995, the new ruling applies to all refrigerating and air-conditioning equipment with more than 1 kg of refrigerant. Heat pumps are exempted from the ruling, as is equipment for use in industrial applications. The government has recommended HCFC-22 and HFC-134a as suitable replacements, although propane or butane may also be used if allowed by the regulations affecting the use of flammable refrigerants.

The use of HCFC-22 is coming under increasing pressure in Germany. Its use in new equipment will be outlawed from 1 January 2000. But in the province of Nordrhein-Westfalen, the installation of HCFC-filled equipment is now forbidden in all new buildings, owned by or supported by the provincial government.

Source: CCI 1&2/96

IIR compares NH_3 regulations

France - A survey by the IIR (International Institute of Refrigeration) has highlighted how regulations on the use of ammonia as a refrigerant, vary widely between different countries and regions. For large equipment, the country with the strictest start-up requirements was found to be France, where a rigorous hazard analysis must be performed before authorization can be given. In contrast, in the Scandinavian countries of Denmark, Norway and Sweden, which have similar regulations, there is no great obstacle to the building of an ammonia refrigeration plant. However, once in operation, the regulations are less strict in France, where there is no requirement for qualified operators.

The survey covers the following countries, either as a whole or in certain regions: Belgium, Canada, Denmark, France, Germany, Norway, Spain, Sweden and USA. Those who can provide further information on these or other countries are encouraged to contact the IIR.

Source: IIR Bulletin, Vol '96/1

Montreal Protocol update

Austria - The 7th Meeting of the Parties to the Montreal Protocol resulted in further limits on HCFC use in industrialized countries and a phase-out schedule for both CFCs and HCFCs in developing countries. For industrialized countries, the consumption cap has been reduced from 3.1 to 2.8% of the equivalent consumption of HCFCs and CFCs in 1989. Furthermore, use of HCFCs is now explicitly restricted to the servicing of refrigeration and HVAC equipment after 2020.

In developing countries, CFCs must be phased out by 2010 and HCFC consumption will be capped in 2016 at the consumption of 2015. Use of HCFCs will be phased out completely in 2040.

Sources: OzonAction from UNEP IE, January '96 and Koldfax from ARI, November/December '95.

RACs up by a million

Japan - Domestic shipments of room air conditioners (RACs) reached a new all-time high in the year to September 1995 (see **Figure 3**), with almost one million more units delivered by manufacturers to Japanese sales outlets than in the previous year. And heat pump RACs continue to dominate, with only one-in-ten Japanese consumers opting for a cooling-only unit. Around 68% of all domestic RAC shipments were for variable-speed inverter systems.

The total Japanese production of RACs, for domestic and export markets, rose 35.6% to over 8 million units for the year to September '95. With a value of 960 thousand million Japanese Yen (US$ 1,000 million), it exceeded by far the production value of any other household electric appliance.

Domestic shipments of packaged heat pump systems in the year to September '95 were up by 7.9% - the first year-on-year rise since 1991. **Figure 4** shows the trend for the past six years. The term packaged heat pump system generally refers to equipment with a capacity of over 2.25 kW, many of which are multi-split systems with up to eight indoor units connected to one outdoor unit. Most are installed in shops and offices although there is an increasing trend for their use in residential applications. Production of packaged heat pump systems reached a total of 1.2 million units for the year to September '95. A large proportion of these are exported.

Source: JARN, October '95 to January '96.

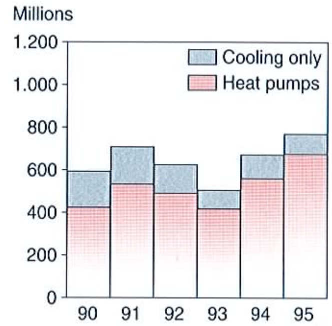


Figure 3: RAC shipments.

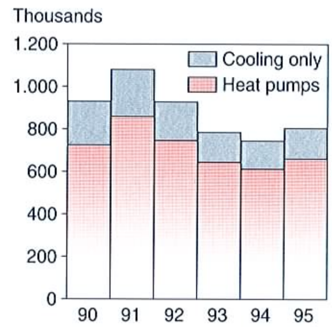


Figure 4: Shipments of packaged air conditioners.

New housing dominates market

Switzerland - The majority of heat pumps sold in 1994 were for new houses and over 90% of those were installed for monovalent operation. **Figure 2** shows a breakdown of Swiss heat pump sales using data from the Association of Swiss Heat Pump Manufacturers.

Source: Swiss National Team

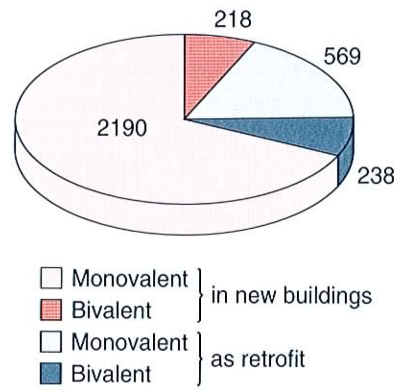


Figure 2: Breakdown of heat pump sales in Switzerland in 1994.

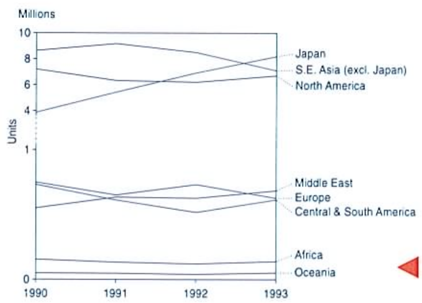
New data on Greece

Greece - A study by the UK research association BSRIA reveals that 115,000 split-system air conditioners were sold in Greece in 1994, nearly all of which were heat pumps. Around three-quarters of these systems go to houses or apartments where they are mainly installed as single-split systems. Users show a preference for wall-mounted indoor units.

Source: JARN, October 1995

Japan loses top spot

Japan - Statistics published by the Japan Refrigeration & Air Conditioning Industry Association no longer show Japan as the world's leading producer of air conditioners (see **Figure 5**). In 1993, more units were produced through the combined efforts of manufacturers in other Southeast Asian manufacturers, notably Hong Kong, the Republic of Korea, and Singapore.



As in previous years, about 75% of the units produced in 1993 were room heat pumps. For packaged air conditioners, North America continues to be a world leader, producing over 70% of the world total in 1993.

Source: The Air Conditioning, Heating & Refrigeration News, November 6 1995

Figure 5: World production of air conditioners.

Introducing Annex 23

Canada - "Heat Pump Systems for Single-Room Applications" is the official title of the latest IEA Heat Pump Programme Annex, which began operation on 1 January 1996.

With the participation of six countries, the Annex will look at the technologies needed to enable heat pumps to serve single-room applications in existing residential and light-commercial buildings. Such applications demand special attention, since many of these buildings have heating and cooling distribution systems that limit the introduction of heat pumping technologies.

Much of today's heat pump research and development work focuses on central forced-air heat pumps using ducted air distribution. Such heat pumps are unsuitable for retrofit applications in the majority of electrically heated buildings in North America, and in many buildings in Europe, where either electric resistance (baseboard) heaters or hydronic (hot water) radiators are installed. In contrast, single-room heat pumps are a much easier retrofit option.

Single-room heat pumps have increased in popularity in recent years. Commonly found features include quiet indoor fan-coil units, air filtering, thermostat setback, multispeed fans, and wireless remote control. However, as with many central forced-air heat pumps, concerns about heat pump reliability and high installation costs limit the market. Development of new varieties of single-room heat pumps will provide the difficult-to-retrofit markets with a viable, cost-effective space conditioning alternative.

Many innovative methods exist for applying heat pumps to existing or new buildings without central distribution. Annex 23 will share common experiences and build awareness on the potential benefits of room-size heat pumping systems to control space conditions and reduce operating costs.

Under the Annex, participants will carry out research and development on single-room heating systems and document existing research. They will gather information on utility or government incentive programmes and demand-side management initiatives, and work to create an awareness of the advantages of single-room heat pumps.

Annex 23 aims to achieve benefits for heat pump users, power utilities and the environment. Users will benefit from lower heating and cooling costs, utilities can look to increased electricity markets and additional demand-side management tools, and increased heating and cooling efficiencies will help the environment by reducing emissions.

Source: Mr Frank Lenarduzzi, Operating Agent Annex 23, Ontario Hydro Technologies. Fax: +1-416-207-6565.

Open seminar on Annex 14

Japan - Six years after the completion of the Final Report, Annex 14 "Working Fluids and Transport Phenomena in Advanced Absorption Heat Pumps" continues to attract interest. On 1 December 1996, the Heat Pump Technology Center of Japan held a "salon-style" open seminar, or "Danwakai" on Annex 14 in Tokyo.

About 60 experts from universities, institutes and industries took part and heard presentations on cycle evaluation and transport phenomena. Several manufacturers reported on recent developments in absorption machines including: a waste-heat driven chiller (Ebara Corp.); low-temperature applications (Sanyo Electric Co. Ltd); a waste-gas driven chiller (Hitachi Ltd); an ammonia-water air-source heat pump (Mitsubishi Electric Corp.) and an air-cooled chiller (Yazaki Corp.).

The Final Report of Annex 14 is now available from the IEA Heat Pump Centre.

Source: Mr Takeshi Yoshii, Japanese National Team

A new library opens

IEA Heat Pump Centre - A new facility at the HPC's Internet site gives worldwide access to the documentation generated under the IEA Heat Pump Programme. The "IEA Heat Pump Programme Library" is a database containing details on every paper, article, book and brochure produced under the IEA Heat Pump Programme - a total of more than 1000 items! Each entry includes an abstract together with other bibliographic information. Those entering the library can find the documentation they need by using a flexible search facility.

Source: IEA Heat Pump Centre.
http://www.heatpumpcentre.org

New Annex on sorption technology

Sweden - A proposed Annex entitled "Sorption Machines for Heating and Cooling in Future Energy Systems" is expected to begin operation in the first half of 1996. As highlighted in the previous issue of the IEA Heat Pump Centre Newsletter, the new Annex will address the reasons for the lack of implementation of sorption technology for heating and cooling. Key objectives are to systemize knowledge on the use of sorption machines and on current activities to increase the competitiveness of the technology.

The Annex intends to cover residential and industrial applications of sorption technology, for both heating and cooling. Significant target groups such as manufacturers, users and authorities, are expected to play an active role. In the proposed first phase of operation, Annex participants will compile state-of-the-art reports on sorption technology. An open workshop to present the first results is planned to be held in conjunction with the 5th IEA Heat Pump Conference on 23 September.

The Annex Operating Agent will be the Swedish Council for Building Research.

The Department of Chemical Engineering and Technology at the Royal Institute of Technology will be responsible for the accomplishment of the programme. Canada, Italy, Japan, The Netherlands, Spain and Sweden are expected to take part.

Source:
Prof. Frederik Setterwall,
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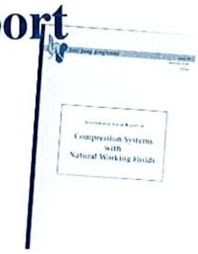
S-100 44, Stockholm, Sweden.
Fax: +46-8-10-52-28;
E-mail: setter@chemeng.kth.se

Annex 22 releases international status report



Norway - A unique report on natural heat pumping refrigerants has just been produced under Annex 22 of the IEA Heat Pump Programme. "International Status Report on Compression Systems with Natural Working Fluids" is the first comprehensive review of worldwide experience in the non-conventional use of ammonia (NH_3), hydrocarbons, carbon dioxide (CO_2), water and air in heat pump, air conditioning and refrigeration systems.

Following a survey conducted in the Annex 22 member countries (see below), and in Austria, Germany and Sweden, the report includes data on the number of installations in various applications and discusses practical experiences. Information is given on state-of-the-art technology and there is a comprehensive listing of accomplished and ongoing research and development (R&D) work and prototype and demonstration (P&D) projects.

The report was printed in February 1996 and is available from the IEA Heat Pump Centre along with the proceedings from Annex 22's first workshop "Compression Systems with Natural Working Fluids - Applications, Experience and Developments". Held in Trondheim, Norway on 16-17 October 1995, this event attracted 46 participants from 12 countries, and resulted in a useful exchange of information and ideas.

The day after this workshop, Annex participants met to discuss the forthcoming R&D and P&D work to be performed under the Annex. Some of this work is highlighted below.

Canadian participants will evaluate hydrocarbon mixtures for industrial refrigeration through laboratory experiments and computer simulation. A field demonstration will take place at an industrial site using the most promising hydrocarbon mixtures.

In Denmark, R&D work will focus on CO_2 pump circulation systems. Under P&D work, participants will monitor a CO_2/NH_3 cascade system with an ice slurry bank.

Japanese work will include an investigation of two-stage regenerative compressors and a comparison of HCFC-22 and propane in a room air conditioner. An air-cycle system in a warehouse will be monitored.

In the Netherlands, R&D work will cover air-cycles, steam compression, ice slurry and CO_2. P&D work will include the application of NH_3 in a supermarket, commercial buildings and in industry, and the use of hydrocarbon heat pumps in commercial and residential buildings.

Norwegian participants will look at the design of efficient air coolers for CO_2, and monitor a commercial refrigerating system based on NH_3 and CO_2. Many aspects of this system will be studied in detail, including safety, energy consumption, reliability and investment costs.

Participants in Switzerland will carry out some fundamental measurements, such as heat transfer and pressure drop, and perform environmental assessments on various natural refrigerants. A 3.5 MW NH_3 heat pump will be monitored.

In the United Kingdom, an investigation will be carried out on an NH_3 chiller and a hydrocarbon heat pump installed in a supermarket (secondary system). A supermarket refrigeration system with NH_3 chiller and R-407C freezer scroll packs will be monitored.

A US study, to be titled "How to get past the fear factor," will investigate regulatory and safety barriers for NH3 and hydrocarbon systems in the United States. Also in the US, a supermarket refrigerating plant using NH3 and a secondary system will be monitored.

All these projects are to be carried out over 1996 and 1997.

Source: Mr Jørn Stene, Operating Agent Annex 22, NTNU-SINTEF Energy, Trondheim, Norway. Fax: +47 7359 3926.

Ongoing Annexes

Red text indicates Operating Agent. Japan is the Co-operating Agent of Annex 18.

Annex 16 IEA Heat Pump Centre	AT, JP, NL, NO, CH, US
Annex 18 Thermophysical Properties of Environmentally Acceptable Refrigerants	CA, DE, JP, NO, SE, UK, US
Annex 22 Compression Systems with Natural Working Fluids	CA, DK, JP, NL, NO, CH, UK, US
Annex 23 Heat Pump Systems for Single-Room Applications	CA, ES, FR, SE, CH, US

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

Systems and applications

An international overview

Bert Stuij, IEA Heat Pump Centre

Even for experts who deal everyday with advanced energy technologies such as heat pumps, "exergy" or "energy quality" can sound mysterious - or at least as of little practical value. And yet, if properly applied it can point the way to radical improvements in the efficiency of energy systems - ranging from individual heat pumps, via buildings and industries, to entire communities. This article discusses some of the principles of advanced energy systems, highlighting the role heat pumping should play in them. Practical applications illustrate the benefits that have already been achieved, and point the way to even better and more integrated possibilities. The article also highlights a few software packages that aid the designer to analyze and optimize heat pump systems. The boxes highlight heat pump systems and applications, and some design tools in HPC member countries.

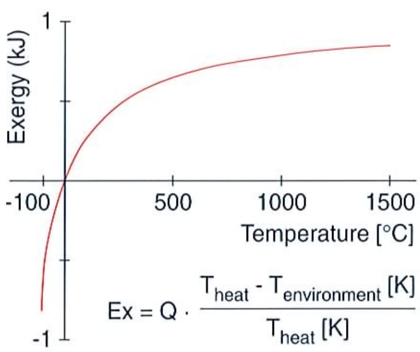


Figure 1: Exergy content of 1 kJ of heat 'Q' as a function of its temperature, taking 0°C as the ambient temperature. In the curve, negative exergy indicates the minimum amount of work required to realize a lower-than-ambient heat flow (cooling).

It is easy to save energy. In fact, whatever we do, it is always and completely saved. According to the first law of thermodynamics energy can neither be lost, nor generated. Energy can be converted, but will not disappear.

However, although the "quantity" of energy stays forever, experience has shown that energy conversions do result in an irredeemable loss. The energy is apparently still there, but it seems as if we can do less and less with that same quantity. There has been a loss of "quality".

This experience has been formulated in the second law of thermodynamics, which states that whereas work can be fully converted into heat (or any other form of energy), heat can only partially be converted back. On the basis of this law, the "quality" of energy can be further defined as its ability to do work. And in line with common experience, this ability reduces with every practical conversion.

Exergy and anergy

Since the 1950s the fraction of a given amount of energy that can be converted into work has been dubbed "exergy", the remainder is "anergy". The thermodynamic laws mean that in any energy conversion the amount of energy stays constant, whereas the amount of exergy is at best maintained, but in practice always reduced. The exergy content of energy is a thermodynamic "quality label" for energy, indicating its convertibility, versatility, and so ultimately its usefulness.

Electricity can be fully converted into work, and is pure exergy. The higher heating value of fuel is, perhaps less obviously, also pure exergy. However, based on the second law, heat is of much lower quality. Its exergy content drops with temperature, with the actual environmental temperature (e.g. 0°C) as a baseline. Heat of 1000°C can for 80% be converted into work, heat of 40°C for 13%, and heat of 0°C not at all - it is pure anergy. **Figure 1** explains how the exergy of heat is derived.

Energy is necessarily always conserved, and strictly speaking the challenge is to save exergy, rather than energy. Quality, rather than quantity is the issue. In an optimized energy system only the exergy demand requires precious energy resources - whether renewable or not. Anergy, by contrast, is free and everywhere around us - in the ground, water or air, where it is continuously replenished by the sun, or in man-made waste heat streams.

Saving quality

Unlike saving energy, saving exergy is far from straightforward. On translating the theory of thermodynamics to the practicalities of designing energy systems, one golden rule emerges: Never use more exergy than absolutely necessary to fulfil an energy demand. This can be called the "minimum exergy rule".

For example, if 100 kJ of work must be done, 100 kJ of exergy is needed, and this requires at least 100 kJ of electricity or fuel. However, if 100 kJ of 40°C heat is needed, only 13 kJ of exergy needs to be supplied. Downgrading 100 kJ of precious electricity or fuel into low-quality heat is an exergy waste of 87 kJ. An ideal heat pump would be powered by 13 kJ of exergy, and use this to raise the temperature of 87 kJ of "anergy" from the environment.

Based on the "minimum exergy rule", practical energy systems will be based on two design principles: *energy cascading* and *energy upgrading*.

Energy cascading avoids unnecessary degradation of heat. High quality heat is first of all used for high quality purposes, such as mechanical drive energy, electric power, or heat for high-temperature processes. The waste heat from these processes is then used for a lower-temperature process, and so on. The original exergy meets a number of demands before it is finally reduced to ambient heat, or anergy. **Figure 2** illustrates the vast benefits of energy cascading over a system where fuel is used for each individual energy demand.

In optimized systems, *energy cascading* is complemented by *energy upgrading* (or heat pumping). Upgrading should be applied if waste heat flows alone are not sufficient to meet the complete low-temperature heat demand of a building, a plant or indeed of a whole society. Fuel or electricity must then be used for full coverage, but as stated before it

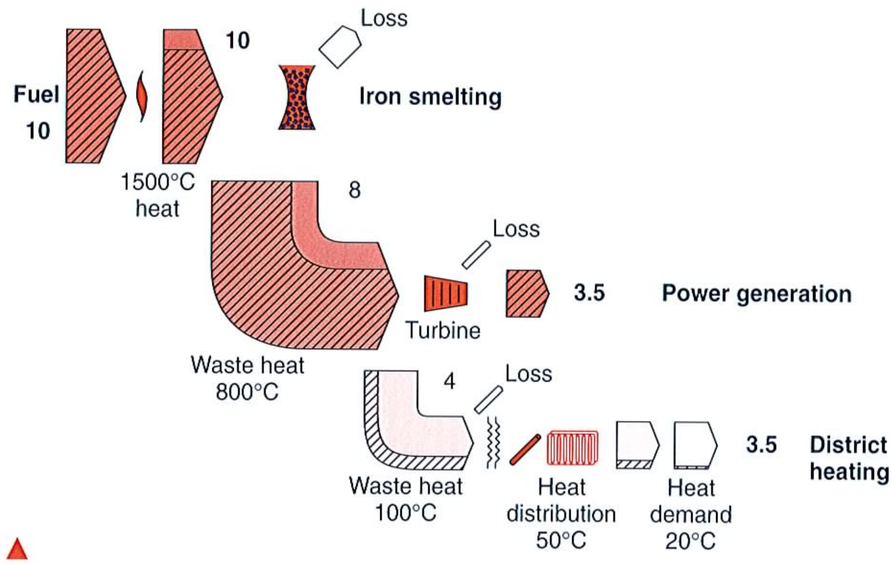
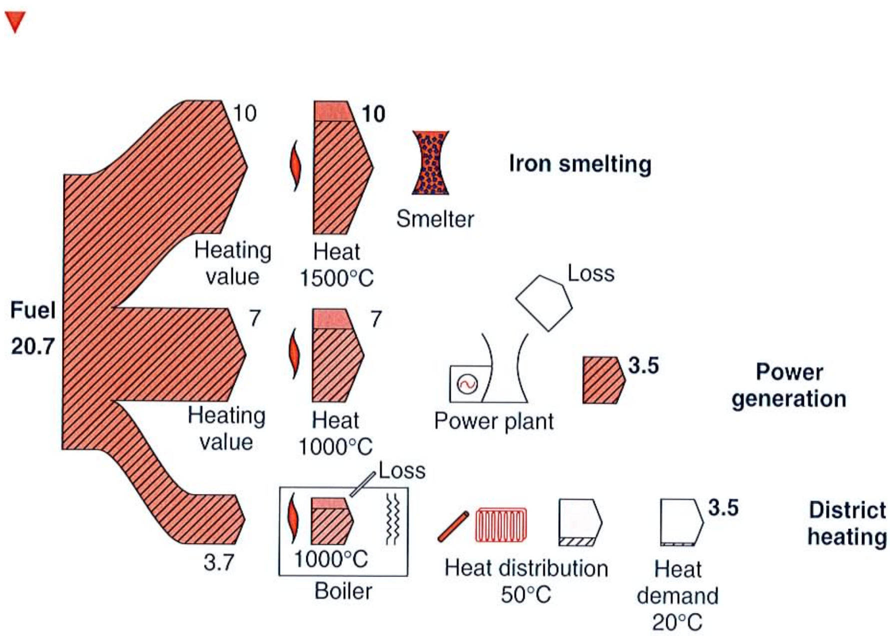


Figure 2: By using energy cascading (top), iron smelting, power generation and space heating is provided with around 50% of the energy consumed when each is provided separately (bottom).

Anergy
Exergy



should never be allowed to "degrade" into the required heat. Rather, it must be used to drive a heat pump which extracts "anergy" from sources such as ground, air, water or low-temperature waste heat streams. **Figure 3** (page 14) shows the benefits of upgrading against degradation.

An optimized energy system is fully integrated. It meets energy demands with minimum exergy resources, and it captures and re-uses all waste heat flows, either directly (in a cascade), or as heat sources for heat pumps (upgrading). As will be shown in the rest of this article, the principles of integration through cascading and upgrading are valid for energy systems on any scale - from complete communities, to individual industries or commercial premises, down to houses, and then even to individual heating equipment. On each of these levels a few typical application examples will be highlighted, with some design or analysis computer programs that can aid the designer.

Optimized communities

The principles of energy cascading and upgrading are more and more recognized as holding the key to vast improvements in national and regional energy systems. Indeed, the wide uptake of cogeneration in national energy systems is an excellent example of cascading. Fossil fuels generate high-temperature heat, from which pure exergy is taken in the form of electricity. Subsequently, the heat demand in buildings and industry is met with a minimum exergy (waste) heat resource.

Energy upgrades on a regional scale have also been realized. Sewage water is commonly used as a heat source for district heating heat pumps in Sweden and Norway. In Japan, a new district heating and cooling system in Tokyo again upgrades waste heat from untreated sewage, while a somewhat older scheme in Sapporo uses subway waste heat.

Austria

Heat pumps will be most efficient if the temperature lift is kept to a minimum, as the temperature lift is a measure of the amount of precious exergy that is added to the "free" anergy from a heat source. This requires the lowest possible heat sink temperature, and the highest possible heat source temperature. Advanced buildings in Austria will be laid out with floor heating systems of 35°C or lower. Heat pumps will preferably use ground-water or the ground as the heat source. Air is less suitable, as the highest heat demand coincides with the lowest air temperature. In some applications, air is sucked through buried ducts to dampen air temperature fluctuations.

Ventilation air is also an excellent heat source for heat pumps, but until now has not been extensively used in Austria. However, a number of interesting examples have been realized in new commercial/institutional buildings, where heat is shifted from high internal gain areas to areas which require heating. Heat pumps are used to supply heat at the appropriate temperature level.

Advanced systems are in some cases applied in the tourist industries. The recreation centre "Kanzelhöhe" (see **Photo**) with a volume of 79,000 m³, has an integrated system with two parallel heat pumps at its heart. Waste heat is recovered, cooling and heating needs are met simultaneously, and both hot and cold storage is included. The seasonal performance factor of the system is 3.5

Industrial heat pumps in Austria are normally integrated in processes. They are also commonly applied for process cooling and low-temperature heating (up to 75°C), and space conditioning of manufacturing lines.

Source: Austrian National Team

Japan

In the continuing drive for sustainable development, much attention is given to the tapping of urban heat sources and sinks for district heating and cooling (DHC) systems. Perhaps the first example was the Sapporo city project, which began operation in 1989. Heat from the underground railway is upgraded in two steps. Heat pumps are installed in the stations to recover waste heat from ventilation air to produce warm water. This water is then used as the heat source for a second set of heat pumps which feed the district heating network in winter. These heat pumps are driven by a steam turbine from which condenser heat is recovered to give a further boost to the DHC supply water temperature. The heat pumps in the subway station provide cooling in summer.

In 1994 an advanced installation began operation in Tokyo which utilizes untreated sewage water as a heat source and sink, coupled with water thermal storage. In comparison with conventional air-source heat pump systems, the sewage water is of a far better temperature to achieve high efficiencies.

Very ambitious is the large-scale thermal cascade project "Eco Energy City", in which industrial waste heat flows are utilized in urban areas. Extensive research programmes are looking into the use of metal hydrides, chemical reactions with methanol, and various sorption techniques, to realize long-distance transport of heat with minimum losses. If necessary, heat pumps will be used to upgrade the waste heat to the required temperature.

Source: Japanese National Team

The Netherlands

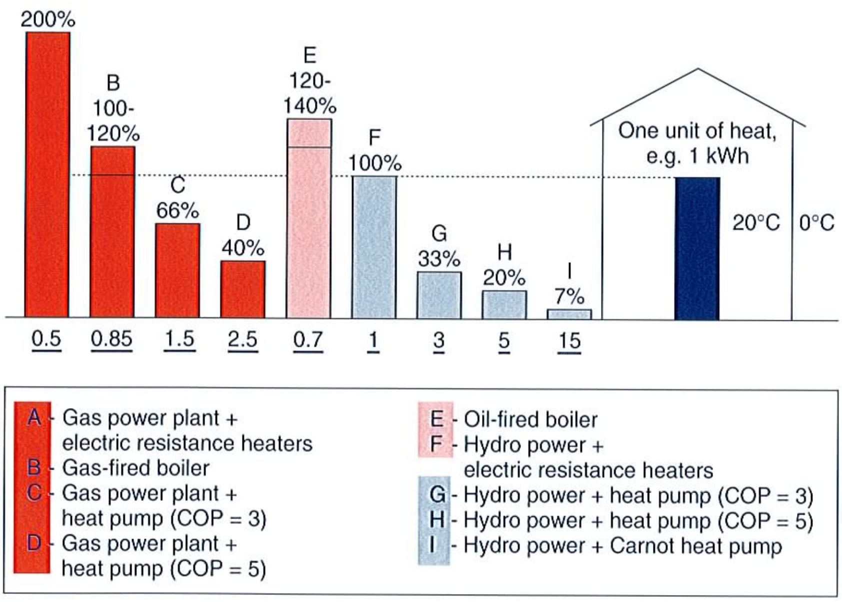
Strongly supported by power utilities, the "exergy method" is being applied more and more in the Netherlands. Policy makers are prepared to view areas as integrated wholes, for which the energy needs must be met with minimum primary energy or "exergy" resources. This is most notably so in the large areas which have been designated for development in the coming decades (the so-called VINEX locations). Near Utrecht in the centre of the Netherlands, for instance, a whole new city will be built. The implications of the "exergy method" for the VINEX area "KAN" in the east of the Netherlands is discussed on **page 26**.

In industries, process integration methods are increasingly applied. A number of major Dutch industries have carried out exergy analyses using the module EXERCOM, developed in the Netherlands and based on the US process simulation package ASPEN. Some companies note that the IEA Heat Pump Programme Annex 21 package "Industrial Heat Pump Screening Program" is highly useful, perhaps one of the best instruments to quickly assess the suitability of heat pumping in specific industries.

Source: Dutch National Team

Norway

An interesting large-scale example designed to minimize exergy losses, and re-use waste heat from space cooling has been realized in Bergen. This project is explained in further detail on **page 23** The system has a relatively low-temperature heat distribution network (25°C), which minimizes heat losses at low costs. The low-temperature loop is used as a heat source by heat pumps in separate buildings, in which the temperature is lifted to the absolute minimum needed for each particular site. Waste heat from space cooling, which is often simultaneously required with space heating elsewhere, is fed to the district heating loop, to be upgraded again elsewhere in the system. An interesting illustration of the benefits of heat pump systems to meet the building heating demand is shown in the figure, which is used for educational purposes in Norway.



Primary energy demand for the heating of buildings. Underlined figures show the energy utilzation-useful heat/primary energy demand.

Various software packages have been developed by SINTEF Energy including PRODIM, which is an aid to the design of heat pump components, and PROSIM which gives a detailed simulation of both simple and complex heat pump systems.

Source: Norwegian National Team

Regional energy cascades receive growing attention. Very ambitious is the Japanese "Eco Energy City Concept" where residential and commercial areas are to be heated by waste heat flows from industrial estates. The main challenge in this project is the transport and storage of heat with minimum losses. Advanced solutions include the use of metal hydrides, and chemical reactions with methanol. If necessary, heat pumps will be used to upgrade the waste heat to the required temperature.

Closer to realization is the imaginative project, known as "KAN", in the east of the Netherlands. The energy infrastructure for an area with 50,000 new houses, 1500 hectares of industrial estates, and 600 hectares of greenhouses will be based on the "minimum exergy principle". Cogeneration will be used to generate electricity. The heat from the cogeneration units will mainly be fed to a compact district heating network for industries and greenhouses. The space heating needs of residences are planned to be met by electric heat pumps, driven by the power from the cogeneration units. Environmental heat will be used as the heat source.

These applications or potential applications show that society-wide application of the "minimum exergy rule" has vast implications for the whole energy infrastructure of an area. The potential savings are enormous, but so are the necessary investments for hardware such as heat transport systems and heat pumps. One computer program which allows an evaluation of such fundamental choices for total energy systems is MARKAL. Developed under the IEA Implementing Agreement, "Energy Technology Systems Analysis Programme" (ETSAP), MARKAL is finding increasing use, for instance, to help shape the energy policies of countries in Central and Eastern Europe. Alternative scenarios, including for instance a "minimum exergy" one, can be evaluated with respect to financial implications, fossil fuel use or CO_2 emissions.

Optimized industries

Many industries offer excellent opportunities for energy cascades. Particularly in process industries, waste heat streams and heat demands are present at a variety of temperature levels. The sound integration of industrial processes can strongly reduce both the heating and cooling needs for the entire plant, with a consequent reduction in primary energy requirements. There is already much experience with process integration techniques such as "pinch technology", and more complete "exergy" or "second law" analyses. Such methods can help to work out which waste heat streams need to be cascaded down, and which need to be upgraded with a heat pump.

A great number of computer programs are available to aid the industrial plant design engineer. The IEA Heat Pump Programme has developed software that allows a quick assessment of the suitability of heat pumping (upgrading) for a large number of industries. Based on pinch technology theory, this Industrial Heat Pump Screening Program is one product of Annex 21 - "Global Environmental Benefits of Industrial Heat Pumps". It is now available from the IEA Heat Pump Centre (HPC). Another program is EXERCOM, an exergy analysis module developed in the Netherlands with the support of Novem (the Netherlands Agency for Energy and Environment), as part of the US process evaluation package ASPEN. And PinchLENI, from Switzerland, is an exergy analysis/pinch technology package incorporating a unique heat pump optimizer module.

Optimized buildings

The energy situation for large buildings, such as schools or offices, can be optimized in exactly the same way as with industries. There will be demand for power (100% exergy), and for heat at various temperature levels - tap-water and space heating, for example. And waste heat streams, such as sewage and ventilation air, will be available which

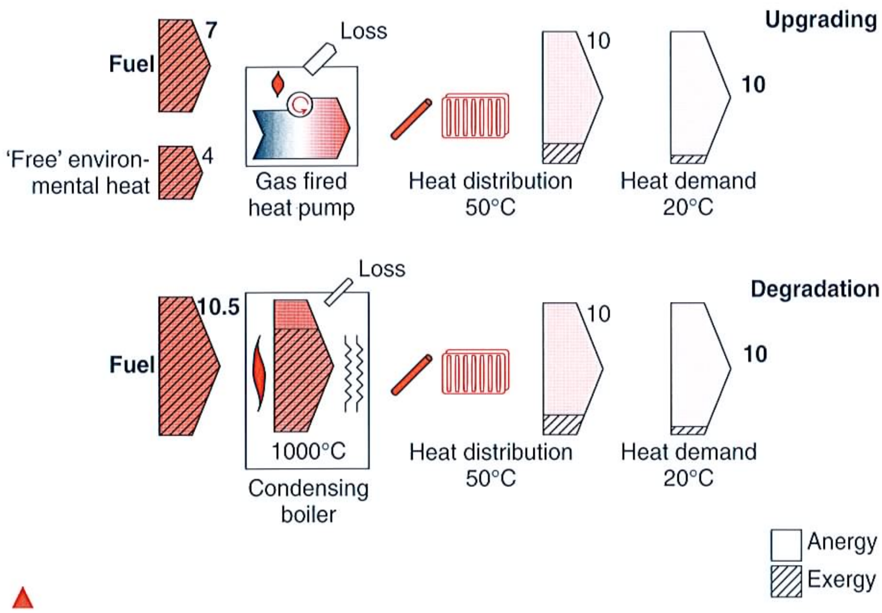
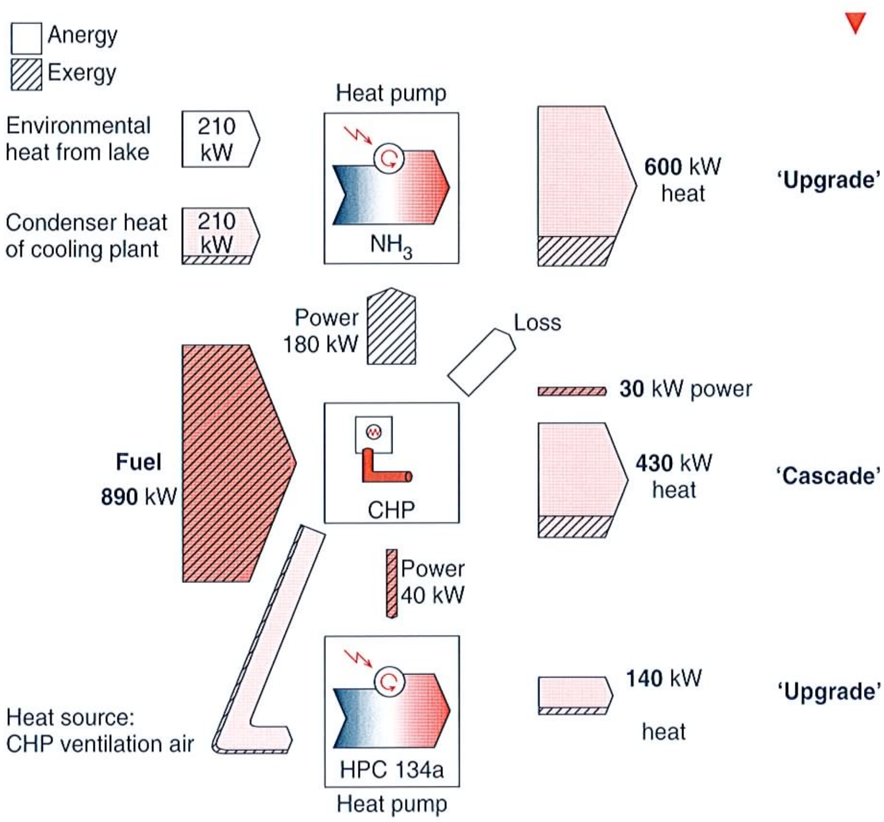


Figure 3: A comparison of energy upgrading using a gas-fired heat pump with energy degradation using a high-efficiency boiler for space heating.

Figure 4: Simplified energy flow diagram for the integrated power and heat supply system at a college in Switzerland.



Switzerland

The benefits of energy upgrading versus degradation is highlighted in a project where a simple heat pump water heater has replaced an existing resistance heater. The heat pump uses an underground garage as its heat source. During the day, only the circulation losses are covered, to avoid disturbing the stratification in the tank. The figure below shows the heat pump system, and the table compares its energy consumption with the resistance heating alternative.

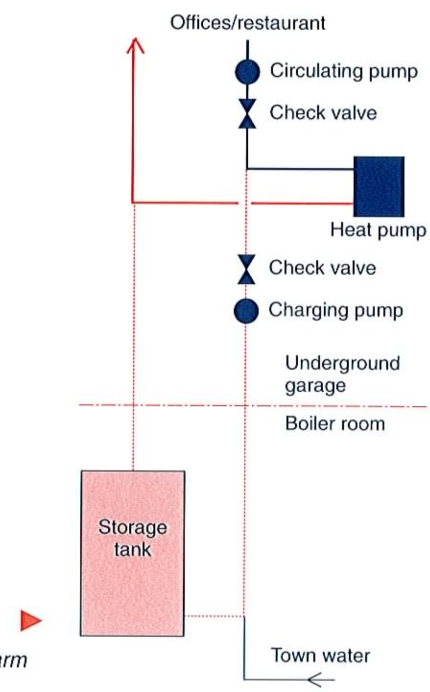
	Old resistance heater	New heat pump system
Electricity consumption	501 kWh	55 kWh
Hot water temperature	60°C	45°C
Simple payback time		4 years

Comparison of a resistance heating (energy degradation) with a heat pump system (energy upgrading) for tap-water heating.

An example of a more complex energy system demonstrating both energy upgrading and cascading is outlined in an article by Gunther Reiner in IEA Heat Pump Centre Newsletter Vol.12 No.3. This describes how a combination of cogeneration and heat pumping technologies is used to meet the heating needs of Alpenquai college in Lucerne. The system is illustrated in **Figure 4**.

Several tools have been developed to aid the design, analysis and optimization of heat pump systems. Yum WP/Holz is a PC program for the design and optimization of monovalent heat pumps, and bivalent heat pump systems with a wood fired boiler. W-Calc was developed to provide engineers with an easy-to-use tool to design and optimize heating systems with heat pumps, cogeneration plants, and large wood-fired boilers. The program allows preliminary design, system definition and dimensioning. PinchLENI is a pinch technology and exergy analysis program, usable for industries and buildings. HPDesign simulates air-source heat pump systems, and aids heat pump manufacturers and developers. Evapcoil simulates the operation of air-cooled direct-expansion evaporators.

Source: Swiss National Team



Heat pump water heating upgrading warm air from an underground garage.

heat pumps can upgrade to the required temperature. **Figure 4** illustrates the energy flows for a college building in Switzerland, where a local cogeneration unit performs energy cascading and two heat pumps provide upgrading.

The Swiss PinchLENI program has been used to analyze the energy use of both industries and buildings. Programs more specifically designed for buildings are available in the US such as the Department of Energy's Building Analysis Program, the Trane Company's System Analyzer™ and Load Express™. All of these software packages model and evaluate building energy use, and evaluate the impact of a variety of factors on HVAC and building performance.

Optimized houses

The principles of energy cascading and upgrading can also be applied to the home. A well-known example of a cascade is the ventilation heat recovery heat exchanger, which pre-heats incoming air. In the Netherlands, "micro-cogeneration units" are being considered for the residential sector, where home owners will produce power and heat in their own little energy cascade. Upgrades are realized by the widely applied residential heat pumps. They may use ventilation air as a heat source, for instance to heat tap-water. Alternatively, heat pump water heaters withdraw heat from non-heated rooms such as garages. More commonly, heat pumps are used to upgrade environmental heat, unlocking a vast renewable energy reservoir.

Design programs to help the installers in the residential sector are often issued by heat pump manufacturers, or are proprietary modelling tools used by private companies. In Switzerland, for example, programs include YUM WP/Holz for modelling monovalent heat pumps and bivalent systems with wood firing, W-Calc for designing heating systems for buildings, and HPDesign for modelling air-source heat pumps.

USA

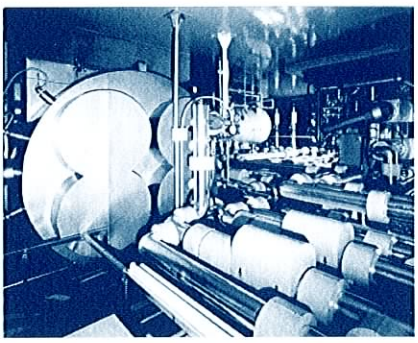
The application of industrial heat pumps in the US is limited primarily to the Chemical and Petro-chemical areas for open-cycle systems (50%), and to lumber drying for closed-cycle systems (40%). However, new pushes from the utility industry, coupled with innovative financing options, appear to be changing this. Several textile mills in the southeastern US are looking to their electrical supplier to design, install, maintain, and own heat recovery heat pumps at their plants. The plant in return signs an "energy" contract to purchase metered kJ from the system.

An important trend in both industrial and institutional applications is the provision of process and storage refrigeration and cooling in conjunction with space conditioning. A food processing company in Southern California has installed an integrated package consisting of a dual-source gas-fired steam generator, a bank of five screw compressors supplying ammonia for process refrigeration and comfort cooling needs, and a thermal storage air conditioning system that uses ammonia to make ice for peak cooling. The company not only enjoyed better performance, but also realized significant savings thanks to a power rebate and by generating some of their own power.

A combined heating, cooling, and power generation system is now being designed for McCormick Place - an exhibition centre in Chicago, Illinois. Three gas turbines will drive motor-generators and screw compressors for chilling an ethylene glycol solution. Steam from heat recovery boilers, supplemented by gas-fired boilers, will provide heating. The system will be fitted with a thermal storage tank for storage of chilled sodium nitrite brine for peak period cooling.

The US government, industry organizations, and the private sector have developed a variety of modelling tools for heat pump system and component design. These tools include building simulation and analysis software such as the US Department of Energy's (DOE's) DOE-2 Building Analysis Program, the Trane Company's System Analyzer™ and Load Express™, and Market Manager from SRC Systems Inc. All of these software packages model and evaluate building energy usage and evaluate the impact of a variety of factors on HVAC and building performance. In addition, the DOE and the Electric Power Research Institute are collaborating on a new program, PowerDOE, which will simplify the DOE-2 user interface and allow for constant improvement and modification of the models. For component design, the Oak Ridge National Laboratory Heat Pump Design Model is widely used by HVAC manufacturers to speed up the engineering design process and model a variety of factors, including alternative refrigerants and variable-speed drive systems.

Source: Sandy Smith of Oak Ridge National Laboratory, Frank Pucciano of Georgia Power and William Richards of William V. Richards Inc.



This Japanese Super Heat Pump meets space heating and cooling needs with a seasonal performance factor (SPF) of 5.3.

Improved heat pumps

The "minimum exergy principle" not only applies to heating systems large and small, it should also be used as an aid to the design of the heating equipment itself, including heat pumps. For instance, heat pumps will be most efficient if the temperature difference across heat exchangers is minimized to avoid exergy losses. This can be achieved through refinements in heat exchanger design or through techniques such as temperature glide and multi-stage condensation. Another example is the application of an expansion turbine rather than expansion valve to recoup the exergy added to the working fluid by the compressor that is lost at the valve.

In the development of the Japanese "Super Heat Pumps", some or all of these design solutions were applied, resulting in machines with truly amazing efficiencies. One example of a super heat pump is shown in the **photo**. More in general, it is important to assess the exergy losses of each individual heat pump component, to find the most viable route for improvement. Heat pump designers can utilize a number of optimization packages such as the US Heat Pump Design Model from Oak Ridge National Laboratory.

Rising to the challenge

In conclusion I would like to stress that exactly the same principles improve the efficiency of equipment, buildings, industries, and even entire communities. The laws of thermodynamics point the way to efficient systems and applications, and a great number of computer programs are available to aid designers. But ultimately it is the designers who must rise to the challenge of meeting an ever growing demand for energy services with less and less of our precious exergy resources.

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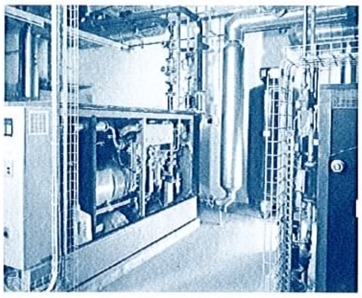
A successful combination

Cogeneration and Heat Pumps in Switzerland

Hanspeter Eicher and Jürg Weilenmann, Switzerland

The combination of electric heat pumps with cogeneration power plants can result in an energy system with a very high efficiency for supplying heat and power. Such a system is now developing in Switzerland where much of the extra power demand from newly installed heat pumps is delivered by fossil-fuel cogeneration plants. This article examines the growing markets for these two technologies and discusses the benefits of this highly successful combination.



This cogeneration unit serves an industrial plant.

According to the targets set by the Swiss Energy 2000 Action Programme, by the year 2000 at least 3,000 GWh of heat per annum should originate from renewable sources, over and above the amount produced in 1990. And 40% of this heat is to be produced by heat pumps, amounting to 1,200 GWh per annum.

To meet the latter target, considerable grants have been made available to support heat pumps through promotion and investment aid. The activities are aimed at the replacement of electric resistance (baseboard) heating systems and at the replacement of fossil-fuel energy carriers. Swiss legislation is also supporting heat pumps. Since December 1990, fixed electrical resistance heating units with more than 3 kW power consumption have been subject to compulsory approval procedures and restrictive conditions for their installation and operation. Furthermore, the tightening up of air pollution regulations is also "helping" heat pumps onto the market.

Overall, the combined effect of legal restrictions, support programmes and information for the public and potential investors, is an improved outlook for heat pumps in the long term. And this will have important consequences for Switzerland's power network.

Power for heat pumps

Some of the electricity used to drive the additional heat pumps, nearly all of which are electric, comes from the reduced demand from resistance heating. But a significant amount of this power demand will be met using fossil-fuel cogeneration plants. Cogeneration (also known as combined heat and power) technology is becoming increasingly important in Switzerland where the current electricity mix is mainly made up of hydropower and nuclear power. Building additional hydroelectric power plants is difficult because of lengthy approval procedures and there is a lack of public acceptance for new nuclear power plants. Consequently, fossil-fuel cogeneration, such as for large buildings or small-scale district heating, could soon become the "third pillar" of the Swiss electricity network.

Environmental benefits

In comparison with fossil-fuel heating boilers, the combination of cogeneration plants and heat pumps improves the efficiency of primary energy use by up to 60% with a heat pump seasonal performance factor (SPF) of 2.4. For example, in the production of 100 units of available heat at normal room temperatures, a conventional gas boiler requires 110 units of natural gas while a cogeneration plant and a heat pump require just 65 units.

Since there is a correlation between CO_2 emissions and the consumption of primary energy, a combined cogeneration/ heat pump technology contributes at least a third less to the greenhouse effect than conventional heating systems. Moreover, the big advantage of combining a cogeneration power plant with a heat pump is the fact that they do not have to be situated at the same place.

The cogeneration market

Table 1 shows data on the status of cogeneration installations in 1994 and the targets for 2005. The 1,330 GWh of electricity produced by decentralized cogeneration in 1994 accounted for 2% of the total Swiss electricity production of 63,700 GWh. At 5,000 GWh, the target figure set by the cogeneration industry for the year 2005 would be equivalent to 8% of current power production of 1994.More detailed figures are available for the 507 small units that are currently in operation. Average power output is approximately 138 kW and average electricity production is 438 MWh (this equates to an average 3,180 hours of full operation). The relative use of primary energy sources is illustrated in **Figure 1**.

The heat pump market

Figure 2 shows a breakdown of home heating technologies in Switzerland. Clearly there is great potential for further employment of heat pumps. The electricity consumption of heat pumps was approximately 500 GWh in 1994, i.e. only just over a third of the electricity produced by cogeneration units.

In 1994, the number of installed heat pumps increased by 3,000 units, corresponding to a rise in installed capacity of 8.5% and an increase in sales of 30% over the previous year. However, the drop in new construction activity, one of the parameters affecting heat pump sales, serves as an example of how the market is becoming harsher: in 1980, 17,000 new buildings were built with a heating requirement of less than 20 kW; in 1994, 8,200 new buildings were constructed in the same sector.

The refurbishment market is not yet able to compensate for the drop in the construction of new buildings. Nevertheless, forecasts for the coming years sound hopeful. 37,000 oil and gas boilers were due for replacement in 1994 and this figure is expected to rise to 53,000 units a year over the next twenty years.

When examining the heat pump statistics closely it can be concluded that it is not just the number of heat pumps but the growth in their use which is rising. Average capacity, although small, is increasing, and the proportion of heat pumps installed during the renovation of buildings has increased steadily in recent years and now constitutes 25% of all installed heat pumps. **Table 2** provides data on installed heat pumps at the end of 1994 and shows the impact of the installation and replacement of heat pumps during 1994. The addition of 3,000 heat pumps in 1994 is calculated from sales of 3,309 heat pumps by members of the Heat Pump Working Group (AWP) or "Arbeits Gemeinschaft Wärmepumpen",

	Number of plants	Installed capacity (MWe)	Electricity production (GWh)
Installed plants in 1994			
Industrial and district heating	24	270	740
Refuse incineration plants	14	110	370
Small-scale plants (<1 MWe)	507	70	220
TOTAL	**545**	**450**	**1330**
Targets for the year 2005 set by the Cogeneration Study Group	1500	1,000	5,000

Table 1: Relative consumption of primary energy by small-scale cogeneration plant in Switzerland.

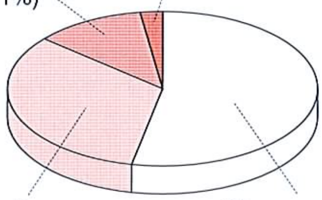


Figure 1: Relative consumption of primary energy by small-scale cogeneration plant in Switzerland.

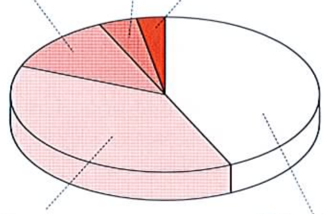
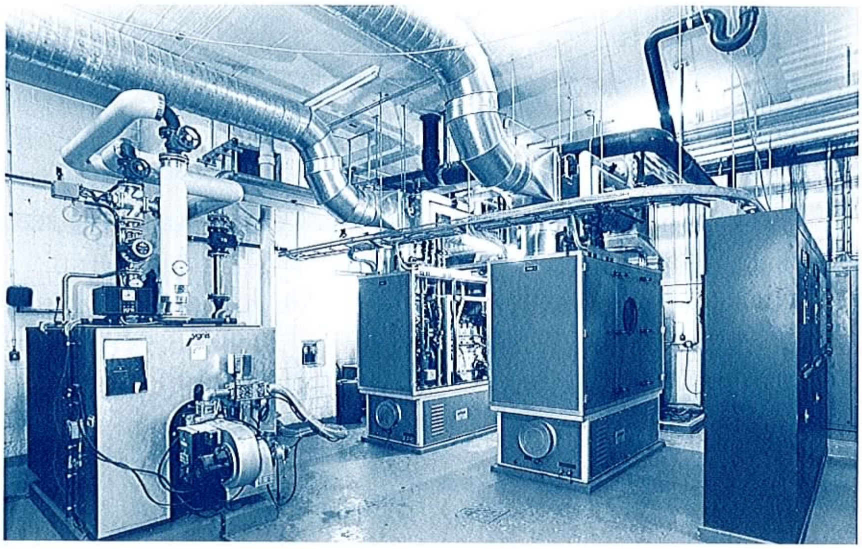


Figure 2: Installation of home heating equipment in Switzerland.

Table 2: Installation of heat pumps in Switzerland

Heat pumps	Situation at the end of 1994		Increase in 1994	
Number of unit	43,000		3,000	
Installed capacity:				
Electrical	285	MWe	24	MWe
Thermal	855	MWth	72	MWth
Electricity consumption	513	GWh	34	GWh*
Heat production	1,231	GWh	81	GWh*

* *data not confirm*



These two cogeneration units serve a small-scale district heating system.

plus 321 units sold by suppliers who are not members of the AWP, less just over 600 units which were replaced. Heat pumps installed in 1994 continued to exhibit an average SPF of 2.4 but the average operating time is estimated to have dropped from 1,800 hours to 1,400 hours.

Promoting heat pumps

In Switzerland a whole series of public and private bodies are involved in supporting heat pump technology. The Swiss Federal Office of Energy has focused on five areas within its Energy 2000 programme: research, a pilot and demonstration programme, quality assurance, heat pump marketing and the Heat Pump Start Up Programme.

The Swiss Federal Office Heat Pump Start Up Programme ran from the middle of 1993 until 30 June 1995. During its two years of activity, approximately 2,800 applications with a total heating capacity of 40 MW were installed with the aid of subsidies. Subsidies were linked to quality criteria and grants were made to a total of CHF 8.1 million (US$ 7.0 million).
Despite the ending of the Start Up Programme, financial incentives are still provided by the Cantons. Some offer actual investment aid for heat pumps and, apart from a few exceptions, tax relief is available throughout Switzerland.

The Swiss Association for the Promotion of Heat Pumps or FWS (Fördergemeinschaft Wärmepumpen Schweiz) encourages the widespread application of heat pump technology and runs marketing, basic and advanced training, quality control and an information centre (see the article by Beyeler in IEA Heat Pump Centre Newsletter Vol.13. No.2, page 25). The FWS is supported by heat pump manufacturers, installation industry associations, the organization representing electricity producers, some large power stations, the cantons of Aargau and Zurich and, in an advisory capacity, the Swiss Federal Office of Energy.

An indispensable contribution to heat pump promotion has been made by the Testing and Training Centre at Winterthur. Established by the National Energy Research Fund, the electricity industry, the Canton of Zurich, the Swiss Federal Office of Energy and various other partners, the centre ensures the quality of heat pump systems in Switzerland.

Utility support

Some electricity suppliers offer special rates for the operation of electric heat pumps - the "Rates for off-peak consumption" as they are known. Thanks to these reduced rates, savings from the operation of a heat pump are between 20% and 30%. As a rule the electricity user can only purchase electricity at the favourable rate if the heat pump is supplied via a separate meter, the installation of which must be paid for by the customer. This condition undoubtedly makes the reduction less attractive, but cannot easily be eliminated. During the winter peak rate times, for example, electricity in Zurich City costs CHF 0.195 per kWh (US$ 0.170) provided that yearly consumption is greater than 4,800 kWh, as is the case, of course, if a heat pump is in operation. The reduced rate for heat pumps is CHF 0.15 per kWh (US$ 0.13) which is 23% less.

A combination with a future

Anyone following innovations in the field of heat pumps and cogeneration systems, who is also aware of their advantages in terms of energy and thermodynamic efficiency, will undoubtedly agree that this technology has a great future. If the electricity production target of 5,000 GWh set by the cogeneration industry for the year 2005 is used consistently for the operation of heat pumps, 12,000 GWh of heat could be provided in this environmentally friendly way, which equates to 12 % of all heat production in Switzerland.

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How to choose a Heat Pump system

Application of the "Analytic Hierarchy Process" selection method

Shigeru Kubota, Japan

When designers considered how a heat pump using river water could supply a district heating and cooling system in Tokyo, they were faced with a number of options. And for every option, there were both merits and drawbacks. To help them make the right choice, they employed a selection methodology known as the "Analytic Hierarchy Process". This article shows how this approach led to a successful outcome for Japan's first river-source heat pump.

The "Analytic Hierarchy Process" (AHP) is a methodology which can be used during the design stage of a heating and air conditioning facility to determine the type of heat pump system to use. Such an approach was taken in the design of a district heating and cooling system for the Waterfront District of Hakozaki in Tokyo, Japan.

Right from the start, the designers elected to choose a heat pump system using the nearby Sumida river as the heat source. This project was the first in Japan to use river water in this way. Although such systems had already been developed in Europe, this new venture called for a careful examination of the available design options. Indeed, many of the conditions were specific to this project, so examples of projects in other countries were not necessarily useful as a reference.

In particular, many features of the river posed specific problems:

- the water quality is corrosive in nature and contains a lot of litter and floating matter
- there is an abundance of marine organisms as the river location is an estuary
- safety controls on the river banks are strict to prevent flooding.

In addition, equipment for utilizing river heat was not manufactured in Japan at that time. And the Public Corporation required that the river bank be used as a public park at the point chosen for the heat pump intake pipes.

Five system options

Figure 1 shows the feasible heat pump systems, labelled A to E, that were considered for this project.

In System A, river water is introduced directly into the heat pump and a standardized combination of a water-source heat pump and intake facility is used. River water is passed through the condenser as cooling water during the summer and through the evaporator as a heat source during the winter.

In System B, which is similar to System A, river water is introduced directly into the heat pump. However, in this system, the heat exchanger between the river water and refrigerant is separated from the heat pump and installed as near to the intake point as possible.

System C uses an open type heat exchanger, many examples of which can be found in northern Europe.

In System D, brine is used to transport heat to and from the river via a vertically-oriented tubular heat exchanger. An agitator is required to prevent a noticeable lowering in efficiency when the river flow stops as the tide changes.

Finally, in System E, the heat exchanger in System D is replaced by one using a spiral tube.

In evaluating these five alternatives, it was not only necessary to consider the operation and construction costs, but to evaluate items which are measured in different ways, such as the safety of the environment, and reliability. This requires a special approach.

Analytic hierarchy

A technique for such evaluations is the "Analytic Hierarchy Process" (AHP), introduced by Prof. T.L. Saaty of the University of Pittsburgh in the USA. This evaluation method deals with a wide variety of elements in a well-balanced manner. It compares opposing ideas and elements which are measured in different ways.

The first step of AHP is to put the evaluation criteria and alternative plans in order of importance with respect to the subject by means of a pair comparison of the respective evaluation criteria. This is done by constructing a hierarchy chart. **Figure 2** shows the one made for the Hakozaki Waterfront project.

As indicated, the first-stage evaluation criteria were "cost", "safety", "ease of construction" and "ease of operation". The evaluation was based on these items by applying pair comparison values of between 1 and 9 according to the relative importance of each pair. For example, a score of 1 is given when one item has equal value with another, and a score of 9 is given when the first item is considered to be very much more important than the second.

Table 1 shows an example of such a pair comparison. As shown, evaluating "cost" on the vertical axis, in comparison to "cost", "safety", "ease of construction" and "ease of operation" on the horizontal axis yields values of 1 (naturally), 3, 5 and 7. Where the evaluation is reversed, it is expressed as the reciprocal number. When the evaluation is completed, the next step is to calculate the weighting for each item. In Table 1 this is done by finding the geometric average.

The weightings shown in Figure 2 are the actual results of comparisons obtained for the Hakozaki Waterfront project, including those made for second-stage evaluation criteria, such as running costs.

The evaluations were carried out by five pairs of experienced experts, representing the designer, the owner, the operation manager, the manufacturer and the contractor. The geometric average of their evaluations was taken.

Evaluating the systems

Having established the weighting for first-stage and second-stage evaluation criteria, AHP can then be used to compare the alternative heat pump systems. This time, however, the evaluation is carried out not by comparing one system with another, but by allocating scores of 1, 1.5, 2, 2.5 or 3. The reason for this was that it was judged to be easier to carry out evaluation by scoring, as the differences between the second-stage evaluation criteria, were small. **Table 2** shows an example of the scoring criteria related to public hazard.In the evaluation, the following points were noted:

System A is the simplest in system composition and has high efficiency. This resulted in the highest evaluation in both the initial cost and running cost categories. Furthermore, it can be said that the maintenance of the intake facility is easy and that there are no space saving concerns. The system also scored well on safety criteria. However, measures must be taken to protect the system from corrosion problems and to remove slime and marine organisms.

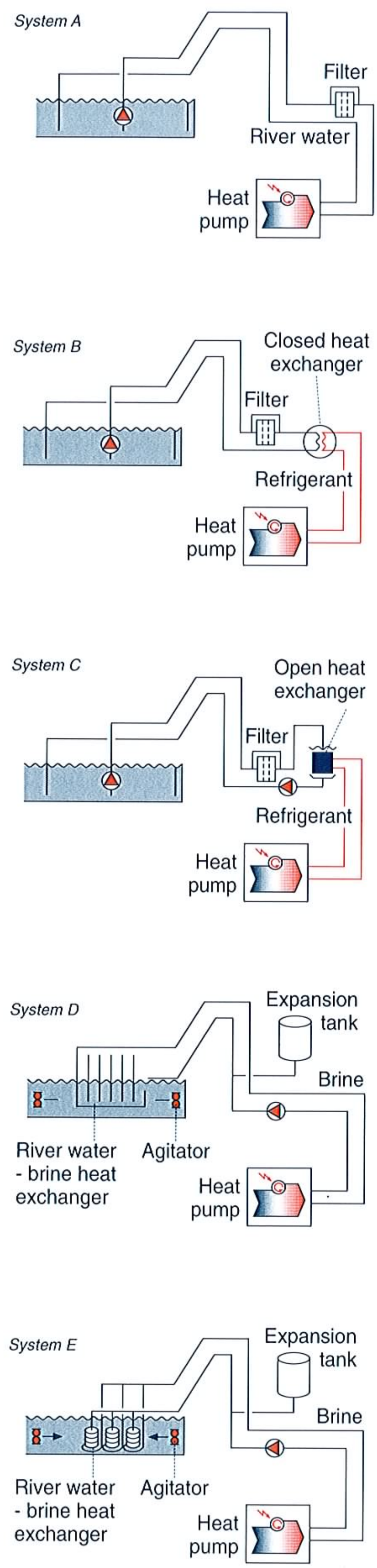
System B is basically the same as System A. Although the merits derived from limiting the scope of the introduction of the river water are high, the disadvantages are that the construction of the structure is more complicated and that the refrigerant piping must be longer.

With System C, the open type heat exchanger is lower in efficiency and maintenance is difficult due to contaminants in the river water. The adherence and formation of marine organisms to the system components is a major drawback. It is also difficult to prevent water leaking by the siphon

Figure 1: Five systems for using river water heat. ▶

Table 1: An example of pair comparisons under the Analytic Hierarchy Process. ▼

	Cost	Safety	Ease of construction	Ease of operation	Geometric average	Weighting
Cost	1	3	5	7	$\sqrt[4]{1x3x5x7}=3.20$	3.20/5.89=0.543
Safety	1/3	1	5	7	$\sqrt[4]{1/3x1x5x7}=1.85$	1.85/5.89=0.314
Ease of construction	1/5	1/5	1	1/3	$\sqrt[4]{1/5x1/5x1x1/3}=0.34$	0.34/5.89=0.058
Ease of operation	1/7	1/7	3	1	$\sqrt[4]{1/7x1/7x3x1}=0.50$	0.50/5.89=0.085
Total of geometric average					**5.89**	



Score	Public Hazard
3	No anxiety at all
2.5	Practically no anxiety
2	It is possible to take measures to prevent accidents
1.5	As it is impossible to completely prevent accidents, the system will be kept safe by maintenance and early replacement of parts.
1	Accident prevention is unjustifiable due to enormous costs. It is feared that the system will be a public hazard in the event of an accident.

Table 2: Example of scoring criteria.

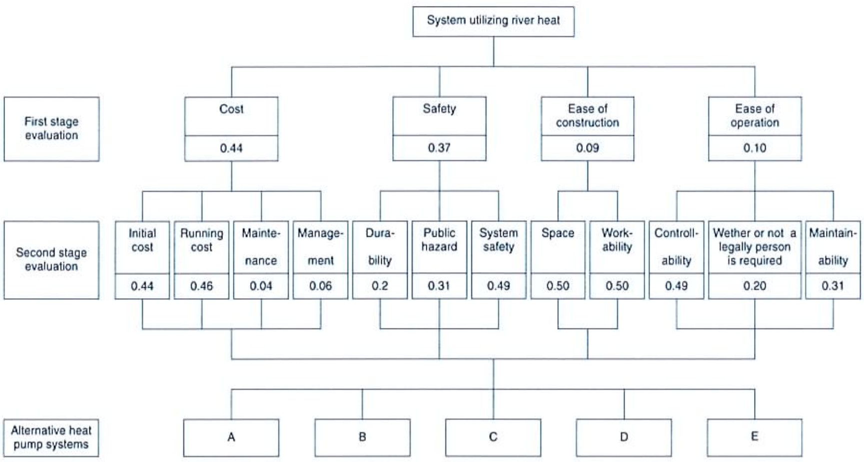


Figure 2: Hierarchy chart for the Hakozaki Waterfront project.

Installation of the intake pipes at Hakozaki Waterfront.

Table 3: Evaluation of System A.

Criterium	Score	Weighting
Initial cost	3	0.582
Running cost	3	0.606
Maintenance cost	3	0.054
Management cost	3	0.078
Durability	2.5	0.453
Public hazard	3	0.345
System safety	2.5	0.185
Space	3	0.135
Workability	3	0.135
Controllability	3	0.147
Requirement for legal person	2.5	0.05
Maintainability	2.5	0.078
Weighting total		**2.848**

phenomenon into the machine room, which is located below the river water level.

System D can be expected to receive a high-level evaluation for economy and maintainability, depending on the restrictions imposed by the "River Act" and on conditions such as the water quality, flow speed and adherence and formation of marine organisms. However, the conditions of the river at the time of assessment required a wide area of heat exchange, making maintenance difficult. This resulted in a low appraisal.

Although System E is basically the same as System D, the evaluation was even worse due to the fact that a larger area of the heat exchanger installation is submerged in river water.

Selecting a winner

By using the AHP methodology to consider all the evaluation criteria, System A was shown to be the best choice of heat pump system. **Table 3** shows the results of the evaluation for System A which led to a weighting total of 2.848 - the highest total. Allocating 100 points to System A, the relative scores for Systems B, C, D and E were 89, 55, 68 and 58 respectively. System A was therefore selected to be the optimum system.

Following the selection of the basic system, the next step was to select the technology to realize a heat pump with the composition of System A. To report on these experiments is beyond the scope of this article. Suffice to say that the system was successfully completed and has been in use up until present, serving the heating and cooling needs of the Waterfront District of Hakozaki and making energy savings of about 30%.

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Two-step district heating & cooling

Jørn Stene and Geir Eggen, Norway

With conventional district heating, the heat distribution temperature must be sufficient to meet the hottest heating need. This requires an expensive piping system for the transport of hot water. And when heat pump technology is used, it severely limits the achievable efficiency. A much better way is to deliver the heat in two steps, with heat distributed at a much lower temperature, and then upgraded to the temperature required for each application. This innovative approach is now being applied at a Norwegian University.

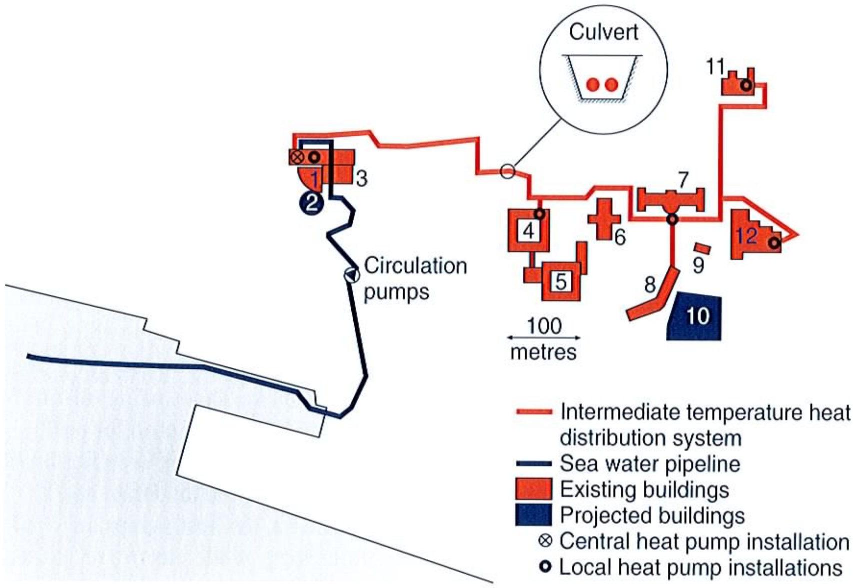


Figure 1: Outline of the University heat pump system.

In 1991, the University of Bergen in Norway decided to install an energy saving heat pump system on its campus. After considering several alternatives the two-step system shown in **Figure 1** was chosen.

A central sea water heat pump supplies an intermediate heat distribution system which circulates water at a temperate temperature. This temperate water serves as the heat source or heat sink for several local heat pumps which provide heating or cooling in individual buildings or groups of buildings. This system was chosen on the basis of a comprehensive technical and economic evaluation.

The first part of this prototype system was completed in the spring of 1995 and includes only the central heat pump system and a heat pump for the Faculty of Law building (building 1 in Figure1). The other nine buildings will be connected to the system during the period 1996 to 1997.

Diverse requirements

The university buildings represent a great diversity with regard to application area, year of construction, standard of thermal envelopes, desired comfort level, as well as heating and cooling requirements and heat distribution temperatures during the year. The total heating load under design conditions is estimated at 3.4 MW, with an annual heating demand of 5.3 GWh. Hot water heating accounts for 8% of the annual space heating demand. The maximum cooling load is 1.5 MW, and the annual space cooling demand is roughly 15% of the annual heating demand (0.6 GWh). Active cooling is required less than 70 days per year.

Low-temperature heating systems are installed in most of the buildings, requiring distribution temperatures ranging from 55°C to 60°C under design conditions. Three buildings, however, require temperatures of between 60°C and 80°C. The two-step system is well-suited to meet such variations in supply temperatures. Since heat is always provided at a minimum temperature level in the buildings, the heat pump system will use less primary energy and obtain a higher SPF than a conventional district heating system with heat pump.

Upgrading sea water heat

The central heat pump unit is located in the new Faculty of Law Building on a hill nearby a Fjord (see Figure 1). Sea water at 30 metres depth is used as a heat source for the heat pump and for space cooling in the building. The temperature is relatively high and stable during the year, with a minimum of 6°C in March and a maximum of 12°C in October. The central heat pump supplies the intermediate temperature heat distribution network at around 25°C. In contrast to conventional district heating and cooling systems, a single

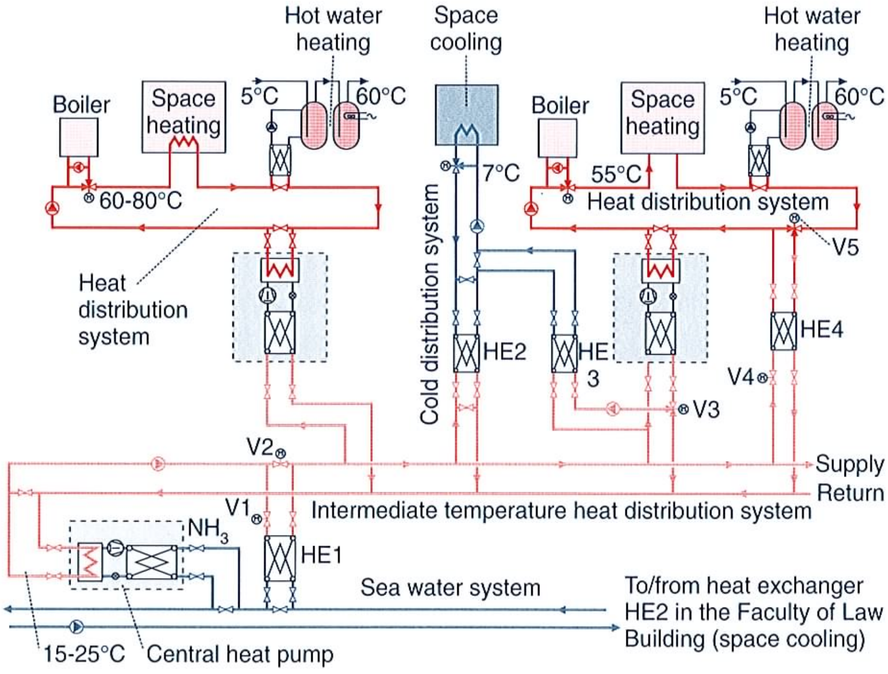


Figure 2: The heat pump system in detail.

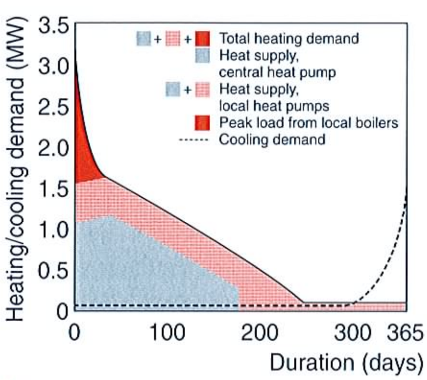


Figure 3: Heating and cooling demand duration curves.

pipeline system is used for heat distribution, in this case by supplying temperate water between the central heat pump and the local heat pumps. The non-insulated plastic pipelines (for or 16 bar maximum pressure) are placed in shallow ditches and covered with insulating filler (pumice-stone and gravel). This inexpensive distribution system offers many advantages, although for this prototype project they are not so significant since the buildings at the campus are located within a relatively small area.

The intermediate temperature heat distribution system is designed for a relatively low temperature difference of 5°C. When more buildings are connected to the heat pump system, the transport capacity of the pipelines can easily be doubled by increasing the temperature difference under design conditions to 10°C. **Figure 2** shows the heat pump system in more detail. The central heat pump is a 25 bar single-stage ammonia unit, equipped with a 16 cylinder reciprocating compressor, a two-speed electric motor, a titanium twin-plate heat exchanger as the evaporator and a standard twin-plate heat exchanger as the condenser. The heating capacity is 1,150 kW under the design conditions of 25°C outlet water temperature from the condenser and 6°C sea water temperature. The heating capacity equals the total evaporator capacity of the local heat pumps. If a higher capacity is needed in the future, two more units can be installed in the machinery room.

Serving local buildings

In addition to the local heat pump that has already been installed in the Faculty of Law Building, four more units with heating capacities ranging from 150 to 620 kW will be installed by 1997. Three of the units, including the heat pump in the Faculty of Law Building, are designed to provide simultaneous heating and cooling. The heat pump units use ammonia as working fluid and are equipped with 40 bar reciprocating compressors, twin-plate heat exchangers as evaporators and shell-and-tube condensers. The heat pumps operate in a bivalent system and are designed to cover the base load for space heating - approximately 50% of the total demand. The existing oil-fired and electric boilers are used for peak load and back-up heating as indicated in **Figure 3**. Due to the moderate hot water demand, the heat pumps are used for pre-heating, while electric resistance heaters provide top-up heating. **Table 1** shows the main performance and economic data for the heat pump system. As shown, the system exhibits a total SPF of 2.8 for the delivery of heating and cooling, including the energy consumed by the peak-load boilers.

Supplying heating

In heating mode, the central heat pump supplies temperate water to the local heat pumps. Since the heat pump system operates in two steps, the distribution temperature from the central heat pump should ensure favourable operating conditions for both the central and local heat pumps, by minimizing the temperature lift. Calculations have shown that a distribution temperature of approximately 25°C under design conditions is an optimum level. The distribution temperatures and consequently the heating capacity of the central as well as the local heat pumps are controlled according to the outdoor temperature as shown in **Figure 4.**

Supplying cooling

During long periods of the year, ventilation is sufficient to cover the entire space cooling demand in the buildings. When active cooling is needed, a cold distribution system is activated (see Figure 2). At low cooling loads, heat exchanger HE2 will transfer heat from the cold distribution system to the intermediate heat distribution system, as long as there is a positive temperature difference. At higher cooling loads, the local heat pump is manually switched to cooling mode. The three-way valve V3 is opened towards heat exchanger HE3, and the cold distribution system is used as a heat source for the heat pump. The compressor capacity is now controlled by the temperature requirement in the cold distribution system. If the condenser heat exceeds the space heating and hot water demand in the building, excess heat is given off to the intermediate temperature heat distribution system by opening valve V4 and V5 towards heat exchanger HE4.

When the heat given off to the intermediate temperature heat distribution system exceeds the total evaporator capacity of the local heat pumps, the water temperature will rise above the required temperature level. The central heat pump is then switched off manually and heat exchanger HE1 is activated in order to give off surplus heat from the system to the sea water, which then acts as a heat sink.

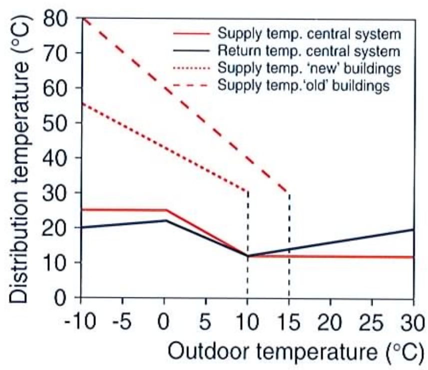
Opting for ammonia

In the tender document, the University of Bergen required working fluids with zero ozone depletion potential (ODP) and low or zero global warming potential (GWP) to be applied to the heat pump units. Both ammonia (NH_3) and HFC-134a heat pumps were offered by several suppliers. The total investment cost of the ammonia heat pumps was approximately 30% higher than that of the HFC-134a systems, but with 20-25% higher coefficient of performance (COP) the ammonia system gave the lowest annual costs in terms of US$/kWh.

Design Conditions:		
Maximum heating load	3,4	MW
Heating capacity, local heat pumps (46%)	1,57	MW
Heating capacity, central heat pump	1,15	MW
Heat Production:		
Local heat pumps (93%)	5,300	MWh
Local peak load boilers (7%)	400	MWh
Total heat production	**5,700**	**MWh**
Total cold production	**660**	**MWh**
Energy Consumption:		
Central + local heat pumps	1,600	MWh
Circulation pumps etc.	300	MWh
Local peak load boilers	500	MWh
Total energy consumption	**2,400**	**MWh**
Seasonal Performance Factors:		
Average SPF, heat pumps	3.3	
Total SPF - heating (incl. peak load boilers)	2.5	
Total SPF - heating/cooling (incl. peak load boilers)	2.8	
Investments and Profitability:		
Heat pump investments	US$ 0.9 million	
Total investments	US$ 2.5 million	
Annual energy costs	US$ 0.05/kWh	
Internal rate of return	13%	

Table 1: Performance and economic data.

Figure 4: Distribution temperatures for the central and local heat pump units.



With the use of ammonia, several safety measures had to be provided. These included gas-tight machinery rooms, leak detectors activating alarm systems, water spray systems (central heat pump only) and fail-safe ventilation systems. The latter include a forced ventilation system for the machinery room with two-speed fans and a natural ventilation system (open duct to the surroundings) in case of a power failure.

Two steps to perfection?

Two-step systems, such as the one at Bergen University, offer a number of advantages compared to conventional district heating and cooling systems with heat pumps. The seasonal performance factor (SPF) is higher since the distributed heat pumps can be optimized according to the heat distribution temperatures of different buildings. And, by taking two steps to reach the desired supply temperatures, the heat pumps operate under more favourable operating conditions. Two-step systems also mean that investment costs are reduced since a simple and inexpensive heat and cold distribution system can be used. Able to meet a wide range of heating and cooling needs, and readily adaptable to future expansion, two-step systems seem in many ways to be the perfect system for district heating and cooling.

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Exergy method takes root

A new approach to energy systems design

Peter Juijn, Pieter van der Ploeg, Bert Doldersum and Onno Kleefkens, The Netherlands

Traditionally, efficient energy systems are designed to maximize the amount of energy supplied by a given quantity of fuel or electricity. But this does not tell the full story. For energy does not only have a quantitative value, it also varies in quality. Electricity and fuel have a higher quality than heat. And the quality of heat varies with temperature. In the Netherlands, engineers are now using the "exergy" method to take account of the quality of energy in the design of better energy systems for industry and buildings.

For the calculation of the optimal energy-supply, the exergy approach is used more and more in the Netherlands. With this approach, energy is considered not only in terms of its absolute value in Joules, but also in terms of its quality. The **Box** explains this further.

In the Netherlands, the exergy approach is applied in two completely different applications:

- in the development of future energy infrastructure for large out-of-town building development areas
- for the minimization of the energy-losses in the chemical industry and in middle-sized process industries.
  In both cases heat pumps play an important role. To develop new tools for the exergy method, working groups have been set up to help both industrial applications and residential areas.

New infrastructures

The Netherlands is one of the most densely populated areas in the world. Until recently, the increase in building volume has been the responsibility of local planners. Now, the Dutch government has developed a central view on the growth in building development up to the year 2015. It has assigned seven areas of rapid growth where about one million domestic houses are to be built. These so called "VINEX-areas" are "green field" sites without any infrastructure and offer an excellent opportunity for energy planners to design optimized energy supply systems.
For the locality between the cities of Arnhem and Nijmegen, the so-called "KAN-area", in the east of the country, the exergy-method is playing an important role in the design of the infrastructure [1].

In this area 50,000 new domestic houses, 1,500 hectare of industrial plant and 600 hectare of greenhouses will be developed over the next 20 years. The exergy method shows that the energy losses are minimal when the production of heat is combined with power generation by using cogeneration (or combined heat and power) equipment. However, there will be a structural over production of electricity if all heat is generated by cogeneration. The heat demand in the area exceeds the power demand, in primary energy, by a factor 4 to 5 (which is typical for the whole country). When the cogeneration system is dimensioned according to the power demand, additional heat will have to be generated by other systems.

Gas or electricity?

Nearly all the houses in the Netherlands are connected to the gas grid. Of these houses, 73% use a gas-fired central heating system, 15% use room heaters and 12% are served by collective heating systems. The standard, or reference, system is the condensing gas-fired boiler.

New developments, and the application of the exergy method, however, mean that there is an increased opportunity for using heat pumps instead of gas boilers in new housing areas such as the VINEX sites. The study to determine the energy system for the KAN-area has therefore closely examined the heat pump option.

In the Netherlands, the "Energy Performance Standard" (or EPN) for buildings sets a standard for the maximum energy use. This standard is worded in such a way that it prescribes an energy use which must be met by both the specifications of the building itself and the method of heat supply. In future, the heat demand for domestic houses will be very low compared to today's annual average of 2150 m^3 (67.7 GJ) of natural gas, of which 445 m^3 (14 GJ) is for hot water. The first target for the Energy Performance Standard is 1000 m^3 of gas (31.5 GJ) per annum for space heating and 200 m^3 (6.3 GJ) for hot water supply. It is expected to decrease this target in the near future to 1000 m^3 for the total annual demand of the house. Such developments will have significant economic consequences.

Connecting a house to the gas grid will be too expensive to render a low-cost energy supply, since the margins for the distributing company will be very small if it can sell only 1000 m^3 a year. So there will be an economic drive to find new solutions for heating. District heating will meet the same economic barriers as a gas grid. However, for electric heat pumps, the costs for the electric grid, which will be built anyway, will increase only marginally. Only a slight increase of the capacity of the electric grid is necessary, while the flexibility of the whole system for the utility increases.

The exergy method

The exergy method is based on both the first and second law of thermodynamics. The first law states that energy cannot be lost. The second law says that work can be fully converted into heat but heat cannot be fully converted into work. This implies that the conversion of work into heat is, by nature, irreversible. Because of this, heat has a lower quality than work.

Exergy can be defined as the maximum work potential - i.e. the maximum amount of work that can be done with a given amount of energy. So electricity, which can, theoretically, be converted completely into work, can be said to contain 100% exergy. Hence 100 MW of electricity contains 100 MW exergy. Heat contains a lower percentage of exergy defined according to its temperature in Kelvin by the Carnot factor:

Carnot Factor = $(1 - T_{surroundings}/T_{heat}) \times 100\%$.

This factor reflects the physical exergy content of heat. Some examples are shown in the **Table** below.

The exergy method is used to analyze where energy with a high exergy value is converted into a stream with a lower exergy value. To realize a minimum requirement for primary energy, it is important to minimize the exergy losses. This can be done by using primary energy in the first place to produce energy with a high exergy value (electricity or steam with a high temperature) and to use the remaining heat as well as possible for low temperature purposes.

Quantity	Type of energy	Exergy	Carnot factor
100 MJ	electricity	100 MJ	1
100 MJ	heat at 2000°C	87 MJ	0.87
100 MJ	heat at 1000°C	77 MJ	0.77
100 MJ	heat at 100°C	20 MJ	0.20
100 MJ	heat at 25°C	0 MJ	0
100 MJ	cold at -50°C	-34 MJ	0.34
100 MJ	methane	100 MJ	1

Exergy and Carnot factor for different types of energy.

The exergy approach

The use of the exergy method strengthens the economic argument for heat pumps by showing that the heat pump solution is also good from an energy point-of-view. The method is based upon an understanding of the *quality of energy* concept. Following this method, energy is used in an optimal way and energy waste is minimized. Quality deterioration of energy - so-called exergy loss - is prevented as much as possible. If heat generating technologies are compared in terms of their energetic efficiency (as expressed by the primary energy ratio (PER)) and their exergetic efficiency, the results show clear differences in favour of heat pumps [2] (see **Table 2,** page 26).

The calculations made for the KAN-area show that an optimum energy system combines cogeneration with the large-scale application of electric heat pumps for low-temperature space heating. Compared to the reference system with gas boilers, a theoretical energy conservation of at least 35% can be achieved. In practice these savings can be even higher as these calculations were made using a modest heat pump seasonal performance factor (SPF) of 3.0.

The KAN-area project is now being developed through cooperation between the local government, building contractors, the national power supply company SEP, the local power producer NUON and Novem (the Netherlands Agency for Energy and Environment). It is seen as a demonstrationproject to show the possibilities of integrating new energy concepts based upon an overall exergy view. If the project can be shown to be both technically and economically feasible, it will show the direction for the other VINEX areas.

	Energy efficiency (PER)	Exergy efficiency
gas boiler	0.90	0.14
absorption heat pump	1.40	0.21
gas-driven heat pump	1.78	0.27
CHP with electric heat pump	2.08	0.31

Table 2: Comparison of the exergy efficiency of delivering heat at 60°C with the temperature of the surroundings at 10°C.

Exergy in industry

For the minimization of energy losses in the chemical industry and in middle-sized process industries, the exergy-method is seen as an opportunity to increase the efficiency of processes. Supported by Novem, an exergy module known as Exercom has been developed by Stork-Comprimo based on the "Aspen" process-integration method. This module is now being tested by several industrial companies including AKZO, Dow-Chemical, Hoogovens and Shell. End-users, utilities, universities, consultants and government departments are working together in a users group to exchange experience in using this module.

An oil refinery provides a good example of the application of the exergy method. In the process for pre-heating crude oil in a furnace, the high exergetic value of the refinery combustion gases at 1200°C is used for heating the oil at 375°C, thus resulting in a large loss in exergy. An exergetically more efficient way is to use the combustion gases in a turbine for power generation, while the relatively colder turbine exhaust gases can be used for heating the crude oil.

At such high temperatures, heat pumps cannot be used. With chemical processes at lower temperatures, however, heat pumps can play an important role. In a de-isobutanizer for example, it has been shown that exergy losses can be greatly reduced by using a heat pump. Other technologies can also play a role in reducing exergy losses. In methanol-synthesis, for example, oxygen burning in the reactor results in a large reduction in losses.

Other examples of using the exergy method have been calculated for the Ammonia Industry [3]. Data indicates that 17% of primary energy can be saved compared to the best technology available, through the application of the exergy method and by using a heat pump. Also a study on a distillation process for halocarbons for the AKZO chemical company calculated, using Exercom, an exergy-loss of at least 9.8 MW in one process. While such calculations can be made very quickly, implementing changes in the processes, including the installation of a heat pump, will not be made very soon, because the risks with a new process are considered to be too high. This is one of the general barriers hampering the quick implementation of these results.

Industrial areas

Meanwhile the exergy method is not only used to optimize the energy situation of individual companies, it is also being applied to industrial areas. For example, the Botlek area near Rotterdam, which has many chemical plants, generates about 1000 $MW_{thermal}$ of waste heat, at temperatures of between 120°C and 250°C, which can be used directly in other processes. A costly and inflexible network of high-temperature heat distribution with great thermal losses can be avoided by choosing the best way of using the heat according to the exergy method. The use of Organic Rankine Cycles to make electricity, and heat pumps with high coefficients of performance (COPs) can increase the flexibility of operation. The conversion of heat into electricity and from electricity into heat is also an interesting concept from an exergy point-of-view, which can be applied on a large scale.

Pointing to heat pumps

Both in regional planning and in the chemical industry, the exergy method points out the benefit of using heat pumps to upgrade low-temperature heat. Exergy analysis is also a very valuable tool for comparing the different types of heat pump. All heat pumps upgrade a source (low-temperature heat) to supply heat to a sink (high temperature heat) using, in general, electricity, natural gas or high-temperature heat. To choose the best type of heat pump for a specific situation, exergy analysis can identify which heat pump has the highest exergetic efficiency by giving the different forms of energy an exergetic value.

[1] "Exergie-proefproject Knooppunt Arnhem-Nijmegen (Exergy Trial Project Arnhem-Nijmegen Intersection)" Report from engineering bureau Haskoning to the steering group Stuurgroep Exergie-proefproject, December 1994 (Dutch).
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Heating with electricity and wood

Thomas Afjei and Dieter Wittwer, Switzerland

Bivalent heat pump systems, with a back-up heater, are commonly used for residential heating. While they may make economic sense, the use of back-up heating tends to downgrade the environmental benefits of an electric heat pump. However, if the back-up heater is a wood-fired boiler, the heating system can combine the energy-saving benefits of the heat pump with the moderate use of a renewable fuel. A study in Switzerland has examined the performance of these increasingly popular and environmentally benign heating systems.

This farmhouse in Hirzel has been demonstrating the use of a combined heat pump/wood-fired boiler.

Many owners of buildings and houses are now faced with the question as to which heating system can best meet their needs with regard to comfort, environmental compatibility and reliability of supply. Modern electric air-to-water heat pumps with seasonal performance factors (SPFs) of up to three offer energy conservation and environmental benefits, particularly as very little CO_2 is released in electricity production in Switzerland.

However, if the heat pump alone were to be used for heating, it would have to have dimensions sufficiently large to provide the required heat output even on the coldest winter day. It is precisely under these conditions that air/water heat pumps operate at low efficiency. Bivalent operation in which the heat pump is supported by a back-up heater on cold days is therefore much more practical. The heat pump can have substantially smaller dimensions, and consequently lower installation costs, and additionally achieves a higher SPF.

A CO_2-neutral resource

In Switzerland, particularly in rural areas, many people are attracted to the use of the large reserves of locally available wood as a fuel. When used on a sustainable basis, wood is a renewable and CO_2-neutral energy resource. With the sustainable use of forests, the share of energy derived from wood in heat production can be greatly increased. Heating with wood-fired boilers therefore offers a promising solution for both new and existing buildings. Combining wood-fired boilers with heat pumps moderates the requirement for wood and is energy-efficient and environmentally friendly.

The addition of a heat pump also offers several other advantages for the operator of a wood-fired boiler. In the spring and autumn, the heat pump alone can meet the heating requirement and the user does not need to operate the wood-fired boiler. Furthermore, during long periods of absence, the heat pump guarantees protection from frost damage. And since heating with wood is possible at any time, the user can choose to use electricity or wood according to which is the most convenient or economic option.

Monitoring

With the growing trend towards the use of combined heat pump/wood-fired boilers in Switzerland, the project "Small Heat Pump/Wood-Fired Boiler" was launched in 1993 by the Commission for Efficient Use of Electricity to study the performance of such systems by monitoring pilot projects.

The photograph shows a farmhouse in Hirzel, in the Canton of Zurich, where a combined heat pump/wood-fired boiler for heating an apartment has been monitored. **Figure 1** shows a hydraulic diagram of the system. The wood-fired boiler has two-stage capacity control and a system to ensure a fixed return-flow temperature. The storage tank has an integrated electric resistance hot water boiler and a heat exchanger for supplying warm water to the nearby cow-shed. The 12.3 kWt_{hermal} electric air/water heat pump is housed in a barn. The system was designed with the aid of the simulation tool YUM Heat Pump/Wood which has developed for the Swiss Federal Office of Energy (BEW) [1]. The design data are shown in **Table 1**.

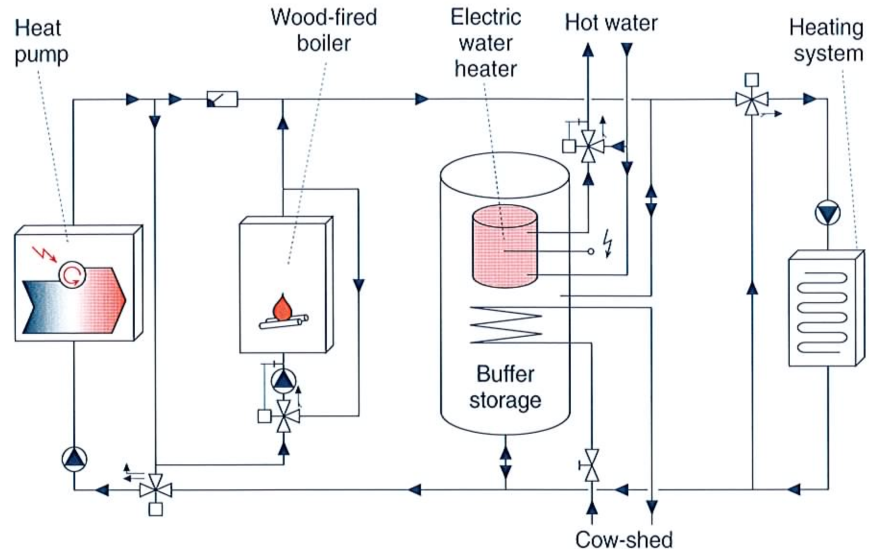
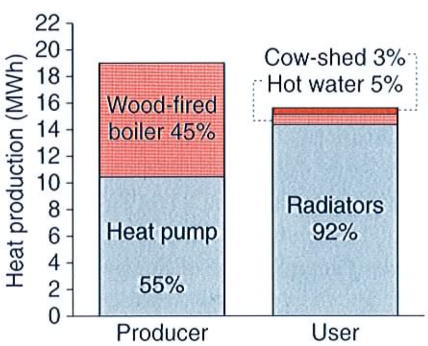


Figure 1: Hydraulic diagram of the "Hirzel" pilot plant.

Table 1: Design data for the "Hirzel" system.

Heat requirement according to Swiss Housing Standard SIA:	2 kW
Actual heat requirement:	6 kW
Supply/return flow temperature:	60/48°C
Heat pump output *(at 7°C outdoor air and 35°C water supply temperature)*	12.3 kW
Wood-fired boiler output:	15-30kW
Storage tank capacity:	1000 l
Water heater capacity:	300 l
Hot water temperature:	50-55°C

Figure 2: Energy balance of the "Hirzel" pilot plant for the heating period '94 to '95.



Measurements

During the heating season, 16,000 kWh of heat was required for space heating and hot water (see **Figure 2**). Just 5% of this was required for hot water and a further 3% was required for the cow-shed water. The installation of an additional heat exchanger for this purpose is therefore questionable.

Although the heat pump could have met the required heat output almost by itself, the wood boiler contributed a notably large share of 45%. This is because the user has his own large stock of wood which he is happy to use in order to save electricity costs. The frequent feeding of the wood-fired boiler is not considered to be inconvenient in comparison with the daily work on the farm.

Almost 17% more heat was generated by the combined heat pump/wood-fired boiler than was actually required for space heating and hot water. This large difference is due to significant heat losses from the storage tank and from the use of long and poorly-insulated feed lines. The losses were especially large because of the relatively high average storage temperatures resulting from the frequent use of the wood-fired boiler and the integrated water heater. Under optimal conditions, the storage and line losses could be halved.

Efficiency

The SPF of the heat pump was measured as 2.4 for the delivery of heat to the space heating and hot water systems. The efficiency of the wood-burner was measured as 82%. In combination, the heat pump and wood burner delivered heat at an SPF of 1.25. This low figure reflects the relatively low usage of the heat pump. Considering the efficiency of the consumption of electricity and wood in relation to the actual consumption of heat for space heating and hot water, the consumption-related SPF was measured as 1.04. This reflects the high storage tank and line losses. The average outdoor temperatures during the heating period was 5.3°C.

Costs

In all energy systems, the costs must not be forgotten. The storage/boiler combination costs very little more than a pure heat storage unit, while the heat pump gives rise to additional costs of about US$ 4,400.

Ecological balance

A combined heat pump/wood-fired boiler also has ecological advantages in comparison with conventional heating systems, especially with regard to global warming. **Table 2** shows the energy and emissions data for a simulated system. As shown, the total equivalent warming indicator (TEWI) is estimated at just 0.05 kg CO_2/kWh.

The data shown in Table 2 are based on a heat pump coverage of 60% at 15,500 kWh effective heat, and CO_2 emissions from electricity at a rate of 0.106 kg CO_2/kWh. The latter figure takes account of the Swiss electricity mix including imports [2].

Market data

According to the statistics of the Association of Swiss Heat Pump Manufacturers (AWP), a total of about 400 bivalent air/water heat pumps were sold in 1994, half for retrofitting and half for new buildings. It is estimated that around half of these were installed as combined heat pump/wood-fired boilers.

The actual market potential is much larger. The current market for wood-fired boilers for new single-family homes is estimated as 1500 per annum. According to the experiences of a specialized design office, every second building owner who chooses a wood-fired boiler opts for the combined wood-fired boiler/heat pump. This should result in the installation 750 combined heat pump/wood-fired boilers every year. Increased marketing pressure from heat pump manufacturers will also help to make this market share achievable.

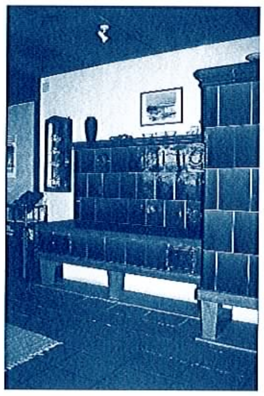
The retrofit market also has considerable potential. According to the Association of Swiss Heating and Ventilation Companies (VSHL), about 50,000 oil and gas boilers will have to be replaced annually in the years ahead. The market potential for heat pumps in this replacement market is about 10% or 5000 units per annum. If 5% of these are accounted for by combined heat pump/wood-fired boilers, this amounts to 250 units annually.

Furthermore, an estimated 6000 small wood-fired boilers must also be replaced each year. Assuming that 5% can be persuaded to install a heating system with a combined heat pump/wood-fired boiler, a further 300 units per year could be sold in this sector.

	Heating system			
Space Heating	**Oil** (new)	**Oil(old)&HP**	**Oil(old)&HP**	**HP/Wood**
Hot water	electric	electric	oil	HP
Oil boiler efficiency [%]	80%	75%	50%	-
Wood boiler efficiency [%]	-	-	-	75%
Heat pump SPF	-	2.6	2.6	2.2
System SPF	0.78	1.42	1.36	1.45
TEWI [kg CO_2/kWh]	0.33	0.14	0.16	0.05

▲

Table 2: Comparison of annual efficiency and the total equivalent warming indicator (TEWI) for various heating systems.



◀

This heating stove is part of a typical residential wood-fired heating system.

A potential for success

As discussed, the total potential for the annual installation of combined heat pump/wood-fired boilers in new buildings and conversions is about 1300 units per year, a factor of six greater than the 1994 sales volume (more detailed information is available in Reference [3]). This potential will be all the more readily achievable as more manufacturers offer combined heat pump/wood-fired boilers as a single package.

From the pilot projects studied, including the one discussed in this article, it is clear that such systems can be very beneficial, both to the user and to the environment. The equipment operates satisfactorily both in the heating mode and in the hot water mode and can demonstrate an improvement in annual efficiency of around 50% and CO_2 emissions reduced to only one sixth of those from conventional oil heating systems.

References:
[1] "YUM HP/Holz: A PC-Based Computer Program for the Design of Monovalent and Bivalent Heat Pump Systems with Wood-fired Boiler" 1995, Switzerland (German). This brochure is available from: INFOENERGIE in Brugg, Tel: +41-56-416080, Fax +41-56-412015.
[2] "Electricity Mix in Ecological Balances" INFEL-Info, April 1994, Zurich, Switzerland (German).
[3] "Bivalent Small Heat Pump/Wood Furnace Systems", Final Report of NEFF project 573, INFEL, 1995, Zurich, Switzerland (German).

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The Geothermal Heat Pump Consortium

Overcoming obstacles for ground-source technology

Melissa Voss and Sandy Smith, USA

Geothermal heat pumps, also called ground-source heat pumps, hold much promise for improved energy efficiency, long-term cost effectiveness, and environmental benefits. But while the technology has evolved to the point where commercialization is possible, factors such as high initial cost and lack of public awareness impede its wide-scale adoption in the United States. Since 1994, the Geothermal Heat Pump Consortium has been working to overcome these obstacles.

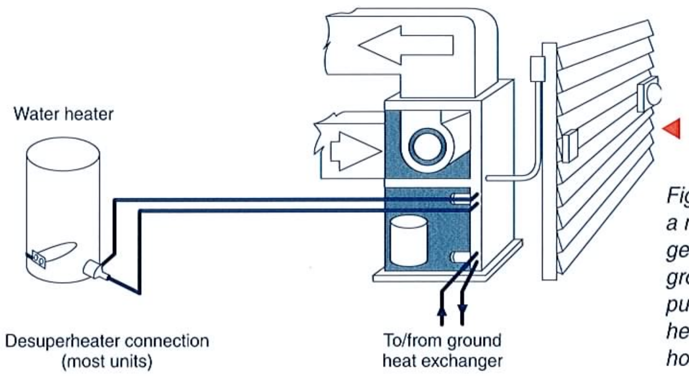


Figure 1: Example of a residential US geothermal (or ground-source) heat pump for supplying heating, cooling and hot water.

Utilizing the earth as a heat source and sink instead of the air, geothermal heat pumps can provide comfort heating and cooling, along with water heating for residential, commercial, and institutional building applications. **Figure 1** portrays a modern geothermal heat pump, indicating its three primary systems: an earth connection, or ground heat exchanger, for transferring heat between the earth and a transport fluid; a heat pump to move heat between the transport fluid and the building; and a distribution system to deliver heating or cooling throughout the building.

Some systems, such as the one shown in Figure 1, also include a desuperheater to supplement a hot water heater or a full-demand water heater during space heating or cooling. Others supply all hot water needs on demand, by diverting the full capacity of the heat pump to that purpose. Large buildings may use heat pumps that only produce hot water.

The relative stability of ground temperatures translates to increased efficiency of geothermal heat pumps versus air-source heat pumps. Geothermal systems thus provide high efficiency comfort cooling and heating, along with water heating.

Some 40,000 geothermal heat pumps are sold annually in the USA, most of which are for residential use. However, there are also many successful large-scale geothermal heat pump applications. Richard Stockton College in New Jersey has the world's largest (5.63 MW cooling capacity) closed-loop geothermal system providing heating and cooling for classroom and administrative buildings. Oklahoma City has 277 independently-controlled geothermal heat pumps providing heating and cooling for buildings in the city centre. And over 200 schools in Texas, Missouri, and Kentucky use geothermal systems. Industries, retirement communities, and office buildings are also taking advantage of this technology.

Benefits

In comparison to other options, such as air-source heat pumps, geothermal heat pumps offer benefits to consumers, utility organizations, local and national economies, and the environment. Consumers benefit through lower operating costs, estimated at an average of about US$ 7500 over the life of the equipment for every residential unit installed, equating to a combined total of about US$ 750 million if 100,000 residential units are installed. Other benefits include the absence of a large, noisy outdoor heating/cooling unit and increased durability and reliability. Geothermal heat pumps feature simplified systems and reduced exposure to weather. Consumers also benefit through higher air discharge temperatures in winter, and better control of indoor humidity in summer.

Utilities benefit from increased system dependability, and long-term system use. Because installing a geothermal system is labour and capital intense, customers who install geothermal systems are more likely to keep using the system. In addition, the reduced load needs and increased efficiency of geothermal systems translate into less peak demand and decreased wear and tear on electrical grids.

Economies benefit through increased energy efficiency. For every 100,000 residential geothermal heat pumps installed, it is estimated that more than 39.6 PJ can be saved over the lifetime of the equipment. In addition, economies stand to gain from job creation offered by geothermal system manufacturing, distribution, installation, and service. Most of these functions are local in nature, so maximum benefit is enjoyed by the local communities.

The environment benefits because of the high efficiency of the geothermal heat pump, which translates into reduced usage of fossil fuels and reduced emissions of CO_2.

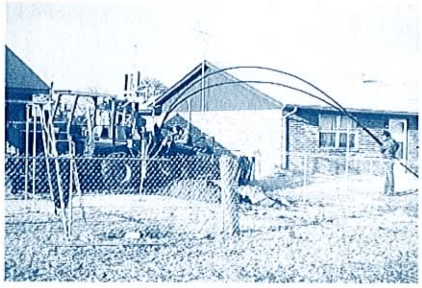
Obstacles

While geothermal heat pumps have been demonstrated to be one of the most efficient heating and cooling technologies, obstacles prevent their widespread adoption. With some residential units costing considerably more than air-source equipment (up to US$ 5,000 more), many would-be consumers are deterred from considering geothermal heat pumps. In addition, the benefits and advantages of geothermal heat pumps are generally unknown among the general public. And the infrastructure needed to commercialize the technology does not widely exist.

The Consortium

In response to these factors, various utility and industry groups joined with the US Department of Energy and the US Environmental Protection Agency to form the Geothermal Heat Pump Consortium (GHPC) in 1994. The Consortium is a non-profit organization dedicated to the development of a larger manufacturing and distribution base for geothermal heat pumps. Contact details for the consortium are given in the box.

The Consortium is the operating agency for the National Earth Comfort Program, which is intended to establish a Geothermal Heat Pump Technology Demonstration and Market Mobilization Program. The National Earth Comfort Program is a six-year, US$ 100 million initiative cost-shared by the private sector on a 2-to-1 basis with the federal government.



Installation of a geothermal heat pump. ▲

The Consortium consists of more than 110 electric utilities and more than 170 manufacturers trade allies (associations), and is governed by a 15-member Board of Directors composed of national utility association representatives and sponsoring utility executives. The Board is served by a full-time Executive Director and staff.

Setting goals

Goals have been set of increasing annual installations of geothermal systems from 40,000 to 400,000, reducing annual carbon emissions by 1.5 million tonnes, and saving over 316.5 PJ of energy annually by the year 2001. The ultimate goal is to create a geothermal market independent of utility rebates and governmental incentives.

The Consortium is achieving its goals by implementing a set of focused, related initiatives designed to improve market conditions for geothermal heat pumps in the market place. The "First Cost Competitiveness" initiative seeks to develop innovative financing for initial costs of geothermal systems and to make the technology more cost efficient. Another initiative, "Technology Confidence Building" seeks to improve industry and consumer awareness of geothermal technologies and their benefits. And "Infrastructure Strengthening" is intended to help establish regulatory requirements to protect the below-ground environment, to train designers and installers, and to set standards for installation quality.

Since its inception in 1994, the Consortium has succeeded in securing funding from its federal partners, retained a staff, and has established a presence on the World Wide Web. It also plays a key role in the geothermal video conference series - periodic teleconferences whereby large numbers of people from around the country can participate in discussions on geothermal heat pumps via satellite links and telephone.

How to join

The Geothermal Heat Pump Consortium has two classes of membership available for potential partners - voting and non voting. Non-voting memberships are available to trade associations, manufacturers, distributors, dealers, installers, universities, and others at no cost. Voting memberships are available to electric utilities who pay dues of 10 US cents per customer each year to a maximum of US$ 50,000. Both membership classes agree to participate during the six-year National Earth Comfort Program.

A major contribution

The Geothermal Heat Pump Consortium is making a major contribution towards increasing the usage of geothermal heat pumps. It is increasing public awareness of their benefits and availability, and is spurring continued development and commercialization of geothermal technologies in the United States.

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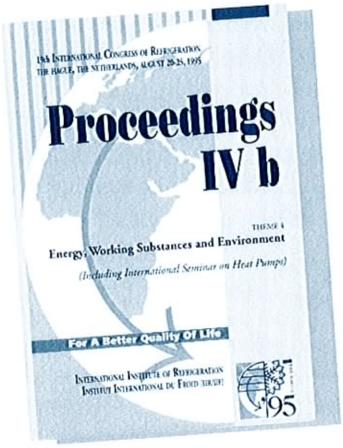
Books & Software

19th International Congress of Refrigeration
Proceedings of the International Institute of Refrigeration Congress held in The Hague, The Netherlands on 20-25 August 1995. Published by IIR, France; Fax: +33-1-4763-1798. Price: US$ 300 for six volume set.



Absorption Heat Pump with Variable Heat Transfer at Two Temperature Levels
(Absorptionswärmepumpe mit variabler Wärmeauskopplung auf zwei Temperaturniveaus)
Alefeld G. et al. Published by IZW, Germany; Fax +49-7247-808-134. September 1995, 195 pages (German). Price DM 40.
Reports on a five-year project in which a double-effect absorption heat pump using water/lithium bromide working pair was developed. A pilot project installed in a museum provides heating at two temperatures and also cooling.

Support Programmes and Support Measures for Heat Pump Applications
(Förderprogramme und Unterstützungsmaßnahmen zum Wärmepumpeneinsatz)
Published by IZW, Germany; Fax +49-7247-808-134. November 1995, 84 pages (German). Price DM 15.
Gives an overview of heat pump support programmes provided by national and regional government, and by 28 regional utilities.

Evaluation of Eight Heat Pumps (Evaluatie acht warmtepompen)
Juffermans P.C.W. and Varwijk J.W.M. Published by KEMA, The Netherlands; Tel: +31-26-356-2204.
Report no. 41885-IES 95-1363. November 1995, 80 pages (Dutch).
See page 5 for more details.

Dutch Leaflets on Heat Pumping
The following single, or double-page leaflets (in Dutch) are available, free-of-charge, from Novem, Apeldoorn, The Netherlands, Tel: +31-55-277877

- *Open heat pumps (Open warmtepompen)*
- *Closed heat pumps/thermal compression (Gesloten warmtepompen/thermische compressie)*
- *Closed heat pumps/mechanical compression (Gesloten warmtepompen/mechanische compressie)*
- *Integration of heat pumps in processes (Integratie in het proces van warmtepompen)*
- *Absorption cooling (Absorptie koeling)*

Absorption Chillers and Heat Pumps
Herold K.E. et al. Published by CRC Press Inc., 2000 Corporate Blvd., N.W. Boca Raton, FL 33431 USA or http://www.crcpress.com
1995, 329 pages. Price US$ 90 (US$ 75 in US).
For students or engineers who are new to this field, this book provides a thorough introduction to simple absorption systems.
The thermodynamic behaviour of systems using water/lithium bromide and ammonia/water are explained and measures for improving efficiency are described.

Going Towards Natural Refrigerants
Elefsen F. et al. Environmental Project No.301 from the Danish Ministry of Environment and Energy, Strandgade 29, 1401 Copenhagen K, Denmark. 1995, 72 pages. Price DKK 125.
This book provides an overview of the use of natural refrigerants in various types of heat pumping equipment. Much attention is given to the use of ammonia which the authors predict will be used in 15 to 25% of commercial cooling equipment over the coming 10 to 15 years.

Retrofitting (Konvertering)
Lundqwist P. et al. CIT, Chalmers Teknikpark, 412 88 Gothenburg, Sweden. 1995, 50 pages (Swedish/ English).
This reports on work carried out by NUTEK for Project A1 of the programme "Replacement of non-environmentally-safe refrigerants in heat pumps and refrigerators." It examines the outcome of several retrofits with respect to performance, chemical stability and lifetime.

New Technologies and Refrigeration Safety
(Nouvelles technologies et sécurité dans le froid)
Association Française du Froid (AFF), 17, rue Guillaume Apollinaire, BP 193, 75263 Paris Cedex 06, France. 1995, 230 pages (French).
A collection of papers presented at the European Refrigeration Conference on 7 and 8 November 1995.

International Seminar and Workshop on Heat Pipes, Heat Pumps, Refrigerators and Dual-Use Technologies
Luikov Heat & Mass Transfer Institute, Academy of Sciences of Belarus, 220072, P. Brovka 15, Minsk, BY Belarus. 1995, 285 pages.
Preprints of this seminar which was held in Minsk, Belarus on September 12-15 1995. They concern applications in the fields of refrigeration and metallurgy and discuss some high-temperature systems.

HPDesign and EvapCoil
Simulation programs available from M. Conde Engineering, Switzerland. Fax: +41-1-431-4175. Price of each program: US$ 1500 for "single license standard package".
HPDesign simulates the operation of small to medium capacity air-to-air and air-to-water heat pumps. It is designed as a rating program and may be used to optimize machine configurations using various alternative components.
Evapcoil simulates the operation of plate-finned-tube, air-cooling direct-expansion evaporator coils. It takes account of the effects of lubricating oil.

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Annex 22 Proceedings, October '95
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International Heat Pump Status and Policy Review
HPC Workshop Proceedings, August '95
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Fax: +39-6-3048-3026

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6-8 June '96 / Capri, Italy.
Contact: EURO MEETING IN.
Fax: +39-81-714-1414

1996 ASHRAE Annual Meeting
22-25 June '96 / San Antonio, Texas, USA.
Contact: ASHRAE Meetings Department.
Fax: +1-404-321-5478

ROOMVENT '96 - the 5th International Conference on Air Distribution in Rooms
17-19 July '96 / Yokohama, Japan.
Contact: Prof. S. Murakami, University of Tokyo. Fax: +81-33746-1449

Indoor Air '96
21-26 July '96 / Nagoya, Japan.
Contact: Dr Koichi Ikeda, The Institute of Public Health. Fax: +81-3-3446-4723

Purdue International Compressor Engineering Conference
21-26 July '96 / Lafayette, IN, USA.
Contact: The Herrick Conference Office, Purdue University. Fax: +1-317-494-0787

TIEES-96 First Trabzon International Energy and Environment Symposium
29-31 July '96 / Trabzon, Turkey.
Contact: Prof. Teoman Ayhan, Karadeniz Technical University.
Fax: +90-462-325-7405;
E-Mail: energy96@risc01.bim.ktu.edu.tr

Sustainable Thermal Energy Storage Conference
7-9 Aug '96 / Chicago, USA.
Contact: Beverly Speer, University of Wisconsin. Tel: +1-608-262-8220

Applications for Natural Working Fluids
3-6 Sep '96 / Aarhus, Denmark.
Contact: Mr Frank Elefsen, Danish Technological Institute.
Fax +45-8943-8543

Research, Design and Construction in Refrigeration and Air Conditioning for the Eastern Countries
10-13 Sep '96 / Bucharest, Romania.
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For further Events visit the HPC Internet Site http://www.heatpumpcentre.org

International Absorption Heat Pump Conference
17-20 Sep '96 / Montreal, Canada.
Contact: Darius Nikanpour, EDRL,
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Contact: Rhona Vickers, IEA Air Infiltration and Ventilation Centre (AIVC), UK.
Fax: +44-1203-416306;
E-Mail:airvent@AIVC.org;
Internet: http://www.demon.co.uk/aivc

Geothermie - Energie der Zukunft (Geothermal Heat - Energy of the Future)
18-20 Sep '96 / Konstanz, Germany.
Contact: 4. Geothermische Fachtagung, c/o Stadtwerke Bad Urach.
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Analysis and Applications of Heat Pump and Refrigeration Systems
(Symposium held within the '96 ASME International Congress and Exposition)
17-22 Nov '96 / Atlanta, Georgia, USA.
Contact: Dennis L. O'Neal, Texas A&M University, USA. Fax: +1-409-862-2762;
E-Mail: doneal@mengr.tamu.edu

Eighth International Stirling Engine Conference and Exhibition
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5th IEA Conference on Heat Pumping Technologies
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Next Issue

Natural Working Fluids

Volume 14 -No. 2/ 1996

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

Set up by the IEA in 1978, the IEA Heat Pump Programme carries out a strategy to accelerate the development and use of heat pumps, in all applications where they can reduce energy consumption for the benefit of the environment. Within the framework of the programme, participants from different countries collaborate in specific heat pump projects known as Annexes.

IEA Heat Pump Centre

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

The IEA Heat Pump Centre is operated by

Novem

Netherlands agency for energy and the environment

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