ISSN 0724-7028

# NEWS LETTER

IEA heat pump center

PERIODICAL OF THE
**IEA HEAT PUMP CENTER**

**Vol 6, No 3, Sep '88**

## This issue: 10th anniversary of the IEA Implementing Agreement

**H. Steeg***

# Introduction

I welcome the opportunity afforded by the 10th anniversary of the IEA Implementing Agreement which set up the Heat Pump Center to send my congratulations to all those who have worked so hard to make the Center a success, and to reaffirm the support of the International Energy Agency for the important work you are doing.

The drive to achieve greater efficiency in the use of energy has undergone many vicissitudes since the Implementing Agreement for a Programme of Research and Development on Advanced Heat Pump Systems was first established in 1978. After a period of rapid growth of energy conservation and efficiency gains in the '70s and beginning of the '80s, a slowdown has to be noted. The developments differ from country to country and sector to sector. Although efficiency gains made in the past cannot be repeated to the same extent, there is still considerable room for further efficiency improvements. More supply than demand on energy markets and smaller government funding must not induce a misguided sense of complacency towards the need to continue the more rational use of energy wherever possible.

However, rather than being discouraged by the present situation, the heat pump community can regard this as a challenge to their further ingenuity and their proven capacity to innovate.


Helga Steeg, IEA Executive Director

Moreover, I feel sure that the growing industrial interest in this important energy-saving device, coupled with the solid base of knowledge and experience acquired over the past ten years, will finally be decisive in achieving a market penetration which could have important consequences for the future energy balance of IEA countries as a whole.

I wish you well in your further endeavors.

**Helga Steeg, Executive Director, International Energy Agency, Paris, France*

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**J. Berghmans***

# Editorial

Ten years ago, the *Implementing Agreement for a Programme of Research and Development on Advanced Heat Pump Systems* of the International Energy Agency was signed. This issue of the IEA Heat Pump Center Newsletter celebrates this occasion by means of articles describing the projects undertaken through the Implementing Agreement and by articles addressing the future direction of heat pump research and development work.

In 1978 the future of the heat pump looked very bright in North America, Japan, and Europe. This led many IEA member states to sign the Implementing Agreement at a very early stage, following the United States and the Federal Republic of Germany who were the main architects of the agreement. Presently, a total of 16 countries have signed the agreement, 13 of which are actively participating in ongoing projects. A total of 14 projects have been undertaken in the Implementing Agreement covering a wide range of topics related to heat pumps of different types and applications.

The number of participating countries, as well as the number of projects, prove that the Implementing Agreement on Advanced Heat Pumps has been a success. In fact, it is one of the most successful agreements of the International Energy Agency. This is in one way surprising considering that the expectations which heat pumps must fulfill differ considerably from one country to another. Fundamental to the success of this agreement has been the openmindedness, and willingness to collaborate and exchange views and experiences, which all participants have shown over the years.

The present outlook for heat pumps is very different compared to the situation ten years ago, especially in the European countries. In particular, the economics of heat pumps are much less favorable due to the low prices of oil and natural gas. However, it is only in the last few years that the positive effects of heat pumps in respect to the environment have been identified. The CFC problem presents a new challenge to heat pumps, as well as to air conditioning and refrigeration equipment.

Likewise, one should not forget the important technical progress which has been made in the area of air conditioning and refrigeration machines during the last ten years, such as speed-controlled compressors and heat transfer augmentation techniques applied in condensers and evaporators. The development of highly efficient heat pumps was certainly the reason for the research and development work that led to these technical improvements. The impact of heat pump research and development appears to be much larger than one would expect.

Future heat pump research and development has to be tuned to the changing economic conditions. The potential for further technical development is far from being exhausted and considerable further improvement of heat pump performance can also be achieved. Therefore, we should endeavor to continue our international collaboration through the *Implementing Agreement on Advanced Heat Pumps* in the years ahead.

**J. Berghmans, Chairman, Executive Committee, Implementing Agreement on Advanced Heat Pumps, International Energy Agency, Paris, France*

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**J. Berghmans***

# Implementing Agreement on Advanced Heat Pumps - History and Future

In the wake of the 1973 oil crisis, 21 industrialized countries agreed to cooperate within an International Energy Program. This program is administered by the International Energy Agency (IEA), an autonomous body operating within the Organization for Economic Cooperation and Development (OECD).[1]

An important element in this International Energy Program is the cooperation among participating countries to reduce their excessive dependence on oil through energy conservation, development of alternative energy sources, and research, development and demonstration (R,D&D) in the energy field. It is on this basis that IEA participating countries have agreed to carry out national R,D&D programs and to cooperate internationally on R,D&D projects and programs.

Presently, the IEA activities with respect to heat pumps are carried out within the "Implementing Agreement for a Programme of Research and Development on Advanced Heat Pump Systems." This agreement entered in force on July 27, 1978. Up to now, it has been signed by the governments of Austria, Belgium, Canada, Denmark, Finland, Fed. Rep. of Germany, Ireland, Italy, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, U.K., and U.S.A.

### Program

The program to be carried out under this agreement can be described in general as cooperative research, development, demonstrations, and exchanges of information regarding advanced heat pump systems. Implementation of the program is achieved by means of tasks in which Contracting Parties can participate. Such tasks are called Annexes. Up to now, 14 annexes have been established in the Advanced Heat Pump Agreement. Participation of countries in these annexes is shown in Table 1. The annexes are:

- Annex I: Common Study of Advanced Heat Pump Systems
- Annex II: Development of a Vertical Earth Heat Pump System
- Annex III: Heat Pump Systems Applied in Industry
- Annex IV: IEA Heat Pump Center
- Annex V: Integration of Large Heat

| COUNTRY | ANNEX | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | XIII | XIV |
| Austria | x | x | x | x | | A | | | | | | x | x | |
| Belgium | x | | A | x | | | | | A | | | x | | x |
| Canada | x | x | x | x | | | x | A | | | | | x | |
| Denmark | x | x | x | | A | x | x | | | | | | | |
| Finland | | | x | x | | | x | | x | | | | x | |
| Germany | A | | | A | x | x | x | | x | | | x | | x |
| Ireland | | | x | | | | | | | | | | | |
| Italy | x | | x | x | x | | | | | | | | | |
| Japan | x | | x | x | | x | | | x | | x | x | x | A |
| Netherlands | x | | x | x | | | | | x | | | | | |
| Norway | | | | x | | | | | | | | | x | |
| Spain | x | | | | | | | | | | | | | |
| Sweden | x | A | x | x | x | A | A | | x | x | x | | A | x |
| Switzerland | x | | | | | | | x | x | | | x | | |
| U.K. | x | | | | | | | | | | | | | |
| U.S.A. | x | x | | x | | x | | x | | A | A | A | x | x |

x - Participant
A - Operating agent

Table 1. Annexes and participating countries

| | |
|---|---|
| | Pumps into District Heating and Large Housing Blocks |
| Annex VI: | High Temperature Working Fluids and Non-azeotropic Mixtures in Compressor-Driven Heat Pumps |
| Annex VII: | New Developments of the Evaporator Part of Heat Pump Systems |
| Annex VIII: | Advanced In-ground Heat Exchange Technology for Heat Pump Systems |
| Annex IX: | High Temperature Industrial Heat Pumps |
| Annex X: | Technical and Market Analysis of Advanced Heat Pumps |
| Annex XI: | Stirling Engine Technology for Application in Buildings |
| Annex XII: | Modeling Techniques for Design of Compression Heat Pumps |
| Annex XIII: | State and Transport Properties of High Temperature Working Fluids and Nonazeotropic Mixtures |
| Annex XIV: | Working Fluids and Transport Phenomena in Advanced Absorption Heat Pumps |

**Completed projects**

Annexes I, II, III, V, and VI are finished and are described below. The other annexes are still ongoing and are described in this Newsletter by the Operating Agents who are directly responsible for the Annex work.

**Annex I: Common Study of Advanced Heat Pump Systems**

The objectives of this annex were to collect and evaluate data obtained by international experience with advanced heat pump systems, derive relevant proposals for expected and desirable developments in this field, and recommend future research and development programs. Sorption heat pumps, as well as compression heat pumps intended for space heating application in the domestic sector, were considered.

The scope of the work for this annex contained the following elements:

-- Technology survey: state-of-the-art and operating experience, performance data for present and new designs

-- Market survey: preliminary market study to determine the needs for advanced technology

-- Identification of new R&D projects

This annex was terminated in 1982. Its results were technology survey and market survey reports and a final report integrating all the results of the task and containing recommendations for future activities.[2]

**Annex II: Development of a Vertical Earth Heat Pump System**

The subject investigated in this annex is the heat pump extracting heat from the soil by means of a vertical heat exchanger. The soil is recharged by means of heat from solar collectors, ambient air collectors, or by means of waste heat from air conditioning systems. Electrically driven heat pumps, as well as combustion engine-driven heat pumps and sorption systems, were considered in the study.

The objectives of this annex were to collect performance and cost data regarding these systems in order to assess the conceivable market potential, outline a program for hardware developments and experimental plants, and develop specifications for components of the storage and heat recharging systems.

This annex was terminated in 1984 and resulted in a final report containing, among others, the following topics:

-- State-of-the-art of vertical sub-soil heat pumps
-- Evaluation of existing and new concepts
-- Assessment of barriers to market penetration
-- Specification of research and development projects for components and heat pump profiles
-- Market potential and applicability of sub-soil heat pumps

**Annex III: Heat Pump Systems Applied in Industry**

The third annex concentrated on industrial heat pumps (compression, as well as absorption heat pumps; and open cycle, as well as closed cycle, heat pumps). A total of ten countries participated in this annex.

Reports concerning existing industrial heat pumps were prepared by each participating country. These reports were incorporated in a final report which, in addition to these reports, contained the following information:

-- State-of-the-art description of all the types of industrial heat pumps currently in use

-- Analysis of the performance of industrial heat pumps

-- Investigation of the cost and competitiveness of the industrial heat pumps

-- Research and development recommendations

Annex III was terminated in 1985.

**Annex V: Integration of Large Heat Pumps into District Heating and Large Housing Blocks**

The main objective of this task was to assess the technical and economic performance of large heat pumps in district heating and large housing block applications. In particular, heat pumps with a thermal output between 1 and 10 MW and which made use of a compression or absorption cycle were considered. Electric motors or internal combustion engines were assumed to drive the compressors. The work program consisted of the following elements:

-- A case study of a 10 MW demonstration plant and a design study for 1 MW heat pumps

-- Assessment of the market potential for large heat pumps for district heating and use in large housing blocks

-- Identification of new research and development projects

The activities undertaken in the course of this annex led to a final report containing the findings of the studies mentioned. The annex was terminated in 1985.

**Annex VI: High Temperature Working Fluids and Nonazeotropic Mixtures in Compressor-Driven Heat Pumps**

The objective of this annex was to gather information on heat pump systems utilizing new working fluids or mixtures and to evaluate their potential compared to other heat pump systems.

Closed cycle systems were investigated with working fluids of either pure fluids capable of condensing at temperatures above 100°C or non-azeotropic mixtures.

The work was carried out in two steps:

Step 1: Production of a state-of-the-art report describing working fluid mixtures and high temperature working fluids, and a comparison of the technical and economic performance of these working fluids to conventional fluids

Step 2: Preparation of a report on a hardware project, involving a heat pump design or experimental activity related to state or transport properties of working fluids. Also a technical and economic evaluation of the working fluids mentioned above was prepared.

Step 1 was completed in 1984 and Step 2 in 1987. Step 1 resulted in a final report in which the following elements were discussed:

-- General thermodynamic and practical aspects

-- State and transport property availability

-- System aspects (equipment and components, flow schemes, and design and simulation)

-- Research and development for ongoing work

-- Applications of interest

**International heat pump conferences**

In addition to the research and development work of the above-mentioned projects, two International Heat Pump Conferences were organized under the Implementing Agreement (Graz, 1984, and Orlando, 1987). See the Bibliographic Review in this issue for information about the conference proceedings. These conferences drew a very large attendance and presented an international opportunity for the acquisition of information regarding the state-of-the-art of heat pumps.

**Future activities**

Research has been conducted under the Implementing Agreement on Advanced Heat Pumps for a period of ten years now. Over the years, the number of participating countries has not decreased. On the contrary, there are presently 13 countries actively involved in the projects. This in itself is a clear indication of the success of the Implementing Agreement. The more so, seeing that an IEA fund, from which financial support for the annexes could be obtained, is not available. Therefore, the expenses incurred during the course of an annex must be borne by the participant. This in itself has not kept 16 countries from participating in the Implementing Agreement. Therefore, it can be concluded that this Agreement has been very successful indeed.

Almost all the annexes have as an objective the gathering and dissemination of available information regarding heat pumps. Few annexes require experiments or tests to be performed. This may have contributed to the success of the Implementing Agreement. Very early on in the agreement, participants realized that information exchange was necessary to avoid duplication of work and was an important activity for international cooperation. Likewise, it was realized that development of new heat pumps and putting them on the market needed to be left to the autonomy of individual participants. It seems likely that topics of a more general nature would be most suited for future annexes.

In the near future, we see as activities a new annex on heat pumps with direct expansion ground coils. This annex is presently being organized. Preparations are being made for the third IEA Heat Pump Conference to be held in Japan in 1990.

In the domestic sector, the development of cost-effective heat pumps for heating only is an important topic for future research. Technical improvements to increase heat pump COP are still possible but with respect to market penetration, it may be more important to direct future research to the development of less costly systems which can be readily connected to conventional heating systems in new, as well as in existing, buildings.

In the industrial sector, the development of cost-effective heat pumps with output temperatures up to 200-250°C would result in a breakthrough for the heat pump. The search for suitable working fluids and cycles will remain an important research topic in the future.

The CFC problem is a new challenge for the heat pump. Similar to many other problems, it is common to the heat pump, as well as to the air conditioning and refrigeration industry. In order to increase the efficiency of the work undertaken in the Implementing Agreement in the future it therefore seems advisable to expand the scope of the agreement to include all thermodynamic heating and cooling machines.

**References**


1. *Annual Report on Energy Research Development and Demonstration Activities of the IEA*, 1982-83, IEA, Paris, 1984.

2. *Common Study on Advanced Heat Pumps*, KFA Juelich, TUV Rheinland, Koeln, 1983.


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**IEA Heat Pump Center***

# Annex IV: IEA Heat Pump Center

*The objective of the IEA Heat Pump Center (HPC) is to promote the commercialization of advanced heat pumps which, from a technical, economic, and environmental point of view, are able to compete with conventional heating systems and other conservation equipment. In particular, the HPC is to foster international cooperation on all aspects related to the research, development and demonstration of advanced heat pump systems and components.*

The HPC was established on December 8, 1982, as Annex IV of the International Energy Agency's Implementing Agreement for a Programme of Research and Development on Advanced Heat Pump Systems. The operating agent of the HPC is the Fachinformationszentrum Energie, Physik, Mathematik GmbH, Karlsruhe, Federal Republic of Germany. Funding for the HPC's program is received in the form of direct contributions from its 11 member countries (Austria, Belgium, Canada, Federal Republic of Germany, Finland, Italy, Japan, the Netherlands, Norway, Sweden, and the United States).

The activities of the HPC have concentrated on the following:

-- Collection and dissemination of information on research, development, and demonstration projects on advanced heat pump systems and components.

-- Measures to enhance knowledge in the areas in which heat pumps have the greatest potential and to support application in the most suitable areas.

-- Collection and dissemination of information on experience from plants in operation to improve standardization and design of reliable heat pump systems.

-- Analysis of specific heat pump installation and management problems to support a suitable infrastructure for heat pump use.

-- Analysis of the specific environmental problems of installed heat pumps and their consequences on the development of environmentally safe installations.

-- Collection and dissemination of information on manufacturers of heat pump units and components, on heat pump installations in operation, and on national rules and regulations affecting the trade of heat pumps.

To carry out these activities, the HPC develops databases and information files, conducts expert workshops, and publishes a quarterly Newsletter and a variety of analysis reports. The HPC is assisted by the National Teams, consisting of selected heat pump experts from each member country. The support of the National Team members is important in fulfilling the HPC's purpose. One of the responsibilities of the National Teams is to cooperate with the HPC in the preparation of analysis reports and in the organization of workshops on special topics of interest.

Figure 1 shows a schematic representation of the HPC's role.

**Results**

During the second working period (1985-1988), the HPC has established a

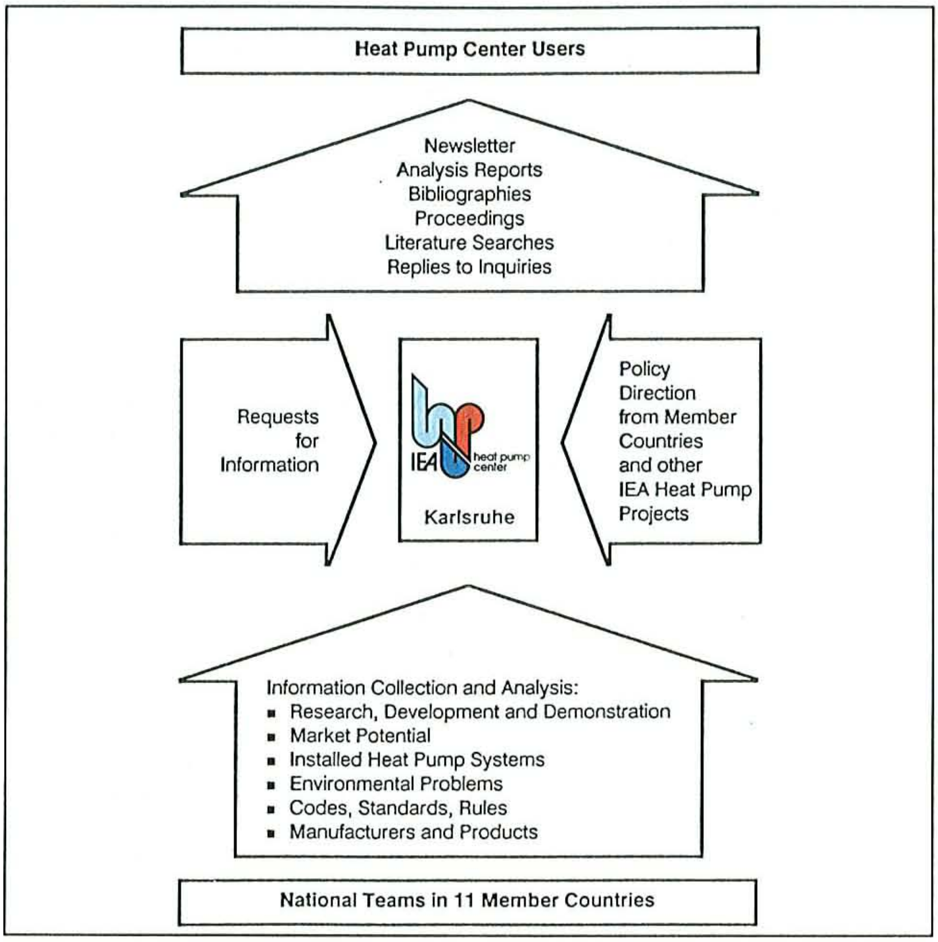


Figure 1. Role of the Heat Pump Center

database on heat pump research, development, and demonstration projects and information files on existing heat pump installations, heat pump manufacturers, and heat pump codes and standards. The HPC has also carried out analyses and has published their results in the form of reports. These reports are reviewed periodically in the Newsletter in the Bibliographic Review section. Topics dealt with in the reports included environmental aspects of heat pump applications, industrial and sorption heat pumps, heat pump research and development projects, heat pump applications, and the international heat pump market. To encourage an exchange of information, a workshop dealing with ground-source heat pumps sponsored by the HPC was held in Albany, New York, USA, in 1986. During the second working period, the HPC has also responded to over 400 inquiries concerning heat pumps.

***IEA Heat Pump Center, Karlsruhe, Federal Republic of Germany**

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**O.J. Svec***

# Annex VIII: Advanced In-Ground Heat Exchange Technology for Heat Pump Systems

*Annex VIII was proposed and established as a natural continuation of Annex II, which was in effect from 1981 to 1983. Annex II, led by Sweden with the cooperation of Austria, Denmark, the United States and Canada, was concerned with system design and performance of ground-source heat pumps (GSHP) employing vertical heat exchangers. Two important points can be stated on the basis of the conclusions of Annex II: (1) there is a need for better understanding of heat transfer processes between the circulating fluid and the surrounding ground using various operational strategies; and (2) unless a more efficient ground heat exchange system is developed, GSHP technology will not significantly penetrate the market. Four countries (Federal Republic of Germany, Switzerland, the United States, and Canada) accepted this challenge and formed a new project known as Annex VIII. Canada is the operating agent.*

Annex VIII is a task sharing project. Each country has been working independently but in close cooperation, sharing their experiences and some resources. A brief description of the research programs in each of the participating countries is presented on the following pages.

**Federal Republic of Germany (FRG)**
(Project Leader: B. Sanner, Dipl.-Geol., Helmut Hund Gmbh)

A combination of field experiments and mathematical modelling has been the principal scope of this research program. The field experiments were conducted at the Schwalbach GSHP Research Station, which commenced its operation in September 1985 (see related article in the Newsletter, Volume 4, Number 4). In addition, four commercially installed GSHP systems have been monitored. Computer modelling has been performed by the Institute for Applied Geosciences of Giessen University.

At the Schwalbach research station, full-scale experiments have been performed during the last three heating seasons. The main objectives were to determine the heat extraction rates, the earth thermal recovery during spring and summer, as well as the influence of climatic parameters and precipitation. Because the geologic and hydrologic environment is well known at this site, obtained results were also used for computer validation.

Four commercially installed GSHP plants, located in different geological situations across FRG, have been monitored in detail. These are two residential houses, a light commercial building and another residential house with passive solar architecture. The Seasonal Performance Factor (SPF) has ranged between 2.45 and 2.9. It has been concluded that SPF is controlled more by the layout of the heating distribution system than by soil thermal properties.

In FRG, the need for space cooling using refrigeration equipment is nominal. Therefore, a very cost-effective cooling system based on the direct cooling principle was developed. It uses circulating brine to recharge the ground without activating the heat pump. This system requires only 100-200W of electricity input for a cooling capacity of 2.5 kW. One such installation has been in operation since the summer of 1987. The system works well in climatic conditions where the cooling load is about 1/4 of the heating load.

The Institute of Applied Geosciences of Giessen University developed a three-dimensional finite difference program, TRADIKON-3D. This code was validated against the Schwalbach experiments, where the brine temperature has been kept constant, as well as against experimental installations of other participating countries. TRADIKON-3D was also distributed to the Annex VIII partners.

The benefits of Annex VIII for FRG can be summarized as follows:

-- Better understanding of the heat transfer processes in rock and soil

-- Development of guidelines for design and installation of ground heat exchange systems

-- Development of computer code TRADIKON-3D for heat extraction simulations

-- Development of the brine system for space cooling

-- Improvement of drilling techniques (light DTH hammer)

**Switzerland**
(Project Leader: R. Hopkirk, Ph.D., Polydynamics Ltd.)

Effort in Switzerland has been concentrated on careful instrumentation and surveillance of three commercially installed heat pumps, feeding typical, modern underfloor heating systems in private villas and drawing heat from vertical earth probes (VEP). Siting of such plants is, at present, subject to some restrictions by water resource authorities because of dependence of this densely populated country on groundwater for drinking water supplies and the wish to avoid the consequences of antifreeze leakage into actively used aquafiers. Measurements are being pursued and analyzed over several years in order to examine the effects on performance of extended heat extraction from the ground.

The measurement campaigns are supplemented by model simulation runs. For this purpose, two numerical models have been developed and tested. They have been used to emulate some of the heat pump/VEP operation. This enables the relative importance of the various heat exchange mechanisms to be identified under typical conditions.

It is concluded that VEP's installed in normally moist ground (marle, limestone and sandstone are most prevalent) with no groundwater flow can operate successfully at average seasonal performance factors of approximately 3 in current space heating applications (delivery temperatures approximately 45°C).

The aim of the work is to formulate recommendations for optimum design, installation and operation of these increasingly popular systems. The experience gained from the investigations is being applied to application of VEP technology to seasonal storage problems.

**United States of America**
(Project Leader: V. Mei, Ph.D., Oak Ridge National Laboratory)

Ground-coupled heat pump systems have long been recognized for their high potential for energy conservation. However, the design of the ground-coil heat exchanger is still largely based on line-source theory, which was developed for heat pump ground-coil application in the 1940's. Although this theory is easy to use, many important factors in ground-coil design have to be excluded because of the limitations of the theory. New models to better predict ground-coil performance are needed.

Based on energy balance, four ground-coil models were developed: one is for vertical deep-well, tube-in-tube type ground heat exchangers; one incorporates a horizontal coil with radially symmetrical temperature profile and a soil freezing effect around the coil; the third one includes a three-dimensional ground temperature distribution caused by heat transfer between the ground surface and the ambient air; and the fourth one contains ground heat transfer and thermal interference effects for two coils in the same trench with one on top of the other. All four models have been validated against the field experimental data provided by Brookhaven National Laboratory, the University of Tennessee, and against laboratory experiments performed at ORNL.

The computer codes developed for each model are easy to use, and can be applied for ground-coil design purposes or for checking the coil design with other methods. These programs have been distributed to all participating countries.

**Canada - Operating Agent**
(Project Leader: O. Svec, Ph.D., National Research Council of Canada)

The Institute for Research in Construction of the National Research Council of Canada (NRCC) has been active in research and development work on ground heat exchanging systems for a number of years. This effort has included laboratory experiments, computer modelling, field prototype testing, evaluation of a new system in an experimental single-family-sized house, and demonstration of this new technology in an industrial project.

The prime objective of the Canadian research program has been the development of an advanced ground heat exchange system capable of extracting more energy per unit length than can be obtained from those currently in use.

This objective is one of the most promising ways to reduce the initial installation cost of a GSHP system. New copper and plastic spiral heat exchangers have been developed in the Institute for Research in Construction laboratory. Prototypes, made of tubing of various diameters and wound into spirals of several sizes, have been tested in vertical and horizontal configurations. They have been subjected to short term and long term, as well as cyclic types of heat extraction/rejection tests. Under some operating conditions, these new heat exchangers are providing up to three times better performance than standard plastic U-tubes.

The new heat exchange systems have been tested in two experimental houses located on the NRCC campus. One house has been fully operational for the last two heating and cooling seasons. All important parameters, such as ground temperatures, energy extracted from the ground, and electrical energy used by the heat pump, as well as its performance, have been monitored in detail. Because of the accuracy of measuring equipment (e.g., temperature measurements within 0.005°C), confidence in the results is high.

In addition to these full-scale trials, many laboratory experiments on heat and moisture transfer have been performed. The effect of freezing of soils on the overall thermal performance has been of particular interest. Moisture movement and segregation potential of frost-susceptible soils were predicted on the basis of laboratory freezing experiments. A problem of settlement of open structured soils after the first freezing/thawing cycle has been identified and evaluated.

**Conclusion**

At the time of this writing, summer 1988, Annex VIII is winding down. In a brief retrospective review of this project, the following conclusions can be drawn:

-- The principle of task sharing is an extremely useful form of international cooperation in research and development.

-- Annex VIII can be credited with development of new ground-source heat exchangers and several computer models, as well as contributions to basic design techniques.

-- Annex VIII advanced fundamental understanding of GSHP technology through detailed monitoring of several field installations in Europe and North America.

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**J. Berghmans***

# Annex IX: High Temperature Industrial Heat Pump Systems

*There is great potential for energy conservation in industry, particularly for heat pump systems at temperature levels from 100 to 300°C. The objective of Annex IX is to provide a detailed analysis of the state-of-the-art in high temperature heat pumps and the potential for energy conservation through application of these heat pumps in industry at temperature levels about 100°C.*

Annex IX started in 1986 and is expected to terminate at the end of 1988. Presently the following countries are participating in this annex: Belgium (Operating Agent), the Netherlands, Finland, Fed. Rep. of Germany, Sweden, Japan, Switzerland, and the U.S.

The work program basically consists of two items:

-- Production of at least one report by each participant on an existing high temperature heat pump system.
-- A final report incorporating the system reports. This final report will also include a state-of-the-art description of the heat pump systems, as well as an analysis (prepared by the operating agent) of the energetic and economic performance of the heat pumps.

All types of heat pumps, including mechanical vapor recompression systems and heat transformers, are investigated in this annex.

In order to obtain firsthand information regarding actual operating experience with heat pump systems, one of the annex activities consisted of visits to industrial heat pumps in the participating countries.

In regards to the economic aspect, it was found that the potential for industrial heat pumps has been drastically reduced by the most recent decrease in oil prices. This, together with the requirement that the heat pump savings over less than two years should be equal to the investment involved, limits the applicability of heat pumps to those processes which are applied during most of the year.

In regards to the technical aspect, the only absorption systems able to reach temperatures above 100°C are the heat transformers. However, corrosion problems limit their output to 135°C. As to compression systems, only vapor recompression machines are applied with an output up to 180 to 200°C. Very few closed cycle systems with output above 100°C are found in industry. This explains the considerable amount of research which is being undertaken to increase, first of all, the output temperature level of industrial heat pumps. The identification of more suitable working fluids and a search for better thermodynamic cycles (e.g., several stages, combination of compression and absorption, etc.) draw a considerable amount of interest. Many laboratories are currently studying chemical and adsorption heat pumps.

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# Annex X: Technical and Market Analysis of Advanced Heat Pumps

*In contrast to other annexes which are formulated to carry out or exchange technical information on R&D aspects of heat pumps, Annex X concentrates on defining the general market, economic, institutional and technical status of heat pumps. The objective of this work is to provide a better foundation for carrying out the Executive Committee's work. In this sense, Annex X continues the work of Annex I. As specifically stated in the text of Annex X, "The purpose of this annex is to provide a means for updating portions of the technical and market data base developed in the earlier annex... This updated information will materially aid the Executive Committee in planning and managing the R&D program, specifically in the creation of new annexes."*

The Annex was initiated in May 1986, and will continue at least through May 1989. Participating countries are Sweden and the United States, with the latter acting as Operating Agent. Much of the work under the Annex is being carried out by Group MAC, Paris, France.

A major output of the work conducted under this annex was presented at the IEA Heat Pump Conference in Orlando, Florida, USA in April 1987. This output includes:

- An analysis of the economic and non-economic factors explaining the rapid growth and the sudden decline of the European heat pump market. This analysis has shown in particular that energy prices were not the only factor explaining the major trends in the European market, but that marketing factors (i.e., market segmentation, governmental subsidy programs) were equally important. This analysis also showed the growing interest in Europe for small heat pumps providing both cooling and space heating.
- An analysis of the government roles in RD&D programs. This analysis highlighted the need for a clear vision and of long term objectives, in order to be successful.

In addition, a significant amount of work had been conducted under Annex X to select papers and speakers for the Orlando conference. As a result, more than 50% of the papers were presented by European speakers.

Past and continuing work conducted under Annex X is also of major assistance in the definition of the scope of work of future annexes within the Advanced Heat Pumps Implementing Agreement.

**John D. Ryan, U.S. Department of Energy, Washington, D.C., U.S.A.*

**W. Teagan***

# Annex XI: Stirling Engine Technology for Application in Buildings

*The objectives of this annex, as stated in the Implementing Agreement, were "to gain through international cooperation a more complete strategic assessment of the technology of Stirling engine-driven heat pumps than can be obtained through present individual programs. A secondary objective is to identify specific topics for further cooperative research efforts."*

Annex XI was sponsored by the United States, Japan, and Sweden. These countries have the major worldwide programs in Stirling engine technology and its application to heat pumps and cogeneration which are the specific focus of the Annex.

The primary mechanisms for achieving its objectives were a series of three workshops with one held in each of the participating countries. The first of these workshops was held in Tokyo, Japan, December 3-4, 1986. This workshop, hosted by the Ministry of Trade and Industry (MITI), focused on key technology issues of common interest. Successful resolution of these issues is critical to the development of commercially viable systems. The second workshop was held in Stockholm, Sweden, September 16-18, 1987. This workshop, hosted by the Swedish Council for Building Research, focused on recent hardware testing results in participating countries with emphasis on those issues pertaining to system reliability and performance, when used in heat pump applications. The third workshop was held in Washington, D.C., July 11-13, 1988. This workshop, hosted by the U.S. Department of Energy, focused on economic, cost, and commercialization issues which are becoming more important as the technical performance characteristics of Stirling engines become more firmly established.

Each of the workshops had associated tours of Stirling engine R&D centers within the host countries. This allowed the national team participants to become better acquainted with the technology status and facilitated information exchange on key technical and economic factors.

A key issue facing the industry in all countries is whether to focus on free piston or kinematic Stirling engine technologies for building applications. Both technologies are being pursued in parallel in the United States, while Kinematic Stirling Engine (KSE) is the focus of the programs in Japan and Sweden. Due to the importance of this issue in shaping R&D initiatives, one of the outputs of the Annex was a study on a "Comparative Assessment of Free Piston and Kinematic Engine Technologies." This study reviews the advantages and disadvantages of both technology options, compares the actual experience with the technologies in the participating countries, and identifies technology trends which might significantly impact on the selection issue. An example of the latter is the recent development of lower cost, high intensity, magnetic materials which could significantly enhance the prospects for a mechanically simple, and efficient means of coupling to the output of a Free Piston Stirling Engine (FPSE) system.

The program was highly successful in accelerating the exchange of information between participants, in general, and helped establish the credibility of Stirling engine technology by:

-- Verifying achievement of key technical goals in each participating country relative to efficiency, size, emissions, etc.
-- Providing a forum for presenting timely information on the results of testing programs which demonstrate increasing life/reliability potential in engines of different designs.
-- Identifying common problem areas relative to performance, reliability, and costs and possible approaches for their resolution.

Based on information presented in the last workshop, the participants were in general agreement that the technical performance and potential reliability of the Stirling engine option had now been verified by developers in all participating countries and future efforts will tend to stress commercialization via lower cost designs and selection of applications where Stirling engine attributes are particularly important.

The participants all agreed that the IEA Annex XI had been highly valuable in helping to facilitate information exchange and enhance the understanding of Stirling engine technology and economics. As such, all the participants agreed that continued cooperative efforts would be useful.

Specific areas of continuing common interest included a more complete understanding of basic loss mechanisms in Stirling equipment by means of closely tied analyses and experimental efforts and exploring the possible use of Stirling cycle heat pump systems as an option to reducing the use of CFC-based refrigerants which lead to severe environmental problems due to their impact on ozone levels.

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**S. Fischer***

# Annex XII: Modelling Techniques for Simulation and Design of Compression Heat Pumps

*Annex XII has two primary objectives: (1) to assess the adequacy of existing techniques for modelling seasonal performance of compression heat pumps; and (2) to define the needs for additional fundamental information and research.*

The United States, Belgium, Austria, Switzerland, and Japan joined the annex in late 1986, and Italy and the Federal Republic of Germany joined in 1988. There have been four annex meetings: an organizational meeting in Karlsruhe, FR Germany in December 1986; and subsequent working meetings in Bern, Switzerland; Orlando, Florida, U.S.; and Graz, Austria.

The participating countries have contributed computer programs, experimental field measurements of weather conditions and building energy use, and technical papers for use in evaluating the adequacy of current modelling techniques. There is a broad diversity in these contributions that reflects the different needs and customs in heating and cooling systems in each of the participating countries. The simulation models include:

1. A program for a central air-source heat pump using a forced-air distribution system, capable of modelling both heating and cooling performance, electrical resistance backup heaters, using binned weather and building loads data, and empirical correlations for cycling, frosting, and defrosting degradation.
2. A program for a central air or water-source heat pump (heating only) with a hydronic distribution system and conventional boiler for backup heat, using either hourly or binned weather and building loads data, and simple correlations for cycling, frosting, and defrosting degradation.
3. A program for an air-to-water heat pump (heating only) with a buffer storage system using electrical resistance backup heaters, hourly loads and weather data, and a transient calculation of frost formation.

Three sets of field data measurements have been contributed to the annex for use in validating the computer models. Early efforts at model validation have shown that simulations with the current computer programs can predict heat pump energy use to within 5-10% on a month-to-month basis. In addition, the participating countries have contributed more than 30 technical papers for use in refining seasonal modelling techniques. Programs have also been contributed for computing psychrometric properties of air and the thermodynamic properties of ammonia.

The research needs that have been identified for future work include more accurate seasonal simulations and capabilities to model variable-speed (modulating) heat pumps. More accurate simulations may only be possible with truly transient calculations. There is interest in a second phase of annex activity in this area. There is also a need for models that can simulate the performance of variable-speed heat pumps. There is very little part load and dynamic data on component performance for use in developing such models.

*Steve Fischer, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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**T. Berntsson***

# Annex XIII: State and Transport Properties of High Temperature Working Fluids and Nonazeotropic Mixtures

*The objective of this annex is to increase the knowledge of state and transport properties of high temperature working fluids and nonazeotropic mixtures. The work within the annex is divided into three parts: identification of important data, assessment of data, and measurement of data. In light of the discussions of the CFC problem, the work of the annex has been extended into new pure fluids and mixtures.*

Annex XIII is a continuation of Annex VI, "Study of working fluid mixtures and high temperature working fluids for compressor driven systems." One of the results from Annex VI was that there is a considerable lack of data on state and transport properties of these fluids.

The participating countries in Annex XIII are Canada, Japan, Norway, Federal Republic of Germany, the United States, and Sweden. Sweden is also acting as the operating agent.

A study will be performed in which the degree of accuracy of various state and transport properties that are necessary for good prediction of the performance of a heat pump cycle is determined. This investigation will be performed with the aid of a sensitivity analysis of various physico-chemical properties. Different correlations/equations of state will be evaluated with the aid of experimental measured data for high temperature working fluids and nonazeotropic mixtures.

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**T. Saito***

# Annex XIV: Working Fluids and Transport Phenomena in Advanced Absorption Heat Pumps

*The objectives of Annex XIV are: (1) to collect and evaluate data on working fluids and transport phenomena in components for advanced absorption heat pump systems; (2) to offer appropriate proposals for future developments in this field; and (3) to recommend future research and development programs.*

The countries participating in the Annex are Belgium, Denmark, the Federal Republic of Germany, Japan, Sweden, and the United States. The Heat Pump Technology Center of Japan, Tokyo, is acting as the operating agent.

Absorption heat pumps driven by heat in the mid-temperature range have been considered to be the optimum in the use of waste heat. One of the heat sources used in heat pumps is water and the other is air. It is not an exaggeration to say that air-source heat pumps are more widely applicable than water-source, so we have chosen to focus on advanced air-source absorption heat pumps.

The refrigerant plays a very important role in heat pump performance. It is closely related to the heat pump cycle. There have been a large number of studies done on refrigerants. Comprehensive surveys of the data resulting from these studies, especially with reference to thermodynamic properties, were written by R. A. Macriss, et al, and H. Bokelmann, et al. Besides the thermodynamic properties, the transport properties of refrigerants are another key factor in the design of heat pumps. Research continues in several areas and is being published in several languages. It now seems appropriate that countries cooperate in an examination of the survey data of both the thermodynamic and transport properties of refrigerants.

The work performed under this Annex is limited to the context of the following advanced absorption heat pumps:

- Compact-type, high-performance water-source heat pumps
- Air-source absorption heat pumps

The working fluids to be studied are

only those related to air-source absorption heat pumps. Such working fluids may be:

- Multicomponent system based on the $H_2O$-LiBr system
- Ammonia system
- Halogenated hydrocarbon system
- Alcohol system

The activators to be studied will be limited to absorption activators.

The transport phenomena to be studied are:

- Momentum transfer
- Heat transfer
- Mass transfer
- Interactions among these three transport phenomena

To accomplish the objectives of the Annex, the participants will undertake a jointly funded study on a task-sharing basis. The study shall consist of the following elements:

a. Study on working fluids
   1. Literature survey
      - Survey of literature on working fluids
      - Transfer of non-confidential reports which include unpublished manufacturers' and government reports in relevant fields by participants, where available, to the Operating Agent
   2. Set-up of the matrix of working fluids
      - Definition of the classification criteria
      - Set-up of the matrix
   3. Evaluation of working fluids
      - Modelling of the thermodynamic evaluation
      - Evaluation based on the model

b. Study of transport phenomena
   1. Literature survey
      - Survey of literature on absorption mechanisms
      - Transfer of non-confidential reports which include unpublished manufacturers' and government reports, in relevant fields by participants, where available, to the Operating Agent
   2. Set-up of the matrix of the phenomena and their related parameters
      - Definition of the classification criteria
      - Set-up of the matrix
   3. Review of absorption performance

Annex XIV will proceed according to the following time schedule:

| | |
|---|---|
| Dec 1987 | Beginning of Annex XIV |
| Sept 1988 | 1st workshop in Chicago, Illinois, USA |
| | 2nd workshop in Europe |
| | 3rd workshop in Japan |
| 1989 | Presentation of final report |

The actual policy and procedures of handling the data will be discussed and decided at the first workshop.

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**IEA Heat Pump Center***

# Heat Pumps - A Challenge for the Future

*Care of the environment and wise and efficient use of energy are of ever increasing importance for any energy planning. The present fossil energy prices are, however, major hindrances for the required investment in energy conservation and environmental protection. Out of the great diversity of highly developed energy technologies, heat pumps constitute one possibility to economize other energy sources and to reduce toxic effects on the environment. The long term market acceptance of heat pumps, however, will depend upon their ability to compete economically and environmentally with conventional heating and cooling systems and other energy conservation equipment.*

Considering the large divergence of the current heat pump market in the IEA member countries, only close international cooperation will ensure the required development of reliable, economic and safe heat pump systems. To foster the international exchange of information is the major function of the IEA Heat Pump Center established in December 1982 as Annex IV of the IEA Implementing Agreement on Advanced Heat Pump Systems. A brief overview of the objectives and activities of the IEA Heat Pump Center is presented in the article on page 5.

The occasion of the 10th Anniversary of the Agreement might be a good opportunity to look into some aspects of the future of heat pumps from a general energy, environmental, and economic point of view.

### Energy and the heat pump

The following conclusions may constitute a general framework for a more precise assessment of the present status and future trends on energy needs for economic development:

- The conventional energy reserves known at present are abundant for the foreseeable future and will ensure medium-term energy demand on a global scale.
- Coal represents about 80% of the proven and additional worldwide fossil energy reserves.
- The present development shows the growing role of electricity in the energy spectrum for sustainable economic development and for increasingly more efficient use of energy.

The present worldwide proven and additional fossil fuel reserves are shown

| Worldwide fossil fuel reserves (Gtoe*) | | | |
|---|---|---|---|
| | Coal | Oil | Gas |
| Proven reserves | 896 | 110 | 74 |
| Additional reserves | 2699 | 340 | 156 |
| (* toe = tons of oil equivalent) | | | |

Table 1. Present worldwide proven and additional fossil fuel reserves[1]

in Table 1, underlining the important role of coal for future worldwide energy supply as well as the possible impact on the environment. A comparison of economic and energy data in the OECD between 1978 and 1984/85 is summarized in Table 2. Contrary to the increasing electricity consumption, primary energy demand remained constant due to the increasingly more efficient use of energy in industrialized countries.

Even more important is the development of the relation between energy consumption and economic growth presented by the energy intensity or energy consumption per unit of Gross National Product (GNP) (see Editor's note at the end of this article) between 1978 and 1984 (shown in Table 2). A 12.6% decrease of the primary energy intensity and a 5% increase of the electricity intensity over the same period of time indicate the important role of electricity for economic development.

The clear trend in almost all countries towards a lower primary energy consumption versus an increase in the Gross Domestic Product (GDP) was initiated by the two oil price shocks of 1973 and 1979. Figure 1 illustrates this trend for the Federal Republic of Germany. At the same time, electricity consumption continued to grow faster than the GDP.

| | 1978 | 1985 | Changes between 1978 and 1985 | |
|---|---|---|---|---|
| | | | Absolute | % |
| Primary energy consumption (Mtoe) | 3791 | 3754 | -37 | -1.0 |
| -- Solid fuel | 770 | 945 | +175 | +22.7 |
| -- Liquid fuel | 1959 | 1564 | -395 | -20.2 |
| -- Gases | 708 | 713 | +5 | +0.7 |
| -- Hydro | 230 | 258 | +28 | +12.2 |
| -- Nuclear | 124 | 274 | +150 | +121.0 |
| Fuel demand for electricity generation | 1147 | 1367 | +220 | +19.2 |
| -- Solid fuel | 443 | 600 | +157 | +35.4 |
| -- Liquid fuel | 230 | 106 | -124 | -53.9 |
| -- Gases | 120 | 129 | +9 | +7.5 |
| -- Hydro | 230 | 258 | +28 | +12.2 |
| -- Nuclear | 124 | 274 | +150 | +121.0 |
| Percentage of total primary energy consumption | 30.3% | 36.5% | | |
| | 1978 | 1984 | Changes between 1978 and 1984 | |
| | | | Absolute | % |
| Gross national product (GNP) (Billion US$ - 1980) | 7291 | 8261 | +970 | +13.3 |
| Primary energy consumption per GNP (toe/1000 US$) | 0.520 | 0.454 | -0.066 | -12.6 |
| Fuel demand for electricity generation per GNP (toe/1000 US$) | 0.157 | 0.165 | +0.008 | +5.1 |

Table 2. Comparison of economic and energy data in the OECD between 1978 and 1984/85[2]

Table 3 presents the total and per capita electricity consumption and the percentage of total electricity consumption of the industrial and household sectors in selected industrialized countries between 1980 and 1986. Interesting to note is the high per capita electricity consumption in the northern countries and the US as well as the changes of the percentage electricity consumption in industry and households.

Taking into account that low and high temperature heat represent about 80% of the total end-use energy consumption in industry and households, electricity should play an increasing role for a more energy-efficient heat generation. Heat storage systems with off-peak electricity-driven heat pumps, integrated cogeneration and heat pump systems, as well as combined heating and cooling processes, are examples of technologies available for a more rational use of the limited non-renewable energy resources under conditions acceptable for the economy.

### The environment and heat pumps

Whereas the close relation between energy consumption and economic growth has been well known for many years, it has only been in recent years that conservation of nature is viewed as a major constraint in energy-related decisions. Specific problem areas are the prevention of pollution, the desire to prevent or reduce highly disturbing phenomena such as acid rain, the destruction of the ozone layer and the accumulation of $CO_2$.

Three types of solutions are possible to reduce environmental deterioration:

1. The rational use of energy which not only improves the availability of energy but also the environment.

2. The use of "clean" technologies. Examples are the choice of less polluting processes, the installation of processes reducing exhaust fumes, especially $SO_2$, $NO_x$ and dust, or the use of depolluted products.

3. The implementation of new technologies involving the prevention or repair of damage or pollution created, e.g., treatment and recovery of waste.

The importance of the environmental concern resulting from energy is not only reflected in legislation and regulation in an increasing number of countries but also in the international progress made in this respect. The 1985 accord of 17 eastern and western European countries to reduce $SO_2$ emissions by at least 50% by 1993 or the 1987 "Montreal Protocol on Substances that Deplete the Ozone Layer" are such beginnings.

What kind of role does the heat pump play in this situation? It is well established that heat pumps can reduce the need for combustion of fossil fuels and therefore the emission of pollutants and the production of $CO_2$. The chlorofluorocarbon refrigerant (CFC) problem, though, presents an obstacle since the majority of today's heat pumps rely upon CFC working fluids. This reliance is due to a number of sound technical and economic reasons such as the safety, low cost, chemical stability, good physical properties, and availability of these compounds. The drawback is that CFCs may play a significant role in the destruction of the earth's ozone layer. At ground level CFCs are considered harmless. The problems begin once they get into the upper atmosphere where they break down and then react with stratospheric ozone. This in turn allows more ultraviolet radiation to reach the earth's surface. According to a report given to the Enquete Commission of the German Parliament (May 2 and 3, 1988) a 5 to 7% reduction in the ozone layer could lead to a 20% increase in ultraviolet radiation at the earth's surface. Such an increase would not only cause extensive destruction of primitive life forms such as microorganisms, aquatic plants and fish larvae, but may also lead to higher incidence of skin cancer in humans. More recently, CFC molecules have also been identified as playing a role in the "greenhouse" effect. Due to the severity of the environmental effects, a decision has been made by governments to limit production of some CFCs. To meet the requirements of this agreement, efforts are being undertaken worldwide aimed at replacing the use of ozone-depleting CFCs with other non-ozone-depleting working fluids or developing new technologies. The solutions which have to be found will insure that heat pumps will continue to play a role in reducing environmental pollution by using available energy resources more efficiently.

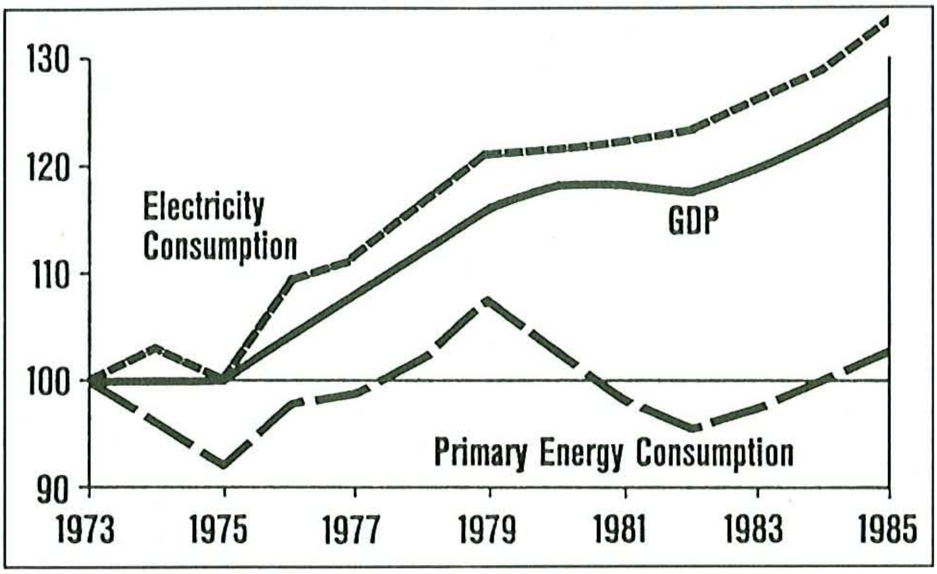


Figure 1. Development of the primary energy consumption, GDP and electricity consumption in the Federal Republic of Germany[3]

## Economy of heat pumps

It is well known that the present fuel oil and electricity prices in many countries put an economic limit on the use of heat pumps in specific applications. One cannot expect decision-makers to install economically non-competitive heat pumps only to contribute to a more efficient use of energy and to the protection of the environment.

As economy is the primary condition for medium-term application of heat pumps, a look into this matter is of great interest.

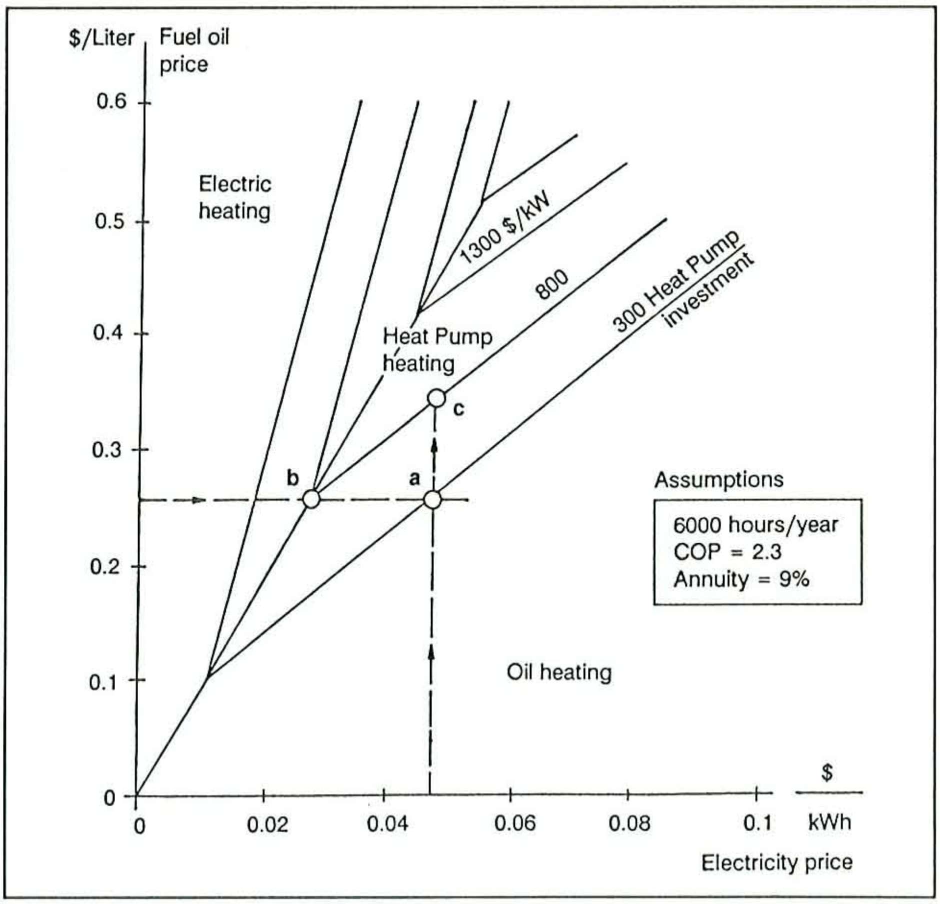


Figure 2. Comparison of relative competitiveness of electric-driven heat pumps, direct electric heating, and oil heating6

| Country | Electricity Consumption | | | | Percentage of Electricity Consumption in: | | | |
|---|---|---|---|---|---|---|---|---|
| | Per Capita (MWh) | | Total (TWh) | | Industry (%) | | Household (%) | |
| | 1980 | 1986 | 1980 | 1986 | 1980 | 1986 | 1980 | 1986 |
| Norway | 18.4 | 22.2 | 83.6 | 99.2 | 52.4 | 48.0 | 31.5 | 34.0 |
| Canada | 12.8 | 15.2 | 350.2 | 436.7 | 46.0 | 45.8 | 27.6 | 28.1 |
| Iceland | 12.5 | 14.1 | 3.2 | *4.0 | 69.3 | *70.2 | 22.6 | *19.7 |
| Sweden | 10.3 | 14.1 | 97.2 | 133.9 | 48.0 | 44.7 | 26.6 | *29.0 |
| USA | 9.5 | 10.4 | 2460.0 | 2676.0 | 39.0 | *35.4 | 33.2 | 34.7 |
| Finland | 7.9 | 10.2 | 41.9 | 55.0 | 61.8 | 56.2 | 22.0 | 25.1 |
| Switzerland | 5.6 | 6.5 | 41.1 | 49.1 | 33.8 | 32.6 | 27.5 | 28.6 |
| FR Germany | 5.5 | 6.3 | 374.5 | 413.4 | 49.8 | 49.6 | 26.3 | 26.2 |
| France | 4.3 | 5.3 | 261.1 | 336.7 | 58.8 | 53.4 | 26.0 | 30.5 |
| Belgium | 4.6 | 5.1 | 51.0 | 58.5 | 56.7 | 53.6 | 30.8 | 32.9 |
| Austria | 4.5 | 5.0 | 38.0 | 43.2 | 44.0 | 42.1 | 20.0 | 27.2 |
| The Netherlands | 4.2 | 4.6 | 64.5 | 69.5 | 50.2 | **48.1 | 26.6 | **25.9 |
| Italy | 2.9 | 3.5 | 191.8 | 213.8 | 61.1 | *56.2 | 23.1 | *25.1 |
| Spain | 2.5 | 2.8 | 109.1 | 127.4 | 60.9 | 56.3 | 21.3 | 22.0 |
| Portugal | 1.5 | 1.8 | 17.1 | 22.2 | 60.0 | 56.2 | 22.4 | 24.8 |
| *1985<br>**1984 | | | | | | | | |

Table 3. Total, per capita and percentage of total electricity consumption in industry and households in selected industrialized countries in 1980 and 1986[5]

Generally, a heat pump installation has to be justified by its own profit which means that the energy cost saving has to pay the installation costs according to the conditions set by the user. The calculated profitability is a function primarily of investment costs, annual utilization period, energy prices, coefficient of performance (COP), and service/maintenance costs. But consequential profits such as decrease in cooling water consumption, increase in product quality, etc., must also be considered.

Due to the large number of influencing factors, the theoretically possible applications and profitability of different types of heat pumps are incalculable. One way to illustrate how an electrically driven heat pump can compete with direct electric heating or oil burning is shown in Figure 2.

The example shown in Figure 2 illustrates for this specific case that an oil price of US $0.25/l and an electricity price of US $0.045/kWh require that the investment costs for the heat pump must be lower than US $300/kW to be competitive with conventional oil heating (point a). For a more realistic investment of US $800/kW, the electricity price must be lower than US $0.027/kWh (point b) or the oil price has to be higher than US $0.34/l (point c).

The present light fuel oil and electricity prices for industry and households in the major industrialized countries (Figures 3 and 4) economically justify the application of the above mentioned heat pumps only in a few limited cases and countries.

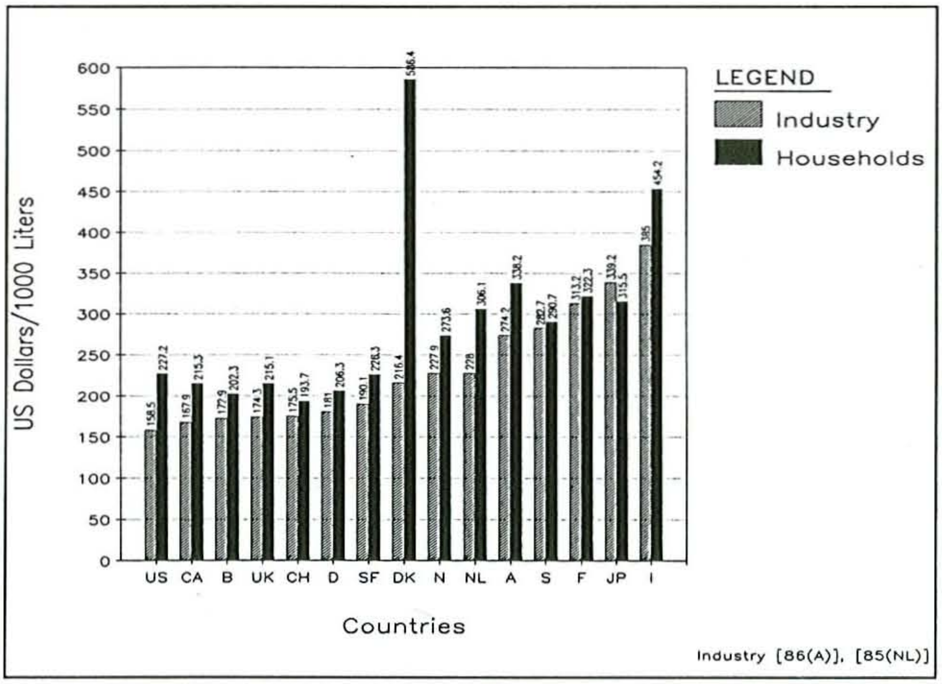


Figure 3. 1987 Light fuel oil prices for industry and households[4]

The example also shows that a general economical breakthrough of heat pumps cannot be expected in the foreseeable future. Possible applications require, therefore, a detailed analysis of all aspects, boundary conditions as well as long-term perspectives.

## Identification of economic heat pump applications

Despite the present uncertainties of the market, the major advantages of heat pumps stem from the lower combustion of fossil fuels resulting from recovery of unused natural energy sources or the heat losses of buildings or industrial processes.

To accelerate the use of heat pumps, governments, industry, and users should be aware of the advantages that can be derived from this development. It requires the following actions:

-- A thorough analysis of heat pump components and systems as an integrated part of the cooling and heating technology.

-- Enhanced knowledge of the fields in which heat pumps offer the greatest potential, and identification of the most appropriate technologies and the most desirable operating conditions.

-- The formulation of energy policy taking into account the advantages of the heat pump for the national economy and the environment.

-- International cooperation in research and development as well as demonstration plants using advanced heat pump techniques.

Considering the usefulness of an exchange of information between different countries and of the transfer of experience gained, the Heat Pump Center will concentrate its future work on the identification and detailed analysis of the role of advanced heat pumps in heating and cooling systems, as well as the most promising markets for heat pump application. Without claiming completeness, the following processes might be of particular interest for future profitable heat pump applications:

-- Combined cooling and heating processes using the condensation heat of industrial cooling plants for process and space heating, preferably at low temperature.

-- Combined cooling and heating processes using the comfort cooling equipment for heating during the cold season of the year (low extra investment costs and increased utilization of cooling equipment).

-- Drying processes, which need both cooling and heating, and commonly require a low temperature difference.

-- Industrial distillation and rectification processes where open cycle compression heat pumps can be used with a low pressure ratio.

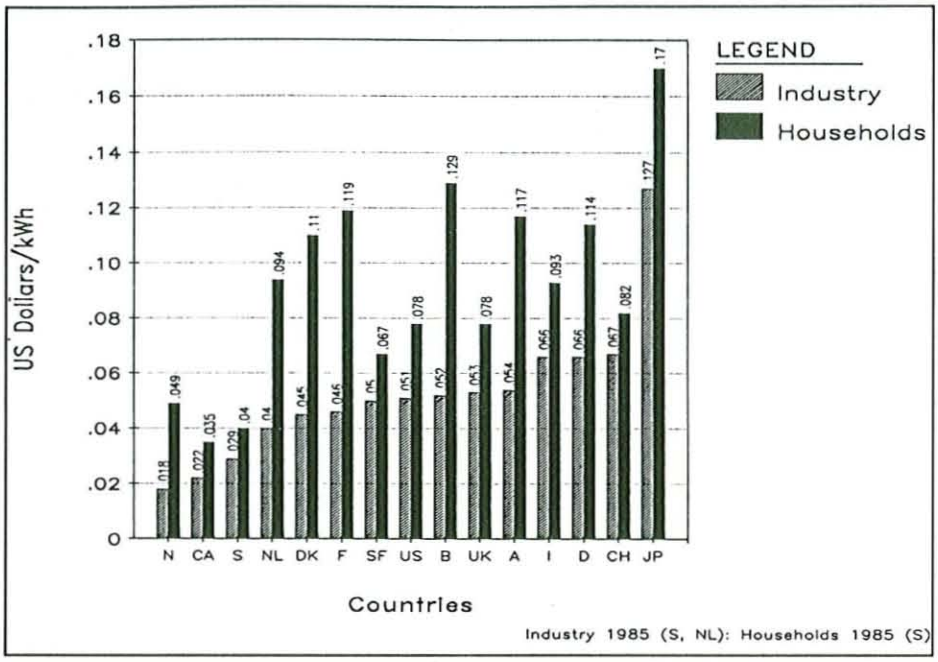


Figure 4. 1986 Electricity prices for industry and households[4]

-- Low temperature sanitary water production in multi-family houses using ventilation air as a heat source.

-- Industrial processes with a high output of waste heat at high temperatures where heat transformers could be applied.

-- Industrial processes with high temperature requirements to which compression-absorption and advanced absorption cycles could be applied.

For most of these processes, currently available and mature heat pump technology can be used.

The present uncertainties with CFCs and new refrigerants not only require international cooperation on R,D&D to introduce new environmentally safe and economically competitive working fluids, but also new heat pump processes and components to replace vapor-compression heat pumps using CFCs.

The IEA Heat Pump Center, presently planning its third working period, is aware of its function to foster international cooperation for a successful heat pump future.

**Editor's note:**

Gross National Product (GNP):
Total production of goods and services by the citizens of a country at home and abroad.

Gross Domestic Product (GDP):
Total production of goods and services by the citizens of a country and foreigners within national borders.

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**W. Paulick***

# Sachs Fuel Oil and Natural Gas Heat Pumps

*Fichtel & Sachs AG has been working on the development of internal combustion engine-driven fuel oil and natural gas heat pumps with a thermal capacity of 20 kW (at -15°C outside temperature) for almost 10 years. This development is based on Sachs' expertise for engines, electronics, research organization and large-volume production. The heat pumps are for use in monovalent and bivalent-parallel applications in all hydronic heating systems as well as for heating sanitary water, small swimming pools or the like. In more than 100 test plants and in test stands, these heat pumps have been optimized on a continuous basis.*

## The system

The aim of the Sachs development activities was a central heat generator which can be mass produced and meets the following requirements:

- Use fuel oil and natural gas, which is used in over 70% of all building heating systems in the U.S. and Europe
- Monovalent operation for all types of buildings having a heat requirement up to 20 kW and bivalent-parallel operation with a peak load boiler for heat requirements of up to 80 kW
- Range of operation from +35°C down to less than -20°C outside temperature
- Use of outdoor air as a heat source (use of other heat sources is also possible)
- Use of thermal energy from engine block, cylinder head, exhaust gas, and lubricating oil
- Over 40,000 operating hours
- Service intervals of not less than 3,000 hours of operation
- Heat pump, boiler, temperatures, mixer, circulation pump, etc., to be controlled and monitored by the Sachs microprocessor control as a central coordinating control
- Applicability to all hot water heating systems (convectors, radiators, floor heating) up to a supply temperature of 80°C
- Continuous capacity control of the heat pump to the heat requirements of the building (capacity control range 13-25 kW)
- Low-noise operation of the heat pump and air evaporator
- Low-pollutant operation (soot, $NO_x$, CO, $CO_2$ in compliance with the German boiler specifications)
- Minimal floor space requirements for the heat pump (0.8 $m^2$)
- Complete heat pump assembly in the factory
- Cost efficient and easy installation (especially bivalent-parallel, if retrofitted)
- Up to 50% savings in fuel oil or natural gas with no reduction in comfort or water temperatures for both heating and tap water supply

All these criteria, which are partly contradictory, could only be achieved by means of a completely new system design.

## Engine compressor unit

40,000 hours of operation, long service intervals, and direct cooling with heater water made it necessary to develop a new unit. The development included a special engine and a special compressor. These two units are connected by a rigid, detachable crankshaft. Figures 1 and 2 show an installed unit.

Engine specifications:
- 1 cylinder, 4 cycle (583 $cm^3$)
- Speeds 1,200-3,000 $min^{-1}$
- Max. shaft performance 6.7 kW
- Natural gas engine: Otto principle (spark plug), lean burn mode engine
- Fuel oil engine: Diesel, direct injection, soot filter regeneration system, exhaust gas recirculation (EGR)

Compressor:
- 1 cylinder Boxer piston engine (280 $cm^3$)
- Refrigerant R12

## Air evaporator

The air evaporator is located outside the house (split version). Two slowly running fans assure an airflow of 5,000 $m^3$/h. The two running fans have a noise level of 45 dB(A), at a distance of 1m. Depending upon the engine speed, the evaporating rate lies between 3 and 10 kW for a temperature variation of 3 to 8°K. Ice is defrosted by hot gas. The microprocessor control starts and completes the defrosting cycle. The defrosting losses are about 3%. Figure 3 shows the outdoor evaporator on a test installation.

## Microprocessor control

The Sachs microprocessor control, a return temperature control based on actual outside temperature conditions, is the central coordinating control for all the component parts of the heat pump and the heating system. It also collects operational and fault data and provides data display, data output, and fault correction.

For commissioning and later during operation, a special interface allows a printout of a comparison of nominal to actual data to be made from the memory of the Sachs control.

The control system has a priority circuit for sanitary water (common practice in Germany). A partial priority circuit ensures that in addition to sanitary water use, space heating system, and swimming pools, etc., can be fed at the same time.

The microprocessor control also regulates and controls the soot regeneration and the injection times of the fuel oil heat pump.

## Noise reduction

The building structure of many houses is quite often very sensitive to noise transmission. The engine compressor unit, the condenser, and all pipes and framing are secured by special spring viscose dampers and compensators so that structure-borne noise cannot be

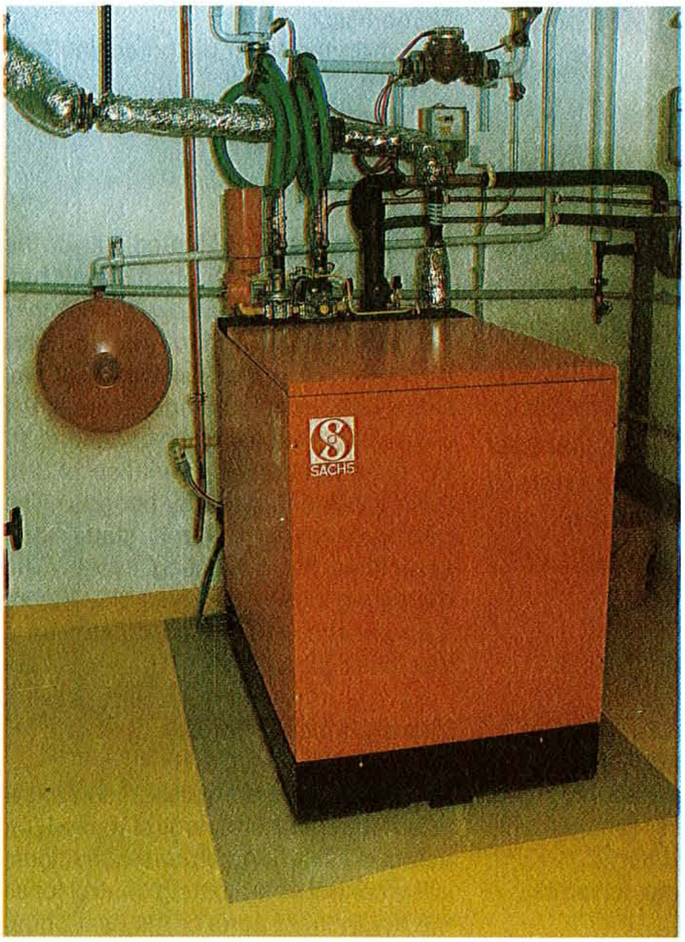


Figure 1. Sachs heat pump installed in a residence with a 50kW heat load

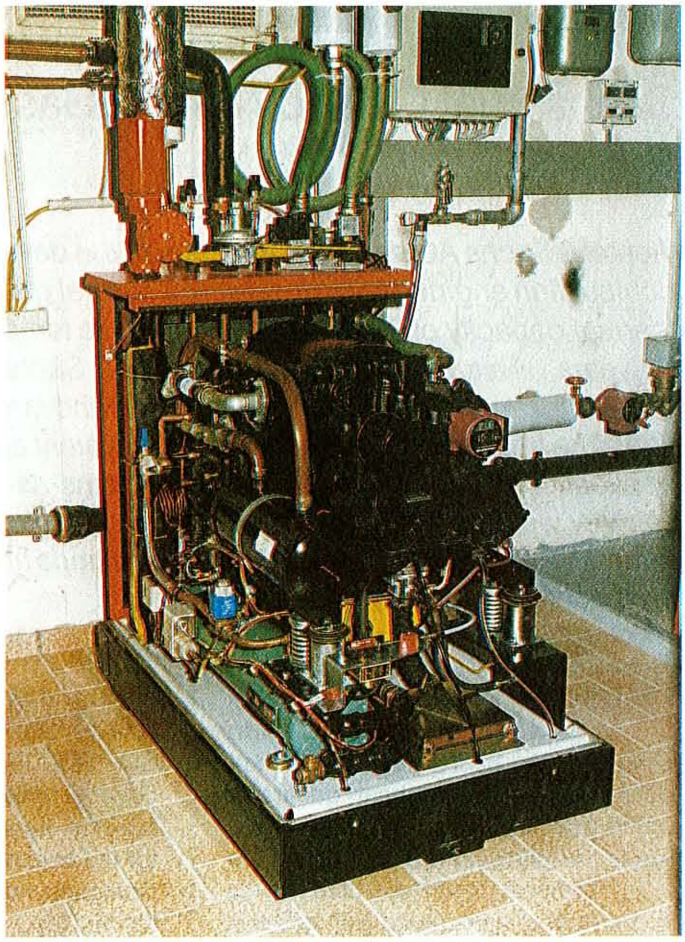

Figure 2. Sachs heat pump installed in a residence with a 40kW heat load (shown without sound/heat cover)

transmitted via the floor, pipes, or exhaust lines into the building. The noise level of the heat pump is reduced by a specially developed sound proofing cover, which also serves as heat insulation. The noise level of the heat pump is 53 dB(A), at a distance of 1m.

**Experience gained during operation**

From 1980 to 1988, as many as six test generations of the Sachs heat pump were developed. A primary prerequisite was maximum safety, followed by function, optimum energy savings, and minimum installation cost. All requirements have been met.

The test units have been installed and operated on internal test stands and in more than 100 residential houses at the same time. The expected 40,000 hours of operation were achieved and the service intervals of 3,000 hours have been realistic.

Each heat pump component had to be optimized for this system. For example, the system components must be able to operate with an 80°C continuous temperature under the sound cover. In particular, hose connections, compensators, noise absorbers, natural gas supply system, and fuel oil feed pumps had to be redesigned. The optimum development of these parts consumed a great deal of time and was possible only by the continuous testing of many heat pumps in actual residences.

Depending on speed and load, the natural gas heat pump uses 1g lubricat-

Figure 3. Roof-mounted Sachs air evaporator

ing oil/h, the fuel oil heat pump up to 2 g/h. Fuel use is 0.8 $m^3$ to 2.0 $m^3$ natural gas/h and 0.9 $m^3$ to 1.7 $m^3$ fuel oil/h.

The efficiency of the fuel oil engine is 33%, while the efficiency of the natural gas engine is 27%. Due to a higher waste heat of the engine, the heat capacity of the natural gas heat pump is about 2 kW higher than that of the fuel oil heat pump.

There are no fixed annual COP's applicable to all heat pump installations. Outside temperature, heating network, comfort requirements, heating and sanitary water temperatures, lowered temperatures at night, or using heat for a swimming pool markedly influence the annual COP. For example, in a specific heat network, the COP varies between 1.05 (at -20°C outside temperature) to 1.70 (at +30° in summer).

For all Sachs installations, the annual COP values measured in different heating networks and buildings are on the average 1.35 to 1.45 for monovalent operation and 1.30 to 1.40 for bivalent-parallel operation. Natural gas heat pumps have a somewhat lower COP than fuel oil heat pumps.

In monovalent applications, the heat pumps work up to 2,700 h/year, while in houses with heat requirements of 80 kW, the heat pumps operate up to 7,100 h/year. This saves about 1 liter of fuel oil or 1 m3 of natural gas per operating hour, respectively.

### Conclusion

The development of a fuel oil and a natural gas heat pump up to the stage where they are ready for production took more time than originally planned. Each component had to be newly developed, engineered, and optimized within the complete system. Long-term experience had to be gained in large-scale testing before such a new system could be launched into the market.

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**G. Alefeld***

# Problems with the Exergy Concept (or the Missing Second Law)

*A proposal for a new IEA Annex entitled "Fundamentals - Second Law Analysis for Heat Pumps" is presented. This article outlines why there is a need for such an activity in basic thermodynamics and what problems could be solved by the annex.*

### The enthalpy method (first law method)

Efficiencies of heat pumps and refrigerators are usually calculated by enthalpy balances. Complete and very accurate data charts are required. In particular, for mixtures of fluids, an enormous amount of data must be measured to be able to calculate COPs. This COP is quite often called "The First Law Efficiency" since enthalpy balances apparently involve only the application of the first law of thermodynamics. Yet this terminology is rather misleading. The statements of the second law have been taken into account in these calculations as well, although in a very indirect way. The second law is actually hidden in the fluid data, which are explicitly used in the calculations. Therefore, none of the calculated COPs ever violates second law.

But here is the point: The statements of the second law are quite general and can be formulated **completely independently of any fluid property**. Therefore, in each design calculation performed by an engineer or by a student, the second law is recalculated each time using fluid data, with all their problems of inaccuracy and possible inconsistency.

### The entropy method (or: second law method)

An alternative method for the calculation of COPs in which the second law is being used from the very beginning has been developed recently.

The second law manifests itself most generally in the existence of the entropy potential. Entropy is not a conserved quantity like mass or energy, and the second law is usually written as an inequality. Yet it may be written as an equality similarly to an additional conservation law, if all sources of entropy production are included in the entropy balance:

$$(\text{Entropy})_{out} - (\text{Entropy})_{in} = \Sigma\,(\text{Entropy Production}) \qquad (1)$$

Although such a formulation of second law can be found in the literature[1], this relation serves in general only to calculate the entropy production. In this sense, it is merely used as a definition of the otherwise apparently unknown right-hand side.

Yet, if the right-hand side can be calculated separately as a function of the process parameters, this equation becomes an independent new relation which, in combination with the first law, can be used to calculate the COP. That this can be done is shown in Reference 2 for compressor as well as absorber heat pumps and refrigerators. The calculation of the entropy production is not difficult. The sum extends over all irreversible process steps, e.g., throttling, heat transfer, compression, de-superheating, etc. Since the entropy is a state function, the detailed mechanism for the entropy production is of no relevance. All one needs to know is the state of the system before and after the irreversible step.

The results are rather encouraging. It turns out that most of the fluid data needed to apply the enthalpy method are just used for recalculation of the second law. Thus, applying equation (1) in combination with the first law, the amount of data required to predict the COP reduces to a few parameters. These can be used to characterize a particular working fluid. Furthermore, analytic equations can be derived for the

| | |
|---|---|
| Description: Topping cycle (for example, a gas turbine) for a power cycle or district heating station for cogeneration. For simplicity, the cycle may be assumed to be a Carnot process. | |
| Entropically averaged temperatures: $T_{in} = T_2 = 1000K$; $T_{out} = T_1 = 500K$; $T_{amb} = 300K$; $\eta_{rev} = \frac{1000\text{-}500}{1000} = 0.50$; $\eta_{real} = 0.25$; $\dot{W}_{real} = 100$ MW | |
| **Heat and Electric Power** | **Exergy $\dot{E}$** |
| $\dot{Q}_2 = \dot{W}/\eta_{real} = 400$ MW | $\dot{E}_2 = \dot{Q}_2 \frac{1000\text{-}300}{1000} = 280$ MW |
| $\dot{Q}_1 = \dot{Q}_2 - \dot{W} = 300$ MW | $\dot{E}_1 = \dot{Q}_1 \frac{500\text{-}300}{500} = 120$ MW |
| $\dot{W}_{rev} = 400 \cdot 0.5 = 200$ MW | |
| $\Delta\dot{W} = 100$ MW | $\Delta\dot{E} = \dot{E}_2 - (\dot{E}_2 + \dot{W}) = 60$ MW |
| **Second Law Efficiency** | **Exergetic Efficiencies** |
| $g = \frac{\eta_{real}}{\eta_{rev}} = \frac{\dot{W}_{real}}{\dot{W}_{rev}} = 50\%$ | $\zeta = \frac{\dot{E}_{out}}{\dot{E}_{in}} = \frac{\dot{W} + \dot{E}_1}{\dot{E}_2} = 78.5\%$ |
| | $\zeta = \frac{\dot{W}}{\dot{E}_2} = 35.7\%$ |
| | $\zeta = \frac{\dot{W}}{\dot{E}_2 - \dot{E}_1} = 62.5\%$ |

Example 1.

COP. These show explicitly the dependence on process parameters More importantly, the contribution of the individual loss mechanism to the reduction of the COP appear quantitatively in these equations. Therefore, these equations are helpful in evaluating competing loss mechanism, minimizing investment cost for given operating cost or for optimizing total cost.

The two methods may be characterized as follows:

Enthalpy method:
First law + very complete and accurate knowledge about fluid properties

Entropy method:
Second law + first law + small but selective knowledge about fluid properties; less accuracy required

**Example**

The textbook example of the Carnot process (as a power cycle) may serve to demonstrate the difference between the two methods.

For the enthalpy method, one needs to know two isotherms, two isentropes, and the corresponding enthalpies. All these quantities are fluid dependent. With the ideal gas assumption for the isotherms and the adiabatic lines, and the further assumption that both $c_p$ and $c_v$ are pressure and temperature independent, one can derive the Carnot efficiency analytically. Although needed for the derivation, in the final result for the COP all fluid dependent properties cancel out. It is very difficult to predict the consequences of real gas effects on the analytic equation for the efficiency.

For the entropy method, one uses first and second law.

First law: $$q_2 - q_1 = w \tag{2}$$

Second law: $$-\frac{q_2}{T_2} + \frac{q_1}{T_1} = \sum_i \delta s_i \tag{3}$$

$q_2$ = heat supplied to the engine
$q_1$ = heat leaving the engine
$w$ = work produced by the engine

The sum $\sum_i \delta s_i$ extends over all sources for entropy production. Each term in this sum makes a positive contribution. Eliminating the rejected heat $q_1$ yields the following equations for the COP:

$$COP = \frac{w}{q_2} = \frac{T_2 - T_1}{T_2} - T_1 \sum_i \frac{\delta s_i}{q_2} \tag{4}$$

For the reversible process ($\Sigma\delta s_i = 0$), one immediately gets the Carnot efficiency without having used any fluid property. The fluid may deviate from ideal gas behavior, it may undergo phase changes and still the result is valid. The result has even much wider validity. No specific assumption about the atomistic details of the thermodynamic process was made in equations (2) and (3). The result, therefore, holds as well, e.g., for thermocouples. The result is also correct for a Stirling process or even a Rankine process with isothermal heat input and output. The result is correct as well for the Lorenz process with changing temperature at condenser and evaporator if $T_1$ and $T_2$ are the entropic averages for the gliding temperatures.

Processes or fluids differ in the contributions to the second term, in equation (4), which can be calculated or taken from data charts.[2]

For a heat pump or a refrigerator, the signs of $q_2$, $q_1$ and $w$ in equations (2) and (3) must be reversed (not so for the $s_i$). Eliminating $q_2$ yields the following equation for the refrigeration power:

$$q_1 = w \frac{T_1}{T_2 - T_1} - \frac{T_1 T_2}{T_2 - T_1} \sum_i \delta s_i \tag{5}$$

and for the COP for refrigeration $q_1/w$:

$$COP = \frac{q1}{w} = \frac{\frac{T_1}{T_2 - T_1}}{1 + \frac{T_1 T_2}{T_2 - T_1} \sum_i \frac{\delta s_i}{q_1}} \tag{6}$$

Applying thermodynamic relations, it

can be shown[2] that this equation for the COP is identical with the familiar equation based on enthalpy balances. Yet, in equation (6) the major part of the COP is determined by the numerator, which is fluid independent. For the fluid dependent denominator, the knowledge of only two or three nondimensional fluid parameters is required.

Equation (6) can be applied to derive analytic equations for COP improvements by internal heat exchange, by fluid injection, by an expansion turbine or by using fluid mixtures. For the latter case, the advantages or disadvantages of mixtures become more transparent than with the enthalpy method. Details still need to be worked out, which would be done in the proposed annex.

It is not suggested that the entropy method should completely replace the enthalpy method. Both should be applied in parallel. If enough information with appropriate accuracy is available about a fluid, a fluid mixture or a fluid pair for absorption machines, it would be a mistake not to use it. The application of the entropy method yields additional information in any case. If the information about the fluid or fluid mixtures is rather limited, the entropy method may still remain applicable to calculate the first law efficiency.

Also for absorption machines[2], the entropy method yields analytic equations for the COP which are functions of a set of nondimensional parameters. These parameters can be used as figures of merit for competing fluid pairs.

In any case the entropy method will pave the way for a second law analysis, which is discussed in the next section.

| | |
|---|---|
| Description: Heat pump operating between head and bottom of a distillation column. The purpose of the system is to pump heat from the head to the bottom. The efficiency is, therefore, measured as "refrigeration power/work input." | |
| Entropically averaged temperatures: $T_{out} = T_2 = 450K$; $T_{in} = T_1 = 400K$; $T_{amb} = 300K$; $\eta_{rev} = \frac{\dot{Q}_1}{\dot{W}} = 8.0$; $\eta_{real} = 4.0$; $\dot{Q}1 = 400\ kW$ | |
| **Heat and Electric Power** | **Exergy $\dot{E}$** |
| $\dot{Q}_1 = 400\ kW$ | $\dot{E}_1 = \dot{Q}_1 \frac{400-300}{400} = 100\ kW$ |
| $\dot{W}_{real} = 100\ kW$ | $\dot{E}_2 = \dot{Q}_2 \frac{450-300}{450} = 166.7\ kW$ |
| $\dot{Q}_2 = 500\ kW$ | |
| $\dot{W}_{rev} = 50\ kW$ | |
| $\Delta\dot{W} = 50\ kW$ | $\Delta\dot{E} = \dot{W} + \dot{E}_1 - \dot{E}_2 = 33.3\ kW$ |
| **Second Law Efficiency** | **Exergetic Efficiencies** |
| $g = \frac{\eta_{real}}{\eta_{rev}} = \frac{\dot{W}_{rev}}{\dot{W}_{real}} = 50\%$ | $\zeta = \frac{\dot{E}_{out}}{\dot{E}_{in}} = \frac{\dot{E}_2}{\dot{W} + \dot{E}_1} = 83.3\%$ |
| | $\zeta = \frac{\dot{E}_2}{\dot{W}} = 166.7\%$ |
| | $\zeta = \frac{\dot{E}_2 - \dot{E}_1}{\dot{W}} = 66.7\%$ |

Example 2.

## Exergy analysis vs. second law analysis

The difficulties and contradictions involved with the application of the exergy or availability concept may be demonstrated by two simple numerical examples (see Examples 1 and 2).

In Example 1, the following discrepancies are apparent:

1. All three definitions for the exergetic efficiency yield values, which not only differ between each other but also differ widely from the second law efficiency.
2. Changing the ambient temperature has no influence on the second law efficiency but changes the quantitative value of the exergetic efficiencies.
3. The lost work W is **not** identical with the exergy loss E, which is 40% lower.
4. The second law efficiency varies between 1.0 (for a completely reversible power station) and 0 (for a completely irreversible power station with W(real) = 0, i.e., pure heat flow between $T_{in}$ and $T_{out}$). The first definition of the exergetic efficiency starts correctly with 1 for the best case, but ends with 57.2% for the worst case. The second definition starts at 71.5% for the best case and ends at zero for the worse case, whereas the third definition (preferred in Japan[7]) at least starts with 1 and ends with zero, but still deviates strongly in between from the second law efficiency.

So one may ask what is the meaning of an exergetic efficiency and how useful is it?

Consider also Example 2. Again the meaning of the exergetic efficiencies is completely obscure. The additional work is 50% higher than the exergy loss.

In many books and journal articles, second law analysis is identified with an exergy analysis. Quite often it is implied that the exergy concept represents the statements of the second law in its full extent. This is not the case. The most vulnerable part of the exergy concept is the reference state, the "ambient state" or the "dead state" as it is quite often called. In contrast to the exergy concept, the second law can be formulated independently of any reference state. The discussion about a reference state for the entropy has ended (or should have ended) with the formulation of the so-called third law.

What can be expected from a Second Law Analysis?

1. First of all, one wants to evaluate processes. How good is a process in respect to the best process possible? When second law analysis is applied as exergy analysis, many competing definitions of exergetic efficiency have been proposed. Only a few authors cared to interpret their definition. What does a statement "exergetic efficiency 0.7" really tell the user of the concept? As the two examples demonstrate, this exergetic efficiency cannot be interpreted, except for rare cases, that 0.7 of the efficiency of a reversible process has been reached.

2. Exergy analysis is furthermore applied to evaluate fuels and resources.

3. It is used to establish correlations between dissipations and thus investment and operating cost. For this rather active area, the name "thermoeconomics"[1,3] is being used.

4. Finally, it is suggested that exergy analysis provides methods in cost accounting for systems, delivering several product streams, like electric power, heat and/or refrigeration.[4]

Although the application of the exergy analysis is strongly recommended by exergy analysts and is even included in the ASHRAE Handbook[5], Kaeltemaschinenregeln[6] or Japanese Industrial Standards[7], it is barely used by the practicing engineer. There are good reasons for this. The contradictions involved are confusing[8], e.g., it has been shown recently that cost accounting in cogeneration according to the exergy content of the products results in thermodynamic relations which violate the second law.[9]

It is obvious that the irreversibilities in a process cause additional operating cost or may be reduced by additional investment cost. But are the exergy losses the correct quantity to establish correlations between thermodynamic and economic quantities?

The exergy loss may be calculated as the product of the ambient temperature with the sum over all entropy sources, i.e.,

$$\delta E = -T_{amb} \cdot \sum_i \delta s_i \qquad (7)$$

So the ambient temperature is used as the conversion from the entropy increase to a quantity with the dimension of energy.

Exergy of heat is the potential work of a unit of heat at the temperature T, which would be recovered in a reversible power station, operating between T and an ambient temperature $T_{amb}$. Of what help is this knowledge, considering a compressor heat pump or refrigerator, an absorber heat pump or refrigerator, a heat transformer, a separation process, etc.

No one intends to use such a fictitious power station and if he would like to, he would not have a reversible one available.

More relevant questions than asking for exergy losses are as follows:

Compressor refrigerators:

a. How much additional work is required to run the refrigerator, in spite of irreversibilities, at a given refrigeration level?

   Answer from equation (5):

$$\delta W = T_2 \sum_i \delta s_i \qquad (8)$$

   $T_2$ = condenser temperature

b. How much refrigeration power is lost due to irreversibilities at a given work input?

   Answer from equation (5):

$$\delta q_1 = -\frac{T_1 T_2}{T_2 - T_1} \sum_i \delta s_i \qquad (9)$$

   $T_1$ = evaporator temperature

Absorption chiller:

a. How much additional generator heat is required to run the chiller, in spite of the irreversibilities, at a given refrigeration level?

   Answer in Reference 2:

$$\delta q_2 = \frac{T_1 T_2}{T_2 - T_1} \sum_i \delta s_i \qquad (10)$$

   $T_2$ = generator
   $T_1$ = condenser/absorber temperature

b. How much refrigeration power is lost due to irreversibilities at a given generator heat input?

   Answer in Reference 2:

$$\delta q_1 = -\frac{T_0 T_1}{T_1 - T_0} \sum_i \delta s_i \qquad (11)$$

   $T_0$ = evaporator temperature
   $T_1$ = condenser/absorber temperature

For work, heat and refrigeration, there are well-defined prices which depend on local commodities. The conversion factors from irreversibilities to these quantities for which a market price can be quoted is not the ambient temperature $T_{amb}$ as in the exergy concept (equation (7)), but well-defined process temperatures which can differ widely from the ambient temperature. (How to calculate the sum over the entropy contribution explicitly is shown in Reference 2.)

Therefore, working with the exergy is like working with a non-suitable currency exchange factor: the price of the products is calculated in \$, but one quantity in the calculation is inserted in Yen.

The problem goes even deeper: Applying a rigorous second law analysis suggests that the exergy specific "ambient" reference state ($T_{amb}$, $\mu_{amb}$) should quantitatively play no role in the final results, except the ambient is really a process state. This may be the case for a condensing power station for which Keenan[10] originally formulated the concept. But already for a district heating station with steam extraction, the situation is different. Clearly the heat extracted at, for example, 120°C and piped into homes for heating finally ends at ambient temperatures. But the performance of this district heating station will not depend on what mechanism and what speed in the homes this heat finally reaches the ambient. Any back reaction of the ambient state on the performance of the district heating station can be taken into account by variations in the extraction temperatures. So these process temperatures will become the relevant temperatures for process evaluation and thermoeconomics and not the ambient temperature.

The problems with the exergy are caused by an unjustified generalization of a concept originally developed for and applied correctly to a power station with a condensing temperature at the ambient temperature level.[10]

For most systems except power stations, the chemical composition of the ambient state is not more than an artificially introduced reference state.[11] This may be done for convenience. But in the final results any quantity, characteristic of an ambiguous reference state, must cancel out. If this is not the case, definitions have been applied, which may not be particularly useful.

### Summary

There is a need for rigorous application of the second law in two areas. The first one is the area in which hitherto the exergy concept has mostly been applied, namely for evaluation of processes and components in a process. The exergy concept is not wrong as such. Everyone is free to define and calculate exergy efficiencies. Yet, the problems arise when quantitative conclusions are being derived from and optimization procedures are based on these definitions. The application of the second law in its most general form will base this part of the field of second law analysis on more firm ground.

The second area, which exergy analysts apparently have not been aware of, is the calculation of the so-called "first law efficiencies" by applying the second law.

Clearly, both areas are intimately connected and both areas are promising to yield new insights on which design and operation decisions can be based.

The field for applications of the second law is by no means limited to energy conversion devices. The evaluation methods for chemical processes and separation processes need reconsideration as well. Yet for reasons of effectiveness, the Annex "Fundamentals - Second Law Analysis for Heat Pumps" should in its initial stage be confined to heat pumps and refrigerators of the compression and/or absorption type.

Anyone who has proposals or who plans to make contributions to this field is invited to send his material to the author.

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# Large Heat Pumps in Stockholm

*This article deals with the use of heat pumps for district heating in the city of Stockholm. Heat pumps are also used for this purpose throughout Sweden. The current installed capacity nationwide is more than 1200 MW.*

### Introduction

One of the main reasons for the rapid introduction of large heat pumps in Sweden's district heating systems has been the relatively low cost of electrical energy. Despite negative predictions, the technology has gained ground rapidly. An official report published as recently as 1979 stated that the large-

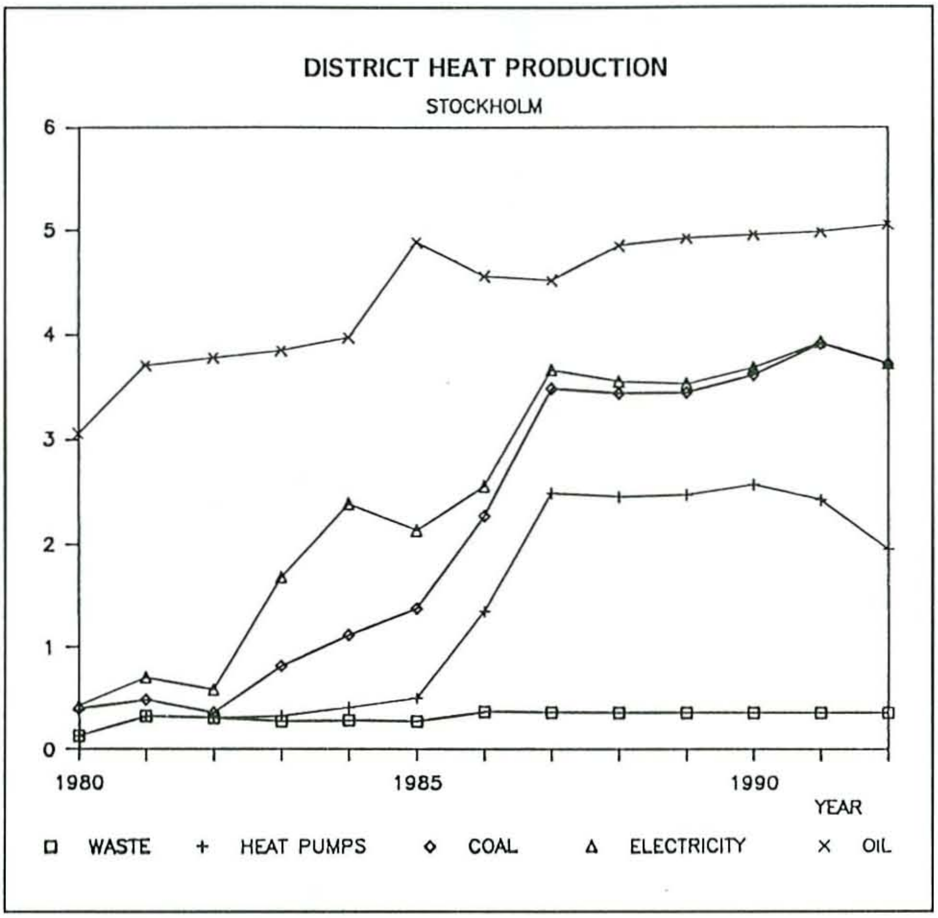


Figure 1. District heat production (Stockholm)

scale use of electric heat pumps was not a viable alternative. Today, a mere nine years later, large heat pumps account for about half of the total heat generated for district heating in Stockholm. District heating offers wide opportunities for quick adjustment to new technologies and new conditions. One example of this flexibility is the relative ease and speed with which large units have been incorporated in the Stockholm system.

Before changing over to new energy systems with the aim of reducing oil dependence, the three vital requirements are that new energy systems must offer lower costs, reduced environmental impact, and better flexibility than their predecessors. One of the most important means for achieving these objectives in Sweden is to expand the district heating systems. Ten years ago, the district heating systems supplied about 20% of the heat demand in Stockholm. This figure has now risen to 50%. The current energy planning envisages that, in the long term, the district heating systems will supply 60-70% of the city's built-up area.

The generation of heat for district heating must be expanded in such a way that the three criteria of low cost, low environmental impact, and high flexibility will be satisfied. Figure 1 shows the development thus far in the 1980's and future plans. In 1980, oil supplied 85% of district heating energy, but this figure is expected to drop to just over 15% in 1990. During the same period, the heat generated for district heating will have increased from 3.6 TWh/year to 4.7 TWh/year. A slight increase in refuse incineration, very heavy investments in large heat pumps, and the introduction of non-polluting coal firing are the factors that contribute towards reducing oil dependence.

Heat pumps can satisfy, with a comfortable margin, the economic, environmental and flexibility requirements. However, it should be kept in mind that the economics vary widely between a large heat pump drawing heat from seawater and an outdoor-air heat pump, for instance, with a rating of only a few MW. The cost of generating heat in the latter case is appreciably higher. Heat pumps also protect the environment by eliminating emissions caused by fuel firing in the city. On the other hand, special consideration must be given to sound attenuation and the handling of the relatively large quantities of refrigerant involved. Finally, heat pumps promote flexibility, since they are not dependent on a certain fuel or a certain method of heat generation. The coefficient of performance of the heat pump also reduces the sensitivity of the heat generation system to changes in the cost of electric power (including taxes). However, a disadvantage from the flexibility aspect is obviously that the opportunities available for generating electric power in combined heat and power plants are reduced and/or delayed.

A further disadvantage of heat pumps is the limitation of the supply water temperature, a factor which means that

Figure 2. Ropsten district heating plant

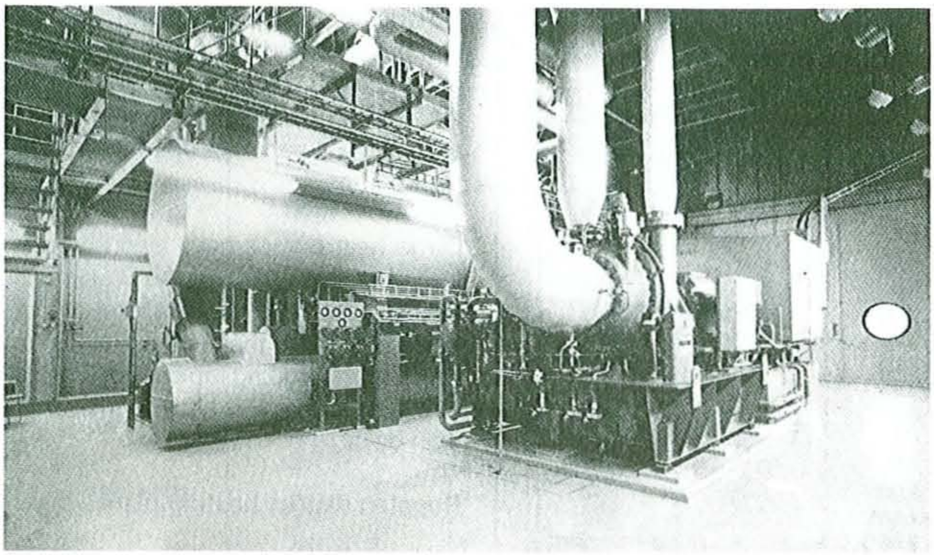

Figure 3. Heat pump compressor and condenser for one unit at the Ropsten plant

other heating sources must be used in addition at times of year when higher temperatures are required.

**The first heat pumps**

In spite of the pessimism which prevailed at the end of the 1970's, Stockholm Energi Produktion AB decided to build a number of smaller heat pump plants, in order to test and develop the technique. The four units involved utilize waste heat, heat from seawater, and purified sewage water. All of the heat pumps are connected to the city's largest district heating system, the Vaerta network, which supplies heat to the central parts of the city. About 75% of all buildings in this area are now connected to the district heating network, and this figure is still growing. The maximum thermal power demand at the present time amounts to about 1000 MW.

A more detailed technical description of the four smaller heat pump plants, i.e., Loudden, VP 1, VP 2, and VP 3, is presented below.

**Loudden**

A decision was made in the winter of 1980/81 to build the first large heat pump for supplying heat to the Stockholm district heating system. This draws heat from purified effluent water. The distance between the heat pump and Loudden is about 1 km, and the distance to the district heating network is a few hundred meters. The location is a result of an economic evaluation which took into account the local conditions and the fact that sewage pipes are less expensive than district heating pipes.

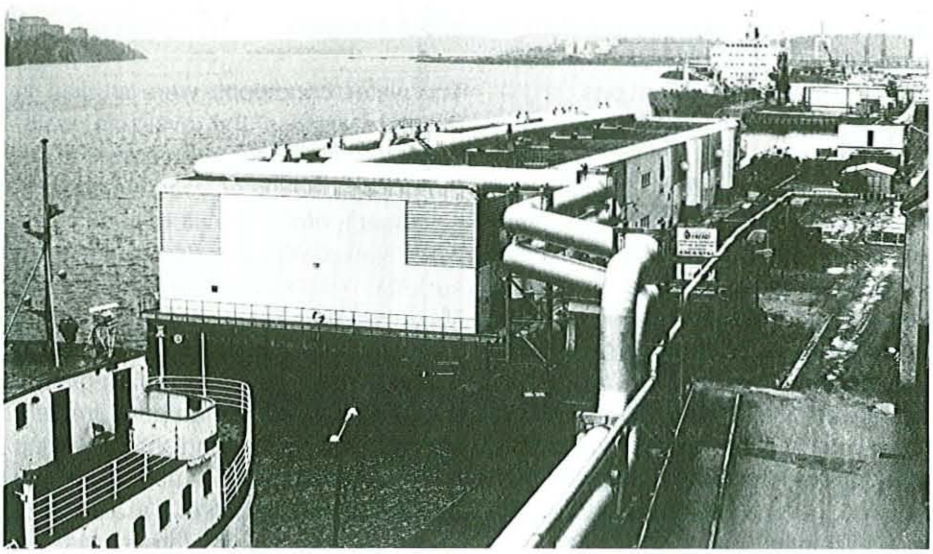

Figure 4. Barge-mounted heat pump

The heat pump, which has a thermal rating of just over 5 MW, is connected to the return pipe of the district heating network. It was placed in operation in 1982, and the capital cost of the plant was about $2.4 million.

The plant consists of two Sulzer Unitop units which are connected in series on the district heating water and effluent sides. Each unit comprises a single-stage turbocompressor. Certain operating limitations may occur if the return temperature in the district heating network is high at the same time as the effluent temperature is low. Each compressor has a rating of about 700 kW. Refrigerant R12 is used and inlet guide vane control is employed. The evaporators are tube-and-shell heat exchangers with copper/nickel (90/10) tubes. The mean COP is 2.7.

**VP 1**

The Vaerta plant has three heat pumps connected to the district heating network. The smallest pump, designated VP 1, has a thermal rating of approximately 3 MW and, during the operating season of the Vaerta power station, draws heat from an internal cooling system of the power station. The temperature of this water is around 25°C, and the coefficient of performance is, therefore, high at around 5. The heat pump is a standard unit comprising a screw compressor of STAL Refrigeration manufacture. During the summer, seawater is used as the source of heat. This enables the heat pump to be operated year round.

**VP 2**

The Vaerta plant also includes two heat pumps that use only seawater as the heat source. These are installed in the old turbine room of the power station and utilize the old cooling water channel.

The larger of the two, VP 2, was commissioned in the autumn of 1983 and can deliver 13 MW of heat. The cost was about $3.9 million and the unit was supplied by ASEA-STAL.

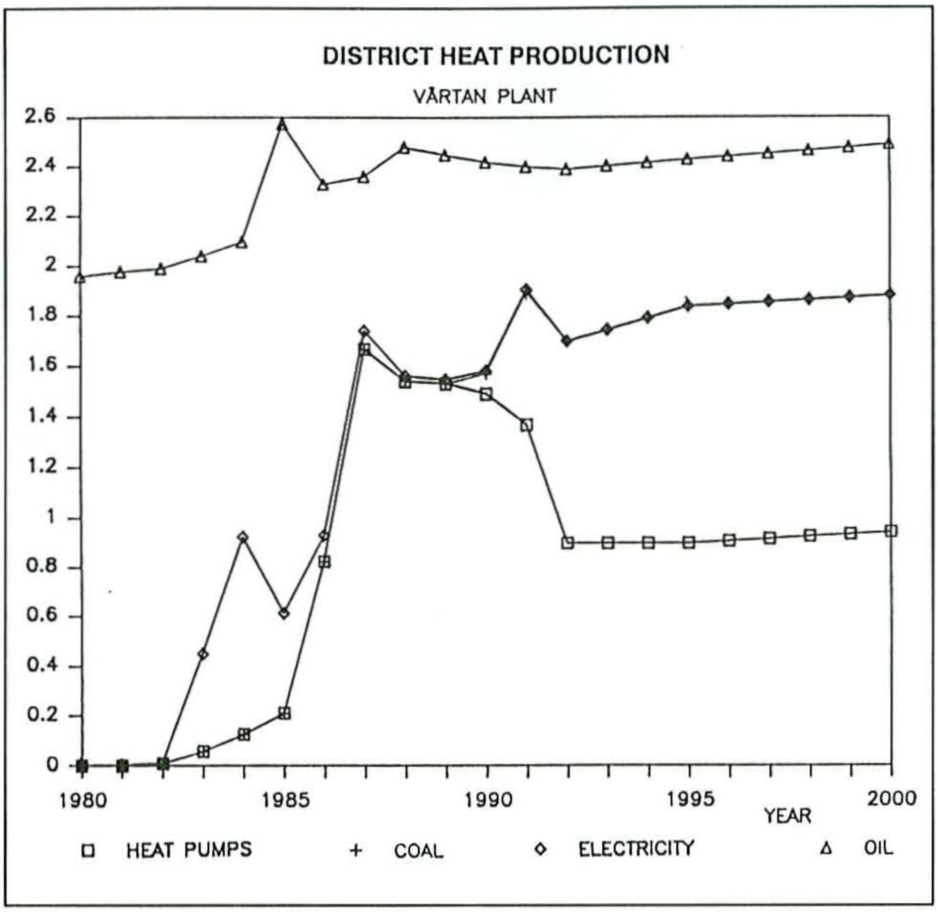


Figure 5. District heat production (Vaertan plant)

The evaporator is of falling-film type (panel type), i.e., the water runs freely on the outside of a number of panels containing refrigerant at saturation temperature. This design enables water at a temperature down to 2°C to be used, without the occurrence of icing problems and consequent reduction in the heat pump output. At such low temperatures, a tube-and-shell evaporator would be susceptible to failure caused by freezing.

The two-stage turbocompressor is of Sulzer manufacture. As all other heat pumps purchased subsequently, the plant includes a computerized control and supervisory system. The COP is just under 3.

Together with a similar plant built on the island of Lidingoe somewhat earlier, VP 2 can be regarded as a prototype for subsequent larger heat pumps in Stockholm employing heat from seawater.

### VP 3

The third heat pump is rated at about 7 MW and was commissioned in the beginning of 1984. It is of STAL Refrigeration manufacture, and the screw compressor is among the largest ever produced. The cost of the plant amounted to approximately $2.1 million.

The evaporator in the plant is a plate heat exchanger, which also enables the plant to operate safely at low water temperatures. It can even withstand being frozen solid without sustaining damage. The evaporator is the first full-scale unit of its type and represents a development stage towards applications on a larger scale. The problem of compressor vibrations has now been solved by making modifications.

### Large heat pumps

The Vaerta plant was originally fired exclusively with oil. Some of the heating demand can be supplied by cogeneration which, apart from the environmental benefits, is one of the advantages of district heating. Electric steam boilers were installed in 1983 to utilize the availability of cheap electricity. This was followed later by the installation of large heat pumps (which use electricity more efficiently) to supply the base load throughout the year. Oil can be used for generating electricity during the six months when prices are highest. Cogeneration based on coal (a project currently under way at Vaertan) may reduce the duration of operation of the heat pumps.

Large heat pumps have also been installed in other parts of the Stockholm district heating network. Most of the heat supplied to the southern network, which is undergoing rapid expansion, is now supplied by this type of unit rather than by oil.

### Ropsten district heating plant

The first stage in the installation of seawater heat pumps on a large scale was taken in February 1984, when it was decided to build a 150 MW plant, combined with an 80 MW electric boiler plant, at Ropsten near Vaertan. The first part was commissioned in autumn 1985, and the plant was completed to full capacity by January 1987 (Figure 2). The plant is the largest of its kind in the world. The total capital cost was about $58.3 million.

The plant was built by a Swedish consortium, with Sulzer as subcontractor for equipment, including the compressors. The installation is located on the coast.

Water is drawn from an intake tower and is connected to the water pumps in the plant by means of a 300m wooden pipe. The water can be drawn from the surface for operation during the summer, or from a depth of about 15m for winter operation. The water is always discharged close to the shore, at a depth of about 4 meters.

The water conditions were studied in detail to assess the available water quantities, the water temperature at different depths over the year, the ecological impact, etc. The salt content in the water varies with the depth, the fresh surface water coming from Lake Maelaren and the salt bottom water from the sea. The influence of the salt content on the density is much greater than that caused by temperature variations. Due to this and the prevailing flow conditions, water at the highest temperature in the winter is at a depth of about 15m, basically throughout the water area. However, the temperature level varies substantially from one year to the next. One of the decisive factors is the weather before the surface is frozen, a cold and windy autumn giving rise to low water temperatures, even well below the surface. At a depth of 15m, measurements carried out during the winter over about 20 years gave readings ranging between less than 1°C and up to approximately 6°C. However, temperatures below 2°C, which is the lower limit for unrestricted operation of the heat pumps, have occurred only seldom.

The six heat pump units, each with a rating of about 27 MW, have evaporators of falling-film type and two-stage turbocompressors, in the same arrangement as VP 2 in the Vaerta plant. The evaporator plates are made of high-alloy stainless steel. The condenser is of tube-and-shell type, with steel tubes. The refrigerant is R22, and the refrigerant charge in each unit is approximately 20 tons. Figure 3 shows the compressor and condenser for one unit.

The plant receives return water at a temperature of 40-60°C from the district heating network and heats it to a maximum of around 80°C. During times of the year when the district heating network requires higher temperatures, this is achieved by operating the heat pumps in series with the electric boilers in Ropsten or with the Vaerta plant, to which the Ropsten plant is connected.

The compressors are driven by synchronous motors, each with a shaft output of more than 8 MW. The total power supplied to the fully expanded heat pump plant is around 50 MW, and the coefficient of performance is just over 3.

### Barge-mounted heat pumps

A decision has been made to build a coal-fired, pressurized fluidized bed combustion (PFBC) plant for combined heat and power generation on the Vaerta site. The plant consists of two fluidized bed boilers pressurized by gas turbines. The steam is used to drive a common steam turbine. Supplied by ASEA, the plant will be commissioned in 1991. Orders for two further plants of the same type have been received from Spain and the USA.

In the meantime, oil dependence will be reduced by means of heat pumps installed on a barge moored at the quay at Vaertan. Figure 4 shows a view of the plant, which has a thermal output of approximately 100 MW. The capital cost was about $27.8 million, and the unit was commissioned in the autumn of 1986.

The heat pump plant, which was supplied by ASEA-STAL in cooperation with the Skanska civil engineering company, includes four units, each rated at about 25 MW. The equipment is installed on barge segments which were produced in a dry dock and were then towed separately to the site, where they were connected to form one unit measuring 25m x 100m. The barge is moored at a quay, and part of its weight is supported by piles driven into the sea bed, in order to eliminate movements in relation to the quay.

During the winter, approximately 8 $m^3/s$ of seawater is drawn from the deep intake located about 200m from the plant. During the summer, surface water is drawn from the vicinity of the barge, and is then discharged close to the barge, but at a greater depth.

As at Ropsten, the heat pump has a falling-film evaporator and a two-stage turbocompressor, but in this case, of ASEA-STAL manufacture. The refrigerant is R500, and the maximum district heating water temperature is 85°C.

On the district heating side, this heat pump is connected in series with the Ropsten heat pump.

### Hammarby district heating station

A new district heating network is under construction in the south of Stockholm. This is supplied mainly by the Hammarby plant, the first phase of which was commissioned in autumn 1986. The station consists of a heat pump installation supplying approximately 100 MW and electric boilers rated at approximately 80 MW. Two 80 MW oil-fired boilers were commissioned in autumn 1987.

Supplied by ASEA-STAL, the heat pump installation consists of four units, each rated at about 25 MW. When the network is complete, the units will supply 75-80% of the demand, the remainder being contributed by electric and oil-fired boilers.

The heat source is the purified effluent water from the Henriksdal sewage plant, the largest in Stockholm. The effluent is conveyed to the station through an underground rock tunnel about 3 km long and is returned through a second tunnel to the sewage plant, where it is discharged into the sea with the ordinary effluent. The temperature of the water supplied by the sewage treatment plant varies from 7°C to 20°C depending on the time of year.

Like the barge-mounted units, the two-stage compressors were supplied by ASEA-STAL. Tubular evaporators are used since the effluent water need not be cooled to the point where freezing is a hazard. The tubes are made of admiralty alloy.

The heat pumps are coupled in series on the district heating side. Different refrigerants have been selected to optimize the process, two of the units employing R22 and the other R500. Each unit is charged with approximately 23 tons of refrigerant. The maximum water supply temperature is 85°C and the average heating factor just over 3.

### Economic aspects

In economic terms, operation of the heat pumps has been generally satisfactory. The capital cost for a complete plant is approximately DM 570 per kW heat and the operating cost (including electricity) is approximately DM 0.02 per kWh. The total cost of the plant, including operation, was equivalent to a heating production cost of DM 0.03-0.035 in 1986, significantly lower than Stockholm Energi's mean production cost for district heating of just under DM 0.06 per kWh in the same year. In other words, the units have helped to minimized overall costs.

### Experience and development

As a whole, the heat pumps have produced excellent operating results. Disturbances resulting in stoppages and discharge of refrigerant occurred on the first heat pumps. The defects leading to these stoppages have now been corrected, and the heat pumps have high availability and low refrigerant emissions.

The experience gained from the first heat pumps was taken into account in the design and construction of the large plants. However, some compressor shaft gland leakage problems have been encountered. These problems have already been solved on some units and are currently being corrected in the case of others.

These measures are producing extremely well-sealed plants with an estimated refrigerant leakage of only a few per cent per annum. Availability has been high despite certain commissioning problems and is expected to be better than 95% in the long term.

Figure 5 shows the recorded and planned heat deliveries from the Vaerta plant between 1983 and the year 2000, distributed over different energy sources. The installation of heat pumps in Vaertan with a total rating of approximately 280 MW covers only six years, from the decision to build Loudden up to the commissioning of the floating heat pump plant. Development was equally swift in other parts of Sweden. During this period, unit sizes have increased from 3 MW to more than 30 MW, the latter being delivered by Goetaverken Energy Systems to the Rya plant in Gothenburg.

## Conclusion

In Sweden, the heat pump has proved to be an efficient and economic means of utilizing electricity for heating purposes. Although a large number of units have been installed, the expansion program has now slowed and the market is approaching saturation. The heat pumps may be expected to deliver many years of service, although operating periods will decrease in time.

Heat pumps are considered to be highly beneficial in environmental terms. However, the controversy of recent years concerning the damaging effects of refrigerants on the atmospheric ozone layer has led to calls for reduced refrigerant emissions. Various measures have been taken to reduce refrigerant leakage, including the introduction of modified shaft glands designed to recirculate leakage refrigerant, leakage indication facilities on equipment such as safety valves, installation of tanks for storing refrigerant during repair work, and further training of operating and maintenance personnel. A further means of minimizing damage to the ozone layer may be wider use of less harmful refrigerants, such as R22.

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**K. Kawahara, H. Ohnishi, T. Matsuzaki, M. Higuchi***

# Refrigerant Circuit Control in the Latest Model of Multi-System Heat Pump Air Conditioners for Commercial Use

*Control of the refrigerant circuit is important in heat pumps having multiple indoor units connected to a single outdoor unit via refrigerant piping (multi-systems). This is because the indoor units are often individually controlled to meet the local cooling or heating load, resulting in a wide operating range for the outdoor unit. A system of this type, manufactured by Daikin Industries Ltd. of Japan, is described which achieves refrigerant circuit control by using two capacity-controlled compressors operating in parallel and electronic expansion valves in the outdoor and indoor unit.*

It has been common in Japan to use hot or cold water as the distribution medium in space conditioning systems for office buildings. Due to recent technical advances, space conditioning systems which use heat pumps and direct expansion are being developed and taking the place of conventional systems for use in office buildings. Daikin Industries Ltd., after a number of years of research and technical development, unveiled its multi-system heat pump air conditioners for commercial use in 1982 and started to market them the same year. This system, consisting of an air-cooled outdoor unit and various small capacity indoor units, has the following benefits:

- Space conditioning where and when required
- Simple installation requiring only refrigerant piping and drain piping work vs. extensive water piping and duct work necessary for conventional systems
- Energy cost savings since water pumps and blower fans are eliminated or decreased in size
- Lack of damage from possible water leakage or corrosion of water piping
- Makes unnecessary the exclusive machine room because the outdoor unit is installed on the roof. Also, occupies very little indoor space since indoor units are ceiling mounted or recessed.

Since this system has been introduced in the market, it has been widely accepted in Japan for use in office building under 3,000m$^2$. Daikin Industries has introduced various units of this type to meet the requirements according to the size or use of the buildings. The remainder of this article describes one of these products and its control system for the refrigerant circuit.

## Features of the system

The system is basically an air-to-air heat pump having a single outdoor unit and

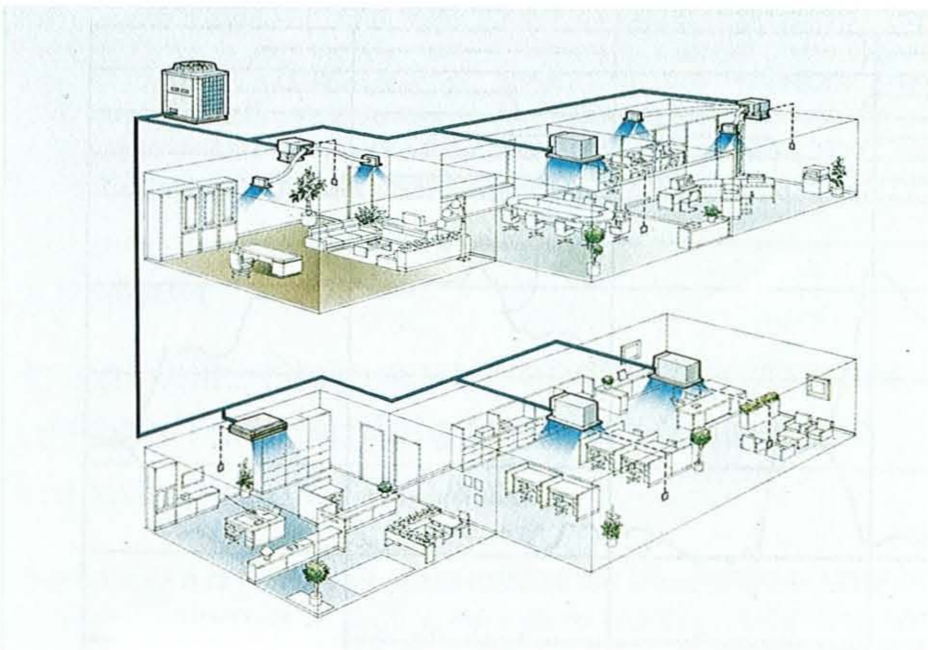

Figure 1. Installation example

multiple indoor units. Each indoor unit can operate individually to maintain a comfortable room environment. Through use of this system, planning and designing for building heating and cooling requirements has become much easier than before. Combinations of large and small spaces such as conference rooms and offices and uneven heating or cooling loads can be handled easily while still maintaining a comfortable environment. Figure 1 shows an example of the installed system, and Table 1 shows the specifications of the indoor and outdoor units. In order to satisfy the above-stated product concept, the following points have been solved technically:

-- Wide range of capacity control of compressors

-- Even distribution of refrigerant to each indoor unit

-- Temporary storage of excess liquid refrigerant in the circuit, according to changes in system operation

-- Prevention of refrigerant oil from remaining in the circuit

-- Control of protective circuit which can deal with sharp changes in operating conditions

The difficulties stated above which require control of the complicated refrigerant circuit have been overcome by using an inverter-driven compressor and electronic expansion valves.

**Refrigerant circuit control**

Refrigerant circuit control is achieved by capacity control of the compressor, discharge superheat control of the evaporator during heating, and capacity control of the indoor units during cooling and heating. The major components involved in this strategy are the compressors and the electronic expansion valves. The system uses two compressors connected in parallel so that a wide capacity range can be covered. One is an inverter-driven type controlled over a 30 Hz to 70 Hz range in steps of 10 Hz. The other compressor uses a refrigerant volume control which controls volume flow rate at 50% or 100%. These two compressors are connected with oil equalizing piping, suction and discharge piping, and essentially function as one compressor. The two compressors are controlled so as to maintain a certain pressure; this is the evaporating pressure in the cooling mode and the condensing pressure in the heating mode. Usually, these pressures undergo complicated changes according to the capacity and number of the indoor units in operation. In order to ensure steady pressure against such changes, a proportional and integral (P.I.) control strategy is used incorporating various practical improvements.

The following rules are also used in the control algorithm:

1. Under small load conditions, operate the inverter-driven compressor.

2. So as not to repeat on/off operation of the capacity-controlled compressor, set its ON and OFF points at staggered positions depending on whether a capacity increase or decrease is needed.

| | |
|---|---|
| Capacity of outdoor units | 3.75 kW, 6.0 kW, 7.5 kW |
| Combined units/possibilities | 12 kW (2 x 6.0 kW)<br>15.0 kW (2 x 7.5 kW)<br>18.0 kW (3 x 6.0 kW) |
| Capacity of indoor units | 3 types with capacities ranging from 0.75 to 3.8 kW |
| Number of indoor units which can be connected to a single outdoor unit | From 1 to 6 |
| Ratio of total capacity of connected indoor units to outdoor unit capacity | 50 to 125% |
| Maximum length of refrigerant piping | 70 m |
| Maximum allowable vertical difference between indoor and outdoor unit | 40 m |
| Maximum difference in height between indoor units | 4 m |

Table 1. Indoor and outdoor unit specifications

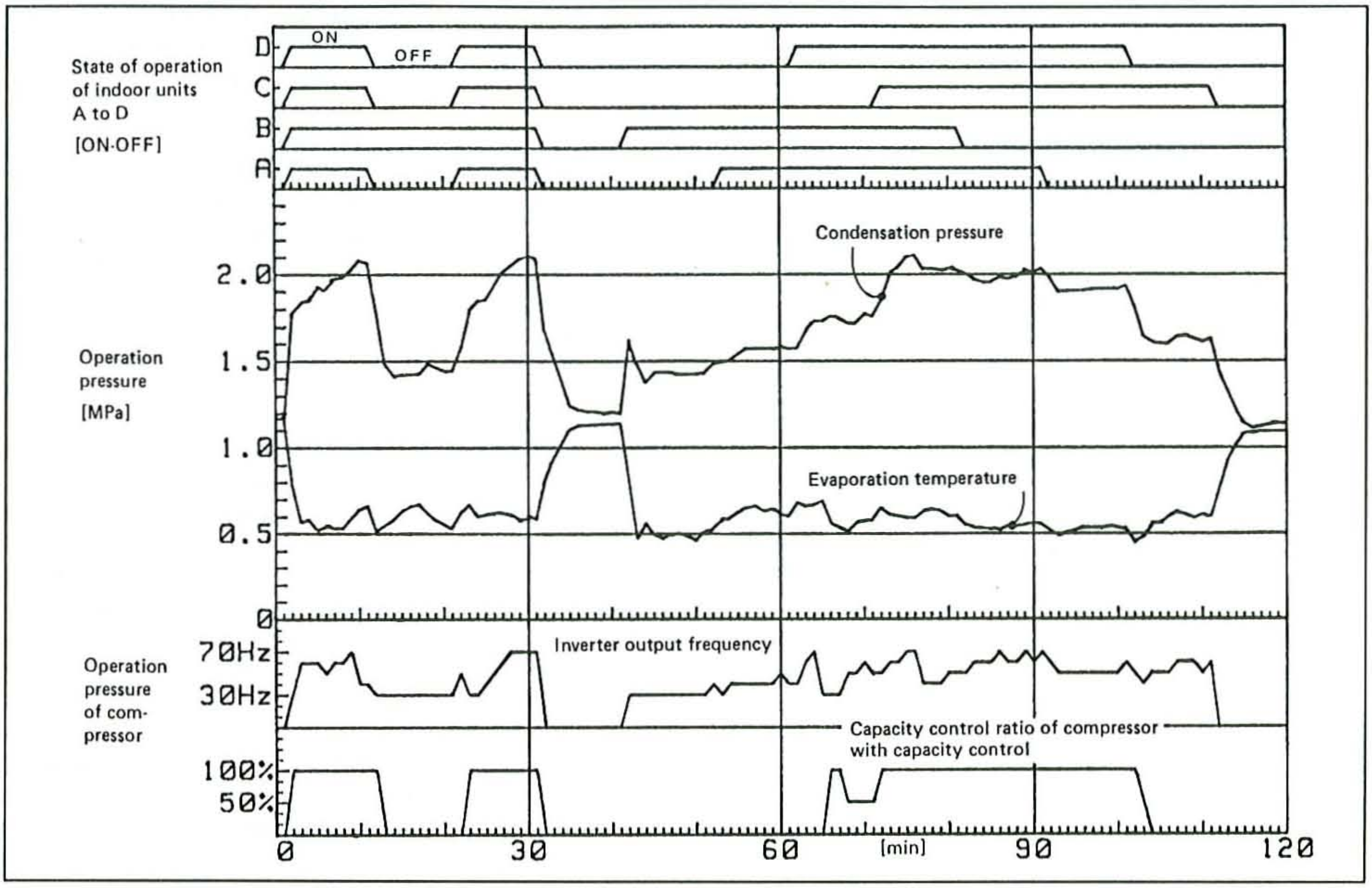


Figure 2. State of operation when the number of indoor units in operation changes

3. When starting the capacity controlled compressor, select an optimum starting timing so that the starting current will not affect the inverter which has the same power source.

4. Periodically check balance of refrigerant oil of the two compressors.

As an example of the performance of this control, Figure 2 shows that even though the number of indoor units in operation changes, the evaporating pressure remains almost constant.

In this system, super heat control at the heat exchanger's discharge must be carried out over a wide range. To meet this requirement, this system employs an electronic expansion valve whose opening is variable between 0 to 2,000 steps. When it is in normal operation, its control method follows P.I. control, while when capacity of the compressor changes the control used is open loop.

For the indoor units, capacity control is conducted between 50% and 100%, according to the inlet air temperature of the unit. This can diminish repetition of on/off cycling of the unit by the thermostat, and also can keep the indoor temperature almost constant by balancing capacity against cooling or heating load. The control is designed to change the capacity proportionately to the difference between the suction air temperature of the indoor unit and the preset temperature on the thermostat. In the cooling mode, the capacity is decreased by increasing the super heat temperature at the discharge of the evaporator, while in the heating mode the capacity decreases by increasing the sub-cool temperatures at the discharge of the condenser. Both of these effects are achieved by decreasing the opening of the expansion valve. In a certain operating area, the capacity and the opening of the expansion valve are almost proportional. This is taken advantage of by opening the expansion valve in proportion to the difference between the inlet air temperature and the pre-set temperature. This method of control works since the evaporating pressure during cooling and the condensing pressure during heating are controlled so as to keep an almost constant level via capacity control of the compressor in the outdoor unit.

## Conclusion

Space conditioning of office buildings in Japan is often done using heat pump systems having a single outdoor unit which feeds refrigerant directly to multiple indoor units. These systems require sophisticated capacity and refrigerant flow control methods to ensure satisfactory operation under varying loads. The inverter-aided compressor and electronic expansion valve have helped to solve these problems. In particular, the multi-system produced by Daikin Industries has become popular due to its reliability and the design and installation flexibility it allows.

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# Water-Source Heat Pump Using Treated Drainage

*A heat pump system has recently been installed in the administration building of the Tokyo Department of Sewage Works' Ochiai Sewage Treatment Plant. The system is designed to air condition the structure and uses treated sewage water as a heat source/sink. Construction was completed in January 1987. The plant is currently in operation and its performance is being monitored to determine the feasibility of using sewage water for district heating and cooling systems.*

## Development background

Up to the 1950's, heat pumps in Japan had primarily used underground water as a heat source. Due to the pumping of groundwater, the ground level in some areas began to subside. This resulted in regulations to decrease the pumping of groundwater. For heat pumps, air became the dominant heat source over the years. The drawback of using cold outdoor air during the winter as a heat source is that more power for compression work is required when compared to a water-source heat pump using warmer groundwater. For this reason, the idea of using treated drainage water as a heat source was implemented. It was found that the drainage discharged from the city contained substantial amounts of waste heat. It is also constant in quantity and quality throughout the year, making it a good heat source and sink for a pollution-free air conditioning system.

## Outline of the system - Former air conditioning equipment of the Ochiai Sewage Treatment Plant

The former equipment comprised an oil-burning boiler for heating and a centrifugal chiller for cooling. This system consumed large quantities of fuel for heating in winter. Each room was supplied from a central unit with cold or warm air by means of a single duct. With an expansion of the facility, the floor space requiring air conditioning increased. Replacement of the air conditioning system was therefore planned.

## New air conditioning system

The new air conditioning system is a heat pump using treated sewage water as a heat source and sink. A schematic of the system is shown in Figure 1. The main system features are as follows:

a. Operating costs, 40% lower than those of the former system.
b. The system uses a specially designed heat exchanger with an automatic tube cleaner which allows direct use of sewage water.
c. Individual fan coil units are installed in each room.
d. Exhaust air heat exchangers are used to recover heat.
e. Automatic control and monitoring systems are used to ensure economic system operation. Performance data is also collected.

## Details of the system's special features

**Heat source** - The output of the sewage treatment plant is much larger than that actually required for the heat pump. Of the 450,000m$^3$ per day treated by the Ochiai plant, only 1,000m$^3$ are used by the heat pump system.

**Operating costs** - The yearly temperature variation of the treated sewage water and ambient air is shown in Figure 2. As can be seen in the figure, the temperature of the treated water is higher than the ambient air temperature in winter. The opposite is true in summer. The sewage water provides a heat source temperature during the winter of about 12°C and a heat sink temperature for cooling of about 25°C. An air source heat pump, on the other hand, only has a heat source temperature of about 0°C available during the winter. During the summer, a cooling tower can provide water at about 32°C. In comparison, the heat pump using treated drainage can sharply reduce the energy consumption of its compressor since the suction to discharge pressure difference is smaller. Comparing the operation of a treated-water-source heat pump to that of a conventional boiler also shows that energy savings are possible. The COP of the water source heat pump is about 4 while that of a conventional boiler is about 0.8. Therefore, the energy-saving effect of the newly installed equipment is about five fold. An operating cost comparison is summarized in Table 1. The conventional boiler/chiller system has the highest annual running cost. Running cost of the water source heat pump, on the other hand, is only 61% of the conventional system, and the air-source system is only 90%.

| | Case 1<br>Conventional System | Case 2<br>Air-Source Heat Pump | Case 3<br>Treated Sewage Heat Pump |
|---|---|---|---|
| Chiller/heat pump installed size<br>Drive motor power consumption | Facilities:<br>90kW x 2 units<br>Summer shaftpower 80kW<br>shaftpower 90kW | Facilities:<br>110kW x 2 units<br>Summer shaftpower 94kW, Winter shaftpower 66kW | Facilities:<br>75kW x 2 units<br>Summer shaftpower 49.5kW, Winter |
| Boiler (gas) | 30Nm$^3$/h x 2 units | -- | -- |
| Cooling tower | 2.2kW x 2 units | -- | -- |
| Cooling water pump | 3.7kW x 2 units | -- | 11kW x 1 unit, 15kW x 1 unit |
| Cooling fan | -- | 15kW x 2 units (each: 1.5kW x 10 units) | -- |
| Annual running cost ratio | 100% | 90% | 61% |

Table 1. Case studies on running costs

**Pollution free characteristics -** In general, it is desirable to install pollution-free heating and cooling systems in densely populated areas. The present system eliminates the need for a boiler and its exhaust gas problems as well as the possible dangers associated with fuel storage. In addition, the lack of a cooling tower reduces the heat rejected to the urban environment.

### Technical problems

Various technical problems had to be solved in order to utilize treated sewage water as the heat source/sink. A discussion of these and their solution is given below. Their adequacy will be verified by actual system operation.

**Selection of a material for heat exchanger tubes -** Since treated drainage is quite corrosive, the material for making the heat transfer tubes must be corrosion resistant. In addition, the material must have good heat transfer characteristics, workability, and a low cost.

To test the corrosion resistance of the materials, actual samples were exposed to flowing treated sewage at the plant. Three types of ferrous and four types of copper alloy were tested. Table 2 shows the estimated annual corrosion rates based on the test results. Of the materials tested, the plain copper tube, typically used in heat exchangers, corroded the least with no severe local corrosion. It was, therefore, used for the heat exchanger tubes.

**Precautions against tube fouling -** One of the problems that occurs when passing treated sewage through a heat exchanger is that scale and slime can build up on the heat transfer surfaces. For this reason, some type of cleaning method must be employed. In ordinary heat pump systems, the heat source water runs through the evaporator and hot water runs through the condenser during heating. During cooling, chilled water runs through the evaporator, and water from the heat sink runs through the condenser. This makes it necessary to design both heat exchangers for sewage water use. To avoid this, a "refrigerant side reverse cycle" was developed which allows the use of a heat exchanger that only passes treated sewage and one that only passes fresh water (chilled or hot). Figure 3 shows the refrigerant flow for this system during heating and cooling operation, respectively.

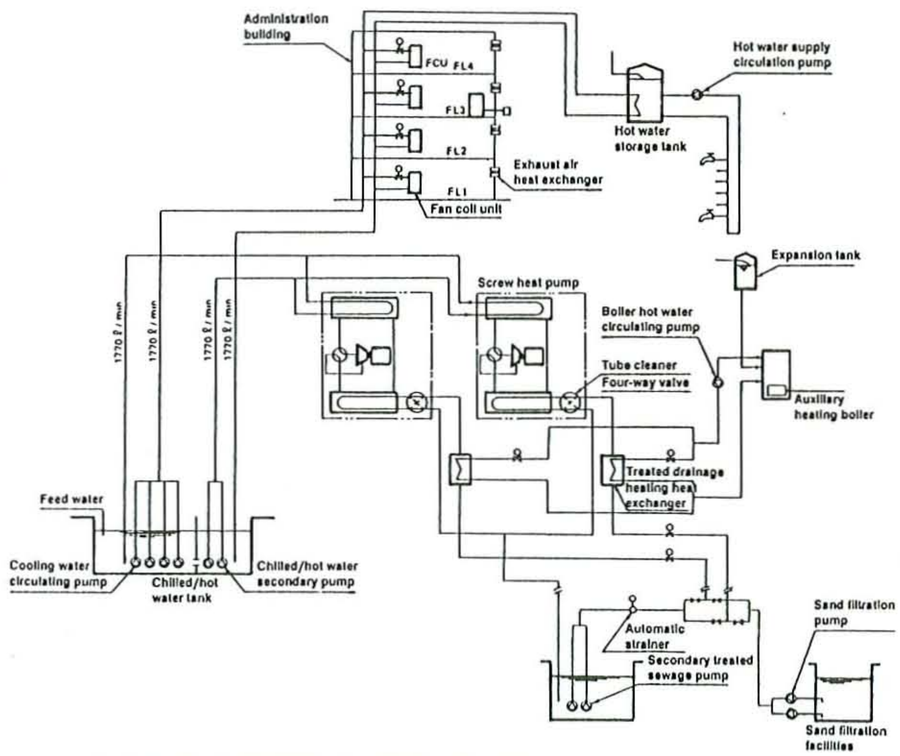
The heat exchanger, designed exclusively for passing treated drainage water through it, has been fitted with an automatic tube cleaner. The cleaner prevents the build-up of scale and slime on the tube's inner surface, thereby maintaining its heat transfer efficiency.

**Precautions against temperature fall of the heat source in winter -** A back-up boiler has been installed for use as an auxiliary heat source during periods for which the sewage water is too cold. Low sewage water temperature can be caused by large quantities of rainwater or melted snow entering the drainage system. The auxiliary boiler maintains the heating capacity of the system by preheating the sewage water before it enters the heat pump. This indirect heating arrangement has the following advantages when compared to a system which heats the hot water produced by the heat pump:

1. The required boiler is smaller and has a lower fuel consumption.
2. The operating efficiency of the heat

| | Corrosion Rate (mm/year) |
|---|---|
| Brass for condenser tube | 0.024 |
| Cupro nickel 95/5 | 0.040 |
| Cupro nickel 9/1 | 0.028 |
| Copper tube | 0.008 |
| Carbon steel tube | 0.140 |

Table 2. Estimated corrosion rates




| Equipment Name | Specifications | Equipment Name | Specifications |
|---|---|---|---|
| Screw compressor heat pump | Cooling capacity: 255,000 kcal/h (296 kW) Heating capacity: 249,000 kcal/h (289 kW) | Fan coil unit | Ceiling-suspended, exposed typed |
| | | Exhaust air heat exchanger | Ceiling-suspended, exposed type |
| Chilled and hot water circulating pump | Ø65 x 450 l/min x 35m$H_2O$ x 5.5kW | Heat exchanger for heating | Capacity of exchanged heat: 200,000 kcal/h (232 kW) |
| Chilled and hot water secondary pump | Ø60 x 900 l/min x 12m$H_2O$ x 3.7kW | Automatic tube cleaner | --- |
| | | Automatic strainer | --- |
| Treated water feed pump | Ø100 x 1,010 l/min x 30m$H_2O$ x 11 kW | Hot water supply and hot water circulating pump | Ø25 x 20 l/min x 5m$H_2O$ x 0.2kW |
| Heating auxiliary boiler | 400,000 kcal/h (465 kW) | | |
| Boiler hot water circulating pump | Ø100 x 670 l/min x 10m$H_2O$ x 2.2kW | Sand-filtration water pump | Ø100 x 1,010 l/min x 34m$H_2O$ x 11kW |

Figure 1. System schematic

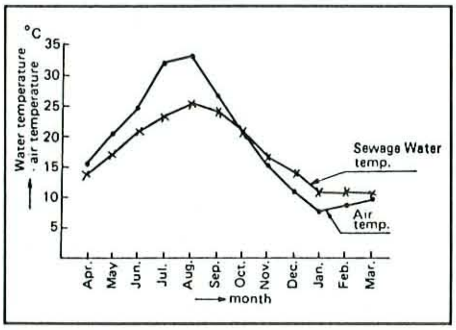



Figure 2. Sewage water and air temperatures

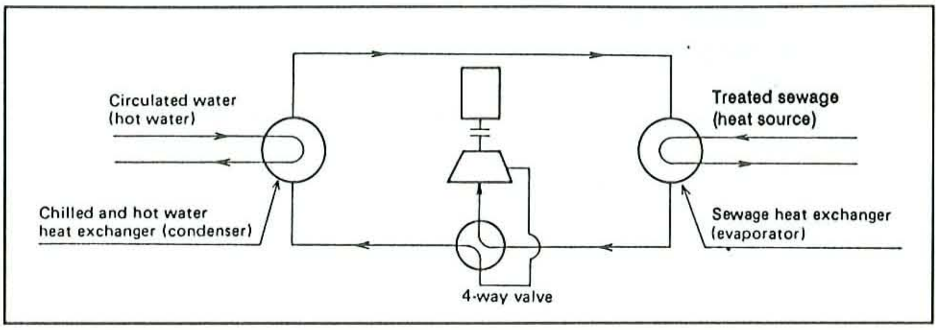



Figure 3. Refrigerant cycle for heating operation

pump is improved since the suction pressure is higher.

The winter of the initial year of operation (1986-1987) was a warm winter so that the lowest temperature of the treated drainage was approximately 12°C. Thus, the auxiliary heat source boiler was not used.

### Automatic measuring and monitoring system

In order to monitor the operation of the system and to collect and analyze the data, an automatic measuring and monitoring system was installed. System functions are as follows:

1. Prepares daily operation records
2. Monitors operation
3. Displays instantaneous operating conditions (COPs)
4. Produces graphical output of:
   a. System COP (hourly and daily values)
   b. Heat pump COP (hourly and daily values)

In addition, the measured data is recorded on floppy disks every 30 minutes for future analysis.

### Conclusions

Sewage water from urban areas contains low-grade thermal energy which represents a new energy source whose use should be further developed. In the near future, use of this energy source in Japan will likely increase. Currently, seven billion m$^3$ per year of sewage water are produced in Japan. Potential applications of the energy contained in this water include district heating systems, pool and greenhouse heating, as well as snow melting in cold districts. The Tokyo Department of Sewage Works has named this energy "urban heat" and has included its use in a plan to renew the air conditioning equipment of its facilities. The system described in this report should provide operating experience, measurement data, and analysis results useful for verifying the performance of a heat pump using treated sewage water as a heat source and sink.

*S. Araki, Refrig.Eng. Dept., F. Sakata, New Product Mktg. Dept. EBARA Corp., Japan

# Feedback

In order to promote an exchange of information, ideas, and criticisms, we are again making space available in the Newsletter for a reader's column. (October 1984 was the last issue in which a reader's column appeared.)

This time, rather than asking specific questions, we will conduct an open forum on anything connected, directly or indirectly, to heat pumps. We are especially looking for comments on those topics that are dealt with in each issue. Comments on the articles and the Newsletter in general are also welcome.

Some rules for submissions to the reader's column are:

1. Language: English
2. Clearly identified contributor (full name and address)
3. Not more than 200 words
4. Where possible, should be received at the Heat Pump Center by the next issue's contribution deadline

We will publish selected comments if the number of contributions received is too large.

# Bibliographic Review

The following pages provide a bibliographic review of publications from the various annexes of the International Energy Agency's Implementing Agreement for a Programme of R&D on Advanced Heat Pump Systems. (All publications described are in English.)

**Editor's note:** The information available to us at the time of publication is presented. Efforts have been made to present relevant publication information and ordering information. We suggest that you contact the IEA (unless otherwise noted) for further information on those annexes which are of particular interest to you. For more detailed information on Annexes I through VI, see the article "Implementing Agreement on Advanced Heat Pumps - History and Future" which appears on page 2 of this Newsletter.

**Annex I: Common Study of Advanced Heat Pump Systems (Duration: 1978-1982)**

The objectives of Annex I were to collect and evaluate data obtained by international experience with advanced heat pump systems. Further tasks were to derive relevant proposals for expected and desirable developments in the field of heat pumps and to recommend future research and development programs. The heat pump systems considered were sorption, heat engine-driven compression cycle, and improved electrically driven heat pumps. Twelve countries participated in this annex. The operating agent was the Kernforschungsanlage (Nuclear Research Center) Juelich in the Federal Republic of Germany. A final report was published in three volumes. Volume I is available to all countries and contains a summary of the technology survey (Volume II) and the market study (Volume III). Volumes II and III are available only to the participants of this annex.

**Annex II: Development of a Vertical Earth Heat Pump System (Duration: 1980-1984)**

The objectives of Annex II were to assess: the state of the art for vertical earth heat pumps, their overall potential in the participating countries, the desirability of joint research, development, and demonstration and to develop a proposal for one or more demonstration plants. Considered in this annex were electrically or combustion engine-driven compressor systems and sorption systems. Five countries participated in this annex. The operating agent for this annex was the Swedish Council for Building Research with assistance from the Earth Heat Pump Group at Chalmers University of Technology. The final report was published in 1983 and is available to member countries of the annex.

**Annex III: Heat Pump Systems Applied in Industry (Duration: 1981-1985)**

The purpose of this annex was to gather information about the application of heat pumps in industry based upon systems in operation. Technical as well as economic information was collected by the participants and exchanged among them. For this annex, industrial heat pumps were defined as heat pumps having a heating power of at least 50kW with the heat sink and/or source connected to an industrial process. Ten countries took part in this annex for which the operating agent was the Katholieke Universiteit, Leuven, Belgium. The final report reviews the state of the art, performance characteristics, research and development and economics of industrial heat pumps. For further information on this final report, contact Prof. J. Berghmans at the Katholieke Universiteit, Leuven, Celestynenlaan 300A, B-3030 Heverlee, Belgium.

**Annex IV: IEA Heat Pump Center**

Publications of the IEA Heat Pump Center are periodically reviewed in the Newsletter. The following is a brief description of the most recent publications available from the Center. See the back page of this issue for ordering information.

**National Reports on the Status of Heat Pumps** (Report Number HPC-WR3, 1987, 105 pages)

This publication contains 16 papers from the World Energy Conference held in Cannes, France on October 5-11, 1986. The papers were presented during expert's meeting number 2 on heat pumps. An overview article, market development paper, and papers from 14 countries are included in this publication. The overview article, prepared by the WEC task force on heat pumps, discusses the energy aspects of heat pumps and compares them to conventional heat generators. Energy savings, fuel flexibility, and reduction of pollution are a few of the benefits dicussed which justify heat pump use. Economic competitiveness was identified as one of the determining factors for further heat pump market penetration. Current products and applications in the private, commercial, and industrial sectors are also described. A review of the market development of heat pumps, also prepared by the task force, summarizes heat pump market information obtained from the Federal Republic of Germany, Finland, France, Japan, Norway, Romania, Sweden, United Kingdom, and the United States. Energy prices and the availablity of information on heat pumps were identified as factors which will continue to strongly influence the market penetration of heat pumps.

Individual reports from the above-mentioned countries as well as Austria, Canada, Denmark, the Netherlands, Norway, and China, provide details on market situation, government policy, and future prospects for the use of heat pumps.

**Proceedings of the Workshop on Ground-Source Heat Pumps** (Report Number HPC-WR2, 1987, 245 pages)

A workshop on ground-source heat pumps was conducted to examine their status, benefits and opportunities. The workshop was held in Albany, New York, Oct. 27-Nov. 1, 1986. Participants at the workshop represented six European and North American countries; they included many internationally recognized leaders in the development and application of systems using the ground as a heat source for heating, and sink for air conditioning, via heat pumps. Some of the main topics addressed included system configuration, markets, utility benefits, soil properties, heat exchanger designs, and installation techniques. An extensive summary of the workshop appeared in the December 1986 (Volume 4, Number 4) edition of the Newsletter.

**Comparison of National Standards Testing and Rating Procedures for Heat Pumps** by A. Edler and P Schaup. (Report Number HPC-R3-1, December 1986, 162 pages)

This report gives an analysis and evaluation of relevant heat pump related standards with special emphasis on a comparison of standardized national testing and rating procedures. The investigation was carried out for Austria, Germany, Japan, Sweden, Switzerland, US, and France. Since the existence of standards specifically for absorption type heat pumps is unknown, this report emphasizes electrically driven compression type heat pumps. The report is of interest for the planner, installer, and user who needs to undertand expressions and acronyms such as COP, SPF and EER as well as their dependence on operating conditions. For the planner and installer, the report provides detailed knowledge of applicable testing and rating proceedures. For the manufacturer, the report provides information on relevant safety codes in various countries which are of interest for exported products.

**Annex V: Integration of Large Heat Pumps into District Heating and Large Housing Blocks (Duration: 1982-1985)**

The main objectives of this task were to assess operating experience and economic performance of large (1-10 MW) heat pumps in district heating and large housing block applications and to assess experience with heat sources appropriate for large heat pumps. Four countries participated in this annex for which Innosys ApS was the operating agent. A final report was published in April 1986 in which 12 projects were selected and analyzed in terms of economic factors such as payback periods. Conditions in different countries resulted in large variations in payback period for the same plant. Some of the conclusions of the report were that large electric heat pumps are competitive in Denmark and Sweden where electricity prices are very low. In contrast, gas and diesel engine-driven systems are economic in all countries whereas absorption heat pumps are slightly less economical. This report can be ordered from Innosys, Heimdalsgade 14, DK-2200 Copenhagen, Denmark (price 244 DKK).

**Annex VI: High Temperature Working Fluids and Nonazeotropic Mixtures in Compressor Driven Heat Pumps (Duration: 1982-1987)**

The objectives of this annex were to gather theoretical and experimental information for heat pump systems operating with new working fluids or mixtures and to evaluate their potential in comparison with other heat pump systems. Work on this annex began in February 1982 with seven participating countries. Sweden and Austria were the operating agents for this annex. The working fluids and systems considered in this activity were pure fluids of any chemical composition capable of working with condensing temperatures above 100°C; nonazeo-tropic mixtures for any condensing temperature in heat pump applications (special emphasis on fluorohalocarbons); and all types of compressor-driven heat pumps with closed circuits used for space heating and cooling and for industrial purposes. The following publications are available from this Annex:

**High temperature working fluids and nonazeotropic mixtures in compressor driven heat pumps. A state-of-the-art report.** Thore Berntsson, Kjell Ljungkvist, Frans Moser and Hans Schnitzer. April 1984.

**Study of working fluid mixtures and high temperature working fluids for compressor driven systems. Final Report. Part A.** Thore Berntsson and Hans Schnitzer. September 1985.

**Study of working fluid mixtures and high temperature working fluids for compressor driven systems. Final Report. Part B.** Thore Berntsson and Hans Schnitzer. September 1986.

These publications are U.S. $15.00 each and can be ordered from the Chalmers University of Technology, Department of Heat and Power Technology, S-41296 Gothenburg, Sweden.

**Annex VII: New Development of the Evaporator Part of Heat Pump Systems**

This annex came into effect in 1986 with five countries participating. The objectives were to collect and evaluate existing theoretical and experimental information for the evaporator part of heat pump systems. The evaporators considered were those used for heat extraction from sewage or industrial waste water; lake, sea, or river water; and ambient exhaust air. Both direct and indirect evaporators were considered in this study. A state-of-the-art report was prepared which included chapters on heat source and refrigerant side heat transfer and pressure drop, recommended design values, computer programs, and R&D trends. A final report will be available to the participants in September 1988.

**Heat Pump Conferences**

Two conferences have been organized since the beginning of the Implementing Agreement for a Programme of R&D on Advanced Heat Pump Systems. The following conference publications are available:

**Heat Pumps: Prospects in Heat Pump Technology and Marketing.** ISBN 0-87371-107-6, 573 pages, 1987 (cost: U.S. $59.95).

This publication contains 42 papers presented at the April 1987 IEA Heat Pump Conference in Orlando, Florida. The topics discussed are operating experience with heat pumps in space conditioning; advances in electric heat pumps; industrial applications of heat pumps; thermally activated heat pumps; heat pumps for district heating; economics, marketing, and promotion; and governments' role in energy conservation. Authors come from private industries and government organizations in Europe, North America, and Japan. For European orders, mail to: John Wiley and Sons Ltd., Attn: Lesley Valentine, Baffins Lane, Chichester Sussex, P.O. 19 1UD, England. For North American orders, mail to: Lewis Publishers, Inc., 121 South Main Street, Post Office Drawer 519, Chelsea, Michigan, 48118, USA.

**IEA Heat Pump Conference: Current Situation and Future Prospects, Proceedings and Conclusions.** ISBN 3-7041-0130-3, 645 pages, 1984.

This conference was held in Graz, Austria, May 1984. 48 papers are included dealing with residential, industrial and district heating applications of heat pumps as well as the policies which affect them. European, Japanese, and North American viewpoints are represented among the various authors. Ordering information can be obtained from: Verlag fuer die Technische Universitaet Graz, Uhlandgasse 8, A-8010 Graz, Austria.

# News Briefs

### CFC Initiatives Approved by ASHRAE

In response to an industry need for data due to impending restrictions of chlorofluorocarbon (CFC) refrigerants as specified in the Montreal Protocol on Substances that Deplete the Ozone Layer, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) took five actions covering research, education, and standards. These and other actions were taken at ASHRAE's 1988 Annual Meeting, which took place June 25-29 in Ottawa, Ontario, Canada. Approximately 1,900 persons attended the meeting.

The first action was to outline the scopes of two proposed research projects. One project will cover chemical analysis and recycling of used refrigerant from field systems to help establish allowable levels of contamination in recycled CFCs. Reclamation is one of the immediate measures being pursued by the industry to conserve existing CFCs. The other project will cover moisture solubility in refrigerants 134a and 123, chemicals now being tested as replacements for fully halogenated CFCs. ASHRAE will now invite proposals to conduct the research called for in the two projects. Also at the meeting, it was reported that results of a research project already underway on the thermodynamic properties of 134a and 123 are expected in October.

Second, the Society voted to invite proposals for other CFC-related research from mechanical and chemical engineering and chemistry departments at universities when it sends requests for specific CFC projects, like the two proposals it developed in Ottawa.

Third, because halons, like CFCs, have a significant ozone depletion factor, the organization approved development of a new position paper on alternative test procedures for halon systems. Today, fire protection system testing involves emission of halons.

Fourth, the development of a position paper on the proposed reclassification of anhydrous ammonia as a poisonous gas also was approved by ASHRAE.

Finally, the first meeting was held of the ASHRAE committee writing a guideline to reduce emissions of CFC refrigerants. The guideline will include all uses, such as building equipment, appliances, and transportation.

"CFCs and their effect to the ozone layer is a vital industry issue that requires expedient ASHRAE action," said ASHRAE President Louis F. Flagg, who was installed as ASHRAE's 1988-89 president during the annual meeting. Flagg announced his intent to reinstate the Society's CFC advisory committee. Flagg also said the organization would hold a second industry roundtable on CFCs in early 1989 and a technical conference on new technology related to CFCs.

### Conserving and Recycling CFCs Best Ozone Protection -- Industry Roundtable Sets Short-Term Agenda

"Conservation practices and reclaiming and recycling procedures must be implemented to allow for a smooth and orderly transition to non-fully halogenated, or hydrogenated, chlorofluorocarbon (CFCs) refrigerants," reported H.E. "Barney" Burroughs, 1987-88 president of ASHRAE.

Immediate steps to conform to legislation, regulation, and international agreement, which will require a 50% reduction over the next 10 years of today's levels of fully halogenated CFCs, were outlined during an industry roundtable sponsored by ASHRAE and co-chaired by Burroughs and Richard Snyder, chairman of the Air-Conditioning and Refrigeration Institute (ARI). The agenda for industry action, developed by some 50 persons representing producers of CFCs, manufacturers of equipment, wholesalers, design engineers, contractors and service groups, and the transportation and refrigerated food industries, was announced at the 1988 ASHRAE Annual Meeting.

"There are specific problems to be solved and specific solutions to be found," said Burroughs on the reclamation and recycling effort. The industry agenda addresses several existing problems in recycling refrigerants:

-- To make reclaiming easier, develop a strategy to prevent the inclusion of CFCs as hazardous material in interpretation of the Resource, Conservation and Recovery Act.
-- Develop a standard method of testing to determine the quality of reclaimed refrigerants. ARI is developing 700P, a standard to set acceptable levels of contamination. The action item is for ASHRAE to establish a test method of contamination to be used with the ARI standard.
-- Accelerate development of ASHRAE Guideline 3P, which covers the reduction of fully halogenated CFC emissions during installation and servicing of air-conditioning and refrigerating systems.
-- License dealers and service stations to recycle CFC-12 used in automotive air conditioning and reduce service usage of CFC-12 by 50% in five years.
-- Design for leak prevention in automotive applications, for example, by improving replacement hoses and improving seals. For new equipment and systems, in all applications, design for easy reclamation and recapture.
-- When possible, for both retrofit and new construction, install systems which do not use fully halogenated CFCs. Also agreed upon was the need to stop using fully halogenated CFC refrigerants to flush and clean equipment.

Mike Harris of ICI, a producer of CFCs, said, "We must learn to live without these fully halogenated CFCs. The key question is how to unravel that CFC thread from the fabric of our society."

In addition to installing systems using alternate refrigerants, an action item was recommended to determine what percent reduction of fully halogenated CFCs can be met by using hydrogenated chlorofluorocarbons (HCFCs), 22 and 502, in the event substitute refrigerants 123 and 124a are not forthcoming.

Refrigerant 134a appears to be a viable substitute for CFC-12 and refrigerant 123 for CFC-11. But toxicology studies must be completed, process and application technology developed, production facilities built, and new lubricants developed before beginning commercial distribution of these substitutes.

Industry action items on the use of alternate refrigerants and the development of substitute refrigerants follow:

- Field test substitute refrigerants now under development. "Laboratory testing is only the first step and must be validated by unbiased field testing," said Billy Guin, National Association of Plumbing-Heating-Cooling Contractors.
- Use HCFC-502 as the preferred refrigerant in new equipment for non-mobile transportation applications, and establish a recovery system for refrigerants in non-mobile transportation applications.
- For insulation applications in the transportation industry, use water-blown foams until a suitable replacement HCFC is available as a blowing agent.
- Re-label refrigerant 22 as HCFC 22 and promote the distinction between fully halogenated CFCs and hydrogenated CFCs.

"Not only do we recognize the need to communicate with each other and to develop vital data, we are exploring ways to make technological information more widely available, more rapidly available, and available through joint educational programs," Burroughs said.

An industry task force will be established to compile information on the status of refrigerant development, on the development of technical data by equipment manufacturers, and on the conservation, reclamation, and recovery of CFC-11 and CFC-12. The findings will be published by ASHRAE and made available as part of a campaign to create full awareness of the issue by consumers, technicians, designers, and builders.

This task force will provide a means for industry organizations to share, validate, and disseminate fundamental data. "We must communicate to the public and exchange information with each other. ASHRAE must provide this platform for exchange," said Hans Spauschus, representing the International Institute of Refrigeration.

Burroughs reported that because technology is changing so fast, a more rapid and comprehensive means of information dissemination is needed. It was agreed that a CFC technical conference sponsored by ASHRAE will be held next year.

Scientific data suggests that because of the long life of fully halogenated CFCs in the atmosphere, when reduction begins is not as critical as the stringency of the reduction and taking the right steps during the transition period. A final industry action item is to study the economic impacts which would result from attempts to alter the Montreal Protocol on Substances that Deplete the Ozone layer, which has been agreed to by the United States, Canada, and more than 30 other nations.

"Because these chemicals are so important to our lifestyle and quality of life, we must take care that our first steps do not unnecessarily disrupt the economy or lifestyles of consumers. We must manage the reduction of fully halogenated CFCs so that the consumer and the public is best served," Burroughs said.

Today CFCs are used as refrigerants in transportation and building air-conditioning and refrigeration equipment; as blowing agents in foam insulation, food packaging, and cushioning foams made of plastic materials; as cleaning agents for microchips and other electronic components; and as solvents, sterilants, fumigants, and pesticides.

"The need for collective thought at this juncture is especially great because our industry is so diverse. No single voice can speak for all of us. We now have achieved step one in finding a solution to the problem by bringing key players together to discuss the impact on each individual segment of the industry and by outlining some recommendations for action," Burroughs concluded.

**New Equipment Volume of ASHRAE Handbook Published**

The latest volume in the handbook series published by ASHRAE focuses on the equipment components and assemblies that perform various heating, ventilation, air-conditioning, and refrigeration functions. The *1988 ASHRAE Handbook, Equipment Volume* provides engineers, architects, contractors, and service personnel with 45 chapters that survey the principles of operation, types of construction, performance characteristics, methods for testing and rating, pertinent standards, and factors for selection.

The handbook is arranged in six sections. The first section covers the equipment that moves, cleans, or modifies the temperature or the humidity of air needed for industrial processes or for human comfort. The second section describes components and controls for refrigeration equipment. The third section reviews the performance and features of furnaces, boilers, chimneys, and other heating devices. The chapter on residential furnaces includes new information on system performance. The fourth section describes the pumps, motors, engines, and pipes involved in installations. The chapter on pipes was completely rewritten to include information on pipe standards, dimensions, and working pressures. It also covers the methods and includes data for handling pipe expansion and contraction as temperature changes. The fifth section discusses unitary refrigeration equipment, air conditioners, and heat pumps. The last section includes a new chapter on solar energy equipment. It describes solar collectors, piping, thermal storage equipment, and controls. This handbook contains inch-pound (I-P) units and the International System (Si) units of measurement.

The price of the handbook is U.S. $100.00. To order, send payment in U.S. funds to ASHRAE Publication Sales, 1791 Tullie Circle, N.E., Atlanta, Georgia 30329, U.S.A. Credit card orders (Visa, MasterCard, and American Express) are accepted by telephone 01-404-636-8400 or by mail (include credit card number and expiration date).

# Schedule of Conferences and Trade Fairs

## Sept. 29-October 1, 1988

Nuernberg (Fed. Rep. of Germany); **Internationale Fachmesse Kaelte-Klimatechnik (IKK '88).** [International Trade Fair for Refrigeration and Air Conditioning] Contact: Nuernberger Messe- und Ausstellungsgesellschaft m.b.H., Messezentrum, D-8900 Nuernberg 50, Fed. Rep. of Germany.

## October 3-7, 1988

Madrid (Spain); **11th International Congress of Electrical Heating**. Sponsored by the Spanish Committee of the International Union of Electrical Heating (U.I.E.). Contact: UIE Kongress 1988, c/o Comité Español de Electrotermia, Francisco Gervas, 3, E-28020 Madrid, Spain, or Viajes Iberia, San Bernardo, 20-3.° Dcha., E-28015 Madrid, Spain.

## October 10-12, 1988

Orlando, Florida (USA); **IGSHPA Symposium and Exposition**. Sponsored by the International Ground Source Heat Pump Association (IGSHPA). Contact: IGSHPA, Crutchfield 105, Stillwater, Oklahoma 74078-0532, USA, telephone 01-405-624-5175.

## October 17-20, 1988

Versailles (France); **JIGASTOCK 1988 Thermal Exploitation of Underground Resources and Storage**. Sponsored by the European Community Commission (ECC) and the International Council for Thermal Energy Storage (ICTES). Contact: JIGASTOCK 88 Office, c/o Agence Française pour la Maîtrise de l'Energie (AFME), Madame M. Leblanc, 27, rue Louis-Vicat, 75737 Paris Cedex 15, France, telephone 33-(1)47652182.

## November 22-26, 1988

Brussels (Belgium); **European Exhibition on Heating, Ventilation, Refrigeration and Air-Conditioning (EXPOCLIMA).** Contact: Foire Internationale de Bruxelles A.S.B.L., Parc des Expositions, B-1020 Bruxelles, Belgique.

## November 23-24, 1988

Brussels (Belgium); **Second European Symposium on Air Conditioning and Refrigeration: Progress Related to Industrial Applications of Air Conditioning and Air Treatment.** Sponsored by the International Institute of Refrigeration (IIR), and the Federation of European Heating and Ventilating Associations (REHVA). Contact: Fabrimetal, Attn: M. van der Horst, 21, Rue des Drapiers, B-1050 Bruxelles, Belgique.

## January 16-18, 1989

Gothenburg (Sweden); **Third Workshop on Solar Assisted Heat Pumps with Ground Coupled Storage.** Contact: Jan-Olof Dalenbaeck, CTH/Installationsteknik, S-412 96 Gothenburg, Sweden.

## January 28-February 1, 1989

Chicago, Illinois (USA); **1989 ASHRAE Winter Meeting**. Sponsored by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). Contact: Judy Marshall or Judith Breese, ASHRAE International Headquarters, 1791 Tullie Circle, N.E., Atlanta, Georgia 30329, USA, telephone 01-404-636-8400, telex 705343.

## January 30-February 2, 1989

Chicago, Illinois (USA); **International Air-Conditioning, Heating and Refrigerating Exposition.** Sponsored by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and the Air-Conditioning and Refrigeration Institute (ARI). Contact: International Exposition Company, 200 Park Avenue, New York, New York 10166, USA, telephone 1-212-986-4232.

## April 17-21, 1989

Hobart (Australia); **Federal Conference and Exhibition of the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH).** Sponsored by AIRAH. Contact: Australian Institute of Refrigeration, Air Conditioning and Heating (Inc.), P.O. Box 1533R, GPO, Hobart, Tasmania 7001, Australia.

## June 24-28, 1989

Vancouver (Canada); **1989 ASHRAE Annual Meeting.** Sponsored by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Contact: ASHRAE International Headquarters, 1791 Tullie Circle, N.E., Atlanta, Georgia 30329, USA, telephone 01-404-636-8400, telex 705343.

## August 28-September 1, 1989

Sarajevo (Yugoslavia); **CLIMA 2000 (The 2nd World Congress on Heating, Ventilating, Refrigerating and Air Conditioning).** Sponsored by the Federation of Representatives of European Heating and Ventilating Associations (REHVA), the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), and the International Institute of Refrigeration (IIR). Contact: Organizing Committee of CLIMA 2000, Masinski fakultet, Prof. Dr. Emin Kulic, 71000 Sarajevo, Omladinsko setaliste bb, Yugoslavia, telephone 071/642071, telex 41 529 IPES YU.

## November 13-19, 1989

Paris (France); **International Heating, Refrigerating and Air-Conditioning Exhibition (INTERCLIMA).** Contact: CEP 7, Rue Copernic, F-75782 Paris, Cedex 16, France.

# Products, Services, & Ordering Information

## Inquiries

### Have a specific question about heat pumps?

Contact the Heat Pump Center directly with your questions about heat pump technology, marketing, economics, etc. HPC staff members will do their best to answer directly or point you to the right expert.

| | | |
|---|---|---|
| IEA Heat Pump Center | Telephone: | 07247-82-4541 |
| c/o FIZ Karlsruhe | Telex: | 17724710+ |
| D-7514 Eggenstein-Leopoldshafen 2 | Telefax: | 07247-2968 |
| Fed. Rep. of Germany | Teletex: | 724710=FIZKA |

## Reports

### The following reports are available from the HPC:

| Report No. | Report Title | |
|---|---|---|
| HPC-WR2* | Proceedings of the Workshop on Ground-Source Heat Pumps (1987), 245 pages | DM 50,--/U.S. $30 |
| HPC-WR3 | National Reports on the Status of Heat Pumps (1987), 105 pages | DM 40,--/U.S. $25 |
| HPC-R2-1* | Heat Pump RD&D Projects Summary Report, Edition 2 (Dec. 1986), 514 pages | DM 75,--/U.S. $45 |
| HPC-R3-1* | Comparison of National Standards Testing and Rating Procedures for Heat Pumps (December 1986), 162 pages | DM 50,--/U.S. $30 |
| HPC-LR-3* | HPC Bibliography - Sorption Heat Pump Systems (Oct. 1986), 372 pages | DM 40,--/U.S. $25 |
| HPC-LR-2* | HPC Bibliography - Industrial Heat Pumps (July 1986), 378 pages | DM 40,--/U.S. $25 |
| HPC-LR-1* | HPC Bibliography - Environmental Aspects of Heat Pump Applications (May 1986), 105 pages | DM 25,--/U.S. $15 |
| HPC-WR-1/1-12* | Workshop: Electric Heat Pumps for Retrofit in Existing Small Residential Buildings (1985), 13 separate reports, 506 pages | DM 120,--/U.S. $70 |

**Sale of this report is restricted to IEA Heat Pump Center member countries only.*
*Write to the HPC for a complete listing of HPC publications. All prices include postage. VAT additional in F.R. Germany.*

**NORTH AMERICAN ORDERS:** You may order in the U.S. by sending your order form to: Mr. Fred Creswick, Oak Ridge National Laboratory, P.O. Box Y, Oak Ridge, Tennessee 37831, USA. If enclosing a check, please make it payable to **Heat Pump Center** (U.S. dollars only).

The IEA Heat Pump Center Newsletter is published quarterly.

Subscribers from countries participating in the IEA Heat Pump Center (Austria, Belgium, Canada, Fed. Rep. of Germany, Finland, Italy, Japan, the Netherlands, Norway, Sweden, and the USA) will receive the newsletter free of charge.

Subscribers from other countries will be billed DM 80,-- per year.

Subscription cancellation is possible with one month's notice to the end of the calendar year.

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# Future Issues:

| Vol/No | Topic | Deadline for Contributions |
|---|---|---|
| 6/4 | Absorption Heat Pumps | October 7, 1988 |
| 7/1 | Topic to be determined | January 7, 1989 |

If you would like to contribute an article on this topic or a related heat pump topic, please send it to the Heat Pump Center.

Our regular features (feedback, bibliographic review, news briefs, and schedule of conferences and trade fairs) will also be included.

IEA Heat Pump Center Newsletter (ISSN 0724-7028). 
Edited by: IEA Heat Pump Center
Editors: Andre Milbitz/Lisa White
IEA Heat Pump Center
c/o Fachinformationszentrum
Energie, Physik, Mathematik GmbH
D-7514 Eggenstein-Leopoldshafen 2
Telephone: 07247-824541
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Published quarterly. Annual subscription DM 80,-- including postage (V.A.T. not included). Free of charge for subscribers from HPC Member Countries. Printed in Fed. Rep. of Germany by Reprodienst GmbH, D-7800 Freiburg i.Br.