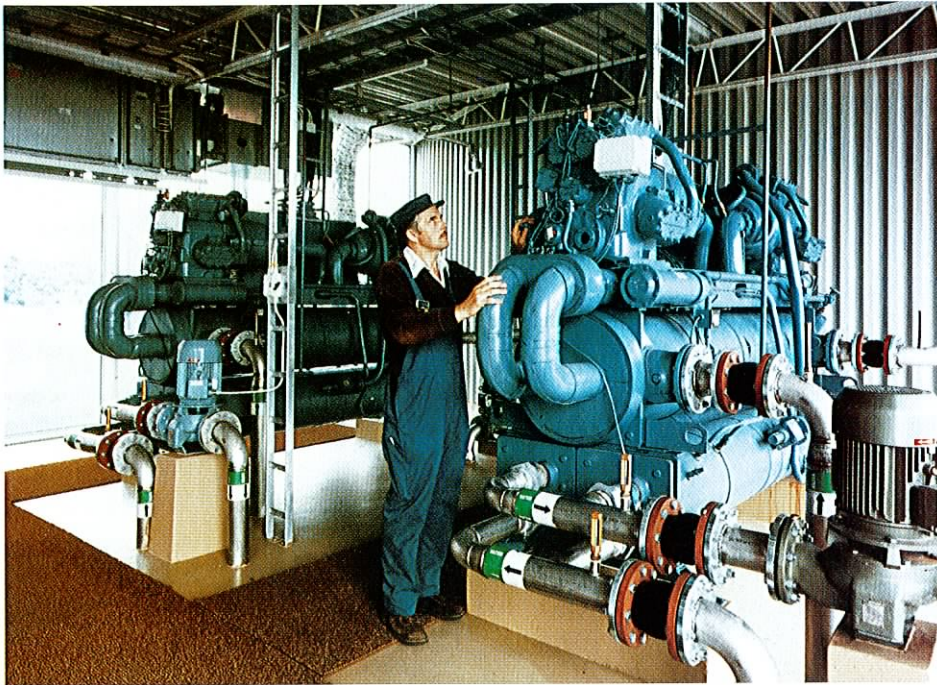


# NEWS LETTER

PERIODICAL OF THE  
IEA HEAT PUMP CENTER

IEA  heat pump  
center

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Two 300 kW<sub>h</sub> heat pumps in Sweden -- what are the environmental hazards of their operation? (see page 15)

**M. Meal\***

## Newsletter Focus: Environmental Aspects of Heat Pump Applications

*"It is today almost axiomatic that the development of energy technologies must go hand in hand with a proper concern for the environment. The lesson to be learned from past experience is that the full impact of technology deployment has unfortunately been recognised only when adverse effects have reached significant levels--insufficient attention has been given to predicting harmful effects in advance and building remedies into the development of the technology as an integrated system. Remedies must be both effective and affordable."--excerpt from the International Energy Agency Report, "Energy Technology Policy," published in 1985 [1].*

In this issue of the Heat Pump Center Newsletter, we are focusing on the environmental aspects of heat pump applications. While heat pump development is being promoted to save energy and reduce oil imports, all aspects of heat pump applications -from reliability problems to macro-economic effects of widespread de-

velopment- must be understood. As the International Energy Agency has recognized in its report on policies for energy technology development, environmental consequences -negative as well as positive- should not be overlooked. Clarification of environmental benefits of heat pump applications can help to encourage heat

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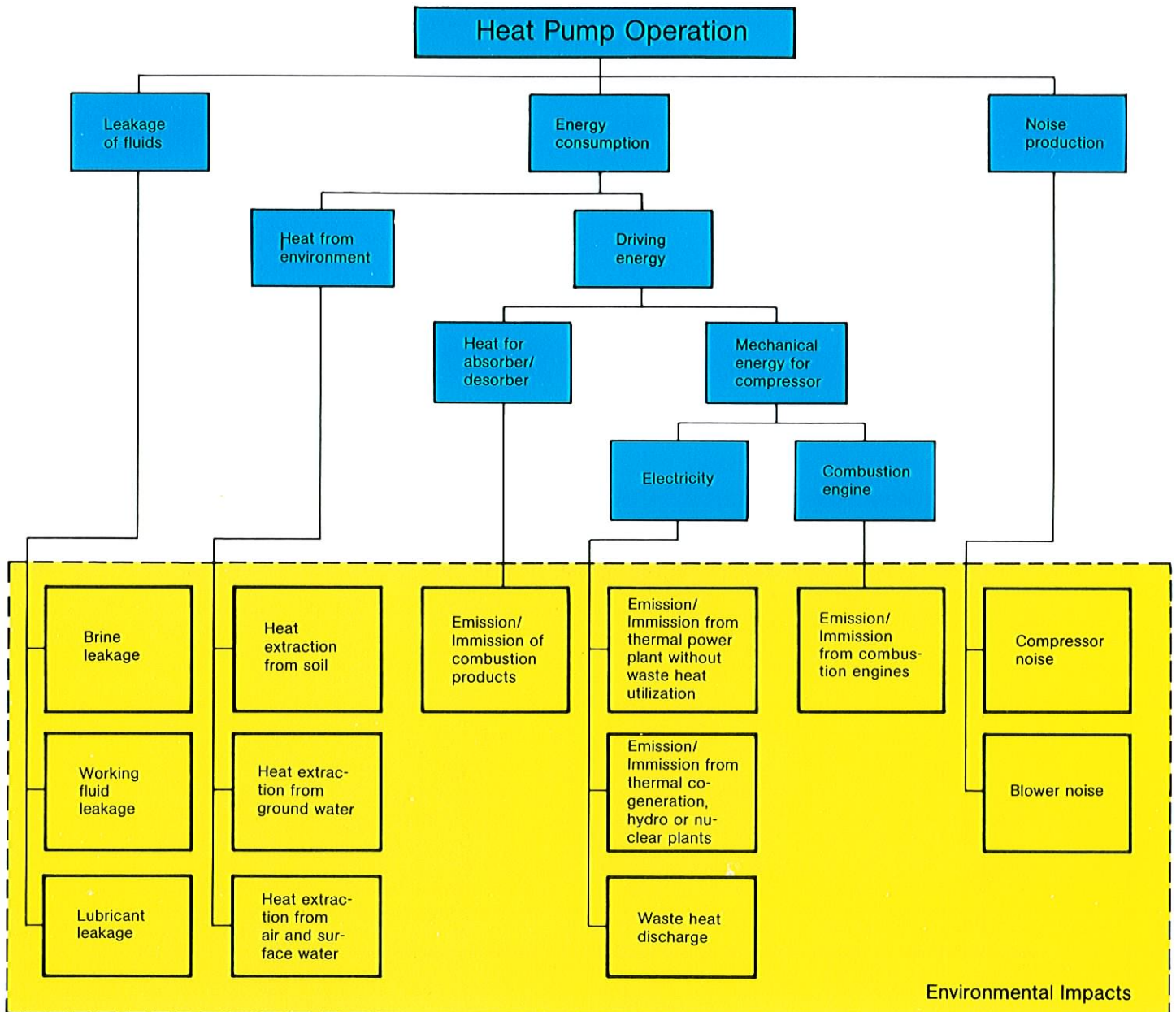


Fig. 1 Environmental effects of heat pump operation [7]

pump development; understanding environmental risks is the first step to their control. In this issue, we have brought together some of the more recent work on environmental aspects of heat pump applications, in order to provide a condensed overview of the key issues in their assessment.

What are the benefits and risks of heat pumps to our environment? This question needs to be broken down further:

1. What are the emissions associated with heat pumps, compared to other heating technologies?
2. What are the risks to humans and the environment associated with these emissions?
3. What is the present state of the environment, and what are the problem areas?

4. And finally, how can hazardous emission be reduced and controlled, what research, development and demonstration programs are necessary, and what are the implications for government policies?

Most of the articles in this Newsletter focus on the first question, quantifying the environmental effects of heat pumps and comparing them to other heating alternatives. The potential environmental effects of heat pump operation are summarized in Figure 1. In Table 1, the impact of emissions resulting from heat pump operation on human health and the environment (question 2 above) are described. From this table, it is clear that environmental hazards are varied in both type and scale of impact; many pollutants and their effects cross national boundaries.

### The State of the Environment

Under the direction of the Organization for Economic Cooperation and Development (OECD) and the International Energy Agency (IEA), present conditions, historical trends, and future projections concerning the environment are monitored and compared among participating countries. Just as the OECD and the IEA have been encouraging reduced dependence on imported oil through international research and development programs and information-sharing activities (such as the IEA Heat Pump Center), they are also promoting environmental protection and improvement on local, regional, and international scales.

Last year, the OECD published its "State of the Environment 1985" report [2]. This report reviews progress and problems with environmental protection in the OECD

Source of Emissions in Heat Pump Applications	Pollutant	Effect on Human Health	Effect on the Environment
Combustion of fossil fuels: e.g. electricity generation used to operate electric heat pump, fossil-fuel-fired heat pump (engine-driven, absorption)	Oxides of Sulfur (SO <sub>x</sub> ) (only from fuels containing sulfur, e.g. diesel and fuel oil)	Can impair lung function	Acid rain/acid deposition, causing damage to aquatic and forest ecosystems  Can reduce visibility
	Oxides of Nitrogen (NO <sub>x</sub> )	May contribute to pulmonary and eye/nose/throat irritations	Acid rain/acid deposition, NO <sub>x</sub> play a role in formation of photochemical smog
	Carbon Monoxide (CO)	Interferes with absorption of oxygen by red blood cells Can affect cardiovascular/nervous system	
	Hydrocarbons (HC)	Possible carcinogens	Role in formation of photochemical oxidant
	Particulates	Some particulate matter toxic/carcinogenic. Respiratory system irritant	Decreased visibility, dust and soot deposition on buildings
	Carbon Dioxide (CO <sub>2</sub> )		Possible increase in global surface temperature
Fluid leakage (Refrigerant, brine, oil, etc.)	Chlorofluorocarbons (refrigerants such as R12, R11)	Possible increase in incidence of skin cancers	Possible decomposition of stratospheric ozone layer, reducing natural screening of UV radiation, possibly resulting in global climate changes, damage to animal and plant life
	Toxic chemicals (refrigerants, brines, oils)	Contamination of drinking water supplies	Hazards to aquatic and soil ecosystems
Ground and water source heat pumps	Heat extraction from soil/ground water/lakes, etc.	Decreased availability of heat source to additional users	Change in lake/sea/ground/ ground water temperatures, and therefore effect on aquatic and soil ecosystems

Table 1. Sources and hazards of heat pump environmental impacts [2]

countries. The report concludes that while progress has been made in the last 15 years (Japan, for example, has increased its gross domestic product (GDP) by 60% while decreasing emissions of sulfur dioxide by 77%), several "major problems" remain. Those problems identified that are specifically related to heat pump applications include:

#### Air Pollution

- "Large scale pollution problems resulting from major air pollutants (SO<sub>2</sub>, NO<sub>x</sub>, HC);"
- "Potential global impacts related to increased concentrations of CO<sub>2</sub> in the atmosphere and to the release of fluorocarbons;"

#### Inland Waters

- "Pollution of surface water and ground water;"

- "Drinking water quality: . . . chemical pollution remains a matter of concern;"

#### Toxic Substances

- "Problems also remain with the screening and testing of existing chemicals, since comparatively few have been adequately tested for their effects on human health and the environment;"

#### Noise

- "The general acoustic environment of OECD countries has not improved."

#### Environmental Conditions in HPC Member Countries

In conjunction with its state of the environment report, the OECD compiled and published data on environmental conditions in its member countries in the report, "OECD Environmental Data, Compendium 1985."

[3] This report was prepared in response to an OECD Council Recommendation to work towards "a core set of comparable environmental information for OECD member countries." Some of these data for HPC member countries are presented in Figures 2 and 3. Figures 2 and 3 show emissions of traditional air pollutants (SO<sub>2</sub>, NO<sub>x</sub>, carbon monoxide, hydrocarbons and particulates) per capita and per unit energy consumption. Caution should be used in drawing conclusions from these figures; data collection methods as well as impacts of these emissions vary among pollutants and among countries.

#### RD&D Programs

In order to protect and improve the environment, research and development is required on both national and international levels. In most OECD countries, this R&D is funded by the government. Figure 4 shows public R&D financing for environmental protection in the HPC member

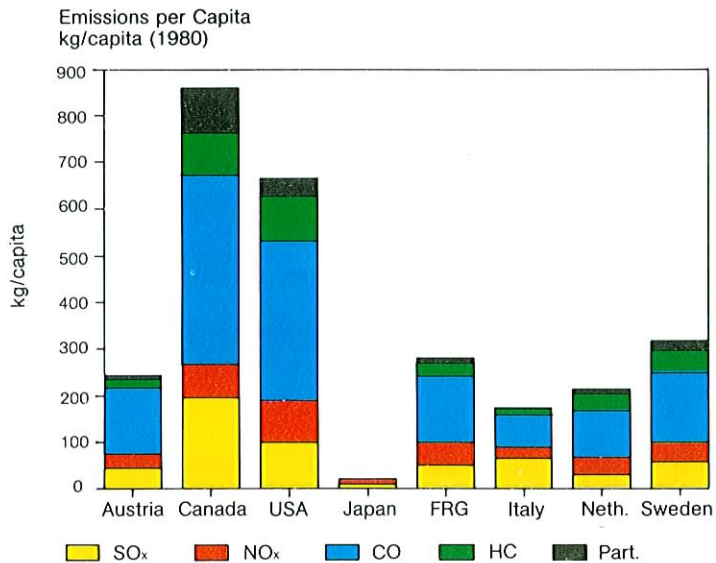


Fig. 2. Air pollutant emissions per capita, HPC member countries, 1980 (CO, HC and Particulate data not available for Japan) [3]

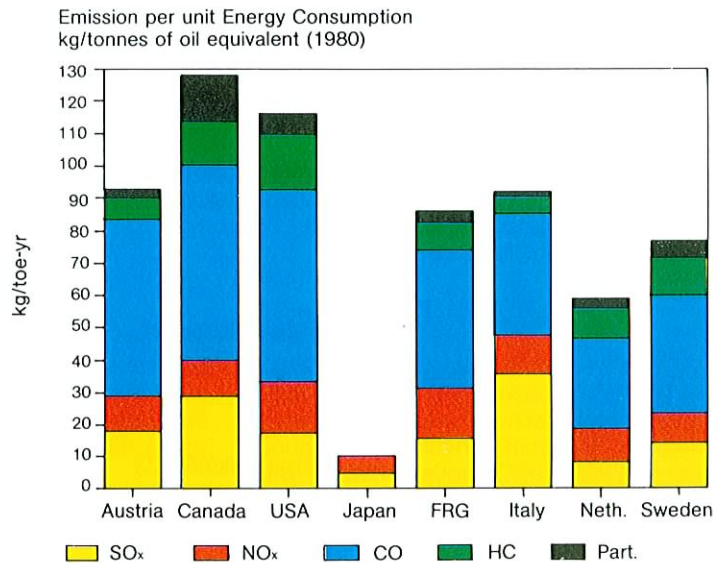


Fig. 3. Air pollutant emissions per unit energy consumption, HPC member countries, 1980 (CO, HC and Particulate data not available for Japan) [3]

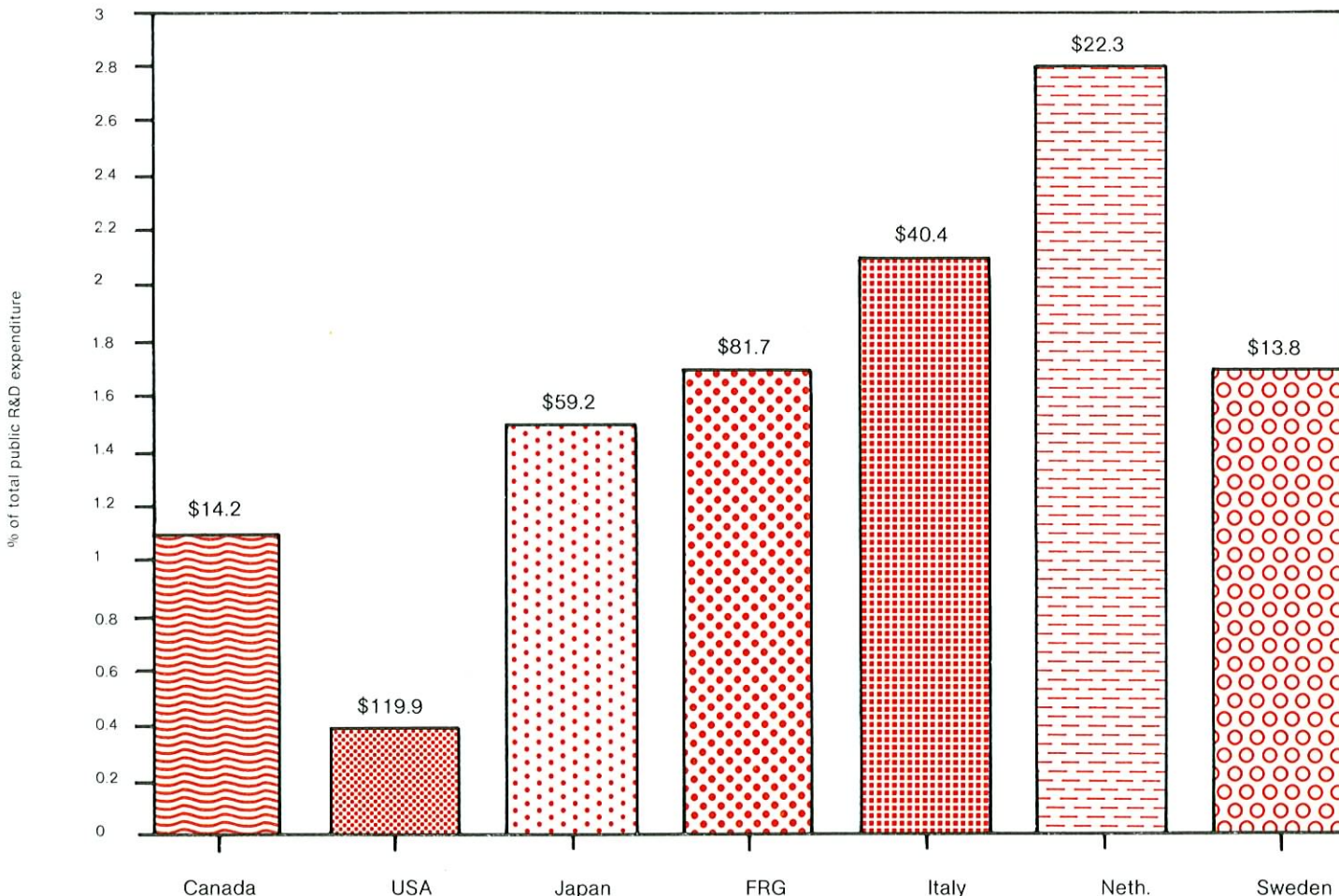


Fig. 4. Public R&D for environmental protection, 1983, as a % of total R&D, with total in 1975 US \$, HPC member countries (1981 data for Japan, Austria not available) [3]

countries as a percentage of total R&D expenditure (Austrian data not available).

Both the IEA and the OECD have supported environmental protection programs on an international level, recognizing the links between energy systems and

environmental insults. Details on these projects can be found in references 1-6.

The articles in this Newsletter are not intended to be definitive or comprehensive on the subject of environmental aspects of heat pump applications. Environmental

questions are inherently complex and controversial. In the process of preparing this Newsletter, the HPC has conducted an extensive literature review of the subject. In this issue, we have listed some related publications by subtopic. For those Newsletter readers interested in pursuing

these questions further, this literature review, with complete abstracts and citations, is available from the HPC for DM 25. Ordering information is included in this issue.

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## Electric Heat Pumps Result in a Reduction of Air Pollutants

*This article is based on a study recently completed at the IEA Heat Pump Center's Analysis Center in Graz, Austria. Results from this study were first presented at the IEA Heat Pump Center Experts' Workshop on Electric Heat Pumps, held in November in Graz, in the paper, "Environmental Effects of Heat Pump Application." The authors' results for comparison of oil-fired boiler and electric heat pump air pollutant emissions are summarized in this article. While a number of other environmental questions are not addressed here, the article presents important quantitative information on the issue of comparison of air pollutant emissions. Full details, assumptions not included here and further discussion can be found in that paper.*

In the years following the two oil price shocks, interest in heat pumps focused on opportunities for energy conservation and oil substitution. Recently, the environmental impacts of heat pump applications have received increased attention.

In this article, the tradeoffs in terms of resulting air pollution between operating an electric heat pump and a conventional oil-fired boiler are described. On the one hand, replacement of an oil-fired boiler with an electric heat pump completely eliminates emissions on site. On the other hand, this reduction in local emissions is offset by an increase in emissions due to electricity production at a power plant located somewhere else. It is not immediately obvious whether the net change in air pollution is positive or negative. In this article, we present calculations that show that under all but the worst-case assumptions, the electric heat pump results in a net reduction in emissions and immissions of air pollutants.

It should be noted that an assessment of tradeoffs in environmental impacts is not straightforward, and can quickly become clouded and misleading unless simplifying assumptions are made at the outset. For example, the environmental hazards of acid rain from sulfur dioxide emissions from a coal-fired power plant can not be directly compared to the hazards of local emissions of hydrocarbons from an oil-fired boiler. The pollutants, the area and intensity of exposure, and type of damage are all quite different. For this reason, our analysis compares emissions per unit of heat delivered by type of pollutant, and immissions (resulting ambient concentrations) on a local scale.

### Factors that Determine the Level of Emissions

For a given heating requirement, emissions resulting from space heating supplied by an on-site direct combustion system depend on:

- Type of fuel burned
- Heating system efficiency
- Pollution control devices used, if any.

Emissions resulting from space heating supplied by an electric heat pump depend on:

- Heat pump system efficiency (SPF)
- Type and mix of power plants used to generate electricity

- For each power plant in the mix:

- fuel type
- power plant efficiency
- pollution control devices used, if any.

One should also account for electricity transmission losses in the case of the heat pump/power plant, and refinery and distribution losses in the case of the boiler. For purposes of our study, these losses were assumed to be the same order of magnitude and have not been included in our calculations.

### Oil Substitution Factor

The oil substitution factor,  $\gamma$ , is an important parameter for assessment of the effects (both energy and environmental) of substitution of oil with some other energy source (e.g. electricity). The oil substitution factor is the ratio of oil savings to consumption of the alternative energy source, e.g. electricity. Comparing an electric heat pump system with an oil-fired boiler system, the oil substitution factor is the ratio of the seasonal performance factor (SPF) of the heat pump to the mean annual boiler efficiency,  $e_b$ :

$$\gamma = \frac{\text{oil savings}}{\text{electricity consumption}} = \frac{\text{SPF}}{e_b}$$

Assuming the mean annual efficiency of boilers ranges from 0.6 to 0.8, and heat pump SPF's range from 2.4 to 3.6, the

Pollutant	Specific Emission, kg/TJ	
	Stoves	Boilers
SO <sub>2</sub>	140	140
NO <sub>x</sub>	27	50
CO	110	70
Aldehyde	?	4
Benzo(a)pyrene (C <sub>20</sub> H <sub>12</sub> )	?	(8)10 <sup>-6</sup>
Particulates including soot (assumed: Bacharach No. 2)	143	12

Table 1. Specific emissions (input related) of oil-fired heating systems, kg/TJ [1].

Emittant	Coal		Oil		Gas
	s* = 1%	2.5%	s = 1%	2.5%	
SO <sub>2</sub>	633	1583	500	1250	10
NO <sub>x</sub>	250		250		85
CO	17		3.4		0.5
Aldehydes	0.14		2		1
Benzo(a)pyrene (C <sub>20</sub> H <sub>12</sub> )	(3)10 <sup>-6</sup>		(2)10 <sup>-6</sup>		(0.3)10 <sup>-6</sup>
Particulates	17		40		0.1

\* Sulphur content of fuel

Table 2. Specific emissions (input related) of power plants, without FGD or Denox, kg/TJ [1].

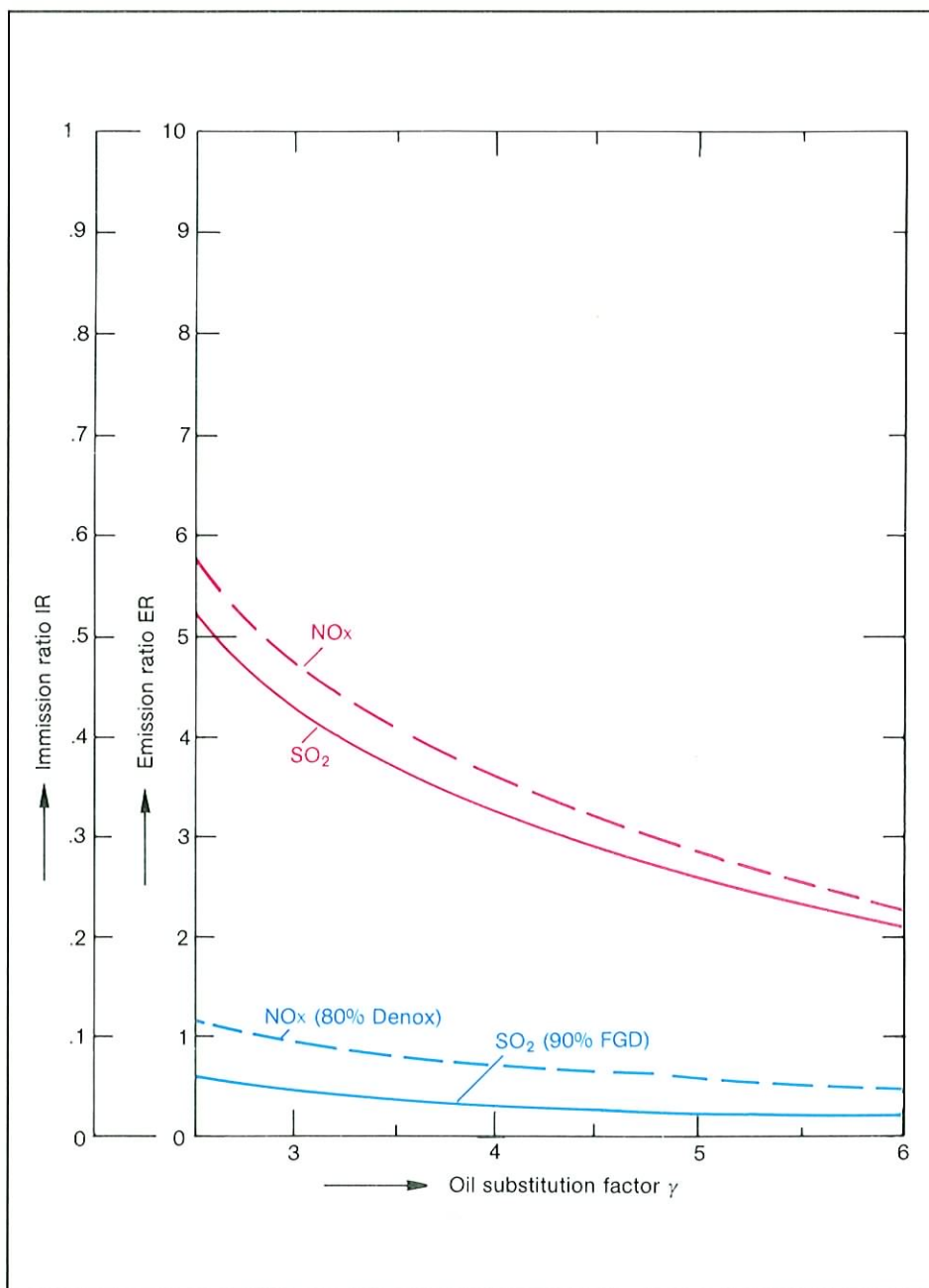


Fig. 1. SO<sub>2</sub> and NO<sub>x</sub> emission ratios, electric heat pump (coal-fired power plant, s=1%, e<sub>pp</sub>=0.35) to oil-fired boiler, vs. oil substitution factor.

range in oil substitution factors for electric heat pumps versus oil-fired boilers is from 3 to 6. A similar but more complex relation can be derived for heat pumps operating in the bivalent mode, but has not been included here for simplicity.

**Primary energy consumption**

Consumption of primary energy to produce the electricity for the heat pump is determined by the heat pump SPF and the efficiency of the power plant, e<sub>pp</sub>. The ratio of primary energy to run the electric heat pump to the primary energy to fuel the boiler then becomes:

$$\frac{\text{power plant energy input}}{\text{boiler energy input}} = \frac{e_b}{e_{pp} \times \text{SPF}} = \frac{1}{e_{pp}} \times \frac{1}{\gamma}$$

**Specific Emissions**

Emissions per unit of energy consumed are given in Table 1 for residential oil-fired boilers (extra-light fuel oil, s=0.3%) and in Table 2 for thermal power plants using different fuels. Except for SO<sub>2</sub> and particulates, there is considerable discrepancy in the literature; specified values are from a recent German study [1]. The values in Table 2 are for the assumed base case power plant with state-of-the-art particulate controls but no flue-gas desulfurization (FGD) or denitrification (Denox). Reduced values for SO<sub>2</sub> and NO<sub>x</sub> can be calculated if the efficiencies of FGD and Denox are known.

**Emission Comparisons**

Total emissions are simply the specific emissions (E<sub>b</sub> for the boiler, E<sub>pp</sub> for the power plant) times the amount of energy consumed to meet the heating requirement. From the equations above, it becomes straightforward to calculate the ratio of emissions resulting from operation of an electric heat pump to emissions from an oil-fired boiler for a given heat load. The "emission ratio," ER, is:

$$ER = \frac{E_{pp} \times \text{power plant energy input}}{E_b \times \text{boiler energy input}} = \frac{E_{pp}}{E_b} = \frac{1}{e_{pp}} \times \frac{1}{\gamma}$$

The ER, then, is a function of four factors:

1. the oil substitution factor ( $\gamma$ ),
2. the efficiency of electricity generation (e<sub>pp</sub>),
3. the specific emissions of the oil-fired boiler (E<sub>b</sub>), and
4. the specific emissions resulting from electricity generation (E<sub>pp</sub>).

An emission ratio of less than one shows a net reduction in emissions as a result of replacing an oil-fired boiler with an electric heat pump. It should be noted that only heating systems based on the same fuel can be compared in fairness. If light fuel oil

Power Plant Efficiency	Hard Coal 0.35		Heavy Fuel Oil 0.38		Gas 0.45		Nuclear Hydro
	without FGD and Denox	90% FGD and 80% Denox	without FGD and Denox	90% FGD and 80% Denox	without Denox	80% Denox	
SO <sub>2</sub>						0.04	
s=1%	2.87	0.28	2.09	0.21	---	---	-
2.5%	7.18	0.72	5.22	0.522	---	---	-
NO <sub>x</sub>	3.17	0.63	2.92	0.58	0.84	0.17	-
CO		0.14		0.03		0.0035	-
Aldehydes		0.022		0.292		0.123	-
Benzo(a)pyrene (C <sub>20</sub> H <sub>12</sub> )		0.24		0.15		0.019	-
Particulates		0.90		1.95		0.04	-

Table 3. Emission ratios of electric heat pumps,  $\gamma=4.5$ , to oil-fired boiler, fuel oil extra light,  $s=0.3\%$ .

is available for heating purposes, it could be used in modern combined cycle power plants, where efficiencies of about 50% are achieved today. [2] In comparison to coal or heavy fuel oil, the combined-cycle power plant operates at a higher efficiency and produces lower specific emissions, due to lower sulfur content and potentially lower NO<sub>x</sub> formation in gas-turbine furnace chambers.

In Fig. 1, emission ratios for two pollutants, SO<sub>x</sub> and NO<sub>x</sub>, are plotted as a function of the oil substitution factor,  $\gamma$ , assuming heat pump electricity is generated by a power plant fired by coal with a sulfur content of 1%, and 1) no FGD or Denox and 2) 90% Denox and 80% FGD. The efficiency of the power plant,  $e_{pp}$ , is assumed to be 35%. This example is based on conservative assumptions; a cleaner or more efficient power plant will result in lower emission ratios.

Table 3 shows emission ratios for other power plant assumptions and other pollutants, assuming an oil substitution factor of 4.5. Emission ratios of less than one, or a net reduction in emissions, result in all cases, except for particulates from power plants based on heavy fuel oil, and SO<sub>2</sub> and NO<sub>x</sub> from coal or heavy fuel oil fired power plants without FGD and Denox equipment.

#### Power plant mix

Of course, most utility generating capacity is made up of a variety of power plant types, and heat pump electricity will be supplied by some combination of these different types. In Fig. 2, emission ratios, weighted with maximum permissible values [1], are shown as a function of power plant mix, assuming a generation system made up of nuclear/hydro electric plants and coal-fired power plants. Hydro plants are completely free, and nuclear plants

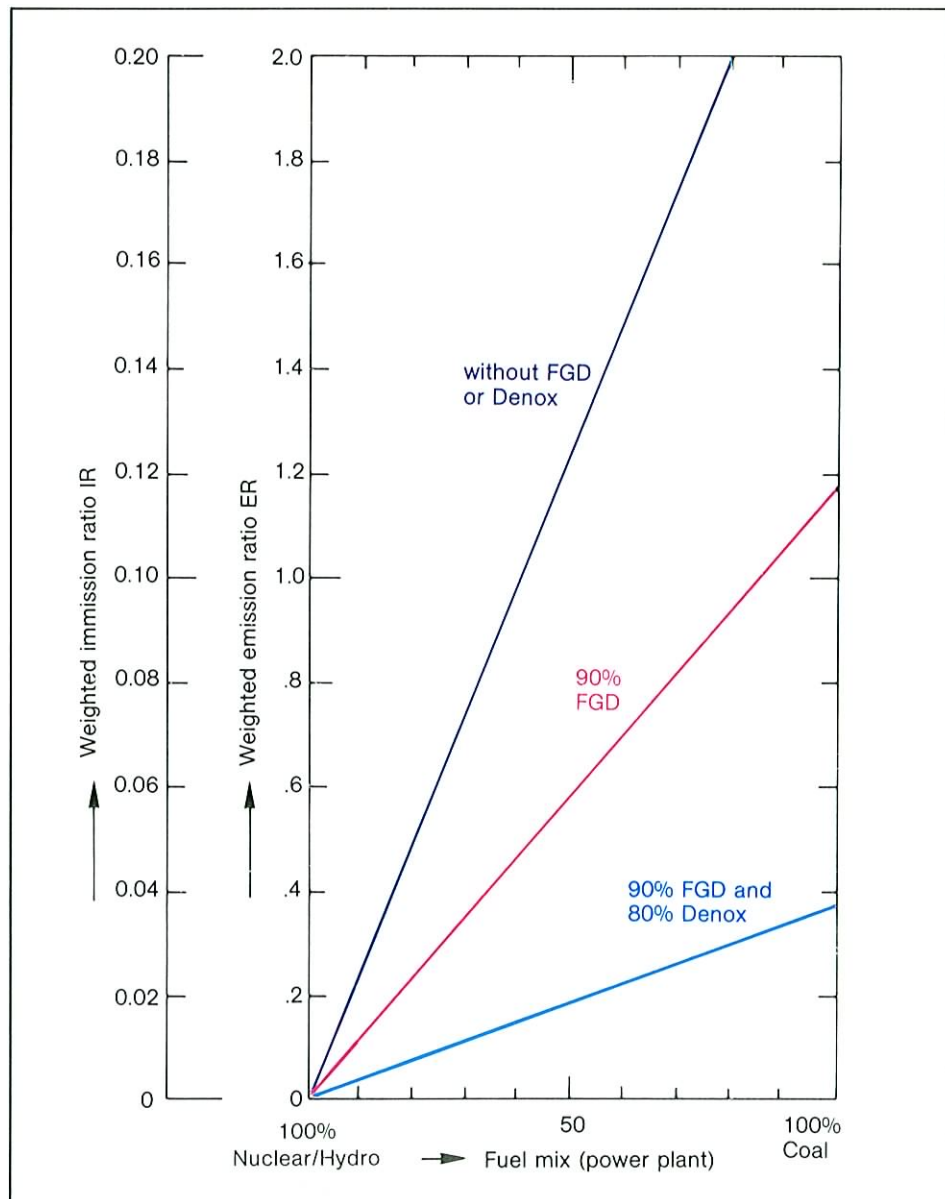


Fig. 2. Weighted emission and immission (TF=0.1) ratio, electric heat pump to oil-fired boiler (fuel oil extra light,  $s=0.3\%$ ),  $\gamma=4.5$ , vs. fuel mix of power plants.

are essentially free of air pollutant emissions. In this figure, the oil substitution factor is assumed to be 4.5. This figure again shows that only under worst-case assumptions (close to 100% coal generation without Denox) do electric heat pumps have a negative environmental impact compared to oil-fired boilers.

### Immissions: ambient air concentrations

Immissions are defined as the impact of air pollutants on man or objects on or near the ground surface (i.e. the ambient-air concentrations in a particular area that result from emissions from a particular source). Emissions from combustion devices are subject to a number of conversion and transportation processes, so that the resulting immission (exposure) will vary depending on the location of the source of emissions, as well as other factors such as stack height, topographical and meteorological conditions, etc. Even though emissions from a power plant and an oil-fired boiler might be the same, the resulting immissions, and therefore environmental hazard and damage, may be quite different.

Realistic estimates of immissions generally require the use of complex computer models. By making certain assumptions about power plant and boiler locations, urban-area immissions from both oil-fired and electric heat pump heating systems can be estimated. Although not presented here in detail, a "transfer factor" can be calculated to relate the emission ratio from two sources to the resulting immission ratio at a specific location:

$$IR = TF \times ER$$

Based on previous investigations [1, 3, 4], the transfer factor for congested areas is of the order of  $TF = 0.1$  or less for power plants relative to small furnaces. This means that the resulting urban-area concentration of a pollutant emission from a power plant is about one-tenth the urban-area concentration of the same emission from a small furnace. Applying this transfer factor to the emission ratios given above results in immission ratios that are less than one even under our worst-case assumptions (scale for IR, based on  $TF = 0.1$ , in Fig.2).

### Summary and Conclusions

The reduction in on-site, local emissions that results from replacing an oil-fired boiler with an electric heat pump is 100% for monovalent heating systems, and typically 80-90% for bivalent heating systems. If the electricity is produced by fossil-fuel-fired generating stations, there is an increase in power plant emissions. A detailed quantitative analysis is required to determine the net environmental impact.

Our comparative analysis of overall emissions has shown the following results: if an oil-fired boiler for residential/commercial

applications that uses light fuel oil with a sulfur content of 0.3% is replaced by an electric heat pump that is supplied by a coal-fired power plant without desulfurization or denitrification, emissions of  $SO_2$ ,  $NO_x$ , and particulates increase, and emissions of carbon monoxide and hydrocarbons decrease. Based on a coal-fired power plant with 90% FGD and 80% Denox, all of the above-mentioned emissions are reduced except emissions of particulates.

The actual change in emissions depends upon the mix of power plants that supplies electricity to the heat pump. There are three methods for determining which mix should be used for emissions comparisons:

1. Assign the type of electricity generation according to the instantaneous load condition while the heat pump is operating (e.g. base load or peak load),
2. Assign the same average power plant mix to each consumer,
3. Relate additional, oil-substituting customers to the mix of new capacity being installed.

We have shown, however, that even in the case of 100% coal-fired electricity generation (with FGD and Denox control), emissions and resulting ambient-air concentrations of pollutants are lower with electric heat pumps than with oil-fired boilers. Evaluations based on the power plant mix will only make the electric heat pump look more environmentally favorable. In terms of long-term environmental impacts, emissions comparisons should be based on the fuel that will be available in the future. For example, if fuel oil will not be available for low temperature applications such as space and water heating, comparison to oil-fired boilers has no relevance. Electric heat pumps supplied by coal-fired power plants should, instead, be compared to local coal-fired boilers. If oil is available in the future, the comparison should be made assuming power plants burning the same clean fuel and, perhaps,

with higher efficiencies. Again, these assumptions only improve the positive environmental impact of the electric heat pump.

Energy supplies in IEA countries are characterized by a multitude of sources. In some countries there is a large share of hydropower, in others there is a small but increasing share of other renewable supplies, such as tidal, wind, and geothermal energy. In most countries, nuclear electricity generation is increasing its share. All these supplies, along with higher power plant efficiencies and improved pollution controls, serve to reduce the average emissions from electricity production, and increase the environmental benefits of electric heat pump application.

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## Air Pollutant Emission Comparison of Gas and Diesel Engine-Driven Heat Pumps to Oil- and Gas-Fired Boilers

### Introduction

With today's concerns for environmental protection and improvement, no amount of energy savings are enough to justify environmental degradation. Many heat pump applications are in densely populated, urban areas where any increase in emissions is unacceptable. It is for this reason that it is important to evalu-

ate and understand the tradeoffs in local emissions between engine-driven heat pumps and the boilers they replace. In this article, emissions from gas and diesel engine-driven heat pumps are compared to emissions from oil and gas fired boilers. In many cases, the engine-driven heat pump results in an increase in emissions in spite of reduced fuel consumption. Pollution control technologies are available, how-

ever, and their use may be necessary for wide-spread commercialization of engine-driven heat pump technology to occur.

### Technologies Compared

This article presents data and compares emissions from gas and diesel engine-driven heat pumps to those from fossil-fuel-fired boiler alternatives, specifically:

1. Oil-fired boiler
2. Natural-gas-fired boiler
3. Natural-gas-fired engine to drive a heat pump
4. Diesel-fired engine to drive a heat pump
5. For comparison, natural-gas-fired absorption heat pump (same specific emissions as gas-fired boiler assumed)

Data for this comparison were taken from several recent studies on emissions from various heating technologies. Review of these studies quickly showed that results vary according to the assumptions made regarding seasonal performance, type of fuel burned, slight differences in heating equipment used, etc. Here, emissions data from these studies are brought together and compared using a common set of assumptions. From the data available in the literature, "worst case" and "optimal" emissions characteristics are presented for the heating technologies above. From these results, it is easy to identify whether engine-driven heat pumps are winners or losers in terms of emissions, and which pollutants pose the biggest problems. At that point, one can focus on methods and equipment to reduce these emissions.

### Emissions from Fossil-Fuel Combustion

The heating technologies compared in this article have one thing in common: they all burn fossil fuel (hydrocarbons). As products of fossil fuel combustion, carbon dioxide, oxides of nitrogen ( $\text{NO}_x$ ), carbon monoxide (CO), unburned hydrocarbons (HC), and particulates will always be present in the exhaust gas. If the fuel burned contains sulfur (diesel fuel and most fuel oils), oxides of sulfur ( $\text{SO}_x$ ) will be present as well. The amounts of these pollutants produced (for a given heating requirement) depend on three factors: the fuel burned, the combustion technology and mode of operation, and the seasonal performance of the heating system (fuel input to meet a given heating requirement).

### Specific Emissions: Emissions per unit fuel burned

In Fig. 1, the specific emissions, or emissions per unit fuel burned (in GJ) are presented by type of pollutant for the different on-site fossil-fuel-combustion heating technologies. These data are taken from

several sources [1-9]. As there is a wide spread in the data from these sources, "worst case" and "optimum" values are given, to bracket the range of possibilities. The following are the "optimum" cases:

- Oil-fired boiler: 1995 vintage
- Gas-fired boiler: condensing boiler
- Gas engine-driven heat pump: with catalytic converter, 85%  $\text{NO}_x$ , 85% CO, and 50% HC reduction
- Diesel engine-driven heat pump: with engine modifications

The differences among the specific emissions are explained as follows:

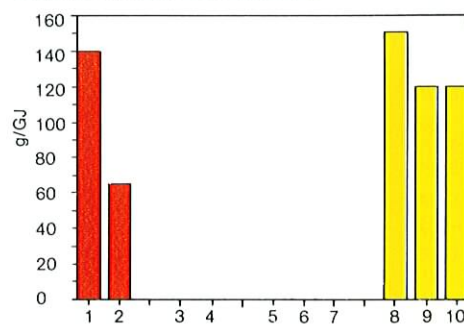
**$\text{SO}_x$ , Soot**—Oxides of sulfur are determined only by the sulfur content of the fuel burned. Natural gas is essentially free of sulfur, and specific emissions for the oil and diesel fired technologies are essentially the same given the same sulfur content. Similarly, soot emissions are determined by the ash content of the fuel, which is essentially zero for natural gas.

**$\text{NO}_x$ , CO, HC**—The operating characteristics of engines result in significantly higher production of  $\text{NO}_x$ , CO, and HC than boiler combustion. This is due to the changes in engine speed, operating temperatures, etc. during operation. Burners for boilers generally operate under more constant conditions. Catalytic converters for exhaust gas treatment and different engine configurations can reduce  $\text{NO}_x$ , HC and CO emission factors for heat pumps significantly (as discussed later).

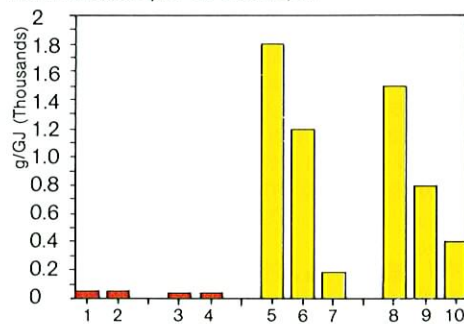
### Heating Efficiency

These heating technologies can not be compared fairly unless the emission factors given in Fig. 1 are adjusted according to the heating performance of the technology; engine-driven heat pumps must be credited with their higher efficiency. Dividing the emission factor by the seasonal heating efficiency or seasonal performance factor gives emissions per unit of

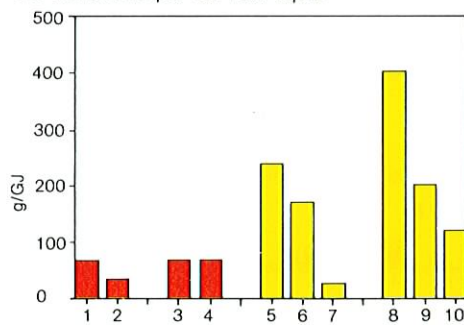
$\text{SO}_2$  Emission per GJ Fuel Input



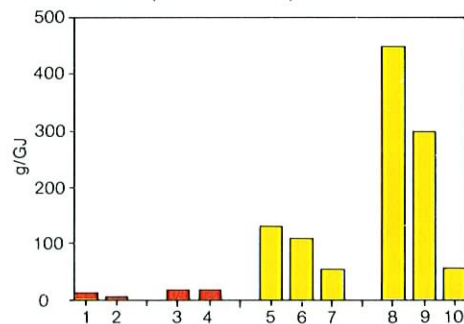
$\text{NO}_x$  Emission per GJ Fuel Input



CO Emissions per GJ Fuel Input



HC Emissions per GJ Fuel Input



Soot Emissions per GJ Fuel Input

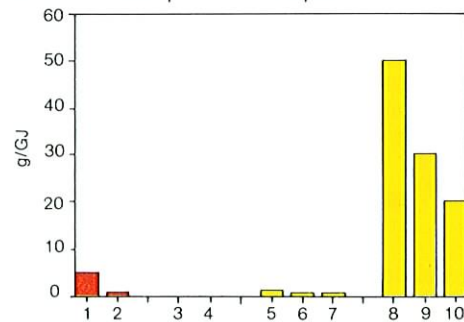


Fig. 1. Specific emissions (g/GJ Fuel input) for different on-site fossil-fuel-fired heating technologies, by pollutant

#### Legend for figure 1

1. Oil-fired boiler, 1985 (worst case)
2. Oil-fired boiler, 1995 (optimum)
3. Gas-fired boiler, typical (worst case)
4. Gas-fired boiler, condensing (optimum)
5. Gas engine-driven heat pump, worst case
6. Gas engine-driven heat pump, typical
7. Gas engine-driven heat pump, optimum; catalytic converter with 85%  $\text{NO}_x$  and CO reduction, 50% HC reduction
8. Diesel engine-driven heat pump, worst case
9. Diesel engine-driven heat pump, typical
10. Diesel engine-driven heat pump, optimum; with engine modifications

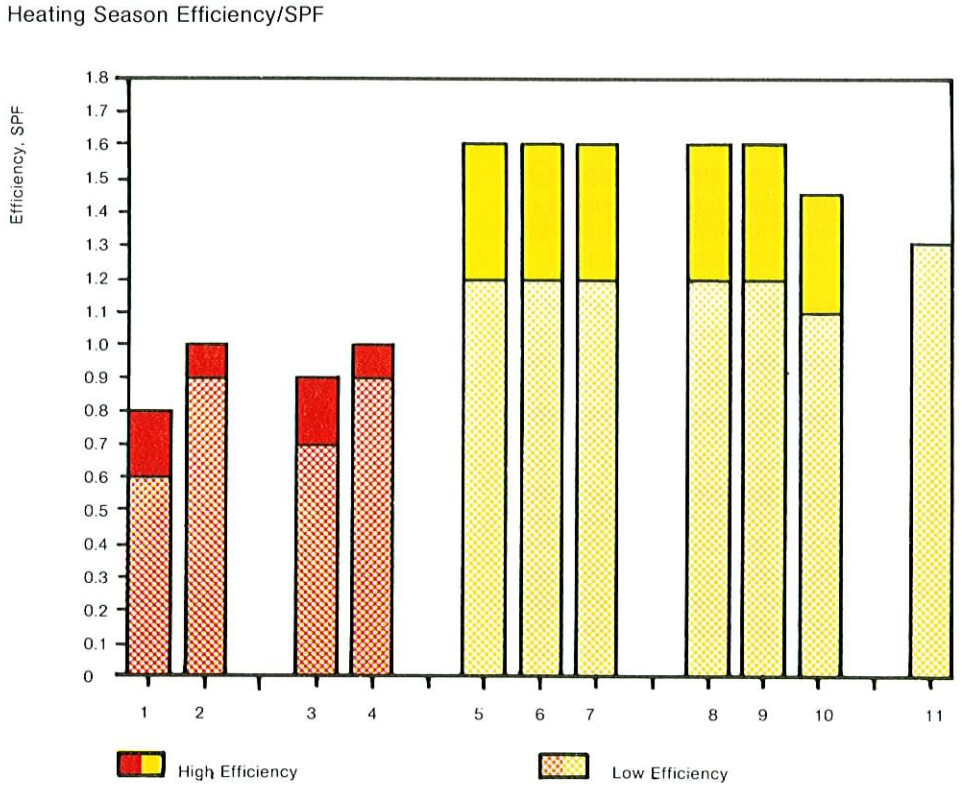
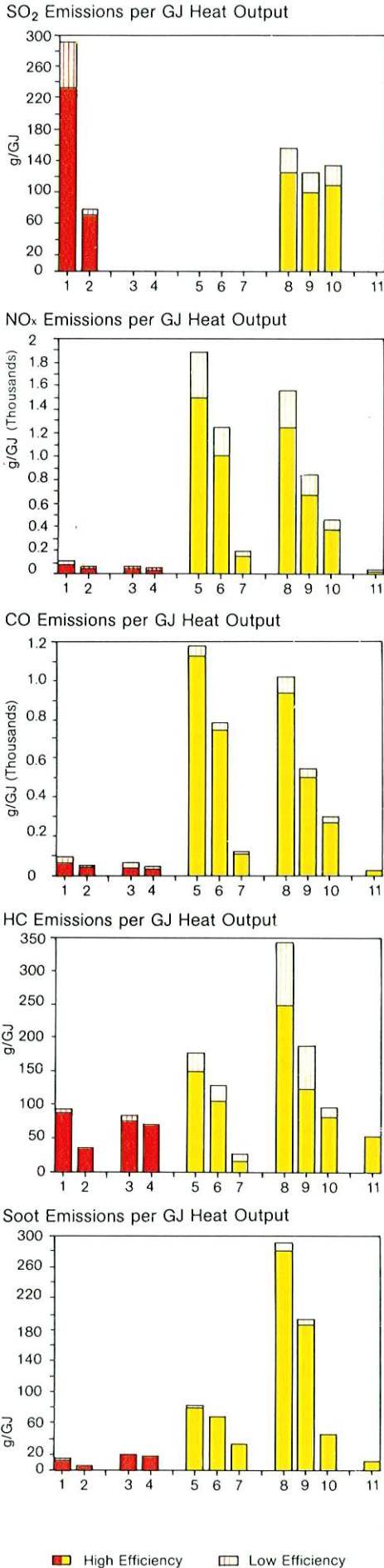


Fig. 2. Seasonal efficiencies and performance factors assumed for each of the heating technologies

heating energy supplied. The assumed efficiency or SPF for a given heating system can significantly affect the results of this comparison. In Fig. 2, a range in performance for each of the heating technologies is given, based on a survey of recent literature [8,9,11].

**Emissions comparisons for a given heat output**

Using the values in Figs. 1 and 2, resulting emissions per unit of heating energy supplied are given in Fig. 3. Emissions of SO<sub>x</sub> for engine-driven heat pumps are lower than SO<sub>2</sub> emissions from sulfur-fuel-burning boilers, due to higher heat pump efficiency. Although not shown in the figures, emissions of carbon dioxide should also be considered because of CO<sub>2</sub>'s role in the greenhouse effect. Engine-driven heat pumps will always result in a reduc-

tion in CO<sub>2</sub> emissions because of their higher efficiency, and therefore lower fuel consumption.

From Figure 3, the improvement in energy efficiency is not, in general, enough to overcome poorer specific emissions for the engine driven heat pumps. With no special pollution control equipment, both the gas and the diesel engine-driven heat pump are losers to the boiler for NO<sub>x</sub>, CO, and HC emissions, even given best-case assumptions of high heat pump efficiency and optimistic specific emissions factors. In fact, emissions are so much higher that less conservative assumptions for the heat pumps would yield the same result. For emissions of NO<sub>x</sub>, HC, and CO, some type of pollution control equipment is necessary to bring emissions down to the level of boiler alternatives.

**Pollution Control Equipment**

Several studies have been undertaken to evaluate pollution-control equipment for heat pumps (including, for example, the installation of catalytic converters on the gas engine-driven heat pumps for the Göttingen district heating system described in this issue). Here, results from some of those studies are described briefly.

**Catalytic converters**

Used for many years to reduce emissions from automobiles, catalytic converters are an effective technique for removing NO<sub>x</sub>, CO, and HC from exhaust gases from engine-driven heat pumps. Some products guarantee reductions in CO and NO<sub>x</sub>

**Legend for figure 2 and 3**

- Oil-fired boiler, 1985 (worst case)
- Oil-fired boiler, 1995 (optimum)
- Gas-fired boiler, typical (worst case)
- Gas-fired boiler, condensing (optimum)
- Gas engine-driven heat pump, worst case
- Gas engine-driven heat pump, typical
- Gas engine-driven heat pump, optimum; catalytic converter with 85% NO<sub>x</sub> and CO reduction, 50% HC reduction
- Diesel engine-driven heat pump, worst case
- Diesel engine-driven heat pump, typical
- Diesel engine-driven heat pump, optimum; with engine modifications
- Gas absorption heat pump (same emissions factors as typical gas boiler assumed)

Fig. 3. Emissions for a given heating requirement (g/GJ heat output) for different on-site fossil-fuel-fired heating technologies, by pollutant

emissions of at least 90%, and reductions have been measured as high as 95-99%. [13]

### Engine modifications

Engine modifications can also reduce pollutant emissions. For example, use of indirect injection (pre-chambers) rather than direct injection in diesel engines has shown reductions of 85% for HC, 65% for CO, 50% for NO<sub>x</sub>, and 40% for soot. These reductions include an adjustment for a 7% degradation in performance. Other options include exhaust gas recirculation and water injection. These two methods will reduce NO<sub>x</sub> emissions, but at the same time increase fuel consumption and emissions of HC and CO.

Particulate traps have been developed for diesel engines for vehicles, and reduction in particulate emissions of up to 90% should be possible for diesel engines for heat pumps. The traps need to be burned off periodically, however. [1]

Taking the most optimistic assumptions of reductions in emissions with pollution control equipment, emissions of pollutants from engine-driven heat pumps come within the range of conventional gas and oil-fired boilers. Development of effective and affordable pollution reduction techniques must continue for engine-driven heat pumps to be competitive with new, high efficiency boilers and even with the absorption heat pump in terms of air pollutant emissions.

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### H.A. Rostek\*

## Catalytic Converters Reduce NO<sub>x</sub>, CO and HC Emissions at the Göppingen District Heating Plant

In 1983, a communal district heating system supplied by two gas-engine heat pumps started operation in Göppingen, West Germany. The district heating system has two unique characteristics:

- The heat pumps use industrial waste heat as a heat source, and
- Three-way exhaust gas catalytic converters are used to reduce pollutant emissions.

During the first heating season (83/84), the seasonal performance of the heating system was monitored. In 1984, both gas engines were equipped with three-way catalytic converters, resulting in more than a 90% reduction in emissions of oxides of nitrogen (NO<sub>x</sub>) and carbon monoxide (CO). Results from this project are described in this article.

### System Description

Waste heat (cooling water) from a gelatin producing factory (the Deutschen Gelatine-Fabriken Stoess & Co., GmbH, DGF) is

used as the heat source for two gas engine heat pumps. This waste heat is supplied free of charge. At the same time, the DGF eliminates discharges of steam from its cooling towers, and saves energy previously required for rejection of waste heat.

Cooperation among the waste heat supplier, DGF, the building owner and operator, the municipal utility Stadtwerke Göppingen, and the gas supply company Gas-Versorgungsgesellschaft Filstal mbH (GVF) was critical for preliminary design, planning, and project realization. For the first stage of development, only local facilities were connected to the district heating system: a secondary school, a swimming pool, a youth center, a few municipal utility buildings, and a gas transfer station for gas preheating. Future additions of residential buildings are being planned.

Based on preliminary investigations, a heating plant with two gas engine heat pumps and a peak-load boiler was installed. Under normal operation, both gas heat pumps supply the heating requirement

	Heat supplied MWh	%	Fuel Con- sumption MWh	Operating hours	SPF
Heat Pump I	1,574	41.8	841	3,354	1.87
Heat Pump II	1,314	34.9	692	2,736	1.90
Total, Heat Pumps	2,888	76.7	1,533		1.88
Boiler	877	23.3	959	507	0.91
Overall Heating System	3,765	100	2,492		1.51

Table 1. Performance results, November 1983 - October 1984

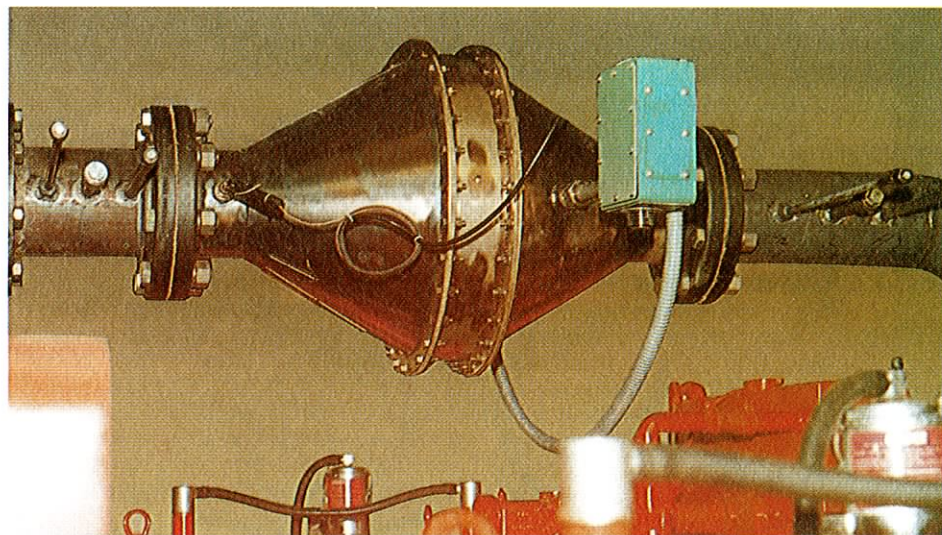


Fig. 1. Catalytic converter installation

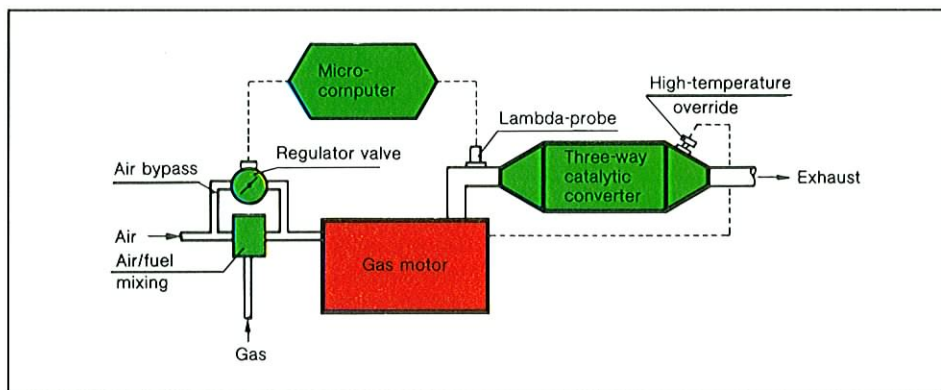


Fig. 2. Three-way exhaust-gas catalytic converter with lambda control (air-side bypass)

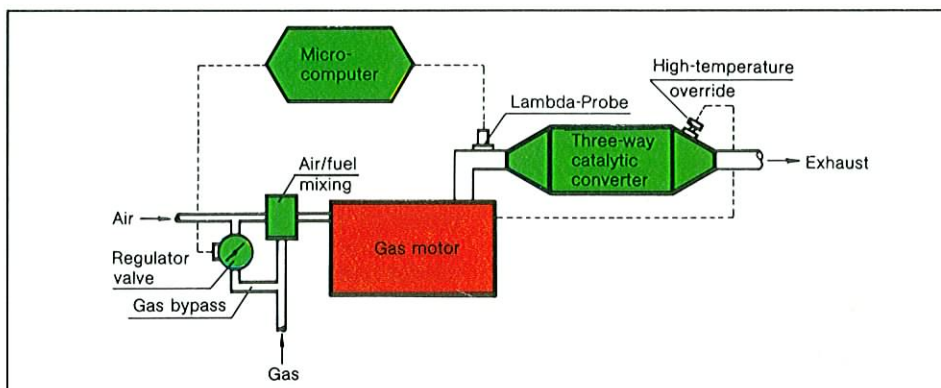


Fig. 3. Three-way exhaust-gas catalytic converter with lambda control (fuel-side bypass)

down to a daily average temperature of  $-3^{\circ}\text{C}$ , and are operated in parallel with the peak-load boiler at lower outdoor temperatures. The design temperature for the Göppingen heating system is  $-18^{\circ}\text{C}$  (climate zone III). The stratified storage system was designed so that the heat pump plant only cycles over intervals of several hours.

**Performance Results**

Results for the first heating period, from November 1983 to October 1984, are shown in Table 1. Table 1 shows that the gas heat pumps supplied 76.6% of the annual heating requirement, the boiler supplying the remaining 23.3%. During this period, the heat source was not available and the heat pumps were not operated for two weeks over Christmas, because the DGF was closed for vacation.

The overall seasonal performance factor for the new system was 1.51. Compared to a conventional boiler system, the heat pumps and the peak-load boiler resulted in a 47% reduction in fuel consumption (assuming 80% seasonal efficiency for the conventional boiler). Savings during heat pump operation alone were 57%. Monthly performance results showed that the performance of the heat pump decreases with lower heat production (e.g. February through August).

**Pollution control**

In August 1984, three-way exhaust-gas catalytic converters were installed on the heat pumps for the Göppingen district heating system (Fig. 1), making this the first operation of its kind in the Federal Republic of Germany.

For optimal catalytic-converter operation, the exhaust gas entering the converter must be free of oxygen. An engine control system must be installed to keep the fuel/air mixture as close to stoichiometric as possible ( $\lambda = 1$ ) without manually readjusting the engine. Conventional controls are not accurate enough to maintain the proper mixture for optimum reduction of pollutants ( $\text{NO}_x$ , CO, HC). Proper control is possible with feedback controls that continuously monitor the exhaust gas with the lambda probe and regulate the intake air (Fig. 1) or fuel (Fig. 2) with microprocessor controls. No German product for automatic lambda control was available, so two U.S. products were selected, one for each heat pump.

**Reductions in emissions**

Pollutants were measured in the exhaust gas going into and coming out of the catalytic converters. These results are summarized in Table 2. Under optimal engine adjustment for  $\text{NO}_x$  and CO reductions ( $\lambda = 1$ ), the reduction in  $\text{NO}_2$  was 98-99%, in CO, 95-97%, and in HC, 54-95%. After 6,000 hours of operation, there was no significant change in these results.

We also measured the performance of the heat pump plant with and without the catalytic converter. During continuous operation, performance without the catalytic converters was measured at 1.95-2.00, and performance with the catalytic converters was measured at 1.90-1.95, resulting in no significant reduction in energy efficiency. The reduction in NO<sub>x</sub> and CO was well within the manufacturers' guarantee of 90%. This 90% reduction is guaranteed for three years.

### Economics

Three-way catalytic converters for 100-150 kW engines can be expected to cost between DM 15,000 to DM 20,000, with an additional cost of DM 15,000 for a lambda control system. The total cost of the Göppingen catalytic converter system was DM 28,000, including catalytic converter with housing, high temperature override, lambda probe, bypass controls, engine adjustment controls and microprocessor. The manufacturer has estimated a service lifetime of 16,000 hours. This lifetime can be extended with the replacement of the ceramic element in the converter, at a cost of about DM 9,000. To date, there has been no increase in operating costs for the

Pollutant	Concentration in exhaust gas entering catalytic converter	Concentration in exhaust gas leaving catalytic converter	% reduction
NO <sub>x</sub>	4,500-5,000 mg/m <sup>3</sup>	45-70 mg/m <sup>3</sup>	98-99%
CO	3,200-4,800 mg/m <sup>3</sup>	90-150 mg/m <sup>3</sup>	95-97%
HC	400-700 mg/m <sup>3</sup>	20-320 mg/m <sup>3</sup>	54-95%

Table 2. Reduction in NO<sub>x</sub>, CO and HC emissions with catalytic converters

heating plant as a result of the catalytic converters. In new installations, the costs of the catalytic converter should be compared to the considerable savings that can result from reduced flue construction costs. In general, it can be assumed that the height of the chimney can be reduced by 30-50%, and this can completely offset the price of the catalytic converter.

To summarize, our results show that three-way catalytic converters can be used to reduce NO<sub>x</sub>, CO and HC emissions from gas engines for heat pump systems, and can be successful in retrofit applications. Reductions in NO<sub>x</sub> emissions

of over 95% can be achieved, resulting in exhaust gas concentrations of less than 100 mg/m<sup>3</sup>. At the same time, CO and HC concentrations are kept low, and there is no significant deterioration in heat pump performance.

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J.A.W. Oldenhof

## Research in the Netherlands on Heat Pumps and the Environment

### Introduction

In the Netherlands, an adequate and complete survey has not been done with regard to environmental aspects in direct or indirect relationship to heat pump applications. Various studies have been executed in the Netherlands, but many problems remain open for further research and discussion. In this article, previously completed studies in the Netherlands are summarized.

### 1. Consequences of Use of Chlorofluorocarbons in Heat Pumps for Space Heating

This 1978 study [1] forecasts the extent to which chlorofluorocarbons (CFCs) will be used in the application of the heat pump for space heating in the Netherlands. The potential emissions of CFCs released as a result of heat pump operation are compared with emissions of CFCs from other sources such as aerosols.

Project results show that forecasted emissions resulting from use of R11 and R12 in heat pumps will not be acceptable in the case of large-scale application, due to depletion of stratospheric ozone. Successful heat pump development will require solving this problem. Possible solutions include:

- Prolongation of the effective period of use for CFCs produced (development of fully hermetic systems with a minimum of coolant content required).
- Recovery of coolants after operational life, to be regulated by law if necessary.
- Development of substitutes for R11 and R12 that will have no, or a negligible, effect on stratospheric ozone, as well as development of coolant alternatives.
- Precautions during heat pump repairs to reduce emissions while the system is opened.

### 2. Large-Scale Heat Extraction from the Ambient Air

Owing to the universal availability of ambient air as a heat source for heat pumps, it makes sense to investigate the possible consequences of large-scale heat extraction from ambient air. This project [2] concerns a block of flats with a total heating capacity requirement of 2000 kW, supplied by a gas engine driven heat pump of 800 kW (bivalent system). Investigations included:

- noise level in the area;
- decrease in temperature in conjunction with expected air currents;
- recirculation of cold air;
- possibility of mist or white frost development;
- an economic evaluation.

Results showed that in the vicinity of the 400-kW heat pump evaporator, the drop in temperature of the ambient air will be below 1.5 K. Application of passive evaporators (without fans) will result in a temperature drop of the air on the roof of 3 K. The study showed that actions to reduce noise output are expensive.

### 3. Noise Pollution

Previous studies and experience show that most heat pumps currently on the market produce too much noise compared to levels allowed in the Netherlands [3]. This is true for both electric and gas-driven systems, for both air systems and water/water heat pumps. High costs will often be incurred to reduce noise levels to the level deemed acceptable by law in the Netherlands. Permitted levels can be found in reference [4].

### 4. Air Pollution

A gas engine heat pump was put to the test in the Netherlands from 1980 to 1983, and the amount of NO<sub>x</sub> produced by the gas engine was monitored [4]. The study compared measured concentrations with forecasts from existing calculation tech-

niques. The study concluded that the Gaussian distribution model as well as Halitsky's model may both serve a purpose in determining discharge outlet location in order to result in combustion-gas concentrations that will not exceed the existing (1982) standards; the models produced pessimistic estimates. More realistic estimates of fields of concentration around buildings require some refinements on the basis of true-scale and wind-tunnel experiments. Further information on these aspects of air pollution is given in [5]. At present, the allowable discharges of NO<sub>x</sub> are under tight control in the Netherlands. Acceptable emissions of harmful gases will be regulated by Dutch law, effective from 1 January 1986, for all new gas engines installed after that date. The permissible NO<sub>x</sub>-amounts are calculated as follows:

$$\text{NO}_x \leq 800 \text{ gr/GJ} \cdot (e_m/0.30)$$

Where GJ is the thermal input in gigajoules (low heating value), and  $e_m$  is the mechanical efficiency of the gas engine. Many authorities already apply this requirement. After 31 December 1990, the value 800 in the formula above will be lowered to 270 for all gas engines with a shaft power greater than 50 kW. The amount of CO is not regulated by this law; permissible CO-emissions may vary from borough to borough. The Dutch "Gasunie," however, maintains a maximum acceptable level of 0.1% CO.

## 5. Ground Water Problems

A study of well-water problems was executed in 1983 [6]. This study provides an insight into the potential possibilities and limitations of using ground water as a heat source for heat pumps, specifically for retrofitting conventional heating systems for buildings or districts for at least 200-300 residents. The problems encountered cover technical, environmental, legal and economic aspects. Most technical problems can be avoided through design changes, although these changes may increase capital costs.

The study's main conclusions with regard to environmental aspects were:

- Discharge of high-quality ground water to surface water is often prohibited in view of drinking water considerations, as is also the case when poor-quality ground water is being discharged.
- In many instances residual water must be injected underground; it is preferable to execute this process in the same water parcel to avoid undesirable effects on the ground water quality.
- Preferably, extracting and injecting should occur under a sealed ground

layer, in view of environmental hazards.

- Injection produces a cooling area that will have a radius a few times in excess of the project area. Projects within this radius cannot be executed simultaneously without regeneration of the cooling area.
- A future levy on ground water extraction may double the operating costs of heat pumps.

## 6. Use of Ground Heat

In the Netherlands, it is not known whether licences are applicable with regard to the extraction of ground heat. It is expected that any project involving such an extraction will have to be reported to the municipal authorities concerned. Future limitations to the amount of extraction remain a possibility. For large-scale applications of ground heat exchangers, authorities may require that only non-toxic coolants be utilized.

## 7. Safety Aspects With Regard to Application of Halogenated Hydrocarbons in Heat Pumps

The goal of this 1985 project was to draw up an inventory of requirements for detectors for halogenated hydrocarbons for heat pump applications. The state-of-the-art with regard to dangers and safety aspects of coolant leakage was reviewed. In keeping with the method of NEN 3380, a procedure that ensures that there will be no danger to man, animal, or environment, even on complete release coolant present, is preferable to protection with detectors. The current Dutch standard NEN 3380 and standards in surrounding countries (usually marked out for cooling purposes) are not suitable for heat pump application, but may be used as a starting point for drafting a modified standard or new directives. Detectors for halogenated hydrocarbons will be required only in certain cases, and specific requirements for detectors will have to be included in standards or directives developed. Therefore, project emphasis has shifted towards normalization and directives for safe application. No quantitative safety limits can be given, due to a lack of data with regard to the effects of coolant leakage under typical heat pump conditions. The discrepancy between the existing (cooling) standards and directives for the heat pump area of application is described, as well as a number of existing detectors for fluoro-hydrocarbon coolants, including their suitability to heat pump applications.

## 8. Conclusion

A number of environmental aspects of heat pump applications have been studied in the Netherlands. In addition, numerous other projects indirectly con-

cerned with issues have been undertaken. It is beyond the framework of this article to include either such projects or current projects in this field. Given the prospect of large-scale heat pump application in the Netherlands, a great deal of attention will still have to be paid to these aspects. For more details on this subject, the reader is directed to Reference [4], which focuses on social constraints imposed on heat pumps in the Netherlands.

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## The Environmental Effects of Large Heat Pump Stations: Aspects of Occupational Safety and Health

### Introduction

Most buildings in Sweden are heated by means of district heating networks. In order to decrease Sweden's dependence on foreign oil, some of these networks are supplied by heat pumps that utilize lake-water, seawater, or purified sewage effluent as heat sources. Heat pump plant output varies from two to 15 MW, depending on the heat source and the number of subscribers (see, for example, cover photo). The working environment in these heat pump plants must conform to certain standard regulations for occupational safety (as given in the "Safety Standards for the Construction, Use, Inspection, etc., of Stationary Cooling Plants," in the Swedish Society of Refrigeration Handbook, No. 6, published in 1965).

### CFC Refrigerants

Eight thousand tonnes of CFC (freon) are imported annually in Sweden, about one third of which are utilized in cooling, refrigeration, and heat pump plants. Roughly, 1,000 kg of CFC are required for each MW of heat pump output. A 15 MW heat pump is thus fed with 15,000 kg of CFC.

### Effects on Humans

CFC refrigerants have been in use for more than 50 years. During this time, several attempts have been made to determine the effects of human exposure to CFC. Experiments on animals have also been performed to determine which concentrations result in adverse effects. In 1982, Sweden's Occupational Safety and Health Administration published "Criteria



Fig. 1. A full-face filter mask for personal protection

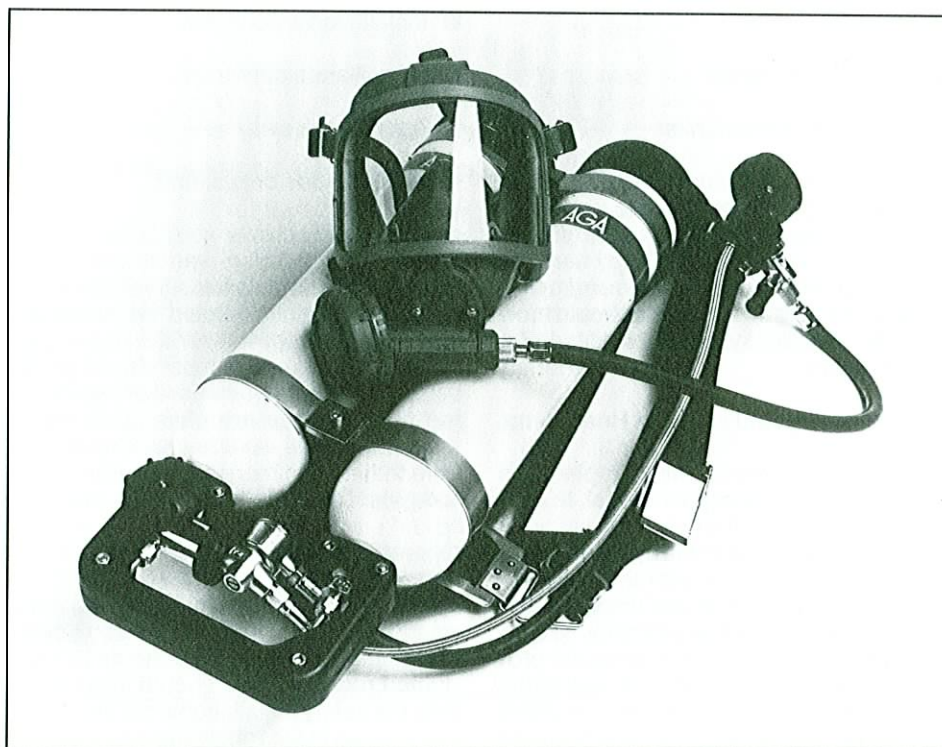


Fig. 2. A breathing apparatus with a cylinder pack must be used in case of substantial emissions of CFC refrigerants

Documents for Allowable Values of Fluorocarbons," and this document has since been used as the basis for the allowable value of 500 ppm for an eight hour exposure to CFC.

Both controlled and uncontrolled emissions present a risk of CFC exposure. Leakage due to faults in plant construction is an uncontrolled emission; emissions due to plant repairs are often controlled. Earlier beliefs that CFC was completely harmless may have led mechanics to be rather careless about handling the gas without increasing ventilation at the same time.

Amounts of CFC refrigerants in large heat pump plants are far above the maximum allowable values given in the above mentioned standards. Uncontrolled discharges on the order of 1,000 kg of CFC gases have occurred at several plants. The consequences of such large discharges of liquid CFC are not yet known. In general, the temperature during discharge falls to about  $-30^{\circ}\text{C}$ . There is also a risk of mist buildup caused by water vapor in the air around the point of emission.

Theoretically, an emission of 1,000 kg of R11 must be diluted by a volume of  $350,000\text{ m}^3$  of air to keep the concentration below 500 ppm. This is equivalent to the volume of a 70 m cube. In order to

avoid such sizeable emissions, alarms that signal the start of uncontrolled emissions should be installed. These alarms should go out to on-site supervisory and maintenance crews, and the fire department.

In case of a sizeable emission, these guidelines should be followed:

- All work in the plant should be performed by at least two people, so that one person can assure that the other is not being adversely affected by CFC gases.
- All available forced ventilation should be used. All doors and gates should be opened to help exhaust the CFC gases.
- To reduce the risk of suffocation, a full-face filter mask (Fig. 1) should not be used, because CFC gases can be highly concentrated, resulting in insufficient oxygen.
- At oxygen levels below 20% (CFC concentrations higher than 10,000 ppm), a breathing apparatus is recommended (Fig. 2). This type of mask prevents leakage around its edges with overpressure inside.

## CFC Alarms

There are several types of CFC sensors, including:

- leak sensor with LP gas
- semi-conductor
- infrared absorption
- oxygen content monitor.

CFC gases are heavier than air, so sensors should be placed at the low points in the plant. In plants where sewage effluent is used as the heat source, sensors should be placed in sewer lines and pump sumps. Of course, all sensors should have a backup electricity supply, in case of a power failure.

## Computer Regulation of the Heat Pump

A computer can never entirely replace the response of operating personnel. In several existing plants, the computer software is not in agreement with the operating conditions of the plant, or with the assumptions first made during the design of the plant. It must be relatively easy for operating personnel to modify the computer program and alter assumptions, as well as the locking devices and alarms. Assumptions should be clearly and accurately specified in the operational instructions for the heat pump plant. It should be possible to operate the heat pump plant manually, so these instructions should include a description of how locking devices are controlled by the computer, and how they can be disconnected. Programmed computer values may be knocked out as a result of storms or other disturbances in the electricity network. The plant should be equipped with a backup system in case the main computer is out of operation.

## Staff Training

Many people are involved with the start-up and maintenance of a heat pump plant, and special training programs should be set up for:

- installation mechanics,
- surveillance personnel,
- operation crews,
- maintenance crews, and
- emergency crews.

In addition, manuals for surveillance and alarm installations should be prepared, and training programs for the use of personal protection equipment should be developed. Personnel that are present during plant start-up are often replaced by new employees, so it is important to ensure that all staff has adequate training on a regular basis.

## Operational Test

The standards issued in 1965 require an operational test to be performed by a certified inspector. These tests should be conducted regularly, and should include not only the safety installations, but also locking devices in the regulating and monitoring equipment, and proper operation and direction of alarms during an emergency.

*\*B. Isaksson, Senior Consultant, Heat Pumps and District Heating, Scandiaconsultant AB, Stockholm, Sweden*

waves as high as 20 cm.

Thermal effects of heat extraction from ground water, lakes, and sea water will depend on the size of the aquifer and the amount of heat being extracted. Temperature changes resulting from extraction of lake heat delays composition, which in turn slows down dissolution of nutrient salts (phosphorous and nitrogen), reducing vegetation. In open systems, this is somewhat counteracted by water pumping that increases the circulation of nutrient salts. The effects of large scale heat extraction must be evaluated on a case-by-case basis. In Sweden, three systems of about 10 MW each have shown no major effect on animal life in the heat-source water.

## Toxic Substances

Perhaps the biggest threat to the environment from ground and water heat extraction is the possibility of a leakage of toxic substances that are used as heat transfer fluids in ground and water coils. The most common heat transfer fluids are based on monoethylene glycol, which is toxic to man and higher animals. Salt solutions that are less hazardous to the environment can be used, however, these increase the need for corrosion inhibitors that are also toxic and should be avoided if possible. Salt solutions without inhibitors are being tested in some installations. Technical steps can be taken to reduce the risk of an accidental leakage. In general, piping materials and joints that are least susceptible to leakage should be used. Where possible, joints should be located above ground, and segmenting the piping should be avoided, and the system should stop automatically in the event of a leak.

## Legal Issues

The heat resource in ground and water can be quite large. However, competing uses of soil and water and systems competing for access to the same heat source can limit the extent to which the resource can be exploited. As installations of ground and water source heat pumps increase, the need for regulations as to who can extract heat and how much can be extracted increases as well. In Sweden, present regulations require only large users (extraction of more than 1 MW of heat, enough to supply 180 detached houses with energy for one year) to report their heat extraction. However, there are presently tens of thousands of detached houses that extract heat from ground or water, and many home owners are planning to install such systems. There is no obligation for these individuals to report their heat extraction. In order to prevent ground subsidence, it is not permissible to extract more than 300 m<sup>3</sup> of ground water per day per property. If several houses in one area extract more than this amount together, and subsidence occurs, who is responsible? The same question arises when enough users extract heat from a

M. Meal\*

## Ground and Water as Heat Sources for Heat Pumps: Environmental and Legal Issues

Using a heat pump to extract heat from the ground, ground water, lakes or sea water is generally thought to be environmentally benign. On a small scale, ground-coupled and water-source heat pumps have little impact on the heat sources they exploit. Given wide-spread development, however, heat and water extraction, along with the possible release of toxic substances, can have adverse environmental effects. At the same time, legal questions arise as to who and how many should have access to a ground or water heat source. Here, the key issues regarding large scale exploitation of these heat sources are described, based primarily on work going on in Sweden.

## Thermal Effects

Heat extraction from the ground, ground water, lakes or sea water reduces the temperature of the heat source to some extent. Heat extraction from shallow soil layers with horizontal ground coils can affect growing conditions. Experiments at the Swedish University of Agriculture have shown delays of vegetation growth in the spring and a shorter vegetation period. The effect of heat extraction at present levels (with current design practice), however, are not considered to be significant. Also not uncommon as a result of horizontal ground coils for heat extraction are frost heaves in the spring, causing ground

lake, for example, so that life in the lake is significantly affected.

Proposals that make the energy in the ground and in water the property of the state have been considered. This solution is attractive, because energy extraction from a particular property often reduces the ability to extract energy from neighboring properties. Normal horizontal coil installations require a rather large surface

area. This can present a problem in densely populated areas where many ground or water source heat pumps are installed. In central Sweden, for example, 400-600 m<sup>2</sup> of ground coil surface area are required. Just as "solar rights" became an issue with the emergence of solar technologies, the increasing use of ground and water source heat pumps, both in and outside of Sweden, will draw attention to the question of "ground and water energy rights."

## Reference

"Ground and Water-Providers of Heat," Swedish Council for Building Research, Stockholm, Sweden, G5:1984, 1984.

\*M. Meal, IEA Heat Pump Center, Karlsruhe, F.R. Germany

H. Halozan\*

## HPC Representatives visit Japan

### Introduction

From September 12 to 22, 1985, representatives from the Heat Pump Center visited Japan. Participants on this trip were K. O. Holzapfel, HPC, J. Reichelt, Fachhochschule Karlsruhe, and myself. The visit was organized by Mr. Fukiwake, MITI/AIST, and Mr. Miura, JRAIA, the Japanese representatives for the IEA Heat Pump Center. The aim of this visit to Japan was:

- To discuss future activities of the HPC,
- To give a presentation on HPC activities and to give an overview of the situation on the European heat pump market,
- To discuss future work of the HPC, including:

continous capacity control for heat pumps,

engine-driven heat pumps,  
large heat pump installations,  
industrial heat pump applications,

- To review Japanese research and development activities in the heat pump field, and to visit Japanese air conditioning and refrigeration industries.

This visit to Japan will improve HPC work, and we gained a better understanding of the needs of Japan and the Japanese heat pump industry.

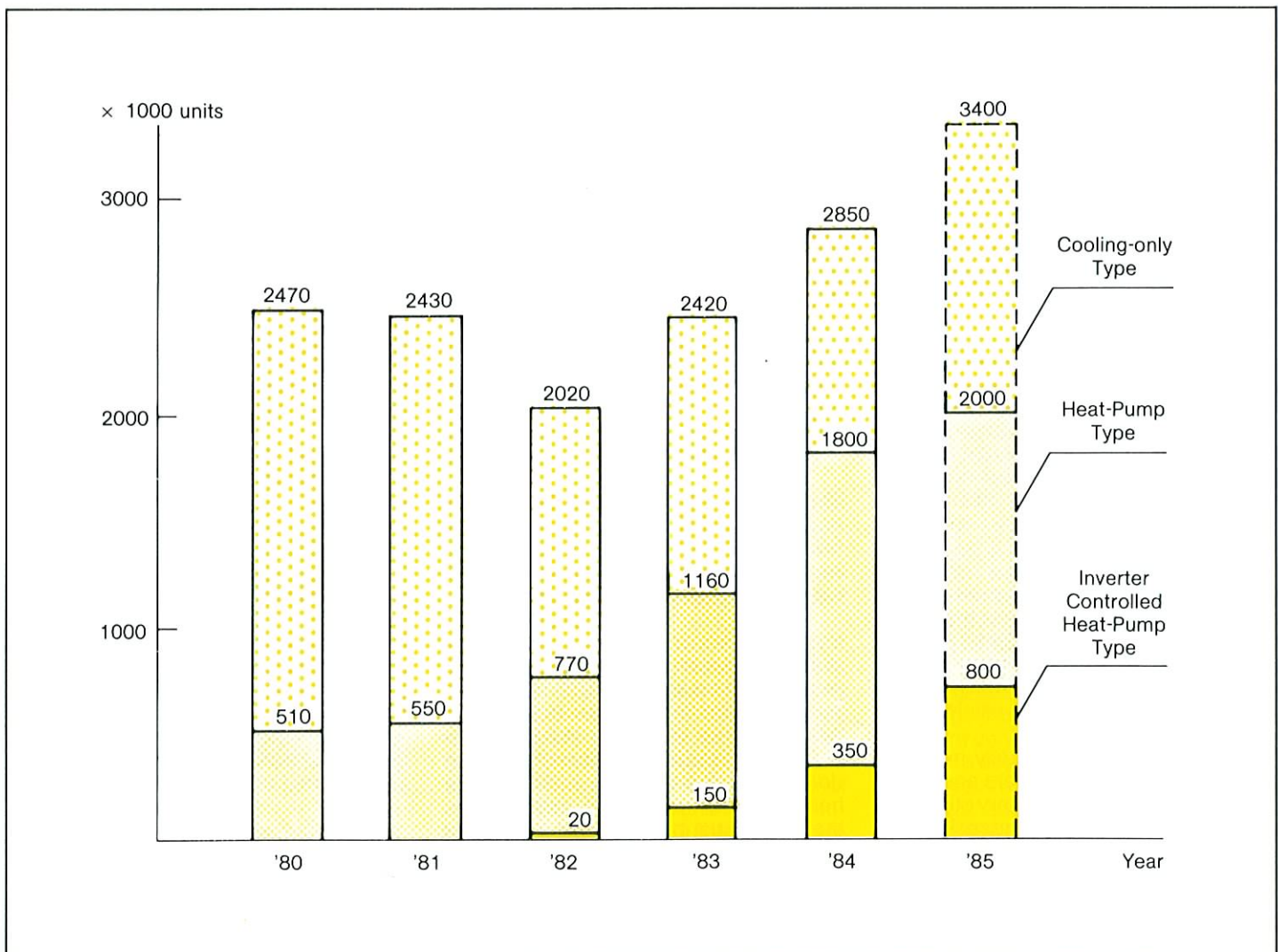


Fig. 1. Sales of residential air conditioners in Japan (6,000-20,000 Btu/h, 1,500-5,00 Kcal/h).

Throughout the visit, HPC representatives had the opportunity to see new developments and the best available equipment on the Japanese market, as well as latest manufacturing techniques. Further, fruitful discussions were held with experts in the field of heat pumps and heat pump applications, even on very recent heat pump developments.

**Heat pump air conditioners**

In 1985, 3.4 million air conditioners ranging from 1.7 to 5.8 kW in capacity were sold in Japan (Fig. 1). Two million, or about 59%, were heat pumps, and 800,000 of these were inverter-controlled. Considering that inverter-controlled heat pumps were first introduced in 1982, sales have grown quite rapidly.

**Capacity Modulation**

The advantages of capacity-modulated heat pump air conditioners are better comfort combined with energy savings of up to 40%, compared to a unit without capacity modulation, assuming continuous heating and cooling operation. These energy savings result from reduced cycling losses and lower condensing temperatures or evaporating temperatures, due to continuous part load operation instead of on/off operation.

Some experts pointed out, however, that the real effect of capacity modulation is only an increase in comfort, due to the behavior of the Japanese consumer. He uses his air conditioner only while using the room, requiring short heat up or cool down, followed by continuous operation. The energy saving effect of capacity modulation is almost lost.

At present, AC and DC motors are used for capacity modulation. The variable capacity inverter with an AC motor converts AC to DC and from DC to a variable voltage-frequency AC. The sine wave approximation is done with pulse width modulation, and the voltage/frequency ratio is constant. The motor used is a three-phase induction motor.

Capacity control with a DC motor with a permanent magnet rotor is achieved by changing the motor voltage. Rotor position is controlled by terminal voltage sensing using a microcomputer. The main advantage of this motor is its high efficiency.

Compressors used for capacity-modulated heat pump air conditioners and packaged air conditioners are rotary compressors, scroll compressors, and reciprocating compressors. The frequency range for rotary compressors now available is 30 to 150 Hz. Continuous operation is possible over a wide temperature range. For scroll compressors with nominal outputs of 2.2 to 4.4 kW, the available speed range is 1580 to 4250 rpm (Fig. 2).

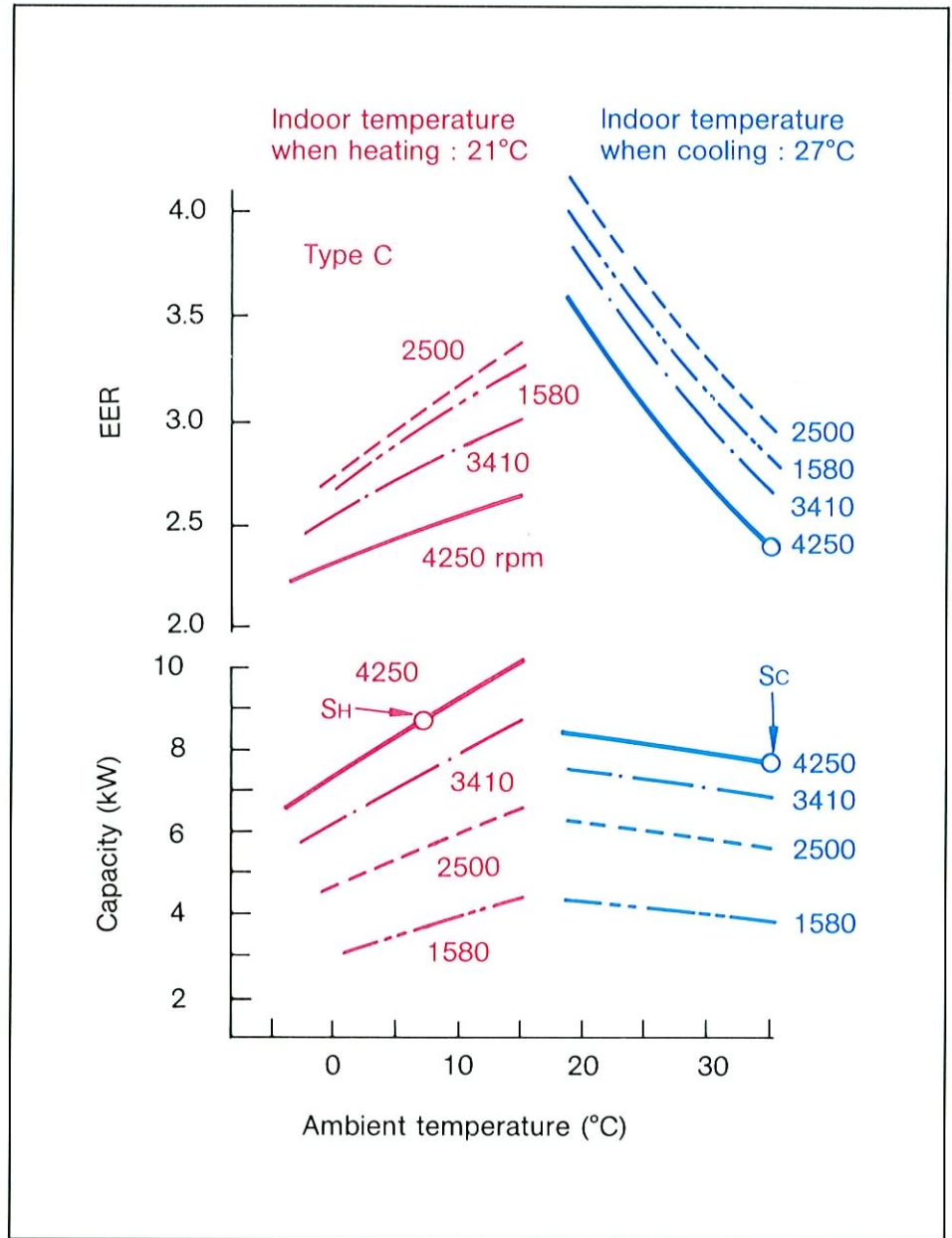


Fig. 2. Capacity and EER, scroll compressor operating at different speeds

**Heat pump performance**

The heating COP of Japanese heat pumps has increased significantly over the past few years, illustrating the importance of heating in Japan, as well as competitiveness of gas and oil with electricity.

Interesting research has been carried out at Tohoku Electric Power in Sendai, north of Tokyo, in cooperation with some heat pump air conditioner manufacturers. In this region, as well as in Hokkaido, the heating demand is higher than the cooling demand, or there is only a demand for heating. Heat pump air conditioners, therefore, must be optimized for heating purposes. Based on results of field tests, changes like improved defrost strategies, optimized fin geometry and improvements in the air flow of the outdoor unit were introduced. The latest development is the introduction of nonazeotropic mixtures, achieving a remarkable increase in SPF.

This seems to be the first step towards improving the performance of heating only units.

**Compressor Development**

Rotary compressors are the most common type of compressor for small residential heat pump air conditioners. These compressors were originally designed for a rated speed of 3000 to 3600 rpm at 50 or 60 Hz, respectively. Today, compressors are operated at up to 180 Hz.

An important further development in combination with the scroll compressor is the introduction of a gas injection cycle. Similar to screw compressors, utilization of the economizer flow sheet is possible, which means increased capacity and increased COP.

## Hot Water Production

Due to Japanese bathing habits, the required domestic hot water temperature is about 65°C. This temperature cannot be achieved using series compressors with R22. Heat pumps can, however, be used for hot water production, especially when operated for cooling purposes.

Japan has developed a heat pump water chiller with a second compressor that uses R12 for hot water production. During cooling operation, it is used for cooling purposes; during heating operation, the heating water is used as a heat source.

Another interesting development is a combined unit for heating, cooling and production of hot tap water at a temperature of 65°C. R22 is well suited for heating and cooling, however, temperatures of 65°C cannot be reached with serial compressors. In this application, a mixture of R22 and R114 is used. Flow sheet and control of this unit are very simple. (See NSL Vol. 3, No. 3, "Heat Pump Hot Water Supply Unit in Japan.")

## Heat Pumps for Industrial Applications

Industrial applications generally have long running times and therefore a large potential for energy savings. At the same time, it is often impossible to stop an industrial process to maintain the heat pump. This is one reason why engine-driven heat pumps are not now used for industrial applications, due to their short service intervals.

### Absorption heat pumps

For industrial applications, two types of absorption heat pumps are now on the market, and both use the working fluid pair lithium bromide and water.

- Type I: The standard absorption heat pump, using high temperature heat as drive energy, with a maximum hot water outlet temperature of 95°C.
- Type II: The heat transformer, using medium temperature heat as drive energy and as a heat source. The maximum hot water outlet temperature is presently 150°C.

Both types are well developed, and problems with corrosion seem to be solved. The range of applications covers many industrial cases as well as district heating and cooling. Construction and calculations, technical as well as economic, are fully computerized.

## Screw compressor developments

Screw compressors are well known as compressors for the medium capacity range. Due to the small number of moving parts, the maintenance interval for such

compressors is about three times longer than that for reciprocating compressors.

Small semi-hermetic screw compressors have been developed for commercial air conditioners and water chillers. Silent operation, essentially loss-free capacity modulation over a wide range and long maintenance intervals are the advantages of these units.

A screw expander, used instead of a common throttling valve, increases the efficiency of screw-compressor heat pumps. Carnotization of the heat pump process and minimization of expansion losses increases the COP remarkably. A screw compressor with a variable volumetric ratio has been constructed, allowing optimal adjustment of the compressor to various operating conditions.

The third project is to develop a screw-type steam engine. Compared to the reciprocating steam engine, the advantages are reduced maintenance and, at higher capacities, higher efficiency.

The heat pump-boiler is a combination of a screw-type steam turbine, supplied by a gas-fired boiler, and a heat pump using a screw compressor and a screw expander. Due to high efficiency and long maintenance intervals, this unit is a serious competitor with engine-driven and absorption heat pumps. (See NSL Vol. 3, No. 3, "Development of a Heat Pump-Boiler System.")

## Basic Research Work

A great deal of basic research work to achieve further energy conservation is being carried out at the National Chemical Laboratory and at the Mechanical Engineering Laboratory in Tsukuba Science City. Projects relevant to heat pumps include hot and cold storage and increased efficiency through utilization of electrohydro-dynamical heat exchangers and advanced Stirling engines.

## Conclusion

The new developments we were shown on this trip were developments applicable to the Japanese heat pump market. Many of these developments could, however, be utilized in Europe as well. Improvements in heat pump efficiency will increase the market penetration of heat pumps, which is necessary for future energy savings and environmental protection.

We were very impressed with what we learned on our visit to Japan. We were shown advanced research and development work, as well as large-scale series production, fully computerized and robotized. At all institutions and companies, Japanese efforts to overcome the energy problem by using high technology equipment were evident.

*\*H. Halozan, HPC Analysis Center, Graz, Austria*

## Heat Pump Center Starts Second Working Period

At the beginning of 1986, the second working period of the IEA Heat Pump Center began. All HPC member countries that participated in the first working period voted to continue their participation and support for another three years, through 1988. In recognition of the start of the second working period, this article reviews HPC activities and products, and introduces its staff members.

The Center was established in December 1982 under the IEA's Implementing Agreement on Advanced Heat Pumps, as Annex IV, and is supported by contributions from its member countries. The participating countries are Austria, Canada, Germany, Italy, Japan, the Netherlands, Sweden, and the United States.

Fachinformationszentrum Energie, Physik, Mathematik GmbH Karlsruhe is the Operating Agent for this international cooperation project. The HPC is currently staffed by two Senior Engineers - Jörg Herrmann and Axel Lehmann; two visiting Scientists - Margaret Meal and Jan Corfee; one assistant - Elke Meujen; and as of April 1st, 1986, the head of the Center, Karl Holzapfel. (The Center is also currently

seeking to employ another Senior Engineer.)

Each member country also maintains a "national team" that acts as a point of contact between the HPC and the member country. Through the national teams, the HPC is able to gather information, monitor activities and identify the research and information needs specific to each participating country.

The direction of HPC activities is determined by a **Steering Committee**, composed of one member from each participating country. The Committee meets semi- or tri-annually to outline projects and programs of interest to all members. The next meeting is scheduled for May 1986.

The HPC is committed to the commercialization of heat pump technology by means of collection, analysis and distribution of objective and reliable information to a wide audience of interested parties. The information coverage includes:

- present and planned RD&D projects;
- national standards, testing procedures and safety regulations;
- results of heat pump installations and demonstrations;
- advances in heat pump design;
- existing heat pump products and manufacturers;
- market developments;
- applications of advanced components and working media;
- boundary conditions and their effect on performance (e.g. energy prices, electric tariffs, climate);
- system modeling methods.

Manufacturers, distributors, building contractors, researchers, utility representatives, and policy makers are targeted users of HPC information.

An important aspect of the Center's work is **information dissemination**. The HPC publishes this quarterly NEWSLETTER, prepared by Margaret Meal. This NEWSLETTER is a key link in the sharing of international experience, updating readers with technical articles, editorials, special features, book reviews, report summaries and a schedule of conferences and trade fairs. As a tool for each national team, the NEWSLETTER offers the opportunity to voice opinions, to report on new developments or to announce the specific technological or market needs of member countries. Newsletter readers are encouraged to submit articles (see schedule of topics for this year's NEWSLETTER in this issue). The information collected by the HPC is from many different countries, written in different languages, resulting in considerable efforts for translation. HPC staff member Elke Meujen assists in translating this material for the Center's engineers.

The HPC staff also routinely responds to many individual requests for information received by the Center, covering the entire range of heat pump markets, technologies and developments.

The HPC develops and maintains up-to-date data bases on: RD&D projects, product specifications and manufacturers, and specific installations in different applications (i.e. residential, commercial and industrial). On the analytical side, the Center produces studies comparing technical performance of new heat pump components and systems, evaluating RD&D projects, comparing product standards, and market performance.

Currently, a high priority project at the Center is the completion of a comprehensive **bibliography** on a specialized topic, "**Non-Azeotropic Refrigerant Mixtures as Working Fluids in Compression Heat Pumps**." The bibliography, compiled by Jörg Herrmann, is scheduled for comple-

tion in May 1986, also will include abstracts of approximately 170 publications and references for another 100 documents.

Also planned for completion in Spring 1986 is an update of the **HPC RD&D Data Base**, with projects through 1985. The computerized data base includes details on research, development and demonstration projects, primarily publicly sponsored, that focus on heat pump technologies and closely related topics. Included in the data base is information on more than 1000 projects, including details on heat pump systems, climate, boundary conditions, and performance.

The HPC also now offers information about **existing installations of heat pumps**. Collected from a variety of sources, the present data base includes approximately 400 references, focusing on heat pumps with a heating capacity of greater than 100 kW. Like all of the HPC data bases, this data base is updated and expanded continuously.

Specific information on heat pump products is also available through the **HPC Products Data Base**. The data base offers a listing of manufacturers, heat pump types (including engine driven, electric driven and absorption heat pumps), and unit performance.

Further analytical work is also being prepared at the Center. Planned to coincide with the installations data is an analytical review and report of **industrial heat pump applications**. Axel Lehmann is now developing a project proposal for the Steering Committee. Guest scientist Jan Corfee is working on a review and analysis of the **1985 heat pump market** that will include sales figures, energy prices and market trends.

Scheduled for October 1986 is an HPC sponsored workshop on **Ground-Coupled Heat Pumps**. Co-sponsored by Niagara-Mohawk Electricity Company (Ithaca, New York), the Electric Power Research Institute (Palo Alto, California), and the U.S. Department of Energy, the workshop will be held in the U.S., focusing on sharing the American experience with experts from the Canadian, Japanese and European community.

As an additional outreach activity, the HPC attends and participates in special exhibits, presentations and industrial trade fairs to provide general information about the use and technology of heat pumps and to collect information on new developments first-hand.

**New countries** are always welcome to join the Center; Belgium, Finland, Great Britain and Norway are presently considering participation. All inquiries regarding the current or planned HPC activities or membership can contact Karl Holzapfel, tel 07247 824541, telex 7826487 fize d.

*IEA Heat Pump Center, Karlsruhe, FRG.*

## New Research on Chlorofluorocarbons and the Environment

Discussion and controversy over chlorofluorocarbons (CFCs) and their possible regulation has heightened recently in the United States. CFCs include some refrigerants used in heat pump equipment. The U.S. Environmental Protection Agency has announced that they will decide by May, 1987, whether to regulate CFCs. At the same time, the National Aeronautics and Space Administration (NASA) has recently completed its report, "Present State of knowledge of the upper atmosphere - An assessment report - Processes that control ozone and other climatically important trace gases," (final version of the report scheduled for publication in late March, as NASA Reference Publication 1162), and Oak Ridge National Laboratory (USA), plans to release a study on the environmental effects of CFCs this year.

The NASA assessment was sponsored by three U.S. agencies, together with the World Meteorological Organization, the Commission of European Communities, and the Bundesministerium für Forschung und Technologie (in the FRG). The Air Conditioning, Heating and Refrigerating News has reported (February 17, 1986) that the advance copy of the executive summary of the NASA report states that although the contribution of CFC breakdown in the upper atmosphere to ozone depletion is somewhat higher than earlier believed, further research is needed to determine the interaction of CFCs with other trace gases that play a role in ozone depletion. The study also lists CFCs as being as great or a greater factor than carbon dioxide in the greenhouse effect.

The U.S. EPA will use the time between now and May 1987 to consider the NASA and other studies. In addition, the EPA has scheduled national and international workshops and conferences to bring together the most up-to-date research. Considerable attention will be paid to international issues regarding ozone protection and CFC regulation.

# NEWS BRIEFS

## Energy Demonstration Program of the European Communities: Call for 1986 Project Proposals

In its mission to speed up the up-take of rational use of energy technologies (RUE) as they succeed in the research and development phases, the European Community began the Community Energy Demonstration Program. "Demonstration" for purposes of this program is defined as the first commercial scale operation of a RUE technology or process. Seeking to remove financial barriers to RUE technologies, the program will provide up to 40% of the eligible cost of the project.

Innovative areas covered by the program are: energy saving in industry; energy saving in buildings; energy saving in transport; energy saving in industry; solar energy; biomass and energy from waste; geothermal energy; hydro-electric power; wind energy; use of electrical energy and heat; use of solid fuels; liquefaction and gasification of solid fuels.

Many heat pump projects have been sponsored in the past. Some examples include: solar assisted, diesel engine, and gas-engine driven ground coupled heat pumps.

The CEC has issued its call for proposals for 1986 Energy Demonstration Projects. Proposals must be received by the Commission no later than noon, 29 April 1986. For more information or to request the proposal form, contact the Commission's Directorate-General for Energy, (Administrative and procedural matters) Mr. Kimman 32 (2) 235 03 18.

## Heat Pump Market Expectations in the U.S.

The Air Conditioning, Heating & Refrigeration News recently reported (January 20, 1986) that only 30% of their surveyed readers expect an increase in this year's sales of residential heat pumps. This is down from a figure of 34% last year and 47% in 1984. According to wholesalers the best prospects for heat pumps this

year: in the Southeast 48% responded that they expected heat pump sales to increase, 47% in the South, and surprisingly, 42% in the Northeast. Contractors clearly marked the Southeast (60%) as the leading market and the Midwest (15%) as the poorest.

Water-source heat pumps sales were expected to increase this year by only 23% of the surveyed readers, down from 26% in 1985. Relatively new to today's marketplace, water-source heat pumps were viewed most optimistically by manufacturers and wholesalers. On a regional basis, gains are expected in all five regions, with weaknesses appearing only among contractors in the Northeast and contractors and wholesalers in the West.

**Heat pump saturations** were also reported: Nearly one-third of all new single-family homes are built with electric heat pumps as the main heating equipment. In the South the saturation for heat pumps in new homes is 42%.

## German Natural Gas Utilities Announce Awards Program

In February 1986, the German natural gas utilities invited participation in their 1986 "Preis der deutschen Gaswirtschaft für rationellen Erdgaseinsatz 1986" (awards for rational use of natural gas). This program offers prizes for installations that result in savings and efficient use of natural gas in new and innovative ways.

Criteria for the awarding of prizes include: utilization factor and efficiency, ecological benefits, economics of the installation, and ease of plant operation. The installation must have been completed after January 1, 1982, and must be located in the Federal Republic of Germany or West Berlin. Winners will be awarded certificates and monetary prizes with a total value of approximately DM 50,000.

Completed applications must be submitted by May 12, 1986. Further information and details for submitting applications are available from: Redaktion "Rationeller

Erdgaseinsatz," Postfach 800650, 7000 Stuttgart 80, FRG, telephone (0711) 61 31 92. Results from this awards program will be announced in a later issue of the HPC Newsletter.

## "Expocomfort" Trade Fair Held in Milano

The 25th annual "Expocomfort" Exhibition was held in Milano, Italy, from February 5 to 11, 1986. The international trade fair included exhibitions from manufacturers of heating, air conditioning, and refrigerating equipment, plumbing and sanitary installations, and bathroom fittings. Over seventy Italian heat pump manufacturers were represented. Mr. Fulvio Trombetti, head of the Italian National Team, gave a presentation on IEA Heat Pump Center Activities, and HPC publications were distributed.

Heat pumps manufactured in Italy are primarily electric heat pumps for commercial and residential space heating and hot tap water applications. Most engine-driven heat pumps installed in Italy are imported. Because most of the electricity supply in Italy is generated by imported oil or gas, the COP of a heat pump must be high enough so that the primary energy ratio is competitive with oil and gas-fired boiler alternatives.

In Italy, heat pumps are commonly installed in conjunction with the installation of an air-conditioning system. The decision to provide heating-mode operation is often justified not by savings in heating costs, but by other factors that prohibit installation of a separate gas- or oil-fired heating system. One manufacturer, for example, said that factors such as space constraints or on-site environmental concerns (noise and/or air pollution) often justify the decision to install air conditioning equipment that can act as a heat pump to meet heating requirements.

## Schedule for Upcoming Issues of the HPC Newsletter

Starting with this issue, the first issue of Volume 4, this year's Heat Pump Center

**Newsletter** will be focusing on specific heat pump topics. The following are the scheduled topics for the next three issues, along with planned dates of publication:

Vol. 4, No. 2: **Industrial Heat Pump Applications**, June 1986. When and where can heat pumps be used in industrial applications? What processes and temperature ranges are suited to heat pumps? This issue will include case studies of industrial heat pump installations, with performance, economic, and reliability results, as well as market data for industrial heat pumps in HPC member countries.

Vol. 4, No. 3: **Engine-Driven Heat Pumps**, September 1986. What has been the experience to date with engine-driven heat

pumps? What types of equipment are available? What are the causes of engine-driven heat pump troubles and failures? This issue will address these questions, and will include descriptions of different system designs, and market data from HPC member countries.

Vol. 4, No. 4: **Ground-Coupled Heat Pumps**, December 1986. Where (and why) have ground-coupled heat pump installations been successful? This issue will include descriptions of installations in different HPC member countries, and will address design, layout, and calculation/modelling issues. This issue will include economics and market data, as well as results from the HPC-sponsored workshop on ground-coupled heat pumps to be held in the U.S. later this year.

For each issue, the Heat Pump Center is preparing a bibliographic database search for each topic. Some publications from each search will be cited in the Newsletter; a complete copy of the literature search, with citations and abstracts, can be ordered from the HPC.

We are encouraging contributions on these topics from our readers, particularly articles dealing with recent and innovative developments. Of course, we welcome contributions on other topics as well. Please send your contributions to the Heat Pump Center in Karlsruhe, at least one month before the date of Newsletter publication.

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# Position Available

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

## Senior Engineer

The IEA Heat Pump Center is looking for a highly motivated and experienced individual for information collection and analysis work covering all aspects of advanced heat pump development, applications, and economics. Extensive experience with heat pump technologies is required, as well as the ability to work independently. Fluency in English and a working knowledge of German are required.

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

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

## Publications: Environmental Effects of Heat Pump Applications

In conjunction with this issue of the HPC Newsletter, the Heat Pump Center staff has conducted a literature search for publications relevant to issues regarding heat pumps and the environment. Here, some of the publications resulting from that search are listed, with a brief abstract. A complete version of the literature review, with full abstracts and citations (for over 50 publications), divided into the subtopics listed below, is available from the Heat Pump Center for DM 25 (U.S. \$10). This literature review is a valuable resource for anyone interested in pursuing environmental issues in more detail. Use the attached card on the last page of the Newsletter for your order.

### General

Organization for Economic Cooperation Development, *The State of the Environment 1985*, OECD, Paris, 1985, ISBN 92-64-12713-5. (in English) This report identifies progress as well as remaining and new problems of pollution and of natural resource management. It examines the pressures on the environment from agriculture, energy, industry, and transport activities and the responses of the public, of enterprises, and of governments to these pressures. Several charts and graphs.

Mueller, P., "Investigation of the effects of heat pumps on the environment," *Energy Saving in Buildings; Results of the European Communities Energy R and D and Demonstration Programmes (1979-1983)*, Proceedings of the international seminar, held in The Hague, the Netherlands, 14-16 November, 1983, D. Reidel Publishing Co., the Netherlands, 1984, pp 199-216 (in German) Where groundwater, earth and air are used as heat sources, the effects on the environment produced by thermodynamic heating plants are quantified.

"Environmental and health effects of future space heating systems: Report to the Energy Committee of 1981, Sweden," Liber Foerlag, Stockholm, Sweden, 1983, ISSN 0346-5675 (in Swedish) This report treats the environmental and health effects of phasing out nuclear power and reducing the oil dependence of the Swedish Energy systems. Electric heat pumps using soil, water or air as a heat source will not cause any serious environmental effects. Individual firing of solid fuels cannot be recommended in residential areas.

### Air Pollution

Urbanek, A., "BHKW und GWP mit Abgas-Katalysatoren die umweltfreundlichsten

Energieumwandler" (Block combined heat and power stations and gas heat pumps with exhaust gas catalysts are the most environmentally acceptable), *Sonnenenergie und Wärmepumpen*, Vol. 10, No. 2, Mar/Apr 1985, pp 9-11 (in German) In gas heated block heating power stations and heat pumps with internal combustion engines, the catalytic process is used to reduce emissions of NO<sub>x</sub>. On diesel engines, solid particles from solid and liquid materials must be caught. Selective reduction of nitrogen oxides with ammonia and subsequent collection of solid particles with a ceramic filter is used.

Köbel, M., "Abgasmessungen an stationären Gasmotoren von Blockheizkraftwerken und Wärmepumpen" (Exhaust measurements in stationary gas engines of cogeneration units and heat pumps), Eidgenössisches Institut für Reaktorforschung, Würenlingen (Switzerland), EIR-528, August 1984 (in German) Exhaust measurements were carried out on six stationary gas engines, four served as heat pump drives. Measurements showed high specific emissions of internal combustion engines, especially NO<sub>x</sub>. Measures to reduce NO<sub>x</sub> will be indispensable for more widespread use of these engines; otherwise, air pollution due to heat and power generation will increase.

### Water/Soil Pollution

"Ground and Water-Providers of heat," Swedish Council for Building Research, Pub. G5:1984, Stockholm, 1984 (in English) This publication contains reprints that summarize Swedish research projects on different applications of subsurface heat storage, including environmental and legal aspects.

Lökke, H., "Leaching of ethylene glycols in subsoils," *Water, Air, Soil Pollution*, May 1984, Vol. 22, No. 4, pp 373-387 (in English) Heat pumps connected to ground coils may involve a risk of ground water pollution caused by leakage of anti-freeze mixture components. Adsorption of individual components, such as ethylene glycol, ethanol, methanol and benzoic acid into different soil types was studied.

Glatzel, W.D., "Ecological and legal problems of groundwater heat pumps," *Heating with Solar Energy*, Proceedings of the 11th international specialists meeting on sanitary facilities, Frankfurt, F.R. Germany, 17 Mar 1981, CONF-8103143 (in German) From the energetic point of view, ground water is an ideal heat source. However, ground water heat pumps may present an

ecological problem as 90% of drinking water is taken from ground water. The author shows how the goals of environmental protection and energy economy can be harmonized by observing certain requirements.

### Refrigerants

Gumsch, K., "Kältemittel und Umwelt" (Refrigerants and the Environment), *Luft-Kältetechnik*, Vol. 18, No. 4, 1982, pp 196-200 (in German) For decades, fluorohydrocarbons used in refrigerating machines have been preferred refrigerants. In recent years some concerns over the effects of refrigerants on the environment have arisen. A comprehensive report is given on the current knowledge of this field.

Brasseur, G., "Critical analysis of recent reports on the effect of chlorofluorocarbons on atmospheric ozone," Commission of the European Communities, Luxembourg, PB-81-22-6474, 1980. (in English) The aim of this analysis is to compare conclusions reached by various reports on the environmental effects of chlorofluorocarbons, to take stock of the certainties and uncertainties surrounding the problem of ozone depletion. A number of projects to be carried out in the next few years are put forward.

### Noise Pollution

Srauch, H., "Geräusche und Erschütterungen, verursacht durch elektrisch angetriebene Wärmepumpen" (Noise and Vibration caused by electrically driven heat pumps), *HLH, Heiz., Lüft., Klimatech., Haustechnik*, Vol. 34, No. 12, pp 506-510 (in German) The author discusses the entire range of questions of noise and vibrations caused by heat pumps, and reports on investigations and measurements. Emissions not only result from the heat pump itself, but are influenced by the method of installation, house construction, and piping arrangements.

Jagenäs, A., "Noise from Small Heat Pumps," *Noise Control Engineering Journal*, Vol. 21, No. 2, Sept./Oct. 1983, pp 56-65 (in English) A questionnaire, sent to all of Sweden's municipal health boards, confirmed that heat pumps are a common noise problem. A complete heat pump system for small houses was installed to obtain well controlled test conditions. Results showed that newer heat pumps are quieter than older heat pumps, but the sound levels of some new heat pumps are rather high and positioning in houses is critical.

# Selected Book and Report Reviews

**The ASHRAE Design/Data Manual for Ground Coupled Heat Pumps;** J.E. Bose, J.D. Parker, F.C. McQuiston; Oklahoma State University, 1985; ASHRAE (in English).

This recently published manual on ground-coupled heat pump systems provides information on soils, materials and techniques for sizing and installing systems. The Manual includes earth temperature variations and thermal behavior of ground-coupled systems, and ground-coupling system design methods.

The price is \$25 for ASHRAE members and \$50 for non-members. Order from ASHRAE Publication Sales, 1791 Tullie Circle, N.E., Atlanta, GA. 30329; 404-636-8400.

**A Survey of Heat Pump Service Life;** EPRI EM-4163, Project 2417-1, Final Report, July 1985; Prepared by Alabama Power Company; Birmingham, Alabama (in English).

A study of actual heat pump service life, the survey identifies a 20 year median service life in the Alabama Power Company (APCo) service territory. The study is based on a telephone survey of nearly 1700 heat pumps installed between 1964 and 1974. The objective of the study was (1) to determine heat pump service lives in the APCo service territory and (2) to determine and quantify reasons for heat pump replacement and factors affecting replacement choices.

The sample was drawn from a list of certified installations from APCo's Assured Service Program (ASP) for heat pumps. The ASP records allowed vintage verification; the survey plan ensured unbiased random sampling. Actuarial techniques were used to analyze results.

Survey results indicate 96.4% of the households were still heating with heat pumps. A large percentage of the original sample installations were still in use, more than 50% of the 20 year old units, 75% of the 15 year old units and nearly 100% of the 10 year old units. There was no con-

vincing difference in the service lives between units of different vintages.

Replacement decisions appear to have been significantly influenced by: (1) marketing and promotional activities of local dealers; and (2) by utility promoters. Consumers showed limited brand loyalty with availability of the brand being a more influential factor.

**Heat Pumps: Unitary;** A Collection of Papers from the ASHRAE Annual Meeting at Honolulu, Hawaii, June 1985; (ASHRAE Technical Data Bulletin, Vol. I, No.8, TDB-48) (in English)

This technical bulletin reviews performance of unitary heat pumps and recent energy-saving technologies in heat pump air conditioners. Papers included are:

"The Development, Design, and Performance Testing of a Single-Unit Dual-Source (SUDS) Heat Pump Evaporator," by D.L. Ewert;

"System Design Optimization and Validation for Single-Speed Heat Pumps," by S.K. Fischer and C.K. Rice;

"The Laboratory Evaluation of the Heating Mode Part-Load Operation of an Air-to-Air Heat Pump," by W.A. Miller;

"Field-Measured Cycling, Frosting, and Defrosting Losses for a High-Efficiency Air Source Heat Pump," by V.D. Baxter and J.C. Moyers;

"Design and Available Energy Analysis of a Heating-Only Residential Heat Pump for the Western Pacific Northwest," by D.F. Elger, G.M. Reistad, and S. Lang;

"Development of Demand Defrost Control System for Residential Heat Pumps," by T. Imaiida, S. Kojima, F. Aoi, Y. Isaka, and M. Ohta;

"Inverter Control Systems in the Residential Heat Pump Air Conditioner," by Y. Shimma, T. Tateuchi, and H. Sugiura;

"Reversible-Flow-Type Linear Expansion Valves for Heat Pumps," by Y. Nakashima, H. Iijima, M. Umehara, and F. Matsuoka;

"Annual Energy-Saving Effect of Capacity-Modulated Air Conditioner Equipped with Inverter-Driver Scroll Compressor," by T. Senshu, A. Arai, K. Oguni, and F. Harada;

"Seasonal Efficiencies of Residential Heat Pump Air Conditioners with Inverter-Driven Compressors," by M. Hori, I. Akamine, and T. Sakai.

**Proceedings: Buildings and their Energy Systems-Technologies and Planning Strategies;** Electric Power Research Institute, EA/EM-4197 Research Project 2034-12; Proceedings, September 1985; October 16-18, 1984, Saint Louis, Missouri (in English).

This report is the proceedings from an EPRI sponsored seminar aimed at utility planners, researchers, and customer service representatives, as well as academic and private sector researchers. The seminar was designed to assist participants in understanding the full range of technologies that can be applied by utilities to affect and analyze the load attributable to buildings.

The proceedings include 25 separate papers presenting American perspectives in the following areas: Building Energy Systems; Electric Energy Use in Buildings; Models and Methods for End Use Data Acquisition; Utility Program Implementation and Assessment; Forecasting and Demand Side Planning. Many of the papers in the "Building Energy Systems" section focus on electrical heating and cooling systems and here heat pumps figure prominently. Also included is a list of participants and the seminar agenda.

# Selected Book and Report Reviews

**Performance of Air-Source Heat Pumps;** Electric Power Research Institute, EPRI EM-4276; Project 1495-I; Final Report; November 1985 (in English).

This report describes a new method for predicting seasonal performance of air-source heat pumps in single-family residences. The reported models, and field and laboratory data should assist utilities in planning demand-side-programs.

Field and laboratory tests of split-system air-to-air heat pumps were performed with the objective of measuring field performance under controlled conditions with a single, well-characterized heat pump and using these results to validate simple algorithms for prediction of heating seasonal performance. Field tests were performed on nine residences, in three climates, equipped with identical and identically instrumented heat pumps. Laboratory tests were conducted to determine heat pump transient performance at various conditions of temperature and cycling rate. Tests were made to quantify frosting and defrosting performance.

The laboratory tests provided the basis for constructing algorithms, whose predictions were compared to the field data. Final algorithms, implemented in a bin type calculation, predicted field-measured heating seasonal performance factors (HSPF) within 4% for all but two residences (10%). Only one field-test-derived empirical parameter, the thermostat cycling rate, was used in the predictive calculations.

**Erarbeitung von Daten und Methoden zur Durchführung von Umweltverträglichkeitsprüfungen für den Bereich Energiebereitstellung aus Lokalen, Erneuerbaren Energiequellen, Teil 2: Einsatz von Wärmepumpen;** (Development of Data and Methods for Performing Environmental Compatibility Tests for Energy Supplies from Local, Renewable Energy Sources: Part 2: Heat Pump Applications); H.M. Knoflacher, E. Lichtl, Institut für Umweltforschung, Graz, Austria, December 1985 (in German)

This report (short title: Umweltverträglichkeit von Wärmepumpen, environmental compatibility of heat pumps) first presents different types of heat pump operation and heat sources, and then presents data and methods for evaluating the environmental impacts of heat pump applications. Environmental impacts are divided into two

parts: 1) effects due to normal operation, and 2) effects due to unexpected disruptions or failures.

Environmental impacts that result from normal operation depend on the specific heat source medium (ground, water, air) and on heat pump operating conditions. The most important impacts on the environment include temperature changes in the heat source, changes in flow conditions in the heat source, noise disturbances, and emissions of pollutants. For unplanned disruptions or failures, the primary concern is material burden on the environment, such as leakage of refrigerants and brines, and by-products of burning substances that are emitted.

At the same time, the authors draw attention to the fact that an "environmental compatibility test" can only be performed given the specific characteristics of the installation. This generally requires an initial analysis to determine the factors and boundary conditions unique to a heat pump application.

**Heat Exchanger Requirements for Potable Water Protection;** Electric Power Research Association, EPRI EM-4217, Project 2033-13, Final Report, December 1985, prepared by Fauske & Associates, Inc., Burr Ridge, Illinois (in English).

This report reviews the current status of building, plumbing and mechanical codes, equipment design and testing standards, and the technical basis for double-wall separation between refrigeration and potable water systems. Included is an analysis of the health and safety issues associated with refrigerants and compressor oil contamination of potable water, and an evaluation of performance and cost impacts.

Objectives of this study were to 1) review the requirements for double-wall heat exchangers in heat pumps specified in existing U.S. building codes, 2) estimate the performance and cost impacts of those requirements, and 3) evaluate the water protection needs associated with water-to-refrigerant heat exchangers in heat pumps.

The authors conclude that there is little technical reason for double-wall separation, and this separation can increase initial equipment costs. The purpose of the double wall is to prevent contamination of potable water by harmful chemicals, but many codes leave the toxicity of refrigerants and compressor oils undefined.

The report analyzes the effects of heat exchanger performance and costs on system economics; for heat pump water heaters and water-source heat pumps, the added costs for double-wall separation are as low as 2-8%.

**Monitoring of Residential Groundwater-Source Heat Pumps in the Northeast;** EPRI EM-4372; Project 1201-14; Final Report 1986; Prepared by: Allegheny Electric Cooperative, Inc.; Harrisburg, Pennsylvania (in English).

A two-year field test on two residential groundwater heat pump (GWHP) systems retrofitted in Central Pennsylvania homes (more than 6,000 heating degree-days). Study objectives were to determine the technical feasibility of using residential GWHP systems in the Northeastern United States; to evaluate seasonal efficiency and impact on utility load shapes.

On-site wells supplied system water at year-round temperatures of 12°C. One heat pump system was reversible, supplying heat and air conditioning; the second system was non-reversible, supplying heat only, with a water-to-air heat exchanger added for cooling. Detailed high speed and hourly average data were recorded on magnetic tape on weather, energy use of each heat pump, water flow and temperature.

Heating performance of the systems varied. The reversible unit's seasonal performance factor (SPF) was only 1.8, but was more reliable than the non-reversible unit, which operated at an SPF of 3.0 and had start up problems. Both units fell below manufacturer published SPFs. Limited data prevented drawing any conclusions about cooling efficiencies.

Results emphasize the need for astute buying and use of comparative ratings between models at conditions consistent with the specific application. Compared to oil at 1984 prices, in this north-eastern application, the non-reversible unit has a 4-6 year payback.

For one heating season (82-83) the systems worked properly and required no supplemental heat. Therefore, if the GWHP system is reliable and sized to carry the heating load under all conditions or if the back-up heat source is not electric resistance, use of such a system will not add load to a winter peaking utility system.

## HPC Products Available

The following products and services are available directly from the Heat Pump Center:

● **Non-Azeotropic Refrigerant Mixtures as Working Fluids in Compression Heat Pumps**, HPC-B1, Edition 2, DM 220 for HPC member countries, postage not included (plus VAT in the FRG).

● **Heat Pump Research, Development, and Demonstration Projects**. Summary Report: Update 85 from the HPC RD&D Database, HPC-R2-1, Edition 1, May 1986. DM 75 (plus VAT in the FRG), postage not included

● **Database services**: on request, the HPC staff will respond to specific inquiries for information retrieval from the HPC databases on:

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● Literature review: **Environmental Aspects of Heat Pump Applications**, DM 25 (plus VAT in the FRG), postage not included, see order blank in this issue

● **General inquiries**. If you have a specific question concerning any aspect of heat pump technology and development, contact the HPC directly.

Orders for HPC products and inquiries to the Heat Pump Center should be directed to: IEA Heat Pump Center, c/o Fachinformationszentrum Energie, Physik, Mathematik GmbH, D-7514 Eggenstein-Leopoldshafen 2, Federal Republic of Germany. Telephone: 07247-82-4541

# Schedule of Conferences and Trade Fairs

## April 14-16, 1986;

Pretoria, South Africa; IIR-Frigidair '86; CSIR Conference Center; Contact: Symposium Secretariat S341, CSIR, Box 395, 0001 Pretoria, Republic of South Africa; telex SA 321 312

## April 14-17, 1986;

Auckland, New Zealand; HEVAC&R '86 New Zealand, Conference and Exhibition; Sponsor: New Zealand Institute of Heating and Ventilating Engineers; Contact: Brylene Enterprises Ltd., P.O. Box 76-237, Manukau City, New Zealand, 09/274-4029 or 274-7587

## April 14-17, 1986;

Anaheim, California (USA); Solar Energy Conference (American Society of Mechanical Engineers); Contact: ASME Meeting Dept., 212/705-7795

## April 14-18, 1986;

Perth, Western Australia; AIRAH Federal Conference; Annual Conference, Australian Institute of Refrigeration, Air Conditioning and Heating; Contact: Airah Conference 1986, Convenor, Robin A. Lyons, 29 Laurence Road, Walliston, Western Australia 6076

## April 16-19, 1986

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

## May 11-15, 1986;

Birmingham (England); HEVAC, Domestic Heating & Plumbing Trade Fair and Exhibition; Contact: Tom Webb, British Trade Development Office, 212/593-2258 (USA)

## May 19-23, 1986;

Espoo (Finland); Industrial Planning, Engineering, and Construction, VII International Symposium; Sponsor: International Council for Building Research, Studies and Documentation (CIB); Contact: CIB W66 VIII Symposium, AREA Travel Agency, Congress Department, Kaisanuemenkatu 13 A, 00100 Helsinki, Finland

## June 10-15, 1986;

Guangzhou (People's Republic of China); China's 2nd International Total Energy Exposition and Conference; Contact: Ms. D.C. Rowe, International Trade and Expositions Ltd., 553/579, Harrow Rd., London W10 4RH, UK

## June 22-26, 1986;

Portland, Oregon (USA); 1986 ASHRAE Annual Meeting; Contact: ASHRAE Meeting Dept., 1791 Tullie Cir., NE, Atlanta, GA 30329, USA

## June 23-26, 1986;

Rome (Italy); Third International Stirling Engine Conference; Contact: Organizing Secretariat, Gibi studio congressi, Via Marco Besso, 40, 00191 Rome, Italy. Telephone: 3273291 or 3286897

## August 4-7, 1986;

West Lafayette, Indiana (USA); International Compressor Engineering Conference; Purdue University; Contact: James F. Hamilton, Conference Chairman, Ray W. Herrick Laboratories, Purdue University, West Lafayette IN 47907 (USA), 317/494-2132

## September 14-17, 1986;

Dublin, Ireland; CIBS/ASHRAE '86; Trinity College; Contact: Steve Comstock, Director of Communications/Publications, ASHRAE, 1791 Tullie Circle NE, Atlanta GA 30329 (USA), 404/636-8400

## October 26-29, 1986;

Dubai, United Arab Emirates; MERVAC 86 (Middle East Refrigeration, Ventilation, Air Conditioning and Heating Exhibition); Contact: Fairs and Exhibitions Limited, 51 Doughty Street, London WC1N2LB, United Kingdom, Tel. 01-831-8981, Tlx. 299708 Efanee G

# ABSTRACTS

**Newsletter Focus: Environmental Aspects of Heat Pump Applications**, M. Meal (F.R. Germany). In light of the importance of considering all aspects of heat pump development (and not just energy savings), environmental impacts resulting from heat pump operation are summarized, as well as the risks to humans and the environment from these impacts. Present environmental conditions in the IEA Heat Pump Center member countries are described briefly.

**Electric Heat Pumps Result in a Reduction in Air Pollutants**, R. Brandner, J. Spitzer, P.V. Gilli (Austria). The trade-offs in terms of resulting air pollution between operating an electric heat pump and a conventional oil-fired boiler are described. The reduction in local emissions is at least partially offset by an increase in emissions due to electricity production at a central plant. The authors present data and calculations that show that under all but the worst-case assumptions, the electric heat pump results in a net reduction in emissions and immissions of air pollutants, compared to an oil-fired boiler.

**Air Pollutant Emission Comparison of Gas and Diesel Engine-Driven Heat Pumps to Oil- and Gas-Fired Boilers**, M. Meal (F.R. Germany). Air pollutant emissions from gas and diesel engine-driven heat pumps are compared to emissions from oil and gas fired boilers. Based

on an equivalent heating requirement, engine-driven heat pumps result in lower emissions of SO<sub>x</sub> (given the same fuel sulfur content), particulates, and carbon dioxide, but significantly higher emissions of NO<sub>x</sub>, CO, and HC. Pollution control equipment, such as catalytic converters or engine modifications, can reduce engine emissions to the same level as boiler emissions.

**Catalytic Converters Reduce NO<sub>x</sub>, CO and HC Emissions at the Göppingen District Heating Plant**, H.A. Rostek (F.R. Germany). Two gas-engine-driven heat pumps were installed to supply the district heating system in Göppingen. This system has two unique characteristics: 1) the heat pumps use industrial waste heat as a heat source, and 2) catalytic converters were installed on the gas engines to reduce emissions of NO<sub>x</sub>, CO, and HC. Results showed a seasonal performance factor of 1.51 (with the peaking boiler) after the first heating season, and reductions of 98-99% in NO<sub>x</sub>, 95-97% in CO, and 54-95% in HC emissions after installation of the catalytic converters, with no significant decrease in heating performance.

**Research in the Netherlands on Heat Pumps and the Environment**, J.A.W. Oldenhof (the Netherlands). Recent Dutch research projects concerning the environmental impacts of heat pump applications are summarized. Topics

covered include: use of chlorofluorocarbons in heat pumps, effects of large scale heat extraction from ambient air, noise pollution, air pollution, ground water problems, use of ground heat, and safety aspects with regard to the use of halogenated hydrocarbons in heat pumps.

**The Environmental Effects of Large Heat Pump Stations: Aspects of Environmental Safety and Health**, B. Isaksson (Sweden). This article considers the occupational hazards of refrigerant leakage from large heat pump systems. Risks of planned and unplanned refrigerant emissions are reviewed, and guidelines are given for reducing the hazards in the event of a large emission, including operational procedures, CFC alarms, computer control of the heat pump, and staff training recommendations.

**Ground and Water as Heat Sources for Heat Pumps: Environmental and Legal Issues**, M. Meal (F.R. Germany). Widespread development of ground and water source heat pumps can lead to adverse environmental effects, through heat and water extraction, and the possible release of toxic substances. Legal questions arise as to who and how many should have access to ground or water heat sources. Key issues regarding large scale exploitation of these heat sources are described, based primarily on work going on in Sweden.

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

Our next issue will focus on industrial heat pump applications, including:

1. Results from the HPC study on industrial heat pump applications
2. Industrial heat pump product data
3. Market data on industrial heat pumps in HPC member countries
4. Case studies
5. A Brief Literature Survey
6. Selected Book and Report Reviews
7. Schedule of Conferences and Trade Fairs

We would welcome any further contributions on this topic. Please send your contributions (results or progress reports from investigations into environmental questions concerning heat pumps) to the Heat Pump Center by February 15, 1986.

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