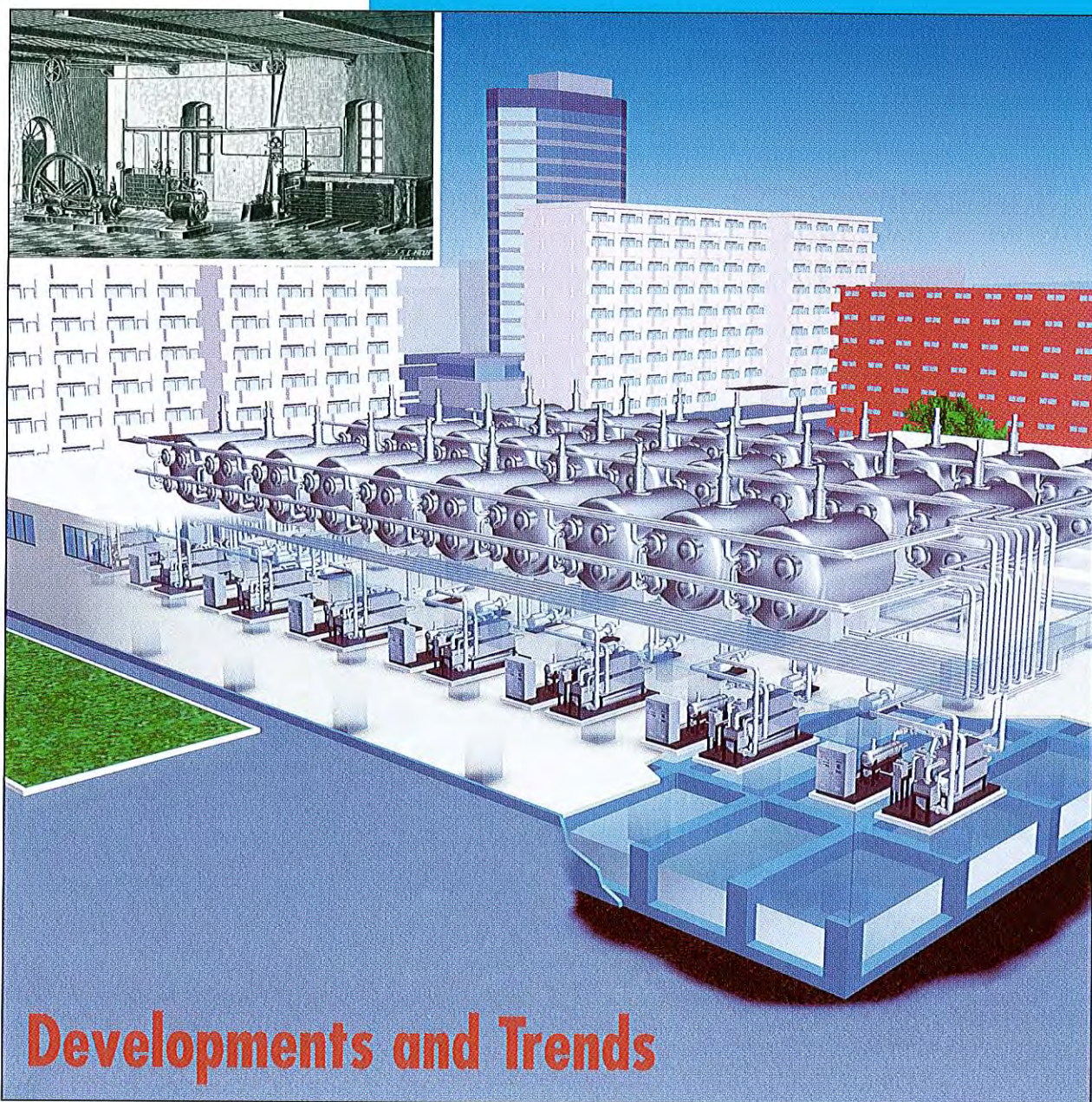


IEA Heat Pump Centre

NEWSLETTER



IEA
OECD

heat pump
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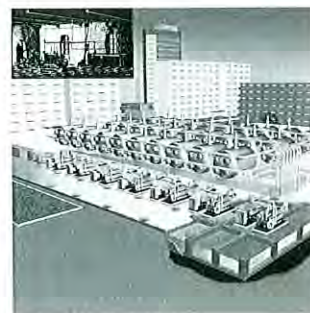
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Front Cover: Separated by 150 years, the concepts of Peter Ritter von Rittinger and the Japanese Super Heat Pump Programme, show how the heat pump continues to set new trends in heating technology. (Sources: ÖZE, Austria and NEDO, Japan.)

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Cooperation and Development (OECD) to implement an International Energy Programme.

A basic aim of the IEA is to foster cooperation among the 23 IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology, and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration currently within the framework of 35 Implementing Agreements, containing a total of more than 60 separate collaboration projects.

IEA Heat Pump Centre

The nine member countries of the IEA Heat Pump Centre (HPC) form a network for exchanging information on heat pump technology. By increasing awareness and understanding worldwide, the HPC aims to accelerate the implementation of heat pump technology as a means to reduce energy consumption and thereby to limit harmful environmental effects. This publication is one element of the HPC activities.

Any part of this publication may be reproduced, with acknowledgement to the IEA Heat Pump Centre, Sittard, the Netherlands.

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Heat Pumps - Are they Worth the Trouble?



This was the title of a thought-provoking article about residential heat pumps in a well-respected American magazine entitled *Consumer Products* (October 1993). This independent publication compares products and publishes results. I would like to draw your attention to the following quote from the article "Although they can be a sensible alternative to conventional heating (and cooling) where summers are long and winters are mild, heat pumps are *expensive*, and they have a reputation for being *less than satisfactory* in practice". "Leaky duct work and refrigeration systems, and improperly installed and used thermostats" are but

a few reasons given. These problems could affect any central air conditioning or heating system. Researchers from two US utilities looked at heat pumps in the households of 48 customers who complained about performance. Not one of the heat pumps was functioning properly.

The article was brought to my attention by a friend who works for an electric utility. It reflects some of the concerns utilities have about heat pumps. These signals should not be overlooked - they should be taken extremely seriously. They should be primary concerns of contractor associations, manufacturers and heat pump researchers, if the acceptance and use of heat pumps is to be increased. In other words, these issues need to be dealt with and solved. Practical issues such as cheaper products and reliable heat pump systems are imperative for continued support and interest from utilities, and for gaining the confidence of home owners or potential owners. The Heat Pump Centre, in a joint effort with the Swiss utility, NOK, and other members of the International Power Utility Heat Pump Committee, will co-sponsor a workshop in 1994 where practical aspects relating to heat pumps will be addressed. This is just a first step towards tackling practical heat pump problems.

Through the analysis, International Heat Pump Status and Policy Review (a joint study with the IIR), the Heat Pump Centre continues working on another essential tool, which will be used to influence policy makers and provide relevant input for new policy. The results of the study will be published in 1994. They indicate that trends in heat pump technology and markets vary between countries and depend on policy and institutional conditions. Some of these trends are reflected in this Newsletter, convincing me that *heat pumps are more than worth the trouble!*

A stylized blue ink signature of Jos W. J. Bouma.

Jos W. J. Bouma
General Manager, IEA Heat Pump Centre.

News & Views

Chinese look for help in reclaiming CFCs

China - At the Ozone Technology Transfer Workshop in October, representatives from Chinese industry expressed interest in acquiring the technology to build CFC reclaim units.

The workshop, held in Chengdu, Sichuan Province, was a Montreal Protocol Initiative organized jointly by Canada and China, to help China meet its obligation to a CFC phase out in 2010.

Recovery and recycling of CFCs is not yet significant in China, and a number of participants at the workshop were interested in acquiring knowledge from Canadian manufacturers.

Furthermore, the two large chemical companies in Sichuan Province who now manufacture HCFC-22, expressed interest in a joint venture with a foreign chemical company to help set up the manufacture of HFC-134a as a replacement for CFC-12.

Contact persons and telephone numbers for the two companies are:

- Mr Duan Zhida, Director of Sichuan Zigong Fujiang Chemical Co.; Tel: +86-813-380-281.
- Mr Zhanh Zai Li, Director of Chenguang Research Institute of Chemical Industry; Tel: +86-813-710-595; Fax: +86-813-710-594.

The workshop was a first step in Canadian/Chinese cooperation in the area of ozone depletion. It was funded from Canada's bilateral contribution to the Montreal Protocol's Multilateral Fund.

The workshop was attended by 75 Chinese delegates with a wide range of interests, including refrigeration, air-conditioning, aerosols and halon replacements. Canada was represented by a delegation from business and government departments which are involved in industries to support the phase out of CFCs.

Material on CFC replacement technologies to help China meet its obligations under the Montreal Protocol was presented at the workshop.

Chinese delegates reported on R&D projects including residential and commercial size absorption refrigeration units using the working pairs water/lithium bromide, and ammonia/water.

(Source: Mr Jeff Linton, National Research Council, Canada.
Fax: +1-613-954-1235.)

Clinton committed to Rio Convention

USA - Global climate change made its way to the front burner of the Clinton Administration's "Agenda for Change" when the President announced the contents of his National Action Plan on Global Change on 19 October.

The plan is based on voluntary programmes with industry and other organizations for the reduction of greenhouse gas emissions. It was established to comply with the USA's commitment to reduce greenhouse gas emission to their 1990 levels by the year 2000.

The administration intends to accomplish its goals without burdensome regulation or new taxes. Just how this will affect heat pump penetration remains to be seen.

(Source: Alliance Bulletin from the Alliance for Responsible Atmospheric Policy, October 1993.)

MITI proposes revised heat pump standards

Japan - The Ministry of International Trade and Industry (MITI) has decided to revise the current energy standards for appliances such as air conditioners and personal computers.

This is part of government strategy to curb the growing power consumption of residential and commercial buildings.

Unlike the current standards, set in force in 1984, the proposed stan-

dard will include heat pump systems. Actual values for the minimum COP are not yet available but the new standards will seek to reduce electricity consumption by 5% for heat pumps and 6% for cooling-only models, in comparison to the consumption of 1992 models.

(Source: Mr Moriyoshi Sakamoto, Tokyo Metropolitan University, Japan. Fax: +81-426-77-2701.)

Moscow-based company markets heat pumps

Russia - The joint-stock company Insolar has developed two heat pumps which are targeted at applications in rural communities.

The first is a 10.3 kW (heating) ground-source heat pump which supplies air heating with a COP of 2.9 at rated operating conditions.

Remarkably, this reversible unit also includes a built-in 250 litre domestic refrigerator. The unit is designed for rural houses with a floor area of up to 60 m² and includes a 4.5 kW resistance heater as back-up.

The second heat pump supplies hot water using ventilation air as the heat

source. The 4 kW (heating) system boasts a COP of 4 and offers air conditioning in the summer.

Insolar, in cooperation with the Bi-Gas-Si Corporation, carries out scientific studies on new heating and cooling technologies with a focus on heat pumps.

Considerable attention is being paid to the development of heat pump engineering for Moscow, where district heating networks are overloaded. Heat pumps offer the opportunity to reduce the energy consumption by 50-70% with the existing heat distribution system.

Heat pumps are also considered to be promising for regions with permafrost. The use of permafrost as a heat source has the added benefit of improving the reliability of the building construction. By taking heat from the permafrost, the heat pump system prevents degradation of the permafrost due to the thermal effects of a building.

(Source: ABOK Newsletter from the All Union Association of Engineers for Heating, Ventilating, Air-Conditioning, Heat Supply & Thermal Physics in Buildings.)

Technology & Applications

Ammonia heat pump warms water for dairy

Norway - In what is thought to be a world first in industrial heat pumps, a CFC-12 heat pump has been retrofitted to ammonia in a dairy.

The heat pump is used to heat water to a temperature of 76-78°C for the pasteurisation of milk. Waste heat from the production process, at a temperature of 35°C, is used as a heat source.

In 1978 Rogalandsmeieriet installed a heat pump from Sabroe to produce hot water, in order to reduce their energy consumption.

To meet the coming CFC-12 restrictions, the unit was retrofitted last year with a two-stage heat pump using ammonia. In the new plant the condensing temperature is reduced

from 80°C to 77°C, and the outlet water temperature is reduced to 71-73°C.

To achieve a condensing temperature of 77°C, the second stage in the heat pump uses a 40 bar compressor. The existing compressor was kept and is now used in the first stage.

The cooling and heating capacities of the heat pump are 372 kW and 477 kW respectively. Steam is used to raise the outlet water temperature the remaining 5°C, to 78°C. The energy unit contains accumulator tanks for the hot water, in order to meet peak demands.

There were initially some problems with unstable operation and it also

turned out to be necessary to put in a new evaporator and condenser to meet the requirements of a new process.

However, since the last modification, the heat pump has been in constant operation without any difficulties. The plant is partly financed by the Ministry of Environment in Norway.

(Source: Ms Trude Tokle, SINTEF Refrigeration Engineering, Trondheim, Norway. Tel: +47-7-591636.)

Vuilleumier heat pumps show promise

Japan - Free-piston action of a Vuilleumier Heat Pump (VMHP) has been demonstrated at a practical level for what is thought to be the first time.

A joint venture with the Japan Gas Association and four city gas companies, plus Mitsubishi Electric Corp. (Melco), has successfully operated a gas-fuelled linear motor-driven "free-piston" type VMHP. As a result, a VMHP dramatically smaller than conventional VMHPs is expected to be realized.

Based on the current results, Melco aims to realize a free-piston VMHP for cooling with a 3 kW cooling capacity

by March 1994. This will be half the size of a conventional VMHP system which uses a crank mechanism. A heat pump system is planned for the fiscal year of '95/'96.

A VMHP has a high-temperature cylinder and displacer combination (known as a thermal compressor) which is driven by a gas combustor to cause pressure fluctuations in the working fluid. These in turn cause a reaction in a low-temperature cylinder and displacer combination to provide a heat pump function.

Connection between the thermal compressor and the heat pump is normally made by rigid mechanical

crank elements. A 20 kW (heating capacity) machine using this technology is now being commercialized in Japan and offers a heating COP of 1.5.

With the newly developed free-piston unit, a linear motor is used to vibrate the high-temperature displacer so the working gas (helium) contained inside is subjected to pressure fluctuations which cause the displacer of the low-temperature cylinder to vibrate in tandem. Compression and expansion of the working gas in the low-temperature cylinder instigates a heat pumping function.

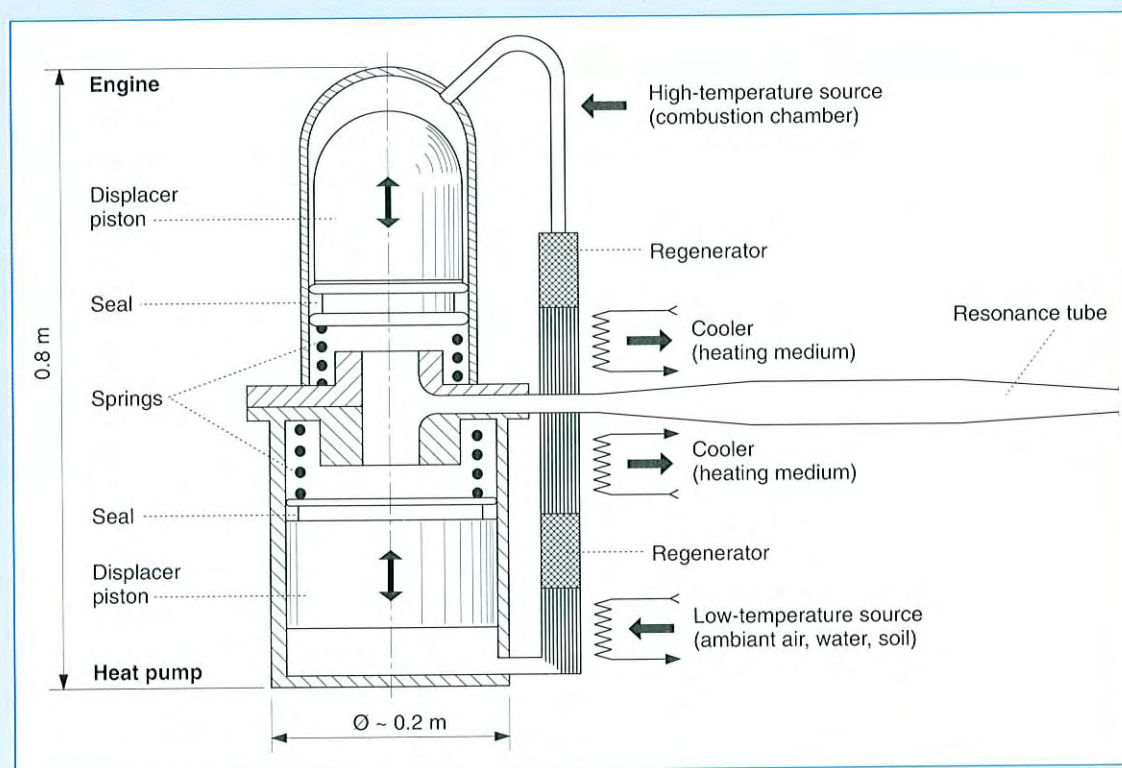


Figure 1:
Vuilleumier
heat pump with
resonance tube.

Switzerland - Another way to connect the thermal compressor and heat pump units is by a resonance tube. Such a system has been developed by Mr J.P. Budliger of Geneva, Switzerland, and is shown in Figure 1.

Although this system is still in a pilot phase, the prototype shows that

COP values of between 1.6 and 1.7 can be achieved. It is therefore appropriate for heating family houses.

A VMHP offers high efficiency, even at low ambient air temperatures, and with minimal moving parts it makes little noise and has a potentially long lifetime. Suitable working fluids are

environmentally benign and NO_x emissions are less than a gas-engine heat pump. It may also operate as a combined heat and power unit.

(Source: JARN, August 1993, and Mr Pierre Renaud of Bureau d'ingénieurs Planair, Switzerland.
Fax: +41-3931-1868.)

District heating using ammonia and sea water

Norway - An ammonia heat pump system is extracting heat from the sea for a renovated district heating plant at Bodø military air base in the northern part of the country.

When the old system, built in 1950-60, was renovated, it was decided to extend the plant by adding a heat pump system. The temperature level in the district heating system is fairly high, making it necessary to build a two-stage, high-pressure compressor system.

Thirty buildings with a total heating demand of 3.8 MW (at design conditions of -13°C outdoor temperature) are connected to the district heating system. Two heat pumps, with a capacity of 1 MW each, deliver 9.9 GWh/year. The yearly energy requirement is 11 GWh.

Sea water from a nearby fjord is used as a heat source. After transport to the sea water pumping well (see

Figure 2), the 7°C water is pumped to the evaporators of the two heat pump units. The evaporators are coupled in parallel and the sea water is cooled down to 3°C before returning to the fjord. The condensers are placed in series so as to heat the return water from the district heating system in two steps of 4°C from 60 to 68°C. If this is not enough, an electric boiler and oil-burners provide extra heat.

The heat pump units are manufactured by Sabroe Refrigeration and the evaporator design is quite special, combining evaporation and liquid separation. Vapour from the evaporators is compressed in the low-stage compressor and delivered at medium pressure: 14 bars. The high-stage compressor raises the pressure to 30-40 bars, or even higher, and makes it possible for the heat pump to work with condensing temperatures of up to 77°C. Oil separators placed after the com-

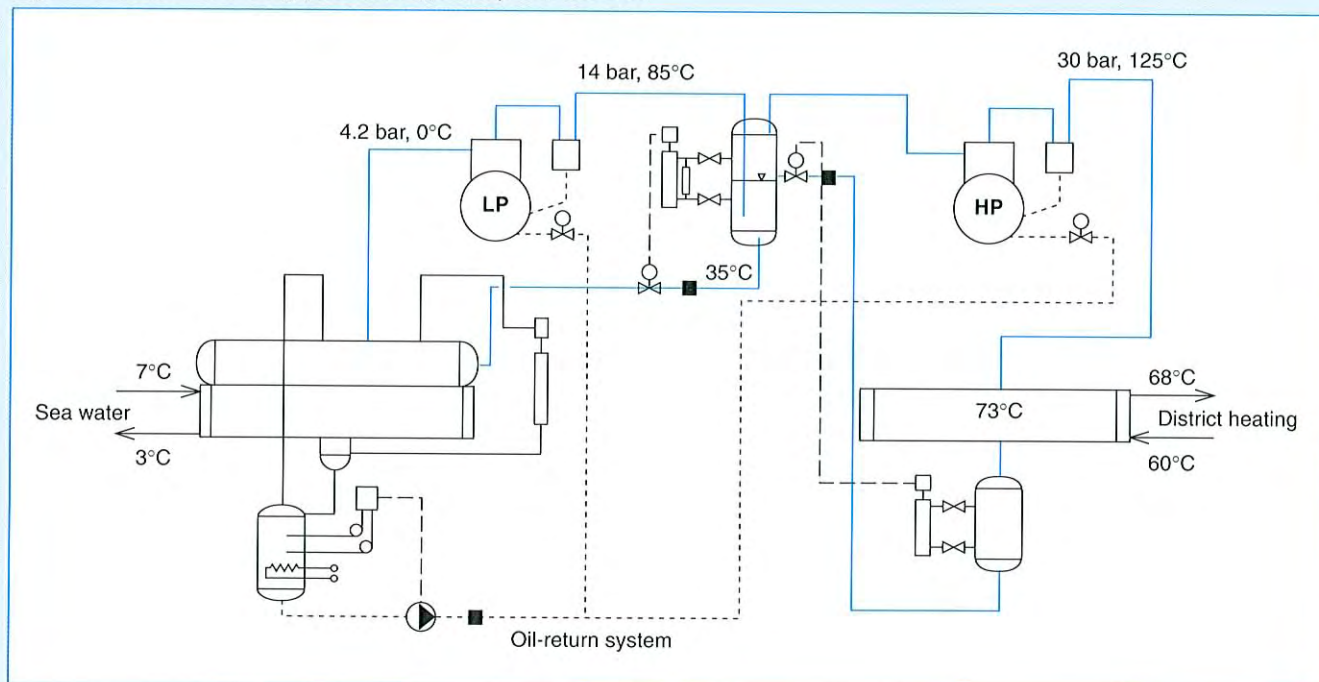
pressors, and a special oil return system (oil boilers) under the evaporators ensure that oil (which does not mix with ammonia) is returned to the compressors.

With a 1000 kg ammonia charge in each heat pump, the heat pumps, electric boiler and oil-burners are, as a precaution, located in a separate building, some distance away from occupied buildings. An alarm system warns of leakages.

The heat pump system was installed last winter and has been in operation since the spring. So far there have been no critical events or problems. During low capacity periods last summer, the heat pump worked with COPs of around 3. The COP is expected to be even higher when the heat pump works at full capacity.

(Source: Ms Marit Sandbakk, SINTEF Refrigeration Engineering, Trondheim, Norway.
Tel.: +47-7-593925.)

Figure 2: District heating plant using heat from the sea.



Diffusion-absorption heat pumps tested in homes

Switzerland - Gas-fired diffusion-absorption heat pumps (DAHPs), have been installed in two homes for testing and demonstration. Based on the equilibrium pressure of an inert gas (the "Sibir-principle"), the heat pumps have no moving parts and use an environmentally-friendly working fluid.

The units, developed by Creatherm, under the management of Dr Hans Stierlin, supply a hydronic heating system with radiators and underfloor heating.

The heating plant is a bivalent system incorporating a conventional gas boiler. The 3.5 kW (thermal power) air-source heat pumps have a compact design and produce no noise emissions.

They operated during the 1992-93 heating season without difficulties

and achieved a COP of 1.4 at an ambient air temperature of 0 °C and a supply temperature of 55 °C.

The project is part of a research programme undertaken by the Swiss Federal Office of Energy in a programme entitled "Use of environmental heat, heat recovery and combined heat and power" known as UAW.

The power characteristics of these DAHPs still have to be tested in the laboratory at the Process and Refrigeration Institute of the ETH (Swiss Institute of Technology).

If these test results are successful, the DAHP may soon be appearing in a lot more family homes.

(Source: Prof. M. Zogg, UAW, Switzerland. Tel: +41-34-220-785.)

Range of propane heat pumps launched

Germany - While discussions continue on the rights and wrongs of flammable working fluids, a range of propane heat pumps has entered the market.

From January onwards, water-to-water and air-to-water heat pumps for homes and small swimming pools are available from the German manufacturer KVS Klimatechnik, based in Stuttgart.

The units not only pose no environmental threat from their refrigerants, but also boast a higher efficiency than conventional systems. Furthermore, the refrigerant content has been halved.

The range includes ground/water-source heat pumps with heating capacities from 6 to 34 kW, designed

for hydronic heating and hot water provision.

Elsewhere, Herco-Kühltechnik have produced a 100 kW swimming pool heat pump using 20 kg of propane. At an outside air temperature of 15°C, this will heat a swimming pool to 35°C with a COP of 4.4. The system was developed in cooperation with the electric utility RWE.

(Source: Mr Karl von Staudach, KVS Klimatechnik Gerätebau GmbH, Germany. Fax: +49-711-855773; CCI magazine 11/93; and Wärmepumpe, September 1993 from IZW.)

Turbo-MVR system for herbal medicine

China - The Guangzhou Institute of Energy Conversion has undertaken research on a small turbine-driven MVR (Mechanical Vapour Recompression) heat pump.

The heat pump uses two turbo-compressors operating in tandem, and recovers heat from secondary steam resulting from the concentration process of a herbal medicine solution.

The centrifugal compressors are each driven by their respective radial turbines which are powered by boiler steam. The turbines may be operated in series or in parallel according to the intended use of their exhaust steam.

The recovered secondary steam may be used as heating steam to replace part of the boiler steam for the evaporator or for other heating purposes.

The construction cost of the heat pump is low, because its key components are from turbo-compressors available in the market.

At present, only the first stage of the heat pump has been tested, but a COP of 14 has been achieved. The sealing of the turbine shaft has however presented significant problems.

Since the turbo-compressors are very compact and the seals are quite simple, steam leaks from the turbine into the lubricant oil sump and mixes with the returning oil, forming a milky-white emulsion. Although this emulsion did not lead to bearing-damage during the limited test time, it did cause wastage of oil and presents a problem that has to be solved in the future.

(Source: Mr Li Song Zhe and Mr He Rong Zhi, Guangzhou Institute of Energy Conversion, China. Tel: +86-75600 ext. 364.)

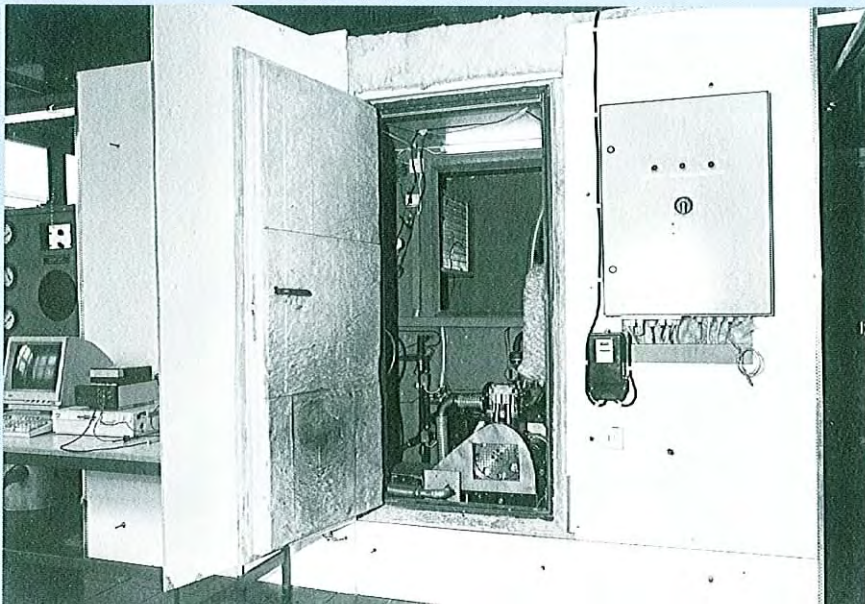
Electro-diesel heat pump has "multivalent" operation

Germany - In regions where gas is unavailable, a diesel-fuelled heat pump can be an attractive option for both economic and environmental reasons.

An electro-diesel heat pump (see Photo) has been developed for heating buildings up to 400 m³. This "multivalent" system offers a high degree of flexibility by using both the earth and ambient air as heat sources. And heat is recovered from the engine air cooling system and exhaust. Further flexibility is offered by a small electric compressor which can be switched in to reduce the short-term operation of the diesel engine, normally using off-peak electricity. If necessary, electricity can substitute for diesel up to 80%.

As there are several heat sources, the area of the horizontal earth heat exchanger needs to be only a quarter of the area of the floor-heated building. Nevertheless it can offer a heat source at temperatures between 10 and 15°C, due to heat added in the summer when the heat pump supplies air conditioning.

This type of heating is ecologically beneficial: its emission of carbon dioxide is 40% of an oil heater and its



A 30 kW electro-diesel heat pump.

exhaust fumes contain no soot. The noise level is very low: just 40 dB in front of the heat pump casing, while outside the installation room (e.g. the cellar) the diesel engine cannot be heard.

A prototype multivalent electro-diesel heat pump has been built to supply 15 to 30 kW heat, depending on the speed of the diesel engine.

Production costs of a commercial system will depend on the numbers produced. But an installation rate of 10 per year is thought to be sufficient to make these systems economically attractive. A manufacturer is now being sought.

(Source: Prof. Hans Möller, Fachhochschule Bochum, Germany. Fax: +49-234-700-7103.)

Markets

A/C market slumps 40%

Canada - According to the Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI), annual Canadian shipments of residential air conditioning (A/C) units decreased 40% in the year to the second quarter of 1993, compared to the year preceding the second quarter of 1992.

Based on a survey covering 90% of all shipments, adjusted year-to-date shipment figures decreased from 67,093 in the second quarter of 1992 to 39,948 in 1993.

(Source: Air Conditioning, Heating and Refrigeration News, 18 October 1993.)

GHP sales rise

Japan - A survey conducted by the Gas A/C Diffusion Center of the Japan Gas Association shows that the number of city (natural) gas fuelled GHPs (gas heat pumps) in use in 1992 has risen to 55,000 units - up 32% on 1991. Sales of GHPs using both natural gas and LPG have risen rapidly since 1987 when they were first introduced, and now stand at over 30,000 units per year.

(Source: JARN, 25 October 1993.)

IEA Heat Pump Programme

HPC agrees work for 1994

The Netherlands - This year's annual meeting of the Heat Pump Centre (HPC) National Teams in Maastricht set out an active work programme for 1994 that will involve the HPC in three workshops, and two studies.

Next year's activities (see Table 1) will address several key issues concerning heat pumps, most notably the need to find both long-term and more immediate, practical measures to phase out CFCs and HCFCs in heat

pumps. Other topics covered include the role of utilities in increasing heat pump use, international and national energy efficiency standards and the application of industrial heat pumps.

The major analysis "International Heat Pump Status and Policy Review" will also be published next year and activities to support the promotion of heat pumps will be continued.

Table 1: 1994 HPC work programme.

HPC Newsletter Topics	
March '94	Heat Pump Working Fluids
June '94	Heat Pumps and Demand Side Management
September '94	Waste Heat Recovery
December '94	Industrial Heat Pumps
March '95	CFC and HCFC Replacements
Workshops	
Sweden:	The Practical Consequences of CFC Replacements in Heat Pumps
Switzerland:	Utilities Perspective on Heat Pumps as Retrofit Alternatives for Resistance and Hydronic Heating Systems (co-sponsorship with Swiss utility NOK)
United States:	Global Environmental Benefits of Industrial Heat Pumps (co-sponsorship with Annex 21)
Studies	
Heat Pump Energy Efficiency Standards and Labelling Requirements	
CO ₂ Emissions from Power Generation	

Annex 18 goes to press

Several reports concerning the activities of Annex 18 "Thermophysical Properties of Environmentally Acceptable Refrigerants" will be published early in 1994, among them an update of the 1991 'Survey of Current Worldwide Research on the Thermophysical Properties of Alternative Refrigerants' as well as scientific papers and 'property bulletins' for HFC-134a and HFC-123. Input from the 'New Fluids Database' at the University of Stuttgart, Germany, is being collected from Annex participants.

The December 1993 meeting of Annex 18 participants will be held in Japan in conjunction with an "International Seminar on Heat Transfer, Thermophysical Properties and Cycle Performance of Alternative Refrigerants".

(Source: Mr Mark McLinden, National Institute of Standards and Technology, USA.
Fax: +1-301-975-5224.)

Annex proposals

Rome, Italy - Delegates at the October Executive Committee meeting of the IEA Heat Pump Programme heard presentations on two separate proposals for an Annex on "Natural Refrigerants". Both Norway and Sweden want to see the Heat Pump Programme taking a lead in expanding knowledge on the use of the so-called natural refrigerants in heat pumps. The new Annex will cover hydrocarbons and ammonia, and possibly also air, water, CO₂, nitrogen and the noble gases. Discussions are now taking place to formulate the exact nature of Annex work. The Annex is expected to begin in 1994 and to have a duration of around three years.

(Source: Ms Susan Ross, Technical Support Services Unit, IEA Heat Pump Centre.)

Annex 21 puts software to work

Participants in Annex 21 - Global Environmental Benefits of Industrial Heat Pumps are now employing the software developed under this Annex to assess the potential of industrial heat pumps (IHPs) in their countries. The program supplies IHP cost and performance data which can be used in a market assessment spreadsheet, also developed by the

Annex, to estimate potential IHP energy savings and environmental benefits. An international workshop to discuss the results of Annex 21 is planned for September 1994.

(Source: Mr Steven Williams, RCG/Hagler, Bailly, Inc.,
Fax: +1-703-351-0342.)

Heat Pump Developments and Trends

An International Overview

Bert Stuij, IEA Heat Pump Centre

The future for the heat pump looks bright. Its strong position in market sectors with a significant cooling demand will remain or be further strengthened. At the same time there is growing policy support for the technology in sectors dominated by the heating demand, to control energy use and CO₂ emissions. With this perspective, it is timely to survey the current trends in the heat pump markets, technologies and applications. How are the markets developing? How does the heat pump feature in national energy policies, and is that influencing sales? What are the main R&D interests? How is the technology developing? What are the application trends in the domestic, commercial and industrial sectors?

* * *

To ascertain the dominant international heat pump trends, the IEA Heat Pump Centre National Teams reviewed the situation in their respective countries. Their appraisals formed the basis for this international overview, which addresses heat pump markets, policies, performance, applications and R&D. The general picture is drawn in the white section of this article, and national highlights are presented in the blue boxes.

Markets

The space conditioning heat pump market is influenced by at least four factors:

Climate

In regions with warm summers and relatively mild winters, a reversible heat pump for cooling and heating is often economical. The worldwide heat pump market is dominated by this type. In areas where the heat demand prevails, the penetration of residential heat pumps is in general modest at best. In some northern parts of the US the heat pump appears to lose some ground to high-efficiency gas furnaces. In Japan, however, the north is identified as a target market, and efforts to penetrate with high-efficiency equipment here have been stepped up. In the "heating-mainly" market of Sweden, a regulatory environment is created, where ventilation heat recovery heat pumps are economical and widely applied.

Energy Prices and Availability

The price and availability of fuels, electricity and district heating will strongly influence the economic logic of the electric heat pump, which is the most widely used. Relatively high electricity prices are a disincentive for heat pumps, but very low electricity prices make it difficult to compete with low-cost resistance heaters.

Electricity Mix

In many countries heat pumps are viewed as a technology to control CO₂ emissions. If electric heat pumps are installed, it is important to take the fuel mix for electricity generation into consideration. In some fossil-fuel based countries, notably Denmark and the UK, a trend towards increased gas use takes place. However, in many other countries coal remains dominant - which complicates the environmental impact of electric heat pumps.

Energy Policies

Well-aimed policies can strongly influence sales. Policy instruments include investment subsidies (widely used), special electricity tariffs (notably Austria), promotion (notably Norway and Switzerland), and building regulations (notably Sweden).

Superimposed on these factors, which mainly affect the choice for a heat pump in preference for its alternative, is the general economic climate. The economic slow-down of recent years has in most cases led to reduced sales. It reduced the funds available for domestic purchases, and adversely affected the commercial market. The market in the US appears to be recovering now, while the market in Norway, aided by a high-profile heat pump programme, continued to grow in spite of the recession.

Policies

In general, it can be said that the space conditioning heat pump market develops naturally if there is a significant cooling demand. This is the case in Japan and the US, and to some extent also in Southern Europe and Canada. It also explains most of the heat pump installations in commercial properties, where growing internal heat gains can make active cooling desirable in most climates. Without a cooling demand, policies are necessary to achieve a significant heat

Austria

Over 110,000 heat pumps are currently in operation, of which some 80% are for tap-water heating. Sales have been relatively steady over the past four years (Figures 1 and 2). Almost 50% of the space heating heat pumps are direct-expansion, ground-coupled systems. In new buildings such systems can reach an SPF of 4. Horizontal systems are well established, but research is still being carried out on systems with vertical probes.

A number of large-scale integrated systems have been installed over the last 10 years, typically for waste and ventilation heat recovery, space heating, tap-water heating and thermal storage. Sophisticated computer-based energy management systems are used to ensure reliable operation and low operating costs.

HCFC-22 remains the dominant replacement for CFCs. HFC-134a and other HFC blends are still viewed with reservation. There is a strong interest in the "old" natural refrigerants, in particular propane and ammonia.

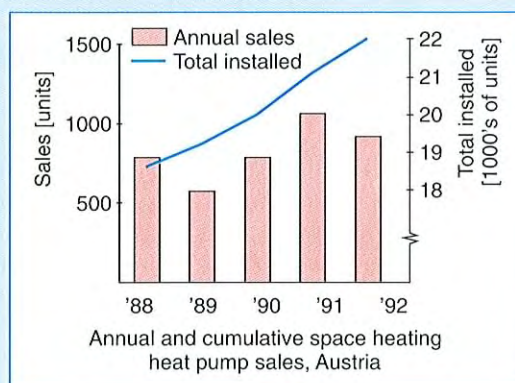


Figure 1.

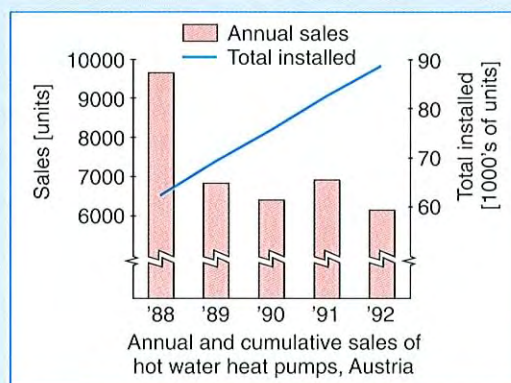


Figure 2.

Canada

Data from HRAI, the Canadian Heating, Refrigeration and Air Conditioning Institute, suggest that annual heat pump sales have fallen from a high of over 30,000 units in 1988 to about 7000 units in 1992. Furthermore, the air-conditioning market in 1993 showed a decline of up to 40% compared to 1992. Falling sales reflect the difficult economic conditions which currently prevail in Canada. Heat pumps are estimated to be installed in about 275,000 Canadian homes.

Heat pump R&D in Canada is currently focusing on performance improvement. Several advanced and recently patented heat pumps are undergoing field tests including both air-to-air and water-to-air systems. A high-temperature heat pump for industrial use is under development.

Italy

Heat pump sales (Figure 3) are linked to air-conditioning sales, and the market has more or less followed the development of the Gross National Product. Heat pumps are often seen as a comfort device, rather than an energy-saving technology.

R&D efforts have concentrated on the development of absorption technology. Research on gas-fired space conditioning with heat pumps continues, as the diffusion of gas in Italian society grows. A number of district heating heat pumps use geothermal energy as heat source.

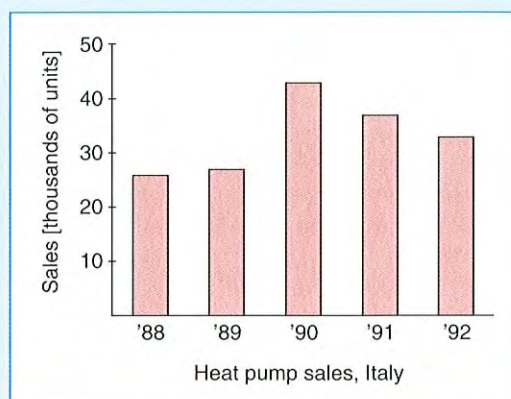


Figure 3.

pump penetration. Policies can be specifically directed at heat pumps (specific subsidies, promotion), but can also affect the "playing field" (general subsidies for energy-saving technologies, building regulations). At this stage, active policy support for heat pumps is concentrated in the countries with a predominantly non-fossil based electricity system. Countries with a fossil based electricity system have so far been more hesitant in supporting heat pumps. However, policy makers in these countries are starting to be influenced by the fact that space heating through direct combustion is, in principle, never the most efficient use of fuel. In the Netherlands, for instance, where condensing gas boilers are the norm for residential heating, and where the electricity system is based on coal and gas, heat pumps are now earmarked as a key technology to achieve energy efficiency and CO₂ emission targets by the year 2000 and beyond.

Performance

The efficiency of electric heat pumps continues to improve, although it has been noted that the necessity of introducing alternative refrigerants could adversely affect performance improvements.

In the US, efficiency regulations have proven effective catalysts for heating and cooling SPF developments. Significant further improvements are still possible. Advanced air-source heat pumps now reach an SPF of 3 in the US, while advanced ground-source heat pumps achieve COPs of 4.4, with a further 10% improvement expected. In Austria, the widely applied direct-expansion ground-coupled heat pump currently reaches an SPF of 4. Systems developed under the Japanese Super Heat Pump Energy Accumulation System (SHPEAS) programme have an SPF of more than 5.5, and are expected to enter the market later in the nineties. High-temperature Super Heat Pumps have also been developed for industrial use.

A residential gas-engine heat pump with a PER of 1.3 and a life expectancy of 40,000 hrs is now marketed in the US. In the Netherlands, a 250 kW gas-fired absorption unit reaches a PER of 1.6 in an institutional building.

Applications

Domestic heat pumps are still mainly sold as reversible units, producing cooling in summer and heating in winter. There is a tendency to integrate the energy demands for heating, cooling and tap-water heating. An optimized integrated system meets all energy needs at minimum costs and minimum primary energy use.

In the heating-mainly, domestic market of Europe a similar trend occurs, with heat pumps using ventilation air as heat source. These heat pumps provide hot tap-water, and in general partially meet the space heating need. Aided by favourable building regulations, sales of these systems are growing in Sweden.

The commercial sector is an important application area in most climates. Growing internal heat gains and improved insulation have increased the cooling need, making heat pumps well suited to provide both cooling and heating. On the other hand, architects are challenged to minimize the active cooling requirement by improved building design, and to incorporate passive cooling and natural ventilation. In some countries, regulations are under consideration to curtail the use of air-conditioning in commercial properties (UK, Germany, Switzerland).

Industrial heat pumps are still mostly found in their traditional application areas: evaporation, drying and distillation. As process integration becomes more popular, it is expected that new opportunities for heat pumps will be identified. One step beyond process integration is "district integration", where waste heat from industry is used as the heat source or drive energy for a district heating heat pump. In Sweden, a number of "district integration" systems have been realised, in some cases with absorption heat pumps which use waste heat from refuse incineration plants. The development of higher-temperature heat pumps will widen the applicability of heat pumps in industry, notably for steam generation.

Research & Development

Heat pump R&D work aims to improve the economic, environmental and efficiency performance of heat pumps, and to widen their applicability. With such an impressive amount of R&D work going on worldwide, this article is limited to providing just a few highlights from some of the most important research areas.

Working Fluids

Perhaps the single most pressing research issue, driven by the agreement to phase out CFCs soon and HCFCs in due course, is research into alternative refrigerants. It is interesting to observe that in the US the main emphasis is on blends and mixtures of HFCs, whereas in Europe much attention is devoted to the "natural" refrigerants. The safety issues related to the use of ammonia and propane are addressed in Europe, and perceived as manageable in many cases. New systems with CO₂ and air are under development. A number of equipment manufacturers from North America, Europe and Japan have joined forces in AREP, the Alternative Refrigerants Evaluation Programme. The main aim of this programme is to come to a good alternative for the massively applied HCFC-22.

Performance Improvement

There is a continuous drive to improve system components and so raise the total heat pump efficiency, a drive which has arguably culminated in the Japanese Super Heat Pump which reaches an SPF of over 5.5. The Super Heat Pump is of a relatively large capacity, and at this stage its main application will be the commercial sector. A Dutch development of a small heat

Japan

Today, heat pumps are installed in over 65% of Japanese homes. Driven by the air-conditioning demand, the heat pump market is mature with annual heat pump sales of well over 4 million units. A moderate slow-down in recent years is attributed to the economic downturn and the associated reduced building activities (Figure 4). The massive penetration of air-conditioning causes large daily and annual power demand variations. Concern about these variations is one of the driving forces for Japanese heat pump R&D work aimed at "peak cutting", through improved heat pump performance; "peak shifting", mainly through thermal storage; and "fuel switching", through further development of gas-driven air-conditioning.

Other R&D work is aimed at higher output temperatures, and a fuller utilization of unused energy, both natural and waste heat. A national programme on the "utilization of unused energy" started in 1991.

The recently finished Super Heat Pump Energy Accumulation System (SHPEAS) programme addressed many of the issues. Heat pump performance was dramatically improved, advanced heat pumps were combined with thermal storage, and high-temperature heat pumps were developed. Figures 5 and 6 illustrate the expected market penetration of super heat pumps in industry and the commercial sector. It is now estimated that in 2010, super heat pumps will generate 7.5% of the steam required in industry, and meet 18% of the space conditioning demand in commercial properties.

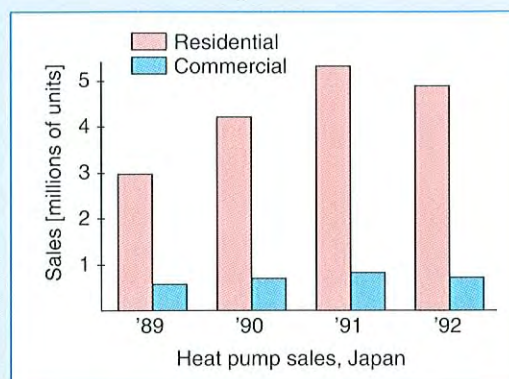


Figure 4.

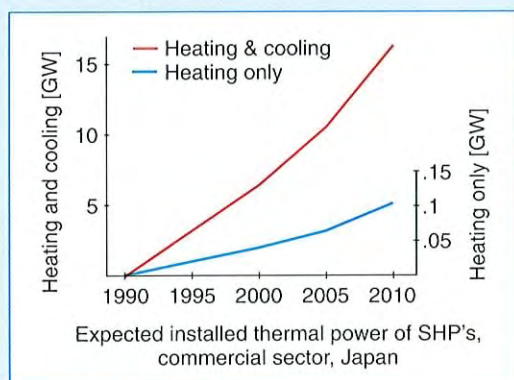


Figure 5.

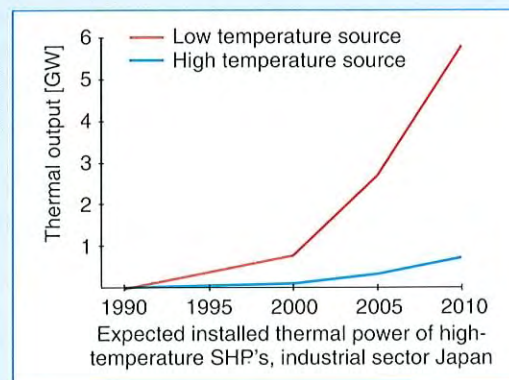


Figure 6.

Other notable developments are:

- cold climate: special heat pumps are targeted at the North; a COP of 3.3 is now achievable with an outdoor temperature of -10 °C;
- gas engine heat pumps: Annual sales are rapidly rising, from less than 1500 units in 1987 to over 30,000 units in 1992. Research efforts are aimed at increasing life expectancy, reducing maintenance, and in particular at low NO_x engines;
- absorption: in low-lift situations using waste heat flows, COPs of up to 1.8 are achieved for single-stage systems, and 2 for double-stage. Twenty-two heat transformers are operating in industry;
- adsorption: Ten adsorption units have been in use since the early eighties. Economic and technical obstacles for further penetration remain.

Netherlands In spite of very limited heat pump sales in recent years, and an almost non-existent market in the residential sector, Dutch heat pump R&D has produced some notable results. In Maastricht, a government and utility supported development of an absorption heat pump has led to perhaps the most advanced gas-fired absorption unit currently commercially available. The unit, now installed in the provincial government building, provides both cooling and heating, and achieves an average heating PER of 1.6. At the same time the development of an advanced compression heat pump with a high-speed compressor continues. Development targets for this heat pump include a COP of over 5 at a lift of 40 °C, and a competitive price. In a separate development, a modular Na₂S/water adsorption heat pump now undergoing field trials, can be driven by district heating to provide cooling and to store thermal energy. The Dutch government has identified heat pumps as a key technology to achieve the government's energy saving and CO₂ emission targets and a new heat pump policy plan is currently being developed together with market parties. The application of heat pumps should save 5 to 10 PJ in 2000 (depending on the development of the heat demand), and policy expectations for 2010 range from 50 to 100 PJ (see Figure 7). The 2010 target figure would equal a heat pump penetration of up to 50% in new houses and offices, and a realization of 40% of the industrial heat pump potential. It is expected that the industrial penetration will commence in processes such as concentration, distillation and drying. A number of MVR systems are already successfully installed.

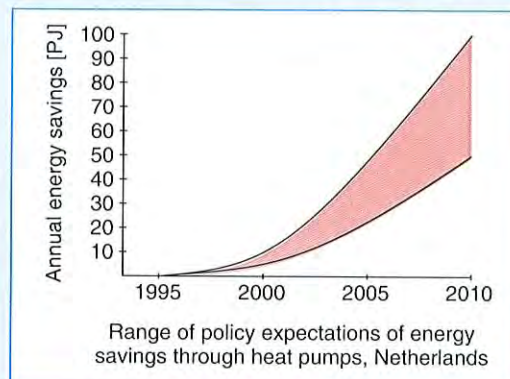


Figure 7.

pump with a high-speed compressor has a target COP of over 5, at a temperature lift of 40°C. In general, there is a clear upward trend in heat pump performance, mainly as a consequence of research done by manufacturers. At the same time, research continues to improve the economics of heat pumps, and widen their applicability. One US example is the development of Alkitrane as the working pair for absorption systems, which will allow significantly higher output temperatures (260°C), and enables the use of cheaper equipment because it is less corrosive than the traditionally used water/lithium bromide working pair.

Gas-fired Technology

Research in Japan and the US is driven by the need for fuel switching to alleviate the electricity peak demands associated with electric air conditioning. Both absorption and gas-engine options are maturing. In other countries, notably Italy, the Netherlands, Switzerland and Germany, absorption research is driven by the potentially high PERs that can be achieved.

Adsorption

Adsorption systems have an inherent storage ability, and are very interesting in specific situations. High-temperature (220°C) developments are taking place in France. In the Netherlands, a relatively cheap modular system is coupled with district heating to provide space cooling and thermal storage.

Towards a Brighter Future

Heat pump markets were restrained in the early nineties, mainly in response to a sluggish economy in most countries. The space conditioning heat pump market is mature in sectors with a cooling demand, but requires policy support in heating-only or heating-mainly situations. Countries with a fossil fuel based electricity system have been hesitant to provide this support, but this is changing as the awareness grows that direct combustion for space heating is in principle never the most efficient use of fuel.

Heat pump technology continues to develop, with the working fluid issue dominant in many countries' research programmes. In the US the emphasis appears to be on HFCs, whereas in Europe, naturals such as ammonia, propane, CO₂ and air also receive extensive attention. Efficiencies show an upward trend, where an SPF of over 3 is achievable for air/air systems, 4 to 4.5 for ground-source systems, and 4.5 to 5.5 for the most advanced systems. Gas-fired systems with PERs of 1.3 to 1.6 are commercially available.

As the performance of heat pumps continues to improve, and the heat pump is recognized in more and more countries as a valid policy option to control energy use and CO₂ emissions, the medium to long-term future for the technology looks bright indeed.

Norway

A significant rise in heat pump sales over recent years is attributed to the first Norwegian heat pump programme which ran from 1989 to 1992 (Figure 8). Promotion and transfer of knowledge were key features of this programme, together with investment subsidies of up to 40% for heat pump buyers. Sales are hampered by falling electricity prices which favour resistance heating, still the dominant heating method in Norway.

R&D work in the coming years will concentrate on the development of environmentally acceptable working fluids, with a strong emphasis on the "naturals" ammonia, hydrocarbons and CO₂. A significant number of heat pumps currently installed use CFCs, although the number of ammonia heat pumps is growing. In future, an effort will also be made to establish a Norwegian heat pump manufacturing industry.

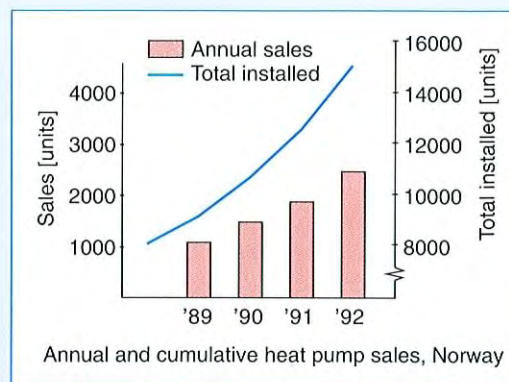


Figure 8.

Switzerland

In spite of recent strong policy support for heat pumps, the market has actually declined over the last four years (Figure 9). It is expected, however, that this trend will be reversed as the amount of heat pumps installed in renovated houses grows. Heat pump water heaters are rare in Switzerland, in sharp contrast with neighbouring Austria. The market is mainly domestic, and dominated by air/water heat pumps (Figure 10).

Within the Swiss "Energy 2000" programme, 40% of the renewable energy target must be met by heat pumps, and an ambitious promotion programme has been set up. The aim is to annually increase heat pump sales by 30%, and to install 15,000 units per annum from 1995 onwards. Key elements of the programme are:

- continuous improvement of heat pump performance (Figure 11);
- improving boundary conditions, e.g. through special electricity tariffs, or simple grants for the use of ground or water as heat source;
- marketing and education, jointly with utilities, manufacturers, installers and consultants.

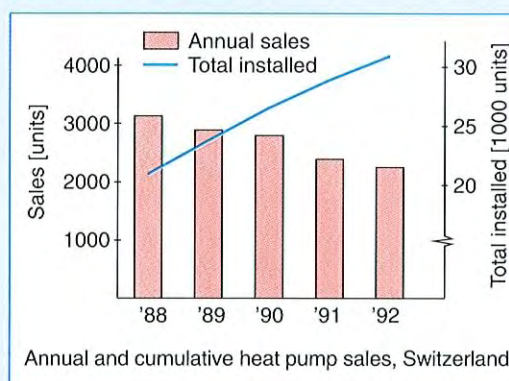


Figure 9.

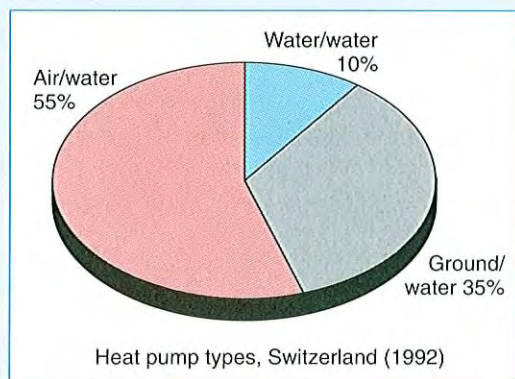


Figure 10.

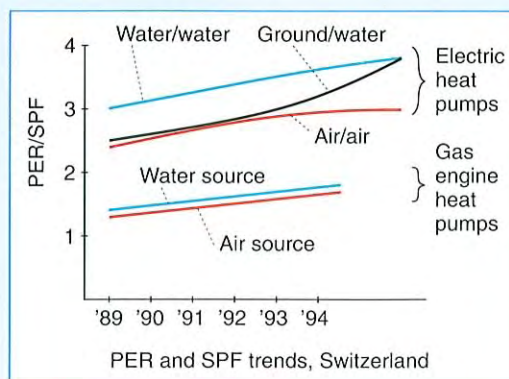


Figure 11.

Sweden

Sweden is a "cool" country with a large domestic heat pump penetration. Penetration has been influenced by energy price settings, notably through high taxes on imported fossil fuels, by the availability of CO₂-free electricity from nuclear and hydro power, and for the residential market by building regulations.

Almost 35% of the domestic heat demand in Sweden is met by district heating, and 15% of this is provided by heat pumps. The district heating heat pump market is seen as "saturated" and few new installations are expected, although refuse incineration plants with absorption heat pumps are planned. Most district heating heat pumps were installed before 1987 and use large amounts of CFCs. A major retrofit effort is expected over the coming years with some installations already converted to HFC-134a.

Some 230,000 small residential heat pumps are currently installed. The growth of ventilation heat recovery heat pumps, now installed in 75% of new homes, is a new trend which has been driven by building regulations which enforce insulation, curtail the heat loss from ventilation air, and limit the maximum temperature in hydronic heating systems to 55°C. Ventilation heat recovery heat pumps always provide warm tap-water, and may also provide space heating.

United States

The heat pump market in the US is mature with heat pumps for space conditioning viewed as commodities. Sales are sensitive to prices and the general economic situation and were therefore restrained in the early nineties (see Figure 12). However, the market recovered in 1992, and 1993 sales are running some 5% ahead of 1992. Significant growth is expected in the replacement market, and the total market is likely to grow by 3 to 5% until the end of the decade. The influence of climate on heat pump penetration remains dominant, and sales in the North are low. In some northern areas a trend away from heat pumps to gas furnaces has been observed. The performance of heat pumps continues to improve, more recently in response to efficiency regulations (Figure 13).

R&D efforts in the US cover most of the heat pump technology areas, with a current emphasis on alternative refrigerants. Ongoing concerns about the safety of propane and ammonia have resulted in a focus on blends and mixtures of HFCs. More in general, the R&D drive is to enhance comfort, economy, efficiency and environmental performance. An extensive review of US R&D activities is given on pages 18-21 of this Newsletter.

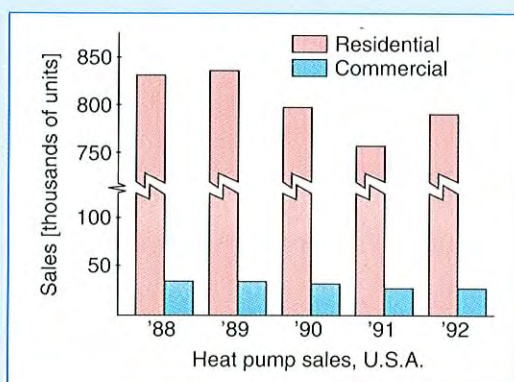


Figure 12.

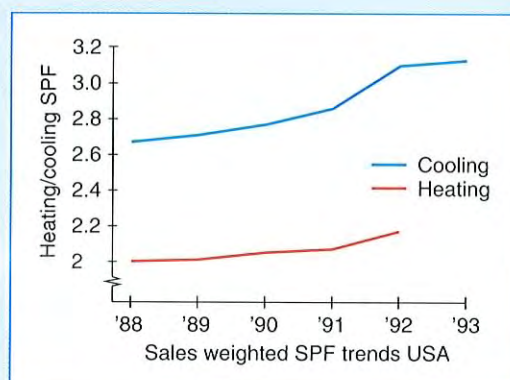


Figure 13.

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Survey of Heat Pump R&D in the United States

Glenn C. Hourahan, USA

A number of organizations that fund and manage research have been surveyed to ascertain their efforts on heat pump and heat pump related issues. The emphasis was to discover the type of work currently being performed and the institutions involved. This article summarizes heat

pump research under the categories alternative refrigerants, controls, ground and water-source heat pumps, alternative cycles, and other heat pump issues. Tables 1-5 list research projects with numbers in brackets indicating contact persons listed in References.

Table 1: Research in alternative refrigerants.

Funded by	Research Project Title [Research Organization]	Start - End [Contact]*
ARI	Alternative Refrigerant Evaluation Program (AREP) [over 30 equipment manufacturing companies in North America, Japan and Europe]	1/92 - 3/94 [1]
ASHRAE	Capillary Tube Performance with Alternative Refrigerants [Iowa State University]	9/93 - 3/95 [2]
EPRI	Alternative Refrigerants Evaluation Program (AREP) [University of Illinois, Iowa State, Lehigh University]	11/92 - 4/94 [3]
EPRI	The Measurement of Evaporative Heat Transfer Coefficients of Refrigerant Mixtures, R32/R134a and R32/R125/R134a With and Without Lubricant [NIST]	11/92 - 12/93 [3]
EPRI	Novel HFC Propanes, HFC Butanes, and HFC Ethers as Alternatives to CFCs [Clemson University]	7/92 - 4/94 [4]
EPRI	Development of Zero-ODP Refrigerant for Centrifugal Chillers [Allied-Signal, Inc.]	7/91 - 7/94 [4]
EPRI/ US EPA	Testing of Environmentally Safe Refrigerants/ Refrigerant Mixtures in Heating and Cooling Equipment [University of Maryland]	7/92 - 9/94 [4/5]
GRI	Materials Research for Improved Ammonia Heat Pump Application.	91 - 96 [6]
US DOE	New Refrigerants [NIST, ORNL]	ongoing [7]
US DOE/ ARTI	Materials Compatibility and Lubricants Research (MCLR) Program [~40 separate contracts]	9/91 - 9/95 [8]
US EPA	Evaluation of a Residential Heat Pump Using a Rectifier for Refrigerant Mixture Separation [NIST]	9/92 - 9/93 [5]
US EPA	Improving Air-Conditioner and Heat Pump Performance with R-22 Replacement Refrigerants [pending]	9/93 - 9/96 [5]
US EPA	Modeling Evaluation of R-22 Replacement Blends [Research Triangle Park]	4/93 - 8/94 [5]
US EPA	Use of Non-Chlorine Refrigerants and Refrigerant Mixtures in Heat Pumps and Air-Conditioning [pending]	9/93 - 9/96 [5]
*See References		

Research Project [Research Organization]	Start - End [Contact]*
Funded by EPRI:	
Microprocessor control system design for a variable-speed ground-source heat pump [University of Alabama]	6/91 - 9/93 [9]
Water-loop heat pump system evaluation and development of control and operation strategies [ClimateMaster, Inc.]	1/86 - 12/93 [10]
Heat pump thermal distribution system study, including determination of the best zonal approach for residential systems [Tecogen, Inc.]	10/87 - 3/93 [11]
Funded by GRI:	
Development of improved emission controls for a residential reciprocating-engine-driven gas heat pump	Ongoing [6]
Advanced heat pump controls development	84 - 94 [6]
*See References	

Table 2: Examples of controls research.

In this survey are responses from the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), the Air-Conditioning and Refrigeration Institute (ARI), the Air-Conditioning and Refrigeration Technology Institute (ARTI), the Electric Power Research Institute (EPRI), the Gas Research Institute (GRI), the US Department of Energy (US DOE), and the US Environmental Protection Agency (US EPA). However, the survey is not to be construed as an exhaustive accounting of on-going research effort within the US. There are numerous projects funded by other interested stakeholders that are not included in this survey. Additionally, research within private manufacturing firms, by its very nature proprietary, is not publicly available; no attempt was made to summarize that research here. Hence, the investigations noted within this article are meant to be representative of the types of work that are underway to satisfy the needs of US equipment manufacturers and their customers.

Research Drivers

There are a number of drivers in the US that influence research on heat pumps utilized in heating and cooling applications:

- occupancy comfort requirements;
- equipment economics (e.g., installation and operating costs);

- efficiency demands of the US National Appliance Energy Conservation Act (NAECA regulates single-phase heat pumps with cooling capacities of 65,000 Btu/h [19 kW] and smaller) and the US 1992 Energy Policy Act (EPAct regulates three-phase heat pumps of 65,000 Btu/h [19 kW] cooling capacity and smaller, heat pumps with cooling capacities between 135,000 Btu/h and 240,000 Btu/h [40 and 70 kW], and packaged terminal heat pump equipment);
- environmental effects of air-conditioning on stratospheric ozone levels and on global warming.

Equipment costs are a key factor in determining heat pump acceptance. In the US, the air-conditioning industry is a mature market, and comfort conditioning and refrigerating products are considered commodities. The market is very sensitive to pricing; market demand gravitates to the lowest cost equipment. Utility rebate and incentive schemes that reward higher efficiency equipment can, and do, alter market dynamics and affect heat pump sales over other types of equipment.

Some of the drivers act at odds with each other. As manufacturers seek to comply with DOE efficiency requirements, the US Clean Air Act of 1990 (which accelerated the phase-out of CFCs and detailed the future ban of HCFCs) has forced manufacturers to also plan for the simultaneous development of units that will use non-chlorinated working fluids. In nearly all instances, it will be a challenging redesign just to regain the efficiency levels of the original HCFC-22 units.

Hence, the previous objective of US R&D to provide cost-effective equipment that satisfies load demand has been superseded by government-mandated efficiency levels and refrigerant obsolescence regulations. This has led to a new focus where the industry is striving to develop and market equipment that efficiently utilizes environmentally-friendly working fluids while also satisfying customer needs. This is a tough balancing act to achieve.

Table 3: Ground- or water-source heat pump research.

Research Project [Research Organization]	Start - End [Contact]*
Funded by EPRI:	
Slinky/spiral ground coil development [Oklahoma State University]	3/92 - 1/94 [9]
Design and development of a triple function two-speed ground-source heat pump [Water Furnace International]	12/88 - 12/93 [9]
Advanced water-loop heat pump equipment development [The Trane Company]	8/88 - 6/95 [13]
*See References	

Research Project [Research Organization]	Start - End [Contact]*
Funded by GRI:	
Advanced gas heat pump development based on chemisorption technology	87 - 97 [6]
Sorption technology and component development	91 - 96 [6]
Dual-cycle absorption heat pump development	96 - 98 [6]
Generator-absorber heat exchange (GAX) heat pump development	92 - 97 [6]
Funded by US DOE:	
Development and commercialization of advanced cycle concepts in absorption and engine-driven heat pumps for residential and small commercial buildings [Phillips Engineering]	82 - ongoing [12]
Development and commercialization of highly-efficient large commercial absorption chillers using advanced cycles with water as the working fluid	82 - ongoing [12]
*See References	

Table 4: Non-vapour-compressor cycle research.

R&D Organizations

There are a number of organizations within the US that are involved in developing and supporting research on heat pump components or their working fluids. These organizations include private equipment manufacturers, chemical producers, industry trade associations, federal agencies and departments (e.g., US DOE and US EPA), national laboratories (e.g., Oak Ridge National Laboratory and National Institute of Standards and Technology), and a myriad of state and local agencies. These entities provide significant funding and in-kind support to many private and university research facilities for the furthering of heat pump technologies.

Alternative Refrigerants

As a result of the mandated final phase-out date of HCFC-22 (the primary refrigerant in US unitary heat pumps) by 2030, increasing levels of effort are being applied to investigating alternative working fluids. In Table 1, it can be seen that there are numerous research programmes geared towards uncovering alternative working fluids, investigating thermo-physical properties, ascertaining compatibility with materials, characterizing heat transfer mechanisms, and comparing performance against HCFC-22 in existing and optimized equipment and cycles.

Many of the replacement candidates under evaluation are blends with two or more constituents. Of these the majority of the fluids are zeotropic mixtures having fractionation concerns that need to be resolved. These concerns are related to temperature glide characteristics, possible flammability scenarios, equipment control and operation requirements, and equipment servicing in the field.

However, zeotropic blends potentially offer large efficiency gains if their temperature glides can be utilized in future innovative heat pumps. Research is in its infancy on whether composition shifting can be advantageously utilized to provide efficiency improvements over the basic cycle during cooling and heating modes. Composition shifting would permit different circulating mixtures for summer cooling operation and for winter heating operation. Optimization of the compositions for both operating modes will be very challenging, but could yield large efficiency gains. Also of particular challenge will be the development of counter-flow air-to-refrigerant heat exchangers that benefit from the resultant refrigerant temperature glides.

Controls

Another key research area is in the development and application of new controls to produce heat pumps that are more responsive to load conditions. Table 2 notes several on-going projects geared towards efficiently applying enhanced controls to heat pumps. Equipment manufacturers are also investigating the use of electronic expansion valves (utilizing algorithms to provide tighter bandwidth), better sequencing of compressors (using microprocessors) and utilization of electronically-controlled variable-speed motors.

Currently, heat pump equipment utilizing two-speed compressor motors and multi-speed blower motors are available in the marketplace. Additionally, variable-speed motors and their associated drive packages have been available for many years. However, as a result of higher first cost, these enhancements were not easily accepted in the US market. Much research is still needed to cost-effectively apply custom design motor and drive packages to specific applications.

Another trend in the US market has been the increased usage of multi-zoning to obtain better thermal comfort and energy utilization. Generally, this was accomplished via multiple units to serve multiple zones. However, newer controls have allowed multi-zone control on a single unitary heat pump. Some sectors of the US market are willing to pay slightly more for the resultant benefits of better comfort matching.

Ground & Water Source

There are a number of ground/water-source applications in the US, with more added every day. The research effort in this area is focusing on providing

Research Project [Research Organization]	Start - End [Contact]*
Funded by ASHRAE:	
Study to determine heat loads due to coil-defrosting and to develop design tools [University of Florida]	4/92 - 7/94 [14]
Design procedure development for thermal energy storage tanks which separate the manufacture of ice from the storage of ice [University of Missouri - Kansas City]	9/91 - 9/93 [15]
Funded by EPRI:	
Development of a dual-fuel heat pump for residential and small commercial buildings [Tecogen, Inc.]	2/87 - 12/93 [9]
Development of a cost-effective heat pump with integrated dedicated year-round water heating capability [Nordyne, Inc.]	8/90 - 3/93 [16]
Development of advanced off-peak or base-loaded heat pump water heaters [E-Tech Division; Crispaire Corporation]	9/89 - 12/93 [9]
Funded by GRI:	
Residential reciprocating engine-driven heat pump development	84 - 94 [6]
Development of an 88 kW (heating) engine-driven heat pump with a heating COP of 1.8 at 8.3°C, a unit cost of US\$ 25,000, and a service life of 20 years	93 - 97 [6]
Funded by USDOE	9/91 - 6/95
Domestic refrigerator-freezers with 50% lower energy use	[17]
*See References	

Table 5: Other research.

better components and installation methods. As with the air-source heat pumps, efforts continue to improve efficiencies and to uncover optimal working fluids. High-efficiency ground-source heat pumps offer the potential to lower energy consumption, thereby reducing pollution while saving money for the customer. Refer to Table 3 for a representative example of some of the work in this area.

Alternative Cycles

There are a number of alternative technologies and alternative cycles that are being assessed by US manufacturers. These include systems that use linear free-piston compression, acoustical compression, electrodynamic compression, and Stirling cycle compression. With regard to some of these long-term technologies, manufacturers of unitary equipment are anxiously waiting to see how well the concepts are

implemented in smaller applications such as household refrigerators, freezers, and window-unit room air-conditioners. Table 4 illustrates some research on non-vapour-compression cycles.

Other Heat Pump Issues

Table 5 provides examples of other heat pump research under consideration. These types of research are associated with new coil-defrosting strategies, thermal storage, dual-fuel usage, and engine-driven heat pumps. Also of interest is the water-heating capability of heat pumps to provide hot water for domestic needs.

Optimal Results

In conclusion, these very diverse research projects are well-coordinated with the sponsoring entities - government, industry, and utilities - cooperating to achieve optimal results. The government-sponsored research is aimed at ensuring better utilization of natural resources. Industry's research is directed towards providing products that satisfy customer requirements. The utilities provide strong support to air-conditioning and refrigeration issues to improve the efficiency of their energy-distribution networks. Ultimately, the research will lead to even more efficient heat pumps that satisfy requirements using environmentally-friendly working fluids.

References:

Ref.	Contact	Telephone No.
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Ice Thermal Storage Systems

Increasing the Role of Heat Pumps in Peak Shaving

Hideo Kuroda, Japan

The number of thermal storage systems installed in Japan has been growing steadily year by year with the encouragement of the electric utilities. By using off-peak electricity, these systems have significant benefits for energy consumption.

A significant number of thermal storage systems now use ice as the storage medium. Ice thermal storage systems can provide a much larger cooling capacity per unit weight than conventional water thermal storage systems. Consequently, their limited storage tank volume makes them easier to install. Since most of these systems are reversible, the trend in their application plays an important role in the diffusion of heat pumps.

* * *

Conventional water thermal storage systems utilize temperature differences (sensible heat) and need a large volume storage tank under the building. In many cases, however, it is difficult to secure such a large tank space, and the diffusion of conventional systems is thus restricted. The design and development of more compact thermal storage tanks has therefore become important.

Table 1: Characteristics required for latent heat storage material.

1. High safety.
2. Chemically stable and easy to treat.
3. Cheap and abundantly available.
4. Easy to extract and add thermal energy.
5. Change of state temperature (melting point or boiling point) is close to the desired level.
6. Does not deteriorate despite repeated use.
7. Capable of storing a large amount of heat or cold.

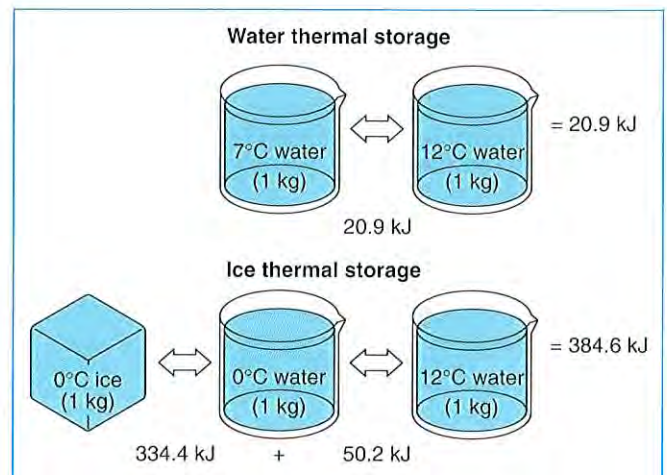


Figure 1: The capacity of an ice thermal storage system is 18 times as high as with water thermal storage.

Latent Storage

To realize a more compact tank structure, thermal storage systems have been developed to utilize the latent heat involved in phase changes (solid to/from liquid) of substances; i.e. latent storage systems. Table 1 shows the characteristics which a latent storage material should have. At present, systems utilizing phase changes between water and ice are employed most widely. Ice thermal storage systems are used in summer to store cooling capacity in ice at night and to melt the ice for cooling during the day. In addition to systems for cooling only, some systems utilize hot water thermal storage in winter when the heat pump operates in the heating mode.

Decreased Volume

Figure 1 shows that the cooling capacity of an ice thermal storage system under total freezing is 18 times as high as that stored by a water thermal storage system operating between 12 and 7 °C. This allows the thermal storage tank volume to be substantially reduced. However, because of practical difficulties in melting ice, it is unrealistic to turn all the water into ice. Figure 2 shows how the ice packing factor (IPF) affects the tank volume for ice thermal storage in comparison to that for water thermal storage. As shown, if 10% of water is made into ice,

the tank volume is 32% of that of a water storage tank. Currently, buildings in Japan have a cooling load to heating load ratio of approximately 2:1 to 3:1 due to the heating load of office automation equipment. If the storage tank is used as a hot water tank in winter, an IPF of about 10% is desirable for a balanced service.

As a result of the reduced tank volume, it is possible to install it on the roof, or even to employ a thermal storage system in small or medium-sized buildings through retrofitting, although this has yet to be achieved. A further advantage of the reduced volume is that the low surface area means that heat losses are much less than with water thermal storage.

Decreased Capacity and COP

A major drawback of ice thermal storage is that, since ice must be produced, the heat pump evaporator temperature level must be lower than that of a water thermal storage system, so heat pump capacity and COP are decreased (see Figure 3). For water thermal storage, the evaporation temperature of an ordinary heat pump is in the vicinity of 0°C. For ice thermal storage, however, there are systems with evaporation temperatures below -10°C so that the capacity and COP drops to about 56% and 71% respectively of those of a water thermal storage heat pump system. A capacity drop leads to an increase in the size and cost of the heat pump, while a COP drop leads to an increase in energy costs. To cut down on both these costs it is necessary to store the minimum of ice permitted by the available space and the desired IPF.

Technology Overview

An ice thermal storage system is composed of a heat source unit on the primary side (the heat pump), an ice making system, a storage tank, and an air conditioning system which can be a conventional central system. The ice making equipment must form the ice and deliver it to the storage tank.

Ice Forming

There are three systems available for forming ice:

- *Direct expansion* forms ice by directly feeding refrigerant into the ice making heat exchanger;
- The *brine system* exchanges heat between refrigerant and brine in the heat pump's evaporator to produce low-temperature liquid brine which is fed to the ice forming coil;
- The *heat pipe system* exchanges heat between the refrigerant evaporator and water, and forms ice on the heat pipe surface.

In the US, direct expansion is used in the majority of large-scale systems, while the brine system is mainly used for medium and small-scale equipment. In Japan,

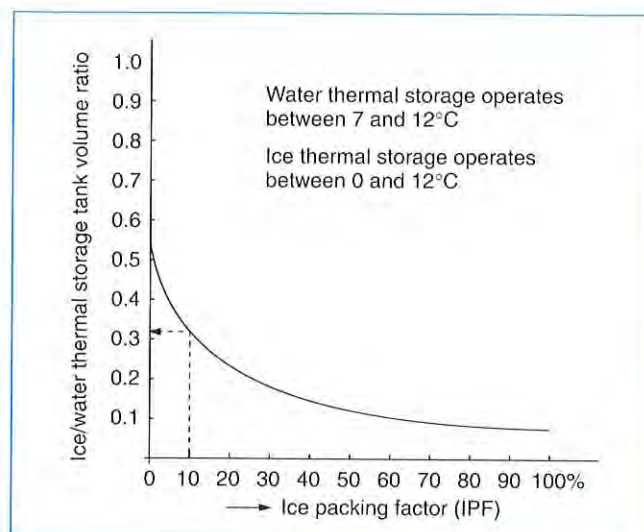


Figure 2: Variation in tank volume (expressed as the ratio between ice and water thermal storage tank volume) with ice packing factor.

the brine system is favoured regardless of building size.

Brine systems require more space and special materials, and have a lower COP because of the additional temperature difference between refrigerant and brine, and power consumption by the brine pump. However they do have the advantage that the tank and heat pump can be located separately.

Direct expansion systems require a much larger refrigerant charge, are more expensive, and are difficult to maintain. Ice adherence is more even with a direct expansion system.

Ice thermal storage systems are classified as *static* or *dynamic* type according to the way ice is delivered to the storage tank.

Static Systems

In static systems, an ice making pipe is installed in the thermal storage tank where ice is formed and later melted. Ice-in-tube systems produce ice inside the ice making coil. Ice-on-coil systems produce ice outside the coil.

The ice may be melted using either an external melting system which melts ice from the outer side by taking out chilled water, or an internal melting system (for ice-on-coil only). Internal melting may be achieved by feeding brine returning after being warmed by the air conditioning equipment into the coil. Alternatively, a refrigerant sub-cooling system passes high-temperature and high-pressure refrigerant from the condenser through the coil. Another type of static system is an ice tube float system which uses a polyurethane tube filled with water.

Dynamic Systems

In the dynamic type thermal storage system, ice is produced outside the thermal storage tank and peeled off continuously or intermittently by various means:

The *harvest ice system* feeds refrigerant which has passed the expansion valve into an ice making plate where ice is peeled off and dropped into the thermal storage tank.

The *chip ice system* continuously produces ice which is scraped off as ice chips.

In the *liquid ice system*, fine ice crystals are formed in an ethylene glycol solution (ice slurry) by cooling with refrigerant. Alternative systems use a binothermo solution.

The *sherbet ice system* produces very fine (sherbet-like) ice by a water or brine sub-cooling system.

Upward Trend

Japanese electric power utilities began recommending thermal storage systems in 1983. As shown in Figure 4, the number of thermal storage systems adopted by the nine power companies has been increasing steadily since 1985. And the adoption of ice thermal storage systems has become more significant, accounting for 16.9% of all thermal storage systems in 1992. The large majority of thermal storage systems in Japan provide both heating and cooling.

The increased use of thermal storage plays an important role in reducing peak electrical loads. For

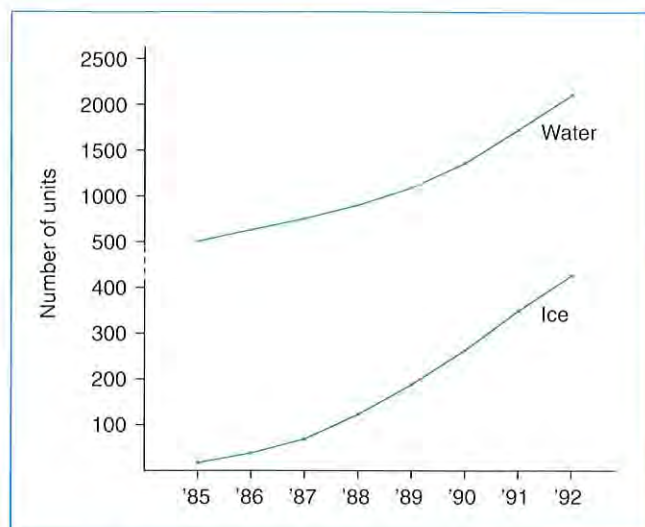
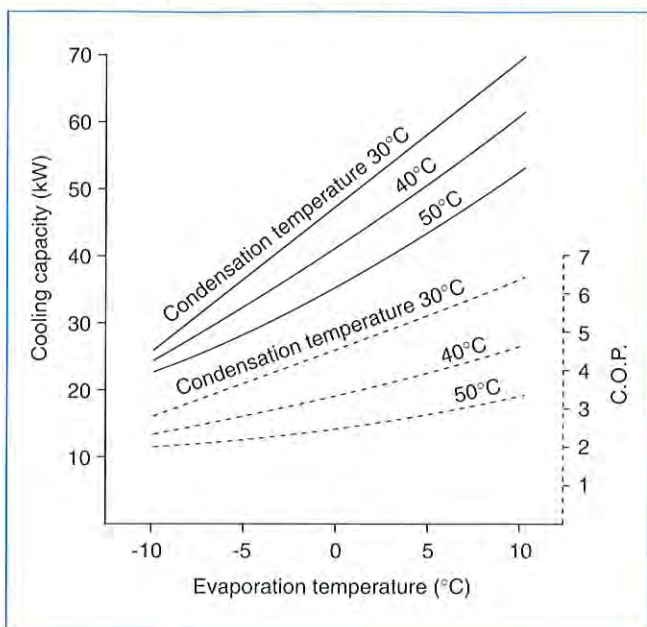


Figure 4: Trend in water and ice thermal storage air conditioners (including heat pumps) under utility contracts in Japan.

example Tokyo Electric Power Company, the largest power company in Japan, recorded a daily maximum peak power load of 53.1 GW in 1992. About 0.2 GW was considered to be shifted to night-time through thermal storage, representing about 0.4% of the day-time peak. This provides valuable economic benefit to the utilities by restraining the need for investment in new power plants.

Ice thermal storage systems are economically beneficial to users since they require less space than water thermal storage systems. This allows heating and cooling capacity to be enlarged within the often restricted area of existing machine rooms.

Figure 3: Variation in heat pump capacity and COP for a reciprocating compressor rated at 44.2 kW.



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Getting More from a Hot Spring

An Example of Intelligent Waste Heat Recovery

Kurt Atzgerstorfer and Hermann Halozan, Austria

An Austrian company for electrical equipment and appliances has developed a concept for energy efficient space conditioning where heat pumps are used for heat recovery. The heat pumps use primarily waste heat occurring in the building, such as from the ventilation system and from waste water. Additional heat sources may be required according to the local situation.

To minimize energy consumption and the peak demand of electricity, a sophisticated computer-based energy management system plays an important role in the concept. Several systems went into operation in Austria during the last 10 years. They work reliably and achieve low heating and operating costs. An interesting system has recently been installed in a recreation hotel where hot spring water is now used more effectively.

Therapeutic Baths

The Gastein valley in the district of Salzburg, Austria, located in the centre of the Alps, is famous for its vacation and recreation facilities. Besides hiking in summer and downhill-skiing in winter, several hot springs are used for therapeutic purposes.

These hot springs offer about 5000 m³ per day of mineral water at a temperature of 43°C. This hot thermal water is pumped to an overhead reservoir, from where it is distributed in recreation centres in the villages of Badgastein and Hofgastein and to several hotels.

To provide therapeutic baths with required temperatures of 37°C, one part of the hot mineral water, daily about 100 to 200 m³, was cooled down to 18°C by means of drinking water. The heated-up drinking water was returned to the sewer system.

The amount of drinking water wasted is 48,000 to 55,000 m³ per year, or in terms of waste heat 1170 MWh per year.



Photo 1: Recreation Hotel Bärenhof (foreground).

One of the hotels, the recreation hotel Bärenhof (see Photo 1) has recently been renovated and expanded. The hotel consists of 90 apartments, three small flats, a hospital station, therapeutic baths, a swimming hall, and gymnastic facilities. The interior volume is 12,400 m³.

To minimize the pollution of this recreation area and to reduce operating costs, a concept for utilization of waste heat from thermal water, ventilation air and waste water has been applied.

Final Heat Supply

The newly constructed part of the hotel is equipped with a low-temperature floor heating system and a ventilation system.

The first approach in system design is to utilize heat sources directly by means of heat exchangers: the heat source for the floor heating system is the water, which is cooled down from 43°C to about 30°C by means of heat exchangers. The fresh air is preheated by means of heat exchangers and again thermal water.

Heating of the old building stock as well as the final heating of the ventilation air and hot water production is carried out by a heat pump with a thermal capacity of 130 kW (Photo 2). The thermal water at a temperature of 30°C serves as the heat source and is cooled down to about 13°C. The heat pump heats water to 50°C - sufficient for space heating, final heating of the inlet air and hot water production.

To overcome control problems of the floor heating systems and to improve comfort, resistance heating panels were installed. A digital control system avoids peak load demand.

Results

With this concept it was possible to reduce the energy demand for heating and hot water production to 24% of the demand of a conventional system (see Figure 1). Of this energy demand (mainly electricity) 18% is consumed by the heat pump, 2% for final heating of hot water and 4% for heating panels.

The remaining 76% of the energy demand is covered by free energy, resulting from direct utilization of the thermal water - 24% of the energy - as well as indirect utilization by means of the heat pump - 52% of the energy required.

Future Prospects

The main heat supply for Bad Gastein is district heating with an oil-fired heating plant. The district heating network is sized for a supply temperature of 110°C and a return temperature of 60°C. The installed boiler capacity is 29.5 MW, the capacity requirement for hot tap water is 2.74 MW. The annual oil consumption of about 4000 tonnes delivers about 40,000 MW heat.

The total potential of waste heat from thermal water is about 5 MW, of which for Bad Gastein about 4 MW are available. The possible heating capacity of a heat pump with a COP of 2.8 would be more than 6.2 MW. This means that a large part of the required heat presently delivered by oil-fired boilers could be provided by means of heat pumps.

The high temperatures required by the existing district heating network limit heat pump operation. Four units sized for hot water production and base-load heating with a total heat output of 3.732 MW and a power

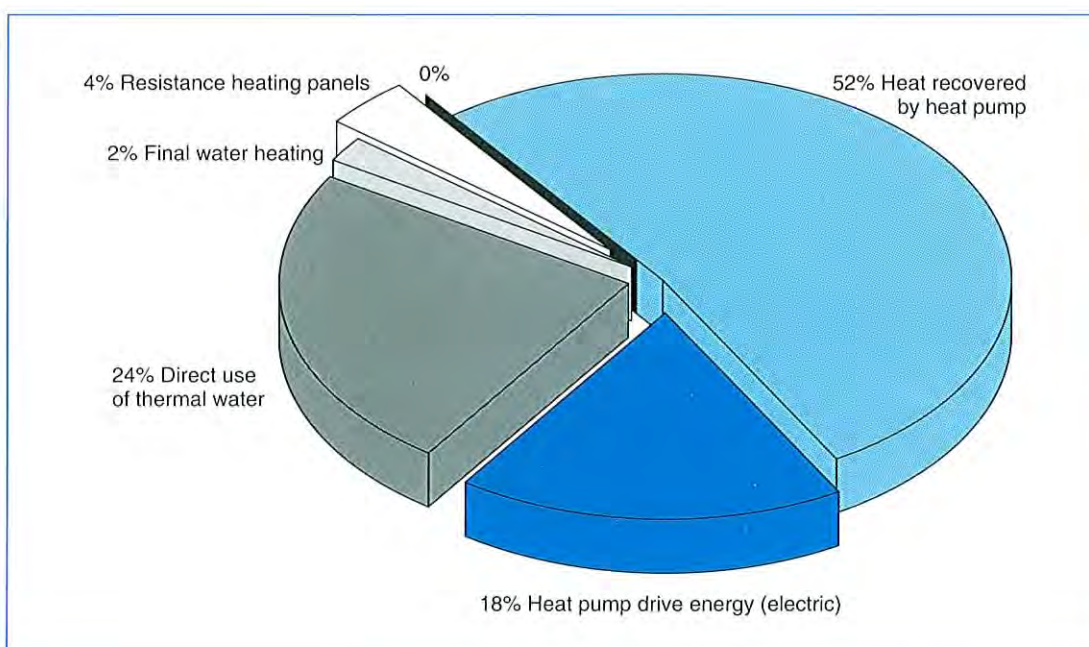


Figure 1: Energy consumption of the Bärenhof system.

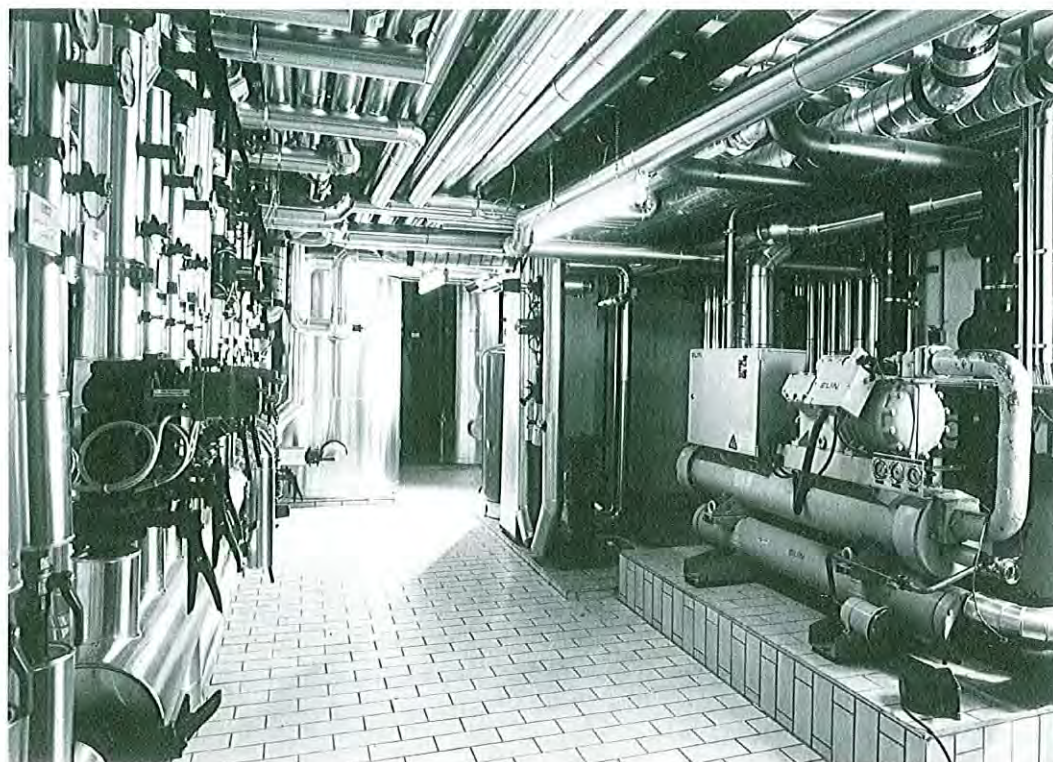


Photo 2: Heat pump unit.

requirement of 1.333 MW can cover the heating and hot tap water demand down to an outside temperature of -4°C . This means that about 50% of the total heating demand can be covered by heat pumps. During summer the heat delivery by the heat pumps would be 4936 MWh, during the heating season 14,394 MWh.

The cost for heat delivery of the oil-fired district heating plant is presently 0.8 AS/kWh (1 US\$ = 11.9 Austrian schillings [AS]); the cost of heat delivery by means of heat pumps would be 0.38 AS/kWh based on a 10 year payback time and a special tariff for electricity offered by the electric utility SAFE of Salzburg.

This means a remarkable cost reduction, but it also means a reduction of emissions caused by the oil-fired plant by about 50%. In a vacation and recreation area, this may be more important than the cost reduction. However, it is a project for the future as, the oil company currently operating the district heating plant refuses to accept the heat pump.

Projects such as this demonstrate how the intelligent use of available heat sources by heat exchangers and electric heat pumps can make significant energy savings. Furthermore, the reduction in fossil fuel use contributes to lower emissions of CO_2 and other greenhouse gases. But the realization of such sophisticated systems can only be achieved if reliable and readily understood information is available to assist the prospective planner, designer, installer and purchaser.

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Advantages of Combining Heat Pumps with Radiant Panel Heating and Cooling Systems

Ibrahim Kilis, USA and Turkey

For space heating and cooling purposes, heat pumps are becoming a key element in energy conservation and protection of the environment. Their performance, however, may be adversely affected by the temperature requirement of conventional space conditioning equipment such as forced-air or high-temperature hydronic heat distribution systems.

Radiant panel heating systems use underfloor or ceiling-mounted water distribution to supply heat or cooling. Underfloor heating reduces heat demand by providing comfortable conditions at a lower temperature. Furthermore, by operating at a much lower water supply temperature than conventional hydronic systems, it allows heat pumps to meet heat demand at lower outside temperatures. This reduces or eliminates the need for a supplementary boiler and improves efficiency (COP). Ceiling-mounted radiant panels offer similar advantages for cooling.

Usually, a high-temperature hydronic heating system is designed for 80°C mean water temperature. In cooling, the chilled water mean temperature is about 10°C. According to the basic nature of radiant panel systems, their temperature requirements in heating and cooling are very moderate and can be easily suited to the heat pump characteristics. The mean water temperature (T_w) requirement may be just 35°C for heating, and up to 18°C for cooling. In order to demonstrate the attributes of radiant panel systems, an air-to-water (AWHP), a ground-source (GSHP) and a solar-assisted absorption heat pump are analyzed in this article.

Air-to-Water

Figure 1 depicts the heating characteristics of an air-to-water heat pump serving a central heating system with radiators. A boiler supplements the heat pump in either parallel or tandem configuration below the equilibrium temperature (T_E) and takes over at the shut-down temperature (T_{SD}) when the heat pump is forced to switch off. Shut-down occurs when one of the following additional constraints, imposed by the hydronic heating system occurs:

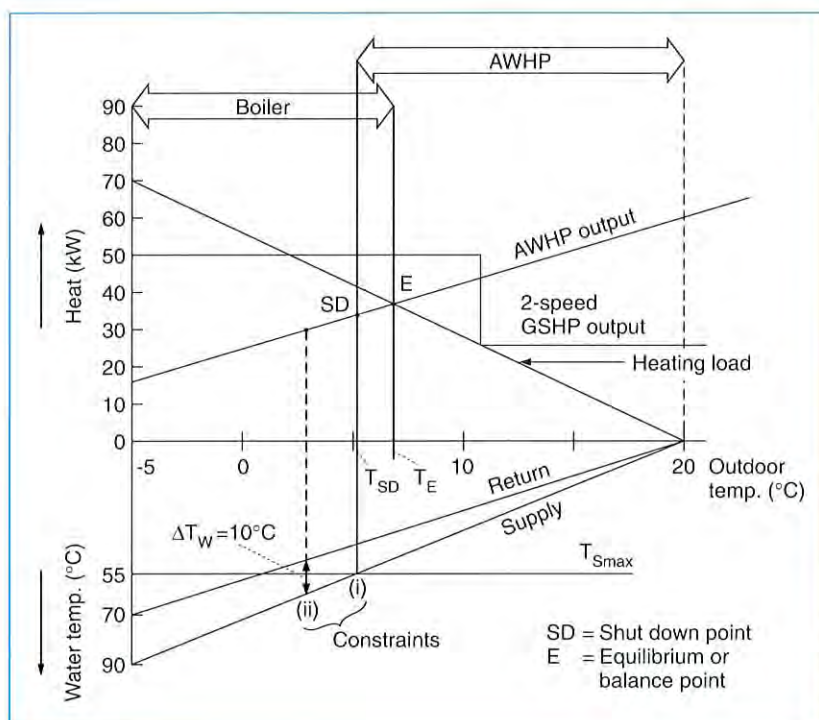
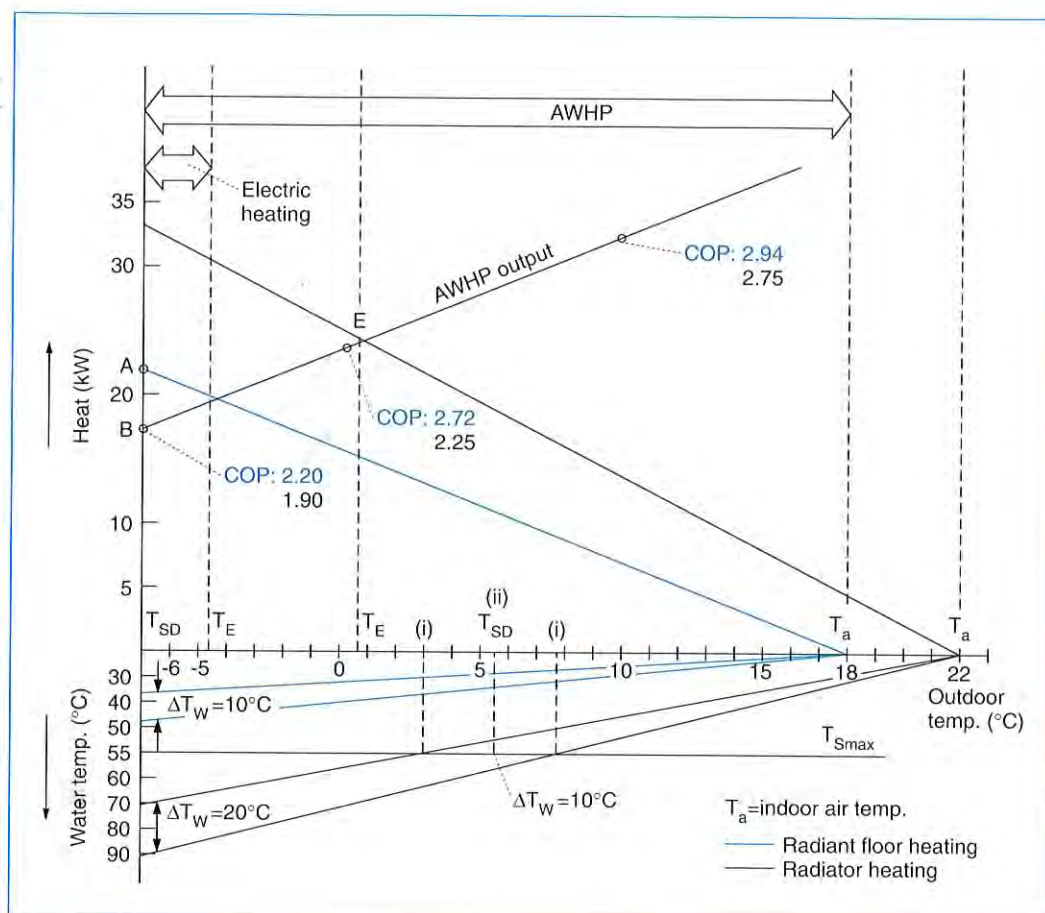


Figure 1: Characteristics of an air-to-water heat pump with conventional hydronic heating.

Figure 2: Radiant panels enable improved performance of an air-to-water heat pump.



- (i) The maximum water temperature that can be delivered by a heat pump (T_{smax}) is exceeded.
- (ii) The condenser side water temperature drop (ΔT_w) is exceeded.

T_{smax} is generally 55°C and in parallel mode operation (illustrated in Figure 1) corresponds with the supply temperature and occurs at +5°C outside temperature [point (i)]. In tandem mode, T_{smax} corresponds with the return water temperature. ΔT_w is generally limited to 10°C whereas a radiator heating system is normally designed for 20°C (maximum load), unless the circulation pump is oversized. Constraint (ii) can thus be effective in parallel mode operation. In this illustration, constraint (i) occurs first as the outdoor air temperature reduces, and determines the Shut-Down Point (SD). In parallel mode, T_{SD} is +5°C. In tandem mode, it is +1°C. In order to avoid an early shut-down, heat pump sizing must also satisfy the condition $T_E > T_{SD}$.

Ground-source

The heating capacity of a ground-source heat pump is virtually free from the effects of the outdoor temperature. However, a GSHP will also benefit from a radiant panel heating system. In order to follow the heat load line closely, a multiple-speed heat pump may be desirable, as shown in Figure 1.

Advantages

A radiant panel heating system has several attributes which will improve the performance and cost-effectiveness of a heat pump:

Low Supply Temperature

The design and operation of a radiant panel ensures that the supply water temperature does not exceed 55°C by using large radiant panel surfaces to deliver the required heat. This low temperature makes it more practical to use a 10°C temperature drop at design conditions. These factors will eliminate constraints (i) and (ii), and consequently T_{SD} . Therefore, the $T_E > T_{SD}$ condition will be automatically satisfied which consequently enables a free choice of any optimum heat pump size. As a result, if other conditions are also satisfied, elimination of the supplementary boiler is possible.

The low supply temperature also enhances the heat pump COP.

Reduced Load

It has been shown that with radiant panels, the indoor air temperature may be 2 to 3°C lower than with conventional heating systems, without any sacrifice of

the desired human comfort [1]. This moves the lower end of the load line in Figure 1 to the left and also reduces heat transmission losses. In addition, a more uniform indoor air temperature and pressure distribution, and a slow air movement contribute to reduced natural infiltration heat losses. Heat (or cool) storage in the panel and the exposed walls and partitions allows peak load shaving of the heating or cooling loads. This enables the heat pump to be sized according to the levelled load instead of the peak load. This overall reduction of the heating load shifts the upper end of the load line downwards. The net result is that T_e moves towards the origin and a deficit in heat delivered by the heat pump is minimized. Consequently the need for a supplementary boiler is either minimized or eliminated for a given heat pump capacity.

The combined effect of these attributes are shown in Figure 2 and illustrated in "Case Study 1". The above attributes also hold true when the heat pump is used for sensible cooling with radiant cooling panels. However, the need for handling the latent cooling load is also important. This can be satisfied by splitting the cooling output to the panel circuit and a small air handler in appropriate and possibly variable proportions. Technically this means a hybrid system, but generally it proves to be economically feasible [2].

Solar Absorption Cooling

Radiant ceiling cooling with solar energy is already an option, at least in technical terms [3]. A typical set up for a water-ammonia absorption heat pump is shown in Figure 3. The most important variable is the temperature of the generator (T_{ge}). This temperature directly affects both the heating and cooling COP. The optimum generator temperature however, depends

on the temperature of the chilled water required by the cooling system on the evaporator side (T_{ev}): if the radiant panel cooling system permits an increase in T_{ev} , the COP increases, and the optimum T_{ge} decreases which improves the solar collector efficiency. Figure 4 illustrates these characteristics.

As an example, the effect of increasing T_{ev} is illustrated below for an absorber temperature (T_{ab}) of 30°C, and a condenser temperature of 28°C:

- T_{ev} increases from 7°C to 10°C
- cooling COP increases from 0.68 to 0.76
- optimum T_{ge} drops from 70°C to 65°C.

The overall improvement will be even better if the evaporator temperature can be increased above 10°C, which is quite possible at the expense of reducing the tube spacing in the cooling panels. This is shown in the second case study.

Case Study One

A two story home has a conventional heating load of 33.6 kW at a design outdoor temperature of -7°C. The standard indoor design temperature is 22°C for a radiator heating system. For radiant floor heating, the peak load shaving factor is 0.88 for the given climate and building construction type [1] and for an equivalent thermal comfort, the indoor air temperature needs to be 18°C. The adjusted heating load with peak load shaving is 22.2 kW. The heated floor is a concrete slab with a carpet (thermal resistance of the floor covering is 0.043 m²K/W). Heat is supplied by a rubber hose of 9.5 mm inner diameter and 16 mm outer diameter at 200 mm centre-to-centre spacing. Figure 2 compares this system with a conventional hydronic heating system.

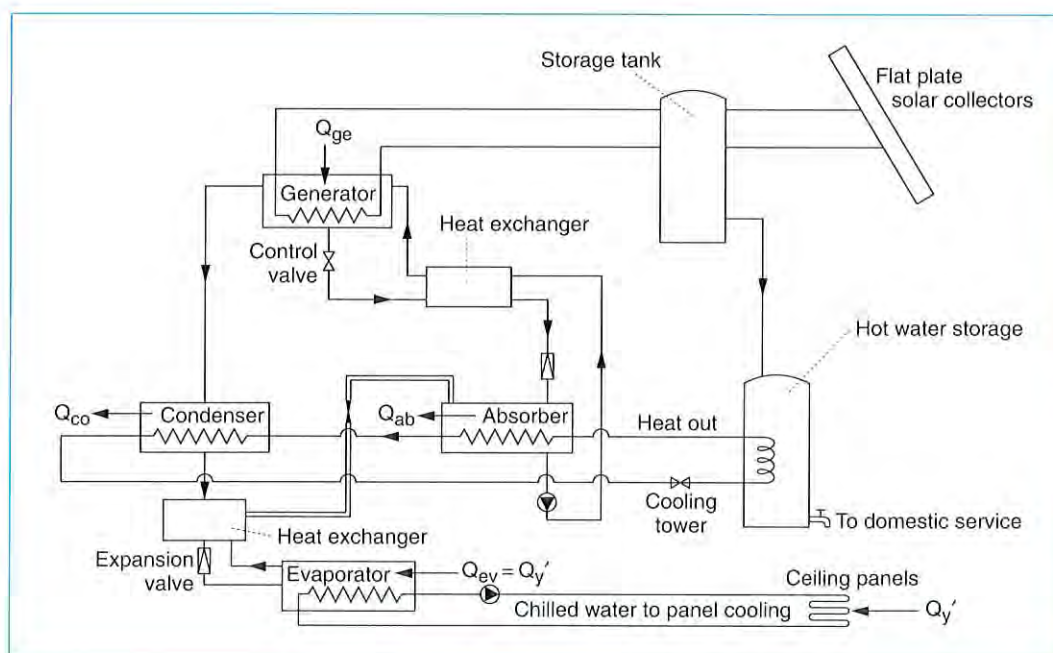


Figure 3: Solar absorption cycle radiant panel cooling system.

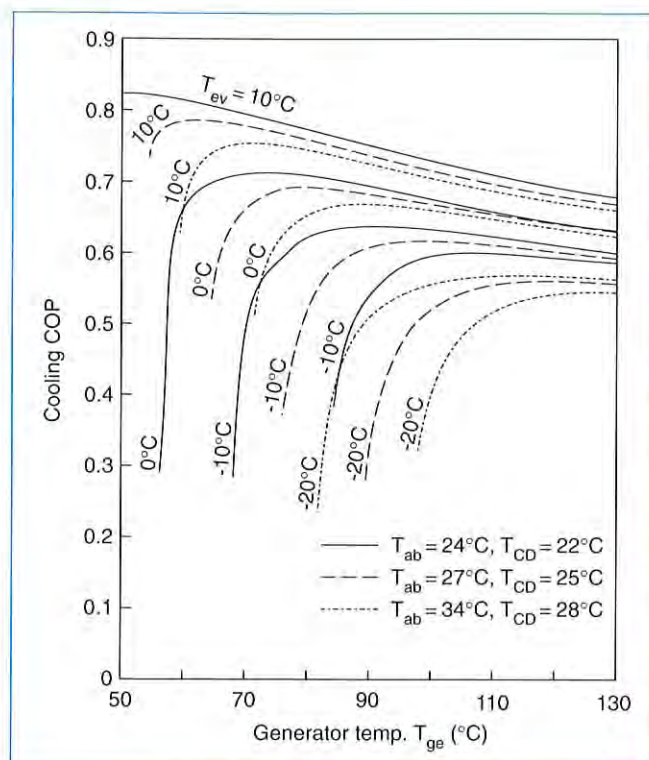


Figure 4: Change of cooling COP with generator and evaporator temperatures [4].

A computer program, developed for the design and analysis of radiant panel systems, set the mean water supply temperature (T_w) at 42°C at design conditions. In order to minimize costs, an air-to-water heat pump was selected with a heating capacity of 19 kW (Point B on Figure 2). Its cut-off point (T_c) is at -7°C when its capacity is only 3 kW less than the design load. This can be easily supplemented by an electric heater rather than a boiler. Of course, the electric heater can be eliminated if a larger heat pump is selected.

If a conventional hydronic heating system were used, the equilibrium temperature (T_e) would be +1°C and the supplementary boiler requirement 11.4 kW (33.6 - 22.2), unless a much bigger heat pump is installed. The theoretical COP of the heat pump at design conditions would be 1.9 instead of 2.20 and the radiator system would force the heat pump to be shut-down at +3°C (tandem mode) due to constraint (i). This means that the supplementary boiler will be required more frequently.

Case Study Two

The second floor is to be cooled in summer. Although the same air-to-water heat can be employed, a separate solar absorption heat pump is used for demonstration purposes. With extra ceiling insulation, the sensible cooling load is 4.9 kW. With design provisions such as peak load shaving, the design cooling load for the cooling panel is 3.0 kW. Indoor relative humidity is maintained at 0.35 by a hybrid system and the indoor air temperature is 24°C. Rubber

hosing with 10 mm inner diameter and 100 mm centre-to-centre spacing is laid in concrete ceiling slabs. Under design conditions, T_w is 18°C while the ceiling surface temperature is maintained at 20°C. This moderate temperature requirement increases the cooling COP and solar collector efficiency.

Compared with a conventional fan coil cooling system for the same sensible cooling load, the system offers several improvements:

- COP is 0.83 instead of 0.68;
- flat plate collector efficiency is 0.72 instead of 0.65;
- generator temperature is 50°C instead of 70°C.

Meeting Key Objectives

Nearly one-in-three new single-family homes built in the United States today are equipped with an electric heat pump for heating and cooling. In addition to this, an increasing number of existing homes are being retrofitted with heat pumps. If air-to-water type heat pumps operate with radiant floor heating systems, the elimination of supplementary boilers can be easily realized. This is one of the key objectives in the quest towards greater energy efficiency. As well as applications in new buildings, radiant floor heating can also be a retrofit alternative for existing ones, because with thin slab or under sub-floor type applications, retrofitting is relatively easy and cheap.

Acknowledgement

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Geothermal District Heating and Cooling

Heat Pumps Make Optimal Use of Renewable Energy

Paolo Leoni, Italy

The discovery of a large low-enthalpy geothermal water reservoir under the city of Vicenza in Northern Italy through an oil prospecting venture, opened up the opportunity to install a district heating system with low energy consumption. Although the geothermal water is at 67°C, this is insufficient for heating the city's

commercial and residential buildings using their existing high-temperature heat distribution systems. Heat pumps are therefore used to obtain optimum useful heat energy from the geothermal source. Experience so far suggests that the system can reduce energy consumption by up to 60%, or 3885 MWh/year.

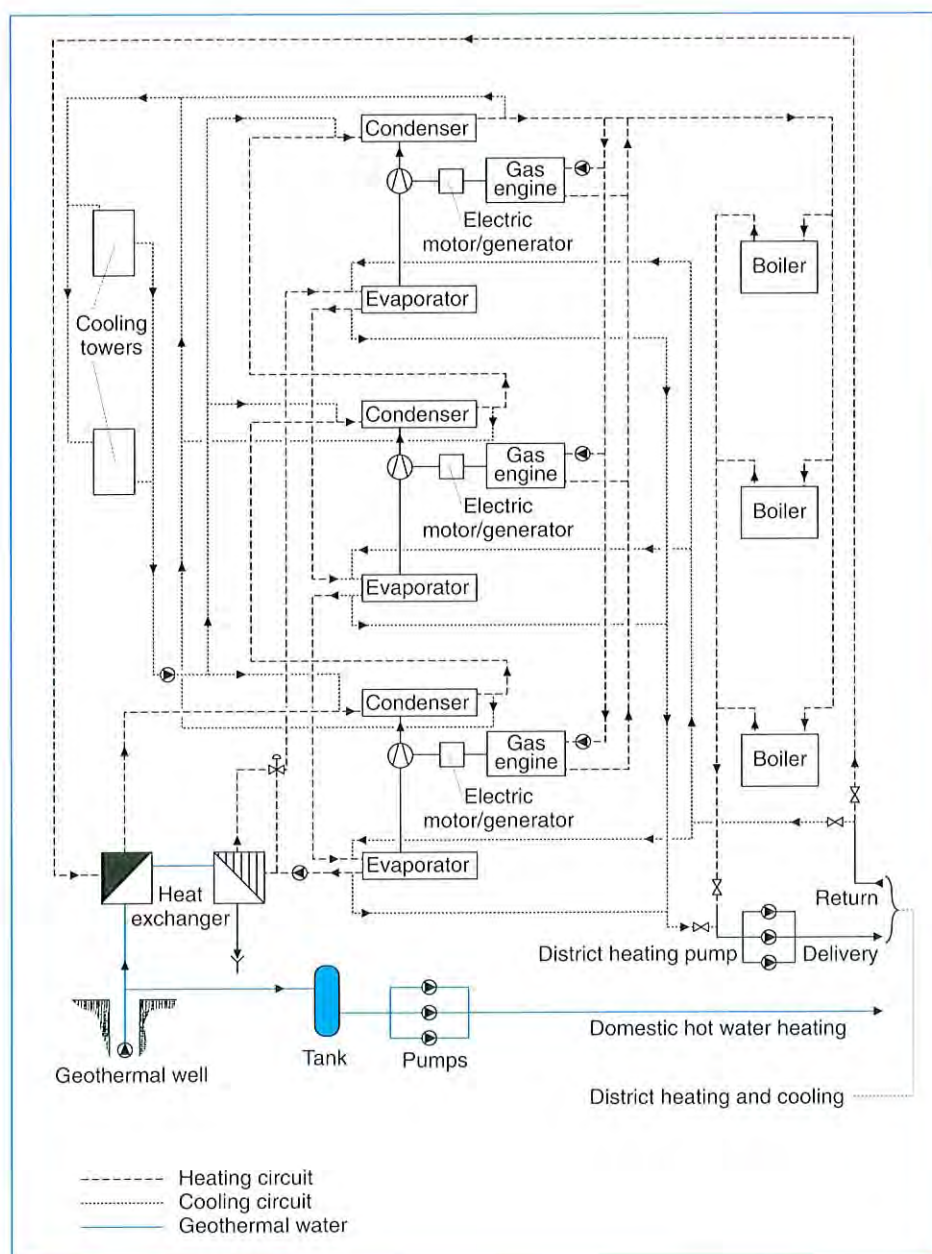
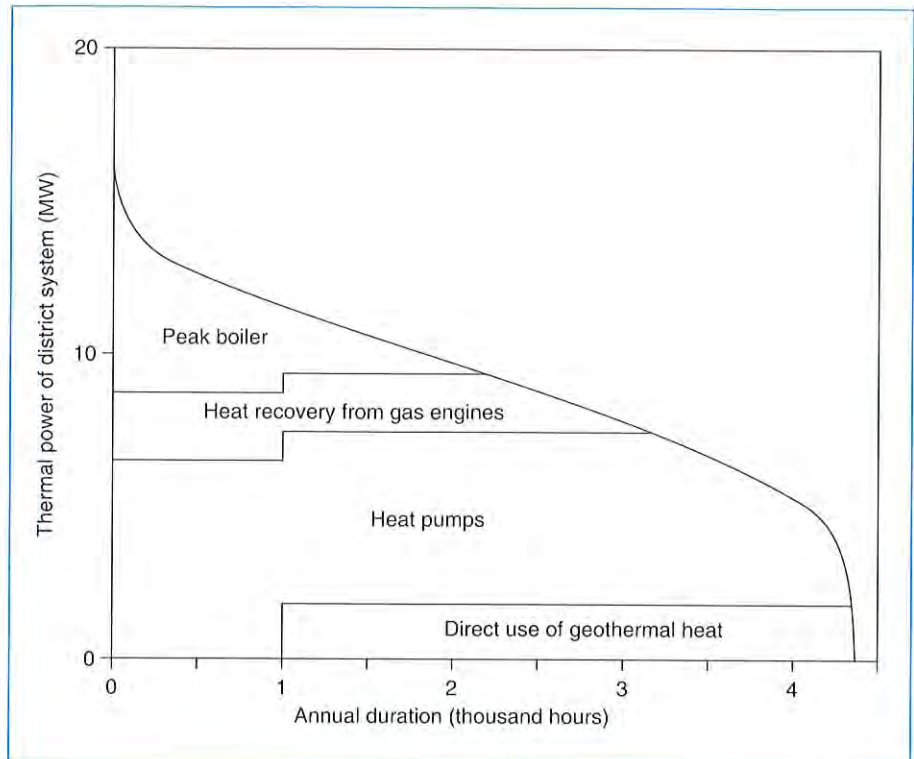


Figure 1: Simplified diagram of the heating and cooling plant.

Figure 2: Heat duration curve of the district heating system.



The 2000 m deep well was completed in 1983 and is the first such well in Italy to be located within an urban area, making it ideal as a heat source for a district heating system. It produces 100 m³/h of low salt-content water.

The "Vicenza" geothermal heating and cooling project was developed by "Aziende Industriali Municipalizzate", a utilities company owned by the city of Vicenza, with the purpose of distributing approximately 40 MWh per year to residential and commercial buildings.

The project includes the installation of a power plant and a district heating and cooling network. A reduction in the consumption of conventional fuels both for heating and sanitary water has been achieved through a highly-efficient thermodynamic system based on reversible heat pumps. The system provides heating in the winter and air conditioning in summer.

Network

The end-users are connected to the plant by a 7400 m long double (supply and return) pipe network, for both heating and cooling, and by a 6000 m supplementary single-line network for domestic water heating. The two lines run parallel. Thermal exchange with the building water distribution systems takes place at 95 substations located at commercial and residential sites.

Domestic Hot Water

With a constant temperature of 67°C, geothermal water from the "Vicenza 1" well is compatible with the requirements for hot sanitary water. A piping network supplies geothermal water to the user where domestic water is heated via a heat exchanger. The geothermal water has less than 0.5 g/l salt and less than 1g/l hydrogen sulphide, and may be safely discharged into the sewage system. It is envisaged that geothermal water will be used directly, once corrosion problems have been resolved.

Heating

For heating purposes, 67°C water is not warm enough, since the existing heat distribution systems in buildings require temperatures of up to 90°C. A system of heat pumps and boilers is therefore required (see Figure 1).

Three water-to-water heat pumps supply 6.5 MW heat and are installed next to the well and may be driven electrically or by gas-engines. The evaporators and condensers are connected in series in such a way that the temperature lift in each heat pump is minimum so the energy efficiency is maximum (Lorenz). An extra 2.3 MW heat is recovered from the gas engines. Three gas boilers, with a total heat output of 17.4 MW, deliver additional heat and provide a back-up facility.

Thermal power	
Heat pumps	6.5 MW (heating) 2.9 MW (cooling)
Gas engine heat recovery	2.3 MW
Gas-fired boilers	17.4 MW
Total	26.2 MW
Annual heat supply	
Heating	39.9 MWh
Domestic hot water	6.4 MWh
District heating and cooling temperatures	
Peak-level heating	90/65 °C
Low-level heating	75/50 °C
Cooling	6/12 °C
Geothermal storage tank capacity	200 m ³

Table 1: Technical data.

The district heating and cooling system has two modes of heating operation. In peak-level operation, the supply and return temperatures are 90 and 65°C respectively and the heat supplied by the heat pumps must be topped up with heat recovered from the gas engines, and by the gas boilers. In low-level operation, the supply and return temperatures are reduced to 75 and 50°C respectively. Geothermal water may then be used to add heat directly to the return side of the district heating system. Figure 2 shows how heat demand is met over the heating season.

Cooling

The heat pumps winter output is balanced by the cooling energy required during the summer, mainly from a local hospital. Operating in reverse mode and in parallel configuration, the heat pumps supply the district heating and cooling network with water at 6°C and 12°C supply and return temperatures. The reversible heat pumps allow for an extended operation schedule of the system, with related economic benefits. Table 1 summarizes the principal technical features of the plant design.

Economics

The total investment costs came to about 16,000 million Italian lira (ITL) (US\$ 9.6 million) which can be broken down as:

- ITL 8400 million for the heating/cooling plant;
- ITL 4300 million for the distribution network;
- ITL 3300 million for the sub-stations.

Successful Experience

The system went into operation in 1992. During the first year the most difficult aspect in the operation of the system was related to the necessity of fine tuning the heat pumps because of the different operating conditions in the summer and winter months.

The energy supplied by the heat pumps, including that recovered from the gas engines, amounts to 70% of the total heating demand. In peak-level operation (90/65°C supply/return temperatures), the Primary Energy Ratio of the complete system is about 1.85. This includes the consumption of the gas-engine heat pumps and the gas boilers.

Based on average operation conditions, the energy consumption has been compared with that of the previous system of individual gas and oil-fired boilers. With electric heat pumps and gas boilers, overall savings are estimated at 50% or 2850 MWh/year. If the heat pumps are gas driven, then the savings are estimated to rise to 60% or 3885 MWh/year.

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Heat Pumps as an Energy Efficiency Tool

Where Does CADDET Fit In?

Stefan Jakélius, CADDET Energy Efficiency Centre, the Netherlands

With so many innovative energy-saving technologies being applied - with varied degrees of success - it is important that the lessons learned from these pioneering projects are made available to a wide international audience. By providing information on demonstration projects, CADDET plays a significant role in meeting this need.

* * *

The Energy Efficiency branch of CADDET (Centre for the Analysis and Dissemination of Demonstrated Energy Technologies) is an IEA information centre located in the same building as the Heat Pump Centre in the Netherlands. Its objective is to enhance the exchange of information on new energy-saving technologies that have been demonstrated in applications in buildings, industry, transport, utilities and agriculture. The information is not only disseminated and used to promote the use of energy-saving technologies by all consumers of energy, but also analyzed for better understanding of the technologies.

Energy savings not only result in cost savings for the user but also reduce the world's claim on the finite quantity of available resources. Better heat integration and the use of energy-saving appliances such as heat pumps in the residential, commercial and industrial sectors can result in a considerable reduction in energy consumption. Demonstration projects covered by the CADDET programme include a wide range of heat pump technologies.

Database

Information on demonstration projects, supplied by 15 National Teams, is examined and compiled at the CADDET Centre and entered into the Register - a database containing information on international energy-saving demonstration projects. Currently the Register includes about 200 heat pump demonstration projects.

Publications

About 30 technical brochures and two analysis reports on heat pump technology have been published by CADDET. A technical brochure describes individual demonstration projects, highlighting significant technical advances and giving energy and economic

Some heat pump related reports published by CADDET:

Analysis Reports

- No. 2: Learning from experiences with Heat Transformers in Industrial Processes.
- No. 3: Learning from experiences with New Technologies for Heating and Cooling Supply in Office Buildings.

Workshop Proceedings

Process Integration - International experiences and future opportunities.



data. Analysis reports present findings from technical and economic analyses on demonstrated end-use energy technologies. Heat pumps and heat pump applications are also frequently addressed and discussed in CADDET's quarterly Newsletter which presents articles on energy efficiency projects together with more general energy information.

Heat Pump Technologies

Examples of heat pump technologies CADDET has covered since its start in 1988 are: ventilation-air heat pumps, heat transformers, solar-assisted heat pumps, absorption heat pumps, ground-source heat pumps, reversible systems, chemical heat pumps and thermal storage.

For further information regarding the CADDET programme, or our products in the field of heat pumps, please contact:

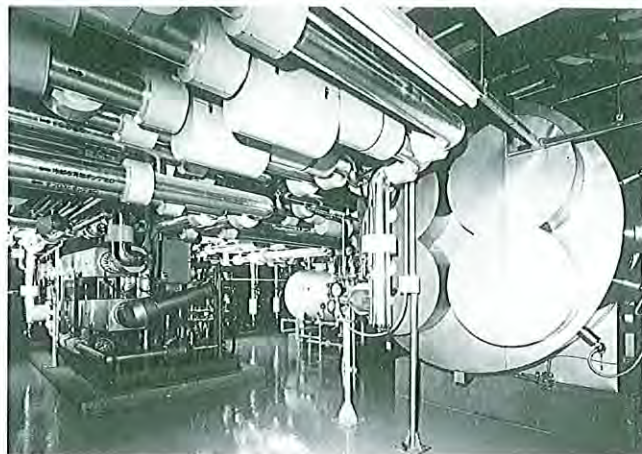
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Bibliography

Research and Development on Super Heat Pump Energy Accumulation System

Final Report from NEDO (New Energy and Industrial Technology Development Organization), Tokyo, Japan; June 1993; 382 pp (English).

The long-awaited results of this impressive project show that all the developed systems met or exceeded the ambitious COP targets set in 1984. For example, a 2.4 MW pilot heat pump demonstrated a COP of 8.2 for heat source and sink temperatures of 35 and 65°C respectively. The photograph shows a 200 kW (heat output) super heat pump in combination with a 838 MJ (200 MCal) clathrate storage tank which is used to supply a space conditioning system at the Kyushu Electric Power Co. This demonstrated a daily average total heating efficiency of 5.0 (based on the heat output and the electricity supplied for storage and heat discharged). Results such as this led to the conceptual design of the district heating and cooling plant shown on the front cover of this *Newsletter*. Copies of this report are available free-of-charge from the IEA Heat Pump Centre.



A 200 kW super heat pump with clathrate storage.

Heat Pump Water Heaters

Workshop Proceedings from the IEA Heat Pump Centre; Order No: HPC-WR12; December 1993; 190 pp (English); Price: 60 Dutch Guilders.

Held from June 30 - July 2 at Breckenridge, Colorado, USA, this workshop was organized as a follow up to our Analysis Report published in April 1993. With the aim of developing a shared strategy for increasing the use of domestic hot water heat pumps, experts from three continents exchanged their technology and marketing experiences on hot water heat pumps. Presentations covered applications in both residential and commercial areas including ventilation-air heat recovery, integrated space conditioning and water heating, and testing and rating procedures. The HPC co-sponsored this workshop with the US Department of Energy and the Electric Power Research Institute.

Heat Recovery Heat Pump Operating Experiences

Report RP-656 from the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), United States; Fax: +1-404-321-5478; Prepared by Caneta Research, Ontario, Canada; 90 pp (English); Price: US\$ 20.

An investigation of 22 sites and eight commercial/institutional buildings in North America reported that experiences with heat recovery heat pumps (HRHPs) were generally positive. Nine sites reported having neither equipment nor design problems with their installation. In

the other sites, prior chemical analysis, proper materials selection and site process evaluation studies could have avoided many of the problems encountered. Interestingly, while many HRHP system sites reported payback periods of five years or less, only half of them cited energy savings as the primary reason for installing an HRHP.

Process Integration - International Experiences and Future Opportunities

Workshop Proceedings from IEA CADDET, the Netherlands; Fax: +31-46-510389; ISBN 90-72647-03-3; 1993; 365 pp (English); Price on request.

Held in January 1992, this two-day workshop included presentations on developments in process integration methodologies along with reports of application experiences in industry. The presentations demonstrated that substantial energy savings can be made by optimizing the use of technologies such as heat exchangers, heat pumps and combined heat and power. It also showed the need for increased R&D and for better dissemination of results and experiences.

Results from ARI's R-22 Alternative Refrigerants Evaluation Program - Volumes 1 & 2:

"Compressor Calorimeter and System Drop-in Test Reports"

Air-Conditioning and Refrigeration Institute (ARI), United States; Fax: +1-703-528-381; 1993; (English); Price: US\$ 250.

Includes 56 reports on compressor calorimeter and system drop-in tests. Purchasers will automatically receive reports on all future tests in this category, free-of-charge.

Conferences

**Call for Papers*

International Absorption Heat Pump Conference '94

January 19-21, 1994 / New Orleans, Louisiana (USA)
Contact: IAHP '94 Conference Secretary, Mechanical Engineering Dep't, University of Maryland, College Park, Maryland 20742-3035, USA. Fax: +1-301-314-9477.

1994 Winter ASHRAE Meeting and Exhibition

January 22 - 26, 1994 / New Orleans, Louisiana (USA)
Contact: ASHRAE Meetings Department, 1791 Tullie Circle, NE Atlanta, GA 30329, USA.
Tel: +1-404-636-8400; Fax: +1-404-321-5478.

Cold Climate HVAC '94

March 15-18, 1994 / Rovaniemi (Finland)
Organized by the Federation of Societies of Heating, Air-Conditioning and Sanitary Engineers in Finland (FINVAC).
Contact: FINVAC/Cold Climate HVAC '94, Mr Ilpo Nousiainen, Sitratori 5, SF-00420 Helsinki, Finland.
Tel: +358-0-563-3600; Fax: +358-0-566-5093.

AIRAH 1994 International Conference and Exhibition

April 15-18, 1994 / Gold Coast, Queensland (Australia)
Organized by the Australian Institute of Refrigeration, Air Conditioning and Heating
Contact: Conference Manager, 191 Royal Parade, Parkville VIC 3052, Australia.
Tel: +61-3-347-4777; Fax: +61-3-347-8571

New Applications of Natural Fluids in Refrigeration and Air Conditioning

May 10-13, 1994 / Hannover (Germany)
(IIR Commission B2)
Contact: Prof. Kruse, University of Hannover, Welfengarten 1A, 3000 Hannover 1, Germany.

Annual Conference of the International District Heating and Cooling Association (IDHCA)

June 18-22, 1994 / Seattle, WA (USA)
Contact: Ms. C. Millunzi IDHCA, 1101 Connecticut Ave. N.W., Suite 700, Washington D.C., 20036.

International Refrigeration Conference

International Compressor Engineering Conference

July 19-22, 1994 / Purdue University (USA)
Contact: Phyllis Hurst, Conference Secretary, Purdue University, 1077 Ray W. Herrick Laboratories, West Lafayette, IN 47907-1077, USA.
Tel: +1-317-494-0117; Fax: +1-317-494-0787

Calorstock '94

6th International Conference on Thermal Energy Storage

August 22-25, 1994 / Otaniemi, Espoo (Finland)
Contact: Mr Markku Kangas, Helsinki University of Technology, Department of Technical Physics, Otakaari 3, 02150 Espoo, Finland. Fax: +358-0-451-3195.

***CFCs - The Day After**

(IIR Commissions B1, B2, E1 and E2)

September 21-23, 1994 / Padua (Italy)
Deadline for abstracts: January 31, 1994.
Contact: Organizing Committee, IIR-AICARR Conference, c/o AICARR - viale Monte Grappa, 2, I-20124 Milano MI, Italy.
Fax: +39-2-2900-0004.

***49th National Congress of the Italian Thermotechnical Association**

September 26-30, 1994 / Perugia (Italy)
Deadline for abstracts: January 31, 1994
Contact (for heat pump topics): Eng. Carlo Nazareno Grimaldi, Istituto di Energetica, Str. S. Lucia-Canetola, 06125 Perugia, Italy. Tel: +39-75-5852735.

***15th AIVC Conference - The Role of Ventilation**

September 27-30, 1994 / Buxton, (United Kingdom)
Deadline for abstracts: February 5, 1994
Contact: Mrs Rhona Vickers, IEA Air Infiltration and Ventilation Centre, University of Warwick Science Park, Sovereign Court, Sir William Lyons Road, Coventry CV4 7EZ, UK. Tel: +44-203-692050; Fax: +44-203-416306.

Ground-Coupled Heat Pumps Symposium

October 17-19, 1994 / Giessen (Germany)
The symposium language is German.
Contact: Dr Burkhard Sanner, Institute for Applied Geosciences, University of Giessen, D-6300 Giessen, Germany.
Tel: +49-641-702-8248; Fax: +49-641-702-4711.

***19th International Congress of Refrigeration - For a Better Quality of Life**

August 20-25, 1995 / The Hague, (The Netherlands)
Organized by the International Institute of Refrigeration (IIR)
Contact: Dr R.W.A.W. Mulder, Scientific Committee 19th Congress IIR/IIF 1995, P.O. Box 15, 7360 AA Beekbergen, The Netherlands or Van Namen & Westerlaken Congress Organisation Services,
Tel: +31-80-234471; Fax: +31-80-601159



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Heat Pump Developments and Trends - An International Overview	No. 4, p. 11
Survey of Heat Pump R&D in the United States	No. 4, p. 18



Available from the HPC

<i>Title</i>	<i>Publication type</i>	<i>Order No.</i>	<i>Price (NLG)</i>
The Impact of Heat Pumps on the Greenhouse Effect	Analysis Report	HPC-AR1	80
Domestic Hot Water Heat Pumps in Residential and Commercial Buildings	Analysis Report	HPC-AR2	80
The Impact of Heat Pumps on the Greenhouse Effect	Workshop Proceedings	HPC-WR10	80
Heat Pumps and Thermal Storage	Workshop Proceedings	HPC-WR11	50
New! Heat Pump Water Heaters	Workshop Proceedings	HPC-WR12	60
Heat Pumps - An Opportunity for Reducing the Greenhouse Effect	Promotion Brochure	HPC-BR1	free
Heat Pumps - Better by Nature	Promotion Brochure	HPC-BR2	free
The IEA Heat Pump Programme	Promotion Brochure	B1-HPP	free
Heat Pumps to the Year 2000 - Strategy Plan	Promotion Brochure	B2-HPP	free
Research and Development on Super Heat Pump Energy Accumulation System	Final Report (NEDO, Japan)	--	free

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