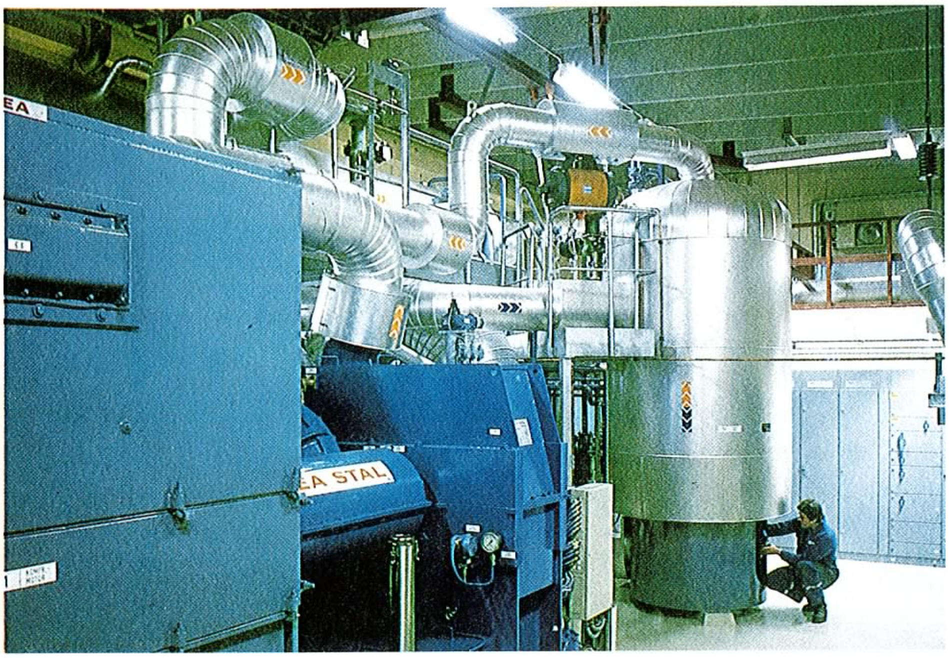
ISSN 0724-7028

NEWS LETTER

IEA heat pump center

PERIODICAL OF THE
IEA HEAT PUMP CENTER

VOL 3, NO. 3, OCT '85



10 MW_{th} Heat-Pump in operation in Sweden, 1985 (see also page 14)

Editorial by K. Holzapfel*

Innovative Utility Programs are the Key to Successful Heat Pump Development

From November 27 to 29, 1985, about 40 heat pump experts representing manufacturers, electric utilities, research institutes and governmental agencies from eleven countries will meet in Graz, Austria. For two and a half days they will discuss the problems of heat pump applications in existing single- and two-family houses. An essential question for this workshop is: How can electric heat pump systems be made so attractive that they are widely used for complete or partial replacement of oil-fired boilers in existing single-and two-family houses? Electric utilities will surely play a key role in achieving this goal. Experience has shown that when electric utilities have fully supported the application of heat pumps with a broad range of activities, heat pump installations have increased considerably. Some examples are programs at the EDF in France, the Swedish State Power Board in Sweden, and, in Austria, the promising development of heat pump installations in the OKA area (see page. 2).

In the FRG, similar programs have been started by the Rheinisch Westfälisches Elektrizitätswerk (RWE), Vereinigte Elektrizitätswerke (VEW), and Badenwerk. The primary emphasis of these programs is to build user confidence in heat pump reliability and the performance of heat pump heating systems. Careful selection of a group of distributors, installers, and systems ensures that the efforts for on-site installation and first costs for

Contents | Page

installation will be kept at an acceptable and appropriately low level.

Activities included in these programs are: technical consulting, selection of appropriate systems, offers for complete systems, system start-up by manufacturer, installer, and utility, extended guarantees, offers for beneficial financing arrangements, and, in some cases, low electricity tariffs.

We hope that such innovative activities will spread and be started by other electric utilities in the FRG. These programs will help to break down many of the barriers to the broad utilization of this beneficial technology, leading to the protection of our environment and many positive macroeconomic effects.

Further details on the new utility programs in the FRG will be presented in an article in the next Newsletter, along with a summary of results from the workshop in Graz.

*K. Holzapfel, IEA Heat Pump Center c/o Fachinformationszentrum Energie, Physik, Mathematik GmbH, D-7512 Eggenstein-Leopoldshafen 2

Schneeberger, M.F.

Heat Pump Activities of an Austrian Electric Utility Company

At the IEA Heat Pump Conference held in Graz, Austria, in May 1984, the impact of heat pump activities of the Oberösterreichische Kraftwerke AG for the time period 1978-1983 were reported /1/. The general trends described in that paper are continuing, and further activities are planned to support the development of this important option for energy conservation and environmental improvement.

The Oberösterreichische Kraftwerke AG (OKA) is a public electric utility company, owned by the state of Oberösterreich. About half of the electricity is generated by its own capacity (hydro and thermal power stations) and by joint projects with other utilities; the rest is generated by the federal utility. One third of the electricity is distributed to small customers, one third to industry and one third to local utility companies. Further data are given in the upper part of Table 1.

The supply area is characterized by areas of low population density and a lack of big cities, limiting the possibilities for district heating. The decentralized application of heat pumps, therefore, is an important option for cost reduction, environmental improvement and energy conservation.

As a consequence of the first and second oil price shocks and following IEA recommendations, the Austrian government has supported the heat pump through tax relief since 1980. This support has been accompanied by supporting initiatives from local authorities.

Supply of Electric Energy	
Area served	10,500 km^2
Number of customers	307,000
Population served	770,000
High voltage transmission lines, total	7,200 km
High voltage transmission lines, cables	600 km
Low voltage transmission lines, total	15,700 km
Low voltage transmission lines, cables	2,000 km
Electricity supplied, 1984	4.94 TWh
Peak load, 1984	828 MW
Peak load, January 1985 (approx)	1,000 MW
Heat Pump Units above 2.5 kW electric (June 1985)	
Hot tap water units	1,859
Space heating units	1,422
Total number of units	3,281
Installed capacity, hot tap water	3 MW_e
Installed capacity, space heating	7 MW_e
Total residential/commercial capacity	10 MW_e
Average size, hot tap water	1.6 kW_e
Average size, space heating	4.9 kW_e
Average size, all units	3.05 kW_e

Table 1 Some Data for OKA

Heat Pumps in the OKA Area

Since 1978/79, installation of heat pumps has increased steadily, and indeed accelerated. The number of residential/commercial heat pumps identified by the tariff system reached 3,281 in June 1985. The heat pumps installed in the OKA supply area make up about 50% of the total number of heat pumps in all of Austria, while the OKA supply area itself is inhabited by only 10% of the Austrian population. Detailed data are given in the lower part of Table 1 and in Fig. 1. (Industrial heat pumps are not included in the figures.) The average size of all the identified residential/commercial heat pumps is slightly above 3 kW electric. This corresponds to the average unit size for all of Austria /2/.

To evaluate regional promotion of heat pump installations, the variation in the local 'heat pump density' (number of heat pumps per 1000 customers) within the OKA region is shown in Fig. 2.

The OKA Heat Pump Program

In 1980, OKA started a heat pump program to monitor and analyze the technical, economic and environmental benefits of 14 projects, concentrating on ground-water-based systems. This program has been extended to further projects, including air/water systems. Some of these projects have recently been analysed by the IEA Heat Pump Center as representative applications in Austria.

The present activities to promote heat pump installation can be summarized as follows:

- Publication of results of heat pump programs,
- Improvment of measurements of thermal and electric parameters of heat pump-systems,
- Collection of information about and discussions with all parties involved in the heat pump business,
- Energy consultation at local fairs with special services for customers inter-

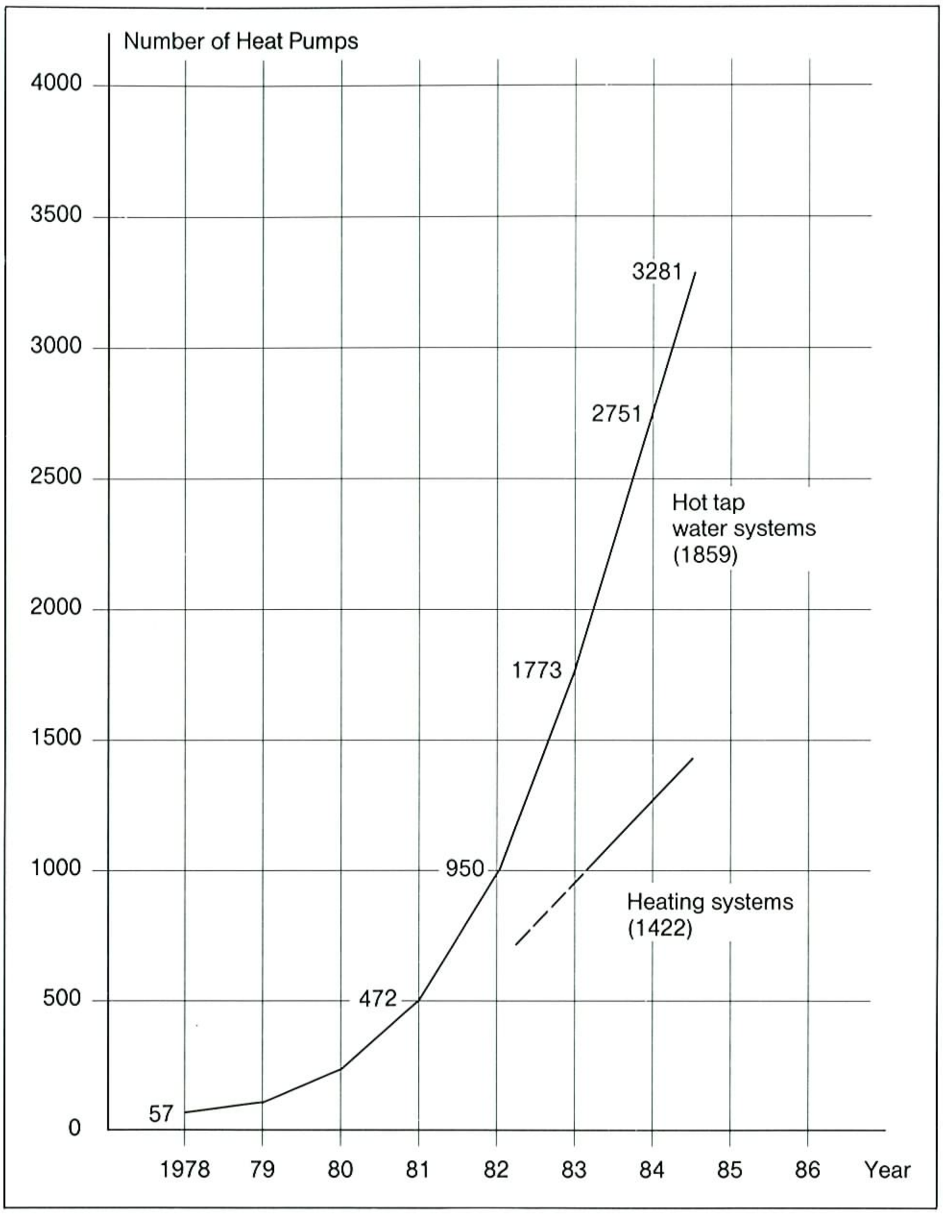


Fig. 1 Total Number of Heat Pump Systems, OKA Area

- ested in heat pumps,
- Development of special computer programs to evaluate heat pump applications,
- Installation of utility-owned heat pump systems for demonstration purposes,
- Modification of tariff structures to overcome initial investment difficulties,
- Financing and support of scientific research work, concentrating on environmental impacts of ground-water systems and on economic questions,
- Support for and organization of conferences and workshops in cooperation with suppliers, architect/engineers and local authorities,
- Foundation of a financing organization for heat pump projects (leasing contracts),

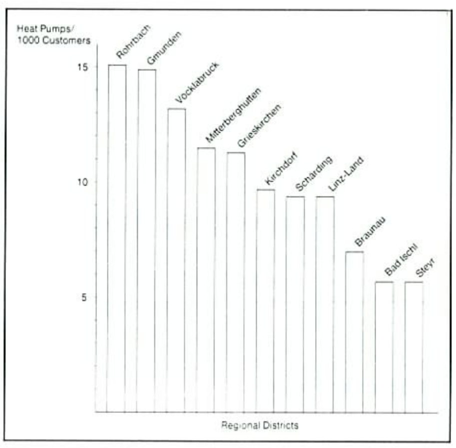


Fig. 2 Average 'Heat Pump Density', OKA Area

- Visits to operating installations in other countries (Germany, Sweden, France) and review of technical and economic results, followed by adaptation of these results to local conditions.

While it is certainly difficult to identify the individual impacts of each of these activities in detail, it is their overall impact that has created a positive climate for innovation in the heat pump field.

Recently, the energy consulting activities of the OKA at a local fair were analyzed (Fig. 3). The analysis showed a dominant interest in heat pump questions, presenting a challenge for the energy-consulting departments of utilities to provide specific information on the subject.

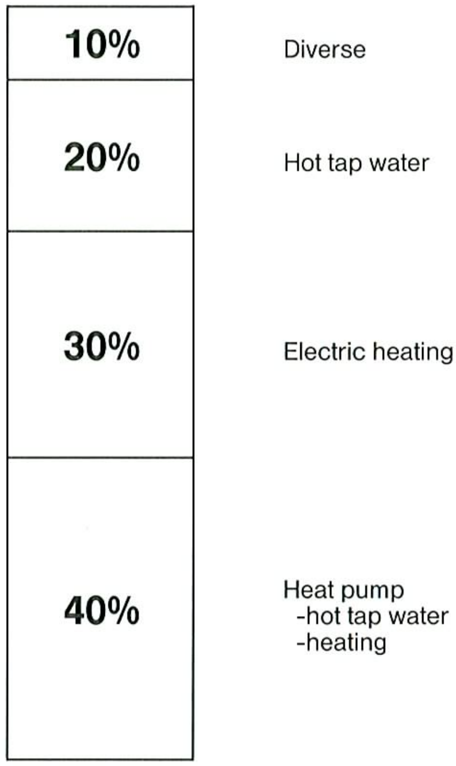


Fig. 3 Breakdown of appr. 1000 Consulting Contacts Made at the Local Fair at Wels, 1984

Energy Savings Program for Residential Buildings

Energy savings in residential buildings is a main objective of the energy-consulting activities of OKA. Detailed knowledge of new developments in heating systems is essential for assisting customers with decision making. A large energy-consulting program that includes the energy analysis of about 1000 small residential buildings has been started. The primary aim of this project is to identify weak points in building structure and energy consumption.

Analysis of this project will generate valuable results. Continued monitoring of selected heat pump installations in residential buildings represents an important basis for consulting actvities. Below, a monovalent water/water heat pump system is described. This project has been selected as an IEA Heat Pump Center reference system in Austria.

The residential building has 130 m^2 of heated area and has a thermal peak load of 11.5 kW (specific load 89 W/m^2). The

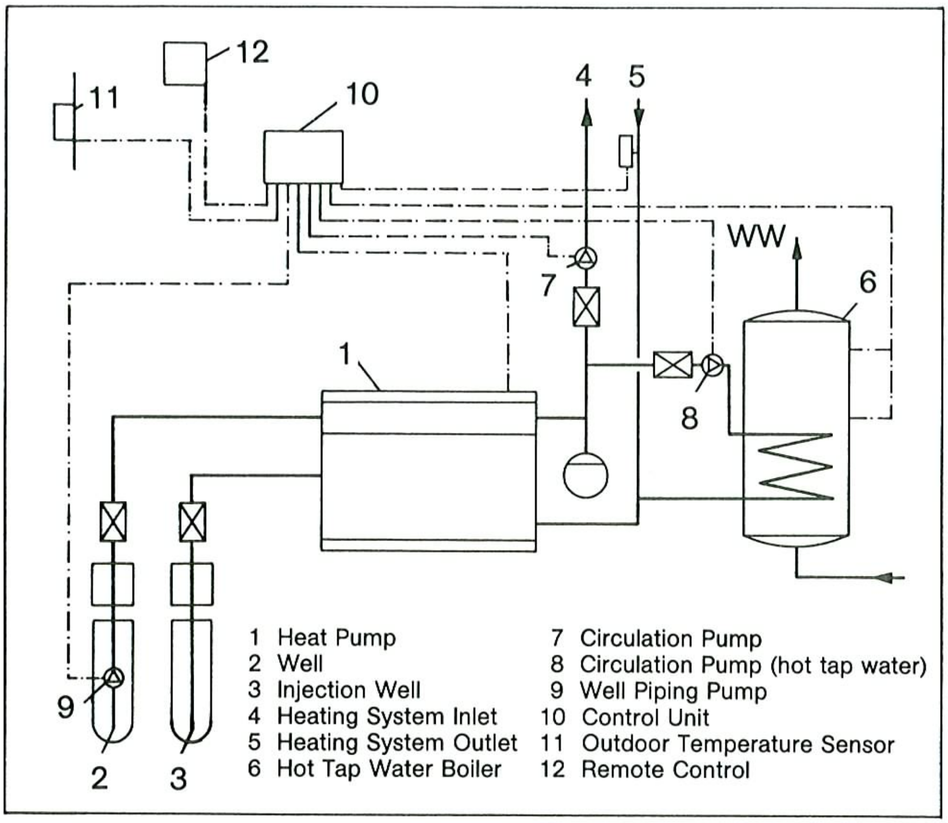


Fig. 4 3.6 kW Electric Water/Water Heat Pump System, Alkoven, Upper Austria

SUBJECT: Public school in Windischgarsten, Oberösterreich

Number of pupils:	620
Heated area:	3,577 m^2
Total space heated:	10,000 m^3
Swimming pool surface:	160 m^2
Swimming pool volume:	170 m^3

TECHNICAL SPECIFICATIONS

		old system	new system (since 1984)
Annual energy consumption,	MJ/m^2	1,860	560
Installed capacity,	W/m^2	170	60

DESCRIPTION OF BIVALENT HEATING SYSTEM

- integration in existing oil-fired heating system (2 AT 400kW)
- 3 x 3 heat pump cascade, electric power 61.7 kW, thermal output 169.6 kW
- 2 6-kW heat pumps for dehumidifying
- measured coefficient of performance of bivalent heat pump sytem (including all auxiliary systems): 2.3

Table 2. Description of OKA Pilot Project

heat pump system has been in operation since 1982 and has shown excellent performance. The 3.6 kW electric heat pump, with 12.9 kW thermal output, showed average coefficients of performance of 4.14 (heating period 1983/84) and 3.36 (heating period 1984/85). The specific energy cost for the hard winter 1984/85 was 78,-- AS/m^2, compared to the average value for Upper Austria of 182,--AS/m^2. A diagram of the heating and hot-tap-water system is shown in Fig. 4.

Energy Savings Program for Public Buildings

In 1983/84, an energy-auditing program for schools in Upper Austria was initiated by OKA in cooperation with local authorities. Analysis of about 600 schools showed a large potential for energy conservation and environmental improvement through increasing the thermal insulation of the building envelope, decoupling space-heating and hot-tap-water production, and application of bivalent heat pump systems.

Based on this study, OKA has started a pilot program for heat pumps with an electric input betweem 50 and 100 kW. Starting with two installations in 1983, this past winter (84/85) - the coldest one in years - 10 installations demonstrated their technical performance. Main areas of program emphasis are:

- Evaluation of heat pump units from different manufacturers,
- Different technical solutions for integration of heat pumps in existing systems,
- Different heat sources (air, water, ground),
- Detailed monitoring program and analysis of results,
- Commercial evaluation of projects.

Below, technical details are described for a pilot project that resulted from the energy auditing program for schools in Upper Austria.

The 620-pupil public school in Windischgarsten had a high annual energy consumption of 1,860 MJ/m^2, due to insufficient thermal insulation, an oversized oil-fired central-heating system, and energy-consuming swimming pool installations. Since the school is situated in a recreation area, environmental concerns of local authorities played an important role in decision making.

On the basis of a detailed analysis, performed in cooperation with the Institut für Energiewirtschaft, Wien, several measures have been implemented, such as improving the thermal quality of the building, decoupling and decentralizing hot-tap-water production, utilizing heat pumps for dehumidification of the swimming pool air and, finally, installing a bivalent heat pump system made up of a cascade of nine heat pumps (air/water). The details of the new energy system are described in Table 2; the photo (Fig. 5) shows the heat-pump cascade, situated in front of the swimming pool.

After one year of operation, the new energy system performed very well. Performance results are summarized below.

- reduction of the peak heating demand of the building from 170 W/m^2 to 60 W/m^2
- reduction in local emissions of about 85% (see Fig. 6)
- improvement of comfort and air quality in the swimming pool area
- an increase in regional activity in heat pump applications due to an improvement in local knowledge of this new technique.

Fig. 5 Heat Pump Cascade, Public School Windischgarsten

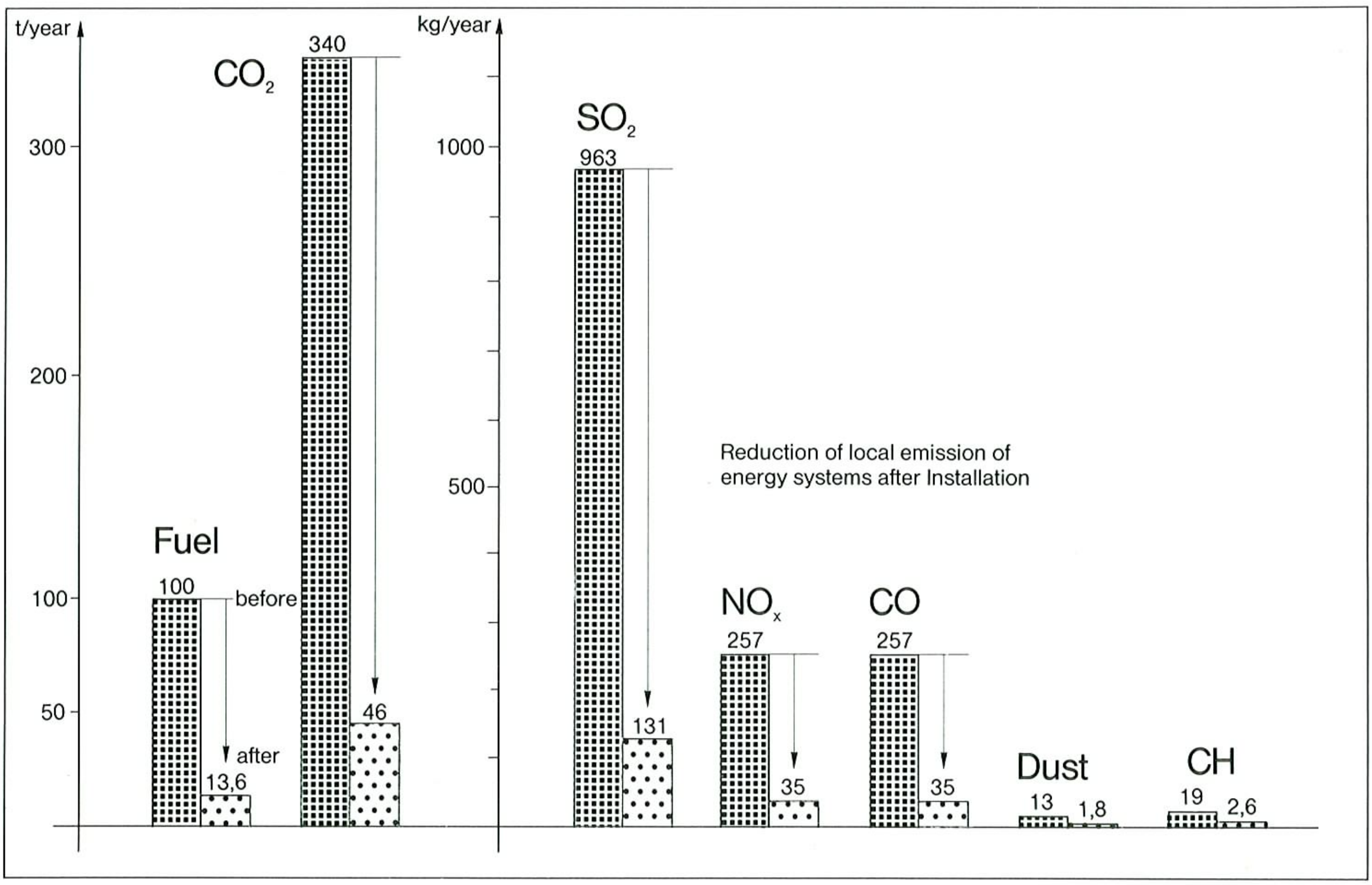


Fig. 6 Public School Windischgarsten - Environmental Improvement before and after Installation

Further Activities and Future Prospects

Based on the present success of OKA heat pump activities, present policy will certainly continue in the future. Main goals for the future are evaluation of pilot projects, optimization of installed systems, a general increase in technical understanding, development of new applications in industrial sectors, and combination of heat pumps with geothermal projects.

References

/1/ Schneeberger, M.F.: The Impact of an Austrian Utility's Heat Pump Initiatives Proc. IEA He, at Pump Conference: Current Situation and Future Prospects (Graz, May 22-25, 1984) dbv-Verlag, Graz, 1984, p. 507-513

/2/ Brandner, R.: Heat Pumps in Austria. HPC Newsletter, Vol. 3, No. 1/2, pp 9-11.

* *M.F. Schneeberger, Head of the Energy Consulting Department of Oberösterreichische Kraftwerke AG (OKA), Linz, Austria*

H. Taniguchi, K. Kudo, K. Kasahara*

Development of a Heat Pump-Boiler System

1. Introduction

It is generally understood that utilization of waste heat or cogeneration of heat and power is an effective way of reducing energy consumption in district-heating or industrial operations. In actual practice, however, heat is often supplied using a simple, conventional boiler. Since boiler efficiencies of over 90% have already been achieved, there is little room for efficiency improvement. Using high-temperature combustion heat for low-temperature heating applications, however, always results in large exergy losses.

Supplying central heat with a cogeneration system has several advantages, including a higher heat-utilization factor, and cost reductions resulting from centralization (such as lower installation and maintenance costs). At the same time, central systems are subject to heat losses in the distribution system, often cancelling out the advantages of centralization.

A better design for a central-heat-supply system is as follows: A heat engine generates power to drive a heat pump. The waste heat from the engine is added to the heat collected by the heat pump, resulting in a higher thermal efficiency.We have designed such a system, using a boiler (fired by petroleum or substitute fuels)and a steam turbine as a heat engine. We have called this system a a 'heat pump-boiler system,' and have estimated its theoretical performance and efficiency. Based on the results of our analysis, the Research and Development Corporation of Japan gave us a contract as part of their objective to develop 'a highly-efficient hot-water-supply system, using both a heat pump and a boiler'. Our research and development work continued for three and a half years, and was completed in February 1985. The work and our results are described in this article.

2. System Development

The heat pump-boiler system we have developed can be used in district-heating or similar applications. Fig. 1 compares the system to a conventional boiler and a cogeneration system, Fig. 2 compares fuel consumption for each of the three systems, and Table 1 lists the capacity range for each system. Since the heat-utilization factor of the heat pump-boiler system is well above the heat-utilization factor of the conventional boiler system, significant energy savings will result. In addition, the heat pump-boiler system can readily deal with variations in load.

Fig. 3 is a flow diagram of the heat pump-boiler system; Fig. 4 shows a T-S diagram of this design. The steam generated by the boiler is led to an expander, such as a steam turbine, and is converted into power. The power generated is used to drive the heat pump compressor and the boiler feed pump. Waste heat from the expander is used to heat the hot-water supply. In a conventional heat pump system, high-pressure working fluid passes through an expansion valve without making use of its potential energy. In order to use this energy effectively, we have replaced the exapansion valve with a power-recovery expander, using the generated power as part of the driving power for the compressor and the boiler feed pump.

Our pilot plant has a capacity of 900 kW, with hot-water supply at 70°C and the low-temperature heat source at 40°C. Fig. 5 is a picture of this pilot plant. The steam expander, heat pump compressor and power-recovery expander are screw types connected in series. The steam on the heat-engine side is at a relatively low-pressure/low-temperature level of about 0.98 MPa, 291°C. A displacement-type (screw) steam exapander is used instead of a velocity-type (turbine) for a higher heat utilization factor at part load. Heat is also recovered from lubricating-oil to further improve system performance.

System	Calorific value generation (MW)	Number of houses	Remarks
Conventional boiler	0.24 ~ 240	100 to 100,000 houses	Domestic record
Heat pump-boiler	0.6 ~ 60	250 to 25,000 houses	
Cogeneration	120 ~ 4,800	50,000 to 2,000,000 houses	Domestic record and record in Europe

Note: Calorific values needed for heating houses are calculated on trial under the following conditions:

120 W per m^2; 20 m^2/house are heated.

Table 1 Comparison of Scales of Various Systems

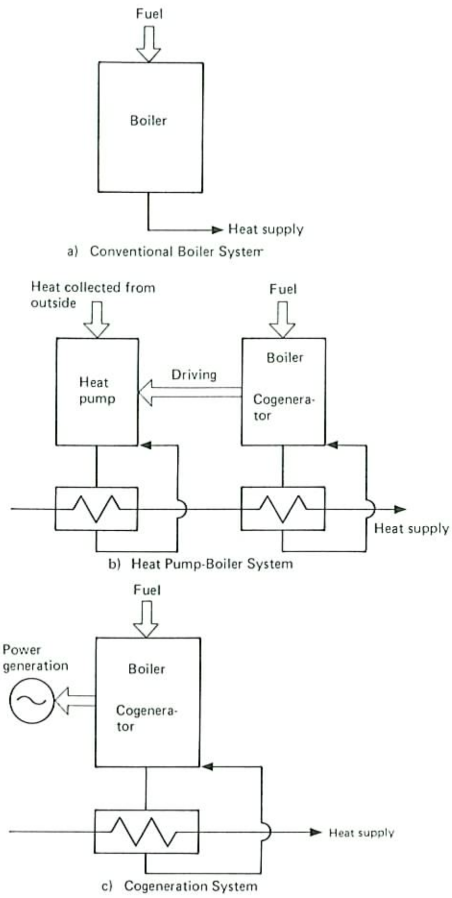


Fig. 1 Comparison of three heat-sypply systems

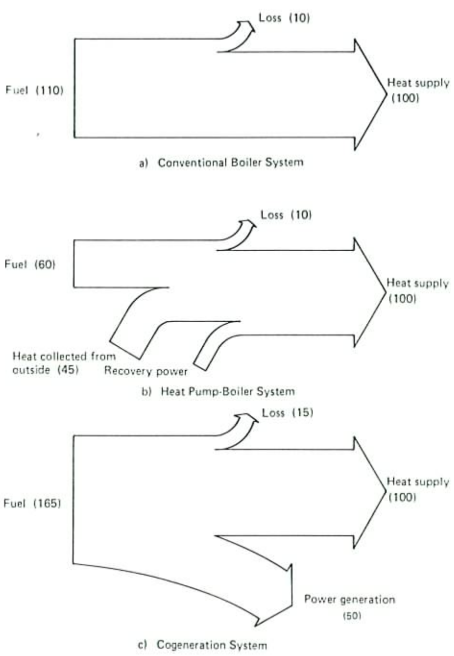


Fig. 2 Fuel consumption for three heat-supply systems

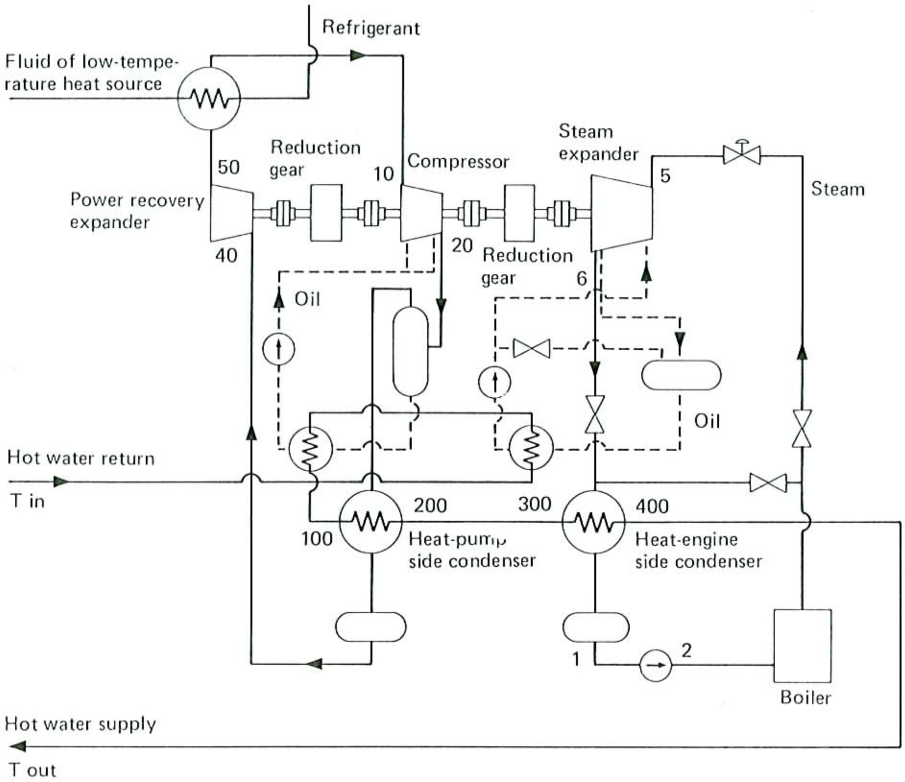


Fig. 3 Flow diagram for the heat pump-boiler system

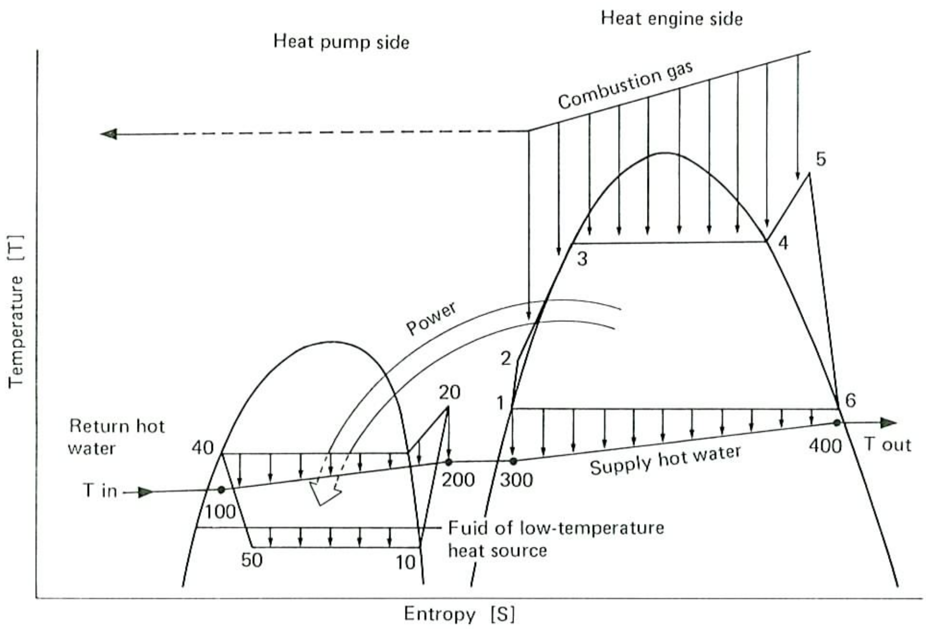


Fig. 4 T-S diagram for the heat pump-boiler system

3. System Performance

Tests on the pilot plant at a rated load of 910 kW show the system has a heat utilization factor of 1.49. Considerable energy savings result when this is compared to the maximum heat utilization factor of 0.9 in a conventional-boiler system.

System performance was measured under various conditions. Fig. 6 shows variations in the heat utilization factor at part load. The heat utilization factor decreases with a decrease in load. One reason for this is a lower thermal efficiency on the heat-engine side. The performance of the steam expander could be further improved. Fig. 7 shows the impact of the the temperature of the heat source on heat-utilization factor. As the temperature of the heat source falls, the heat utilization factor decreases, due to a lower heat pump COP.

The power-recovery expander improves the heat utilization factor by about 5%. This improvement is not related to system heat losses, and cannot be explained using or-

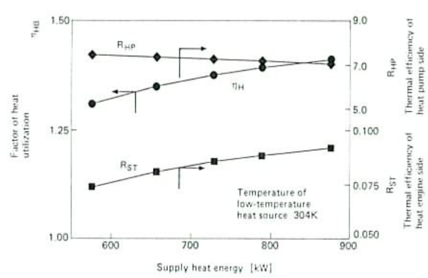


Fig. 6 Part-load characteristics of the pilot plant

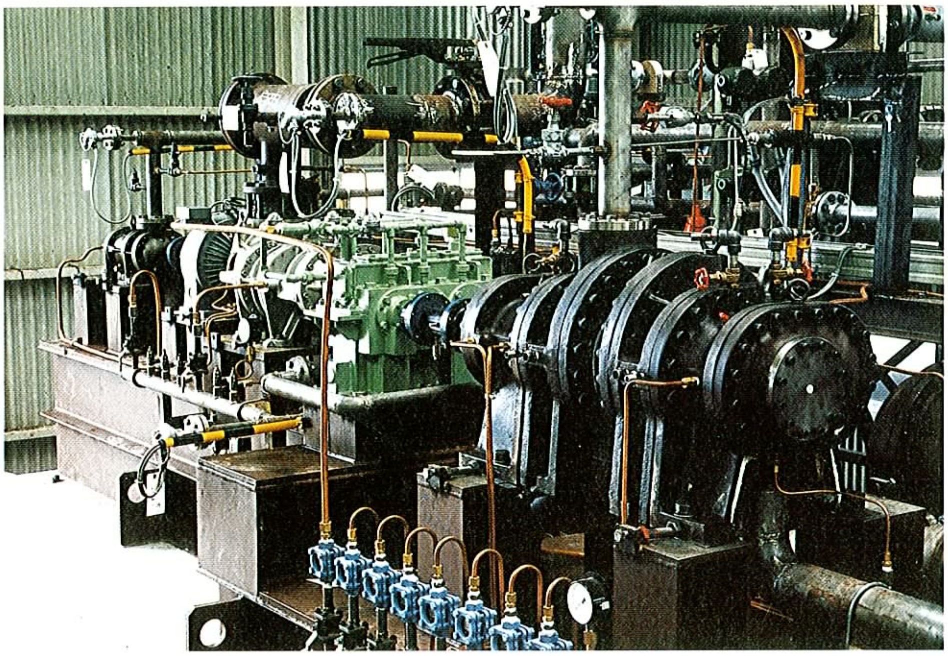


Fig. 5 The heat pump-boiler system pilot plant

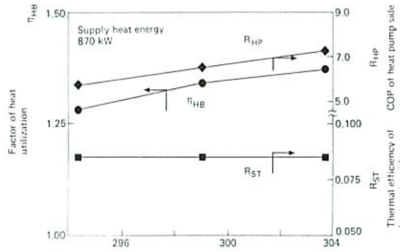


Fig. 7 System performance at different heat-source temperatures

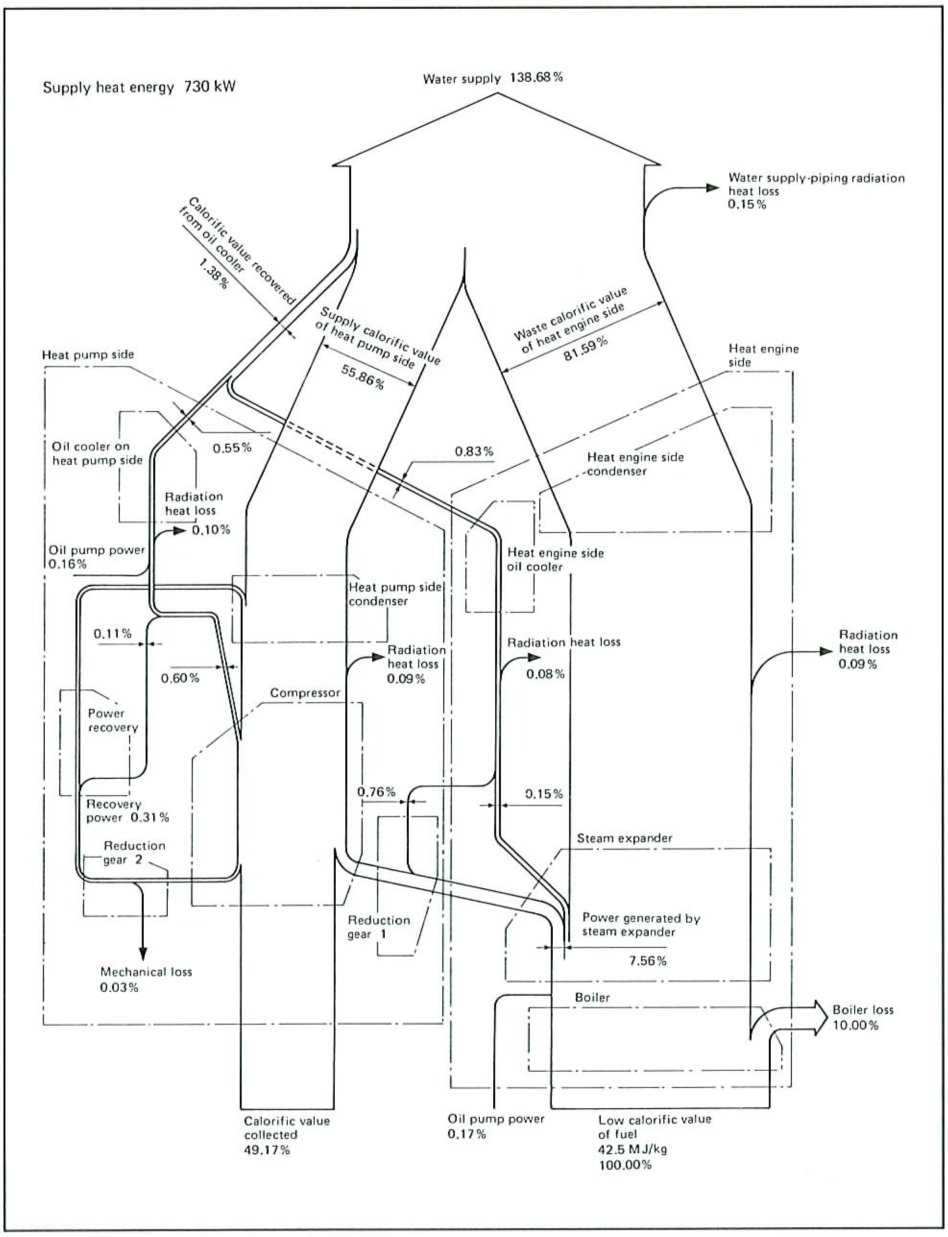


Fig. 8 Energy flow diagram of pilot plant

dinary energy analyses. Exergy analyses become indispensable. In Figs. 8 and 9, both energy and exergy flow diagrams are used to analyze system performance. The energy analysis shows only a 10% loss from the boiler. In contrast, the exergy analysis shows a loss of 70%, due to the low-temperature/low-pressure steam in the system. Increasing the temperature and pressure of the steam can reduce this loss and increase the heat-utilization factor. Our pilot plant is relatively small, making it difficult to acheive this improvement. With today's technology, however, it may be possible to develop a system for larger-scale applications.

4. Summary

In order to produce heat energy effectively, we have designed a heat pump-boiler system. We have built a pilot plant and have monitored its performance. This relatively small system (900 kW) has a heat-utilization factor of 1.49. We tested the part-load behavior of the plant and the effect of different heat source and heat sink temperatures. We have shown the necessity of utilizing both exergy and energy analysis techniques for assessment of improvements in system performance and efficiency.

*H. Taniguchi, K. Kudo, Hokkaido University North 13, West 8, North Ward, Faculty of Engineering, Sapporo 060, Japan
K. Kasahara, Mayekring Co., Tokyo

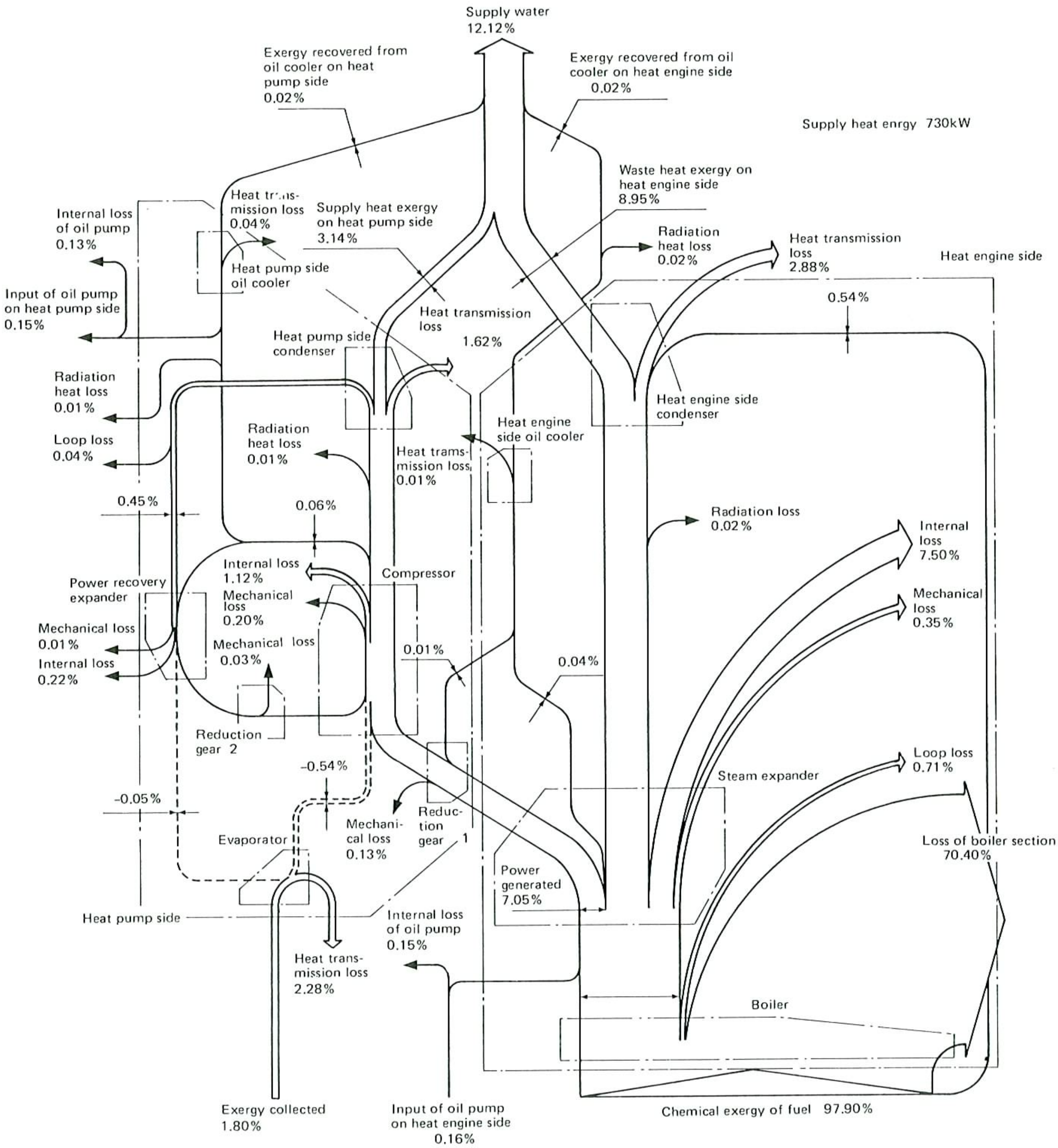


Fig. 9 Exergy flow diagram of pilot plant

H. Yamamoto, T. Iwata, K. Yonemoto*

Heat Pump Hot Water Supply Unit in Japan

One of the earliest examples of a Japanese heat pump hot water supply unit was installed in the 1950s at a famous spa in the Shikoku district. Abundant but low-temperature spring water was used as the heat source for the heat pump to produce the water temperatures required for bathing.

In the late 1960s, heat pump equipment for producing cold and hot water was introduced. In the mid 70s, heat pumps began to be used for cooling and heating in central air-conditioning systems. Since that time, heat pumps have been the most popular equipment for air-conditioning in office buildings, for reasons of cleanliness, safety, and ease of operation. For domestic applications, however, oil- or gas-burning hot-water supply units or electric resistance units have been used, due to compact size and low initial cost.

The oil crisis, however, resulted in a new interest in heat pumps for hot-water supply. In this article, product research and development for various applications is described.

1. Types of Heat Pump Hot Water Supply Units

Several types of heat pump hot-water supply units are now on the market, and new types are being developed to meet the needs of different applications. Some of these products are described below.

1.1 The Heat Pump Unit for Hot Water Supply

Heat pump units for hot-water supply use either water or air as a heat source. Water-source units are available over a wide range of capacities, and can operate reliably with water at 10 to 20 degrees Celsius. If waste heat is available as a heat source, the performance and efficiency of the water-source heat pump is improved.

Air-source heat pumps are of small or medium capacity. While water-source types require a nearby source of warm or hot water, air-source heat pumps can be used conveniently at any location. Installation of air-source heat pumps, however, has not been as widespread as installation of water-source units. Air-source units must operate at outdoor temperatures that range from -10°C in winter and 35°C in summer. The problem is not how to overcome technical difficulties, but how to optimize system operation. In order to supply heat at temperatures below 3-5°C, for example, either a large-capacity heat pump must be installed or some combustion-type or electric-heater backup system must be provided.

R12 is used as a working fluid to supply hot water temperatures of 55 to 60°C, and R22 is used to supply higher temperatures. Some small domestic units use can produce hot water at 70°C by taking advantage of the temperature of the superheated vapor discharged from the compressor.

Item		Model UWQ 15J-S
*Heating capacity (50/60 Hz) Kcal/h		47600/61600
*Volume of hot water (50/60 Hz) l/min		159/205
*Volume of heat source water (50/60 Hz) l/min		108/143
*Power consumption (50/60 Hz) KW		17.0/21.6
Power source		3-phase 220V 50/60 Hz
External dimensions	Height mm	1650
	Width mm	1400
	Depth mm	650
Product weight Kg		680
Compressor		Hermetic, 5.5 Kw x 2
Heat exchanger in the hot water side		Multi-tube condenser
Heat exchanger in the heat source side		Multi-tube evaporator
Note) * mark denotes specifications when hot water inlet temp. is 55 °C, outlet temp. is 60 °C, and the heat source water inlet temp. is 20 °C.		

Table 1 Specifications, Model UWQ 15 J-S

At the present time, water-source units are being produced with compressor output ratings of 2.2 to 45 kW. Air-source units are available with compressor outputs of 5.5 to 15 kW. Small-capacity units for domestic use are being developed, and are being field-tested in various regions.

1.2 Heat Pump Combination Units for Heating, Cooling, and Hot Water Supply

Production and development of combination units is being carried out in the Japanese market. Combination units are of two types: heat pump chilling units and separate heat pump air-conditioners with additional functions for hot-water supply. The operational mode of these combination units varies according to the type of combination and the individual features of each system.

During space cooling in the summer season, it is possible to utilize waste heat produced by operating space-cooling equipment, resulting in a higher energy-efficiency ratio. During the winter season, however, both the space and the hot-water supply require heating, and must be given priority or be aided by additional heating.

Combination units are equipped with three heat exchangers that can switch to endothermic operation or radiation operation in accordance with each mode of operation. In addition, the control mechanisms are complex, in order to allow operation over a wide range of conditions. Therefore, high system reliability is required.

1.3 Hot Water Heat Pumps for Commercial and Industrial Applications

Hot water heat pumps for commercial and industrial applications have been limited in number (for example, in public baths, hot spring hotels, etc.), but their use has been on the increase in recent years.

Commercial heat pumps that can produce hot water up to 60 to 70°C are basically the same as the hot-water supply unit described in 1.1. Many are water-source types, but there are also some air-source types. Most units are of medium capacity. For units with reciprocating-type compressors, output is not greater than 45 kW. Some screw-type compressors have been developed with outputs greater than 45 kW. R22, R12, and R500 are used as working fluids. Some water-source heat pumps with screw compressors can produce hot water at 80-110°C from low-temperature waste heat of 40-70°C.These units are have compressor outputs of 40-1,130 kW and use R114 as their working fluid.

Industrial heat pumps are used for heating greenhouses, and for controlling the water temperature of breeding ponds for fish and shellfish. In some cases, both the heating and cooling capacity of the heat pump can be utilized. For example, food processing operations require a supply of hot water for heat treatment and washing, and may also have cooling and refrigeration requirements. System efficiency can be improved by recovering the waste heat discharged from refrigeration equipment. Utilization of heat pumps for hot-water supply in industrial applications is now in the introductory stage, but promises to be widespread in the future.

2. Product Descriptions

2.1 Heat Pump Unit for Hot Water Supply

(1) Specifications and Characteristics

Fig. 1 shows and example of a heat pump unit for hot-water supply. It is a packaged type with a capacity range of 7.5 to 15 kW. It uses water as a heat source, with an inlet temperature range of 12 to 25°C. R12 is used as the working fluid in order to produce a maximum hot-water temperature

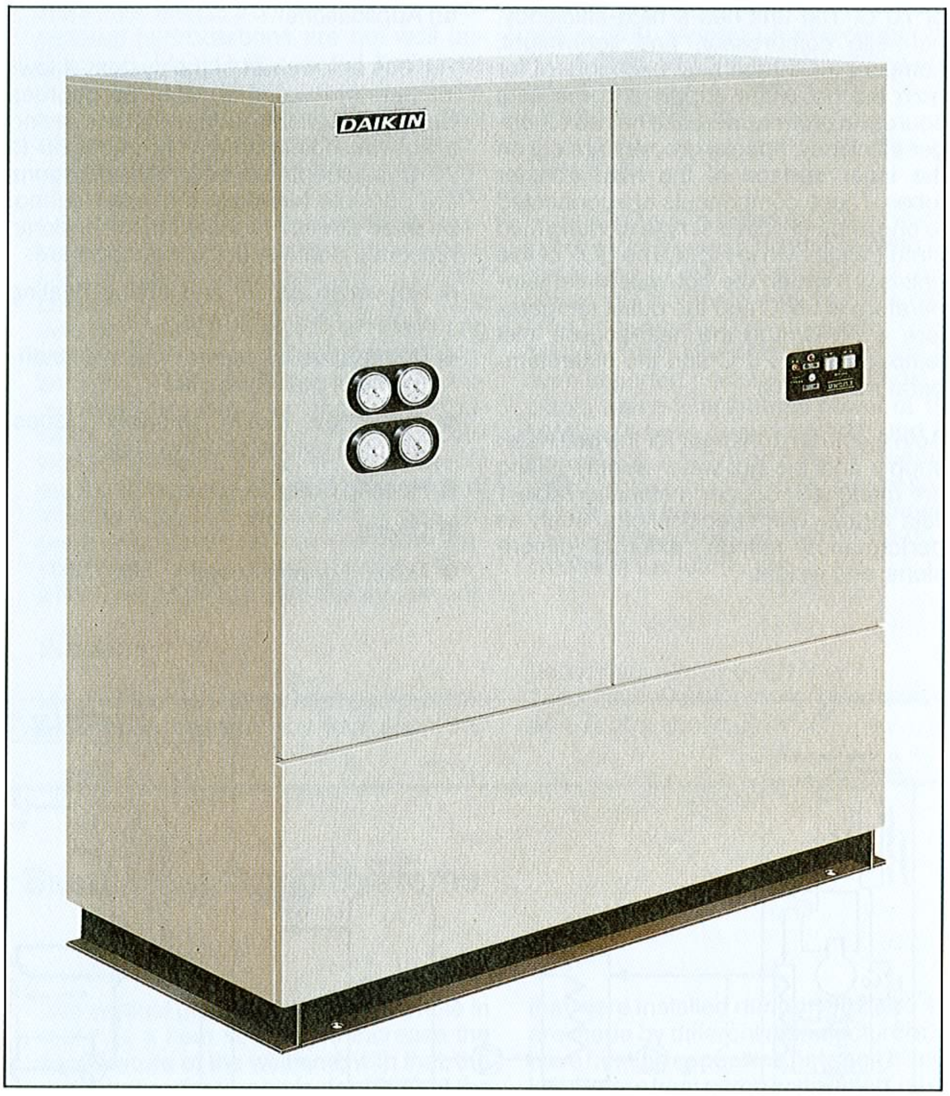


Fig. 1 Heat pump unit for hot-water supply only (UWQ 15J-S/8302 Ⓐ)

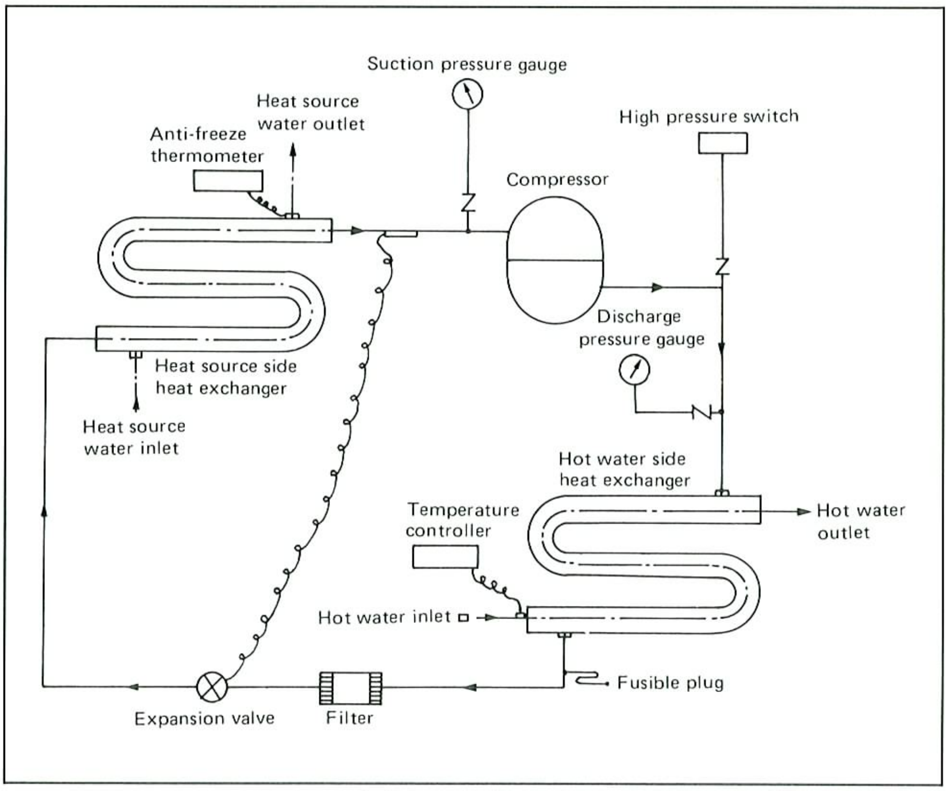


Fig. 2 Piping flow Sheet (UWQ 15J-S)

of 70°C. The unit has a high-efficiency, hermetic compressor, and lightweight, compact multi-tube heat exchangers for both the hot-water supply and the heat source. In order to increase heat-exchanger efficiency, special grooves are cut on the inner surface of the heat transfer tubes. These components are connected to one another with a simple working fluid circuit, as shown in Fig. 2. The COP of this unit is 3.3 (when the hot-water inlet temperature is 55°C and the outlet temperature is 60°C, and the heat-source inlet temperature is 20°C and the outlet temperature is 15°C).

Both the heat exchanger for the hot-water supply and the hot-water supply piping are made with copper materials. Table 1 lists further unit specifications, such as performance ratings, external dimensions, and weight.

(2) Applications

Fig. 3 is a flowchart of the system. If low-temperature water of 12 to 25 degrees Celsius is available as the heat source and a hot-water temperature of about 60 to 70°C is acceptable, several applications are possible (although the water cannot be used directly for drinking for hygienic reasons). Some specific examples are:

- Hot-water supply and space heating (hotels, hospitals, plants, etc.)
- Baths (public baths, saunas, bathrooms of golf-links, etc.)
- Processes (bottle washing places, washing places of dyeworks)
- Heating boiler feed water
- Drying
- Heating greenhouses

Heat source water, hot-water supply and feed water must undergo quality control in accordance with the cooling water standards set up by the Japan Refrigeration and Air Conditioning Industry Association (JRAIA).

2.2 Combination Heat Pump Units for both Hot Water Supply and Space Cooling and Heating

The following four examples of combination equipment are described below.

1. An air-source heat pump chilling unit with a hot-water supply unit.
2. An air-source heat pump chilling unit with a built in heat exchanger for hot-water supply.

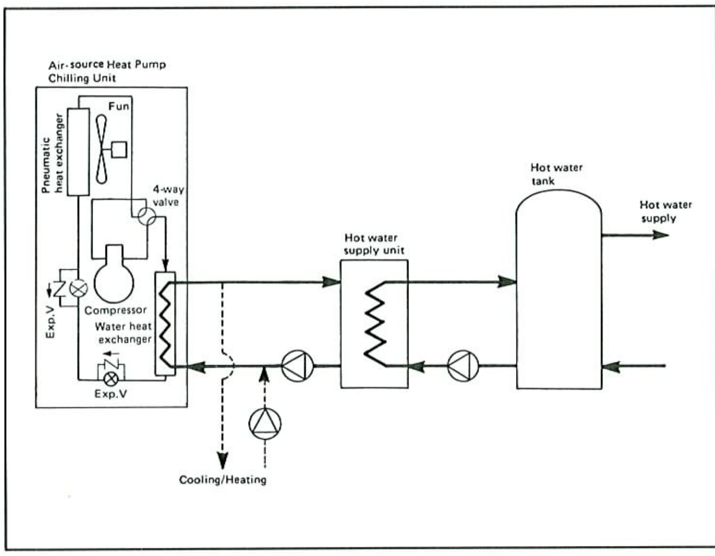


Fig. 4 System Flow Sheet - Example 1 (when operated exclusively for hot water supply)

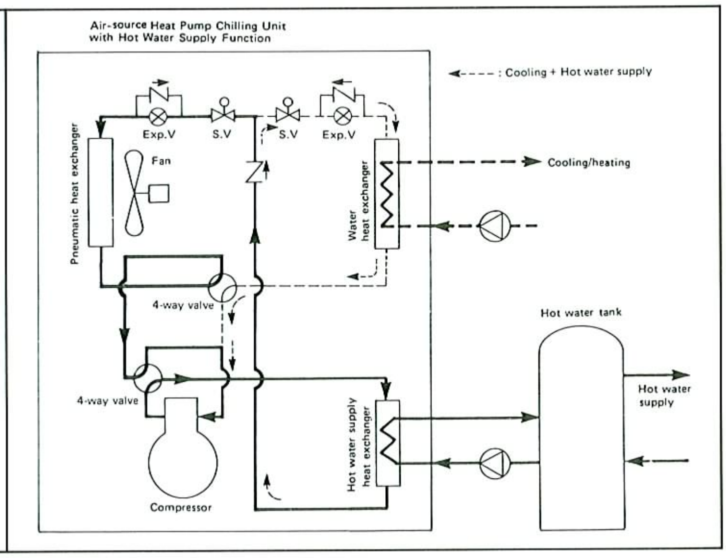


Fig. 5 System Flow Sheet - Example 2 (when operated exclusively for hot water supply)

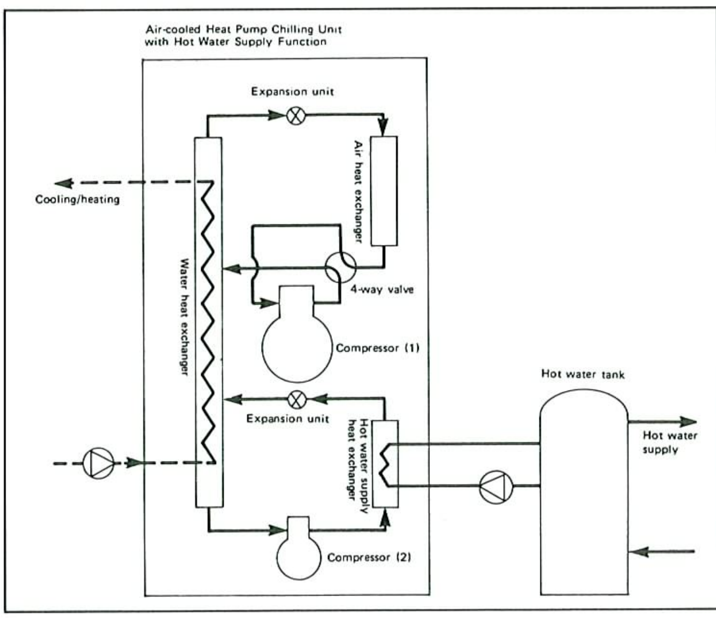


Fig. 6 System Flow Sheet - Example 3 (when operated exclusively for hot water supply)

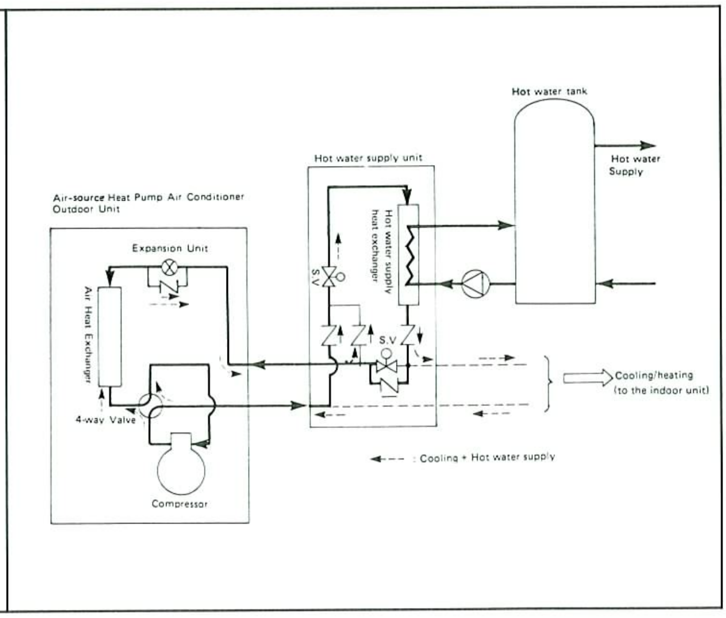


Fig. 7 System Flow Sheet - Example 4 (when operated exclusively for hot water supply)

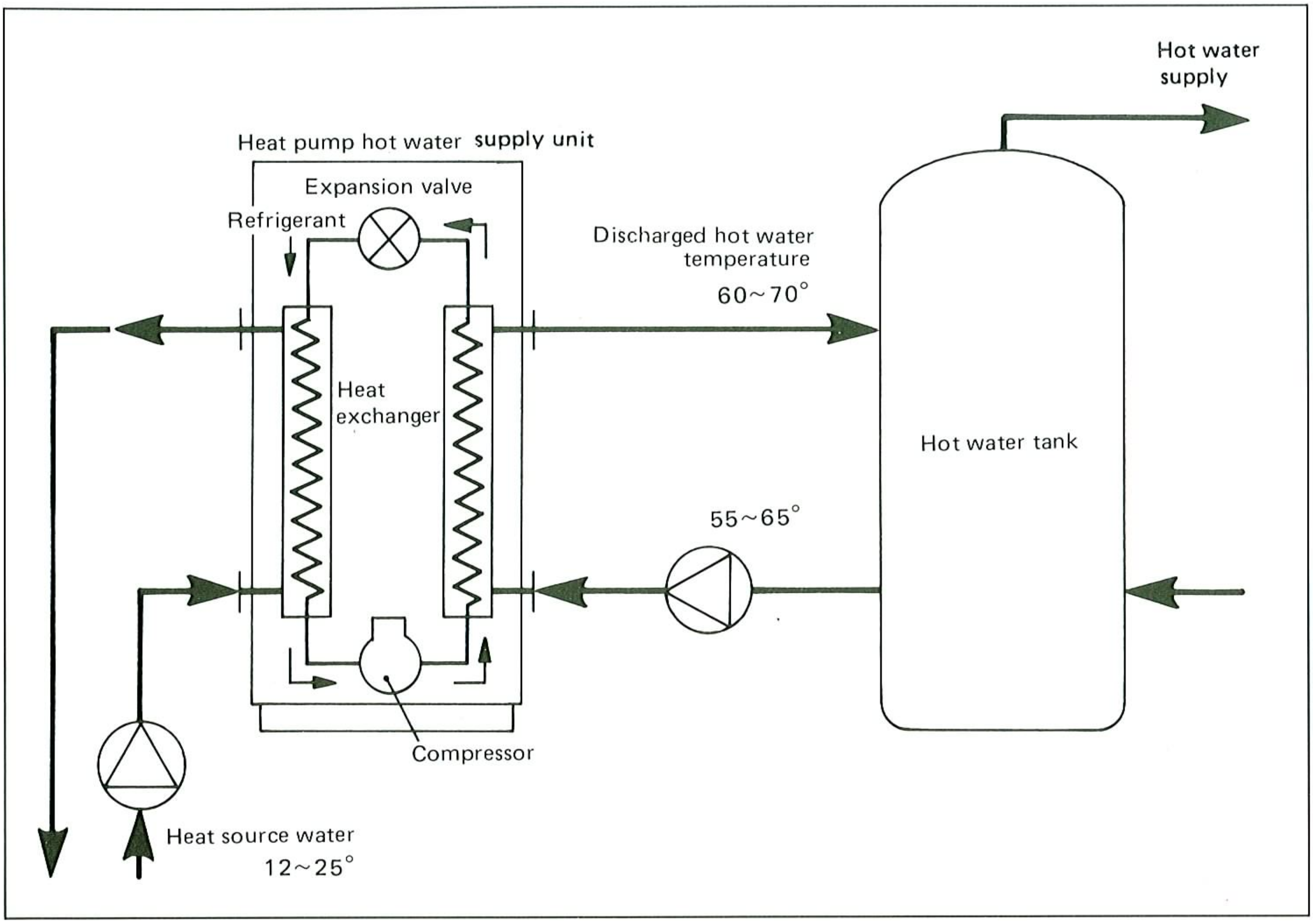


Fig. 3 System Flow Sheet (UWQ 15J-S)

4. An air-source heat pump air-conditioner with a hot-water supply unit.

Table 2 summarizes the operational modes of each system.

(1) Example 1

This system has a hot-water supply unit connected to an air-source heat pump for space cooling and heating. Fig. 4 is a flow chart of this system. Although this is a simple system, it cannot operate in the space cooling (or heating) and hot-water supply modes at the same time. When room cooling (or heating) and hot-water supply are both required, the hot-water supply unit must operate when cooling or heating operation is suspended (at midnight, for example), storing hot water in a tank for later use. The hot-water piping for the hot-water supply unit is constructed of copper or stainless steel, to prevent rust and corrosion. Most of the products are from 2.2 to 15 kW in compressor output capacity.

(2) Example 2

This system is an air-source heat pump chilling unit with an additional heat exchanger for hot-water supply inside the unit. This unit is compact, simplifying in-

Operation mode	Hot water supply, cooling/heating system			
	Example-1	Example-2	Example-3	Example-4
Hot water supply only	x	x	x	x
Cooling only	x	x	x	x
Cooling + hot water supply	–	x*1	x*3	x*1
Heating only	x	x	x	x
Heating + hot water supply	–	x*2	x*3	–

Notes) *1 denotes that hot water supply cannot be conducted without cooling load.

*2 denotes that, with 2 refrigerant systems (2 compressors), both heating and hot water supplying capacities become 50%.

*3 denotes that thermostat stops during cooling and heating, and heat is accumulated at midnight.

Table 2 Modes of Operation for Each System stallation. A flow chart of this system is shown in Fig. 5. When space cooling and hot water are required simultaneously, the waste heat from space cooling is used as the energy for supplying hot water, making the unit a so-called 'heat-recovering type.' When the space-cooling load is small, however, the capacity for hot-water supply will diminish. Furthermore, simultaneous room heating and hot-water supply is possible only for a unit with two working fluid circuits (2 compressors), and both space heating and hot water supply capacities are diminished by about 50%, compared to single purpose operation. This diminished capacity can be avoided if operation for hot-water supply is performed during periods when operation for space heating is not required. Most units are of medium capacity, ranging from 15 to 45 kW.

(3) Example 3

This system has an air-source heat pump for space cooling and heating, and a water-source heat pump unit for hot-water supply, housed in one casing. R22 is used as the working fluid for space cooling and heating, since a hot-water temperature of about 55°C is șufficient for space heating. R12 is sometimes used for the hot-water supply circuit to obtain temperatures up to about 70°C. High discharge temperatures can reduce the size of the hot-water storage tank. Fig. 6 shows a flow chart of this system. Most units are small, ranging from 2.2 to 5.5 kW.

(4) Example 4

This system is a split-type heat pump air conditioner with a hot-water supply unit attached to it. Fig. 7 shows a flow chart of this system. This sytem is different from Example 1 in that it can utilize waste heat produced by space cooling operation. Like Example 1, however, space heating and hot-water supply cannot occur simultaneously, unless hot-water is stored while operation for space heating is suspended. Site installation work primarily consists of refrigerant piping work. Many of the units are small-sized with capacities from 2.2 to 3.75 kW.

3. Plans for Future Development

As mentioned above, a number of heat pump products for hot-water supply have been developed. They have many excellent features, but have some problems that must be solved berfore their use can become widespread. Air-source heat pump hot-water supply units lose some capacity when the outside air temperature is low. To obtain sufficient capacity in low-temperature outside air, improvement of compressors and heat exchangers, optimization of working fluids, circuit construction, control method and defrosting system, and methods for ingenious combination with the auxiliary heat source and heat storage are all being studied. Special efforts are being made to reduce unit cost and size, and to effectively combine the unit with space cooling and heating. As a result of these improvements, the heat pump will surely be a more attractive option for hot-water supply in the future.

Future work on industrial heat pumps will include attainment of high efficiency and high temperatures, as well as aquiring more operating experience in different applications. To achieve a high COP, the efficiency of the compressor and heat exchanger will be improved, and working-fluid mixtures will be researched and developed. To achieve high temperatures, high-output-temperature compressors will be developed and working fluids (concentrating on fluoro-alcohols) and lubrication oils will be studied. The expected increase in efficiency brought about by these efforts will increase the economic benefit of the heat pump, and achievement of high output temperatures will widen the field of possible heat pump applications. For widespread use of heat pumps in the industrial field, different techniques for utilizing heat pumps for different applications are important. The cooperation of users, engineering companies and manufacturers will allow for further accumulation of know-how and operating experience. Although each heat pump is likely to be designed specifically for its application, development and production costs will be reduced as the number of heat pump installations increases.

*H. Yamamoto, T. Iwata, K. Yonemoto, Daikin Industries Ltd., Kanaoka-machi 104, Sakai, Osaka 590, Japan

Bjoern Dahlroth*

Experience with Large Heat Pumps in Sweden

In Sweden, the market conditions for large electric heat pumps are ideal.

- The price of electricity is very low
- There are good heat sources in Sweden's many lakes, in the sea along the coastline, and in the waste water from the pulp and paper industry. The best heat source is treated sewage water. Almost every town has a centralized plant for cleaning and treating sewage water.
- District heating is very common, so there are many large heat sinks.
- There are no coal resources worth mentioning in Sweden, and the distribution of imported natural gas is still too limited to compete with heat pump alternatives.

We define a large electric heat pump as a unit with a heat production capacity over 1 MWth. The first such unit was commissioned in Sweden in 1981. At the end of this year (1985), there will be about 90 units witha total capacity of approximately 900 MWth. The 1000 MWth level, which had been the estimated market potential, will probably be surpassed by January or February 1986. Together, all these large heat pumps will produce almost twice as much heat energy than is now produced by all the 110,000 small electric heat pumps presently installed in single-family houses. The largest single unit so far, installed in the city of Gothenburg, is rated at about 30 MWth.

Large heat pumps have become quite a success in the Swedish energy system. In comparison to the cost of oil-based heating, the first cost of a large heat pump is paid back in three to four years, and in comparison to coal-fired heating, in about eight to ten years.

When a product is developed and put on the market in just a couple of years, isn't there a risk of operational trouble and low availability? This question was posed quite early by several people within the energy business. On the initiative of the Swedish Power Association Development Foundation (VAST) and with cooperation from the Swedish Heat Producers Association (VVF), a working group was formed in 1983 to answer this question. A simple system for quarterly operation reports was set up, and several owners of large heat pumps immediately responded that they were interested in participating in the reporting scheme.

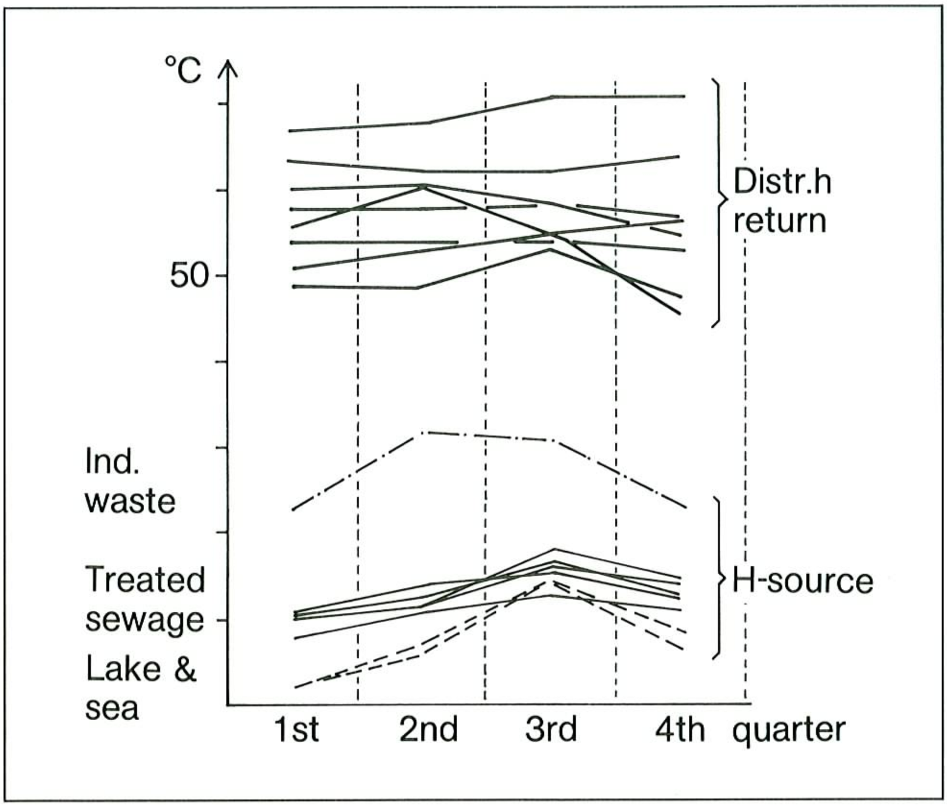


Fig. 1 Examples of quarterly mean temperatures of district-heating and heat source return for some large heat pump plants in 1984.

There were preliminary results after just a few months in 1983, but a more detailed analysis was not made until all data for 1984 had been collected. The results of this analysis are presented here in brief. Results are based on reports from 22 plants with a total of 29 large units. Some of the machines are used for industrial applications, but most of them are used for district heating. The 16 turbo compressors and 13 screw compressors have an average capacity of 7.7 MWth. The screws are generally smaller while most of the turbo units are larger.

Temperature Levels

Examples of the quarterly-mean-return temperatures of heat sources and district-heating systems are shown in Fig. 1. The district heating return temperatures do not vary much during the year. For the return temperatures in the figure, there is a maximum variation of +/- 7 K. Note that one plant has a return temperature of about + 70°C, meaning that the condensing temperature is about 80°C.

The return temperatures of the heat sources vary with season, rather than with district-heating demand. The maximum variation around the quarterly mean is +/-5 K. Of course, lake or sea water will never fall below the freezing point, but evaporators can be designed to extract a great deal of heat even at 1 or 2 K above freezing.

Operation Time

Most of the heat pumps supply the base load in district-heating systems. Average operation time is longer than 70% of the calendar year, or more than 6,000 hours per year. A few heat pumps have yearly operating times of over 8,000 hours. Constant operation with few starts and stops is often considered a favorable duty cycle. In some cases, operation time is reduced due to mechanical failures; in other cases, due to heat source temperatures that are too low.

Average Load

For most of the units the operating load is fairly constant, at an average of about 80%. Some units, however, show large variations in operating load, primarily due to variations in the availability of the heat source. Sometimes the load is reduced due to low heat demand, especially during the summer.

How well do the heat pumps perform?

The coefficient of performance (COP), or 'output divided by input', is the heat pump characteristic that attracts more interest than any other. A high COP is important, but must not be overemphasized. With the energy price situation as it is in Sweden, high availability and high output are more important factors in the economics of a heat pump plant than are a few tenths of variation in the COP.

Nevertheless, the large heat pumps we studied performed very well. For an entire plant with turbo set and including all auxiliary equipment, the highest annual COP is over 3.1. The average annual COP for nine large turbo units with auxiliaries is about 2.8. This is not low, considering that the condensing temperatures of most units are high - above +65°C - and, in some cases, are even above +75°C. The plants with screw compressors have an average-annual total-plant COP of 2.3. If the industrial units that work under the most unfavorable temperature conditions are excluded, the average COP increases to 2.6.

In general, the plant COPs are slightly lower than figures quoted in manufacturers' data and used in the general energy debate that is going on in Sweden. This could be due to optimistic expectations among suppliers and people responsible for 'energy planning'. As mentioned previously, however, a slight decrease in COP has little effect on the favorable economics of a heat pump plant.

Investigations have been made to find out if there is any clear correlation between variations in plant COP and temperature conditions. There may be such a correlation, especially in the stage of designing a heat pump plant. The correlation is quite small or disappears, however, once the plant is built and in operation. In summer, when heat source conditions are favorable, there may be a low heating demand. Under these conditions, the plant runs at part load with many auxiliaries in operation. Additionally, return temperatures in district-heating systems have a tendency to increase during the summer, due to imperfections in the heat-distribution system.

As a first conclusion, in the early design stages, it is reasonable to project an annual total COP for the heat pump plant of about 2.8, based on winter temperature conditions. One can hope for getting a plant that can do only slightly better than a COP of 3.

Output

We found little correlation between quarterly-average output in MWth and quarterly-average temperature conditions. Output depends more on other factors.

Availability

It is difficult to define the rated output of a heat pump. It is not possible to use the same definition of availability for a heat pump as is used, for example, for a thermal power station. Heat pumps either run at the load determined by external conditions or don not run at all. For this reason, we have selected the simple availability definition:

$$\frac{\text{reported operating time}}{\text{reported operating time} + \text{reported fault time}}$$

Note: figures have been rounded

16 Turbo

Type of Trouble	Outside: Heat Source	Outside: Heat Distribution	Outside: Miscellaneous	Ancillary: Control & Protection	Ancillary: Motors	Ancillary: Miscellaneous	Heat Pump Machinery: Compressor	Heat Pump Machinery: Evaporator	Heat Pump Machinery: Condenser	Heat Pump Machinery: Miscellaneous	Total
Oil Leakage						0.2	0.9				1.1
Refrigerant Leakage						0.4	0.3				0.7
Bearings					0.3	0.1	0.4				0.8
Electrical			1.3	1.9	0.3	0.9					4.4
System & Design				1.0		0.6	0.4	0.2	0.1		2.3
Dirt	1.5	0.1				0.7	0.1				2.4
Corrosion	0.1										0.1
Miscellaneous	1.9	1.1	0.2	0.7	0.2	2.3	0.6	0.2		0.3	7.5
Total	3.5	1.2	1.5	3.6	0.8	5.2	2.7	0.4	0.1	0.3	19.3
Total by category	6.2			13.1							

13 Screw

Type of Trouble	Outside: Heat Source	Outside: Heat Distribution	Outside: Miscellaneous	Ancillary: Control & Protection	Ancillary: Motors	Ancillary: Miscellaneous	Heat Pump Machinery: Compressor	Heat Pump Machinery: Evaporator	Heat Pump Machinery: Condenser	Heat Pump Machinery: Miscellaneous	Total
Oil Leakage						0.5	0.5			0.1	1.1
Refrigerant Leakage						0.1	0.3			0.3	0.7
Bearings							0.1			0.3	0.4
Electrical			0.9	2.0		0.3					3.2
System & Design				2.0		0.9	0.8				3.7
Dirt	0.9					0.7	0.1	0.1			1.8
Corrosion											
Miscellaneous	0.9	0.7	0.3	0.5		1.7	0.4			0.4	4.9
Total	1.8	0.7	1.2	4.5		4.2	2.2	0.1		1.1	15.8
Total by category	3.7			12.1							

Table 1 Number of reported 'trouble incidents' per 10,000 hours of unit operation.

With this definition, availability indicates how much of possible production is likely to be lost due to mechanical failure. Losses due to planned maintenance are not considered. The result is that only a few units have not performed very well. Half of the turbo sets have an availability better than 97.5%, and half of the screws are better than 94.8%. Both figures confirm that large heat pumps are very dependable as heat production machines, with an expected availability at least as high as that for a boiler. Some units tested have availability factors close to 100%.

Reliability

Availability describes the possible loss of energy production, and a potential loss of income. Reliability indicates how often mechanical failures occur in the machinery, but does not account for lost production. Both concepts are important for evaluating plant behavior.

For our investigation, we chose to study how many 'disturbances' and 'troubles' were reported for each plant, rather than mechanical failures only. The definition of a 'disturbance' or 'trouble' is subjective. It is an incident that interferes with normal operation such that personnel find it disturbing, must take some action, and must also report it. Usually, the 'incidents' are due to some kind of fault that does not cause a full stop of the machinery. Small incidents that we have judged as trifles have not been included in the evaluation, even if they were reported.

Table 1 shows the number of 'incidents' per 10,000 unit hours of operation, categorized by type of problem. The quality of the data is not high; nevertheless, some conclusions can be drawn. The pattern of 'incidents' is the same for both turbo units and machines with screw compressors.

The total number of incidents is approximately 15 to 20 per 10,000 hours of operation. In practice, this means between 1 and 1.5 incidents per month. This is indeed a low figure. Between 1/3 and 1/4 of all incidents are due to factors outside the plant itself. A closer look at the reports reveals that the most common outside factors are insufficiency in the heat source and floating rubbish. Insufficiency simply means that there is not enough sewage water or that the water is too cold.

In the first plants utilizing treated sewage water, there were certain problems with trash. The water was acceptably clean from the hygienic point of view, but there were still some objects such as pieces of plastic, cork or leaves, or flocks of algae and the like. Several plants have balls of plastic foam circulating through the evaporator to keep the tubes clean, similar to those used for power station condensers. At first, the strainers used for collecting the balls downstream of the evaporators were clogged by floating objects and did not operate well. The water was 'hygienic' from the environmental point of view, but was not clean enough for heat pumps. In the worst cases, the problem was solved by installing self-cleaning strainers in front of the plant. It is indeed doubtful that the circulating-ball systems are even necessary; some plants do well without them.

There were not many incidents that originated inside main heavy equipment; for instance, there were few severe compressor failures. When these incidents did occur, however, the shut down periods were very long.

Most incidents were due to failures in the auxiliary systems. This is typical not only for heat pumps, but for almost all kinds of equipment used in energy conversion or process industries. Some of these were 'system faults,' defined as faulty design, program error, selection of wrong equipment, etc.; some failures were due to dirt.

It still happpens that relays fail, but most 'electrical incidents' are due to computer-system problems. Computer systems are sensitive to transients in the mains' frequency and short power interruptions. It would pay well to equip a plant from the beginning with a robust computer system with optocouplers and with a well-filtered power supply. It is also important to write well-structured computer software. Programming should start the day after signing the contract and should not be postponed until just before commissioning. All this is not, of course, true only for heat pump plants; it applies to any industrial process. Corrosion has not been a problem, but may develop in the future.

Leakage

Leakage of refrigerant is a large concern in Sweden, due to concerns about safety, health effects, the cost of replenishing refrigerants and, last but not least, the loss of heat production. Any reduction in heat production from a heat pump plant must be compensated by burning fuel oil, which is much more expensive than the energy cost of heat from the heat pump.

In 1984, a special investigation on leakage was performed. All the participants in the reporting scheme reported how much refrigerant they had replenished since the commissioning date or the start of operation. The results were:

Slow leakage	= 31 t
Large leakages in connection with faults	= 22 t
Leakages in connection with maintenance and repair	= 7 t
	= 60 t

Of course, these figures are not extremely accurate. When related to the estimated quantity of refrigerant in the machines and the elapsed time, about 20-25% of the total annual filling has been lost. From an environmental point of view, this amount is not very much. The amount is small, for example, when related to the total release of light halogenated hydrocarbons in plastic foaming. This leakage is also reasonable if compared to the leakage from large refrigeration systems. Within the energy business, however, it is considered to be too much.

What can be done? Some of the slow leakage is difficult to reduce, such as leakage from seals. It should be possible, however, to reduce leakage through flanges. In heating systems it may happen that the return temperature suddenly goes up for short periods. These 'hot water short circuits' or 'hot water plugs' are due to various problems and faults with the heat distribution system. Occasionally, a quantity of very hot water will pass through the condenser, causing the safety valves to blow, and some refrigerant will be lost. The extent of safety valves blowing due to 'hot water plugs' is not known, but it should be possible to do something about that as well.

The health effects from inhalation of halogenated hydrocarbons are not well understood. Many halogenated hydrocarbons are believed to be quite harmless. Nevertheless, Swedish authorities have introduced new and very low limits for exposure. For instance, the maximum allowable concentration of R12 for long time exposure is 500 ppm. With a ventilation system of reasonable capacity, it may be possible to keep the concentration in a plant below this limit most of the time. It must also be possible, however, to detect and monitor such low levels reliably and continuously. There are very sensitive instruments on the market, but they react in different ways to almost any compound containing halogens. So far, the most reliable equipment is based on the absorption of infrared light. This equipment is very expensive, however, and owners of average-size plants - a few 100 kWs to a few MWs - will be reluctant to install this equipment.

Suppliers

Most of the very large heat pump plants have been delivered by four suppliers: Messrs STAL-Refrigeration, Messrs ASEA-STAL, Messr ELAJO in cooperation with Sulzer, and finally, Götaverken Energy Systems, a subsidiary of the Swedyard's Group.

Summary

Large heat pump plants have been a great success in Swedish district-heating systems. Due to low electricity rates, these plants can compete not only with plants fired by heavy fuel oil but also with plants fired by fuels like peat, wood chips and even imported coal. By 1986, almost 100 plants with a total thermal power of 1000 MWth will have been installed, and in a time period of less than 5 years. Operation with a high plant availability has been excellent so far. Leakage of refrigerant seems to be a little high, but is likely to decrease in the future.

Björn Dahlroth, Swedish Power Association Development Foundation, (VAST), Stockholm, Sweden.

M. Larsson, L. Spante*

Solar Charging of Wells for Small Heat Pump Systems in Sweden

Introduction

The Swedish State Power Board is promoting the introduction of heat pumps in Sweden by demonstrating their performance in different applications. The purpose of these demonstrations is to encourage a switch from oil to electric heat pumps for heating and domestic hot water production, thereby reducing Swedish imports of oil.

The program includes just over 260 heat pumps for single-family houses. Sixty of these heat pumps are ground coupled with vertical pipes in a well (a borehole in rock) as a heat source. To increase the temperature of the well and, with that, the seasonal performance factor (SPF) of the system, some of the installations are equipped with simple solar collectors or air convectors to charge the well. Heat is transferred between the well, the heat pump evaporator, and the charging device with a closed-circuit pipe filled with brine, allowing operation below zero degrees centigrade. Figure 1 shows a schematic drawing of the system. Twelve of the installations are being monitored to study the effects of charging. The heat pumps that were installed during 1982 and 1983 are made by different manufacturers, and have heating capacities between 8 and 12 kW. Before heat pump installation, oil consumption of the houses ranged from 4-8 m^3/year.

The impact of well charging should be greatest in systems with a high annual energy extraction rate per meter of borehole. One such installation has been chosen for detailed discussion in this paper. The study determines how charging affects the annual-mean and the winter-minimum temperature of the well, and

	Period	June	Dec.	Annual
Insolation (kWh/m^2) horizontal surface	1971-80	184	7.00	980
Insolation (kWh/m^2) tilted plane, 45°	1971-80	171	18.8	1135
Ambient air temperature (°C)	1957-77	15.7	-0.6	6.6
Degree days				3700

Table 1 Climate Characteristics for Stockholm

evaluates the economic benefit of the charging system.

The heat pump systems are equipped with meters for energy consumption, operating time, heat delivery and auxiliary heat. In addition, the temperatures in the well and on the brine circuit are recorded. The analysis is based on weekly mean values gathered during 1984. For comparison and further analysis, especially regarding long-term temperature effects, the computer program SBMA/1/ was used.

Climate Characteristics

The heat pump system chosen for this article is installed in a single-family house in Älvsjö, 8 km south of Stockholm, Sweden, at a latitude of 59.15° and a longitude of 18.00°. The long-term climate characterstics for Stockholm are shown in Table 1.

Description of the Installation

The heat pump is produced and delivered by Thermia AB. It has been in operation since November 1983. Its capacity is 12 kW at a condensing temperature of 45°C and a brine temperature of 0°. The air convector has a heat transfer capacity of 400 W/K at normal outdoor conditions with low wind velocities.

The house has a hydronic heating system. Domestic hot water is preheated by the heat pump and finally heated by electric-resistance heat. Electric heat can also be used to heat radiator water on the coldest days of the year. The existing oil-fired boiler has been kept as a back-up for the heat pump, but was not used during 1984. The annual heating requirement is about 42 MWh, or an oil demand of 5.5 - 6 m^3 oil/year. The design peak demand is estimated to be 15 kW.

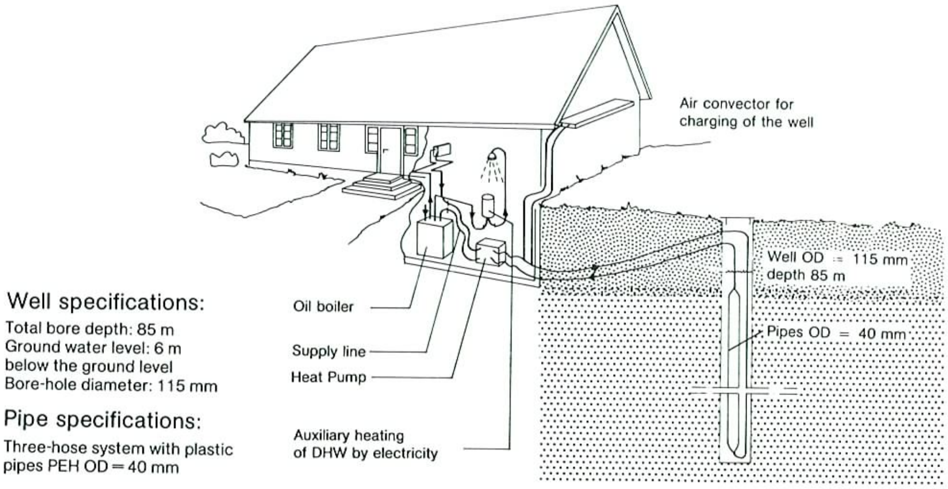


Fig. 1 System Design for a Ground-Coupled Heat Pump with a Charging Device

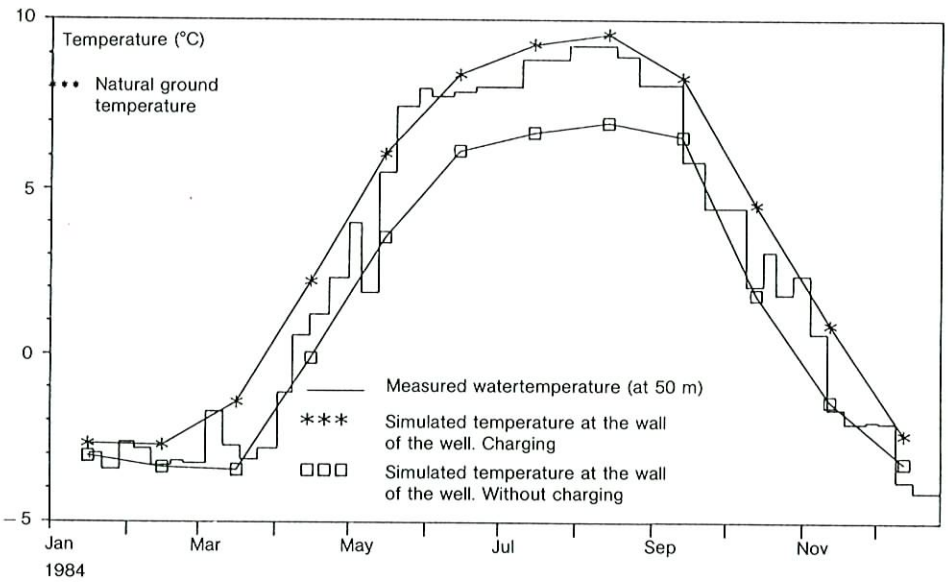


Fig.2 Annual Temperature Distribution of the Well

Results

Recorded temperatures of the well and results from computer simulations are shown in Fig. 2. The computer simulation results are in close agreement with observed temperatures. Results are also shown in Fig. 2 for a simulation of the same system without well charging. As expected, the temperature of the well is lower without charging. The difference is small, especially during the winter period when the heat pump delivers the most energy to the house.

The temperature of the heat source determines the evaporator temperature and, therefore, the coefficient of performance of the heat pump. It is most important to have a high heat-source temperature during the winter period, when the heat delivery from the heat pump is at its peak. The seasonal performance factor is therefore determined by weighting the weekly and monthly mean temperatures (shown in Fig. 2) with the heat-extraction rate from the borehole.

In Table 2, these weighted-annual-mean temperatures are presented for measured values with charging, and for computer-simulation-based values without charging. Long-term temperatures are approximated using values from the fifth year of operation, obtained through computer simulation. The results show that charging increases the temperature of the heat source by 1.5 to 1.9 K. Estimates of performance without charging for 1984 are shown in Table 3, column 2. Operation of the compressor and the main brine pump requires an additional 800 kWh of electricity. The system with charging requires 800 kWh to run the circulation pump for the air convector circuit. Installation of charging equipment results in practically the same system SPF, and no measurable savings on the electricity bill.

	Annual Mean		Annual minimum	
	Charging	No charging	Charging	No charging
Year 1	-1.3°C	-2.8°C	-3.2°C	-4.0°C
Year 2	-2.2°	-4.1°C	-4.5°C	-5.5°C

Table 2 Annual Temperature of the Well

		M	S	S
	Quality:	M	S	S
	Bore depth:	85 m	85 m	95 m
	Charging:	Yes	No	No
Energy delivery from the heat pump to the house QT	(kWh)	355000	35500	35500
Auxiliary energy (electric power)	(kWh)	5000	5000	5000
% of energy supplied by heat pump	(%)	88	88	88
Electric power for the heat pump				
- to the compressor	(kWh)	13600	14300	13800
- to the main brine circuit pump	(kWh)	1000	1100	1050
- to the air convector circuit pump	(kWh)	800	0	0
- Total, ET	(kWh)	15400	15400	14850
Seasonal performance factor SPF (=QT/ET)		2.3	2.3	2.4

Table 3 Thermal Performance for 1984, Measurements (M) and Simulations (S)

Another way to improve system performance is to bore the well deeper. Computer simulations for the Älvsjö system show that an increase in the heat-source temperature, producing the same reduction in compressor electricity consumption as given above, can be reached by extending the borehole 10 meters, from 85 to 95 m. This is less expensive than installing charging equipment, and results in a simpler system design, free from parasitic-pump energy consumption.

Conclusions

The analysis of the effect of solar charging on the performance of a heat pump shows, in general, an increase of less than 2^{o} C in both the annual-mean and the annual-minimum temperature of the heat source. This leads to slightly improved working conditions for the compressor, and a small reduction in its consumption of electricity. Since electric power is needed to operate the pump in the charging device circuit, the savings are substantially reduced. For the installations presented, the savings become negligible.

Computer simulations show that the same improvement in compressor conditions could be acheived by extending the borehole from 85 to 95 meters. With this change, simple system design is maintained and no parasitic pump energy is introduced. For Swedish conditions, extending the bore-hole is generally less expensive than adding charging equipment.

In conclusion, it is more cost-effective to improve a single borehole by boring further, rather than by adding solar-based charging equipment.

Reference

1. Eskilson P. (1985). Superposition Bore-Hole Model (SBMA). Simulation model for oblique or vertical bore-holes. University of Lund, Sweden.

*M. Larsson, L. Spante, Swedish State Power Board Älvkarleby Laboratory 81071 Älvkarleby, Sweden

E. Bollin, J. Schmid, B. Schäfer, Ch. Schmidt, T. Ebih*

New Roof-Absorber Heating Plant with Digital Energy Management

Introduction

In 1981, the electric utility Kraftwerk Laufenburg commissioned the Fraunhofer Institute for Solar Energy Systems (ISE) to design a multivalent heat pump heating plant for a factory in Engen, such that approximately 70% of the required heating energy would be provided through a brine/water heat pump with a roof absorber, or "energy roof".

Automatic monitoring and control of the plant was to be done with a microcomputer that, like an energy management system, controls individual plant components so that maximum energy savings result at a minimum cost. Additionally, single control variables were to be modified and adapted based on operating behavior, building charateristics, and climatic conditions. This system should allow for control modifications at any time, without considerable expenditures during operation.

Since the roof-absorber designs already on the market did not meet the specified requirements, the Fraunhofer Institute (ISE) developed a new absorber element. The following goals for development were emphasized:

- low production cost
- low installation cost
- high load-bearing capability
- high absorber capacity
- good corrosion prevention
- good visual acceptance

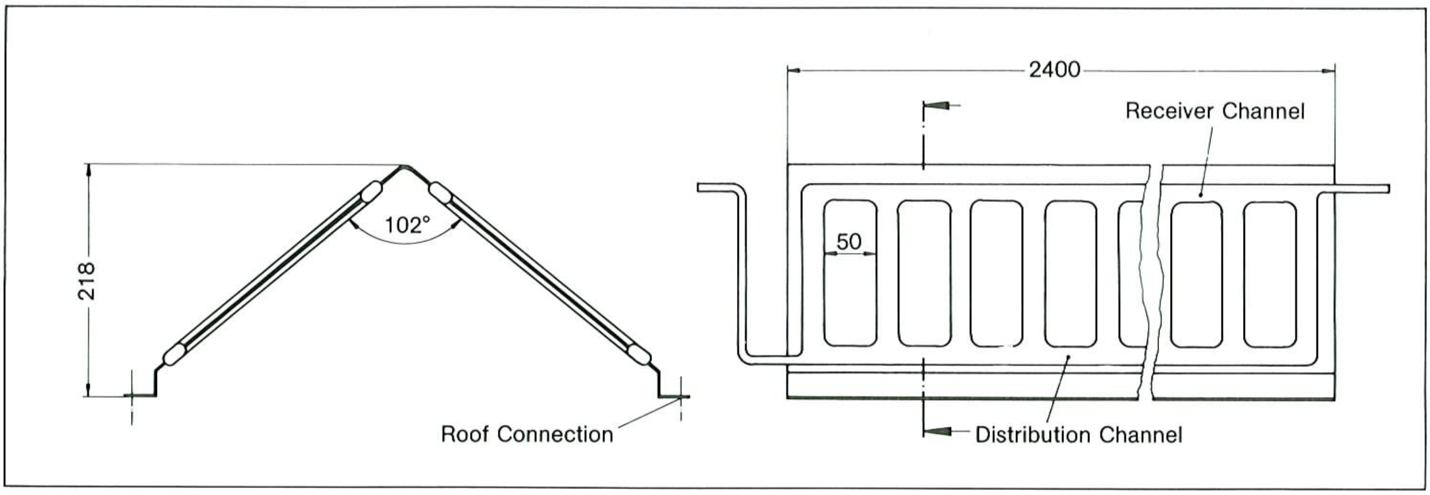


Fig. 1 Cross section and side view of an absorber element

1. The New Roof Absorber Concept

An aluminum absorber element with rear ventilation was developed at the ISE for installation on aluminum industrial roofs. The element is produced using the roll-bond process, already proven successful for producing evaporators for refrigerators. The refrigerant channels are an integral part of the absorber, so optimal heat transfer is important. In Fig. 1, the cross section and the side view of the absorber elements are illustrated. On both parts of the absorber, there are 36 channels that run between the main vertical distribution pipes. The element is bent at an angle of 102°, resulting in a large cross section for rear ventilation. The surface area of the absorber is then 30% larger than the concealed surface area of the roof. The vertical pipes add strength, so that the roof absorber can be subject to surface loads caused by wind and snow.

The element is flexibly attached to the roof with specially designed clamping elements, without a frame. The absorber elements are connected with bolted metal joints. Thermal expansion is compensated for with S-curved connections. Color anodization refines the surface of the aluminum plates. The anodized surface has a relatively high absorption coefficient of 0.7 and effectively protects against corrosion. The absorber can be anodized with many different colors, in order to match the absorber with the outer wall of the building.

Construction costs can be cut in half in comparison with conventional roof absorber construction. The absorber elements have been bench-tested on the roof of the ISE institute. Operation under various climate conditions has been analyzed in long-term tests of resistance and performance characteristics.

Fig. 2 shows the coefficient of heat transfer, α_a, as a function of wind speed for the absorber. A design performance of 120 W/m^2 of absorber surface is acheived for

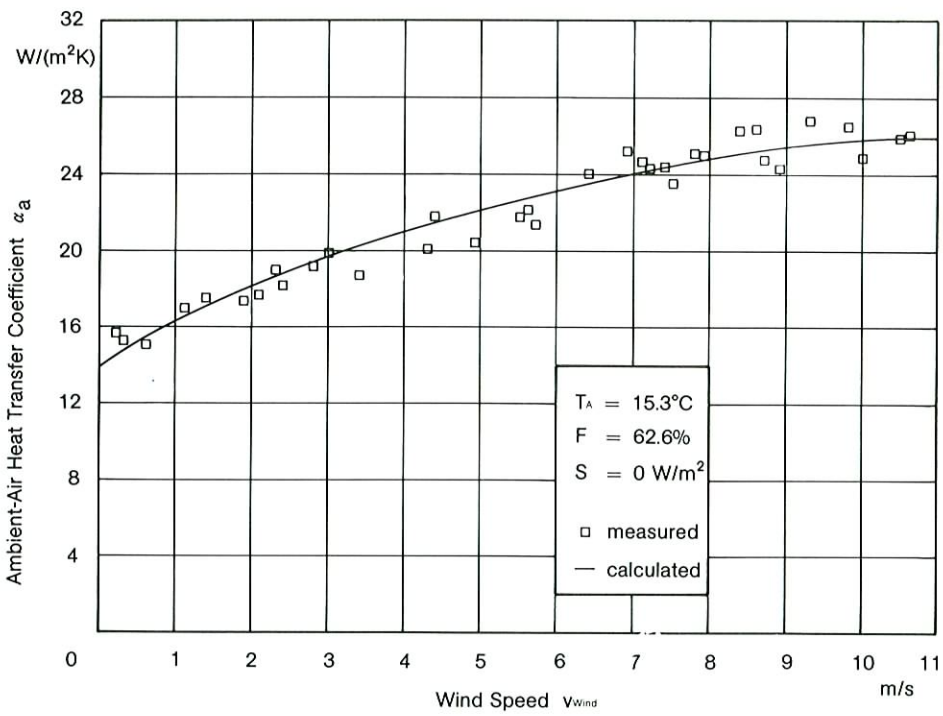


Fig. 2 Outdoor heat transfer coefficient for an absorber element as a function of wind speed

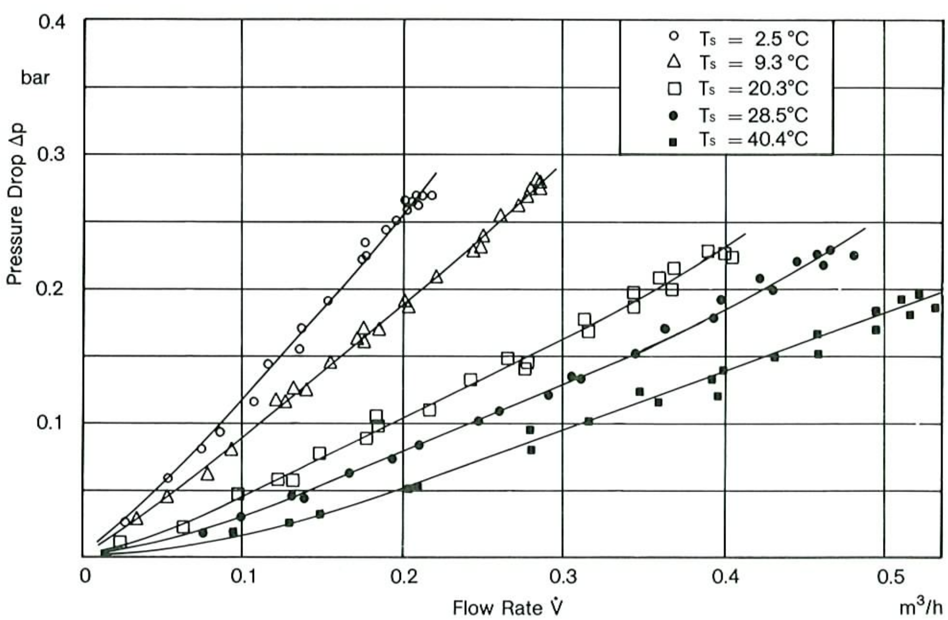


Fig. 3 Pressure drop as a function of brine temperature and brine flow for 3 absorber elements in series

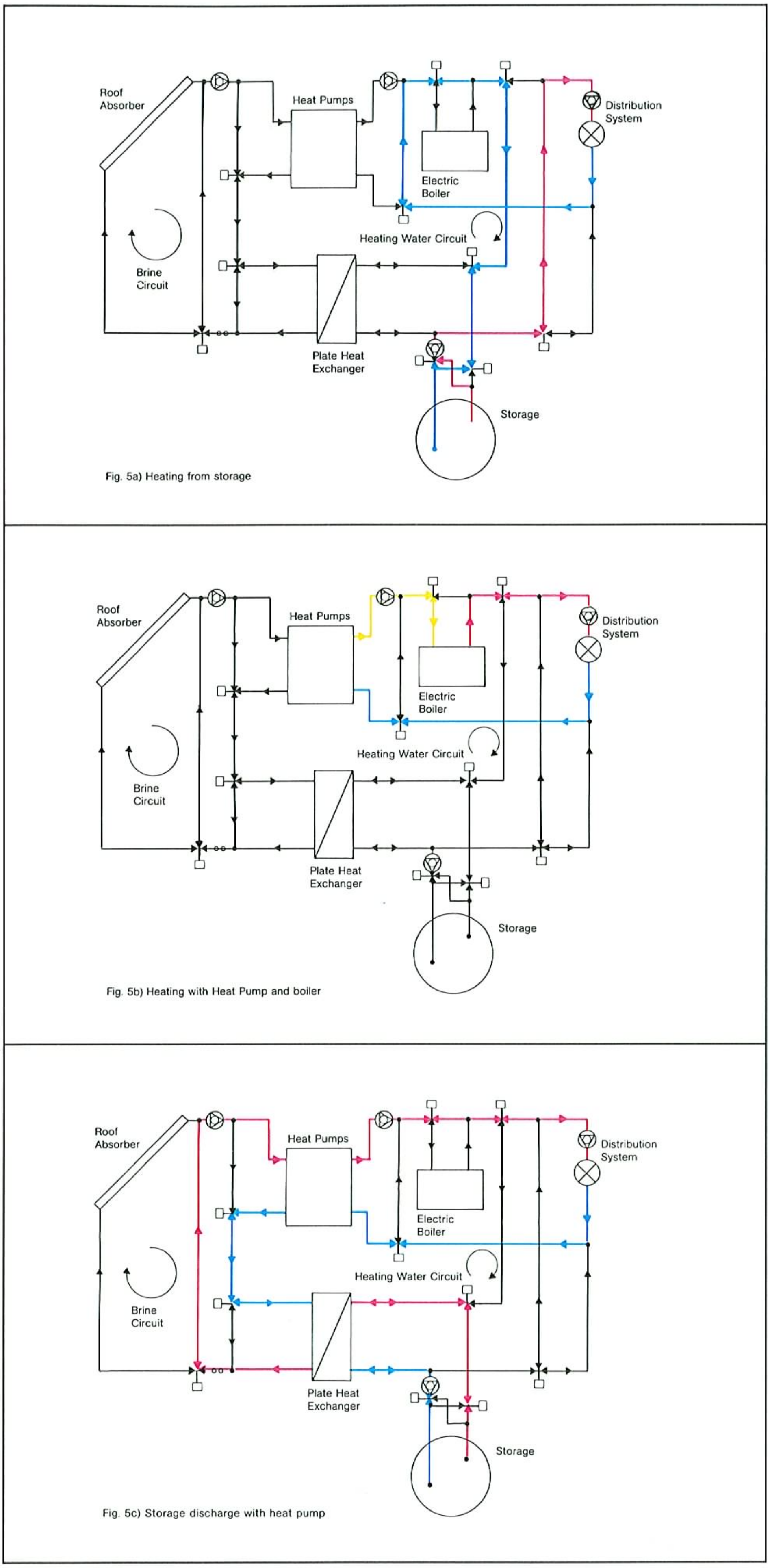


Fig. 5: Three operating modes of the bivalent heating plant: a) heating from storage, b) heating with heat pump and boiler, c) storage discharge with heat pump

the following design conditions:

$\alpha_a = 20 W/m^2 \times K$

Delta $T = T_A - T_{Abs} = 6K$ (average temperature difference between absorber surface and the ambient environment)

Figure 3 shows the pressure loss in the absorber.

2. Description of the Heating Plant in Engen

A bivalent heat pump plant with a roof absorber was designed for two buildings operated by the Kraftwerk Laufenberg utility: a 500 m^2 office building and a 788 m^2 automobile shed and warehouse.

The heating demand of the building is 140 kW. The building housing the automobile shed and warehouse is oriented east-west, with a roof surface inclined by 7^o. The aluminum roof is well suited for roof-absorber installation, and the roof covering will not be damaged. On the roof surface inclined to the south, 300 absorber elements with 500 m^2 of surface area and a design performance of 70 kW were installed. Fig. 4 shows the completed roof-absorber installation. Fig. 5 illustrates simplified flow charts of the system.

The essential components of the plant are:

- Two electric-motor-driven heat pumps with a total heating capacity of 93 kW at a brine inlet of 0^oC and heating supply temperature of 55^oC. Both heat pumps can be operated at 64% of design capacity by means of cylinder unloading.
- An electric boiler with a design capacity of 175 kW, available for meeting peak loads.
- A 25 m^3 water tank for heat storage. It is an underground, cylindrical steel tank with a double-walled design that is thermally insulated with 100 mm PU-foam.
- The heat distribution system can be broken into two parts: office building, and automobile shed and warehouse. In the office building, steel radiators are installed, whereas the shed and warehouse are heated with air heaters. The supply and return temperatures are 75^oC and 55^o, respectively.
- Heat can be directly transferred between brine and water with a plate heat exchanger.

In selecting materials for fittings and pipes, care was taken to prevent contact corrosion in the aluminum absorber elements. The brine system utilizes stainless steel. A compromise had to be made for the heat pump evaporators, which are normally made of copper. At the outlet of the evaporator a superfine filter was installed, in order to prevent the circulation of copper particles out of the heat pump evaporators. The regulation valves were equipped with bellows seals in order to prevent leakage in case of frost on the cold outer surface of the brine system.

Fig. 4 View of the installed roof absorber with a surface of 500 m^2 in Engen

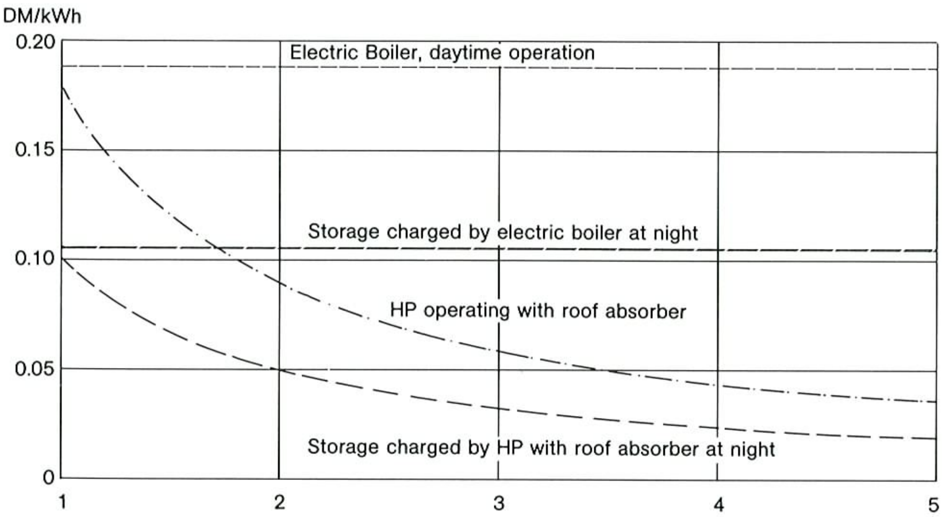


Fig. 6 Heating costs during the day, depending on mode of operation. Prices are DM 0.1789/kWh from 6:00 AM to 10:00 PM (on peak) and DM 0.0958/kWh from 10:00 PM to 6:00 AM (off peak).

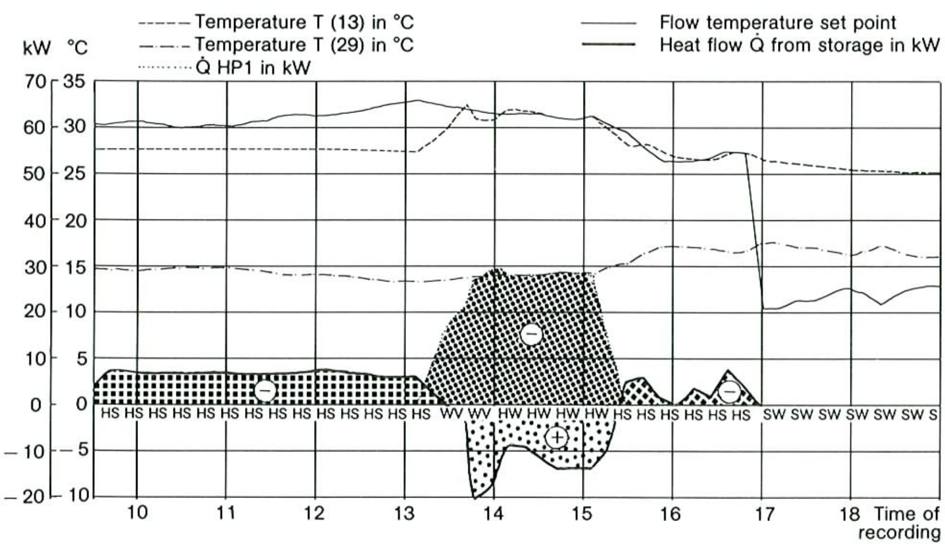


Fig. 7 Energy flows on May 28, 1985, for the 'heating from storage' (HS) and the 'heating with heat pump' (HW) modes (+ = energy input, - = energy output of the heating system), as well as flow temperature (T13) and outdoor temperature (T29).

3. Modes of Operation

Various modes of operation can be set with motorized valves. Some essential modes are illustrated in Fig. 5 a)-c). Charging of the storage with the heat pumps or the electric boiler is preferrably executed at night, when the tariff rate is low. The storage can also be charged by a plate heat exchanger. During heating operation, the 'heating from storage' mode is used if possible (Fig. 5a). If the storage is not sufficient, however, heating is supplied by the heat pump. At times, when the heating demand is high, the electric boiler is operated in addition to the heat pump. The system is then operated in the bivalent-parallel or bivalent-alternative mode (Fig. 5b).

The 'storage discharge with heat pump' mode (Fig. 5c) is a unique feature of this system. This mode is only utilized when, as a result of low outdoor temperatures, no energy supply is available from the absorber, and the storage temperature is below the required flow temperature. Water from storage is directed to the plate heat exchanger and cooled down to + 5°C. Via the brine system, the remaining heat in storage will be utilized for heating purposes through the heat pump cycle.

Heating cost (DM/kWh) is the decisive criterion for selecting the mode of operation. Fig. 6 shows daytime heating costs as a function of heat pump performance or boiler capacity for the various modes of operation. 'Heating from storage' is the most economical mode, where the storage system is charged by the heat pump during the night. Operation of the electric boiler during the day is the most expensive mode. If the storage system is charged at night with the electric boiler, it is more economic to heat directly with the heat pump during the day when heat pump performance is above 1.7.

4. Central Monitoring System

For recording the most important plant data, sensors have been installed and connected to a central monitoring system. Through four multiplex modules with 20 input channels each, data are recorded at intervals of 5-6 minutes and are transmitted to the central computer. Data can be monitored and evaluated, stored on floppy disks and displayed on a screen or printer. The following values are monitored:

- 30 temperatures
- 7 flow rates
- climate data such as wind speed, insolation, relative humidity and outdoor temperature
- system pressures
- all valve positions
- electricity consumption of the heat pumps and the heating system

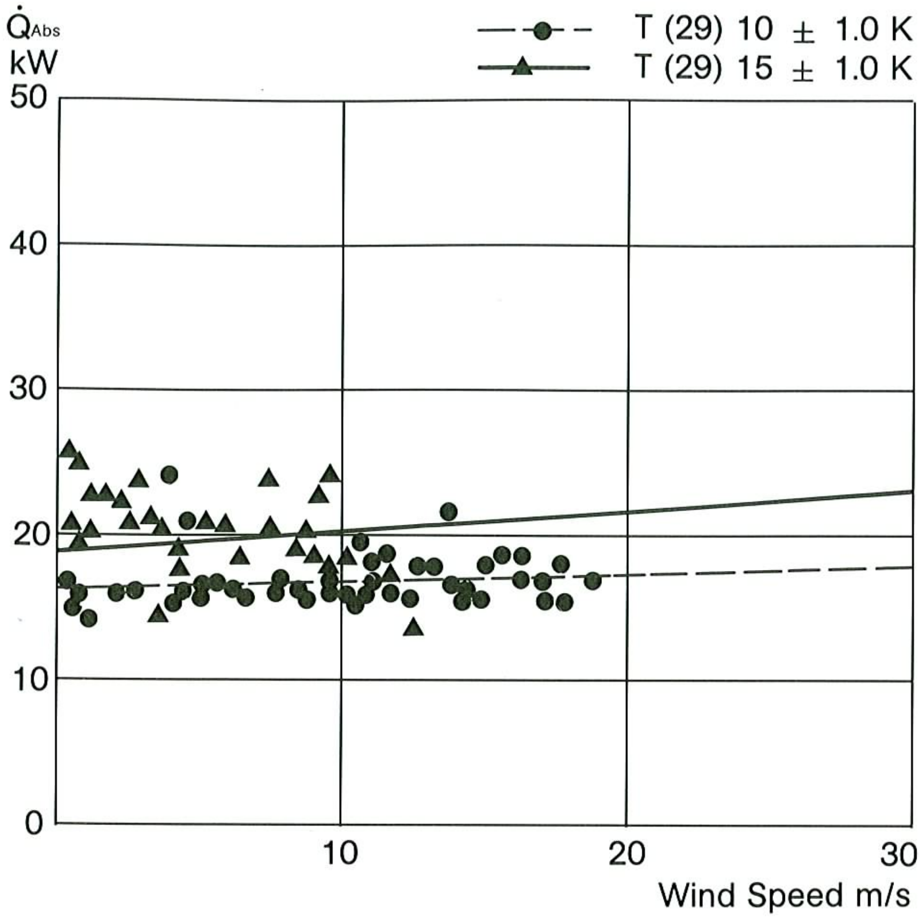


Fig. 8 Influence of wind speed on absorber capacity (ABS) at a constant outdoor temperature (T29)

To determine wind speed and insloation, 40 consecutive measurements are averaged. Analysis software is available for processing data stored on floppy disks. Time trends of temperatures, flow rates, climate conditions and heat flow rates can be illustrated. Heat pump performance characteristics and energy management and control system operations can be monitored.

5. Energy Management

In addition to standard control functions, such as adjusting flow temperatures according to outdoor temperature, the central monitoring system optimizes operation of the heat pump, the heat storage system and the modes of the entire heating system. The mode of operation is dependent upon:

- date and time
- local electricity rates
- outdoor temperature
- brine temperatures

48 relays control equipment directly, using output information from the computer. Between 6 a.m. and 5 p.m., at outdoor temperatures below 20°C, heat is supplied by the storage system, the heat pump or the electric boiler. The storage system itself is

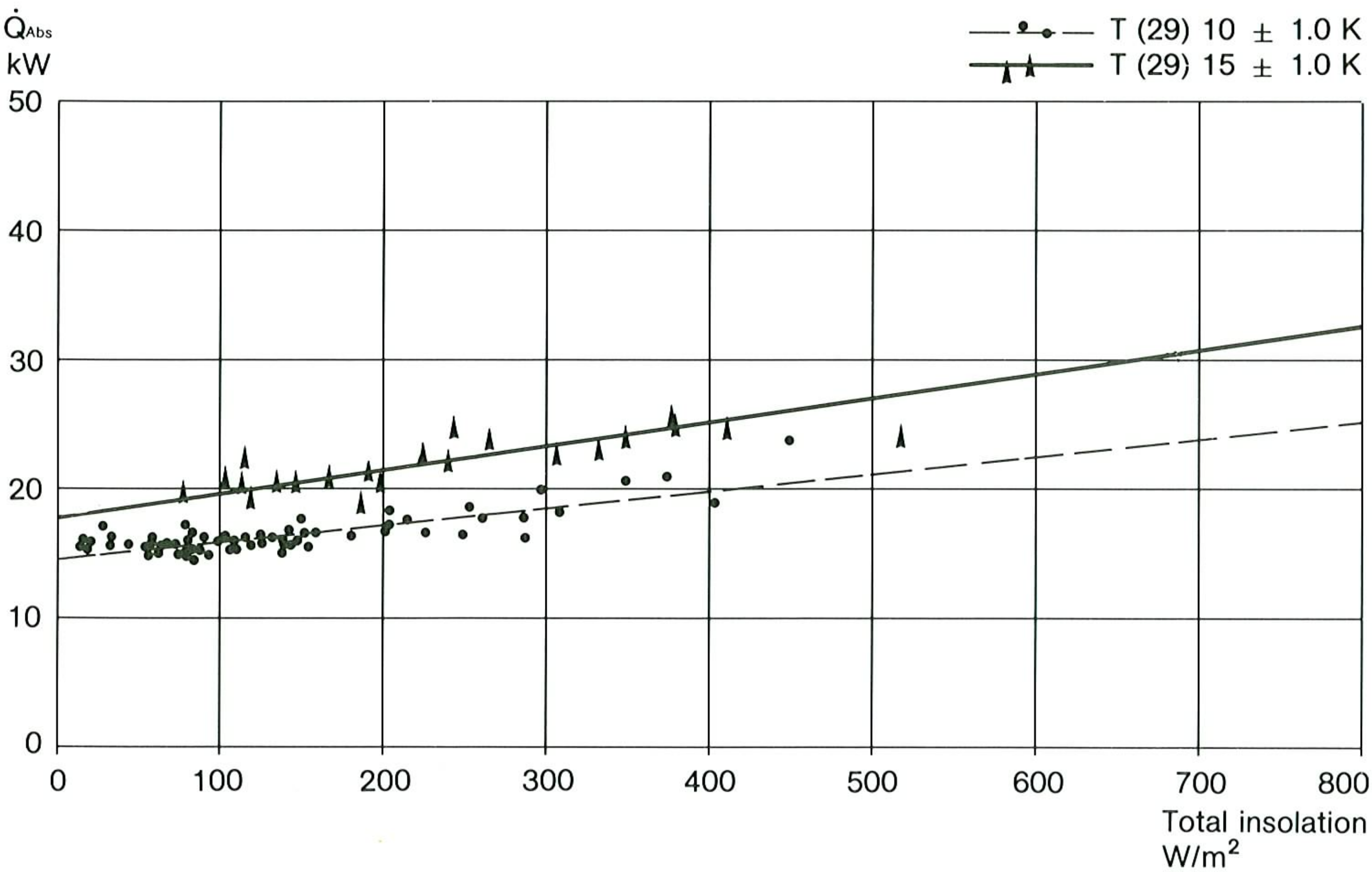


Fig. 10 Influence of insolation on roof absorber capacity (ABS) at a constant outdoor temperature (T29)

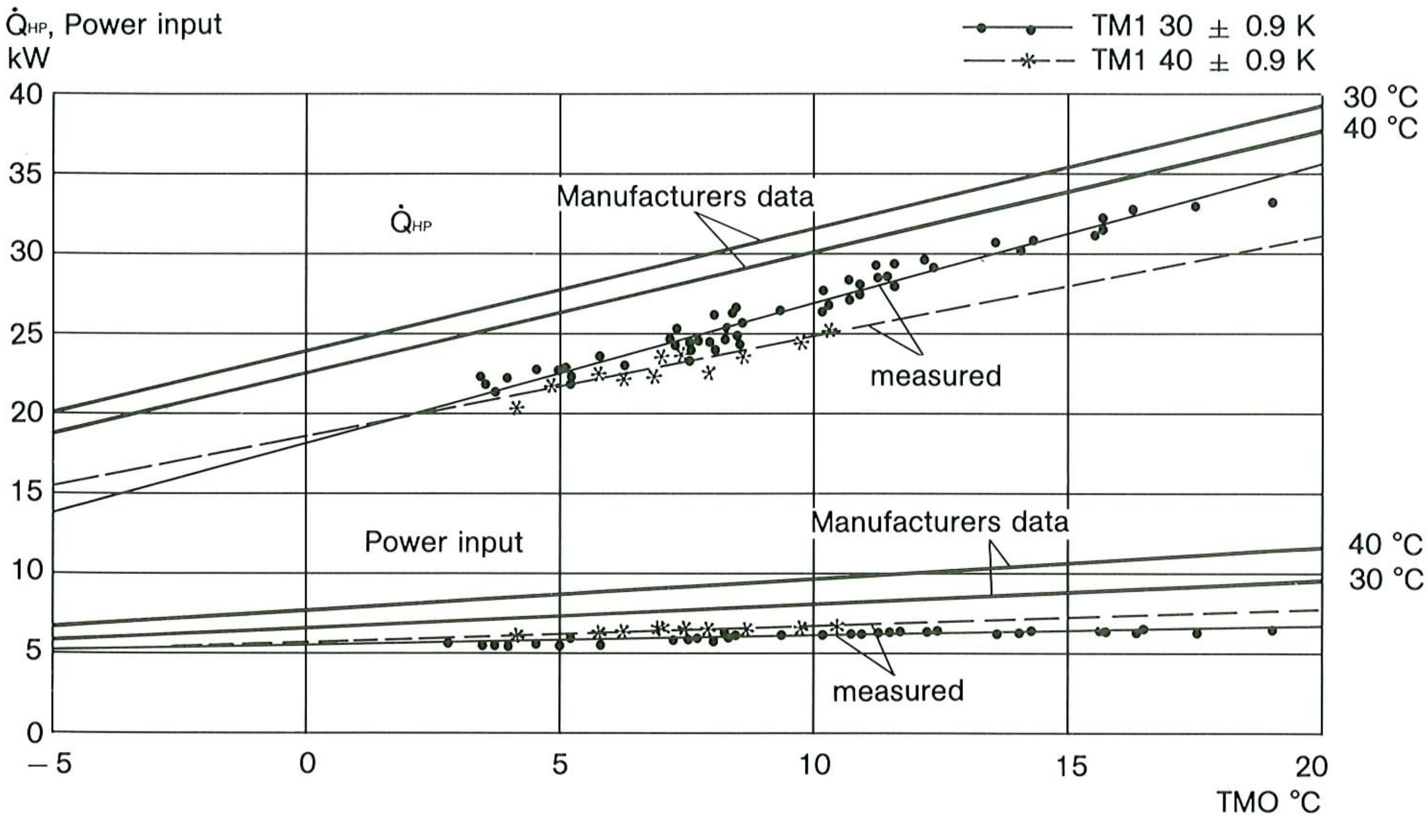


Fig. 11 Heating capacity and power input for the heat pump as a function of average heat source temperature (TM0), measured in May 1985. Manufacturers' data shown for comparison. (TM1 = average water heating temperature)

not charged during the day, unless there is surplus heat from heat pump operation. The storage tank is charged between 10 p.m. and 6 a.m., when electricity rates are lowest. Depending on the outdoor temperature, heating operation is stopped during the night. The computer calculates the optimal stop time for a given outdoor temperature. On weekends and holidays, the heating supply temperature is automatically decreased by 15 K.

During the 'heating with heat pump' mode, heat pump capacity can be automatically adjusted to heating demand with cylinder unloading or by cycling the heat pumps. In this mode, the supply temperature can be adjusted by adding cold water from storage; heat that is not required to meet demand is therefore directed to the storage tank. If the temperature of the storage reaches a given point, the storage system alone will supply heating. Fig. 7 shows the energy flow in each mode of operation.

Charging and discharging of the storage system are controlled by the computer according to minimum cost and maximum energy savings. The temperature of the storage system can be determined at any time by temperature sensors in the heat storage system. The system is generally charged between 10 p.m. and 6 a.m. for economic reasons. The heating demand and supply temperature for the next day are estimated by the computer, based on outdoor temperature and the heat collected in storage for the previous day. Required heat pump operation can be calculated based on the heat content of the storage system. When the supply temperature requirement is above 55°C, the electric boiler is operated in the bivalent-parallel or alternative mode. By comparing the heat that remains in the storage system with the estimated consumption values, the estimated heating requirement for the next day is adjusted by the computer.

6. Operational Experience and First Results

In the fall of 1984, the bivalent heating plant was put into operation.

At first, the plant could only operate with one heat pump, since tests showed that the second heat pump did not meet the manufacturer's specifications (73 kW at 0 °C brine inlet, 55 °C heating supply temperature). The roof absorber was put to the test during the first heating period; even with a snow cover of 10 cm, an absorber capacity of 120 W/m^2 was measured.

Fig. 8 shows the dependence of absorber capacity on wind speed, measured during the heating period of 1984/85. Fig. 9 shows the dependence of absorber capacity on insolation during the same period.

Fig. 10 shows heat pump heating capacity as a function of average heating supply temperature and brine inlet temperature. For comparison to measured data, manufacturers' data are shown in the figure. Both the measured heating capacity values and the measured values for power input are below those given by the manufacturer. Measured heat pump coefficient of performance is identical to that given by the manufacturer.

Fig. 7 shows the supply-temperature control system for different modes of operation. Until 1 p.m. heating is supplied by the storage system. When the actual flow temperature (T13) and the required flow temperature vary by 5 K, the heat pump system starts operation. The temperature of the flow water is controlled by adding colder water from the storage tank and by charging the storage system (from 1.30 p.m. to 3.30 p.m.). From 5 p.m. on, heating operation is stopped.

Further results from this project will appear in an upcoming issue of the HPC Newsletter.

*E. Bollin, J. Schmid, Fraunhofer Institut für Solare Energiesysteme, Freiburg; E. Schäfer, Kraftwerk Laufenburg, Laufenberg; Ch. Schmidt, Fraunhofer Institut für Solare Energiesysteme, Freiburg; T. Ebi, Universität Konstanz

J. Herrmann*

The Second Nordic Heat Pump Days

Initiated by the Energy Ministries of the Scandinavian Countries, the Nordic Building Research Cooperation (NBS) created its Energy Group in 1975. This NBS-Energy Group coordinates several activities, one of which is the Nordic Heat Pump Group, which was founded in 1979. All of the Scandinavian countries (Denmark, Finland, Iceland, Norway, and Sweden) participate in this activity, to exchange experience from R & D projects and to discuss future prospects in the field of heat pump applications. In addition to periodic seminars and expert workshops, the Heat Pump Group schedules the Nordic Heat Pump Days every two years. The first congress of this kind was held in Trondheim, Norway, in 1982.

Under the chairmanship of Sweden, the Second Nordic Heat Pump Days were held in Stockholm, August 12-15, 1985. The congress had been postponed by one year, in order to combine this meeting of heat pump specialists with the Twelfth Nordic Refrigeration Meeting, so that both the heating and the cooling branches could profit from sharing mutual experiences. Both conferences were held at the Royal Institute of Technology, Stockholm, Sweden.

The opening speech was given by the Swedish Energy Minister, Mrs. Birgitta Dahl. She emphasized the importance of energy policy and the improvement of the environment. She singled out the acidification problem as one of the most serious environmental problems today and reminded the audience of the joint initiatives taken by the Nordic countries to reduce acid rain. Referring to the Swedish situation, she noted that discharges of sulphur-dioxide have been reduced by not less than 40% since 1980, and now amount to merely a third of the level they were at in 1970.

Mrs. Dahl identified heat pumps and new energy conservation techniques as the most promising for modern heating and cooling systems, considering their effects on the environment and on the energy picture as a whole. Mrs. Dahl assured the audience that the heat pump will maintain its important role, especially in municipal energy planning. She mentioned that approximately 100,000 heat pumps are in use in Sweden today, compared to some thousand heat pumps a couple of years ago. The considerable reduction in the discharge of sulphur-dioxide has been accompanied by a reduction in energy consumption. Swedish energy consumption has been reduced from 400 TWh/yr ten years ago to 350 TWh/yr today.

After the opening addresses, which were impressively terminated by a presentation of Scandinavian folk songs, the sessions of the two joint meetings began. The program included three sessions on heat pumps and four sessions on refrigeration. The presentations on the first day of the heat pump meeting focused on future prospects for heat pumps in Scandinavian countries. On the second day three presentations focused on technical aspects. The first two of these presentations described experiences with small and large heat pumps and addressed manufacturers. The third session addressed consultants and covered energy planning and economics.

The conference also included excursions to six different heat pump sites, and a visit to the laboratories of the Institute for Mechanical Heat Theory and Refrigeration Technique, where a variety of research in heat pump technology is in progress. An exhibition, given in conjunction with the conference, described current government-supported heat pump activities in the Scandinavian countries, as well as activities at the IEA Heat Pump Center. Additional displays arranged by 16 parties from industry, consulting firms and research institutions described new developments in the heat pump and refrigeration sector. More than 300 participants from utility companies, consulting firms, manufacturing companies, research organizations, and energy ministries were registered for both meetings.

Proceedings of both meetings are available at Svensk Byggtjänst, Box 7853, S-10399 Stockholm, Tel. 08/7305100.

**J. Herrmann, IEA Heat Pump Center, c/o Fachinformationszentrum Energie, Physik, Mathematik GmbH, D-7514 Eggenstein-Leopoldshafen 2*

Heat Pump Study Trip to Japan

Visits to manufacturing facilities and installations of advanced heat pump systems in Japan

A study tour to Japan and Hong Kong from

March 8-21,1986,

is being organized by the 'Promotor Verlag,' Karlsruhe, with technical support from the IEA Heat Pump Center and the Japanese National Team.

Japanese heat pump research projects as well as advanced heat pump applications will be presented. Guided tours will be conducted at Japanese heat pump manufacturing facilities and at heat pump installations.

Participants will have the opportunity to discuss capacity control of refrigeration cycles with Japanese experts, particularly the recent Japanese success with inverter control of electric heat pumps.

Further details can be found in the enclosed brochure (German and Austrian newsletters only).

For registration, please contact the

Promotor Verlag in Karlsruhe directly (Hardtstrasse 26, D-7500 Karlsruhe 21, Tel. 0721-593053).

Schedule of Conferences and Trade Fairs

Dec 3-5, 1985

Cape Canaveral, Florida (USA); Seminar on Principles of Low Energy Building Design in Warm, Humid Climates; Contact: K. Sheinkopf, Florida Solar Energy Center

Jan 19-22, 1986

San Francisco, California (USA); ASHRAE Winter Meeting; Contact: ASHRAE Meeting Dept., 1791 Tullie Cir., NE, Atlanta, GA 30329

Jan 20-22, 1985

San Francisco, California (USA); Western Air Conditioning, Heating, Refrigeration Exposition; Contact: International Exposition Co., 200 Park Ave., New York, NY 10166 (USA), phone 212-986-4232

Mar 5-6, 1986

Los Angeles, California (USA); West Coast Energy Management Congress; Contact: Ms. A. McFarland, Association of Energy Engineers, 4025 Pleasantdale Rd., No. 340, Atlanta, Georgia, 30340 USA

Mar 10-12, 1986

Liege, Belgium; International Meeting on the Rational Use of Energy in Industry; Contact: Association des Ingenieurs Electriciens, 31 rue Saint-Gilles, B-4000 Liege, Belgium

Mar 11-15, 1986

Harumi, Tokyo (Japan); Exhibition of Refrigeration, Air Conditioning, Heating and Solar System Equipment; Contact: The Japan Refrigeration and Air Conditioning Industry Association, Kikai Shinko Bldg. 201, 5-8, Shibakoen 3-chrome, Minato-ku, Tokyo 105 (Japan), phone 03-432-1671, telex 02422222 JRAIA J, telefax 03-438-0308 (Presentation of IEA Heat Pump Center)

April 3, 1986

Bristol (United Kingdom); MIREF '86 - Micros in Refrigeration; Contact: Mr. Peter Fitt, South Western Branch Institute of Refrigeration, c/o Dept. of Mech. Engineering, University of Bristol, Queen's Building, University Walk, Bristol, BS8 1TR (UK)

April 16–17, 1986

Vienna, Austria; Aquatherm 86; Contact: Wiener Internationale Messen, Messeplatz 1, A-1071 Wien

June 23–26, 1986

Rome (Italy); Third International Stirling Engine Conference; Contact: Organizing Secretariat; Gibi studio congessi, Via Marco Basso, 40, 00191 Rome, Italy

Position Available

IEA Heat Pump Center offers a highly qualified person the position of a

Senior Engineer

At least five years experience with heat pump technology, not exclusively research, are expected. Excellent knowledge of English and German is required, as well as the capability to effectively work on the broad range of heat pump development and application tasks undertaken by the IEA Heat Pump Center.

For further information contact Dipl.-Ing. K. Holzapfel, tel. 07247-82 45 41

Written applications to be addressed to Fachinformationszentrum Energie, Physik, Mathematik GmbH, PA/Personalwesen, attn. Mr. Wuest, D-7514 Eggenstein-Leopoldshafen 2

Selected Book and Report Reviews

Proceedings of the CLIMA 2000 World Congress on Heating, Ventilating and Air-Conditioning, P.O. Fanger, Ed., Vol. 7: Summaries and Author Index, VVS Kongres - VVS Messe, Copenhagen, 1985, ISBN 87-88854-07-8 (in English, German, and French)

Volume 7 of the proceedings of the 1985 CLIMA 2000 conference contains abstracts in English, German and French for all of the papers that were presented, over 400 papers from 40 nations. The conference, held 25-30 August, 1985, in Copenhagen, was the first World Congress on Heating, Ventilating, and Air-Conditioning. The conference was sponsored by the Representatives of European Heating and Ventilating Associations (REHVA), the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE), the International Council for Building Research, Studies and Documentation (CIB), and the International Institute for Refrigeration (IIR).

The abstracts in the volume cover six broad topic areas: future perspectives, building design and performance, energy management, indoor climate, solar energy (active and passive systems), and heating, ventilating and air-conditioning systems (see review below). Under each of these topics, papers were presented on modelling and simulation techniques and results, thermal comfort, performance monitoring and measurement, actual operating experience, and environmental effects. Residential and commercial building applications are the primary emphasis.

The first six volumes of the proceedings include the text of each paper in its original language (English, French, or German). Each volume is available from: VVA Kongres-VVS Messe ApS, Ordrup Jagtvej 42 B, DK-2920 Charlottenlund, Denmark. Price: DKK 220 per volume.

Proceedings of the CLIMA 2000 World Congress on Heating, Ventilating and Air-Conditioning, P.O. Fanger, Ed., Vol. 6: Heating, ventilating and air-conditoning systems. VVS Kongres - VVS Messe, Copenhagen, 1985, ISBN 87-88854-05-1 (each paper in English, German, or French)

Volume 6 of the 1985 CLIMA 2000 conference includes papers on the following topics: combustion and boilers, heat pumps, ventilating and air-conditioning systems, heating systems and district heating, HVAC equipment, HVAC operation, maintenance and measuring techniques, HVAC systems simulation, and thermal storage. 22 papers are included on heat pumps.

The heat pump papers include results of theoretical, experimental, and operational studies. Most of the papers deal with residential heat pump applications. Some examples are: a United States demonstration project of a ground-source heat pump with an SPF of 2.5 - 3, an optimization study for heat pump defrosting control strategies that shows defrost on demand to be the most energy efficient, and a review of absorption heat pump control requirements that concludes that microcomputer controls can be cost effective.

Results of performance tests are presented for three heat pump water heaters, several U.S. residential air-source heat pumps (SPF range 1.79-3.32), and 33 Swedish heat pumps installed in single-family houses (SPF range 2.0-2.6).

Other heat pump papers included in the volume deal with multi-family, commercial, and district-heating applications, simulations of heat pump dynamics at part-load and during cycling, and developments in absorption heat pump technology.

See review above for ordering information.

In our next issue you will find contributions to the following topics:

1. Development of a High-Temperature Heat Pump
2. A New Approach for Utility Support of Electric Heat Pumps in Germany
3. Dimensioning of Large Exhaust-Air Heat Pumps
4. Research on Residential Air-Source Heat Pump Dynamic Losses
5. Selected Book and Report Reviews
6. Schedule of Conferences and Trade Fairs

IEA Heat Pumpt Center Newsletter
(ISSN 0724-7028)

Edited by: IEA Heat Pump Center
c/o Fachinformationszentrum
Energie, Physik, Mathematik GmbH
D-7514 Eggenstein-Leopoldshafen 2
Telephone: (0 72 47) 82-45 41
Telex: 7 82 64 87 fize d

Published quarterly
Annual Subscription DM 12,- ($ 5,-)
including postage
(V.A.T. not included).
Free of charge for subscribers from HPC Member Countries

Produced in Germany by
werbe-studio Achim Hohmann,
Bonn 2, Annaberger Straße 113.