

NEWS LETTER

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Exhibition of the IEA Heat Pump Center at ISH '85 in Frankfurt (see also page 21)

Editorial by K. Holzapfel*

Competitiveness of Electric Heat Pumps in Heating-Only Markets

A look at the market trend for heat pumps in Central Europe shows that a breakthrough has not yet been achieved, in spite of all the effort, research, and promotion funds provided. This is especially true for electric heat pumps used in small single and two-family houses. In these applications there is only a demand for heating, in contrast to the major heat pump countries, the U.S.A. and Japan, where both heating and cooling are required.

The reasons for the unsatisfactory market situation vary from country to country. The situation in Sweden, for example, is quite positive when compared with West Germany or Austria. There is a combination of several factors in Sweden that leads to an expansion of heat pump use. Low electricity prices combined with strict regulations governing the use of furnaces and, in

addition, the promotion of heat pumps by the government create favorable pre-conditions for their utilization.

In France, the strong influence of the state-owned electric utility on the price and performance of heat pump systems, together with extensive advertising measures, led to a considerable number of sales. However, sales fluctuate following the intensity of advertising activities, as indicated by the reduction in both advertising and sales during the past year.

In principle, a potentially large market exists in West Germany and Austria. However, after experiencing an upswing until 1981, the sales for heating-only heat pumps have steadily dropped. A major reason for this situation lies in the fact that a large number of heat pump systems in-

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stalled before 1981 could not fulfill the stringent demands placed on them. This refers to reliability, performance, maintenance, and high profitability expectations.

The high purchasing costs alone prevent consumers from further examining the profitability of this technology and often prevent its use. In new constructions, the problem is having to finance an additional investment of DM 10,000-15,000, which represents a 50-100% increase in the first cost compared with a conventional system. In an existing building, use of this technology is often postponed while a series of other retrofit measures for the heating system are given preferential treatment; the only reason is that they require a smaller investment. The rising sales of heat pumps for hot water supply are an indication of this behavior, as their purchasing and installation costs are less than DM 5,000 in most cases but their profitability is generally worse than for space-heating heat pumps.

Independent of an improvement in the profitability of heat pumps (a payback period of less than five years should be achieved), the high capital requirement of such an investment must be reduced significantly in order to increase the acceptance of this technology in the residential sector.

Manufacturers made progress in this direction by offering packaged systems, including circulating pumps, control equipment, etc. This resulted in a simple and time-saving installation. Further, these packaged units can be combined in one casing in a variety of ways with other system components such as buffer storage tank, peak-load furnace, and tap-water storage tank (see the report on the ISH 1985, page 21). These are significant improvements, which required a considerable investment by the manufacturers. With the presently poor market situation, the manufacturers are not receiving a suitable return from their investment, thus further substantial expenditures for heat pump developments can not be expected from them. Mass production, as found in the U.S.A. and Japan, results in lower prices, but such a development will require at best some time in Central Europe.

In West Germany, further cost reductions could be achieved if the requirement for separate electric power meters could be eliminated while maintaining existing rate incentives for heat pumps. Especially in retrofit situations, the installation of a separate electric power meter for the heat pump very often involves substantial cost. Therefore, electric utilities in cooperation with the Ministry of Economics could contribute to significant reductions in installation cost by introducing this simplification.

Finally, there is the question of government support for heat pumps. How far could this support be extended consider-

ing the undisputed advantages to society from the use of heat pumps, including:

- a) the significant reduction of air pollution in residential areas, and
- b) the attainment of economic benefits from oil substitution and an increase in

employment due to the replacement of energy consumption with labor intensive investment.

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

W. Lorch*
New Environmentally-Safe Heating Systems with Heat Pumps

For an incremental first cost of DM 5,000.-, a heat pump heating system for a newly-constructed one-family house can be installed today instead of a conventional oil boiler system. It produces no environmentally harmful emissions and yields an annual energy cost saving of DM 600.- to 900.- and, in addition, a tax reduction of

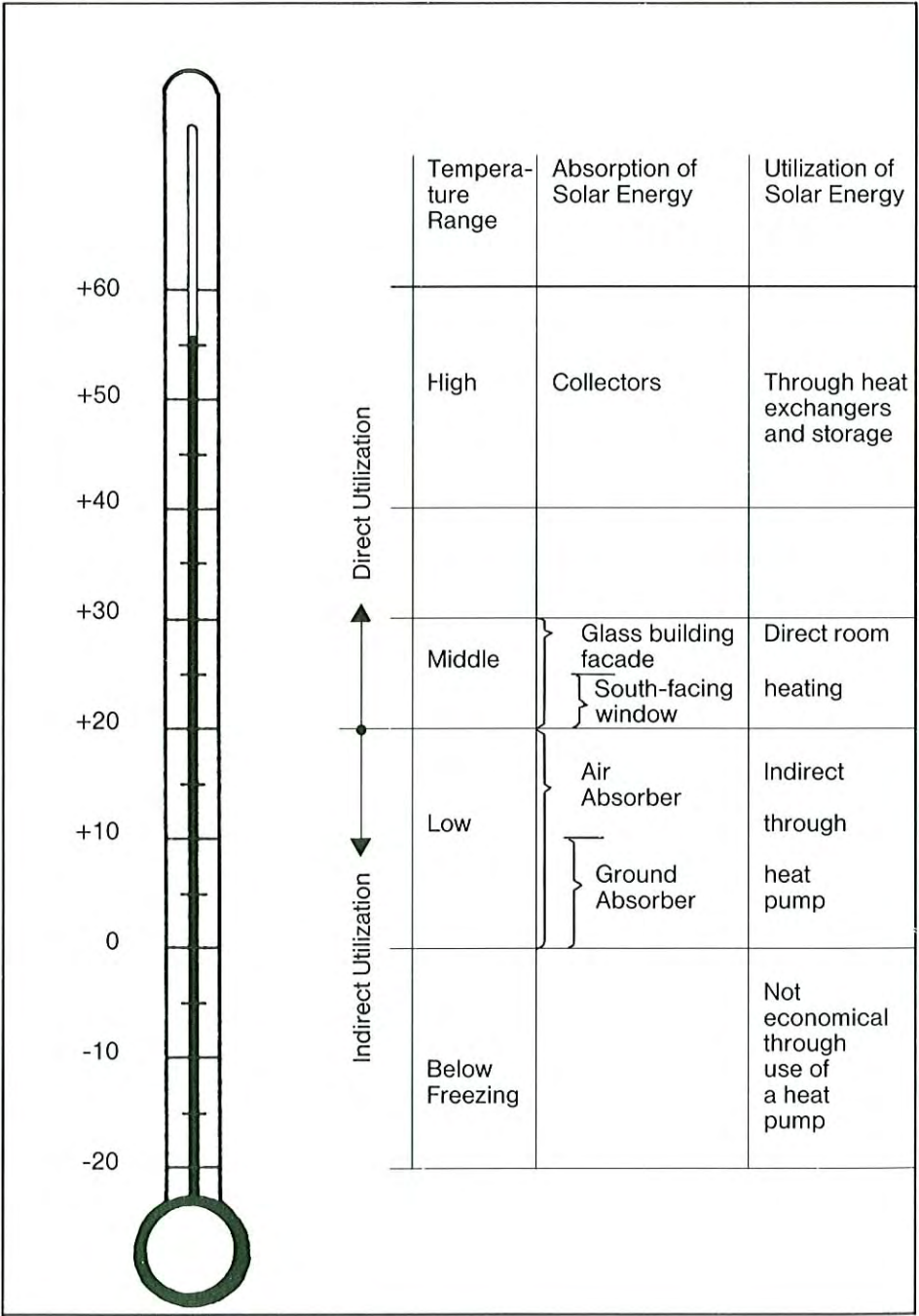


Fig. 1 Direct and Indirect Utilization of Solar Energy

DM 500.- to 800.- per year for 10 years.

The experience of previous years shows that if the additional investment substantially exceeds DM 5,000.-, building owners and architects are not willing to accept new technologies for residential heating, despite the obvious advantages of solar and heat pump technology. Up to now, it was rarely possible to install a heat pump heating system within this cost constraint. However, new developments combined with practical experience are pointing to new possibilities. The objective of this report is to describe the design and costs of such heat pump systems for one- and two-family houses.

Solar Energy Utilization

Fig. 1 shows the possibilities for the utilization of solar energy for low temperature applications. Direct utilization depends on sufficient solar radiation. However, there is still an extremely large amount of solar energy stored in the atmosphere and the ground at temperatures between 0-20 °C, and this source is also available during the winter months and can be used by everyone. The electrically driven heat pump is a good means for utilizing this energy source for one- and two-family houses. Its working efficiency triples the driving power put into it. Due to the good thermal insulation of buildings required by the energy conservation regulations, a relatively small heating capacity is required for new buildings. This results in uncomplicated systems and small heat pumps. Therefore a small and inexpensive heat pump can cover 60-100% of the yearly heat demand, thus reducing or eliminating the need for fuel oil.

Environmentally-Safe Heating Systems

One important requirement for preserving a healthy environment is a change in the techniques of residential heating. Approximately 50% of the dwellings in West Germany are heated with fuel oil. The combustion of 1 liter of light fuel oil emits an average of 12.5 m³ exhaust gas into the environment. With a fuel sulfur content of 0.3 percent by weight, a sulfur dioxide (SO₂) emission of 6.5 grams results. A sulfur dioxide concentration in the air of 0.0005 gr/m³ is harmful to vegetation and human beings. In order to dilute the exhaust gases to a level below this limit, roughly 13,000 m³ of air are required for each liter of light fuel oil burned (Source: ASSA, Wien).

By the combustion of fuel oil, gas, and coal in 1982, households in West Germany shared the total pollutant emissions as follows:

carbon monoxide:	21 %
NO _x :	3,7%
sulfur dioxide:	9,3%
dust:	9,2%
organic compounds:	12 %

These emissions have to be weighted by a factor of 7 compared to industrial emissions and by a factor of 14 compared to power plant emissions because of their proximity to the ground and the resultant direct impact on our living environment. (Source: Peter Wagenknecht, Umweltbundesamt; Vortrag on Sept. 14, 1984, on the BAUTEC in Berlin).

Economic Impacts

Heat pump systems have two major economic impacts. As a result of a decrease in oil imports, the foreign exchange outflow will also decrease and improve our trade balance. In addition, use of this technology yields approximately a 50% energy cost savings. Because of the rapid rise of energy prices in the last ten years, heating costs have consumed an increasing fraction of the private sector's income. Using the present possibilities to reduce heating costs, new funds will be made available. These funds can be used for further investment or consumption, thereby stimulating the economy.

Technical Possibilities

With regards to technical aspects, the many years of experience, which have brought about important findings for the planning and design of plants, can now be utilized. Moreover, new ideas and equipment have appeared in the last two years which simplify the construction of a heat pump heating system. These systems have thus become more reliable, uncomplicated and inexpensive, and are easy to install.

In comparison to a conventional heating system, only DM 3,000.- to 5,000.- of additional first cost is required for a single-family house. These costs are quickly recovered by savings in energy costs and tax reductions.

Objectives of a Modern Residential Heating System

The objectives for residential heating systems today have been redefined and can be satisfied by a heat pump system.

Environmental

- Preservation of a viable environment by reducing the combustion of fossil fuels in the residential sector.

Economic

- Reduction of oil import costs.
- Reduction of heating costs, which result in an increase of private purchasing power.
- Investments in new plants (stimulating the economy).

Technical

- Simple technology enabling every installer to apply standardized system designs.
- Relatively low first costs for new construction and retrofit of existing heating systems.

Therefore, to effect a large-scale improvement for the environment and economy, a heat pump system should be installed in every new building instead of a conventional fuel heating system.

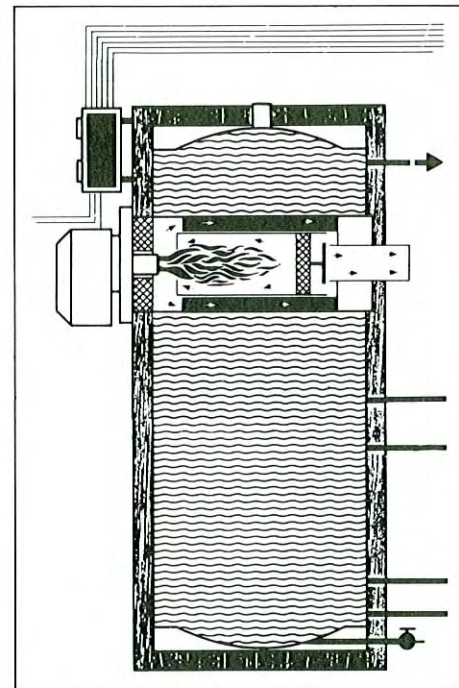


Fig. 2 Combination Buffer Storage + Boiler. (Manufacturer: Carl Capito GmbH, D-5908 Neunkirchen)

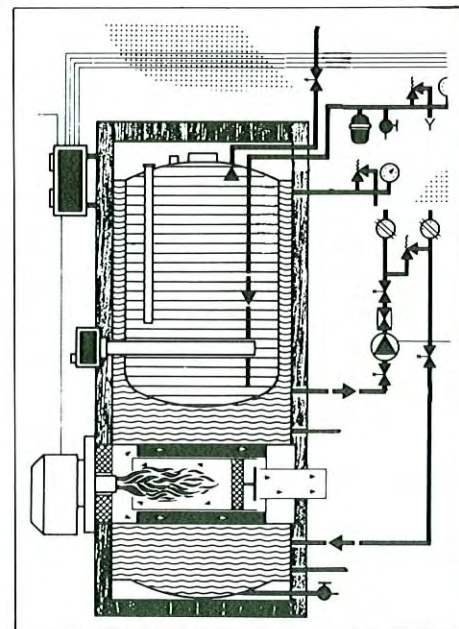


Fig. 3 Three-fold Combination, Buffer Storage + Hot-Water Tank + Boiler. (Manufacturer: Carl Capito GmbH, Neunkirchen)

New heating technologies can only have a noticeable effect on the economy and environment if they are used in large numbers.

New Technologies

The new technologies, several typical installations, and system costs for one-and two-family dwellings will now be described. One way to reduce system costs, energy losses, and equipment space requirements is to combine two or three major components in one packaged unit.

1. Combination Buffer Storage + Boiler (Fig. 2). The combustion chamber was placed directly into the buffer storage. This eliminates the circulation pump and associated controls. This configuration represents a boiler with a large water volume, in some ways similar to earlier boilers, but avoids their disadvantages because of altered operating conditions, for example low water temperature, and a good thermal insulation. This buffer-boiler combination can be combined with any type of heat pump.

2. Combination Buffer Storage + Hot-Water Storage. Several manufacturers are producing so-called 'multi-storages' in which the hot-water storage is placed in the upper part of the buffer storage. There is direct heat transfer so that all respective pipe connections and the pump can be omitted (as in diagram 3, without the boiler part). The heat pump and boiler are connected to the buffer storage by pipes and pumps. Any heat pump on the market can be used with this configuration.

3. Threefold-Combination (Fig. 3). In this case, a buffer storage, hot-water storage and boiler are combined into one single unit. This reduces equipment space requirements and substantially reduces heat losses.

4. Combination Boiler + Heat Pump (Fig. 4). One manufacturer chose this combination in order to combine both heat generators in one casing. Thus, only one piping circuit to the buffer storage is necessary.

5. Combination Heat Pump + Buffer Storage. In addition to the combinations already mentioned, some manufacturers have gone one step further by also placing the heat pump condenser in the buffer storage. This eliminates the water circulation loop between the heat pump and the buffer storage. This configuration with direct heat transfer from the condenser to the storage water is not new but is now receiving substantial attention.

6. Split-Heat Pump with a Passive Evaporator (Fig. 5). The noise from air source heat pumps installed outdoors or from the evaporator fan of split systems is often quite disturbing, even when it complies with noise regulations. A system utilizing a large surface evaporator has been developed to eliminate the evaporator fan.

7. New Anti-Freeze Agents. All heat pumps employing a heat-transfer loop between the heat source and evaporator require a heat-transfer fluid that does not

freeze at the operating conditions, which are often below 0 °C. Presently, a water-glycol mixture is most frequently used but has poor heat transfer characteristics and

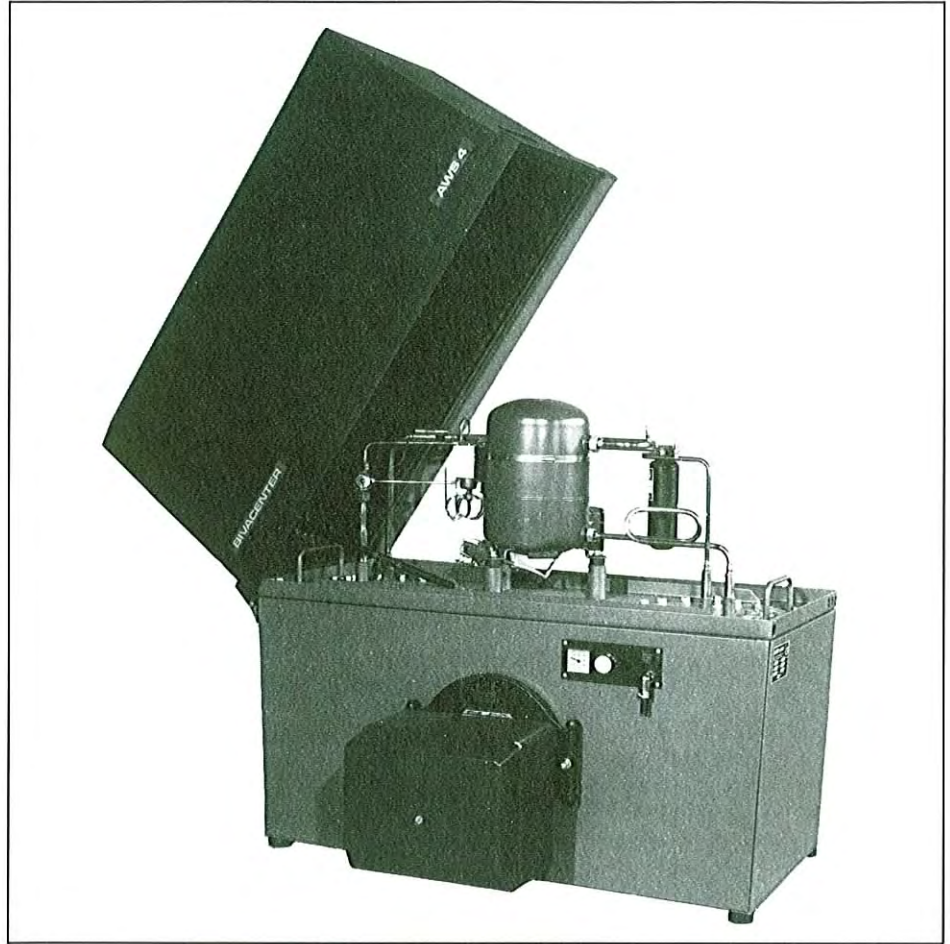


Fig. 4 Combination Boiler + Heat Pump. (Manufacturer: AL-KO Polar, D-8876 Jettingen-Scheppach)

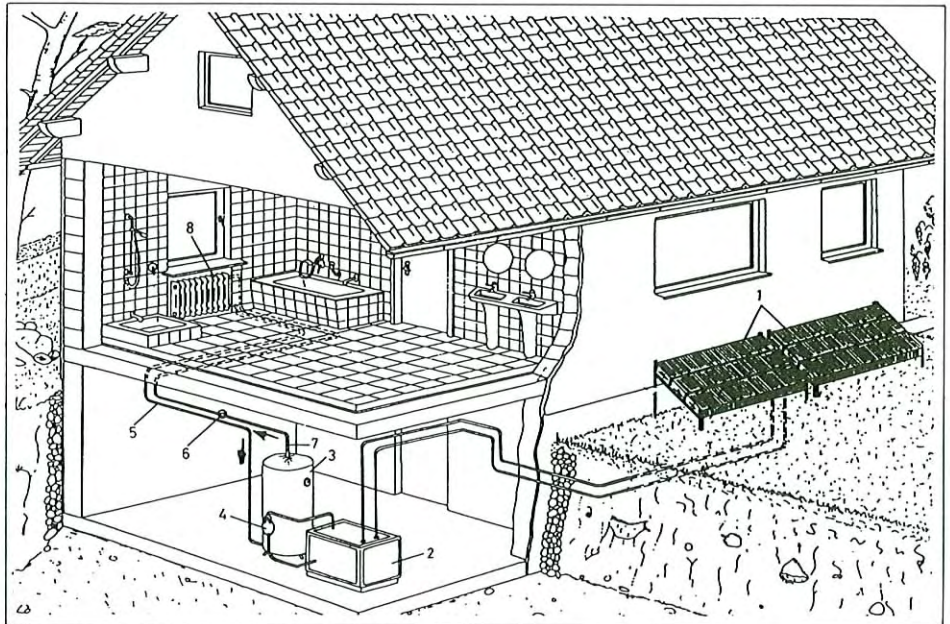


Fig. 5 Split heat pump system with a "silent" evaporator and the condenser installed in the buffer storage. (Manufacturer: OKD, D-7951 Erlenmoos)

- | | |
|--------------------------------|---------------------|
| 1) Evaporator | 5) Return line |
| 2) Heat pump (compressor part) | 6) Circulation pump |
| 3) Buffer storage | 7) Flow line |
| 4) Condenser | 8) Radiator |

⇒ Table 1 Initial costs for a bivalent, air-source, split heat pump system with a three-fold combination of buffer storage + hot-water tank + boiler. The heat pump operates down to +5 °C and supplies 60% of the annual heating load. (costs in DM)

significantly increased viscosity at low temperatures. These characteristics require a high pumping capacity and large heat exchangers. There are other known agents that do not have these unfavorable properties at low temperatures, but which have only been applied in a few cases up to now.

8. New Findings for Ground Coils. A very favorable system for monovalent operation is the ground-source heat pump. The ground coil in which the brine flows absorbs the required ambient heat for the heat pump even in the coldest months. The design of ground coils differed in the past with respect to the depth of the pipes, the pipe diameter and its spacing. The accumulation of experience from many installations has gradually optimized the design and produced satisfying results.

- Plastic pipe made of PE for a price of about DM 1.00/m
- Pipe diameter: 20-25 mm
- Length of one pipe loop: 80-100 m
- Pipe spacing is 15-20 cm. This close spacing results in a more intensive heat exchange with the ground.
- Pipe depth is 1.0 - 1.5 m.
- Previously, a frequently used 'rule of thumb' required a ground surface area that was three times as large as the heated floor area. Today this factor is reduced to 1-1.5. This is because the heat requirement for new buildings is considerably reduced as a result of better insulation. We also know from previous experience that the ground can be used more intensively.

9. Absorber in the Ditch (Fig. 6). An absorber in the ditch can be inserted if no adequate ground area is available for a con-

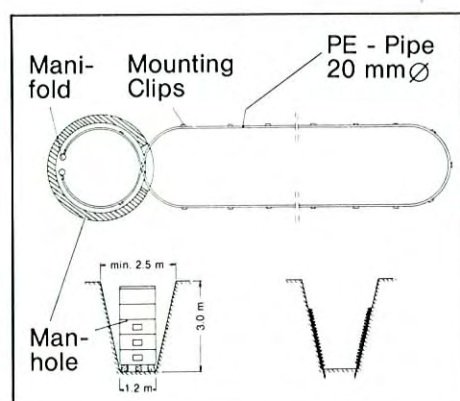


Fig. 6 Ditch Absorber. Pipes placed on both sides of a 3 meter deep ditch. (Manufacturer: OKD, D-7951 Erlenmoos)

		Row House 9 kW htg. load	One-Family House 14 kW htg. load	Two-Family House 20 kW htg. load
1.1	Air-Source Heat Pump Capito	HWP 6 Sp-LW 5.5 kW(L5/W45) 6,470	HWP 8 Sp-LW 6.3 kW(L5/W45) 6,905	HWP 10 Sp-LW 7,275
1.2	Ductwork for Indoor Installations	---	---	---
1.3	Refrigerant Piping for Split Installation	10 m double-piping with insulation 580 580 580		
2.1	Brine-to-water Heat Pump	---	---	---
2.2	Air-Absorber with Installation	---	---	---
2.3	Ground-Absorber and Excavation Work	---	---	---
2.4	Anti-Freeze	---	---	---
2.5	Piping connecting Absorber and Heat Pump	---	---	---
3.1	Starting-current Limiter	not required	not required	INT 330 980
3.2	Piping-connecting Heat Pump and Buffer Storage	not required – heat pump and buffer storage are one unit		
4.1	Combination Buffer Storage + Boiler ("Super-Arkis")	MA 200/14 3,629	MA 200/14 3,629	MA 300/20 4,193
4.2	Flue and Hydronic* Equipement	500	500	500
5.0	Oil Preheater and Burner	1,150	1,150	1,150
6.0	Controls Outside temp. dependant 203 S	1,570	1,570	1,570
7.0	Oil Storage Tank and Accessories installed in the Basement	1,000 l 1,500	1,000 l 1,500	1,500 l 1,700
8.0	Electric Water Heater, 300 l	included in "Super-Arkis"		
9.0	Motorized Mixing Valve with Electrical Connections	700	700	700
10.0	Installation	1,500	1,500	1,500
	TOTAL	17,599	18,034	20,148

*-including guages, circulating pump, and expansion tank

⇒ Table 2 Initial costs for a bivalent, air-source, basement-installed heat pump system with a combination buffer storage + boiler. The heat pump operates down to 0°C and supplies 80% of the annual heating load. (costs in DM)

ventional horizontal ground coil. The ditch has slanted sides and is typically 3 meters deep. Pipes in holding devices are placed on both sides with a separation distance of only 5 - 10 cm. A ditch length of 25 m is sufficient for a house with 160 m² of heated floor area, if the thermal insulation complies with the energy conservation law. For such a ditch a surface area of only 0.4 times the heated floor area is necessary. This area is in general available even in the case of row-houses. This results in lower costs for ground moving compared to a conventional collector.

Heating Systems

1. Control Systems

In 'low-temperature heating systems' the flow temperature varies within narrow limits. This temperature is between 35-50 °C for floor heating systems and between 40-55 °C for radiator heating systems. A simple automatic control system should be used to adjust the flow temperature to the required level.

The following control systems are used for household heating, and work independently of one another.

- For radiator heating, the individual room temperatures are regulated by radiator thermostats. In floor heating systems, thermal sensors placed in the floor slab have proven to be effective for controlling individual heating circuits. This control strategy partially compensates for the time lag of a floor heating system because temperature changes are detected more quickly than with room thermostats.
- The heat losses of modern buildings are relatively small due to good thermal insulation. Therefore, the control strategy can be changed from a flow temperature reduction to a complete shut-down of the heating system during nighttime periods.

Furthermore, this shut-down period for a floor heating system can be shifted from the nighttime period because of the long response time of such a system having a large thermal storage capacity. Therefore, the floor can be heated during the night when electricity prices are low, and this heat is then slowly released during the following day.

- In general, the flow temperature is controlled in accordance to the outdoor temperature by switching the heat pump on and off to maintain the required temperature. If the thermal mass of the heating system is too small, a buffer storage is used to reduce frequent cycling.

		Row House 9 kW htg. load	One-Family House 14 kW htg. load	Two-Family House 20 kW htg. load
1.1	Air-Source Heat Pump Stiebel-Eltron	WPL 8 ki (5 kW) 7,720	WPL 10 ki (7,5 kW) 8,140	
1.2	Ductwork for Indoor Installations	1,500	1,700	
1.3	Refrigerant Piping for Split Installations	---	---	
2.1	Brine-to-water Heat Pump	---	---	
2.2	Air-Absorber with Installation	---	---	
2.3	Ground-Absorber and Excavation Work	---	---	
2.4	Anti-Freeze	---	---	
2.5	Piping connecting Absorber and Heat Pump	---	---	
3.1	Starting-current Limiter	not required	included in HP price	
3.2	Piping-connecting Heat Pump and Buffer Storage	300	300	
4.1	Combination Buffer Storage + Boiler	Capito PA 600/14 3,037	3,037	
4.2	Flue and Hydronic* Equipment	500	500	
5.0	Oil Preheater and Burner	1,150	1,150	
6.0	Controls Capito HR6W Stiebel-Eltron	351 786	351 786	
7.0	Oil Storage Tank and Accessories installed in the Basement	500 I 1,200	500 I 1,200	
8.0	Electric Water Heater, 300 l	SHW 300 AC 2,100	SHW 300 AC 2,100	
9.0	Motorized Mixing Valve with Elec- trical Connections	---	---	
10.0	Installation	1,500	1,500	
	TOTAL	20,144	20,764	

*- including guages, circulating pump, and expansion tank

		Row House 9 kW htg. load	One-Family House 14 kW htg. load	Two-Family House 20 kW htg. load
1.1	Air-Source Heat Pump	---	---	---
1.2	Ductwork for Indoor Installations	---	---	---
1.3	Refrigerant Piping for Split Installation	---	---	---
2.1	Brine-to-water Heat Pump OKD	AWS 4 5,710	AWS 6 6,767	AWS 8 7,675
2.2	Air-Absorber with Installation	---	---	---
2.3	Ground-Absorber and Excavation Work (Ditch-Installed)	4,316	5,840	6,835
2.4	Anti-Freeze	346	432	620
2.5	Piping connecting Absorber and Heat Pump	500	500	500
3.1	Starting-current Limiter	not required	437	437
3.2	Piping-connecting Heat Pump and Buffer Storage	300	300	300
4.1	Buffer Storage with Insulation, 700 l	1,030	1,030	1,030
4.2	Flue and Hydronic* Equipement	350	only hydronic equipment 350	350
5.0	Oil Preheater and Burner	---	---	---
6.0	Controls	279	279	279
7.0	Oil Storage Tank and Accessories installed in the Basement	---	---	---
8.0	Electric Water Heater, 300 l	2,100	2,100	2,100
9.0	Motorized Mixing Valve with Electrical Connections	---	---	---
10.0	Installation	1,500	1,500	1,500
	TOTAL	16,431	19,535	21,626

*-including guages, circulating pump, and expansion tank

↗ Table 3 Initial costs for a monovalent, brine-to-water heat pump system with a ditch-installed ground absorber. The heat pump operates down to -15°C and supplies 100% of the annual heating load (costs in DM).

Up to now, electronic control systems have been relatively expensive. Developments in electronics have now reduced the cost and improved these systems.

2. Bivalent Systems

For a bivalent system with a heat pump and boiler, the share of heat produced by the heat pump depends on its performance in relation to the heat demand of the building. Both the heat pump performance and building heat demand are dependent on the outdoor temperature.

A rough rule for sizing the heat pump is to choose a capacity that satisfies 50% of the design heat load. Some other sizing criteria are:

- Switchover point at $+5^{\circ}\text{C}$, if an air source heat pump is used with no defrosting device. In this case, the heat pump supplies roughly 60% of the annual heat demand for the average climatic conditions in Germany.
- Switchover point at 0°C , if an air source heat pump is used with a defrosting device. The operation of the heat pump can be continued even below this temperature in parallel with the boiler as long as there is an economic advantage in operating cost from use of the heat pump. This results in 70 - 90% share of the annual heat demand.
- Switchover point at about -4°C , if a brine-to-water heat pump is used in combination with an 'ambient heat absorber'. This absorber can be black in color and oriented to absorb solar radiation. This results in roughly an 80% share of the annual heat demand.

In bivalent systems where the heat pump supplies a large fraction of the annual heat demand, the required fuel oil storage can be reduced considerably. For new constructions this results in a significant cost savings. In general, a small plastic oil storage tank placed in a corner of the basement is sufficient.

3. Monovalent Systems

The most critical element of monovalent heat pump heating systems is the heat source. Ground and ground water are the most suitable sources for these systems because their temperatures are relatively constant throughout the year. The brine temperature in ground-source heat pumps is rarely below 0°C even in the coldest months, and the ground water temperature remains near 10°C throughout the heating season. With high-efficiency heat pumps, even air can be used as a heat source for monovalent operation if

	System	Annual Load Share	Row House	One-Family House	Two-Family House
1	Conventional Oil Boiler	100%	16,300	16,300	17,300
BIVALENT SYSTEMS					
2	Capito 3-fold Combination "Super-Arktis" + HP	60%	17,599	18,034	20,148
3	Capito Buffer-Boiler "Puffer-Arktis" + HP	60%	18,375	18,540	20,181
4	Capito Buffer-Boiler + HP with defrosting device	70-80%	9,253	20,585	25,121
5	OKD HP + Boiler, Brine HP with air-absorber	80%	18,558	18,558	23,557
6	AL-KO Polar HP + Boiler, Brine HP with air-absorber	80%	20,893	20,893	25,870
7	Stiebel-Eltron Air-Source HP for inside installation and Buffer-Boiler (Capito)	70-80%	20,144	20,764	---
8	Bosch-Junkers Air-Source HP for inside installation and Buffer-Boiler (Capito)	70-80%	19,667	22,549	---
MONOVALENT SYSTEMS					
9	OKD Brine HP with ditch-installed ground absorber	100%	16,431	19,535	21,626
10	OKD Buffer-Boiler with air-source split HP, "Oeko-Block"	100%	18,191	19,410	---

Table 4 Initial cost comparison of a conventional oil boiler heating system with 9 heat pump systems, both bi-valent and monovalent. (costs in DM)

low flow temperatures are required by the heating system.

The design heat load for modern residential buildings is about 80 W/m² of floor area, thus the required heating capacity amounts to:

9 kW in row houses with floor area	110 m ²
13 kW in one family houses with floor area	160 m ²
20 kW in two family houses with floor area	240 m ²

Such requirements can easily be met by standard heat pumps available today resulting in a relatively small investment even for monovalent applications.

System Costs

1. Conventional Systems

In order to make a comparison, the total first cost of a conventional heating system with an energy-efficient oil boiler should be determined. The following estimates are taken from the low end of typical cost ranges:

- Boiler with a flue connection, fittings, circulation pump and expansion vessel: DM 2,700
- Mixing valve with drive motor and wiring: DM 800
- Separately installed hot water tank with a 300 l volume, feed pump, pipe connections with fittings and associated control equipment: DM 2,900

- Flow temperature control system (based on outdoor air temperature), timer and remote control: DM 1,200

- Fuel oil storage with 3,000 or 4,000 l tank, double-walled, dome-shaped shaft, fittings, pipes, gauges, and underground installation: DM 6,000 to 7,000

- Oil burner with oil preheater (for small capacity): DM 1,200

- Assembly costs (30 man hours at DM 50/hr) DM 1,500

Total Costs DM 16,300 to 17,300

The costs of the fuel oil storage would be reduced by about DM 3,000 if the tanks are installed in the basement. The space taken up for this is then not usable for general purposes, and the lost value of this space should be included in the calculation. This factor makes the costs of both types of installations approximately equal.

2. Heat Pump Systems using Packaged Combination Units

After inquiries and discussions with manufacturers, first costs were determined for 10 different systems. A general cost tabulation format was developed, and the tabulations for three system types are shown in Tables 1-3. As in the previous calculation for a conventional plant, the systems include equipment for tap water heating.

The costs of these 10 systems are combined in Table 4. The chart shows that the additional cost of a heat pump system compared to a conventional system for a newly constructed one-family house or row house is:

Bivalent Plant	DM 1,300 to 4,500
Monovalent Plant	DM 0 to 3,000

If the conventional plant includes an indoor oil tank, the above calculation assumes a DM 3,000 cost for lost space. If one does not wish to include this cost, the additional cost of the heat pump system is DM 3,000 larger.

The additional costs for a two family house are somewhat higher, because the greater heat demand requires the use of larger heat pumps and associated accessories.

A heat pump system will typically save DM 700 to 1000 per year in operating costs compared to a conventional oil heating system and will result in a DM 720 per year tax reduction (DM 18,000 first cost, 40% tax rate). The additional first costs are quickly paid back, and considerable savings are accrued over the years.

Therefore, financial aspects should not prevent the installation of an ecological and energy-saving heat pump heating

system for new constructions. If the boiler and fuel storage tanks must be replaced in older buildings, the same possibilities for the application of heat pumps are available.

The author of this report has published a book describing these new technologies in an easily comprehensible form. Walter Lorch - "Erprobte Heizsysteme mit Wär-

mepumpen" (Proved Heating Systems with Heat Pumps). ISBN 3-9800893-0-4, Price DM 39.-. It can be obtained in book stores or directly from the W. Lorch Publishers, Landgraben 107, 5100 Aachen.

* *Walter Lorch*
Ingenieurbüro für Solartechnik
Landgraben 107
5100 Aachen

Bouma, J.W.J.*
Koppenol, A.D.*

Investigation into a Complete Ground-to-Water Heat Pump System in a Single-Family Dwelling focusing on the Application of a Vertical Subsoil Heat Exchanger

Summary

Vertical subsoil heat exchangers for heat pumps have been studied to establish the state of the art. As far as the design aspect is concerned, a great variety of installations is possible. The types of heat exchangers most frequently used are coaxial tubes and, to a lesser extent, parallel tubes. A review is given for the techniques of making the holes in the ground to accommodate the heat exchanger tubes. Water jetting by hand is favorable from an economic point of view, if only a limited number of tubes are to be installed. Computer simulations have been performed for tube lengths of 10 m, 15 m and 20 m. The present heat exchanger consists of seven tubes with a length of 14.5 m. They are positioned almost completely in ground water. The system consists of an electrical heat pump and a floor heating/radiator system. The system was monitored during the 1982/1983 heating season. It has operated in a monovalent mode only, and a 35% primary energy savings was achieved. Specific heat extraction rates are 40 to 65 W per m of vertical tube length. Natural temperature recovery of the soil during summer is almost complete.

1. Introduction

In earlier research work, a computer model of a ground heat exchanger was developed (1) and experimentally verified for the horizontal concept (2). As a follow-up to this, the attention has been focused on a complete electrical heat pump system with a vertical subsoil heat exchanger, installed in an occupied residence. No heat storage in the ground has been considered, and no domestic hot water is produced by the heat pump.

As far as the different types and installation techniques of this system are concerned, literature concerning vertical sub-

soil heat exchangers for heat pumps has been studied to determine the state of the art.

With the purpose of designing the subsoil heat exchanger, a simulation model has been used to study the characteristics of the system, accounting for the heat exchanger, residence, heat pump and climate.

The system has been in operation since October 22, 1982, and monitoring was completed in September 1983.

Before installation into the residence, the characteristics of the heat pump had been measured in the laboratory under steady-state conditions.

In addition to the type selection and the design of the subsoil heat exchanger, a main objective of the research work is the estimation of the extent to which the behavior of vertical ground heat pump systems in a residence is predictable. Furthermore, drawing up of design and application directives and instructions for such systems will be carried out.

2. State of the Art

Vertical subsoil heat exchangers have been installed only in limited numbers and therefore experience with them is rather limited. The vertical systems dealt with here are closed-type, i.e. no ground water is extracted. The types of heat exchangers mostly used are coaxial tubes, and the outer tube is closed at the lower end. To a lesser extent, parallel tubes (U-shaped) and tubes with a diametric wall inside are also used. The vertical tubes are usually arranged in a network, divided into one or more groups. The groups are coupled together and connected to the heat pump by horizontal tubes. These are installed at a depth

varying between 0.5 m and 1 m below the surface. In practice, this means that heat exchange with the soil does not occur solely via the vertical sections but also via the horizontal lines, unless insulation is provided.

Plastic as well as metal tubes are often used, depending on the method of installation. A common plastic used for the tubes is high-density polyethylene (HdP) and polyvinyl chloride (PVC). Metal tubes are made of steel or copper.

The presence of ground water flow is of great importance as it significantly improves heat extraction and temperature recovery of the soil in summer. In the Netherlands, the larger part of a vertical subsoil heat exchanger is situated in ground water throughout the year.

A great variety of heat exchanger designs exists for comparable installations, especially for the tube depth and the number of tubes installed. Moreover, the tube distance, an important parameter affecting heat extraction and temperature recovery of the soil, is different (3). Depths vary between 10 m and 100 m. The majority of these systems, both experimental and semi-commercial, show a rather satisfying performance.

Two methods of extracting heat from the ground are the direct and indirect method. Most subsoil heat exchangers operate by the indirect method. In such systems, brine circulates through the heat exchanger and the evaporator. In some experimental installations the direct method has been applied. Here the subsoil heat exchanger acts as the evaporator. These installations were tested in Denmark, Belgium and Great Britain. In the majority of these experiments an improvement of performance did not occur.

Vertical subsoil heat exchangers, extracting heat from depths between 10 to 100 m, do not automatically ensure recharging by the spring and summer climate. In Nordic countries it is considered necessary to regenerate the soil temperature artificially at these depths during the summer season. This is done using solar collectors or passive air coils. However, in the Netherlands, significant ground water flows may be expected locally in the vicinity of rivers, canals or lakes. In such cases, recovery of ground temperatures is often complete. Model calculations and experiments with a 10 m single vertical tube of the U-shaped type in the Netherlands show that temperature recovery by natural influences is nearly complete (2) (heat extraction continuous: maximum 40 W.m^{-1} of running length for a period of three months).

Sometimes the tubes are installed in the ground at an angle to the surface. This requires less excavation work and causes less site disturbance, than an advantageous system for existing residences with a garden.

An important economic factor for vertical absorber ground source heat pump systems is the cost of installing the subsoil heat exchanger. This cost depends largely on the length of the tubes, because the required technique of making vertical holes is dependent on the depth, the diameter of the borehole and the type of soil. The following techniques are used, depending on the depth. (3):

- **Auger-technique:** This method is only applicable down to the ground-water table.

- **Water jetting with a lance without casing** (limited to roughly 15 m in the case of holes made with a hand-held device, and 20 to 25 m for machine-made holes): The tubes are inserted after the hole has been made.

- **Water jetting with a steel casing** to prevent the hole from collapsing: The casing is withdrawn by a truck-crane after the plastic tubes have been inserted. Compared with the former method, these holes do not necessarily have to be made in one single operation (realized for 10 m - tubes).

- **Pulsing:** This method is labor-intensive and attractive only when a few shallow (< 20 m) holes are needed. However, with this method high-quality soil samples can be obtained. Most other methods mentioned here only offer limited possibilities for accurate soil sampling.

- **Pressing/vibrating:** PVC-pipes can be pressed at least down to 10 m in clay-soil using a pneumatic device. Steel tubes, which are the outer tubes of concentric tubes, are pushed into the soil. They can be positioned vertically or at an angle from a central point (possible depth 20 to 30 m). In the case of installing the tubes at an angle, the upper ends of the tubes are close together, which makes it easy to interconnect them. Contrary to other techniques, the pneumatic machine can stay at one point. In the Netherlands, a combination of vibrating and water jetting has successfully been used to directly install U-type tubes with a length of about 21 m. This technique requires the use of heavy machinery.

- **Ramming:** A steel liner is rammed into the soil with the aid of heavy machinery. At the lower part of the liner, a plate is mounted which is lost when the liner is pulled up, after the heat exchanger tubes have been inserted. In Sweden, U-type heat exchangers with a length of 35 m have been easily installed in clay soil using this method.

- **Drilling (with washing):** This method can be used for depths up to 150 m and more. There are two manners of circulating the fluid through the drilling tube, namely by suction or pressure. This is done either mechanically or by injecting air into the mud at the lower part. An advantage of sucking the mud through the drilling tube lies in the availability of representative soil samples. This technique is fast, especially in sandy soils. However, as in the case of ramming, the heavy drilling equipment (mounted on a truck) might be a constraint

in applying this technique due to the poor accessibility of existing premises. Moreover, an adequate water supply must be ensured.

Hydraulic and conventional oil well drilling techniques can be used for drilling holes in formations which are difficult to penetrate, such as rock. These techniques, however, are expensive and primarily used in the case of hard formations or deep holes, for instance with the purpose of exploring geothermal energy or applying heat storage on a large scale.

3. Model Calculations

Under a previous contract (1), a computerized predictive method was developed for predicting both heat extraction from the ground and heat pump performance. The calculation method applied uses the finite-element method. The results achieved with the calculation model agreed with the experimental results (2). This computerized method was also used in this investigation for the design of the subsoil heat exchanger and determination of the performance of the complete heat pump system (3). It is assumed that the tube has a uniform temperature throughout a vertical section, heat transfer in the soil is done by conduction only, heat extraction is continuous and operation of the heat p is in the monovalent mode. Calculations are restricted to one tube out of

the group. Only heat extraction during the heating season is considered, heat recharging in spring and summer being governed only by natural processes. To simulate the heat pump and calculate the extracted heat, relatively simple equations are used. For example, a constant temperature difference has been assumed between evaporation and brine temperature and between condensation and water flow temperature, while the Carnot-efficiency is constant. The calculation is carried out step-by-step. During each step, the COP, the extracted heat from the soil and the temperatures of the tube and soil are calculated.

Figure 1 shows the arrangement of the tubes which makes optimum use of the available ground area; seven tubes (diameter 0.05 m) are arranged in two rows and in a staggered pattern. In this figure, one symmetrical half of the upper side of the model geometry has been projected on one tube. Heat extraction takes place both from the garden and from the adjacent ground area. The site is located in an urban area in Apeldoorn.

The boundary conditions include the earth surface temperature, an isothermal plane (10.2°C) 4 m beneath the tube and a uniform water/glycol mixture. The soil at the test site consists mainly of sand and gravel in ground water (thermal conductivity is $3 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$; volumetric heat capacity is $3 \times 10^6 \text{ J} \cdot \text{m}^{-3} \cdot \text{K}^{-1}$).

Calculations were performed for different tube lengths, i.e. 10 m, 15 m and 20 m, over

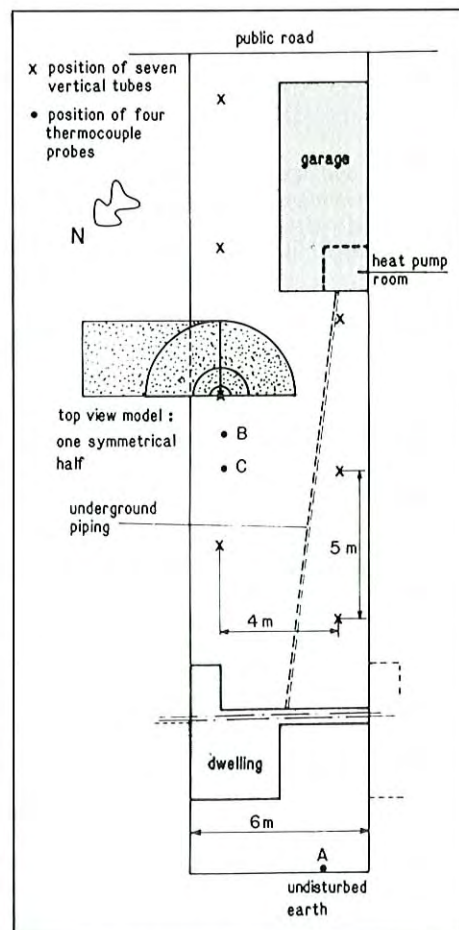


Fig. 1 Map Test Site

Tube length	20 m	15 m	10 m
1st year	3.39	3.29	3.12
2nd year	3.28	3.19	3.05
3rd year	3.23	3.15	3.03

Table 1 SPF Vertical Bundle, 7 tubes

a period of three years. Table 1 summarizes the calculated Seasonal Performance Factors (SPF) for the heat pump system (same heat demand dwelling; auxiliaries and thermal resistance of the tube wall and fluid film neglected). Obviously the tube temperature and the SPF are highest in the case of 20 m tubes, but the quasi steady-state of the soil is achieved more quickly with 10 m tubes, i.e. after two years. The simulation results are presented in Figure 3 for the 15 m tubes.

4. Subsoil Heat Exchanger

The type of heat exchanger tubes selected by technical-economic considerations is the so-called hollow-wall type. This commercial tube system consists of two thin-walled (1.10^{-3} m) concentric PVC-tubes of which the annulus is divided into 11 flow channels, formed by radial walls inside

(see Figure 2a). Parallel tubes (U-type), concentric (loose) tubes and circular tubes with a diametric wall, PVC as well as PE, were also considered (4). One of the factors which played an important role in the process of selection was the choice of drilling technique to be used, especially as far as the installation cost and the accessibility of the ground for drilling equipment were concerned.

The subsoil heat exchanger consists of seven 14.5 m vertical tubes, with 5 m separation (4), coupled with the heat pump via horizontal tubes. The net ground area of the garden is 110 m². In the central tube (diameter 36 mm), the water/glycol mixture flows downwards and through the channels upwards. The tubes are inserted parallel to one another, while technical measures were taken to ensure equal flow in each tube (see Figure 2b). The holes for the tubes were hand-made by water jetting. The horizontal connecting tubing is not insulated and located at a depth of 0.7 m. Before operation, air was vented thoroughly from the heat exchanger and a comprehensive leak-test was carried out. The subsoil heat exchanger is almost

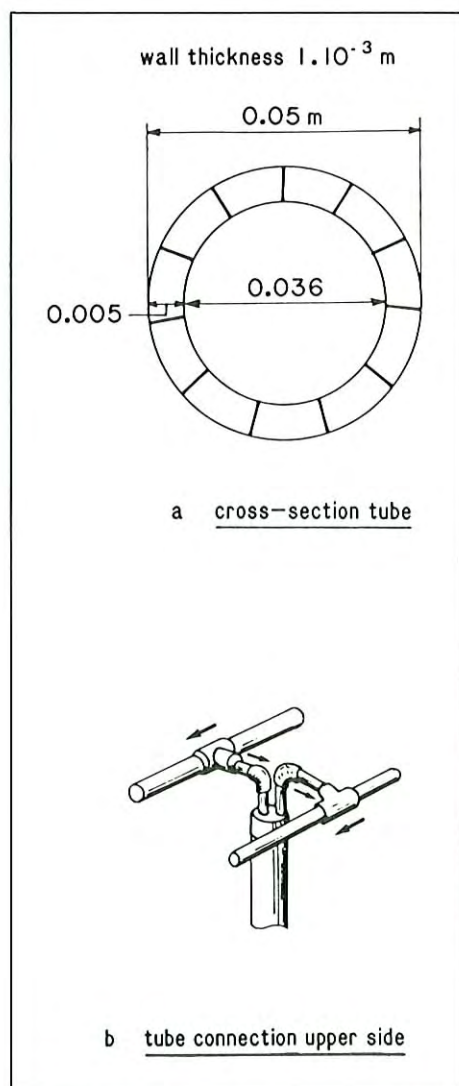


Fig. 2 Details of Vertical Tube

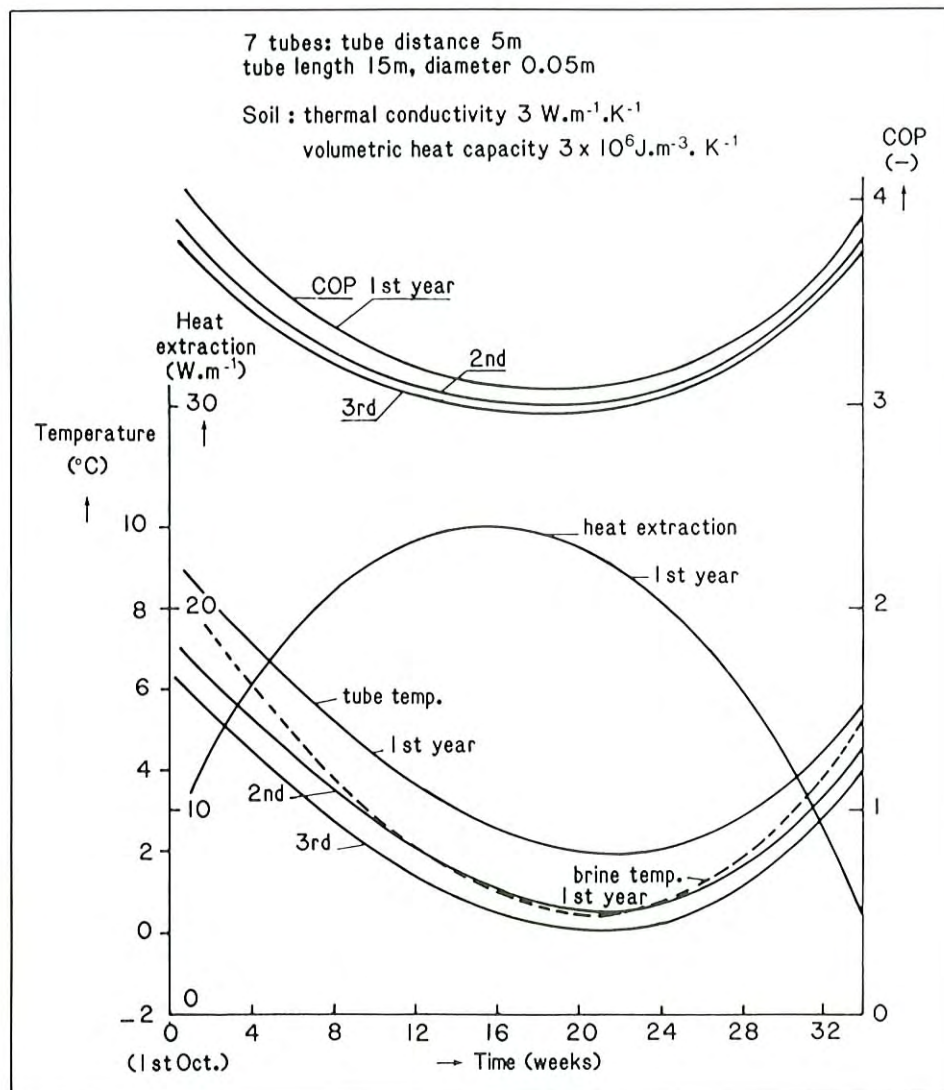


Fig. 3 Calculated Performance of Vertical Tube Bundle

5. Residence - Heating System

The residence, built in 1975, is an attached single-family house with a floor heating system on the ground floor and radiators on the two upper floors. The residence is well insulated; the maximum heat demand is about 7.5 kW at -12°C ambient temperature. The heat pump was installed in a detached garage at a 14 m distance from the residence and connected with the heat distribution system via well insulated underground piping.

The heating system is operated in a bivalent-alternative mode, using the existing natural gas boiler in the dwelling (nominal capacity 23.3 kW). The small-capacity ground source heat pump (5.5 kW heat output at 0°C brine temperature and 35°C flow temperature) is electrically driven. To achieve higher COP, the liquid leaving the condenser is subcooled, partially by heating the surrounding air and by exchanging heat with the suction gas to the hermetic compressor.

completely in ground water (91% of the length). Although about 40 m of trench had to be dug, disturbance of the test site and damage to existing vegetation was minimal.

6. Data Acquisition

The complete heat pump system was monitored with the aid of a data acquisition system, consisting of a programmable data logger and a tape recorder with a compact cartridge. In addition to soil temperatures at four positions and at several depths, water, air and brine temperatures as well as the energy flows in the system were measured. Processing of measured data was done with the institute's computer system.

7. Main Results

Heat pump operation started on October 22, 1982, and finished on May 31, 1983. Monitoring was continued until September 1983 in order to determine to what extent temperature recovery of the soil is na-

turally obtained. The winter 1982/1983 was rather mild. Therefore the heat pump was operated in the monovalent mode only.

In Table 2, the measured results and the COP during the heating season have been summarized on a monthly basis (5). The SPF, including auxiliaries like the brine pump, internal fan and controls, is 3.23. The heat output into the air has not been included in these figures, because

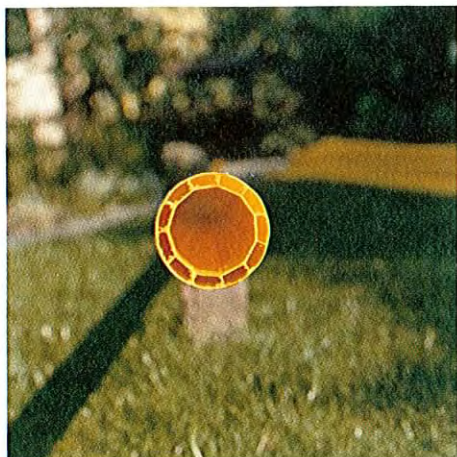


Photo 1 Cross-Section of the Heat Exchanger Tube

exact measurement was a problem and the heated air was not used for space heating in the residence (the COP will be 3 to 6% higher when air heating is included). In order to determine the Primary Energy Ratio (PER), a conversion from the COP by a factor of 0.35 has been made. In Table 3, PER values are given as a function of heat source and heat sink temperatures, on a daily basis. The PER based on the heating season is 1.13. In Figure 4, a plot is presented of the results on a weekly basis, including the average ambient temperature. The specific heat extraction has varied between a maximum of 65 W per meter of running vertical tube length in October 1982 to a minimum of 41 W·m⁻¹ in February 1983 (operating period).



Photo 2 Connection of Heat Exchanger Tube to Flow and Return Manifolds

Month	Run- ning time (h)	Brine temp. (°C)	Water temp. (°C)	Electricity consumption com- pressor (kWh)	Extrac- ted heat from the soil (kWh)	Heat output to the water (kWh)	COP incl. aux. (-)	excl. aux. (-)
Oct*	19.6	---	---	34.1	3.5	127.4	3.75	4.13
Nov	90.3	9.4	30.0	156.4	15.0	505.1	3.56	3.90
Dec	194.6	6.5	32.9	334.7	31.8	915.1	3.30	3.61
Jan	176.0	6.2	33.0	302.8	29.3	822.5	3.25	3.56
Feb	266.6	4.1	36.0	457.9	43.8	1111.3	3.05	3.34
Mar	168.9	5.6	33.0	288.6	29.3	746.9	3.14	3.45
Apr	102.5	6.8	31.8	176.3	20.6	475.8	3.23	3.54
May	65.0	8.4	30.6	112.0	16.0	328.8	3.45	3.78
Total	1082.6			1862.8	189.3	5032.9		6609.1

* - from 22nd to 31st

Table 2 Monitoring results; heating season 1982/83

In Figure 5, the soil temperature at various measuring locations (see Figure 1) and the average brine temperature have been plotted versus time (weeks) for different depths. From the difference between soil temperature at these depths and brine temperature, it can be seen that, during the first period of heat extraction, the upper layers of the soil have played an important role. But heat extraction from lower soil layers has dominated halfway through the heating season and in the spring. The net positive contribution of the horizontal tubes to heat extraction, however, was limited.

The minimum daily average brine temperature at the evaporator inlet was 3.2°C. Freezing of soil did not occur during the heating season under consideration. Due to the relatively mild winter in 1982/1983, these results are slightly better than can be expected for a more rigorous winter.

The results of soil temperature recovery are also shown in Figure 5. Temperature recovery on August 21, 1983, was not yet complete for depths between 2 m and 14 m. However, the temperature difference was small, i.e. 0.5 to 1.5 K. A distinct effect of ground water movement on the recov-

ery process has not been traced. It is expected that temperature recovery will be nearly complete at the start of the next heating season.

A comparison of field and calculation results has been made in Figure 6 on a weekly-average basis. The effect of the horizontal tubes has been included. A satisfying agreement has been obtained since the overall difference in extracted heat from the soil amounts to 7%, and the actual temperature behavior of the soil at various depths has been simulated to a large extent.

8. Economic Aspects

The primary energy savings using the heat pump amount to 35% in comparison with the present natural gas boiler, assuming a combi-boiler efficiency of 73% (lower heating value), in relation with the first heating season 1982/1983. Based on 1983 energy prices, including VAT, energy costs are 7% lower than for the reference heating system. However, due to the relatively high investment costs for the heat pump system, especially the heat pump itself, the total system costs are still too high for economic application in the Netherlands at the present (pay-back time

Temperature of Heat Sink (°C)													
	26	27	28	29	30	31	32	33	34	35	36	37	38
Temperature of Heat Source (°C)													
3											1.06	1.06	1.05
4								1.09		1.07	1.06	1.07	1.05
5							1.11	1.08	1.09	1.08	1.10		
6					1.12	1.11	1.12	1.12	1.12	1.12	1.12		
7				1.18	1.17	1.16	1.16	1.16	1.17	1.17			
8				1.18	1.20	1.19	1.21	1.19					
9				1.23	1.23	1.23	1.20	1.26	1.24				
10		1.34	1.32		1.30		1.26						
11	1.37	1.35	1.35	1.37									

Table 3 Primary Energy Ratio (PER), Heating Season 1982/83

is longer than the life time). When a high-efficiency gas boiler is considered as a reference system, the economic aspects will become even worse for the heat pump.

The specific, commercial price of the subsoil heat exchanger, including the horizontal tubing, amounts to Hfl. 8.30 (3.0 ECU of 1981) per meter vertical tube. Installation costs amount to Hfl. 12.18 (4.3 ECU of 1981) per meter, which includes jetting the holes for the tubes and making the trenches. The costs for the heat source therefore form about 16% of the total cost of the installed heat pump system.

9. Conclusions

- There is great variety in the design of vertical subsoil heat exchangers that can be applied to practical installations. The main differences for comparable installations occur especially in the tube length, the distance of tubes from each other and the number of tubes. The types of heat exchanger used most frequently are concentric and, to a lesser extent, parallel tubes made of plastic. The majority of these systems operate with indirect evaporation.

- Artificial recharging of the soil in the spring and summer period is practiced especially in Nordic countries.

- Existing techniques for making holes for subsoil heat exchanger tubes greatly influence the installation cost. Water jetting with a lance is an inexpensive technique, although practical depths attainable by hand are limited to roughly 15 m, provided no thick clay layers are present. In the case of existing premises, accessibility may be a constraint due to the use of heavy machinery.

- During operation, 65 W per running meter of vertical tube length was extracted at a maximum and 41 W per m at a minimum (coldest period).

- A primary energy saving (natural gas) of 35% was achieved in the heating season 1982/1983, in comparison with the present natural gas boiler.

- Natural temperature recovery of the soil is almost complete for depths between 2 m and 15 m (as of August 22, 1983). A significant effect of ground water movement on the recovery process has not been observed.

- Application of vertical earth heat pump systems, in new and existing residences, looks promising in countries with favorable conditions for heat pump application. In particular, the vertical subsoil heat exchanger system enlarges the possibilities of using the ground as a heat source at reasonable costs for installation and material, and requires only a small ground area.

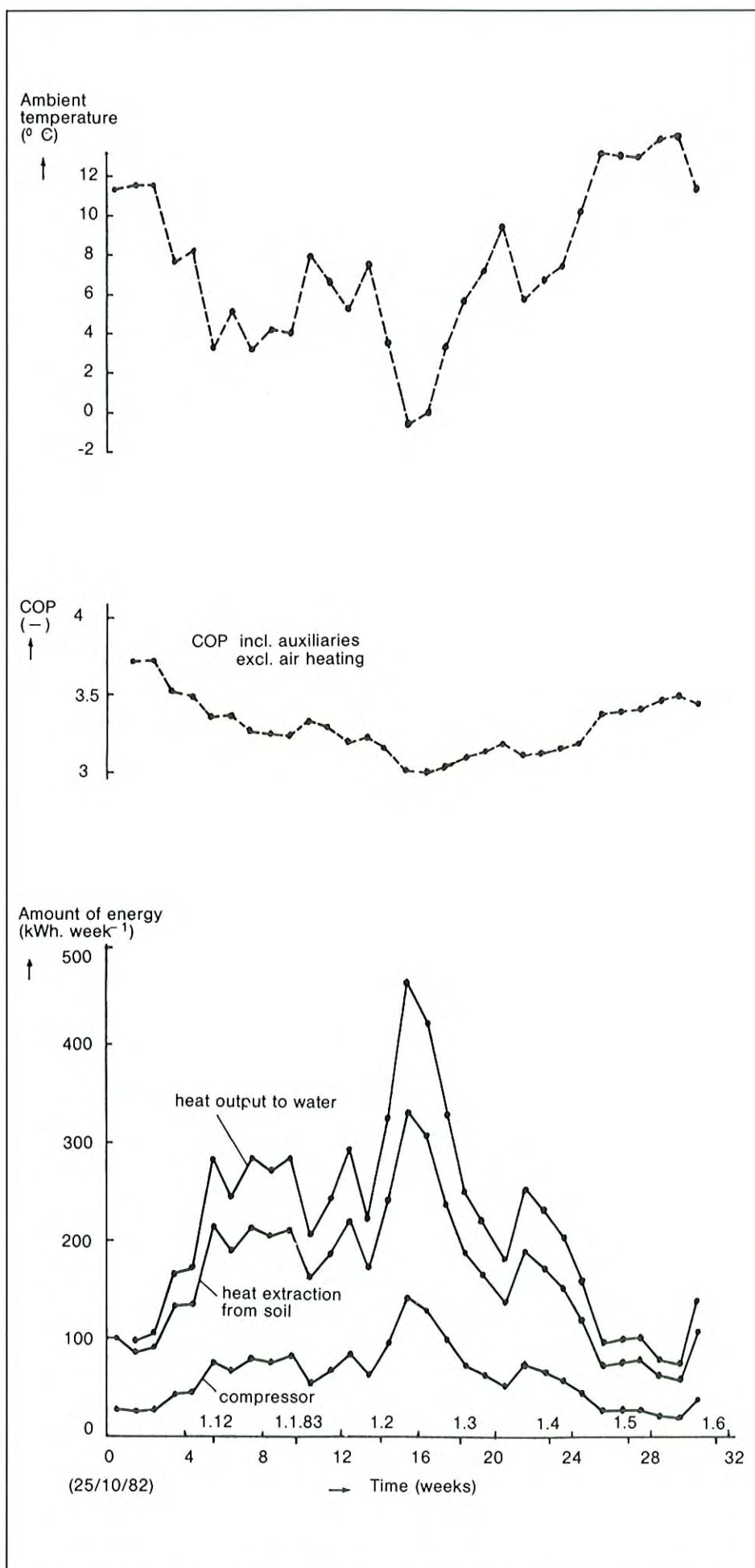
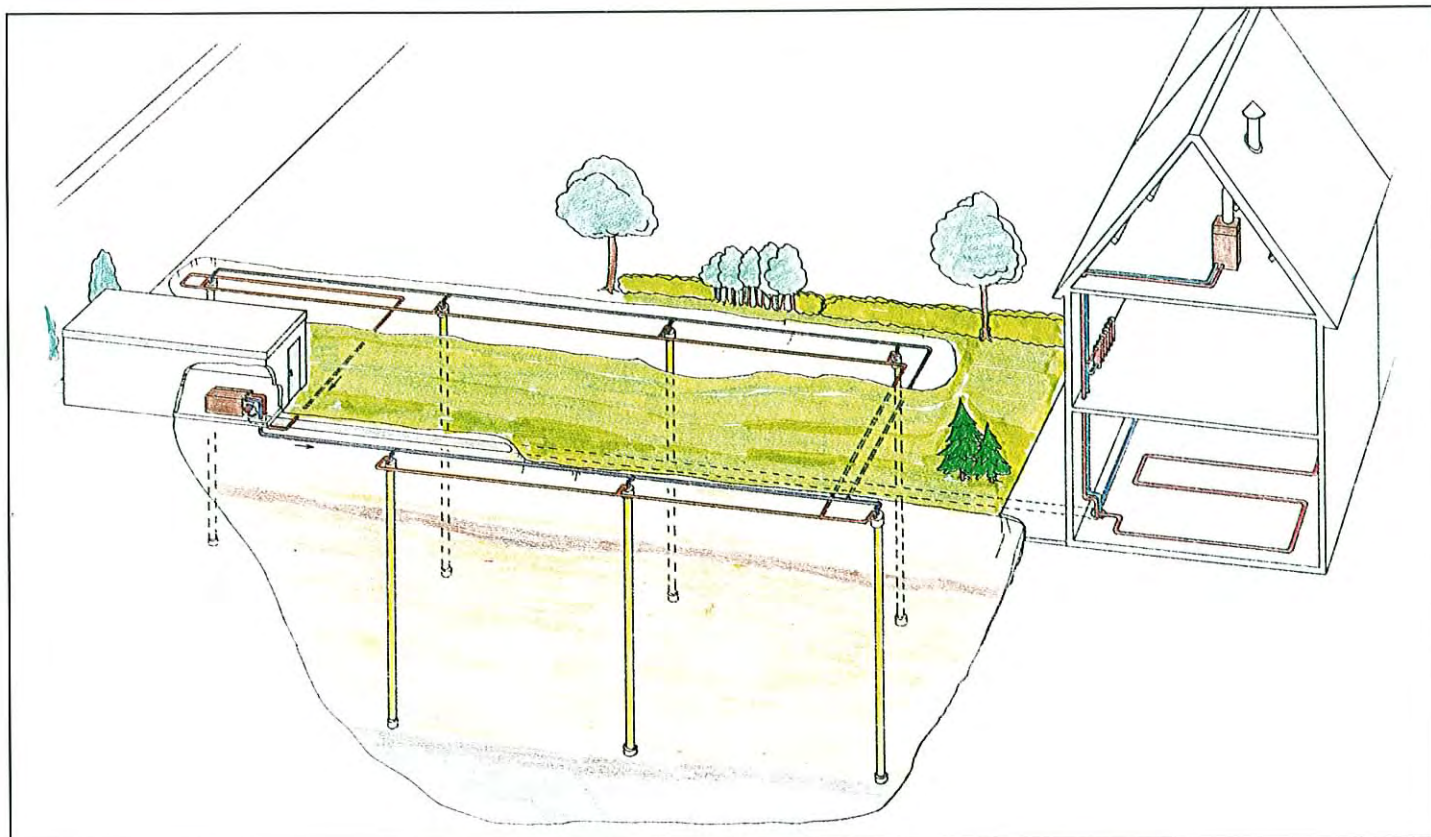


Fig. 4 Heat Pump Performance in the Field (weekly average)



Sketch of a Ground-to-Water Heat Pump System with a Vertical Subsoil Heat Exchanger

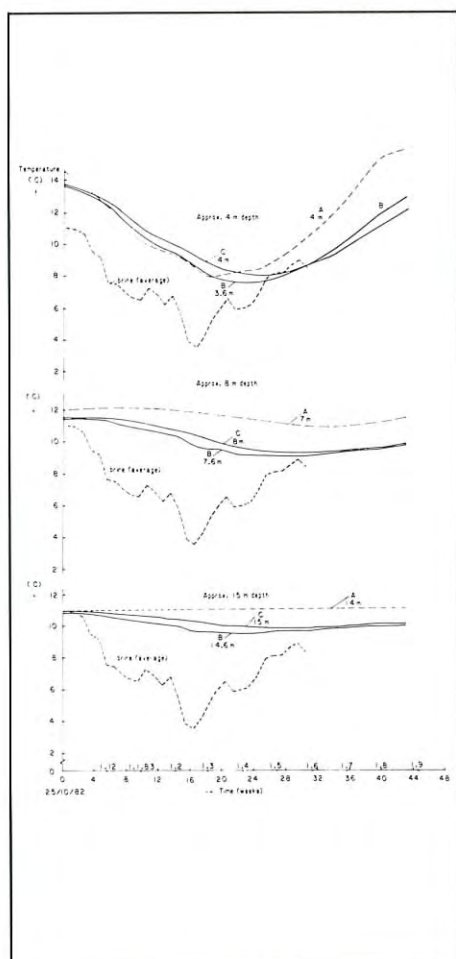


Fig. 5 Course of Soil and Brine Temperatures

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- (3) Bouma, J.W.J., Koppenol, A.D.
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- (4) Bouma, J.W.J., Koppenol, A.D.
Progress report no. 2. Contract EE A-4-033-NL. September 1982.
- (5) Bouma, J.W.J., Koppenol, A.D.
Progress report no. 4. Contract EE A-4-033-NL. September 1983.



Photo 3 The Monitored Residence

*J.W.J. Bouma and A.D. Koppenol
Organization for Applied Scientific
Research TNO, Division of
Technology for Society

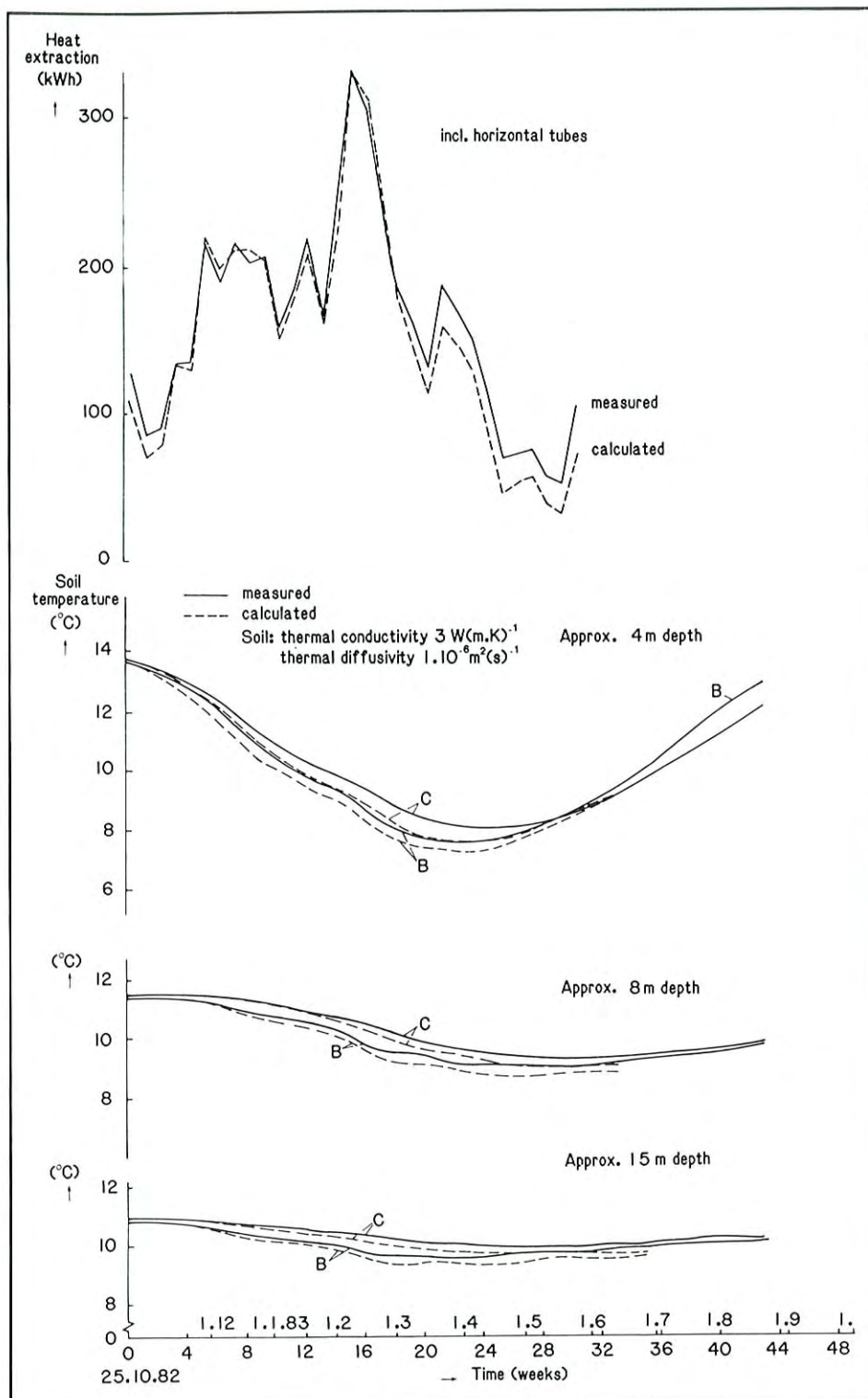


Fig. 6 Comparison of Monitoring and Simulation Results

M. Fukiwake*

Super Heat Pump Energy Accumulation System — R & D Plan

Energy is the most fundamental element for the stability and progress of a nation and its economy. Considering that Japan is one of the largest energy consuming countries in the world while having poor domestic energy resources, the energy problem is so crucial that the nation's future is entirely dependent upon its successful solution. Accordingly, it is quite

necessary to take effective strategies for energy conservation in each of the industrial, private and transportation sectors as well as to shift the industrial structure to an energy-conserving type in the future.

To promote energy conservation, legal measures should be taken to encourage a more rational use of energy as well as to

improve the availability of information concerning energy conservation. At the same time, the technical developments for improving efficiency and waste-heat utilization in every sector of energy conversion, transport, storage and consumption will play a very significant role in energy conservation.

The R&D of energy conservation technologies should cover a variety of aspects as follows:

- Both energy-conserving equipment and control strategies/operational changes should be investigated.
- R&D topics involved should range from fundamental research to practical applications.
- The scale of R&D should vary depending on time and funding available.
- The R&D results should be available in every sector of the national economy.

The promotion of the R&D program should be performed systematically and efficiently by combining appropriate R&D approaches and systems.

From such a point of view, the Agency of Industrial Science and Technology (AIST) started in 1978 the "Moonlight Project", the nick-name of the R&D program for energy conservation technologies. The project coherently and systematically promotes energy conservation R&D for participating national laboratories, industries and universities.

Heat pumps are now widely recognized to be an effective energy conservation technology and are expected to help provide a solution to the energy problem. In order to improve the state of Japan's energy and power consumption and to improve markedly the efficiency and applicability of the heat pump, AIST started the R&D program of the "Super Heat Pump Energy Accumulation System" in 1984.

Introduced below is the outline of this R&D plan.

1. Basic Plan

R&D period: 8 years from fiscal 1984

Total R&D expenditures:
about 10,000 million yen

1.1 Aims of R&D

This project aims to develop a super heat pump energy accumulation system that, by utilizing cheap electric power during the night, stores energy very efficiently and with a high storage density and, in the daytime when the energy is needed, delivers it as hot or cold air/water for the space conditioning of large buildings, district heating/cooling, process heat for various industries, etc., thereby conserving energy and levelling power demand.

Item				Targets		
				Output temperature		Coefficient of performance (COP)
Sub-systems	Super high performance compressor heat pump	High efficiency type	For heating only	85° C		8
			For heating and cooling	(Heating) 45° C (Cooling) 7° C	6 7	
		High temp. output type	For low temp. heat source	~ 150° C		Over 3
			For high temp. heat source	~ 300° C		Over 3
	Chemical heat storage system			Output temperature	Heat storage capability	Heat recovery rate
		High temp. heat storage		~ 200° C	Over 50 kcal/kg fluids	Over 75%
		Low temp. thermal storage		~ 10° C	Over 30 kcal/kg fluids	Over 75%
Total system		This super heat pump energy accumulation system for practical use must be superior to any other existing system in economy, applicability, load levelling effect, etc. The targets of the pilot system should be as follows :				
		Application		Output temperature		Energy efficiency
		Office building air conditioning		(Heating) 45° C		4.5
				(Cooling) 7° C		5.3
		Community cooling/heating and hot water supply		(Heating) 45° C (Cooling) 7° C 85° C		4.5 5.3 6
Industrial process heating		150 ~ 300° C		Over 2.3		

Table 1 Development Aims

Towards this aim, R&D will be conducted on very high performance compression heat pumps and chemical heat storage systems so that optimal total systems can be developed by integrating those sub-systems. The basic development targets are as shown in Table 1.

1.2 Scope of R&D

- While conducting research on component elements of the super heat pump energy accumulation systems, such as working fluids and materials, R&D of high-efficiency and high-temperature type compression heat pumps will be conducted as well as R&D of chemical heat storage systems.
- Based on the results of the above R&D activities, plant systems will be developed by integrating very high performance compression heat-pumps and chemical heat storage-systems, and research on their operation will also be conducted. Research on optimal system configurations and control techniques will be conducted, and conceptual designs of 30,000 kW super heat pump energy accumulation systems for various applications will be developed with the objective of achieving commercialization.

Shown above is the main text of the basic plan established in September, 1984. As

described therein, the systems proposed in the plan are very efficient heating, cooling, and energy storage systems that utilize air, waste water, etc. as heat sources/sinks. The systems combine super high performance compression heat pumps and heat storage systems utilizing chemical reactions and are designed to use inexpensive nighttime electric power as a driving source. As such, these systems should be superior to any other existing systems in economy, applicability, etc. The desired system size is about 30,000 kW, i.e. a large capacity capable of cooling/heating a housing complex having 5,000 houses. For this size of system, only a concept design will be developed. A 1,000 kW plant will be designed for the pilot system, but this size is large enough for commercial operation in ordinary 7 - 8 story buildings.

2. Schedule of R&D

Table 2 shows the R&D schedule for the super heat pump energy accumulation system. "Research and evaluation of working fluids, materials, etc." was started in October 1984 by four national research institutes, including the National Chemical Laboratory for Industry, AIST. "Research for systemization" and "Research on total system" will be conducted by the New Energy Development Organization (NEDO), which will subcontract part of the R&D to private enterprises.

3. Contents of R&D

As shown in Table 1, this plan intends to develop a variety of subsystems suitable for a number of uses. In order to support the development of those subsystems, the national research institutes will conduct basic research on working fluids for compression heat pumps, a variety of chemical reactions for chemical heat storage systems, materials for rotating parts of compressors, compression and heat exchange systems, etc., as well as research on heat pumps for use in cold regions.

In this report, the contents of R&D of subsystems will be described primarily, while referring to basic research when necessary.

3.1 Super high performance compression heat pumps

The compression heat pumps to be developed are roughly divided into the high-efficiency type, which has an output temperature similar to that delivered by existing heat pumps for cooling/heating and hot water supply but has an efficiency (COP) that is twice as high, and the high-temperature type, which has an efficiency that is kept at the highest level available with existing heat pumps but can deliver an output temperature 40 - 190 °C greater than existing heat pumps.

3.1.1 High-efficiency type compression heat pumps

There are two kinds of compression heat pumps in this category. One is for heating-only and is suitable for district heating/hot water supply, while the other can supply cooling and heating and is suitable for space conditioning of office buildings. The goal for the heating-only type is to have a COP twice as high as that of existing heat pumps, while the goal for the heating/cooling type is to have 1.5 - 2 times as high a COP as that of existing heat pumps. Improvements in heat exchanger performance play the most important role in the COP increases. It is expected that the COP value can be improved by about 30% by developing a small-temperature-difference counterflow heat exchanger or a highly-heat-conductive heat exchanger utilizing the EHD (Electro-hydro-dynamic) effect, which removes the working fluid condensed on the wall of the pipes by the force from a high-voltage electric field. The compressor performance will also be improved (by about 25 - 30% in terms of COP) by: i) improving compression systems by approximating isothermal compression through use of liquid injection or a multi-stage compression process, ii) recovering waste heat from the hermetic compressor motor into the working fluid, iii) reducing mechanical losses, reducing the thrust load, reducing leakage of the working fluid by selecting an optimal screw form, etc. For the heating-only type, the standard expansion valve can be replaced by a two-phase flow power-recovery turbine, and the mechanical output of

the turbine can supply part of the compressor drive requirement.

Many other aspects of these heat pumps can also be improved. The most important theme, however, is the selection of optimal working fluids for each heat pump type. Conventional heat pumps have used single refrigerants or azeotropic mixtures. In this plan, however, the high-efficiency type compression heat pumps will use non-azeotropic mixtures, such as a combination of R-12 and R-114 or a combination of R-11 and a hydro-carbon. Various combinations and mixing ratios should be examined and evaluated.

The importance of research on these mixtures was stressed in the Annex VI to the Implementing Agreement on Advanced Heat Pumps (IEA), drawing increasing attention to this topic across the world. Because of their non-constant boiling temperature, non-azeotropic mixtures can evaporate or condense evenly despite the normal temperature gradient found across heat exchangers. Therefore, these mixtures can efficiently transfer heat with heat sources/sinks and are a very important element in the improvement of heat pump performance. In selecting this kind of working fluid, it is quite important to take account of such requirements as: i) the mixture must not form an azeotropic mixture extending over the entire operating range, ii) working fluids having an adequate boiling point difference must be mixed, iii) the mixture must have a large latent heat of vaporization and a small specific volume.

3.1.2 High-temperature type compression heat pumps

Two heat pump designs will be developed, one capable of delivering 150 °C and the other capable of delivering 300 °C. The objective is to obtain COP values equal to the best achievable with existing heat pumps that deliver lower temperatures.

The freon series, the working fluids most commonly used in heat pumps, are unstable in the high temperature region, their temperature lift capability is limited to 30 - 50 °C, and their maximum output temperature is limited to about 110 °C. Accordingly, it is necessary to use alcohol fluoride mediums, such as TFE or perfluorooctane, which have high boiling points. For an output temperature of 300 °C, steam is considered to be the most suitable working fluid.

The heat source temperatures are expected to be 50 °C for the 150 °C heat pump and 150 °C for the 300 °C heat pump. Therefore, the temperature lifts required are 100 °C and 150 °C respectively. These lifts are very difficult to obtain with one-stage compressors, thus necessitating the development of multi-stage compressor systems including the development of a coaxial multi-stage compressor. Similar to the high-efficiency heat pump, optimization of the compressor rotor and development of a high performance heat exchanger are also important for the high-temperature heat pump.

The compression ratio is an important

Item \ Fiscal year	1984	1985	1986	1987	1988	1989	1990	1991
1. Research and evaluation of working fluids, materials, etc.								
2. Development of the system and research on operation								
(1) Research for systemization								
(2) Research on subsystems								
(a) High performance compression heat pump		Component elements		Bench plant (100 kW class)				
(b) Chemical heat storage techniques		Component elements		Bench plant (10,000 kcal class)	Interim evaluation			
(3) Development and operation test of a pilot system							Pilot system (1,000 kW class)	
3. Research on total system (heat utilization, heat sources, load levelling effect, etc.)								

Table 2 Super Heat Pump Energy Accumulation System R & D Plan

aspect of the high-temperature heat pump. It is necessary to develop a variable-compression displacement mechanism. Additionally, the large pressure difference between condenser and evaporator increases the benefits from utilizing a power-recovery turbine for the refrigerant expansion process.

The high-temperature heat pumps described above will be used primarily in industrial applications to produce high-temperature process steam by utilizing industrial waste heat as a heat source.

3.2 Chemical heat storage systems

There has been much research on heat storage systems utilizing chemical reactions and on chemical heat pumps. For example, the TEPIDUS project in Sweden utilized the chemical reaction heat of a Na_2S -water system, and the Rocket Research Institute in the U.S. is researching a system that relies on the heat of dilution of a sulfuric acid and water system. However, no such systems have been put into commercial operation.

Different from conventional sensible or latent heat storage systems, the heat output from a chemical heat storage system is the result of a chemical reaction. With an input of relatively low temperature heat, these systems can deliver high-temperature heat output. Compared to conventional sensible heat storage systems, their heat storage density can be more than 10 times as great. When considering the input/output temperature difference (in the case of latent heat storage, output temperature is less than input temperature), chemical heat storage systems effectively have a far greater storage density than latent heat storage systems. Because of these space-saving advantages, chemical heat storage systems are ideally applicable in buildings and are very promis-

ing heat storage systems for the future.

Chemical heat storage comes in two types: high-temperature heat storage as mentioned above, and low-temperature thermal storage for use in cooling systems. In this plan, R&D on these two types of chemical heat storage will occur in parallel.

3.2.1 High-temperature heat storage

A high-temperature heat storage system can use a heat pump to disassociate a chemical substance into two parts. The heat pump uses waste heat as a heat source and is driven by inexpensive nighttime electricity. When heat is required, these two chemical substances are recombined, and the resulting chemical reaction releases heat. As an example, consider the adsorption of water by zeolite. Dry zeolite and steam are stored separately, and when heat is needed, steam is released into the zeolite container. When the zeolite adsorbs the steam, the heat of adsorption is released. As this process continues, the adsorbing capacity of zeolite is decreased, and the zeolite and steam must be re-separated through dehydration. The heat pump performs this regeneration process during nighttime periods by applying heat to the zeolite.

The following reaction series are considered to be suitable for chemical heat storage systems: methacesis reaction of olefines, amine complex-forming reaction, hydration reaction of calcium and magnesium halides, and other organic and inorganic reactions. All of these reactions are reversible reactions that can generate high-temperature heat. When selecting an optimal reaction series, it is necessary to consider the following: i) occurrence of sub-reactions, ii) corrosiveness, iii) toxicity.

3.2.2 Low-temperature thermal storage

Recently, the electric power demand for cooling has increased considerably, and it is estimated that 1/3 of the power demand in the summer is due to cooling. Consequently, low-temperature thermal storage is the most effective means for power load-levelling.

At present, the most promising chemical reaction for low-temperature thermal storage is one that utilizes the hydration reaction of a gas. The principle of the reaction is simple. When injecting a gas such as freon under pressure into a tank of water, fine, icy crystals of freon hydrate are formed. The temperature of these crystals is usually 5 - 14 °C but can vary depending on conditions. Because of this temperature range, the crystals require less energy to produce than that needed to produce ice. In addition, the heat exchange efficiency is very high because the crystals are in direct contact with water. The crystals are fine and do not form blocks, and the mixture is relatively fluid even when the crystals comprise 50% of the mixture. Furthermore, the latent heat of fusion for these crystals is comparable to that of ice. Basic research concerning the conditions of hydrate formation and other aspects of this reaction is being conducted by the National Chemical Laboratory for Industry. From fiscal 1985 on, a private organization will undertake research for commercialization.

4. An Integrated System

A model of an integrated system that combines a compression heat pump and chemical heat storage units is shown in Figure 1. The heat pump in this system uses inexpensive nighttime electricity to perform low or high temperature thermal storage. During the daytime, the system provides space conditioning and hot water supply for office buildings or housing complexes.

(A) Cooling mode of operation: By circulating freon through the compressor-condenser-expander-low temperature thermal storage unit cycle, freon hydrate is generated within the thermal storage unit and is used for cooling. The heat rejected by the process is used for hot water heating.

(B) Heating mode of operation: By circulating freon through the compressor-condenser-expander-evaporator cycle, heat is extracted from waste gas or water and raised to a temperature sufficient for the regeneration reaction in the high-temperature heat storage unit. During heating periods, the heat-releasing chemical reaction in the heat storage unit is utilized to provide space heating and hot water supply.

A variety of optimal systems may be available for different industrial applications. These will be examined in the "Research

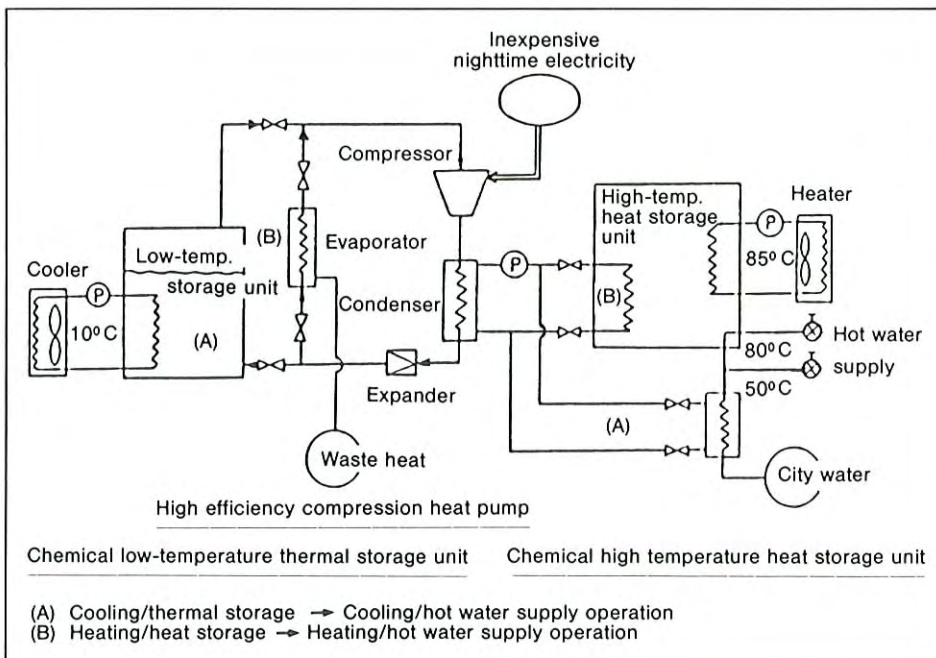


Fig. 1 Heating/Cooling System (An example for office buildings or housing complexes)

on Total System" and "Research for Systemization" parts of the R&D plan.

* Masanori Fukiwake, Senior Officer,
Agency of Industrial Science and
Technology, M.I.T.I.

A. Lamiani*

A New Laboratory for Test of Electric Heat Pumps In Italy

In accordance with the Italian Law 308/82 regarding the qualification of heating equipment, a new laboratory for the testing of heat pumps has been built at CESI S.p.A. in Milan, Italy.

The laboratory is able to perform the development, capacity and life-cycle tests on air/water and water/water heat pumps for residential applications, such as the heating of tap water and space heating.

The services of the laboratory are addressed to manufacturers, distributors and users and are to provide:

- means for the comparison of the performance of different types of heat pumps

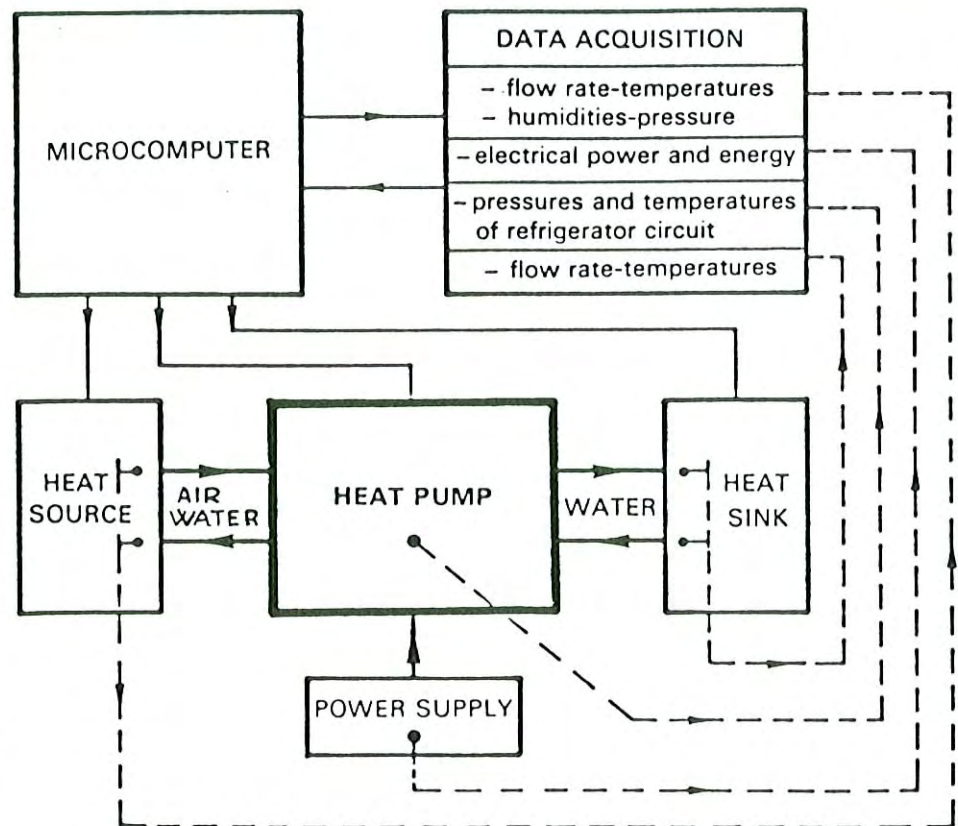


Fig. 1 Schematic Diagram of a Test Line

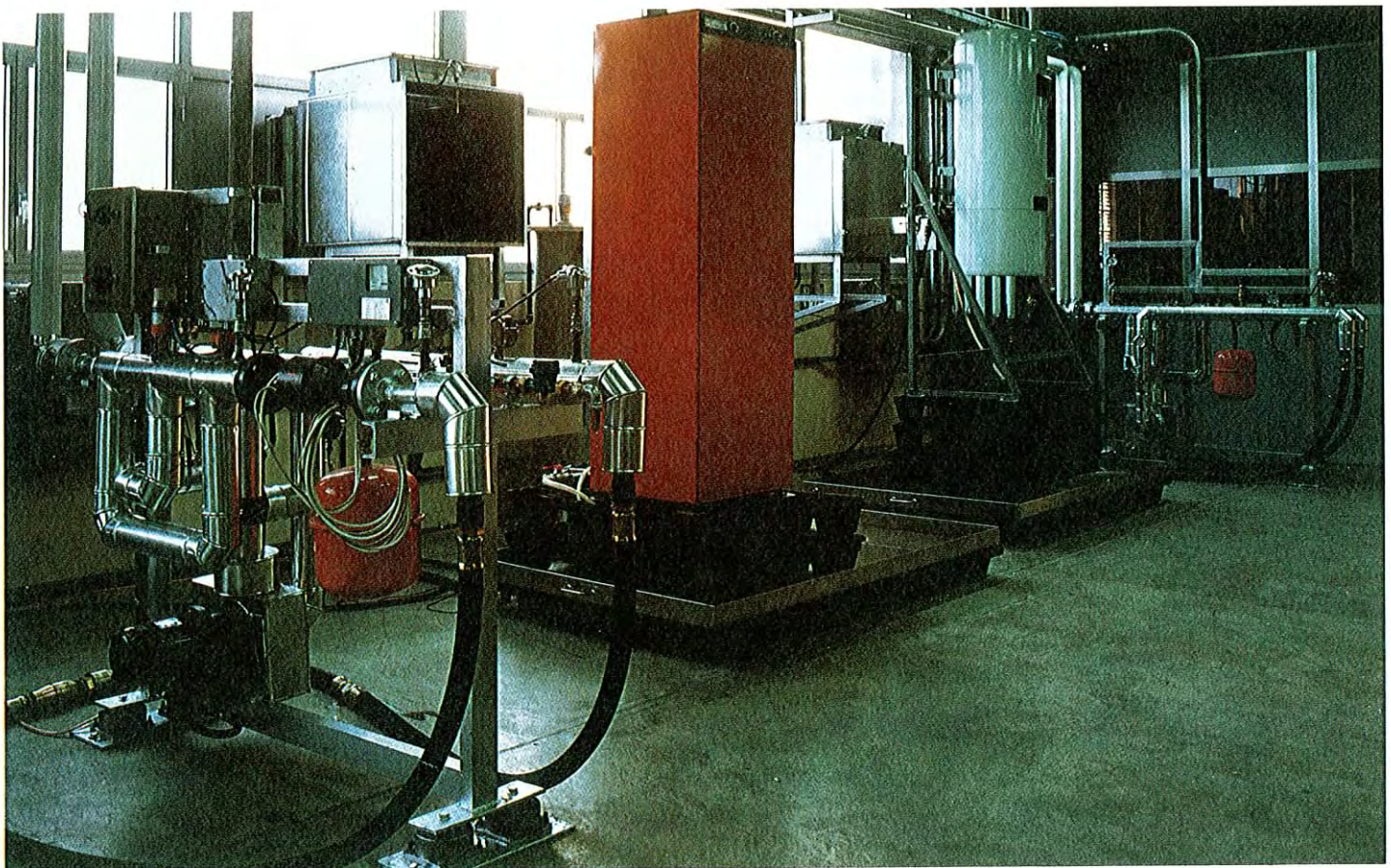


Photo View of the Electric Heat Pump Test Laboratory at CESI

under specified homogeneous test conditions.

- means to determine the reliability during the service life-time.
- support for the development of test methods that are reproducible and sufficiently representative of actual operating conditions.
- support of research and development studies.

The capabilities of the test facilities are:

Number of test lines: seven, two of which are used to test heat pumps for space heating purposes.

Test lines for heat pumps for tap water

heating: electrical power up to 9 kW.

Heat sources:

- conditioned indoor room with control of temperature from 18 to 22 °C and humidity from 60 to 80% (indoor air operation).
- outdoor air (outdoor operation).
- climatic chamber with control of air temperature from -20 to +40 °C and humidity from 30 to 90%.
- chiller for the control of water temperature from 5 to 50 °C.

Measurements:

- COP, utilizing different methods and under different operating conditions.

- important states of the thermodynamic working cycle.

- efficiency (through the evaluation of the energy taken from the heat source).

Control of test equipment, data acquisition and processing: by mini computer (see Fig. 1).

The laboratory works in close cooperation with the main industrial operators in the heat pump field, with ENEL (Italian electricity board), and with the Italian National Team of the IEA Heat Pump Center for a continuous exchange of information.

*Ing. A. Lamiani, CESI

C. De Nard*
E. Piantoni*

First Results of Energy-Saving Measures Subsidized by Law No. 308/1982 in Italy

As mentioned in Newsletter No. 2 Vol. 1, subsidies for energy-saving measures and the use of renewable energy sources in the industrial, residential and agricultural sectors are now available in Italy.

The classification of the subsidized measures and available funds for the main articles of the law are summarized in Table 1.

The request for subsidies regarding the use of heat pumps can be addressed to the articles 6,8,10,11 and 12 of law 308, but are generally referred to articles

6 and 8. These are both managed by the regional governments.

The rules for subsidy requests for articles 6 and 8 have been defined at the beginning of this year for some Italian regions (Lombardia, Umbria, Piemonte, etc.). The first results of a study on the subsidy requests are now available.

The results in the Lombardia region, which first enforced the distribution of subsidies, are reported in Table 2.

Phase Article	I	II	TOTAL
6 Buildings	600	1,400	2,000
6 (Solar Energy)		1,900	1,900
8 Industries	600	600	1,200

Table 2 Law 308/1982, Region Lombardia (Italy), Requests of Private Consumers

Article Number	Measure	Total Funds 10 ⁹ Lire	Funds Managed By
6	Use of renewable sources in residential, industrial and agricultural buildings	590	Regions
8	Energy conservation provisions on services and plants in industry and agriculture	300	Regions
10	Combined heat and power production - Heat from waste	510	Ministry of Industry
11	Demonstration projects of components and technologies for energy saving	51	Ministry of Industry
12	Energy production from renewable sources in agriculture	144	Regions
14	Small hydroelectric plants	70	Ministry of Industry

Table 1 Law No. 308/1982: Main Articles

The ongoing analysis of the data from the preliminary examination of the request for subsidies can be classified into:

- a) the residential sector
- b) industrial and agricultural sectors.

In the residential sector, the number of requests placed have been very high (approximately 3,900 solar collectors included) and are characterized by both conventional measures (double glazed windows, roof and wall insulation, replacement of obsolete boilers) and innovative measures (heat pumps, high efficiency boilers, solar collectors, solar cells, energy management systems, etc.)

In this sector, a strong incentive campaign to promote solar collectors for sanitary hot water production (30% reduction of investment costs from regional funds, and low interest loans for the remaining 70%) is under way from the Electricity Authority Board (ENEL).

Unfortunately, this successful campaign (1,900 requests) influenced the adoption of the competitive technologies in the pro-

duction of low-temperature heat, as in the case of heat pumps, which have had less favorable investment conditions together with quite high 'marginal costs' for electric energy.

In spite of this fact, the number of subsidy requests regarding heat pumps has been significant, showing a trend of increasing interest from the residential and tertiary users. From a total of 2000 requests (excluding solar collectors) received by the Lombardia region (article 6), 5% are heat pump related (1/3 of these are for space-heating purposes while the remaining 2/3 are for sanitary hot water production).

The distribution of the available funds for article 6 (first set of subsidies) started in December '84.

Regarding the industrial and agricultural sectors (article 8), optimization of processes is given more emphasis than technologies specifically for energy conservation. Companies prefer to modernize plant equipment and production lines.

In this regard, the automatization of the production and the substitution of obsolete equipment have been the main priority for subsidy requests (see Table 3).

Besides this, only a small number of requests have been related to heat pumps (electric or gas engine heat pumps), restricted to some applications in 'direct' energy recovery for process heat production.

Up to now, only the first set of subsidies in article 8 has been financed for a total amount of 27 billion lire.

These first results cannot be generalized,

Article	6		8	
Type	%	Requests	%	Requests ⁽¹⁾
- double glazing	6	240	---	
- insulation	23	900	9	110
- high effic. boilers	10	400	---	
- heat monitoring devices and controls	2.5	100	---	
- heat pump	2.5	100	2	25
- balancing	7	260	19	225
- heat recovery			36	435
- furnace and boilers			14	165
- equipment innovation			10	120
- phasing			3	35
- solar collectors	49	1900	7 ⁽²⁾	85
TOTAL	100	3900	100	1200

⁽¹⁾ - Preliminary aggregation of the requests

⁽²⁾ - Miscellaneous

Table 3 Type of Requests in Residential and Industrial Sectors for the Lombardia Region (308/1982 Law)

but they confirm that the penetration of heat pump technology is still limited, and further information and training must be done for the development of a significant market.

*C. De Nard
*E. Piantoni
CISE P.O. Box
12081 Milan (Italy)

K. Holzapfel*

ISH 1985

The International Trade Fair for Sanitary, Heating, and Air Conditioning Equipment, ISH, took place from March 19 to 23, 1985, in Frankfurt/Main, West Germany. This exhibition, held every two years, is probably the most significant and comprehensive trade show in the sanitary, heating and air conditioning field in Europe.

At the 1981 ISH, heat pumps were exhibited by over 150 suppliers; however in 1983, only about 100 suppliers displayed heat pumps, and in 1985, 84 different heat pump suppliers can be found in the index of manufacturers. This downward trend is also seen in the yearly decrease in sales of heat pumps.

The heat pump's reputation has suffered in the past among house and building owners. This was due to high prices of

ready-to-operate heat pump plants, operating problems, and breakdowns. In addition, the interest of installers in this technology faded after having installed some systems due to the many unforeseen difficulties that they encountered in the process.

Heat pump producers and suppliers expended a great deal of effort in attempting to provide help in this area. The efficiency of heat pumps was improved. The reliability was significantly increased by eliminating possible trouble sources.

The trouble-free connection of the heat pump to the heating system and the reliable operation has been guaranteed by the offering of complete systems utilizing preassembled packaged units. These units integrate the necessary system con-

trols and interconnection hardware into one package. However, this considerable expenditure has had little effect on the market with regard to heat pump sales. The downward trend in sales continued in 1984 for West Germany.

With regard to this situation in Germany, the IEA Heat Pump Center decided to develop a special show on Heat Pump Heating Systems for Residential Buildings with the support of the German Ministry of Research and Technology and in cooperation with manufacturers of electric heat pumps, represented by the Association of the Electro-Technical Industry, ZVEI.

Eight different typical applications in residential buildings were presented using two posters for each. Two of these applications will be explained in the following.

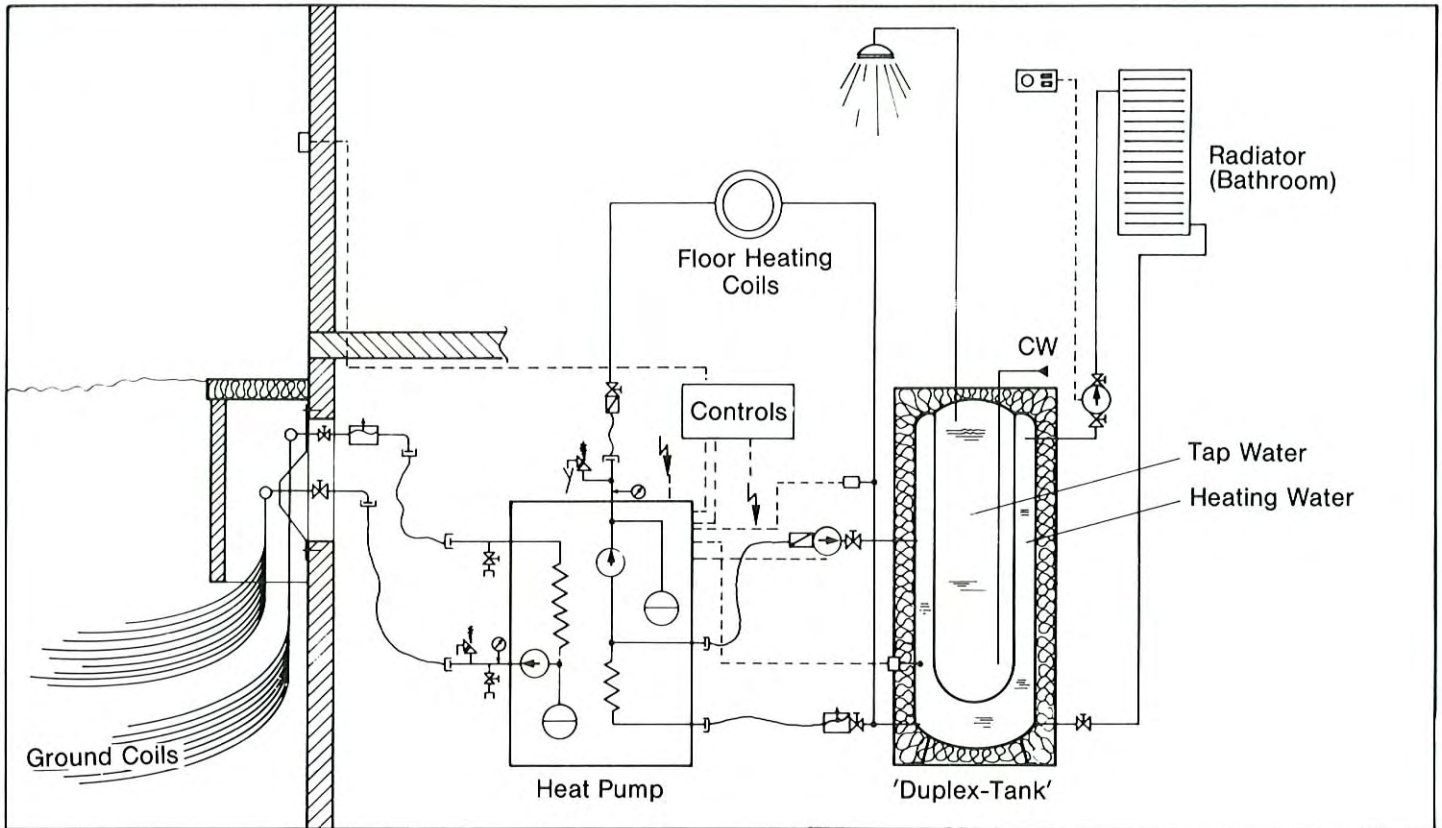


Fig. 1 Flow Diagram for System 1

System 1

This system is suited for single-family new constructions. The house described in this case study is located in northern Germany near Hamburg and has the following characteristics:

ground area = 500 m²
 floor area = 160 m²
 design heat load = 11.3 kW
 (at -12 °C according to DIN 4701)

Floor Heating System with:

flow temperature = 35 °C
 return temperature = 30 °C
 (at design conditions, -12 °C)

In this situation a monovalent ground source heat pump is a suitable solution (Fig. 1 and Fig. 2).

On an area of 220 m² a ground coil is horizontally imbedded in the garden at a depth of about 1 m. It consists of 8 separate circuits of polyethylene tubes with a diameter of 25 mm and a length of 100 m each. The collection and distribution manifolds are installed in a ground cavity in front of the window of the equipment room in the basement. In order to avoid freezing, the fluid circulating in the ground coil is 25% Ethyleneglycol and 75% water.

Due to the large thermal storage capability of the floor heating system, there is no

need for an additional buffer storage on the warm side of the heat pump. The return water temperature is controlled according to the outdoor temperature by appropriately cycling the heat pump. The large capacity of the heated floor slab ensures both long on-periods and long off-periods

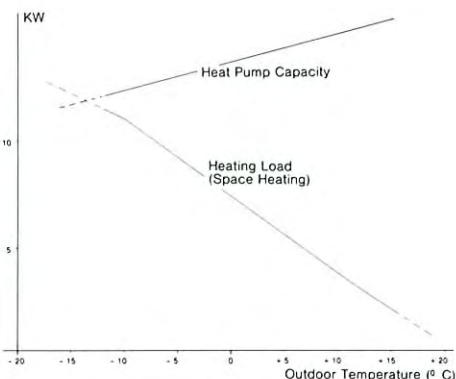


Fig. 2 System 1: Heat Pump Capacity and Heating Load vs. Outdoor Temperature

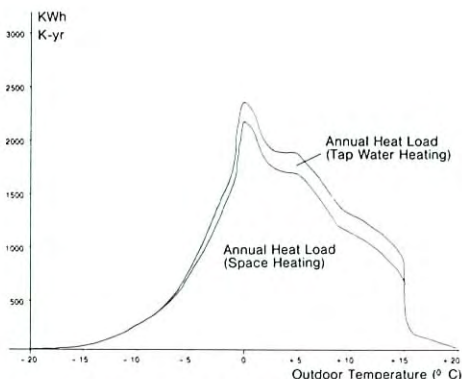


Fig. 3 System 1: Distribution of Annual Heating Load across Outdoor Temperature Bins

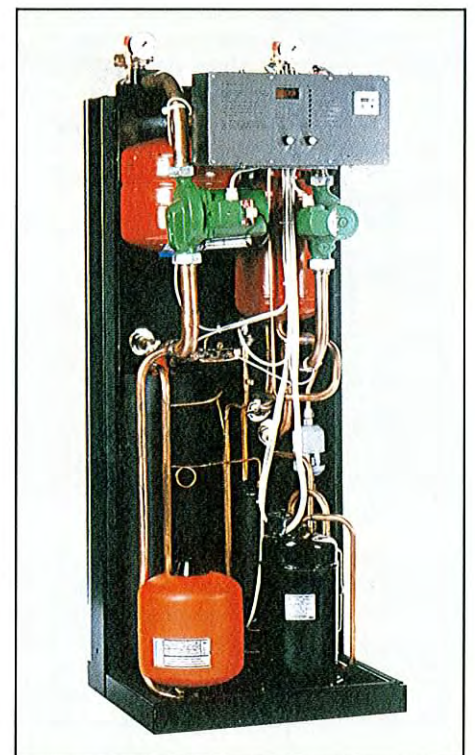


Photo 1 Brine-to-Water Heat Pump, Type CTR 17/S/6. The front cover has been removed in this photo. (Photograph by Löwe Pumpenfabrik GmbH, Lüneburg)

for the heat pump, thereby preventing disadvantages from too much cycling.

Tap water is heated in a so-called "Duplex Tank", a double-wall water storage tank with a large volume of heating water in the outer volume (170 l) and 330 l of tap water in the inner tank. With this configuration the heat pump can heat the tap water with a reasonable efficiency because the large storage volume allows for a low water temperature, slightly above 40 °C, and there is a large heat transfer surface area. This volume is sufficient for the average daily water consumption of a 4 person family. The duplex tank is heated on demand of a thermostat in the heating water volume. An advantageous feature of this configuration is the possibility to supply a radiator (for example, as an additional heating element in a bathroom) with a higher flow temperature than the floor heating system. The radiator is supplied from the heating water volume (outer volume) of the duplex tank with an extra circulating pump controlled by a simple room thermostat.

A tabulation of first costs and an energy consumption calculation follow, using cost and performance data of a heat pump from "Löwe Pumpenfabrik GmbH, Lüneburg." The heat pump, type CTH 17 S/6 (Photo 1), has a heating capacity of 11.9 kW at a brine temperature of 0 °C and a flow temperature of 35 °C. The COP is 3.8 at these conditions. An accurate and simple installation of this heat pump is ensured by the following means:

- The manufacturer offers the complete system, including control equipment, circulating pumps, etc.
- The heat pump unit contains circulating pumps for both the brine loop and for the heating water loop, expansion tanks on both sides, pressure gauges, safety relief valves, and the complete control system. Therefore, no site installation work is required for these parts.
- Flexible tubes with the appropriate connectors for connecting the heat pump to the flow and return pipes on both the cold and warm side are included in the package.
- System start-up is offered as well by the manufacturer for a fixed price.

First costs for this system are given below:

Heat pump unit	DM 11,975
Duplex tank	DM 2,174
Additional hydronic equipment (two circulating pumps, flexible hoses)	DM 657
Ground coil (including manifold and brine)	DM 2,400
Excavation work	DM 1,100

Installation, plumbing	
ground coil	8 h
heat pump	16 h
	24 h
Pipe insulation	DM 960
Installation, electrical	DM 600
System start-up	DM 900
	DM 350
	DM 21,116
VAT	DM 2,956
	DM 24,072
Total First Cost about	DM 24,000

Calculation of Energy Consumption:

According to VDI 2067 the annual heating load (Q_{Ha}) can be calculated by the following equation.

$$Q_{Ha} = b_{vH} \times Q_n$$

with:

Q_n = Design heating load (according to DIN 4701)

b_{vH} = Equivalent full load hours per year

and:
 $b_{vH} = f \cdot 24 \text{ hr/d} \cdot \left(z_z \cdot \frac{t_{im} - t_z}{20 - t_{amin}} + z_s \cdot \frac{t_{im} - t_s}{20 - t_{amin}} \right)$

With the following climatic factors for Hamburg:

z_z = 259.3 d/yr (heating days during heating period)

t_z = 5.2 °C (average outdoor temp. during heating period)

t_{amin} = -12 °C (design outdoor temp.)

t_s = 13.2 °C (average outdoor temp. during heating days in the summer months)

z_s = 35.4 d/yr (heating days during summer months)

And:

f = 0.78

t_{im} = 19.8 °C (mean room temp. in residential buildings)

Using the above, b_{vH} = 2350 hrs/yr and the annual heating load amounts to:

$$Q_{Ha} = 11.3 \text{ kW} \cdot 2350 \text{ hrs/yr} \\ = 27,000 \text{ kWh/yr}$$

The heat pump supplies 100% of this annual heating load. Figure 3 shows the distribution of this annual heating load across 1 K outdoor temperature bins. Displayed in this way, the area under any portion of the curve represents the amount of annual heating load occurring in the correspond-

ing range of outdoor temperatures. This graph can be used to determine the annual average operating conditions for the heat pump. A vertical line at the outdoor temperature of 3.5 °C divides the space heating curve into two parts having equal areas. Half of the annual space heating load is supplied during periods when the outdoor temperature is less than this value, and half is supplied for outdoor temperatures greater than 3.5 °C. At this outdoor temperature, a flow temperature of 30 °C is necessary for the floor heating system, and a conservative estimate of the heat pump brine temperature is 0 °C. The heat pump SPF is about 4 at these conditions, and this value can be used to calculate the annual average energy consumption of the heat pump for space heating:

Electricity consumption, space heating = 6,700 kWh/yr

Tap Water Heating:

Net heating load	3,000 kWh/yr
Heat losses of tank and pipes	1,000 kWh/yr
Total heating load	4,000 kWh/yr

Share of heat pump 100%

Electricity consumption 1,200 kWh/yr (SPF = 3.3 for average conditions: brine temp. = 4.5 °C, flow temp. = 45 °C)

Comparison with an Oil Boiler System:

A typical seasonal efficiency for a modern oil boiler system is 0.85 for space and tap water heating (with a separate, well insulated tap water tank). With this efficiency and the total heating load calculated above, the annual fuel consumption for an alternative boiler heating system can be determined:

Tap water heating load	4,000 kWh/yr
Space heating load	27,000 kWh/yr
Total heating load	31,000 kWh/yr

Fuel consumption 3,600 l/yr

Economic Considerations:

Electricity price DM 0.15/kWh (day/night weighted average)

Fuel oil price DM 0.80/l

Energy cost, heat pump DM 1,200/yr

Energy cost, conventional system (oil boiler) DM 2,900/yr

Energy cost savings DM 1,700/yr

Yearly tax reduction, assumed marginal tax rate = 30% (received for 10 years)
 = 0.3 · DM 2,400 DM 720/yr

Total Savings about DM 2,400/yr

The additional investment for the heat pump of about DM 10,000, compared to a modern oil boiler system, must be amortized and then compared to this savings of about DM 2,400 per year.

System 2

A second example system will be presented in the following (Fig. 4). The system is suited for retrofit in residential buildings with an existing oil boiler heating system. First cost and energy consumption are calculated with the data of a small air-to-water heat pump manufactured by "Siemens AG, Erlangen" (Photograph 2). The case study described here is a relatively new (1978) house located in southern Germany near Regensburg. The characteristics are:

Ground area	300 m ²
Floor area	160 m ²
Design heating load (at -16 °C according to DIN 4701)	11,2 kW
Oil boiler	23 kW
Radiators:	
flow temperature	65 °C
return temperature	55 °C
(at design conditions, -16 °C)	
Separate tap water tank (heated by the oil boiler through a heat exchanger and feed pump)	300 l

The heat pump applied in this case, type LI 4K, has a heating capacity of 4.2 kW at an air temperature of +7 °C and a flow

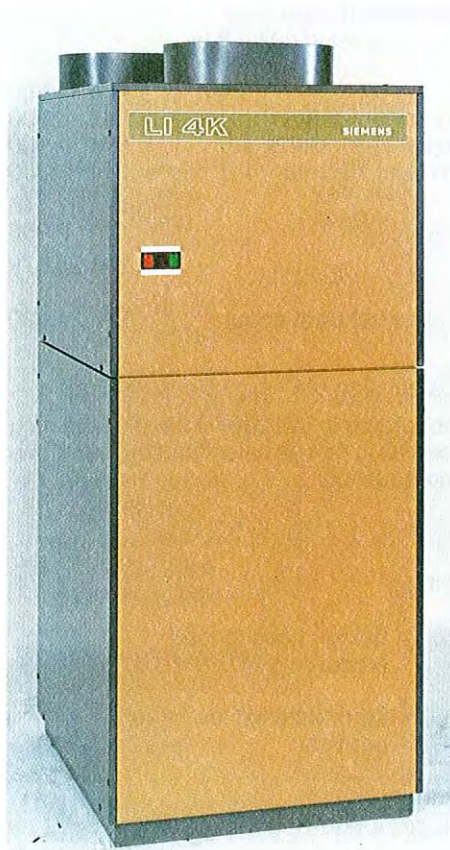


Photo 2 Air-to-Water Heat Pump, Type LI 4K (Photograph by Siemens AG, Erlangen)

temperature of 35 °C. The COP is 2.7 at these conditions. Figure 5 shows the heat pump capacity and space heating load as

a function of outdoor temperature. This heat pump is designed as a tap water heat pump with the additional purpose of supplying the space heating system during periods when there is no heat demand for tap water.

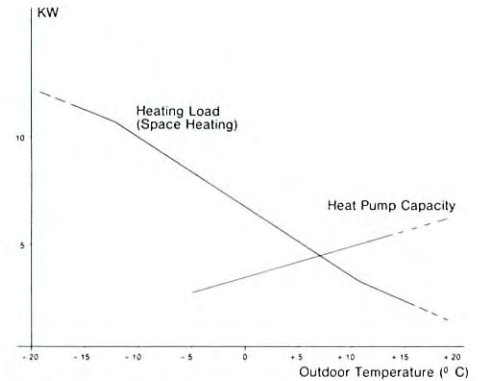


Fig. 5 System 2: Heat Pump Capacity and Heating Load vs. Outdoor Temperature

It is installed in the equipment room in the basement using outdoor air as a heat source. Both return and supply air are ducted through flexible hoses from a single window to the heat pump. The heat pump unit contains all necessary equipment including circulating pumps, mixing valves, controls, and heat exchanger for tap water heating. Therefore, installation effort is minimal. There are four different modes of system operation de-

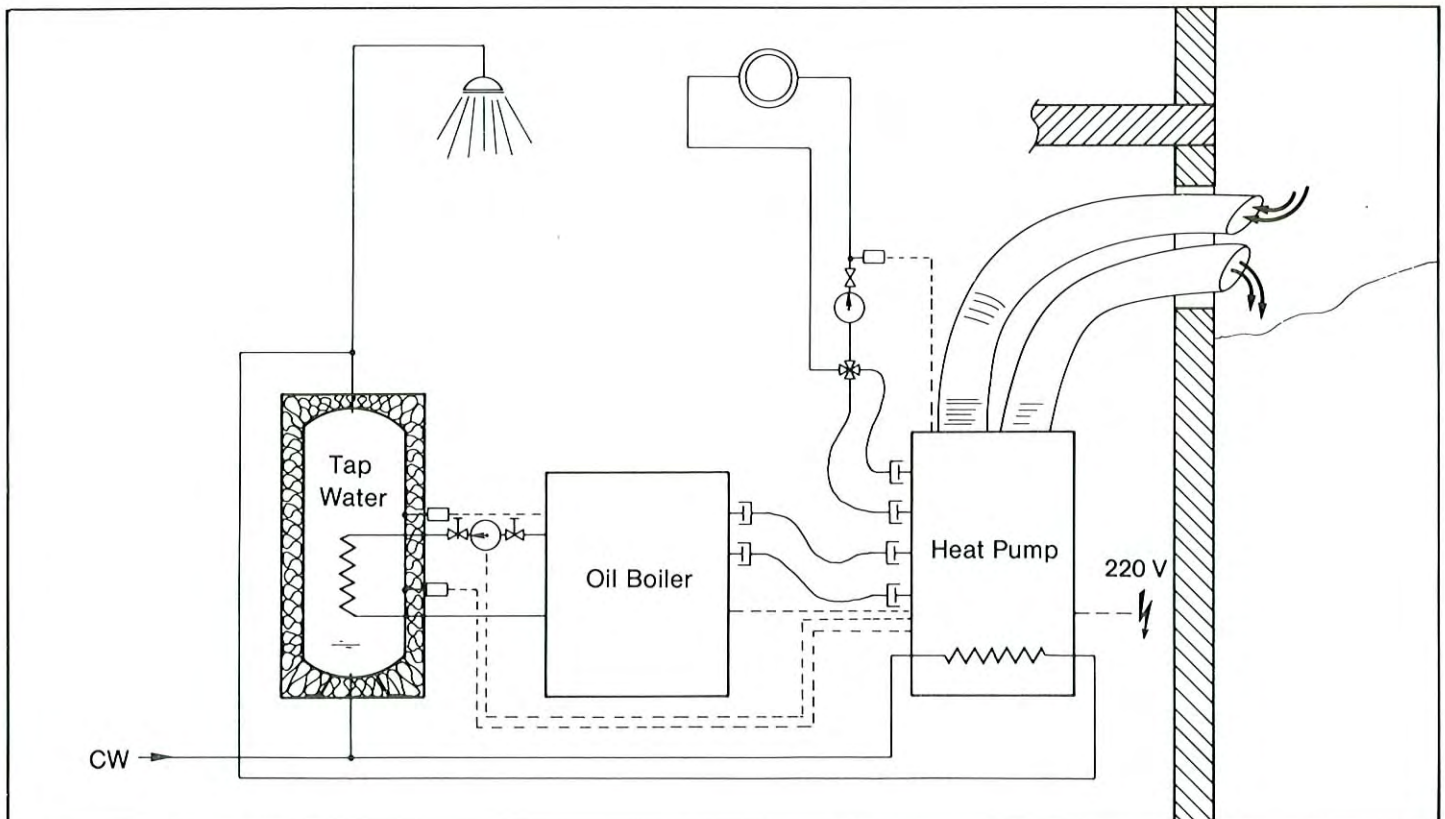
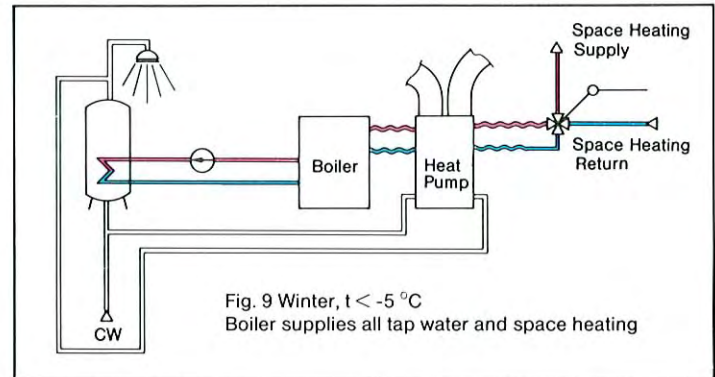
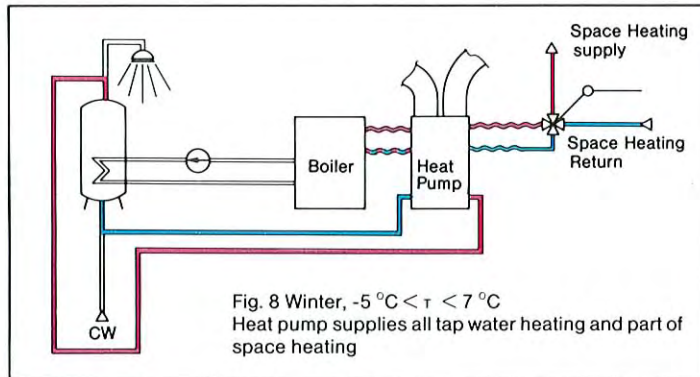
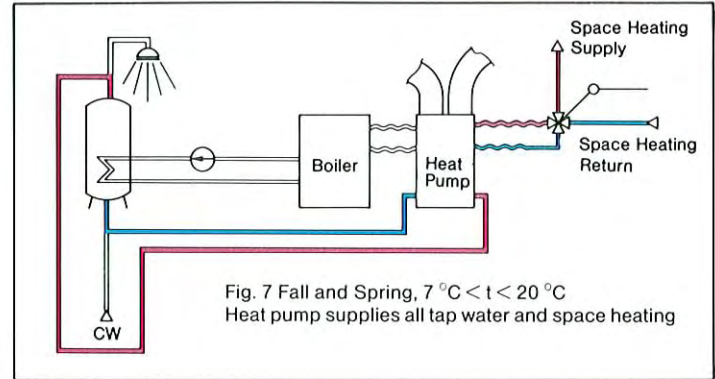
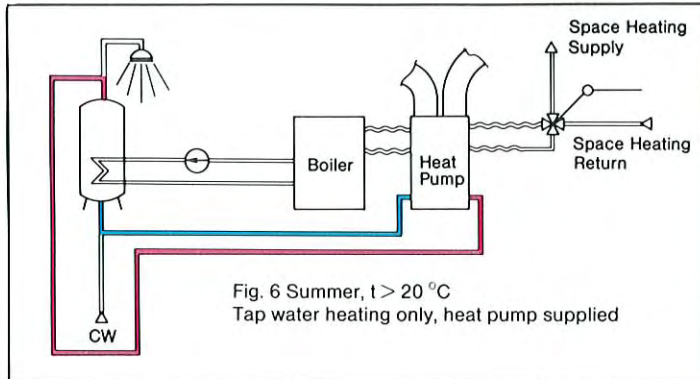


Fig. 4 Flow Diagram for System 2



pending on the outdoor temperature (Fig. 6-9). A microprocessor control system ensures that the heat pump is used to supply as much heating load as possible. The boiler is used only to supply the residual load during periods when the heat pump cannot meet the full demand and at outdoor temperatures below $-5\text{ }^{\circ}\text{C}$ when the heat pump is automatically switched off. A first cost tabulation for the system follows:

Heat pump unit	DM 6,530
Flexible hoses	DM 450
Flexible air ducts with a connector plate allowing both ducts to be connected to a single window	DM 845
Tap water thermostat	DM 70
Installation (plumbing) 14 hr	DM 560
Installation (electrical) 4 hr	DM 160
	DM 8,615
VAT	DM 1,206
	DM 9,821
Total First Cost about	DM 10,000

Annual Heat Load

The annual heat load of the house is calculated again according to VDI 2067. The climatic conditions of Regensburg are different than those of Hamburg. The climatic variables for Regensburg are (variable definitions given previously):

$$\begin{aligned} z_z &= 255.6 \text{ d} \\ t_z &= 4.1\text{ }^{\circ}\text{C} \\ t_{\text{amin}} &= -16\text{ }^{\circ}\text{C} \\ z_s &= 27.5 \text{ d} \\ t_s &= 13.1\text{ }^{\circ}\text{C} \end{aligned}$$

With the factor $f = 0.78$, $t_m = 19.8\text{ }^{\circ}\text{C}$ and the design heating load $Q_h = 11.2\text{ kW}$, the annual space heating load is:

$$Q_{\text{Ha}} = 25,000 \text{ kWh/yr}$$

The heating load for tap water is again assumed to be:

$$\text{Tap water heating load} = 4000 \text{ kWh/yr}$$

Therefore, the heating system must supply:

$$\text{Total heating load} = 29,000 \text{ kWh/yr}$$

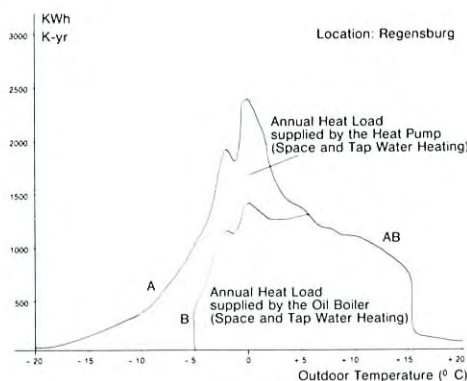


Fig. 10 System 2: Distribution of Annual Heating Load (A) and portion supplied by the Heat Pump (B) across Outdoor Temperature Bins

Figure 10 shows the distribution of annual heating load for space heating and tap water heating across outdoor temperature bins of 1 K (Curve A). Curve B gives the heat load covered by the heat pump for 1 K outdoor temperature intervals. The calculation of these curves requires climatic data giving the average number of

hours per year occurring in each 1 K temperature bin. Averages from the 1951 to 1970 period, as given in DIN 4710, were used for this purpose. The areas enclosed by the curves correspond to the total annual heating load and the amount supplied by the heat pump. The analysis shows that the heat pump supplies 66% of the total heating load, and the oil boiler supplies 34%. The average temperature conditions for the heat pump operation are therefore $+6\text{ }^{\circ}\text{C}$ outdoor temperature and a corresponding flow temperature of about $45\text{ }^{\circ}\text{C}$.

Energy Consumption, Heat Pump System:

The above calculations determine the amount of annual heating load supplied by the heat pump and the amount supplied by the auxiliary oil boiler. With efficiency assumptions for these components, the electricity and fuel consumption for this system can be calculated as follows:

$$\text{Total heating load (space and tap water)} = 29,000 \text{ kWh/yr}$$

$$\text{Heating load supplied by the heat pump} = 19,000 \text{ kWh/yr}$$

$$\text{Electricity consumption of the heat pump (average SPF for space and tap water heating} = 2.3) = 8,300 \text{ kWh/yr}$$

$$\text{Heating load supplied by the auxiliary oil boiler} = 10,000 \text{ kWh/yr}$$

$$\text{Fuel consumption of the oil boiler (seasonal efficiency} = 0.70) = 1,400 \text{ l/yr}$$

Comparison with an Oil Boiler System:

The alternative system uses an oil boiler to supply the total space and tap water heating load. The fuel consumption is calculated below:

Total heating load supplied by the oil boiler 29,000 kWh/yr

Fuel consumption of the oil boiler (seasonal efficiency = 0.65) 4,500 l/yr

Economic Considerations:

Electricity price DM 0.15/kWh (day/night weighted average)

Fuel oil price DM 0.80/l

Heat Pump System:

Electricity cost, heat pump DM 1,200

Fuel cost, oil boiler DM 1,100

Total energy cost DM 2,300

Conventional System:

Fuel cost, oil boiler DM 3,600

Energy cost savings from use of heat pump DM 1,300

The installation of the heat pump also results in tax savings. The house in this case study was a two-family house at the time of the heat pump purchase. For such a house, the entire cost of the heat pump can be deducted from taxable income in the first year. Assuming a marginal tax rate of 30%, this heat pump system, which costs DM 10,000, produces a DM 3,000 tax savings in the year of installation. Therefore, the net investment is DM 7,000, and this investment returns an annual savings of DM 1,300/yr.

The two systems presented here are exemplary for all eight systems displayed at the exhibition. All systems applied advanced heat pump units, developed for simplified and easy installation by utilizing factory-assembled auxiliary equipment in the units. More information on these systems is available at the IEA Heat Pump Center.

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

Schedule of Conferences and Trade Fairs

Jan 27-30, 1985;

Chicago, Illinois (USA); American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 1985 Winter Meeting; Contact: Ralph Burkowsky, Manager of Meetings, ASHRAE, Inc., 1791 Tullie Circle NE, Atlanta, GA 30329 (USA), phone (404) 636-8400, telex 705343

Jan 28-31, 1985;

Chicago, Illinois (USA); International Air-Conditioning, Heating, Refrigerating Exposition; Contact: Ralph Burkowsky, Manager of Meetings, ASHRAE, Inc., 1791 Tullie Circle NE, Atlanta, GA 30329 (USA), phone (404) 636-8400, telex 705343

Mar 4-7, 1985;

Stillwater, Oklahoma (USA); Closed-Loop/Ground-Coupled Heat Pump Workshop, Symposium and Equipment Exposition; Contact: Engineering Technology Extension, 313 Crutchfield, Stillwater, OK 74078 (USA)

Mar 19-23, 1985;

Frankfurt (Federal Republic of Germany); International Sanitation, Heating and Air Conditioning Trade Fair; Contact: IEA Heat Pump Center, c/o Fachinformationszentrum Energie, Physik, Mathematik GmbH, D-7514 Eggenstein-Leopoldshafen (FRG), phone (07247) 82-4541

Mar 29, 1985;

Washington, DC (USA); Conference on Applying Heat Pumps in Industry; Contact: M.L. Heavner, Government Institutes Inc., 966 Hungerford Drive 224, Rockville, MD (USA)

Apr 15-18, 1985;

Melbourne (Australia); Refrigeration, Air Conditioning & Heating Annual Conference and Exhibition; Contact: L.D. Elms, Conference Convenor, AIRAH - TECH '85, c/-L.D. Elms & Associates, P.O. Box 423, Caberwell 3124 (Australia)

May 8-10, 1985;

Vienna (Austria); Workshop on Solar-Assisted Heat Pumps with Ground-Coupled Storage; Contact: D. van Hattem, Commission of the European Communities, Joint Research Center, I-21020 Ispra (Italy)

May 20-21;**May 23-24, 1985;**

Vancouver, Washington; Spokane, Washington (USA); Workshop on Fundamentals of Heat Pumps; Contact: Northwest Public Power Association, P.O. Box 1307, Vancouver, WA 98666 (USA)

Jun 2-6, 1985;

Minneapolis, Minnesota (USA); International District Heating and Cooling Conference; Contact: International District Heating Association, 1735 Eye St. NW, Suite 611, Washington, D.C. 20006 (USA), phone (202) 223-2922

Jun 9-13, 1985;

Cincinnati, Ohio (USA); American Society of Mechanical Engineers Summer Annual Meeting; Contact: American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017 (USA), phone (212) 705-7722

Jun 19-21, 1985;

Trondheim (Norway); Meeting on Systems and Components for Large Heat Pumps; Contact: Norwegian Institute of Technology, IIR Trondheim Meeting, Director of Studies, N-7034 Trondheim-NTH (Norway)

Jun 23-26, 1985;

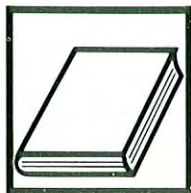
Honolulu, Hawaii (USA); American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Annual Meeting; Contact: Ralph Burkowsky, Manager of Meetings, ASHRAE, Inc., 1791 Tullie Circle NE, Atlanta, GA 30329 (USA), phone (404) 636-8400, telex 705343

Aug 13-16, 1985;

Stockholm (Sweden); Scandinavian Heat Pump Conference; Contact: Nordiska Kylmoetet och 2:a Nordiska Vaermepumpdagarna '85, c/o Stockholm Convention Bureau, Box 1617, S-11186 Stockholm (Sweden), phone 468230990, telex 11556 Congrex

Aug 25-30, 1985;

Copenhagen (Denmark); CLIMA 2000, First World Congress on HVAC&R Technology; Contact: Clima 2000 - Clima Ex, Ordrup Jagtvej 42B, DK-2920 Charlottenslund (Denmark), phone 01633230, telex 16600 fotex DK



Selected Book and Report Reviews

Hama, H., Imanishi, M., and Tani, S.; Combination Q: A Cooling, Heating, and Hot-Water Heat Pump Unit; Mitsubishi Denki Giho, Vol. 58, No. 5, 1984, pp. 12-15; Mitsubishi Electric Corporation, Wakayama 640, Wakayama Works, Japan; (in Japanese)

This article describes the specifications and control characteristics of a new air-to-water heat pump unit that supplies space cooling (5 °C), space heating (55 °C), and hot-water supply (75 °C). The unit can perform space conditioning and hot-water supply simultaneously. In the summer, the energy source for hot-water supply is the rejected heat from the space cooling process, while atmospheric heat is used as the source during the rest of the year. The unit achieves its greatest hot-water heating capacity in the winter time.

Air Conditioning and Compressor Division, Toshiba Corporation; Toshiba Inverter-Controlled Air Conditioners; Toshiba Corporation Corporate Paper, 1984, p. 1-4; Toshiba Corporation, Tokyo 105 Japan; (in English)

This report investigates the use of electronic inverters to control small and medium-sized air-conditioners and heat pumps. Both the evolution of inverter use in this application and the benefits from their use are discussed. By controlling the frequency of electric power supplied to

the air-conditioner compressor and thus controlling its rotational speed, an electronic inverter can vary the output of the air-conditioner according to the magnitude of cooling/heating loads. Inverters have long been used in industrial applications, but only recently have advances in electronics reduced the cost, size, and complexity of inverters to the point where use in small and medium-sized air-conditioners is practical.

Seher, D., and Stephan, K.; Sorption Heat Pump System Working Substances; BMFT-FB-T 85-045, Bundesministerium fuer Forschung und Technologie (BMFT), D-5300 Bonn 2 (Federal Republic of Germany), May 1985, 108 p. (in German)

The working fluids used in absorption refrigeration processes are generally not appropriate for sorption heat pumps and heat transformers. This research program investigated more suitable working substances.

A selection of possible working mixtures was made by means of a catalog of criteria, however, the thermodynamic properties of suitable fluids were not known in many cases. Therefore, the thermal stability, the viscosity and the vapor-liquid equilibrium were measured. In order to facilitate a complete thermodynamic computation, the process material properties

were calculated by appropriate procedures using the measured data points.

The investigation revealed that the mixture trifluorethanol-E181 has some important advantages: a small amount of energy is required for the liquid pumps, no rectification device is needed, crystallization does not occur, a large temperature lift in a heat transformer can be achieved.

Schneider, C., and Doetsch, P.; Development of a Heat Pump System for Saving Primary Energy; BMFT-FB-T 85-035, Bundesministerium fuer Forschung und Technologie (BMFT), D-5300 Bonn 2 (Federal Republic of Germany), May 1985, 35 p. (in German)

The development of a heat pump for heating or cooling driven by atmospheric combustion is described. The operating principle of this heat pump, the Vuilleumier heat pump, was experimentally tested, and a COP of 2.2 with a source temperature of 10 °C was achieved.

Compared with a heat pump driven by an internal combustion engine, this system has advantages including less pollution emissions, less noise, and less mechanical friction and wear caused by the combustion products. However, development of this system into a marketable product is difficult due to high cost and the patent situation.

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2. Gas Engine Heat Pumps in Japan
3. Heat Pumps in Sweden
4. Heat Pump Sales in Member-Countries
5. Sample Installations of Electric Heat Pumps
6. Performance Investigations of Heat Pumps in the USA
7. Current Activities in the Heat Pump Center
8. Schedule of Conferences and Trade Fairs

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