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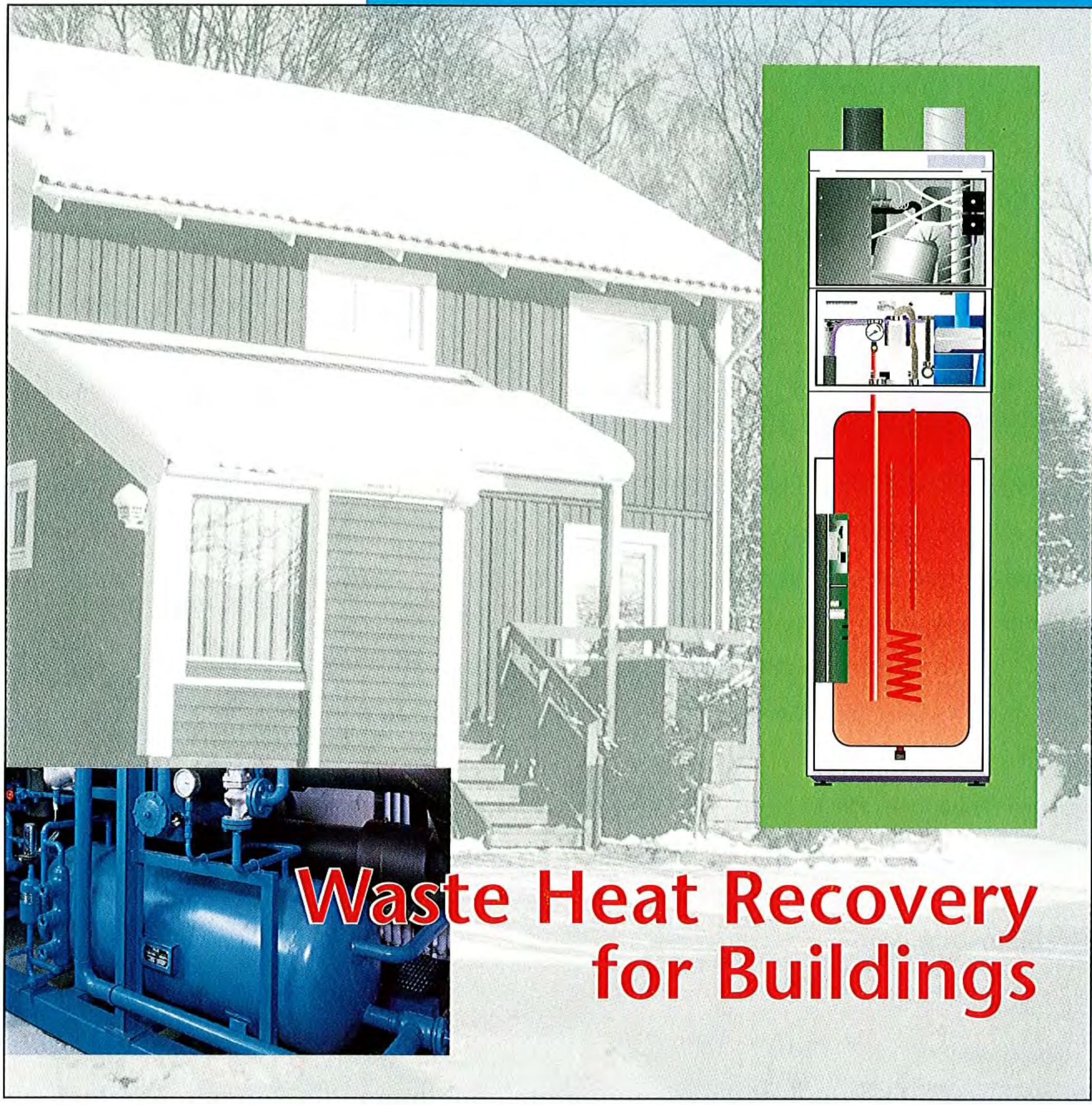
IEA Heat Pump Centre

NEWSLETTER



Waste Heat Recovery for Buildings

IEA
OECD
heat pump
centre

Contents

Front Cover: *There are many ways in which heat pumps can utilize waste heat to meet the heating needs of the home. The systems shown recover heat from ventilation air (right) and from power generation equipment (left). More details are given on pages 20 and 35.*

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 eight 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.

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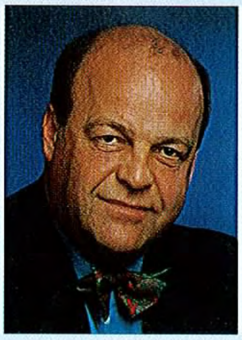
Not to be Wasted



From a heat pump manufacturer's point-of-view, I see waste heat recovery as a significant market opportunity for our products.

To efficiently provide low-temperature heat for space conditioning and hot water production, heat pumps need a heat source meeting the requirements of availability, a preferably high and constant temperature level and simple utilization. The natural heat sources such as outside air, ground and ground water often do not meet all these preconditions.

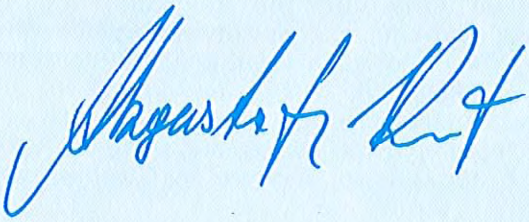
Many interesting projects, some of which are described in this Newsletter, have shown how heat pumps can utilize waste heat streams such as from sewage systems, industrial processes, power generators and cooling equipment. To be successful, such systems require careful design in order to meet the specific requirements of the situation.

A relatively easier source of waste heat is available inside the building itself. Ventilation air is required in every building, it has almost the same temperature during the whole year, and is relatively simple to apply in buildings with a duct system.

Swedish examples show that more than 50% of the annual heat demand for heating and hot water in residential buildings can be covered by the heat pump, and it is expected that in highly insulated buildings this rate can be increased to more than 70%.

Commercial buildings offer further opportunities for waste heat recovery when heating and cooling is needed at the same time. Hydronic systems - preferably two-pipe (water-loop) systems - can shift heat from one part of the building to another. By using this effect, commercial buildings can be heated by internal gains alone, down to outdoor temperatures as low as -5°C or lower.

Concerns over energy conservation and indoor air quality have created a trend towards increased ventilation in buildings. Those involved with heat pump technology should not waste this important opportunity for increasing the penetration of heat pumps in building applications.



Kurt Atzgerstorfer
ELIN-Anwendungs Ges.m.b.H., Linz, Austria

News & Views

NEDO begins Eco-Energy City project

New developments will revolutionize thermal energy supply

Japan - The New Energy & Industrial Technology Development Organization (NEDO) has begun the execution of an ambitious national project that will revolutionize the supply of heating and cooling in urban areas. The "Eco-Energy City Project" will develop technology to transport low-temperature waste heat from remote industrial areas for use in the provision of space conditioning and domestic hot water supply. This will require advancements in many different areas, including the heat pump field.

Under this project, which also goes under the name "Broad Area Energy Utilization Network System Project", some 36 R&D contracts will be implemented to make progress in a wide range of thermal technology, including the fields of recovery, transport, storage and systems. Central to the eventual realization of an "Eco-Energy City" will be the development of technologies for transporting heat over scores of kilometres.

Under consideration will be transport systems based on chemical reactions such as the decomposition of methanol. Heat pumps will also play a key role in supplying thermal energy at the temperatures needed.

The project will be 100% government funded at an estimated cost of JPY 50 billion (US$ 500 million) over eight years. The Heat Pump Technology Center of Japan (home of the Japanese National Team) is conducting a survey of advanced technologies for this project. More information on the Eco-Energy City Project is given in the article on page 32.

(Source: Japanese National Team)

Heat pumps can help curb ground-water usage

Netherlands - The use of ground-water in the Netherlands is causing concern. With some 250 million m^3 of ground water used annually by Dutch industries, water quality is deteriorating and in some parts of the country, water levels are dropping, causing the soil to dry out. The government has responded by restricting licences for ground-water usage and by taxing the used water. With 50% of ground-water usage being used for direct cooling purposes, heat pumps are being considered as a way of curbing ground-water usage.

At the "Ground-Water Congress" held on June 28, Mr Jan de Wit, of research organization TNO, gave a presentation on the application of heat pumps for cooling. The need to restrict ground-water usage is opening up new areas for heat pump applications, especially in the chemical and food industries. Emphasis was placed on the need to conduct process integration studies in order to define potential heat pump projects. Mr Onno Kleefkens, of the Dutch National Team, outlined the availability of government subsidies in support of heat pump installations.

The congress was jointly organized by the Netherlands Agency for Energy and the Environment (Novem), and Krachtwerktuigen - an association for the support of industry in energy and environmental matters. Alongside heat pumps, the congress also looked at the option of long-term cold storage in the ground.

(Source: Mr Jan van Buuren, News Correspondent for the Netherlands National Team; Fax: +31-2510-267400)

HCFC phase-out dates getting closer

Europe - Many European governments are discussing regulations on HCFCs, with a view to phasing them out more rapidly than has already been agreed under the Montreal Protocol. Germany, Sweden and Italy will ban the use of HCFCs in new equipment from the year 2000. This is well ahead of the phase-out date of 2015 agreed recently by the European Union, although the European parliament had been pressing for 2002.

Other countries considering bringing in early phase-out dates for HCFCs include Austria, Denmark and Switzerland. But restrictions on HCFCs in space conditioning already exist in some regions. For example, the German state of Lower Saxony allows the use of HCFC-22 for air-conditioning only with ministerial permission. And in Luxembourg, government permission is required for the use of HCFCs *and* HFCs in refrigeration systems exceeding a capacity of 10 kW.

(Sources: OzonAction from UNEP IE/PAC, March 1994 and H&V News (UK), March 1994)

Europe develops expert system

The European Commission's Concerted Action Group on Heat Pumps (the CAG) is producing an expert system for the selection of heat pumps in buildings. In producing this software for the CAG, UK laboratory, EA Technology, will draw extensively on their wide experiences in designing, installing and testing heat pumps for heating and cooling buildings.

The software will calculate space heating and hot water requirements, and space cooling needs as a function of outside temperature, building construction and use. It will identify the optimum heat sources and heat sinks available for the heat pump, and predict the likely installation and operating costs for the types of heat pump which could be used.

The CAG was set up in 1991 with the objective of ensuring that the results of European R&D in the field of heat pumps and related technologies are effectively transferred to potential users.

Other new activities of the CAG include conducting a pan-European market study on heat pumps and the production of a heat pump handbook. Another new activity is the publication of a newsletter on European heat pump activities.

(Source: Mr Ulf Rivenæs of the Norwegian National Team)

Manufacturer converts to R-407c

This heat pump poses no threat to the ozone layer.

Austria - For many manufacturers, phase out dates for HCFC-22 as far away as 2010 are a cause for concern. But for Austrian heat pump manufacturer Ochsner, the answer is already here. The company's ground-source heat pumps (both indirect and direct-expansion type) are now available with the chlorine-free working fluid R-407c - a mixture of HFC-32, HFC-125 and HFC-134a, sold under the trade name of Klea 66. The photograph shows a heat pump from the new range.

The company considers the non-flammable R-407c to be an ideal replacement for HCFC-22. With the use of flammable refrigerants forbidden in closed rooms under Austrian law, and with perceived difficulties with repairs and servicing, propane was not considered for use in Ochsner's current heat pump range. R-407c poses no threat to the ozone layer and offers further environmental protection by allowing the use of a biodegradable compressor oil. While it will continue to offer HCFC-22 heat pumps, Ochsner hopes that many of its environmentally minded customers will be willing to pay the higher price for its R-407c models.

(Source: Rudel Steinbauer Dagmar, Ochsner Wärmepumpen, Linz, Austria; Fax: +49-7434-5125)

ISO standard defines COP ratings

USA - ISO 13253 is the allotted number for an international standard titled "Ducted Air-Conditioners and Air-to-Air Heat Pumps - Testing and Rating for Performance". The new standard will be published in late 1994 or early 1995 now that approval has been granted by the International Organisation for Standardisation (ISO).

ISO 13253 establishes standard conditions for determining equipment COP. It does not, however, address seasonal energy efficiencies or part load performance.

Under the new standard, the heating COP is defined as the ratio of the heating capacity to the effective power input; and the cooling COP, or EER (energy-efficiency ratio), is defined as the ratio of the cooling capacity to the effective power input. All measurements must be made in SI units. Equipment rated under ISO 13253 must be tested at one or more of the conditions shown in Table 1.

Meanwhile, an international working group is continuing to work on the development of an ISO standard on water-to-air and brine-to-air heat pumps and has recommended the initiation of a new standard covering water-to-water and brine-to-water heat pumps.

(Source: Koldfax from the Air-Conditioning and Refrigeration Institute, April and July 1994)

Table 1: Test conditions for COP rating under ISO 13253.

	Outdoor temp. (°C)		Indoor temp. (°C)	
Condition	dry	wet	dry	wet
Heating				
High	7	6	20	15
Low	2	1	20	15
Extra low	-7	-8	20	15
Cooling				
Moderate (T_1)	35	24	27	19
Cool (T_2)	27	19	21	15
Hot (T_3)	46	24	29	19

Promotion programme shows signs of success

Switzerland - With heat pump sales in 1993 up 7% on 1992, despite the economic recession, the Swiss Heat Pump Promotion Programme can claim a measure of success. In 1993, a total of 2,300 heat pumps were sold, despite a 3% decline in the number of newly-built apartments. The upward trend is continuing in 1994.

Figure 1 shows the structure and main activities of the Swiss Heat Pump Promotion Programme. A number of measures have contributed to its success.

Marketing

Heat pumps are publicized by a professional marketing company at the "Heat Pump Information Centre" in Bern. One of the most powerful marketing instruments has been the organization of "open door days" which take place at an exemplary heat pump installation. These not only attract the attention of potential heat pump users, but can also be used to inform architects, engineers, designers, constructors, politicians and the media.

Quality assurance

The Heat Pump Test and Training Centre in Winterthur-Töss provides independent quality assurance for all heat pump equipment sold in Switzerland. Equally important is the provision of quality support for installations.

The current strategy is to define and distribute standard checklists and installation recommendations for installers and designers. In future, the Swiss Heat Pump Promotion Programme will recommend competent designers and installers who have the necessary experience and training.

Heat pump doctor

Once a heat pump is installed, its owners are served by a unique after-care service known as the "Heat Pump Doctor", which is financed by two electric utilities. Should their system not perform satisfactorily, they can call up a hot line and receive professional advice. The experience so far shows that the companies involved, such as installers and suppliers, quickly respond to the arrival of the heat pump doctor, and the problem is resolved without cost to the owner.

Training

A long-term aim is to improve training on heat pumps. One essential measure is to see that the heat pump heating system is taught in all schools for technicians and professionals of the building sector. Special courses are organized by the Swiss Heat Pump Promotion Programme.

Regulations

As in many other countries, special regulations for the use of ground water, ground-source systems, electricity and noise levels can be real barriers to heat pumps. A working group has been set up to harmonize regulations throughout Switzerland and to help potential heat pump users meet the necessary requirements.

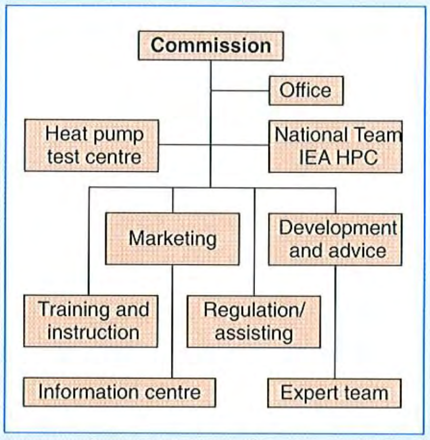


Figure 1: Structure of the Swiss Heat Pump Promotion Programme.

National Team

Finally, the close collaboration of the Heat Pump Promotion Programme with the National Team to the IEA Heat Pump Centre is an important factor for success. Worldwide coordination of research and development helps to optimize the use of research funds. And as the costs of heat pump systems are directly related to the costs of development work, international information and collaboration will yield more economic heat pump systems in the future.

(Source: Mr Dieter Wittwer, Swiss National Team)

Heat pump service costs average 0.6%

Norway - A contractor working in the Oslo area has provided a useful insight into the cost of servicing and maintaining heat pumps. The company deals with some 1500 heat pumps (average size 20 kW) and makes no charge during the first two years of operation. After that, the annual costs for servicing and maintenance ranges between 0.2 and 1% of the initial investment costs, with an average of 0.6%.

It is interesting to compare the operation of this contractor with a similar company servicing and maintaining oil burners in Oslo in the 1960s. Then, 12 people were required to deal with 1200 oil boilers. Today, 1500 heat pumps are handled by one person!

(Source: Mr Ulf Rivenæs, Norwegian National Team)

Technology and Applications

GSHP installations break all records

USA - Work has commenced on the world's largest installation of residential ground-source heat pumps (GSHPs). A total of 4,003 GSHPs are being installed in the homes of military personnel at the US Army's Fort Polk base in west central Louisiana. Beginning in July 1994, the GSHPs are being installed at a rate of 20 to 25 units per day!

Manufacturer ClimateMaster has developed the GSHPs especially for this project. They have a US EER rating of 15.4 (equivalent to a cooling SPF of 4.5) and will replace the existing air-source heat pumps which have been in service for 10 to 15 years.

As well as GSHPs, the homes are also being fitted with heat pump water heaters (desuperheaters) along with improved insulation, efficient lighting and low-flow shower heads. Tests have shown that the combination of these measures with the GSHPs will provide energy savings of up to 40% in some cases.

Financial savings from energy and maintenance costs are expected to exceed US$ 100 million over the coming 20 years. As to the environmental benefit, it is estimated that the project will lead to annual emissions reductions of 32,000 tonnes of CO_2, 147 tonnes of SO_2 and 87 tonnes of NO_x.

The installation and maintenance company Co-Energy Group will take 78% of the financial savings, with the remaining 22% going to the army. Under this scheme, Co-Energy have a clear incentive to maintain the GSHPs' high efficiency levels since the less energy they use, the more Co-Energy will make in savings.

(Source: The DSM Letter, July 18 1994, from Synergic Resources, USA)

Going the natural way

300 participate in IIR conference on natural working fluids

Germany - Over 300 refrigeration experts from 30 countries visited Hannover, to participate in the conference "New Applications of Working Fluids in Refrigeration and Air Conditioning", which focused on natural working fluids. The meeting was organized by Commission B2 of the IIR (International Institute of Refrigeration) and was held on 10-13 May 1994. The number of participants far exceeded expectations, reflecting the worldwide interest in radical solutions for the working fluid issue.

The key question addressed was: "In which technologies, and under which conditions, can chemically manufactured working fluids be largely replaced by natural substances such as hydrocarbons, ammonia, water, air and CO_2."

In the search for an answer, speakers presented the state of knowledge on natural working fluids and a number of recent applications were reviewed. More in-depth discussions took place in parallel sessions, and if the number of presentations is anything to go by, the interest in natural working fluids can be ranked as: hydrocarbons (21 presentations), absorption technology (10), air (8), ammonia (7), CO_2 (5) and water (3).

While the interest in natural working fluids is worldwide, there remains an enormous variation in the perceived market potential. The USA, for instance, although well represented at the conference, remains highly sceptical about the chances for domestic application of working fluids (natural or otherwise) with safety implications. And Japanese manufacturers show only marginal interest in the European tendency towards natural fluids. Indeed, very few Japanese attended the conference.

At the same time, however, developing countries and countries in transition are showing a keen interest. Presentations from India, Brazil and Poland were heard on the application of hydrocarbons in domestic refrigerators.

A particularly strong delegation from India was present. They stayed in Germany, and followed up the conference with discussions with manufacturers and representatives of the German government on intensified collaboration in the field of heat pumps.

The proceedings will be published by the IIR.

(Source: IEA Heat Pump Centre, CCI, Germany, 8/94)

MVR heat pump is the biggest yet

Netherlands - Oil producer Shell is installing a 6.2 MW (electric) mechanical vapour recompression (MVR) heat pump at an oil refinery of its subsidiary, Shell Nederland Chemie (SNC), in Pernis. This is the first example of the application of MVR on this scale in the Netherlands.

The heat pump will be installed in a new installation for the production of high-purity, polymer-grade propene for use as feedstock in a number of SNC's chemical processes. In the distillation step of the process to separate propene from propane, the company opted for the technique of vapour recompression in order to minimize energy consumption. Compared to a conventional installation, the use of vapour recompression technology is estimated to yield energy savings of 1.2 TJ per annum, for an additional capital investment of around NLG 15 million (US$ 8 million).

The 6.2 MW compressor is designed to produce 230 ktonnes of propene per annum and is to be custom-built by Mannesmann Demag of Germany. The unit is expected to be operational in the last quarter of 1995.

(Source: Mr Jan van Buuren, News Correspondent for the Netherlands National Team; Fax: +31-2510-267400)

GAX technology brings ice to Alaska

USA - An absorption ice-maker working on the GAX (Generator-Absorber heat eXchanger) cycle has begun operation in the isolated fishing village of Kotzebue, Alaska.

One of the primary economic activities of this village is salmon fishing, an activity which is only permitted in the months of July and August, for which ice is vital. By using GAX technology, the power for ice-making is derived from waste heat from diesel generators, reducing electricity consumption by 70%. During the initial test period, the GAX ice-maker has reached an evaporation temperature as low as -12°C using drive energy from cooling water of just 70°C.

The GAX ice-maker has been developed by the Energy Concepts Company with financial backing from the Alaska Science and Technology Foundation and the Alaska Energy Authority.

(Source: Mr Donald Erickson of Energy Concepts Co., 627 Ridgely Avenue, Annapolis, Maryland 21401; Fax: +1-410-266-6539)

District energy system taps underground heat

Japan - The first stage of an ambitious district heating and cooling (district energy) system powered by electric heat pumps is now complete. A 620 kW heating (520 kW cooling) heat pump utilizes underground water at 18°C as the heat source or sink (see Figure 2). A 1290 m^3 storage tank allows the system to operate on night-time electricity.

The project, sponsored by the Tokyo Electric Power Co. (TEPCO), will eventually be extended to include four heat pumps with a combined capacity of 14.5 MW heating and 13.2 MW cooling. The district heating system will eventually serve 18.1 hectares of Takasaki City.

(Source: JARN, 25 June 1994)

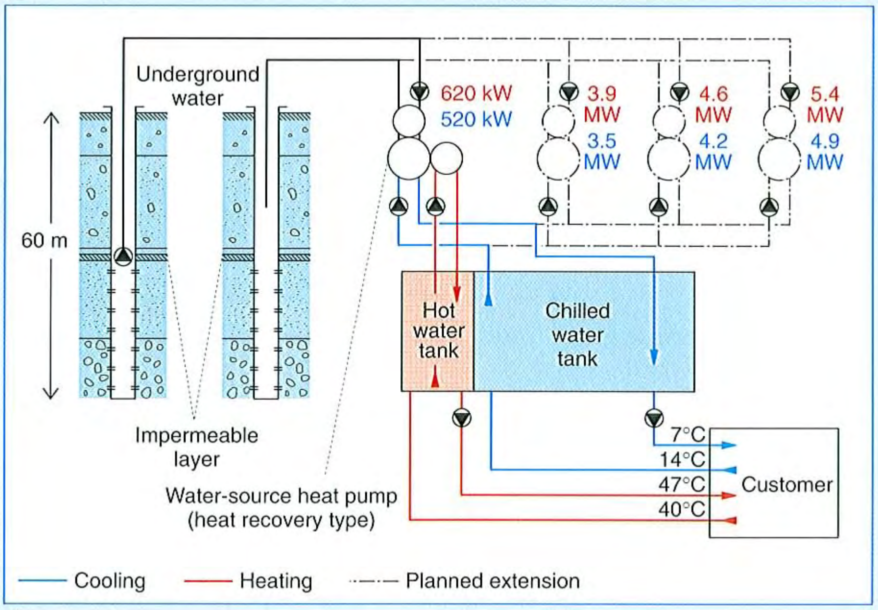


Figure 2: The district energy system at Takasaki City.

Markets

Room equipment in upward trend

Japan - The hot summer is expected to provide a boost to the room air conditioner (RAC) market here, where signs of a recovery are already apparent. Actual sales figures for RACs between Oct. '93 and Feb. '94 show an increase of 8% on the same period a year previously, although much of this increase is attributed to a reduction in selling prices of around 10%. Factory shipments of RACs remained steady for this period, up just 1.6% on the previous year. Of the 2,201,784 units shipped, over 91% were heat pumps.

The most promising signs are found in the production figures: March '94 showed the first year-on-year production increase for 21 months, reaching 821,000 RAC units, up 16% on March '93. Figure 3 plots the production of RACs from June 1992.

(Source: JARN, May 25 and June 25, 1994)

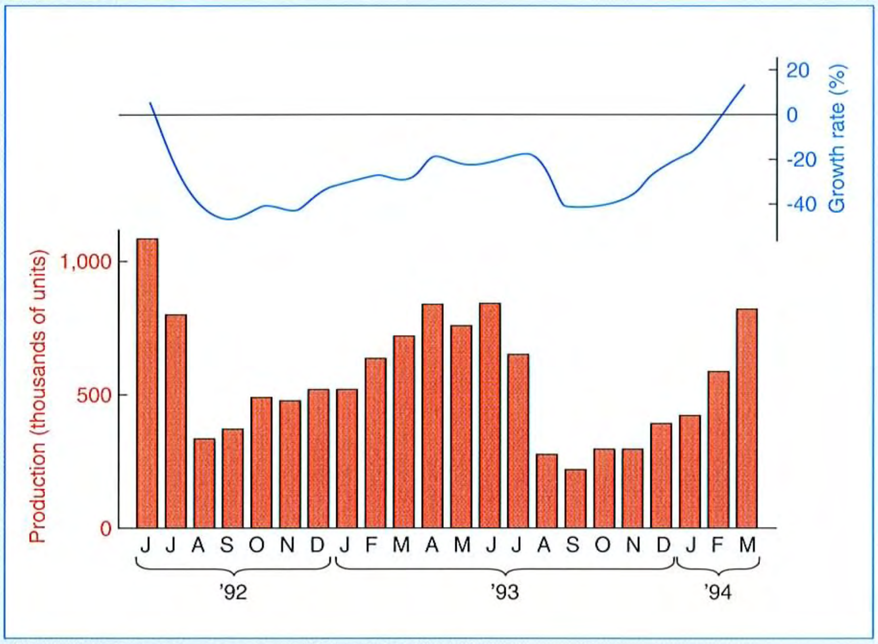


Figure 3: Monthly production of RACs in Japan.

Industrial heat pump market led by food sector

Japan - A survey has plotted the number of heat pumping units sold between Oct.'92 and Sept. '93 (Refrigeration Year RY 1993) for applications other than space conditioning, such as process heating and cooling. As shown in Table 2, the market is dominated by the food industry, for which 46.6% of industrial heat pumps were supplied. The survey was conducted by the Japan Association of Refrigeration and Air Conditioning Contractors.

(Source: Mr Yoshio Igarashi of the Japanese National Team)

Industry	Compression type				Absorption type		
	<3.7 kW	3.7-14.9 kW	>14.9 kW	Total kW	<0.35 MW	0.35-1 MW	Total MW
Chemical	46	67	37	150	1	1	2
Petrochemical	13	8	1	22		2	2
Food	352	405	80	837			
Paper & Pulp	8	7	2	17			
Textile	23	12	4	39			
Machinery (coating etc.)	22	15	5	42			
Horticulture	33	34	1	68			
Ocean culture	24	20	10	54			
Wood drying	1	4	1	6			
Others	270	230	63	563	5	4	9
Total	**792**	**802**	**204**	**1,798**	**6**	**7**	**13**

Table 2: Industrial Heat Pump Sales in Japan, Oct.'92 - Sept. '93.

IEA Heat Pump Programme New Annexes on the table

Paris, France - At the Executive Committee Meeting of the IEA Heat Pump Programme, held 25-26 April 1994, much attention was paid to the introduction of new Annexes. Annex 22, "Compression Systems with Ecologically Safe Working Media", is set to begin its activities in September. Annex 22 will study compression heat pump, refrigeration and air-conditioning systems using ammonia, CO_2, hydrocarbons, air or water. It will be operated by Norway and will consider the most promising application areas for these working fluids and establish design criteria and safety recommendations. A final decision on whether to go ahead with this Annex will be made by 6 September 1994 - the date of its first working meeting in Gothenburg, Sweden.

Another Annex proposal, initiated by Sweden, also considers natural refrigerants. Titled "Performance of Environmentally Benign Working Fluids in Low-Charge Evaporators", this would be a more research oriented task. A possible amalgamation of this Annex proposal with Annex 22 will be discussed at the Gothenburg meeting.

Two Annex topics were proposed by the US: "Dessicant Cooling" would consider the environmental impact and market potential of this energy-efficient technology. "System and Control Advancements for Improved Heat Pump User Acceptance" would consider practical ways in which the performance of heat pumps can be improved. A joint Workshop on this proposal is considered in conjunction with the IEA Implementing Agreement on Buildings and Community Systems.

Canada has also proposed an Annex on "Ductless Heat Pumps for Cold and Temperate Climates". This task-shared Annex would determine the potential market for electric-resistance baseboard retrofits in the participating countries.

Finally, the Executive Committee agreed not to proceed any further with the Japanese proposal on "Chemical Process for Ecological Thermal Energy Systems". However, a new proposal from Japan is now on the table with the title "General Evaluation Method for Introducing Heat Pumps to Various Fields". An overview of currently active Annexes is shown in Table 3.

(Source: IEA Heat Pump Centre/ TSSU)

Annex 18 moves on to mixtures

USA - At a meeting held on 25 June 1994 in Boulder, Colorado, participants of Annex 18 laid out a work plan for its second phase of operation, which concerns the thermophysical properties of HCFC alternatives.

As refrigerant mixtures are likely replacements for HCFCs in many applications, a major task will be to compare and evaluate mixture models with a focus on the reference mixtures R-32/125 and R-32/134a. No single "winning model" will be declared but, the strengths and weaknesses of the various models will be outlined, so users of mixture data can select the model which best meets their needs. Also in Phase II of Annex 18, equations-of-state for the properties of the pure refrigerants HFC-32 and HFC-125 will be evaluated, and the properties of natural refrigerants will be addressed. An assessment of the state-of-the-art for ammonia properties will be published, and Annex 18 will work with Annex 22 to identify the properties needs for other natural refigerants.

(Source: Mr Mark McLinden, National Institute of Standards and Technology, USA, Fax: +1-303-497-5224)

Table 3: Summary of on-going IEA Heat Pump Programme activites.

No.	Annex	Operating Agent	Participants	Start Date	Completion
16	Heat Pump Centre	NL	AT, CA, IT, JP, NL, NO, CH, US	Jan 1990	
18	Thermophysical properties of environmentally acceptable refrigerants	US	AT[1], CA, DE, JP[2], NO, SE, UK, US	Dec 1989 Jan 1993	Dec 1992 Dec 1996
21	Global environmental benefits of industrial HPs	US	CA, FR, JP, NL, NO, SE, UK, US	Jan 1992	Dec 1994

Participating countries: Austria (AT), Belgium (BE), Canada (CA), Denmark (DK), France (FR), Germany (DE), Italy (IT), Japan (JP), the Netherlands (NL), Norway (NO), Spain (SP), Sweden (SE), Switzerland (CH), United Kingdom (UK), United States (US).
[1]Phase one only. [2]Japan is the Cooperating Agent of phase 2.

Waste Heat Recovery Heat Pumps for Buildings

An International Overview

Bert Stuij, IEA Heat Pump Centre

Waste heat recovery heat pumps for buildings are energy efficient, and in many cases economically viable. They are available on any scale, ranging from, for instance, small exhaust air heat pump water heaters, via installations that simultaneously provide space cooling and tap water heating in commercial premises, to very large district heating heat pumps recovering waste heat from sewage. On an even grander scale the setting up of waste heat networks is being considered, whereby the waste heat production from industrial zones is coupled with the heat demand of urban areas.

This article reviews the technology and applications, and argues in conclusion that waste heat recovery heat pumps are essential components of optimized, integrated energy systems for buildings and building complexes. In the blue boxes the application of waste heat recovery heat pumps in HPC member countries is discussed, as well as in France, Germany and Sweden.

* * *

Some 375,000 PJ of primary energy resources are needed annually, to meet the total human demand for food, comfort and mobility. After having met this demand, most of these resources turn into waste heat, and then decay further to 'heat of ambient temperature'. Ambient heat is normally of little value, although heat pumps can tap into it and upgrade it to a useful temperature level again.

Obviously it is beneficial to intercept waste heat before its final decay, either by using the heat directly, or by using a heat pump. Because of its higher than ambient temperature, the use of waste heat as heat source allows operation with a lower temperature lift and a significantly higher COP, as illustrated in Figure 1. Furthermore, waste heat of a somewhat higher temperature can be used to drive absorption heat pumps.

The benefits need to be large enough to finance the effort to capture waste heat flows, and feed them into heat pumps. Many economic opportunities have already been identified in industry, where there are very large waste heat flows at relatively high temperatures. Increasingly, opportunities are also

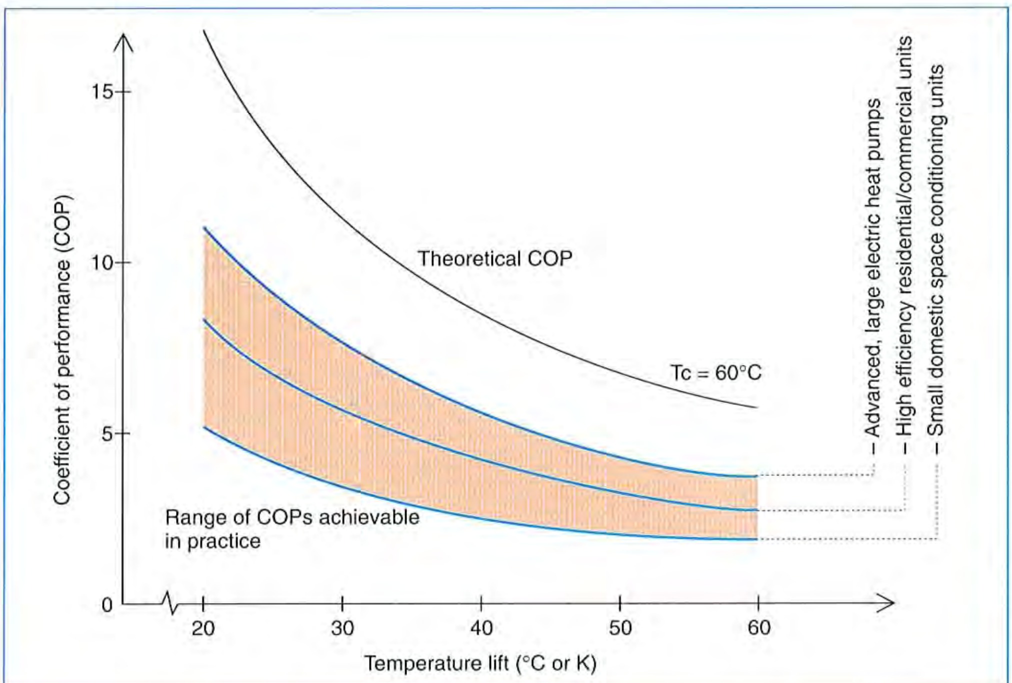


Figure 1: Theoretically achievable and practically realized COPs, as a function of temperature lift.

being recognized in buildings. Significant waste heat flows include ventilation air, sewage water, and the condenser heat of cooling installations.

Practical systems to utilize such waste heat flows exist on any scale. There are, for instance, small domestic heat pump water heaters that recover heat from ventilation air. On a larger scale, district heating may use sewage or industrial cooling water as heat source. And ultimately, perhaps, there is the grandiose Japanese 'Eco-Energy City Concept', in which whole areas are coupled in what could be termed a 'waste heat recovery network'.

Residences

Ventilation air has proven to be an excellent heat source for domestic heat recovery heat pumps, in particular for tap water heating. Many of these heat pumps also meet the space heating demand to some extent. The heat recovery system is illustrated in Figure 2. A strong market has developed in Sweden, partly in response to air-quality and energy efficiency regulations. Application oriented research is going on in several countries, including the Netherlands, Switzerland, and the UK. A compact and highly competitive unit was developed with support from the Electric Power Research Institute (EPRI) in the US, and introduced in October 1993.

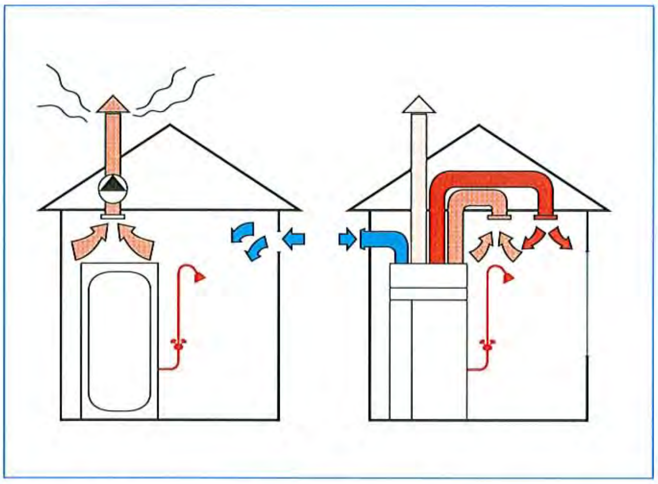


Figure 2: Conventional water heater vs. heat recovery heat pump systems for tap water and space heating (illustration courtesy NOBØTHERM, Norwegian manufacturers of heat recovery heat pumps).

In countries with significant space cooling demands, systems that recover condenser heat for tap water heating can be attractive. It must be said, though, that such systems are particularly competitive if they are somewhat larger, and penetration of the residential market has been difficult.

Austria

Waste heat recovery heat pumps for residential buildings are reportedly rare in Austria. However, it is noted that forced ventilation systems are becoming increasingly common, which can open up possibilities. It may help, in this respect, that hot water heat pumps are already an accepted technology, as exhaust air heat pumps are particularly suited to provide hot water.

In the commercial sector heat recovery is much more common. Heat from exhaust air is most often recovered with heat exchangers, while heat pumps are generally applied for internal heat recovery; heat gained in one part of the building is transferred to areas with a heating demand.

Some advanced integrated systems that include heat recovery from exhaust air and sewage water have been realized in alpine tourist complexes.

(Source: Mr Hermann Halozan, Austrian National Team)

Canada

The market penetration of heat recovery heat pumps for buildings is at this stage modest at best. Heat recovery heat pumps for commercial premises have not always met customer expectations, and residential exhaust air hot water heat pumps show a limited economic viability. However, it is expected that upcoming regulations could improve the market potential significantly. Ventilation requirements are becoming much more stringent, and this is expected to create opportunities for exhaust air heat pumps, both in the residential and commercial sector. Regulations may include energy efficiency provisions, such as the requirement of heat recovery. In such a regulatory environment, heat pumps are expected to become a more competitive option.

(Sources: Caneta Research Inc.: ASHRAE Report RP-656 'Heat Recovery Heat Pump Operating Experiences' and Mr Daniel Giguère, CANMET: 'International Heat Pump Status and Policy Review - National Position Paper Canada')

France

The market perspectives for heat pumps in general are poor. Improved insulation, has significantly reduced the heat demand, and the market is driven to heating systems that require low capital investment, such as direct resistance heaters. At the same time, fuel prices are low, and heat pumps have difficulty competing on operating costs with gas and oil boilers. The reduction in CO_2 emissions that can be achieved with heat pumps is neither enforced by regulations, nor financially rewarded. In these circumstances, heat pumps must be operated under optimum conditions to stand any chance of economic success. Such conditions include an easy and high- quality heat source (e.g. waste heat), a low-temperature heat distribution systems, and long operating hours.

For the residential sector, exhaust air heat recovery systems are suitable. Multi-family applications have been realized, for instance with an exhaust air heat pump providing a basic, common level of heating, to be topped up by individual users with decentralized heaters. Another example is a project whereby a heat pump uses air from the Paris underground transport system as heat source. The air has a temperature of 22°C at an outdoor temperature of 0°C, and the heat pump covers 70% of the heating demand of a building with 14 apartments, with an SPF of 3.2.

In the commercial/institutional sector, dehumidification with heat recovery of indoor swimming pools is an attractive niche market. More in general many commercial/ institutional buildings have a simultaneous heating, cooling and ventilation requirement over long periods. This can be utilized by centralized heat pump systems, recovering the heat from extracted air. Alternatively, water loop systems may be applied, with the water loop used as heat sink for cooling units, and as heat source for heating units. Thermal storage systems may be included to smooth out the building's thermal load curve. In the commercial/institutional sector, health care buildings are viewed as particularly promising. It is expected that the further development of the air-conditioning market, coupled with the demand for improved air-quality will speed up the market penetration of exhaust air heat pumps.

(Source: Mr. J.P. Moreau, Electricité de France, Paris)

Germany

Today the demand for space heating heat pumps has shrunk to near insignificance. However, in the years up to 1984, about 60,000 heat pumps were installed in Germany, some 300 of them with a thermal output of more than 100 kW. Most of these 300 use waste heat as a heat source, and many are still in operation. They recover heat from industrial cooling water, ventilation air, and, for instance, the humidity of the air in large indoor swimming pools. The heat produced is either used for heating local industrial or commercial buildings, or fed into a district heating network. There is still a modest market for hot water heat pumps in Germany (about 8000 units per annum). Recently more and more units use ventilation air as the heat source.

Two new regulations may have a significant impact on the future heat pump market in Germany. First of all, the "Ordinance on Thermal Insulation", which curtails heat losses from buildings. The use of heat recovery techniques such as heat pumps to meet the stringent criteria is explicitly allowed. However, it is generally believed that the energy price must rise considerably (e.g. through an energy tax or CO_2 levy) before the heat pump option will truly be competitive. A second regulation with a big potential impact, is the planned "Ordinance on Heat Utilization". If enforced, a detailed concept for heat production and utilization has to be produced for any building having more than a certain heat demand. All available processes and technologies must be considered, and amortization times up to the technical lifetime of the equipment must be accepted. The proposed ordinance was met with considerable resistance from industry, and it is not yet clear when, and in what form, it will come into force.

(Source: Mr Jürgen Reichert, Fraunhofer Institute for Systems and Innovation Research)

In an interesting development in Switzerland, outside supply air is drawn in through the insulation between the inner and outer roof, recovering heat that would otherwise be lost through the roof. A heat pump is part of the system, and supplies a hydronic floor heating system using exhaust air as heat source. The air supply system has been called 'dynamic insulation', and can in principle avoid any heat loss through the shell of a building.

Large Buildings

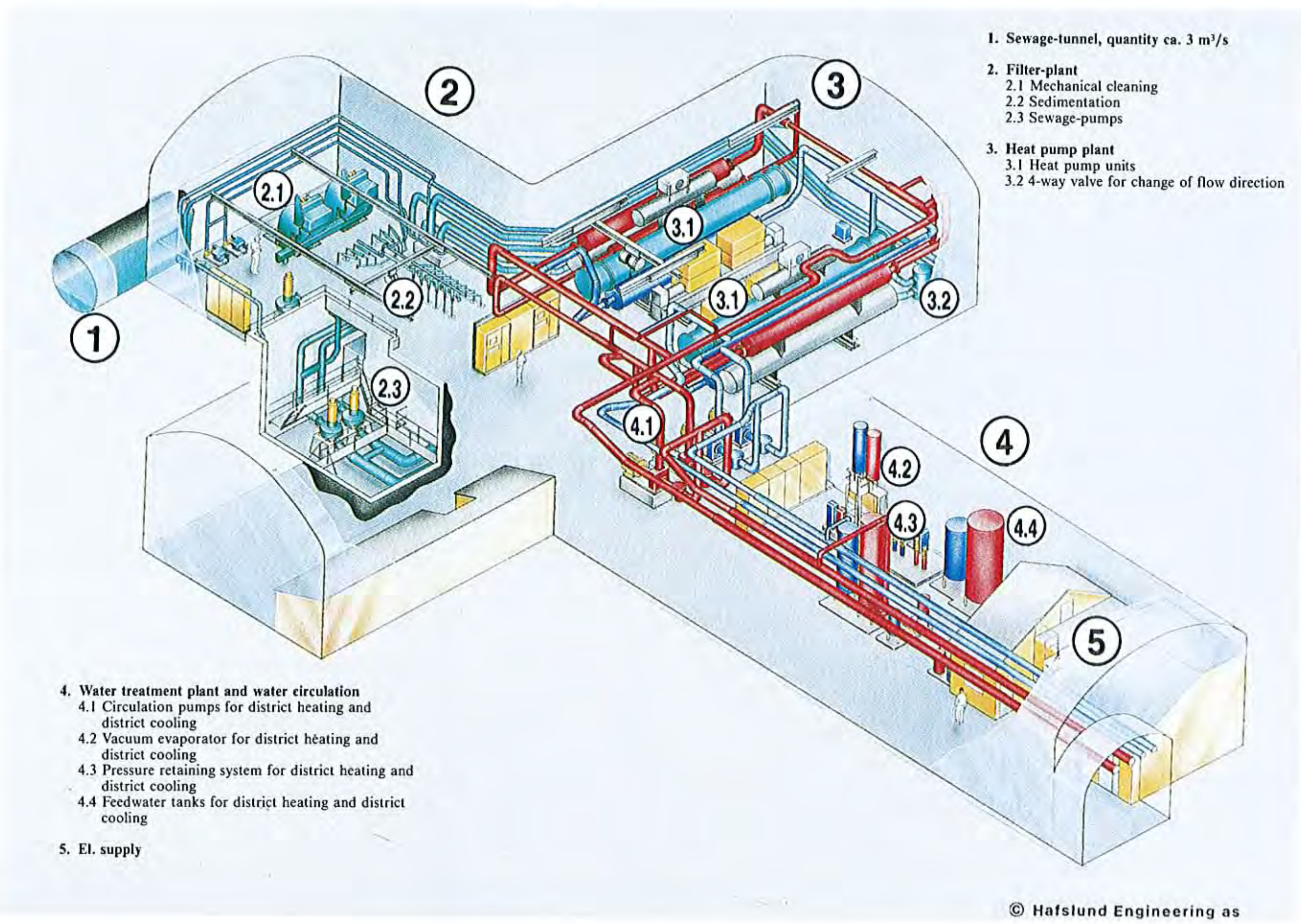
The heat recovery options for the residential sector in general also exist for the larger buildings of the commercial and institutional sectors. Here, in particular, the air-quality can be tightly regulated, and the ventilation requirements improve the opportunities for systems that recover the heat from ventilation air. Additionally, space heating and space cooling demands can occur simultaneously in large buildings. Computer rooms may require year-round cooling, while other parts of the building have to be heated. In other buildings the core may need cooling whilst the perimeter requires heating. In principle, heat pumps are well suited to recover heat from the cooling zones and use this for heating purposes.

More in general, larger buildings can benefit from the economies of scale. Heat pump performance generally improves with system size, and specific investment costs tend to fall. Many energy saving technologies need a certain size to become economically attractive. Examples of large, integrated heat recovery heat pump systems for space conditioning and tap water heating may include waste heat recovery from sewage (e.g. Austria, Switzerland), underground transport systems (France), and seasonal storage.

District Heating

District heating heat pumps are well suited to tap into large waste heat flows. Examples include systems that use heat from sewage water (Sweden, Norway - see Figure 3), industrial cooling water (Sweden, the Netherlands), and ventilation air from apartment buildings (Sweden). Absorption systems that use waste heat of a higher temperature have also been realized, notably in Sweden and Denmark.

Figure 3: District heating and cooling heat pump plant, using sewage as heat source. The two heat pumps (7 MW each) are placed in a rock cavern next to the main sewage tunnel from Oslo, Norway, to the sewage treatment plant.



Italy

Some installations recovering heat from summer cooling or ventilation air are reportedly installed in large buildings. However, the penetration of such systems is insignificant, and no innovative developments are reported from the field. The general lack of innovative heat pump developments or applications is linked to the economic situation, which remains weak for the moment.

(Source: Ms Laura Manduzio, Italian National Team)

Japan

Waste heat flows have long been recognized as a significant domestic energy resource in Japan. Indeed, three major heat pump related research projects had the direct or indirect aim of improving the utilization of waste heat. Under the 'Super Heat Pump Programme', very high efficiency compression heat pumps were developed for a wide range of source temperatures. The developed technologies widen the possibilities to use waste heat, and allow a more efficient use of the resource.

Under the 'Unused Energy Project', which started in 1991, a number of specific heat recovery heat pumping technologies are being realized. They include a turbo-compression heat pump to recover heat from sewage, and compression and absorption heat pumps driven by the steam of waste incineration plants.

Recently the project 'Broad Area Energy Utilization Network Systems' was started, better known as the 'Eco Energy City Project'. This project, coordinated by NEDO (New Energy & Industrial Technology Development Organization), is composed of 36 R&D contracts on topics including heat recovery, heat transport, heat storage, and heat supply. The HPTCJ (Heat Pump Technology Center of Japan) is in charge of the survey of the advanced technologies required. One of the aims is to transport low grade heat efficiently over long distances to allow the utilization of industrial waste heat in urban areas, for instance for cooling or hot water production. One method under consideration is the conversion of waste heat into chemical forms of energy at the source, which will then be transformed back to thermal energy at the user. Heat pumping technologies, in particular sorption processes, will be an essential technology in the 'Eco-Energy Cities'.

(Sources: Mr Yoshio Igarashi, Japanese National Team, and Prof. Ichiro Tanasawa, University of Tokyo)

Netherlands

An exhaust air heat pump system for residential applications is currently under development at KEMA, a Dutch Test, Research and Development Institute with a traditional focus on electrical applications. The heart of this system is a water thermal storage unit, which is fed by the exhaust air heat pump, and which in turn feeds both a tap water and hydronic space heating system. The heat pump is supplemented with resistance heating.

In the early eighties, a number of gas engine heat pumps were realized under the national project 'Warmtepomp Nederland B.V.' (Heat Pump Netherlands Ltd). Demonstration plants include two sewage heat recovery systems, and three systems utilizing heat from exhaust air. A district heating heat plant using industrial cooling water as heat source is achieving an SPF of 5.

A related development is the growing interest in the use of excess district heat in the summer, to drive absorption systems. Applications under consideration are cooling with absorption chillers, and steam generation with a heat transformer. A pilot plant providing space cooling in a commercial building with a solid sorption system has been realized.

(Source: Dutch National Team)

Norway

Two of the largest heat pump plants in Norway use untreated sewage water as heat source. Both are located on the main sewage tunnel from Oslo to the sewage treatment plant. One of them provides both heating and cooling, and is currently the largest district heating and cooling plant in Europe (2 units of 7 MW heating power each). Extensive research at SINTEF in the early 1980s led to the development of heat exchangers for untreated sewage (some mechanical filtering is still required).

Exhaust-air heat pumps in large apartment buildings have proven technically successful, and economically viable. A large potential market exists for ventilation air heat pumps in detached and semi-detached homes. Integrated systems that provide space heating, tap water heating and a cold store at minimum energy costs, are becoming popular. Current R&D for such systems is focusing on the use of natural working fluids.

(Source: Mr Ulf Rivenœs, Norwegian National Team)

Sweden

Over the last ten years, exhaust air heat pumps have grown to a market share of well over 50% in newly-built one-family dwellings in Sweden. The units provide hot water, and partially meet the space heating needs. The market for this type of heat pump is strongly influenced by the presence of mechanical ventilation systems, installed in all new Swedish homes. In most cases direct resistance heating is used as back-up, but units that use natural gas as supplement have also been developed.

There are about 90 district heating heat pumps in Sweden, and over 50 of them recover waste heat. There are a number of examples of heat pumps for multi-family homes that use ventilation air as heat source. Others recover heat from sewage and industrial cooling water. Figure 4 shows the relative significance of waste heat as heat source for district heating heat pumps.

The majority of district heating heat pumps are closed cycle vapour compression systems, but a number of absorption machines have also been installed. In many cases these are an integral part of solid waste incineration plants. The incineration heat drives the absorption cycle, and the condensing flue gases (condensing is often necessary for flue gas cleaning purposes) are used as heat source.

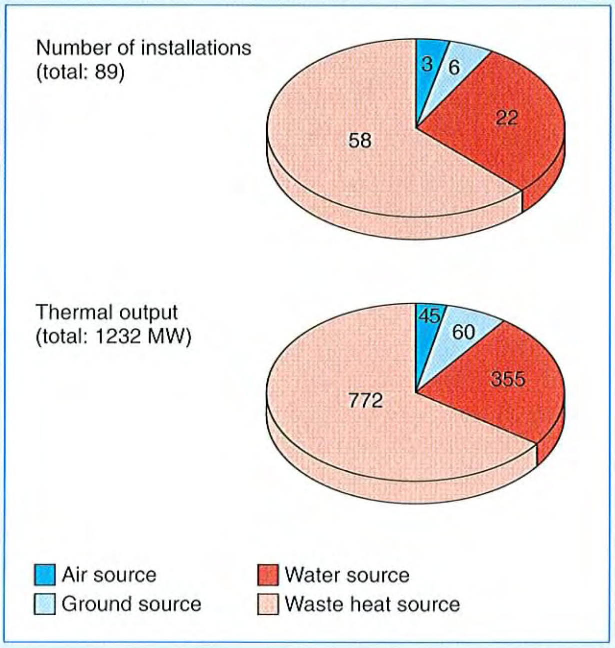


Figure 4: Relative significance of waste heat as heat source for Swedish district heating heat pumps.

(Sources: Mr Mats Fehrm, Elektro Standard AB, and the IEA Heat Pump Centre.)

Switzerland

Application oriented research is being carried out on waste heat recovery heat pumps. For the residential market, controlled space ventilation systems with waste heat recovery are now undergoing field tests, and are compared with conventional oil fired systems. In the same context, the concept of 'dynamic insulation' is being pursued. Outside air enters through the insulation layers between inner and outer roof, and before being supplied as fresh air to the building, it recovers heat that would otherwise be lost. In principle, the system can avoid any heat loss through the shell of a building. Exhaust-air is used as the heat source for a heat pump, which feeds a hydronic floor heating system. This concept is illustrated in Figure 5.

For large buildings heat is recovered from cooling installations in a number of demonstration projects. They include heat recovery from an ice rink to heat a school, and heat recovery from the cooling installation for power generators to heat the control centre. In 1992, a bivalent heating system was installed in a hospital. A sewage waste heat recovery heat pump meets the complete hot water demand, and about 40% of the space heating needs. The remainder is made up by an oil boiler.

In Switzerland the need for air-conditioning has to be proven before installation is allowed. However, no case needs to be made if the cooling is provided by a hot water heat pump.

(Source: Mr Thomas Afjei, Swiss National Team)

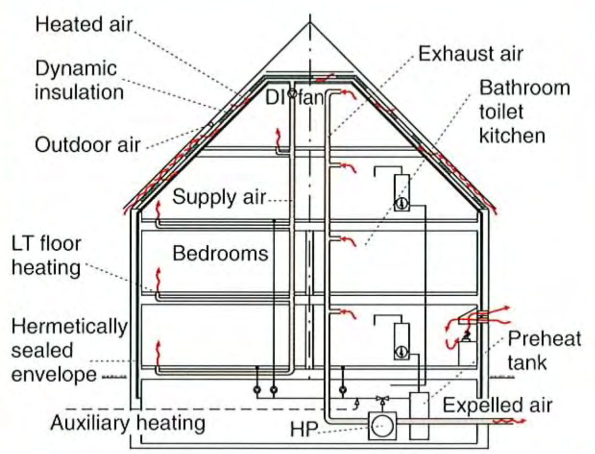


Figure 5: The Swiss concept of 'dynamic insulation', with a heat recovery heat pump feeding a hydronic floor heating system (illustration courtesy CADDET Energy Efficiency, Sittard, the Netherlands).

In a related development the interest is rising to use excess district heat in summer to drive absorption systems. That way cooling can be provided, and in some countries heat transformers to generate steam (e.g. for use in hospitals) are being considered.

Waste Heat Networks

One of the grandest schemes towards the fuller utilization of waste heat is probably the Japanese 'Eco-Energy City Project'. Waste heat flows from industrial areas are converted into latent or chemical forms, and then converted back to thermal energy at users in urban zones. Heat pumping technologies, notably sorption processes, play a key role in these waste heat networks. More than 35 research activities are being carried out in the context of the programme, in areas such as heat storage, heat recovery and heat transport. (See also page 32.)

Turning Theory into Reality

Looking at buildings and building complexes, there is a notable parallel with industrial processes and plants.

USA

Waste heat offers large opportunities for using heat pumps. The market for waste heat recovery heat pumps in buildings continues to expand, stimulated by more stringent ventilation requirements for large buildings, and a growing interest in heat pump water heaters for the home.

Many buildings in the US require cooling - either year-round or on a seasonal basis - and this presents many opportunities for heat recovery systems, especially when there is a simultaneous heating and cooling demand. This can be the case if certain parts of the building need cooling (e.g. the core, or computer rooms) while others need heating, or if there is both a space cooling and hot water demand. An active market for heat recovery systems exists, in particular for large systems that provide space cooling and water heating at the same time.

Significant for large buildings is that ventilation needs are rising, in response to growing concerns about indoor air quality. Recently, ASHRAE standard 62 has raised the fresh air requirements by 50%. In this context, systems that capture the heat from exhaust air are becoming more attractive.

In the residential sector heat pump water heaters are perhaps the most significant heat recovery technology. A compact and highly competitive unit was recently developed by E-Tech and EPRI (Electric Power Research Institute). Ductable air flow allows the use of ventilation air as heat source. A proposed energy efficiency regulation on hot water heaters (see IEA Heat Pump Centre Newsletter Vol 12, No 2, page 4) could have a dramatic impact on the market, as it would leave hot water heat pumps as the sole electric water heater option. It should be noted, however, that several arguments against the rule have been raised, and that it may not be adopted in its current form.

(Source: Mr John Tomlinson, Oak Ridge National Laboratory)

It is not so much the use of heat recovery heat pumps that has to be promoted, rather it is the concept of system integration: as in industry, the demand for heating, cooling and power in buildings should be met by an integrated system which meets the complete energy demand with minimum resources. Process integration and plant integration find their parallels in the optimization of energy systems for houses and districts.

Optimized, integrated energy systems are needed on any scale - from the individual house to complete cities. And for any scale suitable heat recovery heat pumping technologies are available to turn the theory into an energy-efficient and cost-effective reality.

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Exhaust-air Heat Pumps in Sweden

Developments and experiences

Mats Fehrm, Sweden

Exhaust-air heat pump technology has proven to be the most efficient way of recovering heat from a ventilation system. In Sweden this technology is now playing an important role in the heating market, particularly in new single-family homes. However, larger exhaust-air heat pump systems are also being installed here, the largest unit, with a heat output of 3.4 MW, serves 2,500 flats.

This article describes some of the projects that have contributed to the development of exhaust-air heat pumps in Sweden. Details are also given on the latest technology trends including an integrated exhaust-air heat pump and gas boiler.

* * *

Since 1980, exhaust-air heat pumps have grown from a market share of zero to more than 50 % in newly-built single-family homes in Sweden. During the same period, other types of heat pumps did well in the beginning of the eighties, lost almost the entire market in the middle of the eighties, and are now slowly making a comeback.

Single-Family Homes

The "Sigtuna Project"

In Sigtuna, about 60 km northwest of Stockholm, 39 single-family homes were built in 1985. The houses are semi-detached, each having a floor area of about 120 m^2. The houses are equipped with exhaust-air ventilation systems and electric panel heaters.

Each house has an exhaust-air heat pump which recovers heat from the exhaust air to supply domestic hot water. The available heat for recovery is

Swedish home equipped with an exhaust-air heat pump.

House type	Annual consumption (kWh)			Mean value
	85/86	86/87	87/88	85 - 88
2-storey with heat pump	10,134	10,652	11,006	10,597
2-storey with air-to-air heat exchanger	13,841	14,002	13,873	13,905
1-storey with heat pump	8,658	8,730	9,890	9,093

Table 1: Total annual electricity consumption of houses in the Sturefors project.

The "Sturefors Project"

In the little village of Sturefors, 10 km south of Linköping, a competition was arranged to build a group of single-family homes with very low energy demand. The winning building company, ABV, built 22 double-storey houses with a heated floor area of 125.4 m^2 and heat transmission losses of just 60 W/°C. Nineteen of these houses are equipped with exhaust-air heat pumps, while the other three have air-to-air heat exchangers for heat recovery. The company also built four single-storey houses with a heated floor area of 86.5 m^2, each equipped with an exhaust-air heat pump.

The heating system in all the houses is forced air, backed up with electric panel heaters in the bathrooms and toilets. The heat pump houses also substantially more than required for the domestic hot water. The design of these houses offered a convenient way to use this heat.

The houses are built with a concrete slab directly on the ground. To accommodate building technicalities and for reasons of comfort, the joint between the outer wall and slab is often electrically heated. In these houses, a 20 mm copper tube of 42 m length was laid in the slab about 0.4 m from the outside and 50 mm down into the concrete.

During the heating season, domestic hot water is pumped through the pipe in the slab. This brings the temperature on the floor surface at the periphery of the bottom floor to a maximum of 25 to 28°C, depending on the outdoor temperature.

Of the 39 houses, two were monitored according to actual electricity consumption for the heat pump, the ventilation system, electric heaters, lighting and cooking equipment. For the other houses, only the total annual electricity consumption is available.

The measurements revealed that the mean value of electricity consumption for all houses is 14.5 MWh per year. But, as always, there is a very big discrepancy between the smallest and the biggest electricity consumption. The house with the biggest consumption used 119% more electricity than the house with the smallest consumption.

Consumption in the two monitored houses was 12.3 MWh and 13.3 MWh, with energy savings by the heat pumps of 6.8 MWh and 5.4 MWh respectively.

Figure 1: Exhaust-air heat pump including all necessary functions such as heating, hot water, ventilation, heat recovery and controls.

have an electric panel heater in the kitchen, and a hydronic (copper pipe) heater at the perimeter of the floor for both comfort and building protection.

The houses were built in 1985 and were monitored from October 1985 to June 1988. In 1991, the last measurement of total electricity demand was made. Table 1 shows the total electricity consumption. The values are normalized mean values for the different types of houses, meaning that the measured values have been corrected to reflect the normal use of water and household electricity, and the normalized outdoor temperature.

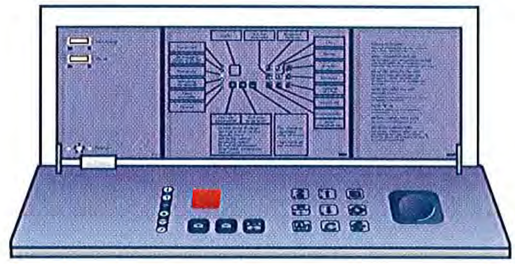

Figure 2: The control panel of an exhaust-air heat pump.

Multi-Family Homes

Bergshamra

Exhaust-air heat pumps have been installed in five 25-apartment blocks in Bergshamra. A single heat pump in each block, recovers heat by means of a brine system connected to the exhaust-air cooling coils in each apartment. Each heat pump serves four 700 litre domestic hot water tanks with a hot gas cooler used for final heating of the water. The exhaust-air is cooled from 15 to 5°C. The total cost for the installation was SEK 1.1 million (US$ 140,000).

Since operation began in 1985, the systems have provided continuous service except on one occasion in 1991 when a motor breakdown occurred in the semi-hermetic compressor. A new compressor was installed at a cost of SEK 110,000 (US$ 14,000). Besides this one incident, the system has proved almost 100% reliable.

In 1987, the compressor operated for 6531 hours and delivered 1170 MWh of heat with an electric input of 412 MWh - an SPF of 2.8. Technical details of the heat pump are shown in Table 2.

Täby

Since February 1986, a 3.4 MW exhaust-air heat pump has provided space and water heating for 2,500 flats, a school, a daycare centre and some commercial buildings in the town of Täby, north of Stockholm. One 9 MW oil boiler was replaced by a heat pump system unit consisting of two screw compressors (type STAL VSP 73 E). Additional heat is provided by a 4 MW electric boiler and some oil boilers. The total cost of the installation was SEK 14 million (US$ 1.8 million). Technical details of the heat pump are shown in Table 3.

An SPF of 2.22 was recorded in 1987 after 6531 hours of operation over one year. In this period, 23,181 MWh of heat was delivered with an electric input of 10,365 MWh. The performance of this system was somewhat limited by the high temperature of the heat distribution system. If this could be changed to allow a feed forward temperature of about 55°C, then the SPF could be expected to increase to 3.0, leading to a 30% reduction in the heat pump running costs.

New Developments

The market for exhaust-air heat pumps is strongly connected to the presence of mechanical ventilation. Due to the development of more insulated and tighter buildings in Scandinavia almost all newly-built houses are equipped with mechanical exhaust-air ventilation. In Sweden this ventilation system is installed in all new houses.

Table 2: Technical data of the Bergshamra heat pump systems.

Heated floor area	680 m²		
Exhaust-air flow	383 m³/min.		
Heat output	185 kW at:	water temp.	45°C
		exhaust-air temp.	20°C
		extract-air temp.	5°C
Balance point	5°C outdoor temp.		
Refrigerant	60 kg of HCFC-22	(0.3 kg/kW heat)	

Table 3: Technical data of the Täby heat pump system.

Heated floor area	13,060 m²		
Exhaust-air flow	5800 m³/min.		
Heat output	3450 kW at:	water temp.	70°C
		exhaust-air temp.	20°C
		extract-air temp.	5°C
Balance point	10 to 15°C outdoor temp.		
Refrigerant	1800 kg of CFC-12	(0.5 kg/kW heat)	

There are may ways [1] in which heat pumps can be used to recover heat from exhaust air. In Sweden, the trend in recent years has been towards exhaust-air systems where the recovered energy heats domestic water as well as radiator or floor-heating water. The supply air is taken through vents in the windows or special supply air devices in the outer wall. The latter can have silencers and/or pollen-filters.

In almost all systems, electricity is used for back-up heating. As natural gas is available in the very south of Sweden, an exhaust-air heat pump with an integrated gas-boiler has been developed. The heat in the flue-gases is recovered by the heat pump. This gives the heat pump a COP of more than 4, depending on running conditions. The overall energy efficiency of the heat pump and gas-boiler will be 130% or more, depending on running conditions. Another positive aspect of this concept is that no chimney is needed. The extract ducting for the heat pump will lead the mixture of extract air and flue-gases out of the house.

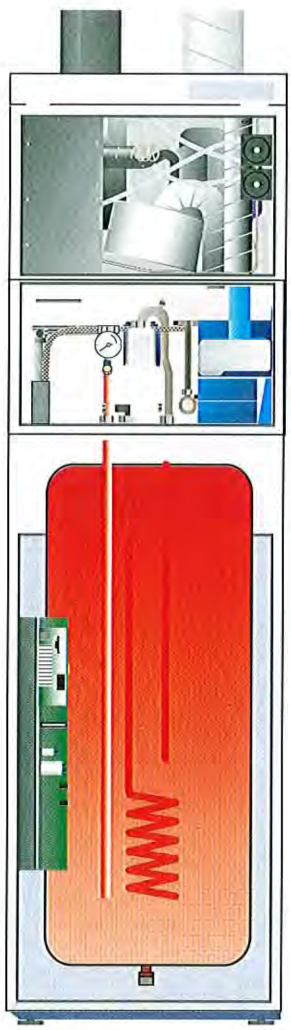

Figure 3: Exhaust-air heat pump with integrated gas boiler.

With flue-gas concentrations of only 10 to 20 %, and a temperature of no more than 35°C, the extract ducting is a part of the ventilation system and not a chimney.

For smaller multi-family homes, concepts with standardized exhaust-air heat pumps systems have been developed. These systems allow the required design to be built up from a standard range of heat pump, storage tank, domestic hot water tank, supplementary heating system (electricity, gas, oil or district heating) and exhaust-air system. It is also possible to use the ground as a complementary heat source.

Setting the Lead

With experience dating back over many years, Sweden has set a lead in exhaust-air heat pump technology. The projects discussed in this article have demonstrated that exhaust-air heat pumps can provide reliable heating at low energy consumption. With the trend towards the increased use of mechanical ventilation in new Swedish houses, coupled with regulations to limit heat losses, it can be expected that the market for ventilation air heat pumps will continue to grow.

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Combining HPWHs with Residential Air Conditioning

Ted C. Gilles, USA

With the widespread use of air conditioning in homes in the United States, vast quantities of heat are rejected outside during the summer. At the same time, other equipment is used to produce hot water. But despite the potential benefits from heat recovery, heat pump water heaters (HPWHs) using desuperheaters or full-condensing heat exchangers do not have a significant market share.

A new type of HPWH takes a different approach to the problem. Rather than recovering the heat from the air-conditioning condenser, the prototype HPWH described in this article provides hot water heating in summer, with no extra power consumption, by recovering heat from recirculated ventilation air and pre-cooling the return air to the air conditioner.

* * *

Of the 1.3 million single-family homes constructed in 1993 in the United States, 802,000 had central air conditioning and 246,000 had all-season heat pumps [1]. Consequently 79% of new single-family homes built that year had ducted cooling systems. In summer, a counterpoint relationship exists between the need to *reject* heat from the air conditioning system and the need to *add* heat to potable water for domestic use such as bathing, laundry, washing dishes, etc. One way to take advantage of this situation is to recover heat from the air conditioner's condenser.

Prototype HPWH.

Using Condenser Heat

Desuperheaters and full-condensing heat exchangers, applied within the refrigeration circuit, can provide the interface necessary to optimize the energy balance between rejected and added heat from space cooling and water heating. In general terms, these refrigerant heat exchanger systems have not found widespread acceptance due to the problems outlined below.

In typical residential applications, it is generally less costly to locate the refrigerant-to-water heat exchanger in the outdoor section of the space conditioning system near the compressor. However, the requirement for outdoor water pipes means that this arrangement is generally limited to locations where below-freezing temperatures are unlikely, such as in Lower Florida or Hawaii. The problem of freezing can be avoided by locating the heat exchanger in, for example, a partially-conditioned environment such as a garage or basement. But this requires additional refrigerant and refrigerant piping.

Either of the above cases requires modification to the refrigeration piping of the outdoor unit of the space conditioning system. Additionally, any failure of the heat exchanger puts both the hot water heating and space conditioning systems out of service.

Integrated Heat Pumps

Fully integrated heat pumps that combine space heating, cooling and hot water heating functions into

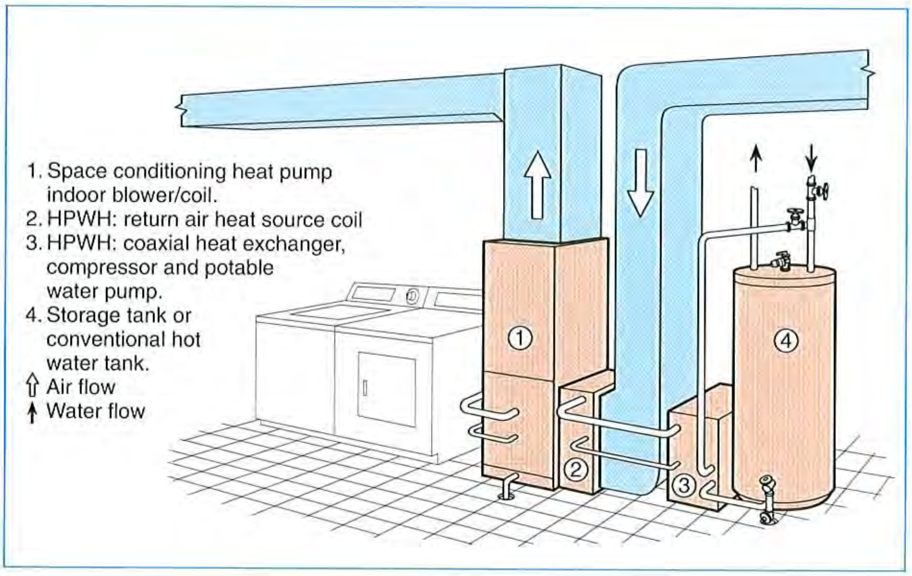

Figure 1: Typical arrangement of the prototype HPWH.

one system, have been marketed by some manufacturers. One such system has recently been withdrawn from the market due to poor sales resulting from installation costs of at least 50% higher than conventional high-efficiency heat pumps. Other systems are being offered at a somewhat lower cost, but suffer from a lack of flexibility since they require a specifically matched combination of two indoor units and one outdoor unit in addition to the hot water storage tank. All integrated heat pumps suffer from the weakness mentioned above, in that a failure in a single component can cause a total breakdown in space conditioning and water heating.

Energy Transfer Concept

Figures 1 and 2 shows a new system which avoids the problems associated with desuperheaters while transferring energy between the two systems [2]. A small, dedicated domestic heat pump water heater (HPWH), typically 3 kW heating capacity, has the heat source (evaporator) coil located in the return air stream of a ducted system. This approach keeps the refrigeration circuit of the space conditioning system isolated from the one associated with heating the potable water.

With this concept, the HPWH heats the potable water and simultaneously pre-cools the circulating air before it is ducted to the indoor unit of the space conditioning system. Energy is conserved by assisting with space cooling rather than by using reclaimed heat from the condensing operation of the space conditioning system.

A prototype of this combined system has been developed and one or two years of field testing is planned before the product is marketed in 1996. A similar arrangement with a return-line heat exchanger could be applied with a hydronic distribution system.

Significant Savings

The use of a domestic heat pump water heater (HPWH) can save a significant amount of energy for the homeowner compared to heating water with a conventional electric water heater (CEWH). The United States Department of Energy (DOE) has estimated that the future average use of hot water in a residence would require 4703 kWh per year with a CEWH, but only 2317 kWh with a HPWH [3]. This is based on a conservative estimate of an annual coefficient of performance (COP) of 2 using indoor ambient air, but with no credit taken for the useable cooling effect during the air conditioning season.

Prototypes of the concept shown in Figures 1 and 2 have exhibited cooling season COPs as high as 3.7 when the HPWH is operated concurrently with a space conditioning system in summer. Considering this situation, 1 kWh of power for the HPWH at a COP of 3.7 provides a total of 3.7 kWh of heat to heat service hot water. Of this, 2.7 kWh (thermal) is extracted from the return air stream to the space conditioning evaporator and 1 kWh (thermal) from the compressor motor [heat losses, such as from the compressor, would alter these figures slightly, but can be neglected in this case - ED.].

Cooling Season

A standard efficiency cooling unit with a DOE seasonal rating of 10.0 SEER (equating to an SPF of 3.2 in dimensionless units) typically has a COP of 2.7 at 35°C outdoor operating conditions. Hence 1 kWh of power consumed by the HPWH provides the same cooling effect (2.7 kWh thermal) as results from 1 kWh consumed by the standard efficiency cooling system. In other words, the combined system has provided both service hot water and space cooling for the same amount of electric power as consumed by a stand-alone air-conditioning system producing the same amount of cooling. It can thus be stated that during the cooling season, the combined system heats hot water with no additional energy consumption.

Heating Season

In the heating season, the situation is not so favourable. Since the HPWH heat source evaporator coil is in the return air stream of the space conditioning heat pump, that heat pump will be required to reheat the air stream. When these losses are taken into account, it can be shown that in winter, the HPWH exhibits an effective SPF of 1.45 heating.

Readers may wonder whether the need to reheat the air stream could be avoided by exhausting the air discharged from the HPWH evaporator coil to the outdoors during the heating season. However, the following paragraph explains why this is considered to be neither practical nor cost-effective in most cases.

The HPWH evaporator coil requires an air supply of at least 10 m^3/minute to provide an acceptable COP. Residences in North America with outdoor air intake/exhaust systems typically provide 0.35 air changes per hour. Therefore, a 170 m^2 residence with 3 m ceilings would have 180 m^3 per hour, or 3 m^3/minute, of ventilation air introduced into the heating and air conditioning system. The additional 7 m^3/minute of outdoor air to make up for the 10 m^3/minute discharged and exhausted from HPWH evaporator coil during the heating season would impose a greater reheat loss on the heating system in cold climates than the evaporator coil temperature drop. Additionally, to retain the benefit of the cooling effect during the air conditioning season, a complex system of additional ductwork, dampers and controls would be required.

Close up of HPWH with compressor and condenser encased in foam insulation.

Energy Analysis

Table 1 compares the energy efficiency of the prototype HPWH with a CEWH for a location in the central region of the US. The prototype HPWH is used in combination with a conventional 3-ton (10.6 kW cooling) air-source heat pump with a heating SPF (seasonal performance factor) of 2.05 (equivalent to a US heating performance factor (HSPF) of 7.0). In the "mild" season, in March, April and October, it is assumed that the HPWH will utilize passive solar energy transferred from within the residence by operating the space conditioning system air handler.

The energy consumption is calculated using equipment COPs and the *energy factor* - a term

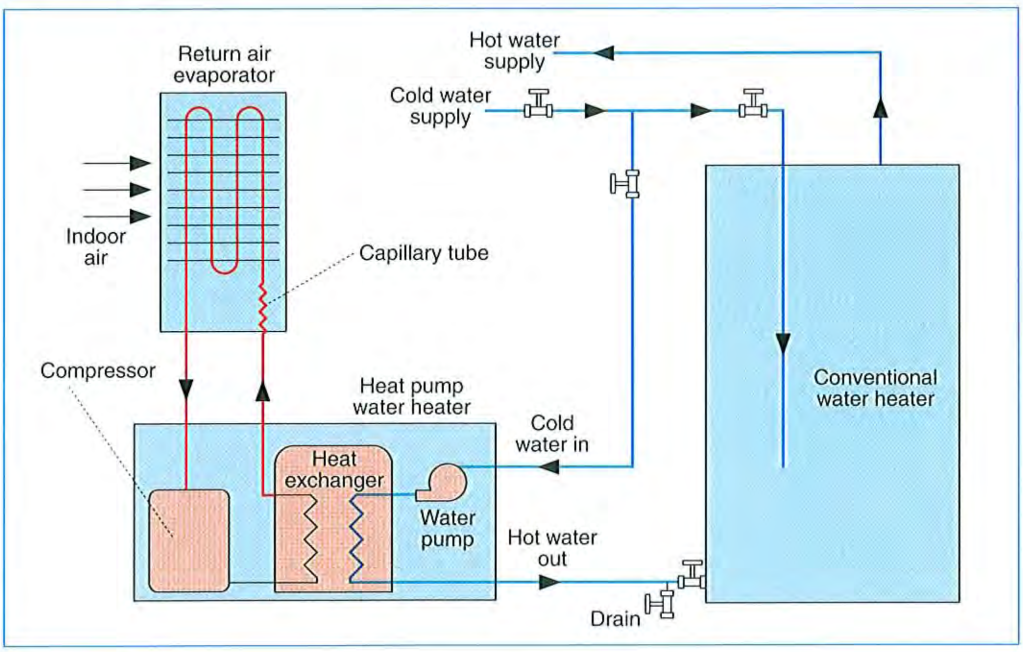

Figure 2: Typical piping layout of the prototype HPWH.

describing the losses associated with supplying hot water from a tank. Minimum energy factors for gas and electric hot water heaters are typically 0.58 and 0.93 respectively. The hot water heating demand is based on a daily requirement to heat 240 litres by 43°C.

The analysis estimates an annual COP of 2.02 for the prototype HPWH, without taking credit for the cooling effect supplied by the HPWH during the summer. This is identical to the figure estimated by the US DOE in its report on HPWHs [3]. But as shown earlier in this article, the 351 kWh consumed by the prototype HPWH in summer is compensated by a similar reduction in electricity consumption by the air-conditioning system. When this additional benefit is credited, the "net" power consumption is 1980 kWh with a resulting annual COP of 2.38 and annual savings of 2730 kWh.

This means that if the rate of construction remained at 246,000 heat pump conditioned homes per year, and each was equipped with a HPWH of the type described, 1.7 TWh would be saved annually from reclaimed heat during the cooling season after 20 years of cumulative construction. Overall, the annual savings of 2730 kWh per residence would then amount to 13.4 TWh per year. [According to IEA statistics, this is just under 0.05% of the total US electricity consumption in 1991 (2913 TWh) ED.].

Value for Money

It is anticipated that the additional cost of the prototype HPWH will typically be US$ 800 to US$ 1,200 more than a CEWH. With currently typical annual repayment rates for loans in North America of about 10% of the loan value, the additional cost of a HPWH over and above the cost of a CEWH would be US$ 80 to US$ 120 per year. Table 2 shows the first year operating cost savings with the prototype HPWH for a range of daily hot water use rates and marginal power costs.

By showing only the first year savings, Table 2 presents a conservative estimate of the value to the owner/user. The real value of the savings are likely to increase every year as inflation affects the power costs while the actual value of the loan repayments remains the same. Since most single-family residences in the United States use at least 190 litres (50 gallons) of hot water per day, Table 2 shows that the prototype HPWH would provide a first year positive cash flow in nearly all cases. Even the few combinations with first year savings below US$ 80 would result in an attractive return on investment for the owner/user when the impact of inflation on future power cost is considered.

Good for the Environment

The HPWH also has potentially advantageous environmental attributes. Table 3 compares the primary energy consumption of the prototype HPWH with a CEWH and a gas boiler, using data from a recent study in the United States [4]. The CEWH requires 136% and the natural gas water heater requires 11% more source energy than the HPWH. Accordingly, the emissions to the atmosphere would be 58% less with the electric HPWH than with the CEWH.

Daily heating demand		12 kWh
DOE Energy Factor		0.93
Conventional electric water heater		
COP = 1		
Annual electricity consumption:	$\frac{12 \times 365}{0.93}$	4710 kWh
Prototype Heat Pump Water Heating System		
100 days cooling		
COP HPWH = 3.68 @ 24°C evaporator temp.		
Electricity consumption HPWH:	$\frac{12 \times 100}{0.93 \times 3.68}$	351 kWh
200 days space heating		
COP HPWH = 3.33 @ 21°C		
COP space conditioning heat pump = 2.05		
Electricity consumption HPWH:	$\frac{12 \times 200}{0.93 \times 3.33}$	775 kWh
Additional electricity consumption of space heating heat pump:	$\frac{12 \times 200 \times (3.33 - 1)}{0.93 \times 2.05 \times 3.33}$	881 kWh
65 days mild season		
COP HPWH = 2.59 including blower motor		
Electricity consumption HPWH:	$\frac{12 \times 65}{0.93 \times 2.59}$	324 kWh
Total electricity consumption		**2331 kWh**
Annual COP:	$\frac{12 \times 365}{2331 \times 0.93}$	**2.02**

Table 1: Calculated energy consumption of conventional and prototype water heating systems.

Daily hot water use US gallons	Litres	Annual CEWH kWh	Annual HPWH kWh	First year HPWH savings, US$ US$ 0.04/kWh	US$ 0.06/kWh	US$ 0.08/kWh
40	150	2,925	1,230	68	102	136
45	170	3,300	1,390	77	115	153
50	190	3,660	1,540	85	127	170
55	210	4,025	1,695	93	140	187
60	230	4,390	1,850	102	154	204
65	245	4,755	2,000	110	165	221
70	265	5,120	2,155	119	178	238
75	285	5,490	2,310	127	190	255
80	300	5,855	2,465	136	204	271

Table 2: First year operating cost savings using a HPWH in place of a conventional electric water heater (CEWH).

Comparing the emissions from using the HPWH with those from a natural gas water heater is complex, as many factors concerning the electricity mix have to be considered. One way to make the comparison is to consider that a choice can be made between supplying natural gas directly to the users of gas water heaters, or to a gas-fired power generator for meeting new electrical demand from HPWHs. In the latter case, less gas would be needed for the same amount of water heating, with a consequent reduction in emissions.

Practical Heat Recovery

The prototype HPWH described in this article demonstrates a practical way to recover heat from household air-conditioning systems making it suitable for application in a large number of homes in the United States. It has the potential to avoid billions of kWh each year while providing lower total costs to the users than conventional electric hot water heaters. The widespread introduction of this technology in new homes would make a significant contribution to the conservation of primary energy for power generation and the reduction of associated emissions to the atmosphere.

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Table 3: Primary energy consumption with three different types of water heater.

	Annual load (kWh)	DOE energy factor	COP	End use (kWh)	Cumulative efficiency %	Primary energy consump. (kWh)
Gas	4395	0.58		7580	91.2	8310
CEWH	4395	0.93	1.00	4730	26.7	17,700
HPWH	4395	0.93	2.38	1990	26.7	7440

Note: "Cumulative efficiency" includes losses from extraction, processing, transportation, conversion and distribution.

Heat Recovery in Thermal Baths

Pinch Analysis Leads to Optimal Heat Pump Usage

Pierre Krummenacher, Frederic Staine and Daniel Favrat, Switzerland

Pinch analysis is a powerful analysis and design methodology for the integration of thermal processes. Although originally developed for and applied to continuous industrial processes, pinch analysis can be equally beneficial when applied to buildings. In this article, the retrofit of a heat recovery scheme in a thermal bathing resort is discussed, with pinch analysis used to optimize the placement of a heat pump and the operating temperatures of the supply manifolds.

* * *

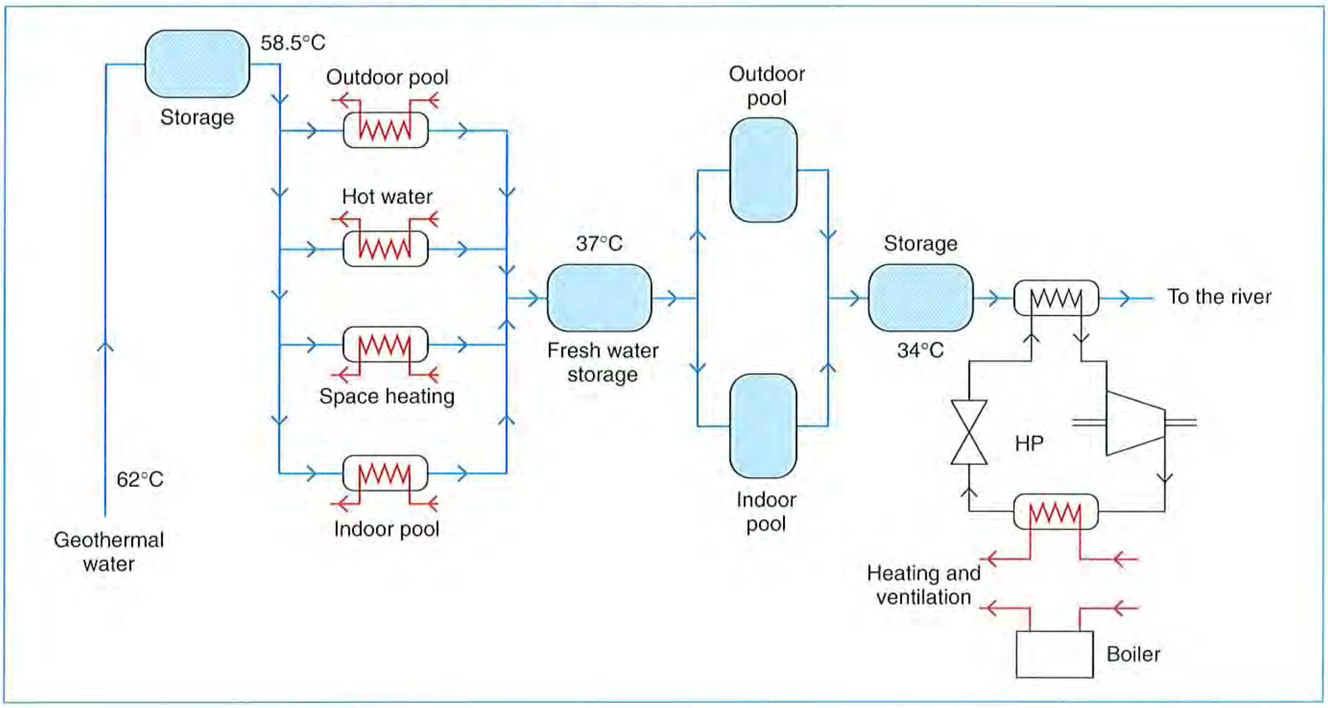
The thermal bathing resort at Lavey-les-Bains includes two swimming pools (indoor and outdoor), a health care facility, a hotel and a clinic. It was developed around a geothermal hot spring from a 201 m deep borehole dug in 1973. A simplified flow diagram of the system is shown in Figure 1.

The geothermal water is pumped at a rate varying between 200 l/min and 500 l/min and used to heat the swimming pool and tap water, and to supplement room heating. The cooled geothermal water capacity is used each night to replenish the outdoor and indoor swimming pools. The used swimming pool water is pumped into a buffer storage.

Heat Recovery

Up until 1983, only a small portion of heat from the used water, which is still lukewarm, was recovered by preheating tap water. Excess heat was lost in outdoor fountains before it was finally discharged in the nearby river Rhône at a maximum temperature of 28°C. In 1983, a heat pump was installed to recover more heat from the used water. The heat pump provides baseload space heating while the existing oil-fired boilers are only used for peak load at outside temperatures below 4°C. The heat pump has a 145 kWe electrically driven, reciprocating compressor working with CFC-12, an evaporation heat rate of 425 kW at 11°C and a condensation heat rate of 560 kW at about 60°C. Heat is presently distributed at two temperature levels (typically 70/50°C and 50/40°C, with the actual flow set-point temperature depending on the outdoor temperature). The seasonal performance factor (SPF) of the heat pump is 3.8.

Figure 1: Simplified flow diagram of the thermal bathing resort.



Unfortunately, the combination of increased power costs and low oil prices has meant that the operating costs of the heat pump are now more than 10% higher than those of the oil boiler. In addition, the tube bundle type heat exchangers perform poorly and are costly to maintain.

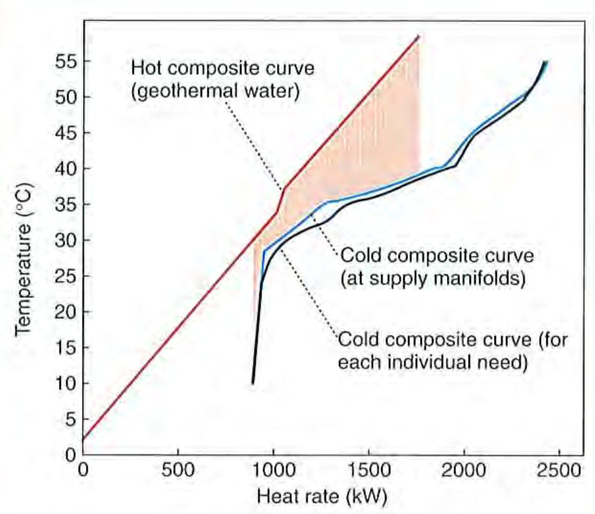
In order to improve this situation, a study has recently been started, with support from the Swiss Federal Office of Energy, to upgrade the performance of the heat recovery scheme. Taking a lead from work done for industrial processes, the study is applying the methodology of pinch analysis.

Pinch Analysis

Pinch analysis (also referred to as *pinch technology*) is a powerful analysis and design methodology for the integration of thermal processes (ranging from industrial processes to thermal energy systems in buildings, district heating, etc.). The ultimate goal is to design or retrofit existing processes to use as little primary energy as possible at minimum annual total cost. Pinch analysis provides the engineer with a systematic approach which leads quickly and with confidence to this goal by making the most out of the energy involved in the process. Intermediate steps include:

- determination of the minimum practical amount of energy required to operate the process;
- determination of the energy saving potential;
- examination of opportunities for process change;
- design of the heat exchanger network;
- optimization of the heat and cold supply system.

Figure 2: Composite curves for the original system.



Pinch temperature 30.08 °C
High utility (hot) 669.87 kW
Low utility (cold) 899.43 kW
ΔT_{min}=3.0°C

Two graphical tools assist in this analysis, namely the composite curves and the grand composite curve. These curves show the temperature characteristics of the process considered, indicating the heating and/or cooling rates needed at each temperature. The pinch temperature derives from the composite curves and plays a central role for both the analysis and design phases, hence the name of this methodology. A general overview of pinch analysis can be found in [1].

Collecting the Data

Collecting data on the heating needs (cold streams) and heat recovery opportunities (hot streams) is an important step in pinch analysis. In buildings, as opposed to industrial processes, most of the heating needs can vary over a large range of heat rates as well as temperature levels throughout the year. In the study, heat streams were measured at outdoor temperatures of between -3°C and +7°C, and extrapolated to the lowest design temperature of -7°C for the purpose of pinch analysis.

The level at which a heating need is defined and assessed is important and depends on whether one is doing a retrofit or a completely new design. Take, for example, the stream associated with a heating need for space conditioning. When a new design is being considered, this will be defined as an air flow to be heated from the outdoor temperature to the prescribed temperature, since one still has the freedom to design the space conditioning unit and the heating coil. However, for a retrofit project for which modifications have to be minimized, the stream should be associated with the water flow supplying the existing heating coil which must be left unchanged. The cold stream should only be considered at the air flow level when the space conditioning unit is close to the end of its service life, or if the composite curve analysis proves that this unit acts as a single major limiting factor for heat recovery.

At the thermal bathing resort at Lavey-les-Bains, the existing heat exchangers are planned for replacement soon, so the associated heat streams have been measured on the secondary side (from a heat transfer point of view). In addition, each space heating and ventilation network has been individually monitored since measurements during cold days have shown that for many networks the temperatures at the inlet manifolds were significantly higher than the flow temperature, suggesting opportunities for lowering the inlet temperatures using an improved control system.

Composite Curves

The composite curves (at -7°C outdoor temperature) for the measured heat streams are shown in Figure 2. The hot composite represents the global heat recovery opportunity from the geothermal water (assuming it could be potentially cooled down to 2°C). The cold composite represents the numerous heat demands including that for hot water, swimming pool water and space heating via radiators, ventilators and underfloor heating.

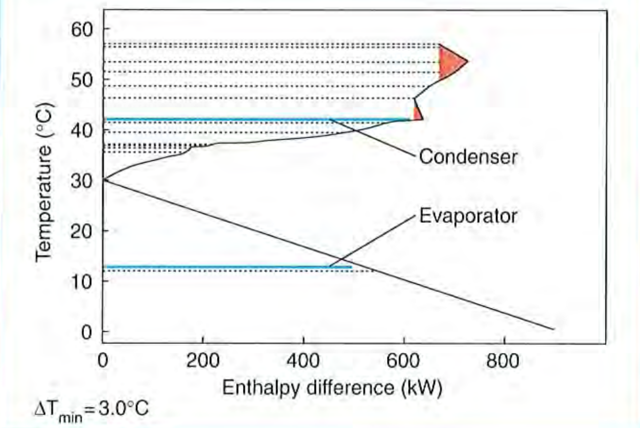
To illustrate the effect of supply manifold operating temperatures, two cold composite curves are drawn, one using the complete stream data (a stream being associated with each single heating or cooling need) and another where the manifold temperatures are adjusted as closely as possible to the highest temperature requirement of the supplied heating networks. The difference between a direct supply of each single heating need and a supply through manifolds is in this case particularly important considering the fact that those streams occur in the critical pinch region.

From the composite curves, the particular streams contributing significantly to the pinch point can be identified for retrofit.

Operating in a better way

The grand composite curve (Figure 3) represents the minimum temperature levels of heat to be supplied by hot utilities (above the pinch temperature of 30°C), as well as the unused heat profile (below the pinch temperature). According to pinch analysis, the red zones represent temperature ranges that can be self satisfied. A heat pump is particularly well suited with such temperature profiles. If a new heat pump was considered, it would ideally be of the Lorenz type (zeotropic mixture of refrigerants) or consist of two single units in series. In this particular case, the study will probably confirm that the existing unit should be kept, with an evaporation level adjusted to the highest suction pressure level tolerated by the compressor (to be further investigated). Using HFC-134a as the working fluid would result in the following calculated values: 497 kW (11.4°C/4.4 bar) on the evaporator side, 591 kW (43°C/11.1 bar) on the condenser side, 94 kWe to drive the compressor and a COP of 6.3 (compressor efficiency is assumed to be 70%).

Figure 3: The grand composite curve.



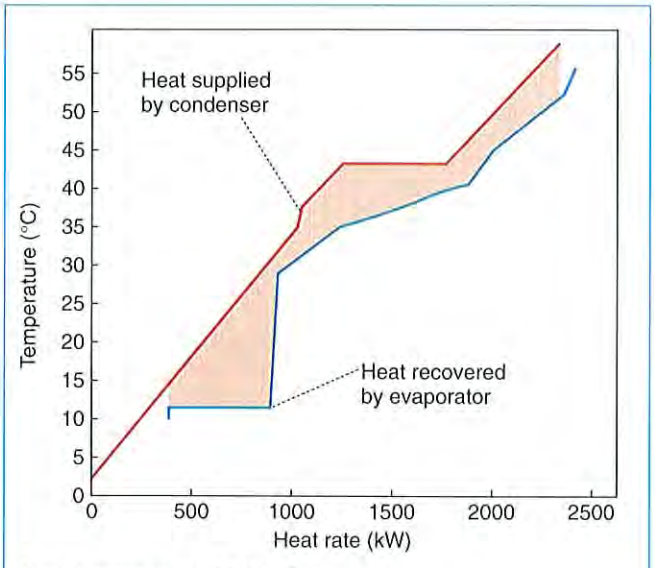


Figure 4: Composite curves with proposed heat pump.

Based on the proposed retrofit, Figure 4 shows the resulting composite curves including the heat pump streams. It can be seen that about 80 kW of heat must still be supplied. This could probably be met by a small increase in the pumping rate of the hot spring (the effect of such an increase has to be investigated) or by the existing back-up oil boiler. Calculations show that the heat rate supplied to the heat pump evaporator would practically drop to zero at outdoor temperatures above 7°C, corresponding to a mean yearly heat pump use of about 3600 hours.

Pointing the Way

The study shows how pinch analysis, initially developed for the energy integration of industrial processes, can significantly contribute to the design of energy recovery schemes in buildings. The study made at the thermal bathing resort has identified ways to improve the use of an existing heat pump and points the way to the further use of pinch analysis as a tool for optimizing waste heat recovery in buildings.

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Meeting the Challenge of Waste Heat Recovery

Ichiro Tanasawa, Japan

With a huge demand for low-temperature heat for buildings, no one can doubt that the use of waste heat from industry and other sources is a good idea. But many technical and other barriers must be overcome if the introduction of large-scale waste heat recovery is to be more than a pipe dream.

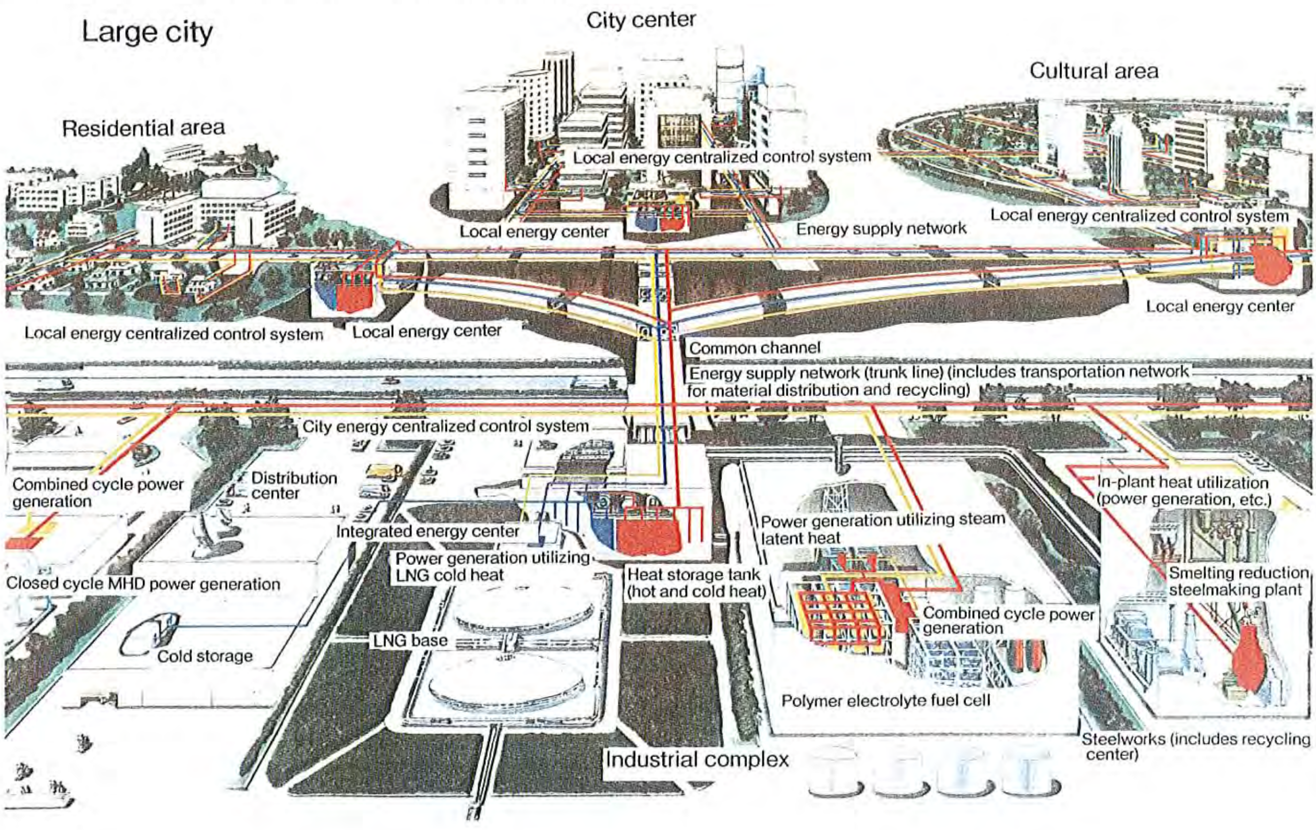
In Japan, waste heat recovery is seen as one of the most realistic medium-term options for energy conservation. Three national projects have made and are continuing to make significant progress in the development of the required technologies. This article outlines some of the advancements made in the fields of heat pumps, large-scale thermal storage and long-distance thermal transport.

* * *

In the last two decades, tremendous efforts have been made in Japan to reduce the consumption of petroleum, and to develop new technologies to exploit new energy sources in place of oil. However, the primary purpose of reducing energy costs has so far been unsuccessful. In particular, power generation from renewable energy sources has turned out to be far more expensive than conventional electricity.

While the decline in the oil price may initially have caused a slowing of these efforts, today's environmental concerns have revived interest in new energy technologies. Looking at the development of energy supply and demand in Japan, not much can be expected from new technologies such as solar, wind, geothermal, OTEC (Ocean Thermal Energy Conversion), fuel cell, biomass and thermonuclear fusion for at least 20 years.

Figure 1: Conceptional diagram of the Eco-Energy City.



Realistic Option

The most realistic option is to make more effective use of thermal energies at medium and low temperature levels. The use of such low-grade thermal energies, or waste heat, for office and residential applications is reasonable in terms of both the thermodynamic principles and the characteristics of energy supply and demand in Japan. But before effective use of waste heat can be accomplished, a number of problems must be resolved, including social and legal regulations, along with economic and technical issues.

Among the technical issues to be addressed, progress in heat pumps has received considerable attention as a means for making efficient use of waste heat. However, progress in other technologies such as thermal storage and transport are equally important. In Japan, research and development work has centred around three national projects sponsored by the Ministry of International Trade and Industry (MITI) and implemented by the New Energy and Industrial Technology Development Organization (NEDO):

- The Super Heat Pump Energy Accumulation Systems Project (SHPEAS Project);
- Development of Technology for Load-Levelling Air-Conditioning Utilizing Unused Energy (Unused Energy Project);
- The Broad Area Energy Utilization Network System Project (Eco-Energy City Project), illustrated in Figure 1.

Waste Heat

Where to find it

As is well known, in using primary energy sources, nearly 100% of the energy ends up as waste heat. Of course, not all of this heat can be recovered - some of it is at a very low temperature or liberated in very small quantities. And most high-temperature, large-quantity waste heat sources are already used to increase the total efficiency of the relevant processes. However, there still exists an enormous amount of waste heat at medium and low temperature levels.

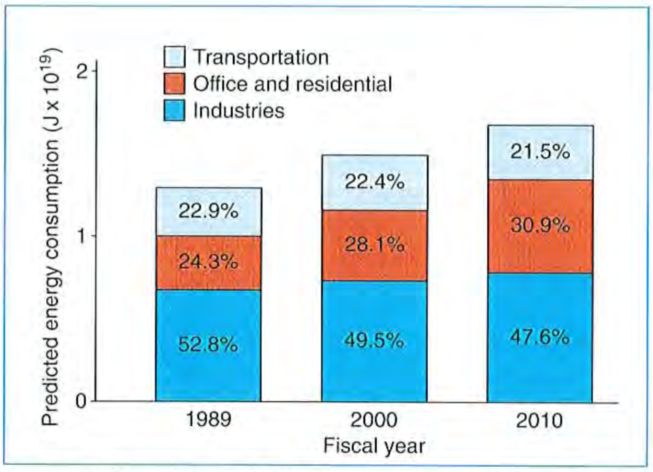


Figure 2: Development of energy consumption in Japan.

How to use it

Figure 2 compares the predicted energy consumption in the years 2000 and 2010 with the actual consumption in 1989 [1]. The most striking feature is the increase in energy consumption for office and residential use, while the share of energy consumption in industry is expected to decrease. Most of this increase is for air conditioning and hot-water supply - applications which can utilize low-grade waste heat. Given that heating, cooling and hot water supply are the most appropriate ways of utilizing waste heat, the use of heat pumps is essential.

Super Heat Pumps

Focusing on compression heat pumps, great efforts have been made to develop high-performance heat pumps (super heat pumps) under the SHPEAS project started in 1984. Table 1 summarizes the systems developed under this project. As shown, these systems demonstrate the use of waste heat at various temperatures, and very high COPs were achieved. However, several issues need to be addressed before these systems will be broadly accepted in the commercial market:

Table 1: Compression heat pumps developed under Japan's Super Heat Pump Project.

Type of heat pump	Heating only	Heating and cooling		High temp. output from low temp. heat source	High temp. output from high temp. heat source
		Heating	Cooling		
Heat source temp. (°C)	50	10	32	50-95	150-200
Output temp. (°C)	85	45	7	150	300
COP	8	6	7	3-5	3-6
Output capacity (kW)	1465-4070	1000	200	600-2400	1000
System weight (ton)	15-35	35	7	18-50	40

- the heat transfer efficiency of heat exchangers such as in condensers and evaporators;
- the optimum concentration ratio of the components of binary or ternary refrigerant mixtures;
- the thermodynamic and heat transfer performance of current and new working fluids, including mixtures;
- efficiency of the thermo-fluid-dynamic devices used in the system.

Although these issues may appear to be purely technical, they are closely related to economic issues. For example, improvements in the heat transfer efficiency of heat exchangers will reduce energy losses and improve the cycle efficiency. Consequently, the size of the heat exchangers will be reduced, so less materials are used in manufacture, and dynamic losses in the refrigerant flow are lessened. These improvements are all connected, directly or indirectly, to reducing the cost of heat pump systems.

Unused Energy

Under the Unused Energy Project, started just three years ago, several different types of heat pump system are being developed. One of them is a turbo-compression type heat pump which uses sewage water as heat source. Another compression-type heat pump for supplying hot and cold water to buildings, is driven by the high-temperature steam generated from waste incineration. The steam from the waste incineration plant is also supplied to absorption heat pumps for heating and cooling. A key technology pursued in this project is to improve the performance of heat pumps under partial loads and unsteady operating conditions. This aspect is important because of the variation in the thermal conditions of heat sources between day and night and seasonally.

Eco-Energy

Heat pumps play a vital role in a thermal energy system by overcoming the mismatch between the temperature of the heat source and that required by the user. But the effective use of waste heat is also limited by mismatches in time and space between supply and demand. The global efficiency of waste heat utilization would be improved to a great extent if we could transport thermal energy to distant consumers without causing substantial losses, and if we could store it for use as required. The Eco-Energy City project, started last year, is trying out some novel solutions to heat transport and storage, along with other innovations in the areas of heat recovery, heat supply and heat utilization.

The most essential concept for the transport and storage of heat in this project is the conversion of thermal energy from a waste heat source into a form of chemical energy. One of the most promising chemical processes is the decomposition of methanol (CH_3OH) into carbon monoxide (CO) and hydrogen (H_2) by an endothermic reaction.

Industrial waste heat at 150-200°C is used to generate a mixture of carbon monoxide and hydrogen which is transported through pipelines to an urban area. Here it is converted back to methanol by an exothermic reaction, releasing the energy absorbed in the industrial area for use in heating and/or cooling. The synthesized methanol is then transported back to the industrial area. Transport and storage is much more effective than with conventional systems using water, ice or steam, as heat loss problems are avoided. In the Eco-Energy City Project, thermal waste energy from industries will be transported to cities as far as 30 km away.

Another technology under investigation is the use of hydrogen as the energy carrier. The technique employs at least two different metal hydrides. For example, one absorbs or desorbs hydrogen at a pressure of 1 MPa (10 atmospheres), the other at 0.1 MPa (1 atmosphere). Industrial waste heat is used to desorb hydrogen from a metal hydride at 1 MPa. The hydrogen gas is then transported to a city area, where it is absorbed by the other metal hydride at 0.1 MPa, releasing the heat of absorption. It is intended that industrial heat is transported by this method to urban areas 10 km away. If various kinds of metal hydrides operating at different temperature levels are employed, supply of heat or cold at arbitrary temperature levels becomes possible.

Worthy of the Challenge

The importance of waste heat recovery as a measure to reduce energy demand cannot be overstated. While much work is still needed in the development of various technologies, waste heat recovery is seen as a realistic medium-term energy option in Japan.

Government sponsored projects are making significant progress in the development of heat pump technology and of other supporting technologies such as transport and storage. While many difficulties must be overcome before these technologies are utilized successfully, the potential environmental benefit from making effective use of waste heat, means they are surely worthy of the challenge.

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District Heating Using Waste Heat and Fuel from a Hydropower Plant

Kurt Atzgerstorfer, Wilhelm Scheidel and Reinhard Steiner, Austria

A small district heating system by the river Danube is demonstrating an excellent way to utilize both waste heat and solid waste efficiently and to avoid damage to the environment. Waste heat produced by the generators of a nearby hydropower station is used as the heat source for an electric heat pump. Floating wood collected in the storage lake of the hydropower station provides an additional waste energy source. In this way both thermal waste heat and biomass are utilized and greenhouse gas emissions from fossil fuels are avoided.

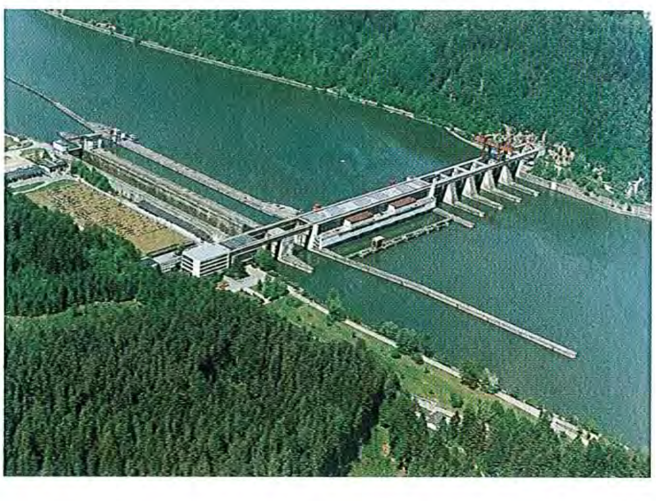
* * *

Photo 2: Electric heat pump - 1 MW (thermal) - using HFC-134a.

In the villages Aschach and Hartkirchen in Upper Austria, a district heating system is supplying 307 residents with heat for both space heating and hot water production. In future, the system will be expanded to serve a total of 540 users. The heat supply is produced exclusively by the utilization of renewable energy sources:

- waste heat from the generators of the Danube hydropower station Aschach (see Photo 1) which is upgraded by means of a heat pump from 20°C to the temperature level required;
- floating wood from the Danube, which is collected, dried and burned during the heating season in two biomass boilers for peak load operation.

Photo 1: Hydropower station Aschach on the Danube.



The installed thermal capacity is 5 MW: 1 MW is covered by the heat pump, and 4 MW by the biomass boilers. Two electric resistance heaters with a capacity of 2 MW are installed as an auxiliary system. Figure 1 shows the flow diagram of the district heating central station.

Heat Supply

The heat pump (see Photo 2) is a sophisticated design, comprising an electrically driven, open screw compressor equipped with an economizer, a desuperheater, a sub-cooler and an internal heat exchanger. This expensive system offers high efficiency, recording COPs of 4.5 to 4.8 during test runs at an evaporation temperature of 20°C and a condensation temperature of 75°C. The refrigerant used is HFC-134a, the only safe refrigerant available for operation at the supply temperature of 80°C required by the district heating network.

In summer, the heat pump operates in monovalent mode to supply hot water. During the heating season, the heat pump is used for preheating the district heating return, with end-heating carried out by the biomass boilers. This means that the heat pump operates throughout the year, with running times expected to be in the range of 7000 to 8000 hours a year, covering 35% of the total heat requirement.

The two biomass boilers only operate during the heating period, and supply 60% of the annual heat requirement. The 4 MW heating capacity of the biomass boilers is split into two parts of 1.5 MW and 2.5 MW each, to achieve a good match with the heat load required and to reduce part-load operation. The smaller biomass boiler is operated down to outside temperatures of +8°C, the larger one to -2°C. At lower outside temperatures, both biomass boilers are used. About 5% of the load is met by the electric heaters, mainly to avoid part-load operation of the biomass boilers at moderate outside temperatures at the beginning of the heating season. Figure 2 shows a typical breakdown of heat delivery over the year.

Heat Distribution

The district heating network of Aschach Hartkirchen has a length of 17 km. The supply temperature to the users depends on the outside temperature with a minimum of 70°C to ensure hot water production and a maximum of 90°C for an outside temperature of -20°C. This ensures that the customer who requires the highest temperature level for his distribution system can be supplied with sufficient heat at the lowest outside temperatures.

A data cable is installed alongside the piping. This allows the instantaneous operating conditions (heating and hot water production) including temperature demands to be checked at the district heating plant. Users have the possibility to adjust their individual heating curves (the dependency of required supply temperature on the outside temperature) and to program night or even day setbacks. These values cannot be directly read in the central station, but they can be calculated from the supply temperature of the district heating network and the temperatures required by the users.

Improving the System

Several options can be considered for optimizing the district heating network:

Reducing the Supply Temperature

The heat pump COP can be improved by minimizing the supply temperature: a reduction of the heat pump outlet temperature by 1 K means an increase in COP

Figure 1: Central station of the district heating system.

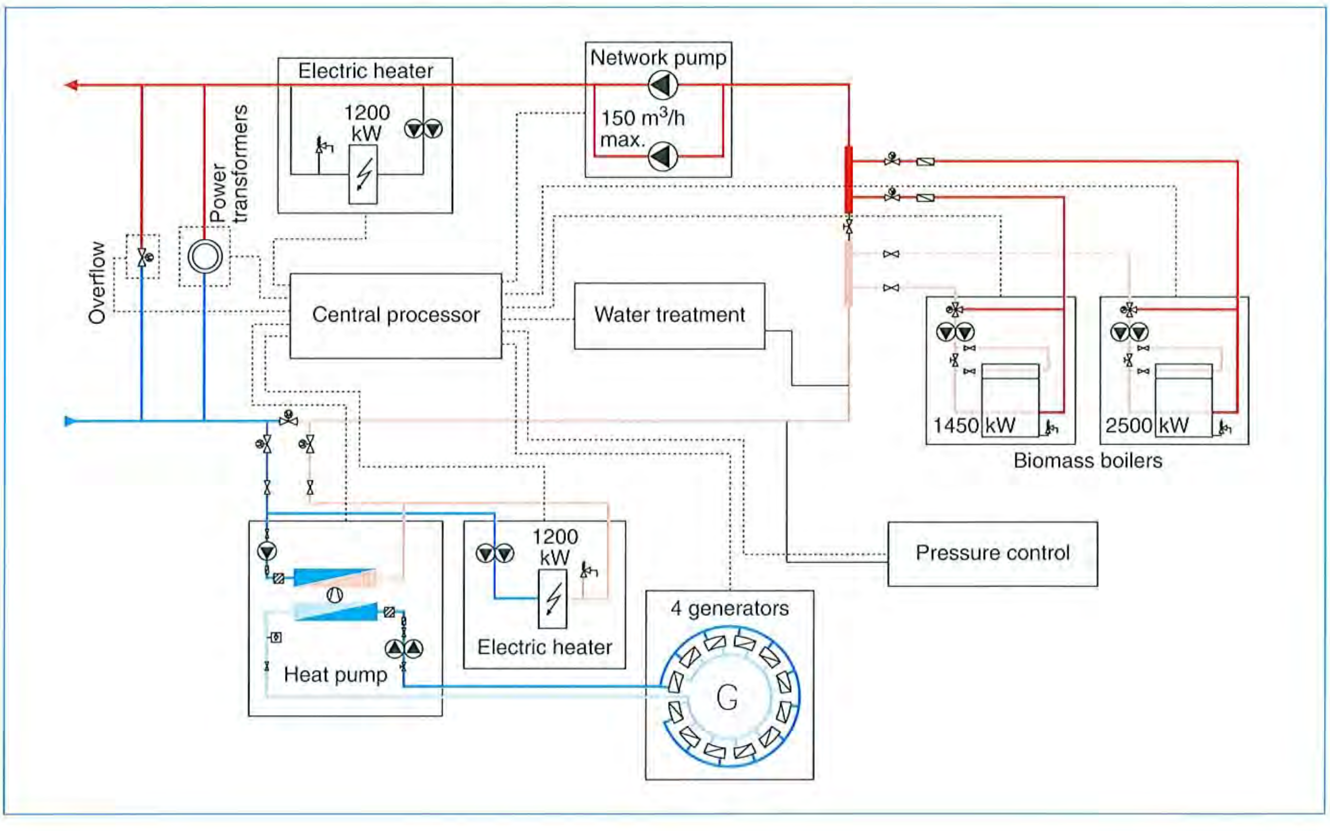
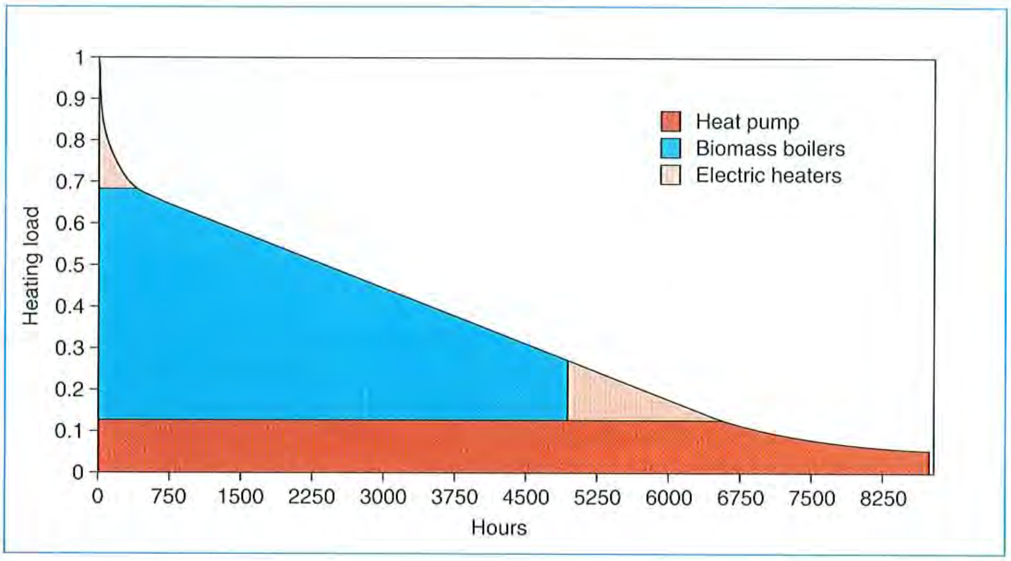


Figure 2 : Annual heat delivery profile for the district heating system.



of about 2% and a corresponding reduction in energy consumption. At the same time, this temperature reduction means an increase in heating capacity of about 1%.

The required reduction in the district heating network supply temperature can be achieved by monitoring the actual supply temperatures at user substations and identifying those users which have higher supply temperature requirements than the average. For these users it is possible to reduce the supply temperature requirement by increasing the radiator area or by using a decentralized small heat pump using the district heating return as heat source.

Reducing the Peak Load

Further improvement in system performance can be achieved by reducing peak-load operation. Heating up the network earlier in the morning reduces the effect of the morning peak demand by taking advantage of the inherent storage capacity in the network.

Improving the COP

There are some additional possibilities to improve the efficiency of the heat pump. The present design, although it is very expensive, is on the safe side of the operating parameters. It should be possible to increase the evaporating temperatures from the current 20°C to at least 24°C. This would increase the COP by about 8% and the heating capacity by at least 12%.

A second possibility is to optimize the intermediate pressure of the economizer together with the use of superheating. Increasing the capacity in this way is limited by the axial bearing of the compressor, which is one of the critical parts of the screw compressor, and by the lubrication circuit.

Exploiting Available Resources

This unusual project provides an excellent example of how to exploit locally available energy resources. The combined use of waste heat and floating wood has eliminated the need to burn fossil fuels with consequent benefits to the environment.

The sophisticated monitoring system is helping system designers to make further improvements to the efficiency of the district heating network by optimizing the supply temperature and the operation of the heat pump. The results of this work can influence the design and the economic criteria of future district heating networks with waste heat recovery heat pumps.

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College Heating System Exploits its Local Heat Sources

Gunther Reiner, Switzerland

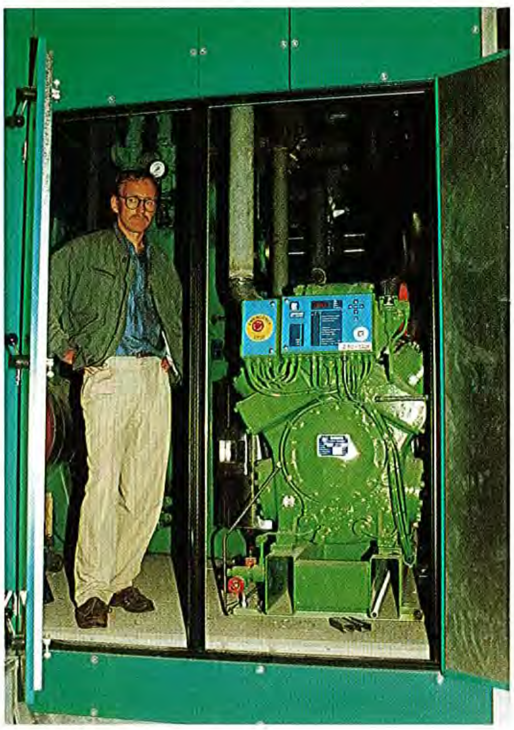
The energy management system adopted for a new college gymnasium has taken a novel approach to the use of heat pumps. By using two heat pumps with different working fluids, the system is able to recover heat from a variety of heat sources.

An ammonia heat pump utilizes heat from a refrigeration unit and lake, while an HFC-134a heat pump recovers heat from a number of warm air streams. Both electric heat pumps are driven by a gas engine driven cogeneration unit.

* * *

In building a new gymnasium for Alpenquai college in Lucerne, the local authority wanted to demonstrate advanced solutions for reducing pollution. With its location at the shore of Lake Lucerne, adjacent to an ice rink and the cold storage depot of a local butter manufacturer, the new gymnasium presented a perfect opportunity for a waste heat recovery heat pump application.

Photo 1: Project manager, Urs Bickal with the ammonia heat pump.



The heating system chosen for the new building (see Figure 1) features two electric heat pumps: a high lift ammonia heat pump and a smaller HFC-134a heat pump. A gas engine driven cogeneration unit delivers the necessary electric power for the heat pumps. The system supplies domestic hot water and space heating via a hydronic distribution system.

Heat Sources

Heat is recovered from different sources by the two heat pumps:

Ammonia Heat Pump

A newly installed pump station at the shore of Lake Lucerne feeds a ring pipe that supplies the cold storage depot and the ice rink with coolant. After the cooling water is warmed up by the refrigeration plant, it is used as a preferred heat source for the ammonia heat pump. If the heat rejected from the refrigeration plant is insufficient, the deficit is supplied by lake water.

HFC-134a Heat Pump

The hot air from the noise protection cabins of the ammonia heat pump and the gas engine is used as a heat source, along with the heat obtained from cooling down the supply air of the gas engine.

Heat Pumps

A 158 kW (heating) HFC-134a heat pump was chosen as the most suitable system for operation with a high-temperature air heat source and for the supply of space heating. With the small temperature lift, the HFC-134a heat pump achieves a COP of 3.6.

In contrast, the ammonia heat pump using the lake water must operate at heat source temperatures as low as 3.5°C and reach a supply temperature of 65°C in order to provide hot water. This extreme temperature lift is most suited to an ammonia heat pump with two-stage compression and expansion. This is now possible due to the newly available high-pressure ammonia compressors which can operate at 40 bar.

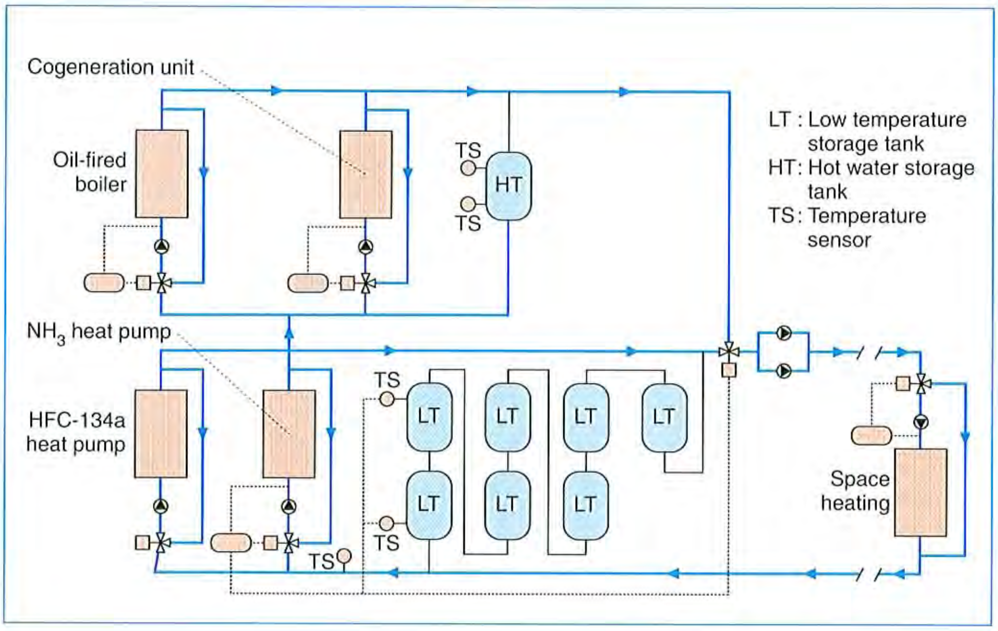


Figure 1: The heating system at Alpenquai college.

Ammonia compressors have the advantage of operating at evaporation temperatures of up to 20°C. The two-stage heat pump process, together with the ability to use a high-temperature heat source, means that the chosen ammonia heat pump can yield much higher operation cost savings than a conventional heat pump. COPs of between 2.8 and 4.8 have been registered.

Technical data on the heat pumps is given in Table 1. Figure 2 shows the configuration of the ammonia heat pump.

System Design

As shown in Figure 1, both heat pumps heat the return water from the heating system. The HFC-134a unit supplies heat to the heating system via seven 10 m^3 storage tanks, while the ammonia heat pump preheats water before it is heated by the gas engine cogeneration unit. The cogeneration unit adds heat to the hot water supply via an additional storage tank. When excess heat is produced by the cogeneration unit or when a shortage of heat pump capacity occurs, the heating water from the high-temperature storage tank is also used for space heating. If at low outside temperatures the heat production of the cogeneration unit and the heat pumps is insufficient, then the deficit is covered by an oil-fired boiler.

Precautions

Several precautions have been taken to ensure that there is no significant risk from the toxic effects of ammonia. As a first step, risk has been reduced by using plate heat exchangers to minimize the working fluid charge.

To avoid exposure to people (ammonia affects the respiratory tracts and may cause respiratory paralysis at high concentrations), the gas-tight noise protection cabin is always kept below atmospheric pressure so that leaking ammonia cannot reach the heating room. In addition, ammonia sensors are located in the water (pH-value) and in the air streams.

Precautions are also taken to protect the local environment. Although the impact of ammonia can be quickly reduced in nature due to its good reaction ability, even small concentrations can be lethal to fish. Therefore a glycol/water loop connects the lake water and the ammonia refrigeration circuit to ensure the highest possible security for the lake.

Photo 2: This cold storage depot provides a year-round heat source for the heating system.

Heat Consumption		
Max. required heating capacity	1500 kW	
Supply return temperatures for space heating	70/50°C	
Consumption of tap water (60°C)	5000 litres/day	
Heat pumps	**ammonia**	**HFC-134a**
Heating capacity	575... 670 kW	158 kW
Heat source	lake water	air from noise protection cabins
	refrigeration plant	air from gas engine
Min./max. heat source temperatures	3.5/30°C	25/30 °C
Max./min. heat sink temperatures	65/45°C	60/54°C
Min./max. electrical power consumption	135... 205 kW	44 kW
Coefficient of performance	2.8... 4.8	3.6
Cogeneration unit		
Heating capacity	430 kW	
Electrical power output	255 kW	
Primary energy consumption	890 kW	
(gas at higher heating value)		

Table 1: Technical data of the heating system.

A Good Combination

By combining heat pumps with different working fluids, this system exploits local heat sources to the full. It demonstrates a number of techniques that can play an increasingly important role in heat pump technology:

- heat recovery from a variety of heat sources;
- the combination of heat pumps and cogeneration;
- the use of ammonia working fluid in building applications.

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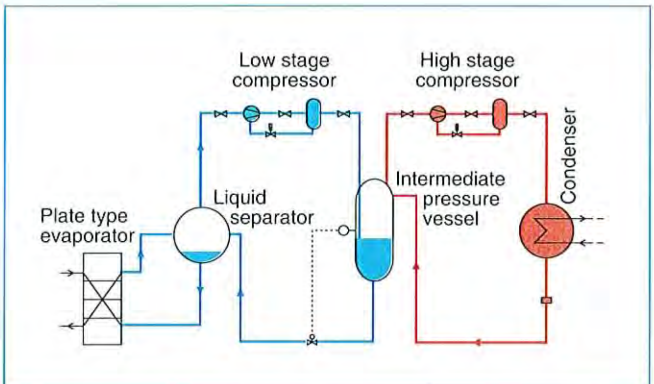

Figure 2: Two-stage ammonia heat pump.

Bibliography

International Heat Pump Status and Policy Review
Published by the IEA Heat Pump Centre; Order No. HPC-AR3; 1994; English, Price NLG 250 for all three volumes.

The culmination of a worldwide effort to determine the facts, this report assesses the heat pump situation with regard to markets, technological progress and policies. With the help of the International Institute of Refrigeration, the report reveals many new data from both member and non-member countries of the IEA Heat Pump Programme. In Volume 1, key information on 16 countries is brought together, compared and discussed. Volume 2A provides detailed reviews of these countries in the form of *National Position Papers (NPPs).* Volume 2B, to be issued in late 1994, will include NPPs on several more countries. Separately bound NPPs can be purchased for NLG 40 each. All those concerned with the implementation of heat pump technology should obtain a copy of this report.

Refrigerant Mixtures
10th Informatory Note on CFCs, HCFCs and Refrigeration. Published by the International Institute of Refrigeration (IIR), Paris, France; Fax +33-1-4763-1798.

This leaflet provides basic information on the use of refrigerant mixtures as alternatives for HCFC-22 and R-502. It describes the advantages and disadvantages of various mixtures, and emphasizes the consequences associated with their use. It calls for further work to improve understanding on the economic, efficiency and flammability issues concerning mixtures.

ARI Flammability Workshop
Published by the Air-Conditioning and Refrigerant Institute (ARI), United States; Fax: +1-703-528-381; 1994; English; Price US$ 30.

Held on March 8-9 1994 in Chicago, Illinois, USA, this workshop addressed the key issues concerning flammable refrigerants, including testing and evaluation, risk assessment and equipment design. The plenary session produced many suggestions for actions which should be taken to help evaluate the need for flammable refrigerants, to estimate the hazards involved in their use, and to provide information to mitigate these hazards. These proceedings provide an important insight into this contentious issue.

R-22/R-502 Alternatives
Published by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), United States; Fax: +1-404-321-5478; 1994; English; price US$ 42.

Proceedings of the conference organized by ASHRAE and the National Institute of Standards and Technology (NIST) on 19-20 August 1993.

4th International Workshop on Heat Pump Research and Applications: Energy, Economy and Environment
"Heat Recovery Systems & CHP" Volume 14, No.3, published by Elsevier Science Ltd., Oxford, UK, Fax: +44-865-843010.

Selected papers from the workshop held at the CHISA '93 Congress in Prague on 29-31 August 1993.

Montreal Protocol on Substances that Deplete the Ozone Layer - 1994 Report of the Technology and Economic Assessment Panel
Published by the United Nations Environment Programme (UNEP).

This report examines the use of ozone depleting substances in many applications including air conditioners and heat pumps. It provides a useful insight into the factors that will influence any future adjustments to the Montreal Protocol. For example, in assessing alternatives for HCFC-22 in air-cooled air conditioners, the report states that a large scale change over to alternatives in new equipment cannot be expected before the year 2000.

International Absorption Heat Pump Newsletter
Reinhard Radermacher, University of Maryland, CEEE, ME Department, College Park, MD 20742-3035, USA; Fax: +1-301-405-2025, quarterly; English; Price US$ 25 per annum.

Dedicated to absorption heat pumps, chillers, refrigeration systems, heat transformers and related equipment, this new publication will highlight ongoing research work and will list relevant publications and forthcoming events. The first issue is planned for October and will be available free-of-charge.

Conferences

*Call for Papers

Heat Transfer Enhancement by Additives
10-11 October 1994 / Munich, Germany.
A discussion meeting concerning sorption heat pumps.
Contact: Dr Felix Ziegler, Technische Universität München, Germany. Tel: +49-89-3209-2535; Fax: +49-89-3209-2536.

Ground-Coupled Heat Pumps Symposium
17-19 October 1994 / Giessen, Germany.
The symposium language is German.
Contact: Dr Burkhard Sanner, University of Giessen, Germany. Tel: +49-641-702-8248; Fax: +49-641-702-4711.

1994 International CFC and Halon Alternatives Conference
24-26 October 1994 / Washington, DC, USA.
Contact: PO Box 236, Fredrick, MD 21701, USA. Fax: +1-703-243-2874.

Application of Adsorption for Energy Transport and Storage
13-18 November 1994 / San Francisco, USA.
Contact: Dr Orhan Talu Dept. of Chemical Engineering Cleveland State University Cleveland OH 44115 USA.
Tel: +1-216-687-3539; Fax: +1-216-687-9220.

**7th International Conference on Stirling Cycle Machines - ISC '95*
5-8 November 1994 / Tokyo, Japan.
Deadline for abstracts: 1 October 1994.
Contact Mr Shigeji Tsukahara, Power & Energy Engineering Division, Ship Research Institute, 6-38-1, Shinkawa, Mitaka, Tokyo 181, Japan.

2nd European Refrigeration Forum/Expotherm
21-22 November 1994 / Lyon, France.
Contact: Infoconcept, 157 Bis Avenue Général Frère, 69008 Lyon, France.
Tel: +33-7877-9206; Fax: +33-7877-6474.

1995 ASHRAE Winter Meeting
28 January - 1 February 1995, Chicago, USA.
Contact: ASHRAE Meetings Section, 1791 Tullie Circle, NE Atlanta, GA 30329, USA.
Tel: +1-404-636-8400; Fax: +1-404-321-5478.

Design and Application of Ground-Coupled Heat Pump Systems
19-24 March 1995 / Hawaii, USA.
Held in conjunction with the 1995 ASME/JSME JSES International Solar Energy Conference.
Contact: Prof. Dennis L. O'Neal, Texas A&M University, USA.
Tel: +1-409-845-8039; Fax: +1-409-862-2762.

**AIRAH 1995 International Conference and Exhibition*
April 30 - May 3 1995 / Melbourne, Victoria, Australia.
Organized by the Australian Institute of Refrigeration, Air Conditioning and Heating.
Contact: AIRAH 1995 Melbourne Conference & Exhibition, James Harrison House, 52 Rosslyn Street, West Melbourne, Victoria 3003, Australia.
Tel: +61-3-328-2399; Fax: +61-3-328-4116.

Indoor Air Quality, Ventilation and Energy Conservation in Buildings
May 10-12 1995 / Montreal, Canada.
Contact: Fariborz Haghighat, Concordia University, Quebec, Canada. Tel.: +1-514-848-3200; Fax: +1-514-848-7965.

**24th National Heat Transfer Conference*
5-9 August 1995 / Portland, Oregon, USA.
Sponsored by the American Society of Mechanical Engineers (ASME).
Deadline for abstract: 5 October 1994.
Contact: Prof. James R. Welty, HTD Conference Chairman, Dept. of Mechanical Engineering, Oregon State University, Corvallis, Oregon, USA.

19th International Congress of Refrigeration - For a Better Quality of Life
20-25 August 1995 / The Hague, The Netherlands.
Organized by the International Institute of Refrigeration, IIR
Contact: Van Namen & Westerlaken Congress Organisation Services, The Netherlands.
Tel: +31-80-234471; Fax: +31-80-601159.

International Symposium on Two-Phase Flow Modelling and Experimentation
9-11 October 1995 / Rome, Italy.
Organized by the Assembly of World Conferences on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics.
Deadline for abstracts: 5 September 1994
Contact the Symposium Scientific Secretary: Dr Tommaso Setaro, ENEA Casaccia, Energy Department, Via Anguillarese 301, I-00060 SM Galeria, Rome, Italy.
Tel: +39-6-3048-6466; Fax: +39-6-3048-3026.

**1995 International Gas Research Conference*
6-9 November 1995 / Cannes, France.
Deadline for abstracts: 31 July 1995.
Contact: Gas Research Institute, 8600 West Bryn Mawr Avenue, Chicago, Illinois 60631, USA.
Tel: +1-312-399-8300; Fax: +1-312-399-8170.

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The IEA Heat Pump Programme	Promotion Brochure	B1-HPP	free
Heat Pumps to the Year 2000 - Strategy Plan	Promotion Brochure	B2-HPP	free
The Behaviour of HFC-134a, HFC-152a and HCFC-22 in Evaporators	Annex 17 Report	HPP-AN17-1	100
Working Fluid Safety	Annex 20 Report	HPP-AN20-1	100
International Heat Pump Status & Policy Review	Analysis Report (Vol. 1, 2A & 2B)	HPC-AR3	250
	National Position Papers	HPC-NPP-**	40
Research & Development on Super Heat Pump Energy Accumulation System	Final Report (NEDO,Japan)	NEDO-SHP	free

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