IEA Heat Pump CENTRE
NEWSLETTER
VOLUME 15
NO. 3/1997

Residential heat pumps

In this issue:

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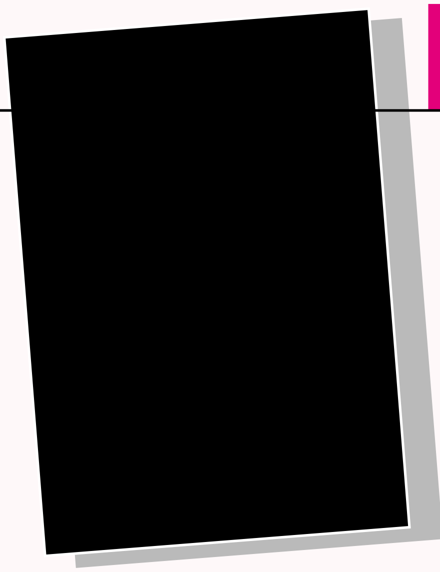

Residential Heat Pumps

Residential heat pumps provide a cost-effective, energy-efficient alternative for providing heating and cooling in both new and existing houses. This issue evaluates some applications and highlights several approaches which aim to achieve even more efficient systems, consisting of heat source, heat pump and distribution system.

Front cover:
The front cover shows a compilation of two photographs: one showing residences in Switzerland, equipped with a heat pump, the other showing the heat pump itself. More information can be found in the Swiss 'country box' on page 15.

COLOPHON

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Language editing:
Barbara Shapland
Production: Novem Support Group
Illustrations: Offermans EPS
Printer: Huntjens, Stein, the Netherlands

Frequency: quarterly
Printed September 1997

HPC Newletter subscriptions are automatically renewed unless written cancellation is received by 1 October

ISSN 0724-7028

TOPICAL ARTICLES

Heat pumps - The new means of residential heating

The Danish company Lodam Energi a/s recently participated in the project group which won the Heat Pump Competition held in the Netherlands. This competition is described in the article on page 16.

In order to obtain an optimum solution it is important to consider the heating system as a whole. The project group chose a heating system based on a heat pump combined with balanced ventilation heat recovery. Space heating is achieved using a combination of floor heating and radiators, as it is the most favourable solution when it comes to economy and comfort. For this particular project, vertical ground heat exchangers were developed and tested and Lodam Energi developed a new range of heat pumps based on propane.

Propane was chosen as it offers the client optimum economic and environmental advantages. Results of tests carried out by technological testing institutes in Denmark (DTI) and the Netherlands (TNO) show that optimising the refrigerating circuit leads to a COP (coefficient of performance) increase of up to 30%. Thus the COP for normal operating conditions now ranges from 3.0 to 5.4.

The flammability of propane has led to changes in the heat pump design in order to comply with current standards for heat pumps using natural refrigerants. TNO prepared a quantitative risk analysis showing that the risk of personal injury due to fire or explosion caused by heat pumps installed in buildings is negligible.

To ensure a good energy economy the heat pump is equipped with a state-of-the-art microprocessor control, based on the outside temperature. General trends are towards dynamic control in accordance with the heating requirement of the building and the reduction of auxiliary equipment energy requirement, since this constitutes an increasing share of the total consumption.

As to energy and environment, heat pumps pose a serious alternative to other means of heating. Compared with electric heating the energy consumption may be reduced by up to 60% and CO_2 emissions reduced by up to 20%. By using propane, the contribution of refrigerants to ozone layer depletion and the greenhouse effect are reduced to a minimum.

Jens Andersen
Lodam Energi a/s
General Manager

Heat pump news

Thermal storage systems may become mandatory

Japan - The Ministry of International Trade and Industry (MITI) is considering making it compulsory for company and building owners to adopt thermal storage-type air conditioning systems to reduce the daytime power consumption by utilising night-time electricity. Night-time electricity is stored in the form of ice or chilled water. MITI intends to improve the load factor (which represents the ratio of actual power generation to the generating capacity), since a poor load factor leads to high electricity charges to end-users. MITI recently submitted its recommendations to the Electric Industry Committee (EIC), who are expected to make a decision before the end of the year. The EIC intends to further improve the load factor by increasing the difference between the daytime and night-time electricity rates.

Thermal storage type air conditioning systems cost some 20% more than ordinary air conditioners, a fact which has hampered their market introduction. At present, newly constructed business facilities larger than 1000 m^2 will probably be required to install thermal storage systems, and in retrofit situations existing air conditioning systems must be replaced by thermal storage systems. In order to facilitate this introduction, the EIC intends to take several steps which include increasing the difference between daytime and night-time electricity charges, expanding the lease business currently implemented by Tokyo Electric Power Co., Kyushu Electric Power, etc., and by improving the financial incentives for companies purchasing thermal storage systems. The EIC also intends to increase the target load factor value, which is currently about 55%. Since the factor currently differs between utility companies, individual target values will be set for each company.

It has been pointed out that Japan's high electricity charges are a major hindrance to expansion of domestic demand. MITI's comments on the economic restructuring programme are that charges will be lowered to a level comparable to the international level until 2001.

The high interest in thermal storage was proven by the many visitors of the TEPCO Thermal Storage Air Conditioning Fair, co-sponsored by Tokyo Electric Power Company (TEPCO) and the Federation of Electric Power Companies, which was held on 28-30 May at the New Tokyo International Exhibition Centre. The fair attracted some 20,000 visitors over three days, most of them architects, facility managers, building owners and developers. This event therefore provided an excellent opportunity for system manufacturers and users to meet and compare systems.

Source: JARN, 25 June 1997

New Swedish heat pump research programme

Sweden - A large national research programme on 'Energy-efficient heat pumps and refrigeration systems' started on 1 July 1997. The programme is financed by Swedish industry and the Swedish National Board for Industrial and Technical Development (NUTEK), in collaboration with several technical universities. The total budget of the programme is SEK 55 million (approx. USD 7.1 million) over 3.5 years.

Source: Peter Rohlin, Royal Institute of Technology. Fax: +46-8-203007.

Heat Pump Quality Label in Three European Countries

Germany - Three organisations aiming to stimulate the use of heat pumps in Germany, Austria and Switzerland (IWP, LGW and FWS respectively) have decided to collaborate to ensure that high quality heat pump equipment is available on the market. The working group D-A-CH has set up testing regulations for heat pumps in cooperation with the heat pump test centre in Tss, Switzerland, where the Coefficient of Performance (COP), reliability and noise levels etc. are tested. Heat pumps which meet all test criteria will be awarded an HP-Quality Label, which will be valid in all three countries. The introduction of the quality label was at the request of manufacturers (members of the aforementioned organisations), who wanted independent proof of quality of their products, to convince installers and consumers of the high quality and reliability of heat pumps.

Source: Wärmepumpe, June 1997

HPTCJ broadens scope

Japan - As of 1 July 1997, the Heat Pump Technology Center of Japan (HPTCJ) has changed its name to Heat Pump and Thermal Storage Technology Center of Japan (HPTCJ: no change in the abbreviation). This corresponds to its expanding activities, which will include thermal energy storage technologies. This name change is a result of the stringent requirement from the national energy policy to enhance electrical energy supply efficiency through load levelling by promoting thermal storage systems, specifically by storing cold during off-peak hours in summer. Japan recently joined the IEA Implementing Agreement on Energy Conservation through Energy Storage (ECES), and HPTCJ has been designated by MITI and the Ministry of Foreign Affairs as the organisation to implement this activity in Japan. HPTCJ has thus expanded its field of activity in the IEA End-Use Working Party programme.

Source: Takeshi Yoshii, Heat Pump and Thermal Storage Technology Center of Japan

Investment programme E2000 creates jobs

Switzerland - The Swiss parliament has approved the investment programme E2000. This means that over the next two years, energy-efficient solutions will be promoted using federal funds.

The following measures are included:

- Energy-relevant renovation of the building shell
- Heat recovery with air conditioning systems and their optimisation
- Renovation of inefficient lighting installations
- Replacement of existing heating systems by renewable energy sources, e.g. heat pumps

A condition for subsidy is that the investment costs must exceed USD 34,500. Combining two measures is also possible, e.g. renovating windows, together with replacing an old heating system with a heat pump. This means that a 20kW thermal output heat pump heating system, depending on heat pump type, qualifies for a promotion subsidy of between USD 2,800 and USD 4,100. An additional 20% of the total subsidy is paid out for combined measures.

To qualify for subsidies to the building envelope, U-values of $\leq 0.3 W/m^2K$ are required for outside walls, and U-values of $\leq 1.5 W/m^2K$ for windows including frames. These conditions favour the possible use of a heat pump heating system, since the installation costs are reduced. For district heating systems the investment programme is ideal for heat pump use in the apartment building sector, where lower investment limits can certainly be reached. Also interesting is the replacement of oil heating systems with heat pumps which can use waste heat.

The final application date for the programme is September 1998, provided that funds are not exhausted before then. Altogether the Swiss parliament decision is seen as positive, since it will create additional jobs in the sector of new heating technologies. The investment sum stimulated is expected to reach approximately USD 500 million.

Source: Dieter Wittwer, INFEL
Member of the Swiss National Team
Fax: +41-1-2994140

Management Committee to visit China

The Executive Committee of the IEA Heat Pump Programme is planning a study visit to China in August 1997. The purpose of the visit is to inform China about the IEA Heat Pump Programme and to find out about the latest developments in heat pumping technologies in China with its potentially large market. Meetings are planned with governments and industry in Beijing and Shanghai. A report of the visit will be included in the December issue of the newsletter.

Heat pump exposition in Switzerland

Switzerland - On 20-22 November of this year the second National Heat Pump Exposition will be held in Zurich. In conjunction with this exposition special workshops will give the visitors an overview of the developments and advantages of heat pumps in newly built areas as well as retrofit buildings. For further information see the events section on page 31.

Contact: FWS, Fax: +41-31-3524206

Swiss National Team on the Internet

Switzerland - From July 1997 the Swiss National Team has its own Internet home page. It provides up-to-date information on:

- heat pumping technologies;
- market trends;
- new studies and research results;
- heat pump-related standards;
- events schedule;
- links to related organisations.

The Website (http://www.waermepumpe.ch) of the Swiss National Team and the Swiss Association for the Promotion of Heat Pumps (FWS), available soon, has been established to inform users about heat pump-related topics. It also covers promotion, statistics, publications and international transfer of know-how.

Further information: Thomas Afjei, Swiss Nat. Team, c/o INFEL. Email: afjei@infel.ch;
Fax: +41-1-299 4140.

▼ *Figure 1: Home page of the Swiss National Team http://www.waermepumpe.ch/hpc (currently only available in German).*

Can heat pump water heating leasing work for your condominium association?

Hawaii, USA - The Hawaiian Electricity Company (HECO) has found a way to promote the installation of heat pumps in condominiums for the purpose of water heating by leasing the equipment. Equipment leasing can be particularly beneficial for both the association and the individual condominium owners. For the association, leasing preserves cash reserves and the fixed lease payment make monthly operating expenses easier to control and more predictable.

Equipment leasing for heating pumps has another advantage. Currently, the State of Hawaii has an energy tax credit of 20% for heat pumps. These tax credits will be available until the end of 1998. But, how do tax credits help a condo association that doesn't pay taxes? Present tax laws permit the finance company to claim these benefits and pass them through to all customers (including condominium owners and other non-profit organisations) by reducing the lease payments. In most cases the energy cost saving brought about by the heat pump water heater are equal to, or greater than the lease payments. This means that leasing won't increase maintenance fees. Also, since heat pumps are replaced every 10 to 15 years, the association will continue to receive all the energy cost saving from the heat pump after the initial term of the lease (five to seven years) is completed. Leasing has helped many condominium associations install heat pumps and their owners save money on water heating costs.

Contact: HECOs Marketing Services
at +1-543-4751.
Source: Powerlines, June 1997, HECO
(Hawaiian Electricity Company)

Earth-pipe collectors fill the gap

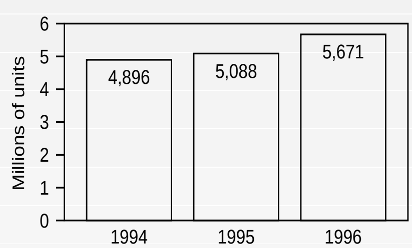
Switzerland - In Switzerland, ambient air is the most common heat source for residential heat pumps, even though temperatures can fall below -10°C during the winter. In earth-pipe collectors the supply air for the heat pump can be preheated, thus reducing the gap between the heating capacity of the heat pump and the building load during the very cold days of the year.

The Swiss Federal Office of Energy has supported a study implementing a cost-benefit analysis of this technique. To calculate the benefits of earth-pipe collectors, models were developed to simulate the air temperature at the end of the piping system. These models were validated by comparing them with measurements taken by the Laboratory of Energy Systems at the Swiss Federal Institute of Technology (ETH), Zurich. To calculate the increase in the seasonal performance factor (SPF) of using earth-pipe collectors, the heat pump simulation program (YUM) was used.

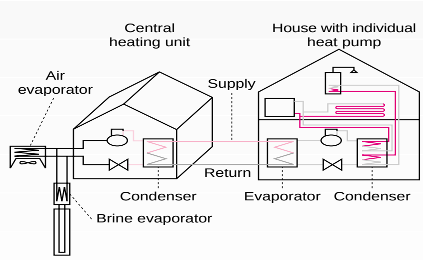
Compared with systems without preheating a 10% increase in the SPF can be achieved. Approximately one-third of this improvement is effected by using a smaller heat pump supplying the same amount of heat due to pre-heating the supply air in the earth. This smaller heat pump operates longer during the less cold days, which reduces the start-up losses of the heat pump. More importantly, this type of preheating allows an air-to-water heat pump to operate without any auxiliary heating, even in regions with cold winters.

Contact: Mr Arthur Huber,
Huber Energietechnik, Ingenieurbro.
Fax. +41-1-4227953.

▼ *Figure 1: Earth-pipe collector system in a house in Laufen, Switzerland.*



▼ *Figure 2: Smaller heat pump due to preheating the supply air.*



STIEBEL ELTRON presents new heat pump series

Germany - STIEBEL ELTRON has developed a new heating-only heat pump series. The previous problems which hindered application in retrofit situations have now been solved by the new modular system. Supply temperatures up to 65°C can be reached, in eight different capacities varying from 8 to 36 kW. The modular system also makes installation very easy. The three base products of the series (WPWE 8/11/14 kW) can easily be combined to form other capacities varying from 16.6 to 28 kW for brine systems and 22.6 to 36.6 kW for water systems. By optimising the working fluid cycle, excellent Coefficients of Performance (COPs) of over 5 have been achieved, depending on the heat source.

Environmental issues have also been taken into account. R-290 (propane) is used as the working fluid as it contains no chlorides, has a zero ozone depletion potential and a zero global warming potential. A further stimulation of environmentally friendly heating systems is provided by STIEBEL ELTRON in the form of a special gift, on condition that the owner is willing to make the installation available for promotional activities, for the press, and for a limited number of group visits per year. This gift can be as high as DM 4,000 (USD 2,400), depending on the size of the installation. This campaign continues till the end of 1997.

Source: Wärmepumpe, June 1997

Trondheim workshop highlights interest in CO_2 technology

Norway - Almost 90 participants from 15 countries gathered in Trondheim, Norway, on 13-14 May to discuss the development of CO_2 technology in refrigeration, heat pumps and air conditioning systems. This workshop was organised by NTNU-SINTEF Energy, and co-sponsored by the IIR and the International Energy Agency Heat Pump Centre.

The workshop provided an in-depth understanding of CO_2 as a working fluid via the 18 papers which were presented. The topics included fundamental and system studies, various applications and component development. Several working prototypes and test rigs with CO_2 were presented at SINTEF's laboratories. The workshop concluded with a panel discussion on the potential of CO_2 in various applications and the main challenges/barriers to realising this potential. Heat pump water heaters and dryers were mentioned as typical examples of applications where CO_2 has been shown in practice to be a good alternative working fluid, with regard to both efficiency and cost, despite the poor theoretical efficiency. Commercial and industrial refrigeration, heat pumps for retrofitting in high-temperature hydronic systems and cooling applications combined with tap water heating were mentioned as other promising CO_2 applications. Both the presentations and subsequent discussions revealed a considerable interest in CO_2. Several companies and research organisations are developing components, conducting prototype tests and doing theoretical studies on CO_2. The availability of compressors, heat exchangers and other components is much better than it was 12 months ago. Proceedings will be available from the IEA Heat Pump Centre in December.

Source: Peter Nekså / Jostein Pettersen, IIR Bulletin 97.4 (June)

CO_2 heat pump: the future?

New Zealand - A joint venture between the Massey University Centre for Post-Harvest and Refrigeration Research, the Electricity Corporation of New Zealand and Flotech Limited (an international supplier of engineered equipment and systems, based in Auckland) has been set up to develop a transcritical heat pump using CO_2 as the working fluid. The New Zealand group has embarked on an ambitious programme. The group has quickly moved through a short but detailed engineering design phase straight into production of an industrial scale prototype with a heating capacity of 150 kW. They thus hope to skip the traditional theoretical and laboratory-based approaches being taken by many groups around the world looking at using CO_2 as a refrigerant. Their very tight time schedule gives them 12 months to determine whether they have a commercially viable product.

Source: Market Matters, June 1997,
Prof. D.J. Cleland, Massey University.
Fax: +64-6-3505654

EU ecolabels for environment-friendly refrigerators and freezers

The European Commission has announced that refrigerator and freezer manufacturers which produce energy-efficient machines, refrain from using ozone-depleting substances (ODS) and only apply low GWP (global warming potential) chemicals, may attach EU ecolabels to their products. The logo, a stylised letter 'E' surrounded by a flower with the EU's 12 stars as petals, may be used only after the EU verifies that a product meets specified energy efficiency and environmental requirements. Refrigerators using ODS as refrigerants or in the manufacture of the insulation will not be permitted to display the label.

Contact: EC DGXI. Fax: +32-2-2969559
Source: OzonAction, April 1997

AREP test reports available

USA - Presentation materials from additional testing, reporting and data-sharing conducted as part of the Alternative Refrigerants Program (AREP) are now available from ARI (Air Conditioning and Refrigeration Institute).

The material, offered as a set of 97 reports and briefing packs, represents all the information collected from and shared among the AREP participants over the past two years. AREP was an international cooperative effort, sharing data and practical experiences on the performance of air-conditioning and refrigeration equipment using non-ozone-depleting alternatives, HCFC-22 and R-502 (a mixture of HCFC-22 and CFC-115).

The initial phase of the AREP effort was successfully completed by the summer of 1994. The programme was then continued, with the focus shifting from identifying and exploring new refrigerants to addressing the practical issues of implementing chlorine-free refrigerants. This second phase began in March 1995 and was completed in January 1997.

The report "Results from ARI's Alternative Refrigerants Evaluation Program (AREP): Volume 5 (Presentation Materials and Reports from Additional Testing): is available at a price of USD 300 (USD 150 for ARI members) to cover printing, handling and standard US shipping charges.

For ordering information contact
Dave Godwin, ARI,
fax: +1-703-5283816.

Source: Koldfax, June 1997

Japanese GHP Shipments Show 20% growth

Japan - According to an industrial source, shipments of gas engine heat pump air conditioners (GHPs) in the first half of the 1997 refrigeration year (Oct. 1996 - Mar. 1997) totalled 19,393 units, up 19.9% compared to the same period last year. Heat pump air conditioners using LPG numbered 9,653 units, up 5.2%, and those using city gas numbered 9,740 units, an increase of 39.1%.

Source: JARN, 25 June 1997

New ARI rating standards value integrated heat pumps

USA - Integrated heat pump technology received a boost recently when the Air-conditioning and Refrigeration Institute (ARI) adopted a new rating procedure. Until recently, the energy performance of integrated heat pumps was rated according to a seasonal energy efficiency ratio (SEER) and heating seasonal performance factor (HSPF). These ratings did not address the substantial savings achieved by integrated water heating capabilities and, as a result, did not provide a realistic measure of the technology's overall energy saving benefits.

The new ARI rating standard is based on measuring the energy required to meet both space-conditioning and water-heating loads. ARI's Directory of Certified Unitary Equipment now lists new measurements known as 'Combined Cooling Performance Factor' and 'Combined Heating Performance Factor'.

Growing utility and customer interest in integrated heat pumps has prompted manufacturer NORDYNE to add a 5-ton unit to its residential product line and develop a series of 2-, 3-, 4- and 5-ton units specifically designed for commercial applications.

Source: EPRI Heat Pump News Exchange, Spring 1997.

Overcapacity of AC production equipment in China

China - An overcapacity of air conditioner (AC) production equipment is becoming a serious problem in China. According to a local industrial source, the production capacity is more than three times the actual amount of production, meaning that two-thirds of the total available equipment is idle. In China, there is also an overcapacity of refrigerator and car production, making it necessary to modify the production equipment expansion policy.

There are currently approximately 408 AC manufacturers. This is a result of advances by overseas manufacturers, due to the economic reform policy, as well as small/ medium local companies, which have mushroomed recently. Since many have expanded their production lines, the total annual production capacity has increased by some 20 million units, a level close to the total world demand. Despite the fact that actual production was 6,460,000 units in 1996, supply still exceeds demand so that, due to the huge stock levels, many manufacturers are being compelled to reduce their product prices. A price war is already appearing in the market, and foreign manufacturers operating in China feel they are facing severe competition.

Only 10 manufacturers are capable of producing more than 300,000 units, and only five can produce more than 500,000. Due to lower production efficiency and technical knowledge of local manufacturers, it is difficult for most of them to explore overseas markets and develop new products which can create new demand.

Source: JARN, 25 July 1997

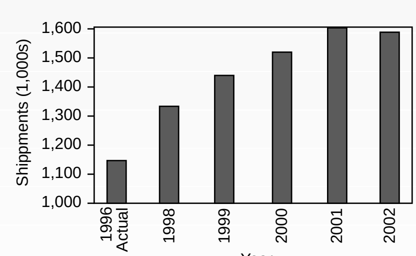
Steady growth in US residential heat pump market predicted

USA - A new industry forecast of appliance shipments anticipates steady growth in residential heat pump sales in the US through the year 2002 (see **Figure**). The five-year forecast by the trade journal Appliance predicts that manufacturer's shipments of heat pumps will increase from 1.27 million in 1998 to 1.52 million in 2002. Actual 1996 shipments of air-source heat pumps totalled 1.15 million, up 12% from 1995.

Recent information from utilities and industry indicates that demand will grow for integrated heat pumps providing water heating and space heating, as well as for add-on heat pumps, and heat pumps for manufactured housing. EPRI (Electric Power Research Institute) is currently sponsoring research into these and several other promising new technologies, including geothermal heat pumps, and an air-source commercial heat pump using a non-ozone depleting refrigerant. Through its Residential Heat Pump Target, EPRI is also conducting market research to identify barriers to widespread customer acceptance of heat pumps, supporting the development of technician training programmes in order to ensure proper installation and servicing of heat pumps, and promoting the development of better equipment for northern climates.

Source: EPRI News Exchange, Spring 1997.

▼ *Figure: Projected Heat Pump Sales 1998-2002. (Source: Appliance, Jan 1997 and ARI)*



Workshop on Ab-Sorption Machines

The Netherlands - On 2-3 June 1997 the first Annex 24 workshop on Ab-Sorption Machines for Heating and Cooling in Future Energy Systems was held in Maastricht, the Netherlands. Twenty participants from the Annex member countries, Germany, Japan, and Norway and the IEA Heat Pump Centre took part in the workshop.

During the workshop the member countries presented their national reports, which they had prepared during the first phase of the Annex. Throughout the afternoon session of the first day, a number of case studies were presented by invited speakers. These included a Swedish presentation on comfort cooling from district heating, a German presentation on fuel cells and absorption heat pumps, a Dutch presentation on comparing heat pumps for greenhouses, and a presentation on the current status of absorption heat pumps in Japan.

During the plenary discussion on the second day, participants agreed that training and education should be emphasised. They also proposed recommending to national research boards that research and development should concentrate on reducing investment costs by enhancing mass and heat transfer and by system studies.

Furthermore, topics were selected for the case-studies which will be performed by the individual countries during the second phase of the Annex. The workshop concluded with a visit to an absorption heat pump in the Oranje-Nassau building in Heerlen, the Netherlands (see Newsletter Vol.15/1).

The proceedings will be published by the IEA Heat Pump Centre in September.

Source: M. Gustafsson, Royal Institute of Technology, Sweden / Hanneke van de Ven, IEA Heat Pump Centre

Annex 25 gets underway

Norway - During the IEA Implementing Agreement on Heat Pumping Technologies Executive Committee (ExCo) meeting last May in Trondheim, Norway, the proposal for a new Annex was approved. The title of Annex 25 is “Low-Temperature Low-Cost Heat Pump Heating Systems”. The project will incorporate a study of the most promising concepts for space and tap water heating. These include:

- an earth-coupled heat pump connected to a heat distribution system with integral water heater heated by the same heat pump;
- an air/water heat pump with capacity control and separate heat pump water heater with heat recovery from the exhaust air or solar assistance;
- a combination with controlled air ventilation (for supply and exhaust air).

Other aspects will include the development of new intelligent, robust control strategies, the testing and optimisation of prototypes, and the building and testing of pilot plants in low energy houses, designed in accordance with recommendations made in preceding project phases.

The operating agent for Annex 25 is INFEL, Switzerland. The Netherlands are currently the other participating country, but Austria and Germany have also expressed interest in joining the Annex. The Swiss have already performed a national study, the results of which are presented in the article by Mr Thomas Afjei on page 26. The project should be finalised by December 1999.

French Annex proposal

At the ExCo meeting a draft proposal for an Annex entitled Year-round Residential Space Conditioning using Heat Pumps was presented by Mr Beck from Electricit de France (EdF). This proposal covers not only heating applications and hydronic distribution systems, but also air distribution and space cooling. A decision on this proposal was postponed until the next Executive Committee meeting in October.

HPP Annual Report

For the first time, the IEA Heat Pump Programme has published a promotional annual report. To obtain a free copy, contact the HPC.

Annex 23 (Heat Pump Systems for Single-Room Applications) has produced a promotional brochure entitled Heat Pumping Solutions for Single-Room Applications. This brochure contains summaries of the status in the participating countries. For further information contact: Mr Frank Lenarduzzi, Ontario Hydro, 800 Kipling Ave., Toronto, Ontario, Canada, fax: +1-416-207 6565, or the HPC.

Ongoing Annexes

Red text indicates Operating Agent. Japan is the Co-operating Agent of Annex 18.

Annex 16 IEA Heat Pump Centre	AT, ES, JP, NL, NO, CH, US
Annex 18 Thermophysical Properties of Environmentally Acceptable Refrigerants	CA, DE, JP, SE, UK, US
Annex 22 Compression Systems with Natural Working Fluids	CA, DK, JP, NL, NO, CH, UK, US
Annex 23 Heat Pump Systems for Single-Room Applications	CA, FR, CH, US, SE
Annex 24 Ab-Sorption Machines for Heating and Cooling in Future Energy Systems	CA, IT, JP, NL, SE, UK , US
Annex 25 Low-Temperature Low-Cost Heat Pump Heating Systems	CH, NL

IEA Heat Pump Programme participating countries: Austria (AT), Belgium (BE), Canada (CA), Denmark (DK), France (FR), Germany (DE), Italy (IT), Japan (JP), The Netherlands (NL), Norway (NO), Spain (ES), Sweden (SE), Switzerland (CH), United Kingdom (UK), United States (US).

Residential Heat Pumps

An international overview

Hanneke van de Ven, IEA Heat Pump Centre

Many types of residential heat pumps are used throughout the world. Most mature markets for residential heat pumps are found in Japan and the US, but the number of installations of residential heat pumps is also increasing in other countries. China, for example, is a rapidly expanding market. This article gives an overview of the market, and highlights the constraints and success factors for market diffusion. The individual country information describes the situation in several countries in more detail.

In most countries only a very small part of this residential heat demand is covered by heat pumps. The highest scores are achieved in the US and Japan with 6.8% and 7.9% respectively. This is mainly due to the larger space cooling demand in these markets.

Technology available

Residential heat pump installations available on the market can be classified according to the type of heat source, heat sink and drive energy.

Heat source type

Ambient air, ventilation air, the ground, water (ground, lake, sea, sewage) and waste heat can all be used as heat sources for residential applications. Air is often used as the heat source for the reversible heat pumps providing cooling in the summer as well as heating in the winter. In colder climates, the ground is a very suitable heat source, since its temperature is relatively stable throughout the year. Ground-coupled heat pumps show increasing popularity in countries such as Norway and Austria. In the US ground-coupled heat pumps are being actively promoted as both cost-saving and comfort-providing appliances. In Europe dual heat source heat pumps have been introduced which preheat ambient air by feeding the air through ground ducts.

Heat sink type

The heat distribution system also varies with geographical regions. In Japan and the US air systems are dominant. In the US ducted systems are common, whereas in Japan spaces are conditioned individually with ductless equipment. In Europe, hydronic systems are far more common. While many hydronic systems installed in Europe require relatively high (70°C) supply temperatures and use radiators, development trends are towards low-temperature heat distribution using floor, ceiling and wall heating systems. Because of the lower distribution temperature, relatively larger heating surfaces are required. On the other hand space heat demand is decreasing in new houses, requiring less surface. The existing hydronic systems hamper the possibilities for a large market penetration of heat pumps, because the higher supply temperature needed limits the system coefficient of performance (COP). However, for new low energy houses heat pumps provide an efficient and cost-effective heating system, as they are increasingly equipped with low-temperature distribution systems.

Drive energy

Electricity is the drive energy for the majority of residential heat pump applications. Few thermally-driven systems (including engine-driven and direct-fired absorption heat pumps) have been installed, but their number is slowly increasing. Approximately 45,000 thermally-activated systems are installed worldwide, most of these in commercial, institutional and industrial applications. However, as highlighted in a previous issue of the HPC Newsletter (Volume No. 15/1, pages 14, 20-22) there is a potential for absorption heat pumps in residences. An advantage of thermally-activated heat pumps is that they can supply the high temperatures needed in retrofit situations with traditional heat distribution systems. It is also relatively simple for an absorption heat pump to provide backup heating by operating as a gas boiler. Electric heat pumps are usually equipped with electric backup heating.

Application

Heat pumps are used for space heating (and cooling), for water heating or for all these functions. These integrated residential heat pumps are available on the market, mainly in the US and Europe.

Market characteristics

Important markets for residential heat pumps can be found in the US and Japan. In Japan most residential heat pumps are reversible air-to-air room type heat pumps. Practically all units are electricity-driven and installed as monovalent room-type heat pumps. Most systems in the US are central reversible electric air-to-air heat pumps (for cooling and heating purposes), although several other types are also being used, e.g. the use of ground-coupled heat pumps is growing fast.

In Central and Northern Europe space conditioning residential heat pumps utilise different heat sources. The ground is the dominating heat source, both open (ground water) and closed (ground). Both air and water are used for heat distribution, but hydronic systems dominate the market. Air systems are mainly found in Southern

Europe. In European countries heat pumps used to be combined with auxiliary heating devices, such as boilers. Today heat pumps are increasingly equipped with strip heaters.

In Austria, Belgium, Germany and the Netherlands more than 80% of all residential heat pump installations are for domestic water heating. In Norway and Denmark heat pump water heaters comprise approx. 30% and 50% of the installations respectively. Only in Germany and Norway have integrated systems (providing water heating as well as space heating) penetrated the market to some extent, approx. 15%. In some countries industry is challenged to improve the performance of new equipment and reduce first cost through procurement projects and competitions.

Market size

In terms of volume Japan is by far the largest market for residential heat pumps. The sales figures for room-type heat pumps in Japan exceeded over 7 million units in 1996. A trend is graphically represented in **Figure 1**. The penetration rate is very high, exceeding 80% of the total number of dwellings in Japan. The second largest market for residential heat pumps is the US. Approximately 1,148,000 centralised residential units were sold in 1996. This meant an increase of more than 12% over 1995.

In 1996 Austrian annual sales of heat pumps for space heating totalled approx. 1,700 (see **Figure 2**). This represents a growth since 1988. Remarkable is the increased share of direct-expansion ground-coupled heat pumps (see the article of Mr Halozan on page 22 of this issue) which is more than 60%. In Norway the share of ground-coupled heat pumps is increasing rapidly, although this market has been dominated by reversible air-to-air-units. In recent years the sales figures for heat pumps in Norway have been fluctuating between 1,100 and 1,500 per year. In Switzerland sales figures for residential heat pumps have increased slightly in 1996 (see **Figure 3**).

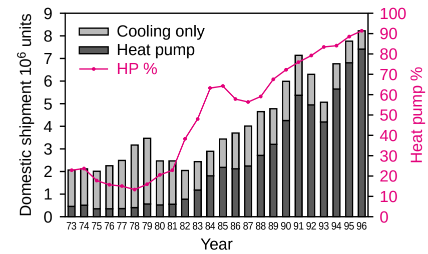
Almost every third newly erected single-family house is equipped with a heat pump.

In the Netherlands heat pumps have not had a breakthrough in the market yet. A database at TNO (Organisation for Applied Scientific Research) contains 8,250 heat pump systems, of which 1,500 are installed in buildings (commercial and residential), most being used for water heating. However, at least 400 residential electric heat pumps will be installed in projects in newly developed areas, where most of the heat pumps are used for space heating as well as hot water heating, replacing the commonly used gas boiler. The Dutch Heat Pump System Competition which was finalised in June (see the article by Messrs Oostendorp and Van Doorn on page 16 of this issue) is expected to provide another important contribution to the acceptance and increased use of electric heat pumps for residential buildings in the Netherlands.

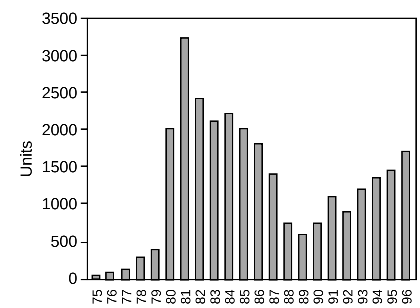
A similar competition was held in the Scandinavian countries in 1995. In Sweden heat pump sales increased by 37% between 1995 and 1996 (from 9,028 to 12,431 units), mainly because of marketing efforts and information coupled to the aforementioned competition.

In Spain market data on heat pumps are scarce. Heat pumps have hardly penetrated the residential market. Heating-only electric heat pumps were not competitive a few years ago. Very few electric air-to-air and air-to-water units had been installed for heating in 1995. They are installed in some demonstration projects and their seasonal performance factor should be higher. Domestic heat pump water heaters have been installed in single-family houses with small storage tanks. The number of manufacturers and distributors is increasing, which indicates that conditions have improved. The application of reversible heat pumps is hampered by the low penetration rate of air conditioning equipment in the residential sector: only 3.5% of the existing households had air conditioning

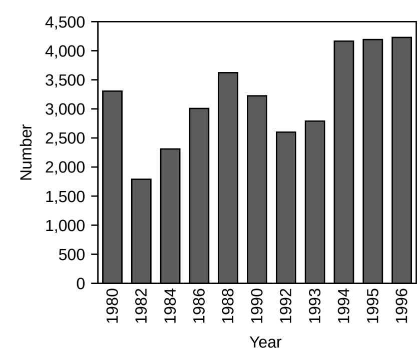
▼ *Figure 1: Trend in residential heat pump sales in Japan.*



▼ *Figure 2: Number of heat pumps for space heating sold annually in Austria.*



▼ *Figure 3: Trend in residential heat pump sales in Switzerland.*

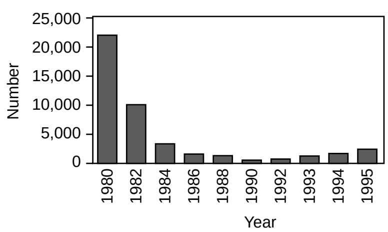


in 1994. On a European scale however Spain is a key player. In 1993 it was ranked number one in heat pump imports, followed by Italy and Greece. Germany was the top exporting country.

In Germany the amount of heating-only heat pumps has been increasing since 1990 (see **Figure 4**).

In France only a small share of the residential heat demand is covered by electric heat pumps. Some 37% of the 36,000 fixed air conditioners sold in 1995 for residential use, i.e. 13,300,

▼ *Figure 4: Number of heating-only heat pumps installed annually in the residential sector in Germany.*



were reversible heat pumps. Approx. 1,000 dwellings were equipped with a heating-only heat pump with floor heating system, around 10% of the total floor heating market. Electricité de France (EdF) has recently embarked on a new programme aimed at increased use of heat pumps for space cooling and heating.

The existing residential market in the UK is small. Improvements can be expected where underfloor heating systems are being installed in new homes. Currently the fuel use balance in the UK has important implications for the penetration of electric residential heat pumps. Only dramatic changes in heating equipment costs will change this. Moreover, CO_2-emissions from UK power stations do not encourage the government to invest in electric heat pump technology. If the number of combined-cycle gas-fired plants increased, prospects for the electric heat pump would be much better.

In Canada sales of residential air-source heat pump units have declined since 1988, from 23,000 units in 1988 to approx. 5,000 in 1995. Ground-source heat pump sales saw an increase in the years 1990-1993. Practically all air-source units are imported, while a few small companies manufacture ground-source heat pumps.

China is a rapidly growing market. The total sales volume of domestic air conditioners amounted to 5.2 million units in 1995, which meant an increase of 35% as compared to the year before. The first air conditioners installed in China were mostly window-type, for cooling only, but their function as a heating source is increasingly being appreciated and the number of heat pump types (reversible and separate type) currently used is approx. 30%. Because of a power shortage there is also wide interest in thermal-driven heat pumps. The use of thermal storage systems is also encouraged by the Chinese government.

In Korea the diffusion of air conditioners is mainly limited to cooling-only types (98%). However, for commercial buildings the use of the heat pump air conditioners is increasing, though for residences this is not yet expected.

Influencing factors

The data in the previous paragraph show that there are wide differences in market penetration rates in the various countries. Several factors can be identified as relevant to successful promotion of heat pumps.

The most important market factor is a demand for both cooling and heating, e.g. in Japan and the US. In these countries reversible heat pumps provide cost-effective cooling in summer, and energy-efficient heating in winter. This offers perspectives for countries such as China, Greece, Italy, France and Spain which have a similar climate. A space heating demand alone has failed to generate a strong market.

The investment costs are still a draw-back for the increased implementation of heat pumps for heating only. A heat pump can cost 1.5 to 5 times as much as a gas or oil-fired heater of the same capacity, and the difference with the price of electric resistance heating is even larger. International competition has demonstrated that opportunities for cost reduction do exist.

The ratio of electricity to fuel prices can also be a constraint. In spite of the high efficiency of heat pumps the reduction in energy costs can be moderate. In terms of energy value, the electricity consumed by electrical heat pumps is typically about one third to one quarter

▼ *Table 1: Project data for Norwegian project.*

Floor area	200 m²
Indoor temperature	20°C
Design outdoor temperature (DOT)	-28,°C (three-day average over a 30-year period)
Mean annual outdoor temperature	3°C
Maximum heating load at DOT	10 kW
Annual space heating demand	32,000 kWh/year
Annual hot water demand	5,000 kWh/year
Working fluid heat pump	R-404A
Heat source	100 metres 110 mm well -rock / ground water - indirect system
Heat distribution	Low temperature hydronic underfloor system
Design conditions evaporator - condenser	-6°C/+45°C
Heat pump - design load at DOT	5.0 kW (50%)
Auxiliary heating needed	Below -8.2°C ambient temperature (maximum 5 kW)
Annual heat supply from heat pump	29,340 kWh/year (91,6%)
Annual heat supply from auxilary heat source	2,660 kWh/year (8.4%)
Primary energy to heat pump and aux.	11,390 kWh
Energy savings system	20,610 kWh (65%)
Seasonal Performance Factor - heat pump	3.4
Seasonal Performance Factor - total system	2.8
Total investment costs 90,000 NOK	(approx. USD 13,850*)
Electricity price (heat pump and aux. system)	NOK 0.5/kWh (app. USD 0.077*)
Annual reduction in energy costs	NOK 9,800 (approx. USD 1,510*)
Simple payback period	9 years

*) USD 1 = Norwegian Kroner (NOK) 6.5

of the energy consumption of fossil-fuel equipment. The price ratio must therefore be less than 3:4 for financial savings to be made, depending on the efficiency of power generation. Since the trend is that this efficiency increases, the opportunities for heat pumps improve.

Building practice in most countries is moving towards increasingly higher standards of insulation. A high level of insulation can reduce the heat demand to such a low level that the energy saved with a heat pump has little value to the consumer. On the other hand, a sealed building requires forced ventilation, for which a ventilation-air heat-recovery heat pump provides a cost-effective system for further reducing heat losses.

Finally, an active stimulation policy by governments and utilities can be fruitful. A number of policy instruments are available, which can be divided into financial stimulation measures and measures aimed at improved information campaigns. A mix of these instruments has proved to be successful in several countries, for example in Switzerland.

Low electricity tariffs

As previously stated, relatively high electricity tariffs can limit the cost effectiveness of a heat pump installation. One way to stimulate the use of heat pumps is to find ways to reduce electricity costs.

In Germany experience has been gained with reduced electricity tariffs for heat pumps. In exchange for allowing the power required for the heat pumps to be switched off during peak hours up to two hours, the utility company charges lower electricity tariffs for heat pumps. This is beneficial for both the consumer, who has less costs and therefore a shorter payback period for the heat pump, as well as the utility company, which does not have to install more peak capacity, but can cover the electricity demand for heat pumps in periods with a lower demand. To bridge the two-hour off period without loss of

Austria

The Austrian sales figures of heat pumps for space heating purposes continue to increase.

Some 133,000 heat pump units are currently used in the Austrian residential sector. Approximately 27,700 are used for space heating purposes and exhaust air heat recovery, while the remaining105,300 are mainly small heat pump water heaters. The installed thermal capacity is approx. 632MW and the heat delivery is approx. 1.55 GWh per year. The CO_2 emissions reduction based on the oil equivalent is approx. 660,000 tonnes per year. Additionally, an increasing number of reversible heat pump air conditioners have been sold, not primarily for the commercial sector, as in previous years, but with an increasing share of the private sector. Unfortunately, sales figures are not available.

Over the past few years successful developments have been carried out on heat pump units to increase both efficiency and reliability. One of these successful developments is the use of direct evaporation, which offers highly efficient systems at a lower price than secondary loop systems with the same efficiency. Ground-coupled systems can achieve a seasonal performance factor (SPF) in the range of 4 to 5.The problem of soldering at the site to connect the ground coil to the heat pump unit has been solved: prefabrication, filling and testing of the refrigerant circuit in the workshop is already possible. Industry has also changed from the HCF-22 to alternative refrigerants, mainly hydrocarbons such as R290 and R-1270.

Source: Mr Halozan, Austrian National Team

Japan

The market for residential heat pumps in Japan has successfully evolved over the past 15 years. This resulted in a market of 7 million units in 1996 and in a dissemination rate exceeding 80% of the total number of dwellings in Japan. This development has been supported by favourable economic growth and the need for improved living conditions, coupled with improved performance of heat pumps and their reliability. The Japanese residential heat pump market is dominated by split-type air-to-air reversible electric heat pumps.

It is not easy to describe the overall picture of residential heating and cooling systems. However, the trend over the past 10-30 years shows a move away from heating only by a traditional ‘kotatsu’ (foot warmer) or kerosene heater, to the addition of cooling (room air conditioner) to conventional heating devices. This trend is followed by the reversible heat pumps of today. It is estimated that the share of heat pumps based on the total number of rooms amounts to 40%. This means that the remaining 60% are heated by other means, such as kerosene or gas heaters and, specifically in the cold-climate region, by central kerosene-boiler systems.

Traditionally, heat pumps have been used in combination with other heaters, mainly because of a poor heating performance. However, with the improvements in heating performance and reliability at low ambient temperatures, as well as improvements in the thermal performance of the building envelope, heat pumps have evolved to satisfy residential heating demand without the need for other heating devices.

Although a noticeable market has not yet been established, domestic hot water heating is potentially a prospective new market area for heat pumps. Thermally-driven residential heat pumps, such as gas engine heat pumps and absorption heat pumps have also been looked at as competing technologies for electric heat pumps, and developments are being carried out by gas utilities and manufacturers.

Source: Mr Yoshii, Japanese National Team comfort, a heat storage medium is often used in the form of the floor slab or a water storage tank .

Another approach is taken in Austria, i.e. heat contracting for space heating and hot water production. In a group of multi-family houses a heat pump system is installed either by a utility or a private company. The heat pump is operated by the installer and the heat supplied is charged to the consumers at district heating tariffs. For companies running a small district heating network in a community, buildings outside the district heating network are supplied with heat from heat pumps. These consumers are charged the same heating tariff as the consumers of district heating. This is a very promising approach, especially when the district heat is produced by a cogeneration plant and the heat pumps are powered with electricity from this plant.

Peak shaving

Peak shaving using thermal storage in summer is of special concern in Japan, but is also increasingly used in other countries with a relatively high or growing electricity demand. In particular, the growing summer peak in electric power demand from air conditioners, has increased the market for thermal storage systems in Japan. These systems are used to shift the electric power demand to night-time, thus helping to reduce the daytime peak. For storing cold, the focus is on high-density thermal storage, e.g. using ice, because such systems require less space in a building.

Examples

Cold climates also offer good opportunities for residential heat pumps. An integrated residential heat pump was installed in a standard 200 m2 Norwegian single-family house by Normann Energiteknikk AS, Oslo, Norway. The system provides both hot water and space heating. The layout of the system is given in **Figure 5**. The design outdoor temperature is as low as

Norway

Approximately 13,500 heat pumps are currently being used for space and hot water heating in Norwegian residences, of which approximately 5,300 are exhaust air heat pumps, 5,800 are reversible air-to-air heat pumps and 2,400 are water-to-water and water-to-air heat pumps. However, over the past year interest in water-to-water (ground-coupled) heat pumps has been growing. Systems are either designed for space heating only or for combined space and hot water heating.

The total installed capacity of residential heat pumps is approx. 60MW, and the annual heat production is approx. 0.4 TWh/year. This is approx. 10% of the total annual heat production from Norwegian heat pumps. Typical payback periods are currently 5-8 years, depending on the type of heat pump system and annual heating demand.

Investment costs for a 4-5kW heat pump unit including drilling, heat source connection and control system range from USD 7,500 to 10,000. The depth of the drilled holes range from 75 to 150 metres, depending on the heating demand, rock type and trickle of ground water in the terrain. Typical power and energy output from the holes are 45W/metre and 150kWh/metre/year, respectively. The water-to-water heat pumps, which are always connected to indirect water/glycol systems on the heat source side, supply heat to hydronic heat distribution systems, i.e. underfloor heating or low temperature radiators. In addition to space heating, many units also provide pre-heating of domestic hot water. Maximum supply temperature is approx. 55°C.

Space heating heat pumps in residences are always designed as bivalent heating systems. The heat pump covers the base heat load (50%), and supplementary heating is provided by oil-fired or electric boilers, electric resistance heaters (baseboard heaters) or wood-burning stoves. During the heating season the heat pump typically covers 80-95% of the total heating demand.

The dominating working fluid in residential heat pumps with temperature requirements below 55°C has previously been R-22. Use of R-22 is regulated by the Montreal Protocol, but it is still used to some extent in residential heat pumps. Propane water-to-water heat pumps can be an alternative. They typically achieve 10-15% higher COPs than similar systems using R-22. The relative heating capacity is similar to R-22 (same compressor size needed), and the exhaust gas temperature is considerably lower than R-22. This is very important when considering the operating conditions and the reliability of the systems. Despite these facts no residential heat pumps using hydrocarbons as working fluids have been installed. The main reason for this has been the lack of appropriate standards and regulations for the safe use of flammables in this kind of application. However, the Norwegian Directorate for Fire and Explosion Prevention (DBE) has now started to prepare revised regulations and guidelines for the “Application of Flammable Working Fluids in Refrigeration and Heat Pump Systems”. This activity, which should be finished next year, will be partly based on the new European Standard prEN-378. The new regulations are expected to considerably improve the market for propane and propylene as working fluids in residential heat pumps, and other refrigerating systems with low charges.

Source: Jørn Stene, SINTEF Energy (Norwegian National Team)

Switzerland

In the near future, inexpensive and efficient designs will be required for heat pumps and low energy houses with an annual heat demand below 200MJ/m^2. **Figure 1** shows the development of the heating energy consumption. Sales of residential heat pumps have slightly increased in 1996. Almost every third new single family house is equipped with a heat pump.

However, the biggest market over the next few years will be retrofit applications. A typical example is a single family house with a ground-coupled brine/water heat pump equipped with two vertical earth collectors, each 65 m in length. The total heating capacity is approx. 8kW at an ambient temperature of -8°C. The system replaced an old oil system in July 1995. An SPF of 4.5 is achieved for space heating, though the energy used by circulation pumps reduces the SPF to 3.9. The total costs of the installation amounted to CHF 36,340 (USD 25,000). The heat pump is manufactured by CTA. **Figure 2** shows the division of the total installation costs.

Figure 1: Development of specific heating energy for new buildings in Switzerland. (Source: Swiss Association of Engineers and Architects (SIA)).

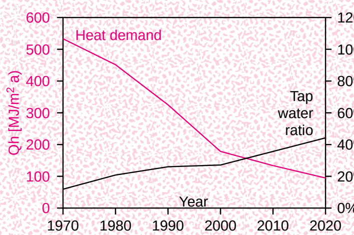
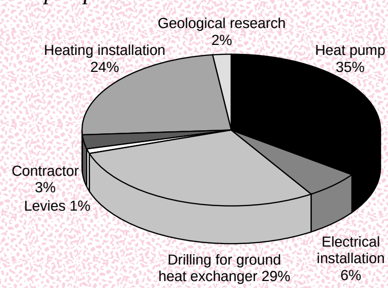


Figure 2: Distribution of total costs of heat pump installation.



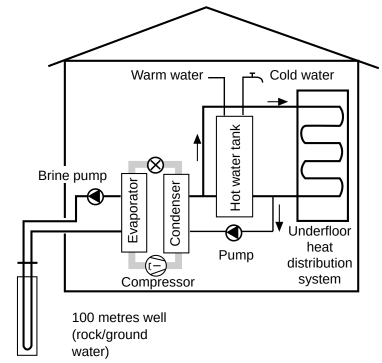
USA

Residential heat pump applications in the US have continued to grow over the past year, bolstered by increased new housing construction and even stronger system replacement markets. While the combined market for central residential heating equipment, unitary products and room air conditioners was up 11% to a record 14.3 million units, the heat pump market segment showed even greater growth, with shipments totalling 1,147,828. This represents an increase of 12% over 1995. Installations of air-to-air heat pump applications in the US topped 1 million units over the past year, double the rate of the early 1980s. Air-to-air heat pump systems are now found in 8-9 million homes in the United States. An important factor in this growth is the greater efficiency achieved by new systems, averaging 55% higher than units produced 20 years ago.

Growth in the number of heat pump applications for residential water heating is being encouraged by new programmes offered by the utilities. Water heater rental programmes sponsored by the utilities encourage home owners to change to more efficient systems as an alternative to switching to other fuels to heat water. Programmes such as these provide benefits to home owners in the form of off-peak rates, no initial investment for installation, no maintenance costs, and improved quality of hot water service from the larger tanks employed. Even in the cooler climate of the Northeast, utility support for heat pump water heating applications is strong. In cooperation with a manufacturer, Northeast Utilities plans to install 2,600 units in residences and light commercial facilities during the coming year, reducing these customers water heating energy usage by as much as 50%. The programme follows proven tests which led to improvements in the circulation pump, condenser coil, and defrost controls, as well as simplified installation of the heat pump water heating system.

Source: Mr Phil Fairchild (US National Team), Mr Russ Johnson (Northeast Utilities) and Mr Glen Hourahan (US National Team).

Figure 5: Lay-out of an integrated heating system in a Norwegian residence.



-28°C. It concerns an indirect system using rock/ground water as a heat source. All essential data are presented in **Table 1**, including the economic data. The installation has a simple payback period of around nine years.

In Boven-Leeuwen, the Netherlands, two new projects will have heat pump systems developed by the runner-up of the Dutch Heat Pump Systems competition. In total, 72 houses will be equipped with the new system. An ID Kompact heat pump of 6.6 kW heating capacity will be installed using ground water as the heat source. Water is heated by the heat pump to 60°C. A buffer tank of 3,000 litres makes it possible to run the heat pump with cheap night-time electricity only.

Conclusions

In general the number of residential heat pumps is growing. Application potential is particularly high in newly emerging markets (e.g. China) and in countries with both a cooling and heating demand. In other countries increased implementation of heat pumps is difficult due to financial reasons. Measures such as government or utility promotion programmes and reduced electricity tariffs in exchange for the possibility to switch off the heat pump during peak hours could stimulate the market in these countries. This would lead to economy-of-scale effects for the equipment cost.

Ms Hanneke van de Ven, IEA Heat Pump Centre

Heat Pump System Competition in the Netherlands finalised

Jan van Doorn and Peter Oostendorp, the Netherlands

On 12 June 1997, Ed Nijpels, former Dutch Minister of Environment and Chairman of the World Nature Fund, announced the winner of the Dutch Heat Pump System Competition at the TNO-MEP (Organisation for Applied Scientific Research) offices in Apeldoorn, the Netherlands. This announcement marked the end of a competition that started in April 1996. It can generally be concluded that heat pump technology for Dutch building and installation practice has now matured and can be successfully introduced onto the Dutch market. However, within the next few years a major breakthrough will not be possible unless initial investment costs are substantially decreased.

The award was granted to a team led by Innovatiecentrum Groningen. The consortium will share the supply of 400 heat pump systems to new Dutch building projects with runner-up De Beijer RTB BV, if suitable projects can be found and if further talks with the participating utility companies lead to acceptable price offers. More information on the winning system design is given in the box.

Dutch situation

Heat pumps, when properly designed and installed, provide considerable advantages in terms of primary energy use and protection of the environment. However, there are several reasons why this technology has not yet been widely disseminated in the Netherlands. First of all, the Dutch energy market is characterised by low natural gas prices. Also, there is no large residential space cooling demand to stimulate the use of reversible heat pumps. Finally, investment costs are high, making heat pumps part of a vicious circle of high investment costs, low demand, little experience gained, high risk and uncertainty, high investment costs, etc.

The advantages of heat pumps have recently been recognised by the Dutch government, whose energy conservation policy aims at saving 65 PJ per year by the year 2020 using heat pumps. Heat pumps are also stimulated by the Dutch energy distribution companies in their efforts to abate CO_2 emissions and stimulate rational use of electricity. The opportunities for electric heat pumps for individual home heating have now greatly improved. The Dutch cogeneration programme has resulted in a considerable amount of electric power generated with high overall efficiencies. Electric heat pumps provide an excellent application for the electricity thus generated. By the year 2020 no less than 17% of all electricity is to be generated from renewable energy sources, which makes the use of electricity even more attractive with respect to fuel efficiency and the environment.

The national heat pump competition was organised on the initiative of the Netherlands Agency for Energy and the Environment (Novem), Sep (Co-operating Electricity Producers), EnergieNed (Cooperating Energy Distributors) and the regional energy companies REMU, ENW, ENECO and NUON, hereafter referred to as Pg-SO. Manufacturers, suppliers, consultants, installation contractors and all other interested parties were invited to submit one or more complete heat pump system designs for individual homes.

Aims of the competition

The aim of the competition was threefold. Firstly, to stimulate parties to combine efforts to improve technology, applicability and operation practice. Secondly, to achieve a better trade-off between investment costs and energy costs; and finally, to create momentum in the market and thus break the vicious circle.

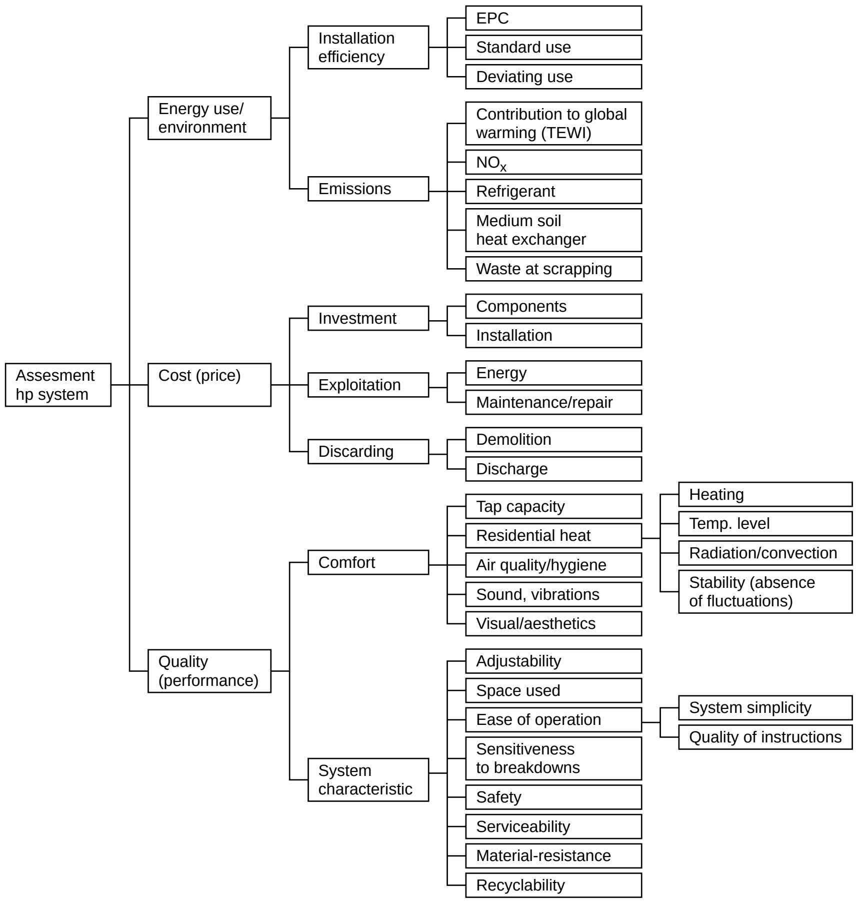
The winner is granted an award, free publicity and the opportunity to install 400 systems on behalf of REMU, ENW, ENECO and NUON, if suitable projects are found and supply conditions agreed upon.

System requirements

The systems had to be compatible with Dutch building and installation practice and applicable to three given types of homes. They had to provide acceptable comfort for heating, hot water supply and ventilation, according to given standards. They also had to be more energy efficient than natural gas heating. Finally the systems should use electricity only and comfort should be maintained if electricity was switched off by the energy utility for two hours a day. All these constraints should be fulfilled at a minimum initial investment and operating cost level. The systems were evaluated by TNO-MEP at their test facilities in Apeldoorn, according to criteria available to the participants in the form of a System Assessment Diagram (see **Figure 1**).

The response to the competition was well above expectations. Twelve consortia consisting of 50 companies produced a total of 26 different

Figure 1: Criteria for systems evaluation.



installation concepts. In the majority of heat pump systems the ground was used as the heat source. **Table 1** provides an overview.

Evaluation procedure

Selecting the winner(s) was the task of the Pg-SO. During a pre-selection the system designs were checked according to variables such as the total installed capacity and the ability to maintain comfort if the system was switched off for two hours a day. TNO also looked for any indications that the systems would not function properly. After the pre-selection, five consortia were still in the race with 11 system designs.
In the final evaluation, TNO prepared an extensive evaluation matrix for the jury, where scores were given for all criteria of the diagram in **Figure 1**.

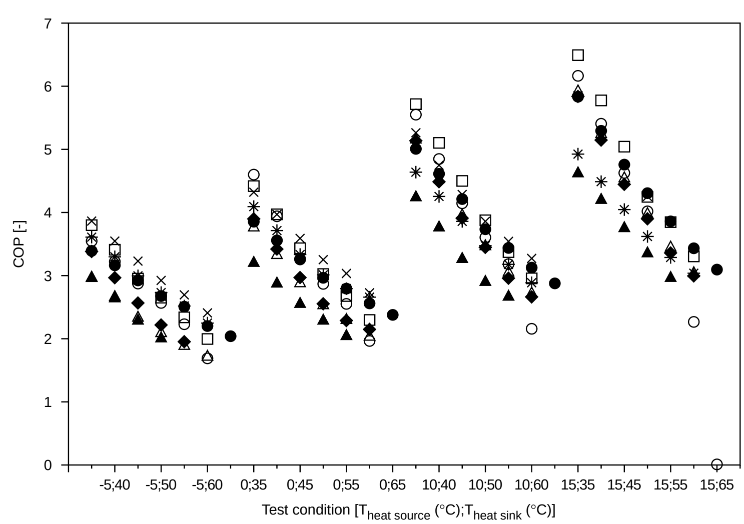
As an important part of the systems evaluation, TNO tested the heat pumps in their Development and Test Centre for Heat Pumps using 26 different combinations of source and sink temperatures. The test procedure used was derived from EN255. **Figure 2** shows that the heat pumps vary largely in measured COP-values. Noise levels were determined according to ISO 9612-2, part 2, using sound intensity measurement by scanning.

A next step in the evaluation was predicting the performance of the heat pump *system* through simulation. TNO has developed a powerful tool to simulate dynamically the interaction of inhabitant, building, installation and climate during a (shortened reference) year. In this Dynamic Installation and Building SImulation Model (DIBSIM) a model of the heat pump, is simulated based on the aforementioned measurements. DIBSIM produces data (both for “low” and “high” inhabitants’ behaviour): the annual electricity

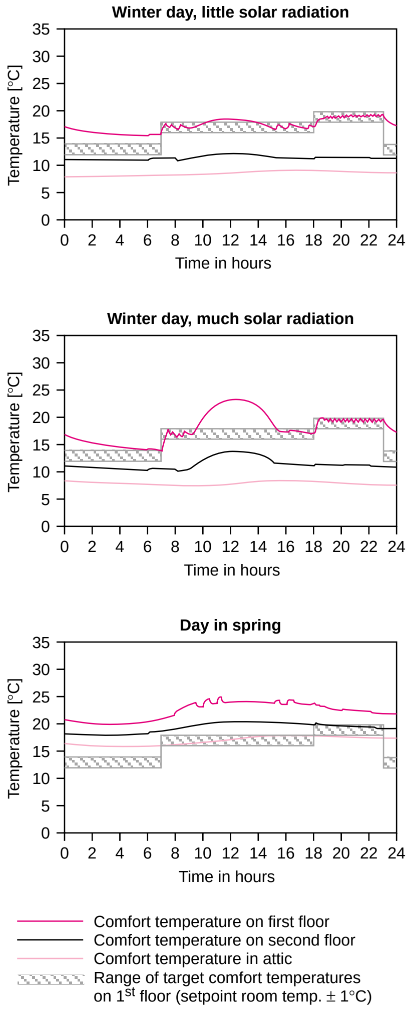
Table 1: Survey of the types of heat pump applied.

Source/sink of heat pump	Number
Ground / water	12
Water/Water	5
Ground (direct expansion)/water + air	2
Water/Water (integrated buffer)	5
Ventilation air / domestic hot water (integrated buffer)	1
Outside air / air	1
Outside air / water	2
Total	28

Figure 2: Measured COPs of seven water-to-water heat pumps at 26 pairs of heat source and heat delivery temperatures.



▼ *Figure 3: Calculated comfort temperature in different zones of the dwelling during three typical days.*



consumption, realised temperatures in various rooms of the house (see **Figure 3**) and the annual averaged COP-values for the heat pump alone, as well as for the total system, with a distinction between space heating and domestic hot water functions.

Observations

In the evaluation process several observations were made. First of all, the system simulations showed that none of the systems scored well on all criteria. A number of systems were quite strong in many aspects, but also showed failures on 'obvious' issues, thus jeopardising the overall system performance. For example, by applying a manually controlled backup heating system in combination with an automatically controlled heat pump system. This leads to comfort problems. Hence, most (if not all) systems had a considerable potential for improvement.

Secondly, the total costs of the heat pump systems (for heating, domestic hot water and ventilation) are still quite high. The least expensive system was NLG 22,000 (~USD 11,500). A conventional system of the same size would cost approximately NLG 9,000 (~USD 4750) in the Netherlands.

While some of the heat pumps showed good performance (a yearly average COP value of 3 and above for space and domestic hot water heating) the *systems* showed considerable losses. The calculated system-COPs a little over 2. These major losses were caused by the heat storage vessels, particularly in the case of a low heat demand and long domestic hot water lines. Poor functioning of control systems causes backup heating to be active instead of the heat pump. In some cases the performance of the heat pumps themselves could have been higher if better use had been made of the low supply temperatures occurring in the heating system. Also the control of the domestic hot water system could generally have been better.

Recommendations

TNO is preparing general rules and recommendations on heat pump systems for domestic applications, mainly based on the evaluations performed for the heat pump competition. Some of the lessons learned are:

- selecting the size and control mechanism of thermal storage vessels for domestic hot water should be carried out very carefully. A tank filled with hot water, when only a low hot water demand exists, gives high losses. It is better to select the size and a (demand dependent) control strategy in such a way that the buffer is almost emptied regularly: the advantage is smaller losses and a higher COP; all vital functions should be controlled by the control system;
- if a combination of heat distribution systems is chosen, e.g. floor heating and radiators, the same design supply and return temperatures should be used;
- in most cases the simulations showed room temperatures much higher than desired in summer. When room temperatures are higher than the outside air temperature, the heat recovery system, if there is any, is counter-productive: its heat exchange function should be switched off (ventilation, of course, should continue);
- system heat losses in rooms without a heat demand should be avoided;
- systems should be as simple as possible. Combining various energy-saving techniques within a single home should be avoided because investment costs will increase, while the maximum energy saving is limited.

TNO, acting on behalf of the Ministry for Economic Affairs, provides 'second opinions' on heat pump system designs made for the Dutch new housing market. This provides relevant feedback and advice to system designers, which in turn leads to better system designs.

▼ *Photo: Former Dutch Minister of Environment Ed Nijpels presents the first price trophy to Mr Janika Horvath of Innovation Centre Groningen.*

The Winner

The winner of the Dutch Heat Pump Competition was the consortium led by Innovatiecentrum Groningen. The consortium consists of energy utility EDON, heat pump manufacturer Lodam Energi, ground heat exchanger contractor Van den Berg and heating system contractor Unica. A schematic drawing of the concept is given in the Figure.

Optimised vertical ground heat exchangers are used to extract heat from the ground. For a high comfort level low-temperature floor heating is used to distribute the heat on the ground floor, with radiators used upstairs. Balanced ventilation in combination with ventilation air heat recovery is also used to reduce the losses that would otherwise have occurred in these well-insulated houses. The system is sized to cover the base heat load at an ambient temperature of -7°C. Only at very low outside air temperatures is additional electric resistance heating required. Propane is used as the refrigerant, because it has favourable thermophysical properties and is environmentally friendly.

The heat pump used is the most recent model “Combi” produced by the Danish manufacturer Lodam Energi a/s. Features of the heat pump include easy installation and maintenance.

For further information contact: Innovatiecentrum Groningen, J. Horvath, Tel: +31-50-5214567, Fax: +31-50-5212577

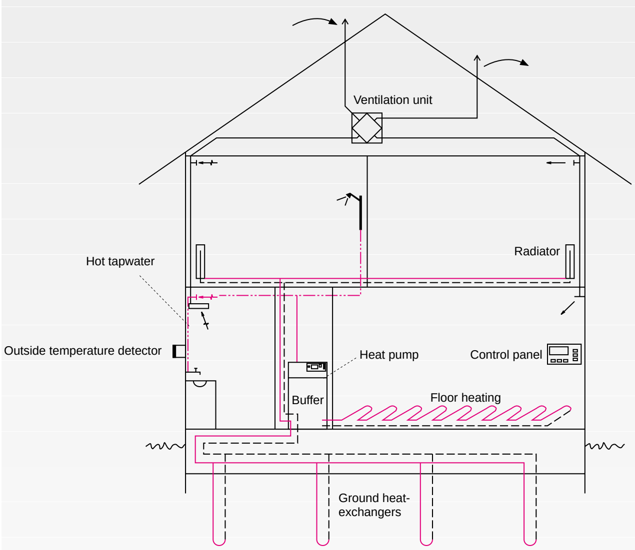


Figure: Layout of the winning system design.

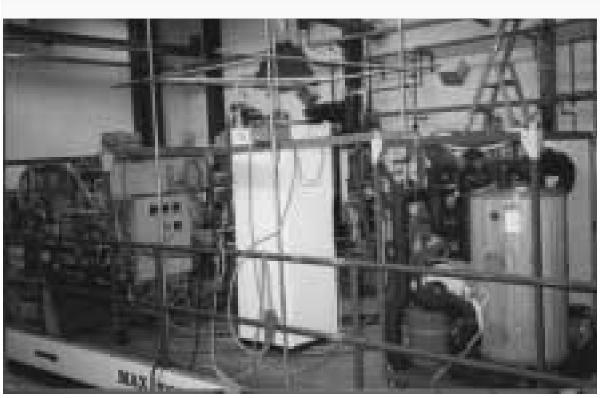


Photo: The winning heat pump under test at TNO.

Conclusions

In general, the systems included in the final evaluation proved satisfactory with respect to technical quality and compliance with standards of comfort. The feasibility of building systems using components already available on the market has now been demonstrated. However, all designs can be considerably improved by using existing know-how and materials, particularly regarding system sizing and control.

The jury regretfully concluded that none of the nominees succeeded in reducing the initial costs to a level where the incremental costs could be compensated by higher energy cost savings. This is mainly due to high initial costs of the heat pumps and the tendency to include excessive risk allowances. Successful market introduction is dependent upon the initial costs being substantially reduced.

In spite of this, the Dutch heat pump competition has been a success. It has made both suppliers and purchasers aware that the necessary equipment improvements and price levels are within reach. It has given a strong impulse to manufacturers, suppliers and installation contractors to combine their creativity and knowledge. If this approach is followed up, heat pumps will soon break through on the Dutch market for residential space heating.

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Ammonia Heat Pump in a Norwegian Residence

Ola Jonassen and Jørn Stene, Norway

Ammonia (NH_3) has been the dominating working fluid in industrial refrigerating systems for more than a century, but the toxicity and flammability characteristics have hampered its use in commercial and residential applications. However, a considerable technological development has taken place in recent years, resulting in reduced charges and new component and system design. Low capacity ammonia heat pumps and refrigeration systems (< 10 kW) are still considerably more expensive than conventional HFC systems, and further development is needed before profitable systems can enter the market.

In 1994 a space heating ammonia heat pump was installed in a residence in Trondheim, Norway. Ambient air is used as the heat source, and heat is supplied to a low temperature floor heat distribution system.

Ammonia as working fluid

The owner of the heat pump system wanted to construct a technically innovative plant using an environmentally acceptable working fluid. Ammonia was the primary choice since there is considerable experience with this working fluid. It has excellent thermodynamic and physical properties resulting in a high seasonal performance factor (SPF) and low operating costs. Last but not least, the fluid is a long-term alternative to CFCs, HCFCs and HFCs, with its zero ozone depletion potential (ODP) and global warming potential (GWP). The only problem has been the limited availability of components at a reasonable price. With the exception of the evaporator unit, steel tubes, bends etc., all components have been selected from former industrial plants.

Ammonia is toxic as well as flammable at extreme concentrations in ambient air. However, due to the pungent odour even the smallest leakage will be detected at an early stage. As long as the heat pump is designed in accordance with prevailing standards and regulations and the necessary safety precautions are taken, ammonia is a safe working fluid. In this case the heat pump unit is located at a safe distance from the residence, with abundant possibilities for ventilation.

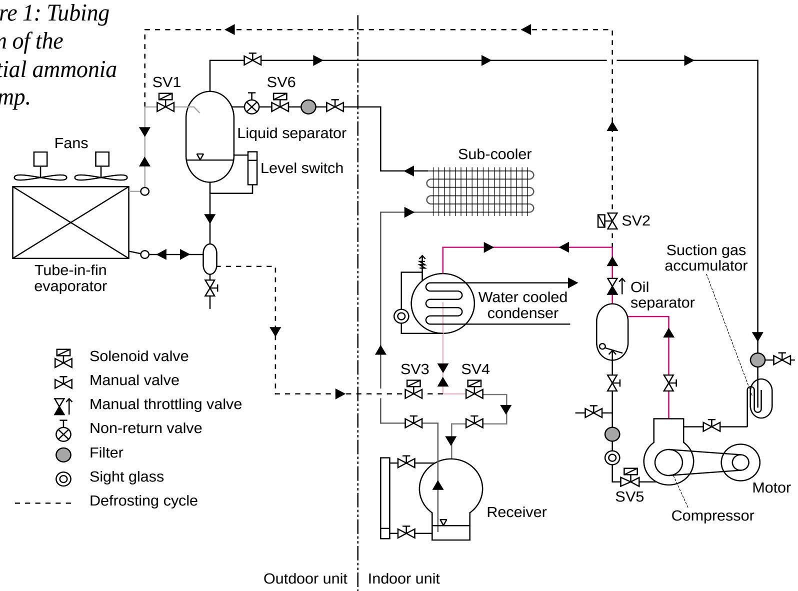
Heat distribution system

The heat pump provides space heating for a single family house with a total floor area of 220 m^2. In order to achieve low supply temperatures, a floor heat distribution system has been installed, using a separate circulation pump and individual room thermostats. The 22 mm plastic tubes are either mounted on aluminium foils under the wooden floors or placed in the concrete floor in the bathroom.

The heat pump unit is located in the garage about 15 metres from the house. Heat from the subcooler and the non-insulated heat pump unit (condenser, vessels, etc.) contributes to the heating of the garage. Hot water is distributed from the heat pump condenser to the residence through insulated steel tubes installed in a concrete culvert. Similar systems are used for distributing heat from a central heat pump to groups of houses.

The heating capacity of the heat pump is 6-7 kW at -8°C ambient temperature. Additional space heating below -8°C ambient temperature is provided by a wood burning stove located on the first floor. Hot water heating using a desuperheater is favourable in ammonia heat pump systems because of the high exhaust gas temperatures from the compressor. However, due to the long distance between the residence and the heat pump a desuperheater was not considered. As an alternative a HFC-134a heat pump is planned for hot water heating, and the unit will be placed next to the hot water accumulator in the residence.

Figure 1: Tubing diagram of the residential ammonia heat pump.



Heat source

The evaporator is specially designed for cold climate operation using the computer program EVAC, developed by SINTEF Energy. This component, which was built by TTC Norge a.s, is made from aluminium tubes (15.5/13.5 mm) and fins. In order to reduce frost formation on the evaporator surface, the optimum fin spacing is as high as 8 mm. This is considerably higher than that of conventional air coolers designed for warmer climates. The defrosting system has also been optimised, resulting in minimum defrosting cycles of 24 hours. For a fully frosted battery, the complete defrosting cycle takes approximately 20 minutes. At air temperatures above approximately 4C, the unit will defrost naturally during the day.

Figure 1 shows a diagram of the residential ammonia heat pump. The different parts are discussed in a separate box.

Control procedures

The heat pump capacity and subsequently the supply temperature from the condenser, is controlled using a thermostat in the return line of the heat distribution system. The heat pump compressor is run on/off, and a 700 litre water accumulator in series with the condenser ensures stable distribution temperatures to the residence. When the return temperature reaches 37°C the heat pumps stops. This corresponds to a maximum supply temperature of 40°C from the condenser. At higher distribution temperatures there is a risk of oxygen diffusion into the PEX-tubes, resulting in corrosion of heat exchangers, valves etc. The use of an ambient temperature compensation curve would have improved the SPF. However, since the supply temperature is rather low, a simple control procedure with constant supply temperature was preferred.

During the first two heating seasons the heat pump was stopped at ambient temperatures below -8°C in order to keep the gas compression temperature at an acceptable level. The installation of a water-cooled cylinder top on the compressor now enables the heat pump to be operated down to -14°C ambient temperature, and the maximum exhaust gas temperature has been lowered from 135°C to 70°C.

Evaporator system: The ammonia is circulated from the liquid separator through the tube-in-fin evaporator unit (fan coils) using gravity, so no pump is required. SV1 is open during normal operation. Liquid is fed from the condenser line to the separator through a solenoid valve (SV6) which is connected to the liquid level switch. A manual throttling valve is installed in series with SV6.

Compressor and condenser: Suction ammonia gas is drawn off from the top of the separator to the compressor through a suction gas filter and a suction line accumulator. The hot gas leaving the compressor passes through an oil separator and a non-return valve before entering the water-cooled shell-and-tube condenser. Ammonia liquid is drained from the condenser through the solenoid valve SV4 into the receiver. For safety reasons, the heat pump unit has a spring-loaded relief valve at the condenser, as well as pressure controls for high/low working fluid pressure and oil pressure.

Oil return system: Insoluble mineral oil is used as lubricant for the heat pump compressor. The oil is drained from the oil separator through an internal float valve, filter, sight glass and solenoid valve SV5. This last valve opens when the separator wall temperature rises above 50°C, to avoid any accumulated ammonia liquid draining into the compressor. The installation of an automatic oil return system, which drains oil from the lower part of the evaporator system to the suction line, is not yet completed.

Operational experience

The heat pump, which has been operative for three years, is equipped with several thermometers, a heat flow meter (kWh) and an electricity meter (kWh). Unfortunately the heat flow meter has not been operative and consequently no accurate measurements for calculation of the SPF are available. However, estimates indicate an SPF above 3.0, which is exceptional for a residential ambient air heat pump operating in a cold climate.

There were some initial problems with leaking solenoid valves, and pollution of the mineral oil from grease etc. The latter was solved by thorough cleaning of the entire system and installation of a new suction gas filter. The heat pump system is now running satisfactorily.

Concluding remarks

The design, construction and operation of the ammonia heat pump has been an interesting and worthwhile practical experience for the owner. The operation of the plant has been easy after correcting the initial faults. Moreover, the energy savings are as predicted during design.

However, the plant cannot be duplicated for commercial use, since most components are far too expensive, and many are not even commercially available. Even simple components, such as sight glasses and tube fittings, are hard to find or too expensive for plants with heating capacities below 100-200 kW. It is obvious that component manufacturers have a future niche market with regard to residential ammonia heat pumps. The main problem is that manufacturers do not see a viable market for the time being, since only a few prototype systems have been installed, and plants will not be installed in larger quantities before suitable components are available at reasonable prices.

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Direct-Evaporation ground-coupled heat pumps in Austria

Hermann Halozan, Austria

Sales figures of heat pumps for space heating in the residential sector are steadily rising although no national heat pump programme is in force in Austria. Reasons for this development can be mainly found in the activities of the Leistungsgemeinschaft Wärmepumpe (LGW), the heat pump manufacturers and distributors association of Austria, and in the promotion activities of some far-sighted utilities. The main market consists of new single-family houses. In Austria the market share of direct-evaporation ground-coupled heat pump systems is almost 66 % (see **Figure 1**). This article discusses the reasons behind the success of this highly efficient technology.

The heat pumps that were installed in Austria after the oil crisis in 1979 were either ground water heat pumps for monovalent systems for new buildings or outside air heat pumps for bivalent systems. The latter was often combined with existing oil-fired boilers for retrofitting existing buildings. The rapid drop in oil prices in 1985 significantly reduced the sales figures of bivalent outside air heat pump systems integrated into high-temperature hydronic heat distribution systems, due to their low seasonal performance factor (SPF). The operation of an oil-fired system alone was cheaper than that of a bivalent outside air system.

Ground-source heat pumps

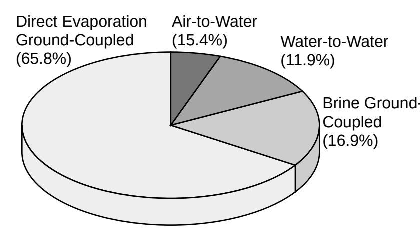
Ground water heat pump systems were still competitive. However, ground water was limited and licencing often caused problems. Therefore another heat source had to be found, i.e. the ground itself. Various system designs have been developed to utilise the ground as a heat source for heating-only operation. Differences are mainly due to the capacity of the system and the area available. Several types of ground heat exchangers are discussed below.

Horizontal ground coils are usually installed at a depth of about 0.3 m below ground frost level, i.e. at a depth of about 0.8-1.2 m. At this depth, the ground temperature changes during the year. At the beginning of the heating season it is higher than the undisturbed ground temperature. During the heating season it drops below 0°C, caused by heat extraction, but moisture migration to and frost formation around the coil increase the heat conductivity and help to stabilise the heat extraction temperature. At the end of the heating season natural recharging starts and solar heat is delivered from the ground surface to the coil. The vegetation above the ground coil is hardly influenced at all.

Vertical wells are required if the surface area available is insufficient for horizontal systems. Two vertical well designs are possible, either shallow wells down to a depth of 20 m or deep wells to 100 m or more. The depth depends on the ground conditions and the drilling equipment available. The heat exchangers are either coaxial or U-tube types. Other versions of ground heat exchangers are the ditch collector, which is a compromise between a horizontal and a vertical system, and spiral heat exchangers as developed by Otto Svec in Canada under Annex 15.

The systems installed in the past were mainly indirect systems, i.e. secondary fluid systems with a circulation pump. For the ground coils plastic materials were used, even though the heat transfer of these plastic coils is much lower than that of metal tubes. However corrosion problems were solved. Now direct-evaporation (expansion) systems have been introduced, particularly in combination with horizontally installed ground coils, but also as vertical wells. The discussion as to which system is best and most efficient, and which concept is the least harmful to the environment and the ground water, has only just been settled.

Figure: Heat Pump Sales in Austria in 1996.



Direct-evaporation systems

Direct-evaporation systems, where the evaporator of the heat pump is buried in the ground or placed in a bore hole, have some advantages over secondary circulating fluid systems. An initial advantage is the elimination of the secondary fluid heat exchange and the circulation pump, which has a significant power requirement, especially at low heat source temperatures, due to the antifreeze solution used. The result is a higher coefficient of performance (COP) and also a higher SPF.

Additionally, heat transfer conditions of copper tubes (coated with a thin plastic film to avoid corrosion) used in direct-expansion coils are better than those of plastic tubes used for indirect systems. The heat conductivity of the plastic material used for the ground coil tubes is relatively low.

However, there are also some disadvantages with direct-evaporation. The refrigerant velocity in the evaporator must be kept as small as possible to achieve a small pressure drop, which also means a drop in the evaporation temperature. On the other hand, it must be high enough to ensure oil return. To achieve this velocity and to make a sufficient mass of ground accessible, the diameter of the evaporator tubes must be smaller than that of indirect systems. This means that the temperature difference between the ground and the tube surface becomes larger.

A second disadvantage is that the design of the coils in vertical systems must be made very carefully to compensate the pressure wins in the downpipe and to guarantee oil return through the riser. Soldering at the site seems necessary to connect the ground collector and the heat pump unit. However, refrigerant losses can still occur and pollute the ground water. Finally, as the ground coil evaporator becomes much larger than the evaporator of a compact heat pump unit, the refrigerant charge increases. Looking at this list, there seem to be more disadvantages than advantages. So why are direct-evaporation systems so successful on the Austrian market?

This is because the disadvantages have been solved by manufacturers and installers of direct-evaporation systems. These manufacturers and installers, usually small companies with employees who are highly skilled in both refrigeration and heating system installation techniques, are system constructors as well as heat pump manufacturers or installers. Because of this system approach, direct-evaporation systems often achieve higher SPFs than secondary fluid systems. In new well insulated buildings with specific heat loads below 60 W/m^2 equipped with low-temperature floor heating systems actual SPFs are between 4 and 5.

Suitable installers

These small companies have looked for market niches and they have developed this technology to produce highly efficient and reliable systems. Usually they install not only the heat pump and the ground coil, but also the heat distribution system, often a floor heating system. In some rooms they install both a wall and floor heating system to keep the supply temperature as low as possible. The control is usually a reference room temperature control with two-speed compressors and temperature set-back or increase at various times. The temperature increase function is used to utilise cheap night-time electricity. The heat is stored in the concrete floor of the floor heating system, which is 7-9 cm thick. In principle, these small system constructors use their specialist knowledge and experience to produce less expensive systems.

It is possible to achieve high SPFs, even with secondary loop systems, and some companies are successful in achieving these values. However, the systems become more expensive due to a larger ground coil, which results in an increase of the secondary fluid temperature as well as the evaporation temperature. This increase is used to reduce and compensate for the electric power consumption of the circulation pump.

These secondary fluid ground-source heat pumps, i.e. brine/water heat pumps, are the speciality of medium and large heat pump manufacturers, who sell their products to distributors and installers. Very often they are not aware of the specific installations for their units. Errors which are sometimes made by inexperienced installers include undersized ground collectors. Either the space for the horizontal ground coil is too small or one bore hole is omitted to reduce high drilling costs. Other errors are heat distribution systems with too high supply temperatures, which also reduce the SPF.

Packaged heat pumps

In this context it is interesting that a small heat pump manufacturer and system constructor has developed a packaged direct-evaporation heat pump, as was shown in Newsletter Vol. 13/3. This heat pump unit, using propane as refrigerant, is designed for outdoor installation, according to Austrian regulations. It is prefabricated and connected to the ground evaporators, filled with the refrigerant charge required and tested in the factory. The complete unit is then transported to the site on a pallet. The heat pump is mounted on a small foundation; the evaporator coil, folded on the pallet, is laid out in the excavated ground and covered with sand before the excavated ground is replaced. The connection to the heating system in the building consists of the water supply and return pipes and cables for power supply and control. The control itself and the heating water circulation pump are mounted in the building.

Summary

Direct-evaporation systems, either with horizontally installed collectors or with bore holes down to 50 m, show increasing sales figures and dominate the Austrian market. They are expected to continue to do so in the future, because direct-evaporation ground-source heat pumps already achieve SPFs of 4-5, provided the building standards are adhered to and the design of the overall system is made carefully. Such high SPFs are achieved by highly skilled system constructors, who sell complete systems instead of just the heat pump units.

Mr Hermann Halozan,
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(see back cover)

Fuzzy logic controls for thermal comfort and energy saving

Naomi Kidokoro, Japan

In 1996 over 80% of the homes in Japan used residential air conditioners. More than 8 million units were produced in 1996, about 90% of which were reversible. This is because Japanese consumers now recognise that air conditioners can be used all year round. So, as air conditioners are now running for longer periods, there is a growing interest in their performance.

In recent years developments have focused on improving energy efficiency while maintaining thermal comfort. In a recent article Mr Sakamoto of Tokyo Metropolitan University outlined three essential areas of technology where successful improvements in energy consumption were being introduced (IEA Heat Pump Centre Newsletter Volume 14 - No.4/1996). These areas include: electronic devices such as microprocessors and inverters, variable speed compressors and fans, and an advanced control algorithm.

Improvements

Mitsubishi Heavy Industries (MHI) have recently developed an inverter-driven reversible heat pump which uses the three aforementioned technologies to respond to the high demand for thermal comfort and lower energy consumption. A recent example of this is the inverter system that uses the two level PAM (pulse amplified modulation) method. This is an inverter system which changes the voltage level according to the rotation speed of the compressor. In contrast to the conventional method, which uses a high voltage, the new method uses a low voltage when the speed is low. This system decreasese the electricity consumption.

An example of the second type of technology improvement is the IPM (Internal Permanent Magnet) motor for a scroll-type compressor. This motor is composed of many layers of silicon steel plates and a permanent magnet. As vortex electric current does not occur in an IPM motor, electric power loss can be decreased. This motor realises a higher efficiency than a conventional one, particularly at low speeds of compressor rotation.

Fuzzy logic control is an example of advanced control algorithms. It has been developed in response to the high demand for thermal comfort. The advantage of this type of controller is the improvement in comfort by reducing room temperature fluctuations.

Introduction to fuzzy logic

Fuzzy logic is an intelligent information management method. The first paper to discuss this was published in 1965 by Prof. Zadeh of California University. Its first application in the field of control engineering was the automatic operation of a steam engine by Prof. Mamdani of London University. The first industrial application was the cement kiln control by F.L.Smidth Co. in Denmark in 1980.

After 1980, several companies in Japan selected fuzzy logic as a research theme, and it was introduced in various fields such as control, decision making and scheduling. It is also widely used to control underground railways, waste incineration plants, etc. Since a strict model is not always required, parallel control is provided by several control rules, which can be described using similar expressions to manual control by human operators. The practical application of fuzzy logic in industrial fields is increasing.

MHI adopted a fuzzy logic control system in the small-sized Beaver air conditioner for general household use. The fuzzy control system offers a fast response and good stability, and provides stable and comfortable room air conditioning. In the fuzzy logic control for this air conditioner the change rate of the compressors rotation speed is calculated from several inputs: the difference between desired room air temperature, inlet air temperature and the change rate of the inlet air temperature.

Control rules are described in the “if ... then ... system”. More than 50 rules are included for cooling and heating, based on the experience and knowledge obtained from manual control of the room temperature. For example, “if in the heating start-up phase, the inlet air temperature is lower than the temperature setting and the temperature change is smaller, then operate the compressor at higher rotation speeds” or “if in the stable heating mode the inlet air temperature is almost equal to the temperature setting and there is no temperature change, then maintain the compressors current rotation speed”.

Evaluation by experiments

By performing certain experiments the characteristics of the developed fuzzy logic control are compared to those of a conventional control.

Figure 1 shows the comparison of test results under light load conditions. These tests also show that the new air conditioner provides stable control, and can decrease the number of on/off cycles. As air conditioners generally

Figure 1: Comparison of test results under light load condition.

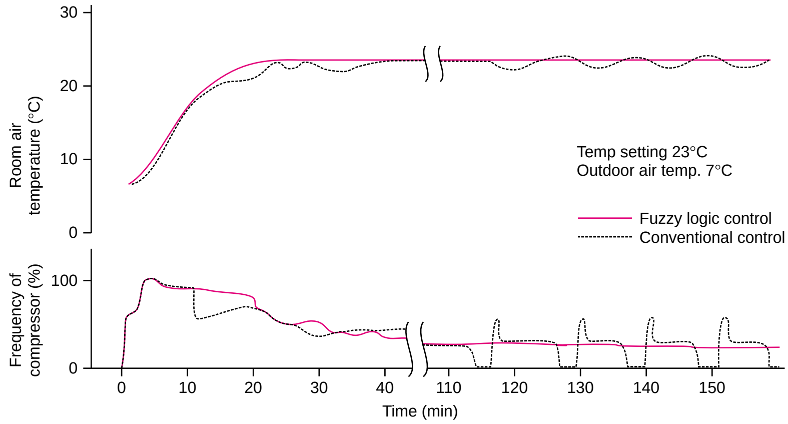


Figure 2: Test results for the response to disturbance.

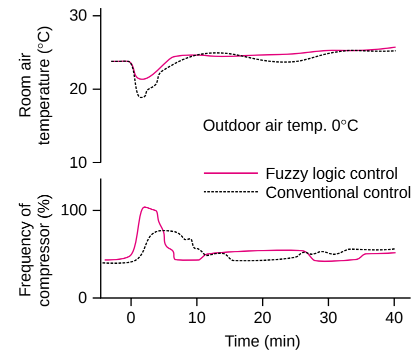
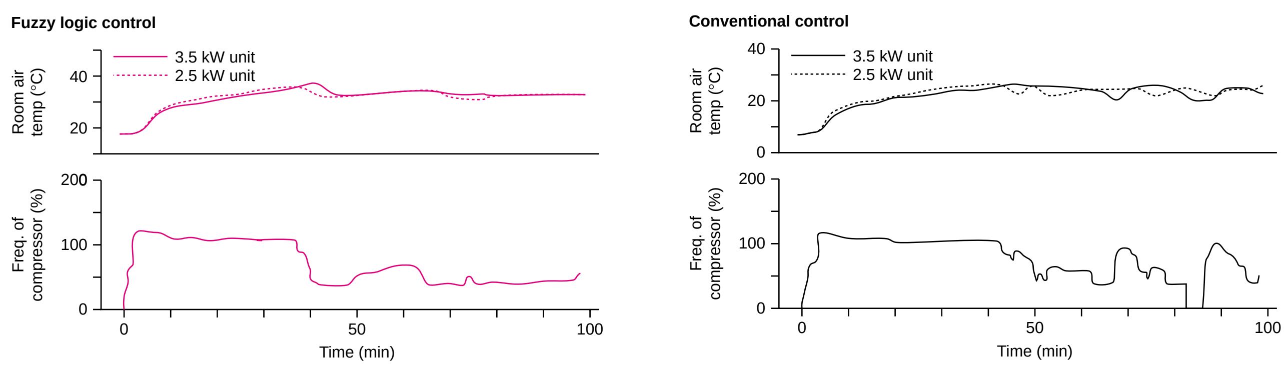


Figure 3: Comparison of results for control of multi-zone air conditioners.



require a certain amount of power to start or restart, this decrease in the number of on/off cycles also reduces energy consumption. The power consumption was reduced to 76% of that of a conventional system. The result is based on the total power consumption required to raise the average temperature from 2 to 20°C (measured at 48 points in the room) and to operate the air conditioner for six hours at a temperature of 23°C. Thus, energy was saved while comfort was improved. These results show the remarkable effect of fuzzy logic control.

Figure 2 shows the test results concerning the response to changing conditions caused by introducing outside air into the test room for one minute by opening the door during stable operation of the air conditioner. The new control quickly increases the inverter frequency when the indoor air temperature drops. The figure shows the speedy and stable response of the fuzzy logic control.

Multi-zone air conditioners

After the positive results of fuzzy control for the Beaver air conditioner, MHI also applied fuzzy control to a multi-zone air conditioner. This type of air conditioner is not unusual in Japan. It consists of one outdoor unit and several indoor units to meet the demand for air conditioning of several rooms. This causes non-linearity between inputs and outputs. Good control under non-linear conditions is one of the main technical challenges for improving multi-zone air conditioners. Experiments were conducted in an environmental simulation room. **Figure 3** compares the characteristics of the newly developed fuzzy control for multi-air-conditioners with those of a conventional control.

In the figure the conventional control and the fuzzy control are compared in terms of starting up the heating mode. When the fuzzy control is applied in environmental conditions where the operating state is likely to vary, both the frequency change and room air temperature are stabilised, and the control performance is enhanced. As can be seen from this experiment, the fuzzy control performs better in maintaining the stability of the room air temperature, and is less influenced by fluctuating conditions in other rooms.

Conclusion

In this study, fuzzy logic control shows good response speed and stability. It maintains stability and improves the comfort of the air-conditioned environment, as well as saving energy.

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Low-cost low-temperature heating with heat pump systems

Dr Thomas Afjei, Switzerland

Future low-energy dwellings will have an annual heat demand of less than 200 MJ/m². The hot water heating component, which presently accounts for some 15% of the heat demand, increases to 30-40% in low-energy dwellings. The objectives for the planning phase of this project were a feasibility analysis, problem analysis and preparation for constructing a functional specimen of a buffer storage-free, low-cost, low-temperature heat pump heating system. With a system that is easy to install potential fault sources can be avoided, enabling a high energy efficiency to be achieved. The annual costs for systems of this size approach that of oil-fired heating.

For future low-energy dwellings there is an urgent requirement for low-cost heat pump heating systems with a high annual energy efficiency. Such heating systems must be competitive with conventional fossil fuel-fired heating in the new building sector. A solution for heat distribution might be a low-temperature heating system with a supply temperature of under 30°C, which has a good self-regulating effect without additional controlling elements. The heat pump is connected directly to the heat distribution system without buffer storage and mixing valves, and should have an intelligent control integrated in the heat pump. This simple construction will result in low installation costs.

Factors to be determined by simulation are:

- how should the low-temperature heating be structured?
- what requirements must the building satisfy?
- what control range is necessary for the heat pump?
- what effect will disturbance variables have on comfort, i.e. solar radiation, temperature change, heat sources, etc.?
- what utility off-periods can be tolerated?
- what will be the annual energy efficiency of the heat production?

The information and experience gained serves to assess the feasibility and indicate the problems of such heating systems. Also of interest are the achievable seasonal performance factor (SPF) and the level of market opportunities for such a system in the new building and renovation market, which includes hot water heating systems.

Reference building

The NOAH-System house, owned by the Swiss firm A. Piatti AG, was selected for this project. The basic reasons for this choice were the wide market acceptance of this building, a uniform small thermal energy requirement over the ground plan and no excessively large glazed surfaces. Also important for this project was the fact that a good data basis was available for engineering and costs. The most important characteristics are given in **Table 1**.

▼ *Table 1.*

Annual thermal energy requirement	174 MJ/m²
Energy reference surface (EBF)	147 m²
Heat output (-11°C, without hot water)	3.1 kW
Average specific heat output	22.0 W/m2
Assumed air change (-11°C)	0.3 h⁻¹

The simulated systems

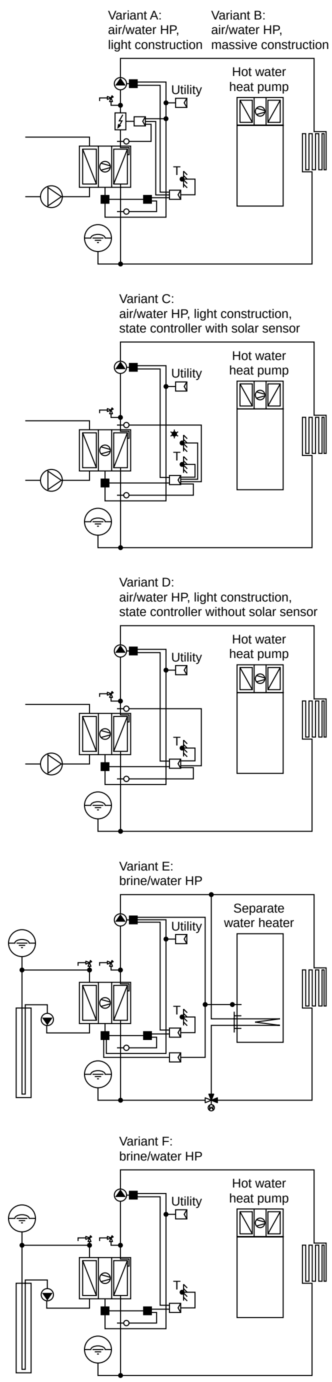
Figure 1 gives an overview of the considered basic variants. The feedback of the room temperature to the heating system takes place exclusively via the self-regulating effect of the floor heating. The controllers are set manually at the start of the simulation to an operative temperature distribution considered “optimal” by the user. With all main variants, operation is interrupted by the power station at fixed times each day.

Simulation results

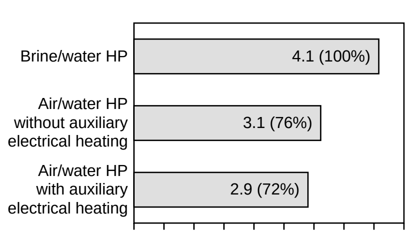
The annual energy efficiency shows the ratio of the energy directly benefiting the user (profit) and the energy to be expended for heat production, including energy for transporting the heat carrier during operation, and the heating system losses (expenditure). The data also include the consumption for the brine pump and the evaporator fan, as well as icing and thawing losses. Consumption of the circulation pump is not taken into account. This would reduce the annual energy efficiency by some 5%. **Figure 2** compares the SPFs of the different heat pumps without hot water heating and heating circulation pumps. All three are therefore for space heating only.

The electrical auxiliary heating leads to just a 4% impairment of the SPF for the space heating system. As a result of the auxiliary heating, the air/water heat pump can be 40% smaller, reducing the investment costs. However, if an incorrect ON/OFF-time criterion is used, the impairment of the SPF is considerably more than the aforementioned 4%. Furthermore, the electrical resistance heating runs on cold winter days, i.e. at

▼ *Figure 1: Schematic diagrams of the simulated systems.*



▼ *Figure 2: Seasonal Performance Factors (space heating, no water heating).*



the very time the supply system is loaded to full capacity.

Figure 3 shows the SPFs achieved with the different heating and hot water systems. Clearly the best is the brine/water heat pump with separate hot water heat pump. The improvement of 7% compared with hot water heating from a heat pump is due to the high source temperature of the hot water heating. The brine temperature has a maximum of 4.5°C and is therefore below the basement temperature of 10°C throughout the year. By increasing the source temperature of the heat pump hot water heating, its performance factor can be substantially raised.

The SPFs, which at first glance are low, are explained by the fact that small heat pumps have lower COP values than large units. Although, where available, the best of the small heat pumps tested at the HP Test Centre "Töss" were used for the variant comparison, their COP values are between 20% and 24% lower than the best units in the 8-10 kW capacity range. If the COP values of the best units could have been achieved, it would have been possible to achieve an SPF of 5.1 with the brine/water heat pump (variant F) in heating mode and an SPF of 4.0 in combined heating/hot water mode.

Response to off-periods

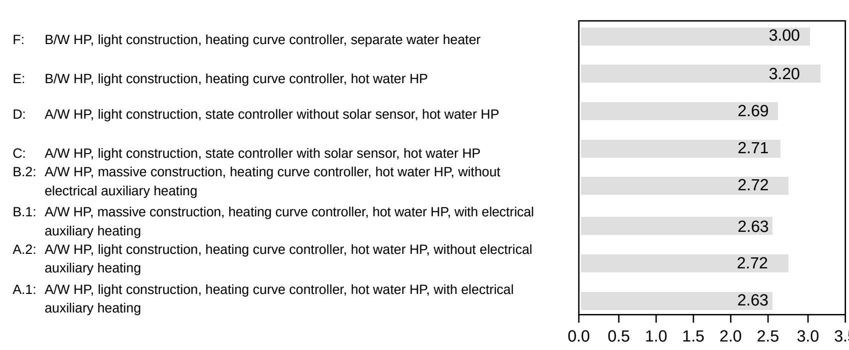
No loss of comfort occurred with respect to the room temperature curve during a two-hour utility off-period. Only the two-hour night-time off-period was noticeable by a minimal drop in room temperature. However, this was barely perceptible and essentially less than the normal room temperature fluctuations. Therefore as far as comfort is concerned, a two-hour off-period can be accepted without problems. However, because of higher supply temperatures, the total four-hour utility off-period resulted in a performance factor impairment, and hence in an increase in the annual heating energy consumption, of some 5%.

Profitability

The profitability of low-temperature heating is assessed based on the annual costs, comprising capital costs, energy costs and maintenance or operating costs. As a reference case we have selected a building with oil-fired heating of the same size, in massive construction, which satisfies the conditions of the specimen regulation rational use of energy in buildings.

The annual costs of all important market competitors were determined in order to perform a complete market evaluation. The main competitor in heating is oil-fired heating. In the case of separate water heating, the electric water heater is considered for reasons of cost. The costs of gas heating are known on the basis of the data of A. Piatti AG. It is usually very difficult to make a successful market penetration with the heat pump, given the existence of a gas network. For these reasons the annual costs of the following combinations are compared:

▼ *Figure 3: Comparison of SPFs of the main variants.*



- 10kW oil boiler;
- air/water heat pump with 2.5kW heating capacity at A-7/W35 + 2 kW electric resistance heater for supplementary heating, in combination with an electric water heater;
- air/water heat pump with 3.5kW heating capacity at A-7/W35, in combination with an electric water heater;
- air/water heat pump with 2.5kW heating capacity at A-7/W35 + 2 kW electric resistance heater, in combination with an exhaust air heat pump (=Variant A1);
- brine/water heat pump with 3.9kW heating capacity at B0/W35, in combination with an electric water heater;
- brine/water heat pump with 3.9kW heating capacity at B0/W35, in combination with a separate water heater (=Variant F);
- brine/water heat pump with 3.9kW heating capacity at B0/W35, in combination with an exhaust air heat pump (=Variant E).

Figure 4 shows an overview of the annual costs. It is interesting to note that the cost of a small capacity system with an auxiliary electrical system is similar to that of a larger, monovalent heat pump. **Figure 5** shows a comparison of the annual energy efficiencies of all variants in combination with a combined cycle power station (cogeneration).

From this figure it is clear that only the combinations with an exhaust air heat pump or a separate water heater are suitable as trend-setting solutions. Similar results can be obtained using current from combined cycle power stations, which today achieve up to 58% efficiency at the generator terminals. The calculation of the annual energy efficiency was performed excluding the energy for the circulation pump.

Conclusions

For comfort reasons there are no objections to off-periods. However, a reduction in running time does have a disadvantageous effect on the seasonal performance factor. An interruption of four hours per day requires a 20% increase in heat pump capacity. This impairs the seasonal performance factor by 5%.

Figure 4: Annual costs for heating and hot water production (in USD).

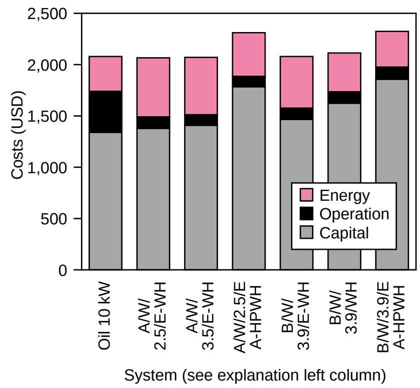
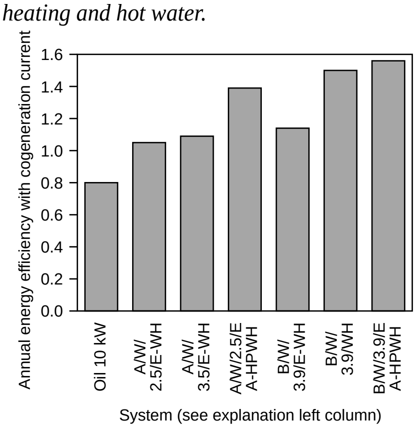


Figure 5: Annual energy efficiency levels with the use of cogeneration current for heating and hot water.



Integration of the heat pump

The storage capability of the floor is quite sufficient to operate the heat pump heating without buffer storage. The heat pump switches off no more than three to four times per day. Accordingly, a buffer storage would only lead to additional heat losses, render the regulating concept more complex and increase investment costs.

It is necessary to switch the heat pump on and off according to the return temperature, not the supply temperature. Only then can the storage capability of the heat distribution system and the floor be utilised. Using a supply temperature control, the heat pump would continuously switch on and off.

System selection

The most energy-efficient system is the brine/water heat pump with separate water heater heat pump. An increase in energy consumption of 10% must be accepted in the case of hot water heating from the heating heat pump. The seasonal performance factor of the space heating system is 18% better when a ground heat exchanger uses ground heat as a heat source instead of air. If the air-to-water heat pump is dimensioned 30% smaller and the capacity loss covered by an electrical resistance heater, the cost of electricity for the heating only increases by 4%. A precondition, however, is the correct ON/OFF switching of the auxiliary heating, otherwise the extra consumption is considerably higher.

Cost considerations

With annual costs as a criterion, the monovalent air/water heat pump with separate electric water heater is the least expensive. The extra costs of the exhaust air heat pump for the hot water heating, compared to the electric water heater solution with the brine/water and air/water variants, are not compensated by the lower energy costs. On the other hand the exhaust air heat pump has the advantage that a controlled air change takes place, thus improving the air quality.

Acknowledgements

The project was commissioned by the Swiss Federal Office of Energy (SFOE). A project team was assembled as follows:

- Information Center for Electricity Applications (Project Manager)
- Basler + Hofmann AG/DIANE Eco-construction (Building)
- Bircher + Keller AG (Underfloor heating)
- Swiss Federal Institute of Technology Zurich, Measurement and Control Laboratory (Controller)
- Central Suisse Engineering College Lucern ZTL (TRNSYS simulation)

Literature (German language)
INFEL: Kostengnstige Niedrigtemperaturheizung mit Wärmepumpe, Schlussbericht Phase 1, BEW-Projekt 55701, ENET, 1996, CH.

Further information available from:
Dr Th. Afjei, project manager INFEL,
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Technology Procurement: competition for domestic heat pump clothes dryers

Ruud Trines, the Netherlands

The long-term target of the international IEA-DSM (Demand Side Management) Dryer Promotion competition is to stimulate the production and support the successful launch of a domestic clothes dryer which is 50% more efficient than the present market-best dryers, at price and performance levels which guarantee a significant share of the market. Although manufacturers are free to meet the specifications in any way they choose, heat pump technology will probably have to be used in order to achieve sufficient efficiency.

Domestic white goods account for almost 50% of the domestic electricity consumption. Dryers have the fastest growing penetration rate and the largest specific energy consumption of all domestic appliances. Within the present range of models the efficiency range is rather low: current market-best dryers can claim an EU Energy Label Class “C” or “D”. Manufacturers compete on price, service and endurance rather than energy. The basic technical principles have not changed in the last 20 years.

A Class model

The IEA-DSM Dryer Promotion competition aims to stimulate production of the first “A” Class model for the European market. There is a technical alternative that provides the same functionality and comfort at a much higher efficiency. By using a heat pump as heat source the dryer can be made up to 50% more efficient. Manufacturers know about this technique, but a heat pump dryer has not yet appeared on the market due to the higher price. The IEA-DSM expert group estimates that, based on mass production, a heat pump dryer will be some 20% more expensive than a conventional dryer, and at that price there is a good market opportunity for this new “A” Class dryer. This competition hopes to stimulate the first buyers so that manufacturers can start mass production of the heat pump dryers, once the first production series for the buyers in the competition have been completed.

Procedures

The procedures for this competition and the international cooperation are established within Annex III (Co-operative Technology Procurement) of the IEA Demand Side Management programme. Other procedures are being carried out for incandescent replacement lamps, copiers and motors. This mix covers both business-to-business markets and mass-production consumer goods. Sweden, United Kingdom, Spain, Finland, Germany and the Netherlands are involved in the dryer programme. The Netherlands Agency for Energy and the Environment (Novem) is project leader for this project.

The dryer promotion competition was launched at Domotechnica 97. Novem is responsible for providing technical specifications for the products and the technical verification of product entries. The specifications not only describe energy efficiency but also environmental, safety, comfort and economic aspects. The competition will take place in two categories: “tumble dryers” and “cabinet dryers”. All specifications are based on discussions with manufacturers, national energy agencies and buyer groups (such as retail chains). Entries are judged by an international jury.

Manufacturers are invited to send in prototypes or production versions of a highly efficient laundry dryer. Entries for the opening round had to be submitted before 15 July 1997, but further competition rounds are envisaged. All entries/products meeting the specifications will receive an IEA Award of Excellence and a jury report which can be used in any national rebate, educational or procurement scheme in participating countries.

Champion

The overall “champion” will be the product which is the most energy-efficient. In the case of a tie, other criteria such as consumer costs will be evaluated. The “champion” will receive additional public relations support and marketing support from national energy agencies. The international jury consists of experts working at European consumers organisations.

Manufacturers may submit entries to Novem every three months in order to receive an IEA Award of Excellence and be eligible to participate in national stimulation schemes. The first jury decision on the “Champion” and the “Awards” will be issued in September 1997. The title “champion” can be used for one year after the publication of the jury’s decision.

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JARN Directory 1997
Available from: Ms Sjigekiyo, Circulation Dept. JARN Ltd.
Fax: +81-3-35844708.
Price: DHL/Courier: USD 110, Air Mail: USD 72, Sea Mail: USD 65. 230 Pages, 1997, English language.
JARN Directory 1997 (Japan HVAC&R Buyers Guide & Industry Statistics) is specially written for people interested in the international trade of HVAC&R equipment. It contains the latest information on some 400 Japanese companies and industry organisations, as well as detailed statistical information. Special features in this issue: companies in Asia - Oceania region, and a worldwide list of top manufacturers.

Heizen mit Wärmepumpen
Authors: Kruse and Heidelreck. Available from: Verlag TV Rheinland GmbH, 51149 Köln, Germany. Price: DM 22, 1997.
ISBN 3-8249-0118-8. German language.
This brochure is published by IZW and of the University of Hannover. It provides potential users, energy advisors, architects and installers with a comprehensive overview of the current status of heat pump technology and its applications.

IZW Informationspakket
Available from: Fachinformationszentrum Karlsruhe, Bibliographischer Service, Postfach 2465, D-76012 Karlsruhe, Germany.
Fax: +49-72-47808134. Price: free of charge.
This information package is a guide for contractors, planners and installers. It gives useful information and references, including literature references and a list of manufacturers.

EUROVENT Directory of Certified Products (Air-Conditioners, Fan Coil Units and Liquid Chilling Packages) /
February 1, 1997 - January 31, 1998.
Available from: EUROVENT, 15 rue Montorgueil, 75001 Paris, France.
Fax: +33-1-40260126.
This directory contains a list of companies supplying certified products within the scope of the certification programmes in which they participate. Performance data are included for participants whose products were tested in the EUROVENT Laboratory during 1996.

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Energy-Saving Devices and Equipment: Residential and Commercial
Available from: Business Communications Company Inc., 25 Van Zant Street, Norwalk, CT 06855, USA. Fax: +1-203-8530348.
Pre-publication price: USD 3,150. August 1997. No. E-070R.
This updated report presents information on the current and future domestic markets for energy-efficient end-use equipment for the residential and commercial sectors, including heat pump and HVAC markets. Data on energy-saving technologies are presented along with current and projected sales, dollar savings realised, and reduction in net energy consumption. The report includes a regulatory overview, an analysis of export markets, and a selected list of relevant industry players. Markets are forecast through the year 2002.

ARI Directory of Certified Applied Air-Conditioning Products
Available from: ARI, 4301 North Fairfax Drive (Suite 425), Arlington, Virginia 22203, USA. Fax: +1-703-5283816. Diskette version, July 1997.
The diskette version contains the same information as the printed version but allows the information to be accessed and searched via a computer. It contains information on all ARI certified air-conditioning products, enabling consumers, for example, to compare energy efficiencies.

1997 ASHRAE Handbook, Fundamentals
Available from: ASHRAE Customer Service, 1791 Tullie Circle NE, Atlanta, GA 30329, USA. Fax: +1-404-3215478.
E-mail: orders@ashrae.org. Price: USD 124.
This volume of the ASHRAE Handbook Series provides improved guidelines and recommendations on economical design, construction and operation of HVAC building systems. It contains approved techniques for energy conservation cost savings and efficient system performance and is a concise reference source with procedures to operate healthy indoor environments.

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held in Trondheim, Norway on 13-14 May 1997

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Comparisons of equations of state with experimental data for R32 and R125
Annex 18 Final Report, March 97
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Industrial Heat Pumps
Annex 21 Proceedings, October 96
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5th IEA Conference on Heat Pumping Technologies
Conference Proceedings, September 96
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Ab-Sorption 96
Conference Proceedings, September 96
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23-26 Sep. 1997 / Greece
Contact: Ms Rhona Vickers, Air Infiltration and Ventilation Centre,
Fax: +44-1203-692050
E-mail: airvent@aivc.org

Refrigerants for the 21st Century
Sponsored by ASHRAE & NIST
6-7 Oct. 1997 / Gaithersburg, MD, USA
Contact: W. W. Seaton at ASHRAE
Fax: +1-404-3215478
E-mail: bseaton@ashrae.org

Heat Transfer in Natural Refrigerants
6-7 Nov. 1997 / Maryland, USA
Contact: Dr Radermacher, Center for Environmental Energy Engineering, University of Maryland. Fax: +1-301-4052025, E-mail: rader@eng.umd.edu

Reducing refrigeration running costs Practical and cost-effective solutions
20 November 1997 / London, UK
Contact: The Secretary, Institute of Refrigeration.
Fax: +44-181-07730165
E-mail: instor@ibm.net

Heat Pump Expo 1997
20-22 November 1997 / Zürich, Switzerland
Contact: Fördergemeinschaft Wärmepumpe Schweiz FWS, Fax: +41-31-3524206

3. Symposium Erdgekoppelte Wärmepumpen
20-22 Nov. 1997 / Giessen, Germany
Contact: Dr B. Sanner, Fax: +49-641-9936109

Natural Working Fluids 98
IIR Gustav Lorentzen Conference
2-5 June 1998 / Oslo, Norway
Deadline for abstracts: 1 Sep. 1997
Contact: Turid Slotnaes, NWF 98,
Fax: +47-22067350

Air-Conditioning & Refrigeration New Tech '98 (ART'98)
Environmentally Friendly Refrigeration '98 (EFR'98)
9-12 June 1998 / Beijing, China
Organised by the Chinese Association of Refrigeration. Contact: Beijing Onis Expo Co., Mr Liang Liang. Fax: 86-10-62172249
E-mail: nis@public3.bta.net.cn

1998 International Compressor Engineering Conference; and 1998 International Refrigeration Conference
14-17 July 1998 / West Lafayette, Indiana, USA. Contact: Cynthia Quillen, Purdue University. Fax: +1-765-4940787,
E-mail: herlconf@ecn.purdue.edu

Eurotherm seminar on thermo-dynamics, heat and mass transfer of refrigeration machines and heat pumps
6-7 July 1998 / Nancy, France
Deadline for abstracts: 1 November 1997
Contact: Prof. M Feidt LEMTA - University of Nancy. Fax: +33-3-83595551
E-mail: mfeidt@ensem.u-nancy-fr

Hygiene, quality and security in the cold chain and in air conditioning
16-18 September 1998 / Nantes, France
Contact: Symposium Nantes 98.
Fax: +33-02-51882020

IEA HEAT PUMP PROGRAMME EVENTS

IIR - Linz 97 Heat Pump Systems, Energy Efficiency and Global Warming
Sponsored by IEA Heat Pump Centre.
28 Sep. - 1 Oct. 1997 / Linz, Austria
Contact: Mrs Ulrike Gerhard, TU Graz, Austria. Fax: +43-316-8737305

2nd Annex 22 Workshop on Compression Systems with Natural Working Fluids
2-3 October 1997 / Gatlinburg, USA
Contact: Mr Jørn Stene, SINTEF Energy, Trondheim (see back cover).

Heat Pump Systems for Single-Room Applications
Annex 23 Workshop.
16-19 June 1998 / Niagara Falls, USA
Contact: Frank Lenarduzzi, Ontario Hydro Technologies. Fax: +1-416-2076565

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Space Conditioning with Heat Recovery
Volume 15 - No.4/1997