State of the art document

On

Heat Pumping Technologies

1 Description of the Research Area

1.1 Worldwide R&D history and outlook

Based upon the development of the technology a change of focus of primary R&D topics can be discerned over the last twenty years since the first oil crises due to:

- Increased technological know-how;
- Increased experience in market applications;
- Development of competing technologies.

The Oil Crisis started an intensive effort to become more independent of imported oil by developing heat pumps for different applications. In later years as heat pumps were increasingly applied, specific topics were highlighted, ranging from refrigerants to heat exchangers and ground sources. As more and more experience poured in, the focus widened to system integration. The main current areas for research and development are related to market developments and can be segmented into:

- Improvement of heat sources, with air-coolers, ground source loop-systems, open soource systems and the use of waste heat.
- Improvement and development of heat pump technology and components, such as:
    - Development of retrofit heat pumps to replace oil and gas burners
    - Development of heat pumps with natural working fluids (ammonia and CO2)
    - Development of heat pumps with sorption cycli;
    - Improving components such as compressors, heat exchangers and other equipment
- Improving systems for heating at low temperatures and cooling at high temperatures in new buildings and methods for renovation of buidlings
- Improving the integration of the heat pumps in new and existing buildings incl. improvement of control equipment and control strategies;

A striking observation on the type of published R&D on heat pumping is that the main research topics are dealing with heat pumps in the built environment. Practically no research topics are mentioned on industrial heat pumps and if mentioned these are categorized under refrigeration technology or technology for process integration.

Next to these practical topics on the short to medium term there is interest in advanced systems which on the long term may replace existing systems. These latter developments are more fundamental research topics executed within technological institutes.

1.2 The EOS-long term research programme for Heat Pump technology

In the LT-EOS programme, the knowledge import theme "Using ground/air heat for the built environment via heat pumps" is described as follows:

Major research themes for heat pumps focus on integrating and standardising systems. In a Novem-implemented strengths-weakness analysis of Dutch market parties, some 14 subjects [4][1] were selected. The market is already active in a number of these themes, and it is

[1] Small electrical heat pumps for residences, larger electrical heat pumps for non-residential buildings and the glass horticulture sector, small sorption systems for residences; larger sorption systems for non-residential buildings; quality assurance; industrial heat pumps; high-temperature industrial heat pumps; combinations with cogeneration, open ground sources/aquifers;closed source heat exchangers; compact chemical storage; CO_2 as working fluid for building applications; compact heat exchangers, long-term experience through project monitoring.

expected that government support for applications, support of field experiments and demonstrations is still needed to ensure continued development in the immediate future.

Many developments concerning components are currently taking place in other countries; however heat pumps for residential heating have also been developed in the Netherlands over the past few years. For larger systems, the Netherlands has mainly built up experience with open-source systems, in combination with cold storage. With regard to quality in relation to regulations, the BEB (ground as energy source and buffer) programme has gained a lot of knowledge that is important for the development of future European regulations. Large systems have also been standardised, allowing Dutch suppliers to be competitive at European level.

Working fluids CO_2 and air-air systems are important areas for new technological developments with huge potential in almost all markets with a high temperature requirement. The Netherlands has expertise in smaller sorption systems for housing renovations, but this knowledge needs to be extended. Since commercial companies are already active, facilitation by the government is sufficient to ensure that this technology is developed further under the right conditions.

Knowledge import
A compact source and easily integrated systems (heat pump and source) are important for the renovation market. Other countries have considerable knowledge of these aspects, although the development thereof is in general still in its infancy.

Objective: To create compact heating/cooling systems using heat pumps that (exergetically) optimally meet (low-grade) energy requirements for heating and cooling in the built environment, which form the basis for heat-neutral concepts.

This primarily concerns research subjects such as:
- CO_2 as cooling agent for use in buildings;
- Compact physical and chemical storage;
- Closed-source heat exchangers;
- Innovative source systems to obtain heat from ground or air.

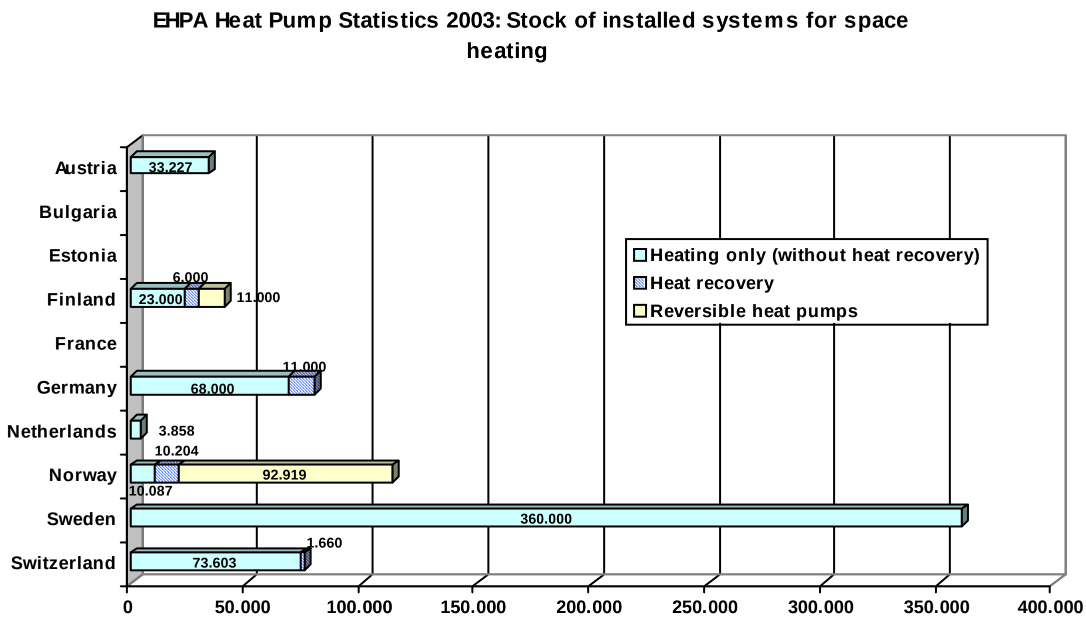
2 Indicators

In this chapter indicators are given and analysed for the market development, application areas, configuration of technology, system competitiveness, energy performance, manufacturers and institutes. This is done to analyse in which direction the development of new technology is most likely to be succesful and effective. It is interesting to see that governmental long-term research programmes, as in Sweden and Switzerland, have the same focus as concluded from this analysis.

2.1 Installed numbers and capacity in MWth

Over 130 million heat pumps are installed worldwide at this moment with an installed capacity of over 1300TWh/year. The corresponding reduction of CO_2-emissions is 0,13Gtons/year. The potential for further reduction is 1,2Gtons/year being 6% of the total CO_2-emissions worldwide. This potential is based upon the assumption that the penetration of heat pumps in the building sector will be about 30%. With the further technological developments in heat pumps and its applications, the increase of the effeciency of power generation and the use of more renewable power (PV, Wind and Bio-energy), a reduction of 16% of the total CO_2-emissions lies within ‘easy’ reach. Heat pumps are therefore seen as the key-technology in future energy systems.

The largest number of heat pumps are in use in Japan, VS and China. Especially South East Asia is a booming market with China as the largest manufacturer. High quality (grade) heating systems with heat pumps applicable in the Dutch situation are mainly found in European countries, like Switzerland, Sweden, Austria and Germany.

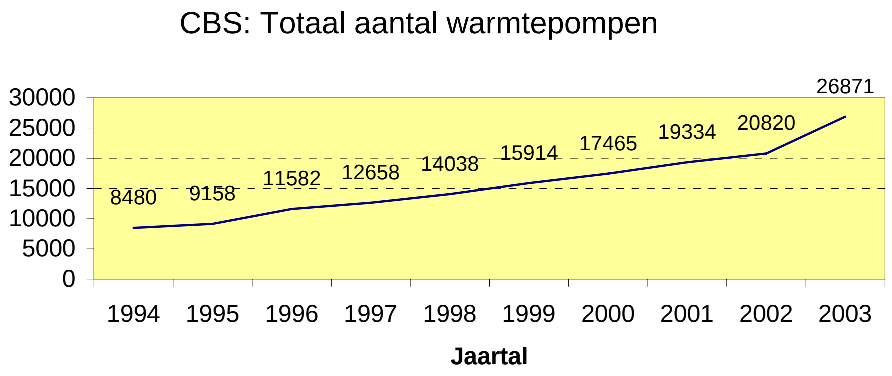


It should be mentioned that in heat pump statistics, there is always a definition problem. The European Heat Pumps Association (EHPA) includes only those systems which are dedicated to deliver heat to a heating system for space heating, water heating or process heating (in industry). The main body of heat pumps manufactured and installed in countries like China and Japan are according to this definition not considered as heat pumps because space cooling is their most important function.

According to the definition of the EHPA the data for the Europaen market can be given as:

- Total sales of space heating heat pumps: Minimum 185.000 (including heat recovery and reversible heat pumps)
- Sweden clearly dominating the market with 68.100 installed annually; 60% of them heating only heat pumps (without heat recovery HPs)
- Market increase > 100%: Finland and the Netherlands
- Heating only: Ground source heat pumps are dominating systems in most countries
- Reversible heat pumps are dominant in Norway (94%) and Finland (59%); mostly air-to air heat pumps primarily used for heating purposes
- DACH (Germany, Austria, Switzerland) countries and the Netherlands: Apparently no significant market for reversible heat pumps

The total number of heat pumps in the Netherlands is according to the figures given by CBS (Centraal Bureau voor de Statistiek) 27.000 in 2003 with an installed capacity of 270MWth. The average thermal capacity is therefore 10kW.



However at this moment it is unclear if these heat pumps can be considered as ‘real’ heat pumps according to the standards of the EHPA. The “Stichting Warmtepompen” (SWP), which oversees the market in residences, reports 2500 new installations in 2004, as compared to 1500 in 2003. This suggests a lasting market growth. CBS data, which also include heat pumps in commercial buildings, agriculture and industry, are as yet not available for 2004.

2.2 Application areas

The focus of policy and the market has been mainly on the implementation of heat pumps in new buildings of different sizes in order to provide more energy-efficient heating and cooling systems. Later on the focus became on the effect of heat pumps to lower greenhouse gas emissions, mainly CO_2. This is because heat pumps can be applied in most market segments where low temperature heat is used and an adequate heat source is available, which is not primarily the case for existing buildings. Some first projects are now being demonstrated in existing buidlings.

Heat pumps are applied for these segments in various configurations. The leading technology is the electric driven compression heat pump with an air or a ground source.

A short general overview for the Dutch market is presented in the table below:

Market	Segment	Heat Pump	Source	Size (kW)
Residences (individual)	New	EHP	Ground	2 – 4
	Existing	EHP/AHP	Air	4 – 10
Residences (collective)	New	EHP	Ground	40 – 100
	Existing	AHP	Ground/Air	40 – 100
Commercial buildings	< 5000 m2	EHP	Air/Ventilation	15 – 50
	> 5000 m2	EHP	Ground	50 – 2500
Greenhouses		EHP	Ground	500/ha
Industry	Food	MVR	Waste Heat	200 – 2000
	Chemical	MVR	Waste Heat	500 – 6500
	Misc	EHP	Waste Heat	50 – 250

An extensive description on the types of heat pumps used in the Dutch market is given in the EOS-report on the state of art of the Dutch Heat Pump Market [1].

Like all alternatives for conventional systems, heat pump systems are more expensive than their conventional competitors. The economy of heat pump systems has to be based upon the capital costs, maintenance costs and energy costs compared to those of conventional systems or competing systems for energy conservation.
For commercial and residential buildings an extensive competitive strength analysis has been done for the Netherlands. The main conclusions are:

- Only very few BIRES[2] - segment combinations are competitive.
- For some options, the higher attractiveness compensates for the higher costs per GJ.
- Some BIRES - segment combinations are nearly attractive or could become attractive within changing market circumstances or with newly developed technology.
- Some BIRES - segment combinations may never become competitive.

An overview of the conclusions is given in the table below:

Segment:	**BI-RES:**
New apartment buildings	Competitive: passive solar energy, aquifer based heat pumps. Nearly competitive: solar water heaters, heat pump water heaters.
New terraced houses	Competitive: passive solar energy, heat pump water heaters. Nearly competitive: collective electric heat pumps, solar water heaters.
New (semi-) detached houses	Competitive: passive solar energy, heat pump water heaters. Nearly competitive: solar water heaters, photovoltaic solar energy.
Existing apartment buildings	Competitive: aquifer based sorption and electric heat pumps.
Existing terraced houses	No competitive option in this segment.
Existing (semi-) detached houses	Nearly competitive: solar water heaters, heat pump water heaters, photovoltaic solar energy.
Large office buildings	Competitive: aquifer based heat pumps, daylight application.
Medium size office buildings	Competitive: aquifer based heat pumps, daylight application.
Small office buildings	Competitive: air source heat pumps
Industrial buildings (production, storage)	Competitive: aquifer based heat pumps. Nearly competitive: small scale wind energy.

2 BIRES = Building Integrated Renewable Energy System

In new buildings, apartment buildings, terraced houses as well as in office buidlings there is a great freedom of system design. Besides a heating system, a cooling system is in high demand in such buildings. Low temperature heating is ‘state of the art’. This is an ideal market for heat pumps, which are almost the only viable economic option when installed in ‘larger’ housing/building projects.

3 Research in Netherlands

3.1 State of the art

The main focus of research into heat pumps is focusses on the application of heat pumps in the domestic and commercial building sector. Only scattered research is known of for industrial heat pumps, mainly in the high temperature area.

The main barrier for individual and semi-detached houses and small office buildings are the initial costs for heat pump systems compared to other sytems. In the cost break down of the heat pump system the main costs can be found in the ground source.
A Swedish study [7] shows that the costs can be devided into:

- Heat source, normally vertical or horizontal ground loops, 35-40%
- Heat pump, 40 %
- Installation, 20-25%

In larger projects these problems do not occur so prominent, because an open source system can be used or a larger series of closed loops are installed.
This suggests that R&D should aim to bring these costs down. Air source heat pumps are therefore widely used for heating because of the relatively low installation costs. A major disadvantage is that the heat output and COP decrease for low outdoor temperatures, when most heat is needed[3].
In new building projects due to the high freedom of design the heat load can be reduced largely, making the heat pump system smaller and competitive in most cases. New stricter energy regulations in the Netherlands more or less leaves the heat pump for new buildings as almost the only available and viable solution.
The challenges for the retrofit situation however are the availability of heat pump technology for the different heating systems installed in building structures which have been built over the last decades and century in the Northern part of Europe in general and specifically in the Netherlands. The main technological barrier for the use of heat pumps for retrofitting are:

- the high distribution temperature of conventional heating systems in existing residential buildings with design temperatures up to 70 – 90°C.
- the high initial costs of heat sources, which preferably due to the outside air temperatures should be ground coupled
- the bad quality of the building envelope on insulation and air-tightness.

Heat pump solutions for this type of renovation are not yet readily available or so expensive that these are only applied in a niche market. Effort in R&D should be focused on finding solutions for this market, since it could be the largest market for the application of heat pumps. Heat pumps with CO_2 as a working fluid could fulfill this requirement. Japanese as well as some major European companies invest significantly in these ‘strategic’ developments.

3.2 Research in the Netherlands

[3] A typical solution is presented by Lyndholm et al [6] in a dual source system in Sweden

The focus for researchers is on increasing the yearly performance of the heat pump system defined in an SPF. This SPF of the heat pump can be translated into the primary energy ratio (PER) as the amount of useful heating energy delivered divided by the used (fossil) primary energy. The efficiency for the different types of fossil energy for heat pumps are thus included in the calculation of the PER.
Starting from the COP for heat pumps (which are widely known), the PER will be the COP multiplied by the efficiency of the generation of the driving energy[4] (electricity, gas etc.). In principle heat pumps can use renewable energy as driving force for electric heat pumps and sorption systems. The use of fossil energy becomes zero and the PER becomes infinite.

Several factors other than those laid down in the test and qualification standards for heat pumps (the COP at diferent temperature levels) influence however the system performance: actual temperature lifts, distance between heat exchangers, performance under partial load conditions, and quality of the installation being the most important. In the monitoring of several projects the measured COPs can be far apart, see table below. This is part of the reason for the high monitored COPs for closed-loop systems is the small temperature lift in practice compared to the CEN standard conditions:

Coefficients of Performance for heat pumps in commercial buildings

Source	COP standard conditions	COP monitoring		PER standard conditions
Closed loop	3,0	4,6	(4,1 - 5,1)	1,2
Air	2,8	*unknown*		1,1
Ground water	4,2	3,7	(2,4 - 5,0)	1,6

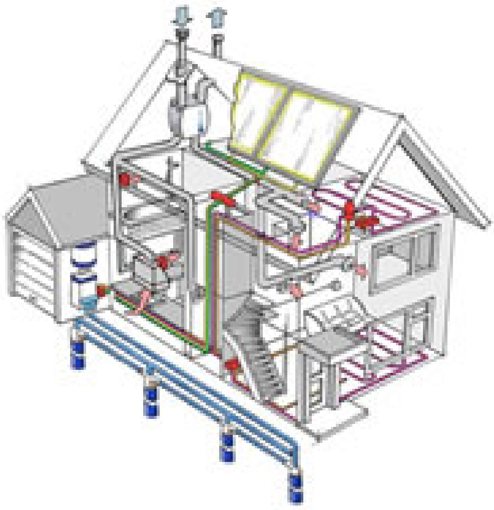
For domestic buildings heat pumps are standardised and designed for heating purposes. Special certification schemes and test procedures have over the years given a boost in performances of these heat pumps made by several competing manufacturers. COPs of 4.0 – 5.0 are commercially available nowadays for the domestic sector.

Away from the heat pump itself and broadening the view to the heat pump system, it is clear that the Netherlands has a unique expertise concerning open ground loops (aquifers). Furthermore, quality assurance and system integration get significant attention – a circumstance which we share with relevant European countries such as Germany, Switzerland and Austria.

Residential heat pumps
In the Netherlands the main developments in the past few years have been on residential heat pumps, electric as well as gas-driven Special heat pumps for the Dutch domestic market have been developed in collaboration wirh TNO and Gastec and are manufactured in/for the Netherlands by Inventum, ITHO, Techneco and Daalderop[5]. Other manufacturers mainly from European origin adapt their heat pumps for the Dutch market. These heat pumps are

[4] For an electric heat pump the average efficiency for Power Generation in the Netherlands of 43.9% is used. After substraction of the distribution losses in the net of 2%, 41.9% remains as net average efficiency of Power Generation for an electricheat pump.
[5] In a period of four years since 2001 four manufacturers for heat pumps have started their business. These companies are mainly well establihed firms adapting to new markets

mainly ground source electric systems. The air source heat pumps are mainly Japanese/Chinese and from Norway.
There is still a need for better system-integration and integration into the building procedures.
There is a tendency with Dutch heat pump manufacturers to focus more on the installation and building process in an integrated approach of the market.



The ITHO-concept

The development of these concepts is accelerated by new Dutch regulations on energy use enforcing new domestic building to a standard EPC lower than 0.8. Local community councils even go further than these regulations creating a heat pump boom in the market and a stimulus for increased product developments.

For retrofit, which is the largest potential market, the Netherlands is building expertise with heat pumps in a number of projects with sorption systems for collective housing.
Small sorption systems for individual retrofit are still in their infancy, but they could be of utmost importance for application in existing residences. There are no Dutch manufacturers active in this field, even though there is a lot of knowledge available (KIWA, Gasunie).
With the support from Gasunie and KIWA it has been possible to adapt products from the Italian manufacturer Robur to reach a PER of 1,6 in the Dutch market, which is excellent for sorption heat pumps for retrofit in collective systems.
This knowledge needs to be extended to individual houses and expanded to electric driven heat pumps. It is important that the Dutch knowledge of gas-technology is shared with the (foreign) heat pump manufacturing industry. Some large Japanese manufacturers already outsource their R&D-efforts on applied gas technology to the Netherlands.

Working fluids, such as CO_2, suitable for higher supply temperatures, and air-air systems, aiming at cost reduction for installation, are important areas for new technological developments with huge potential. Developments on components are currently mainly occurring in other countries with a manufacturing industry for these components. Only in the case of heat exchangers developments are also ongoing in the Netherlands.

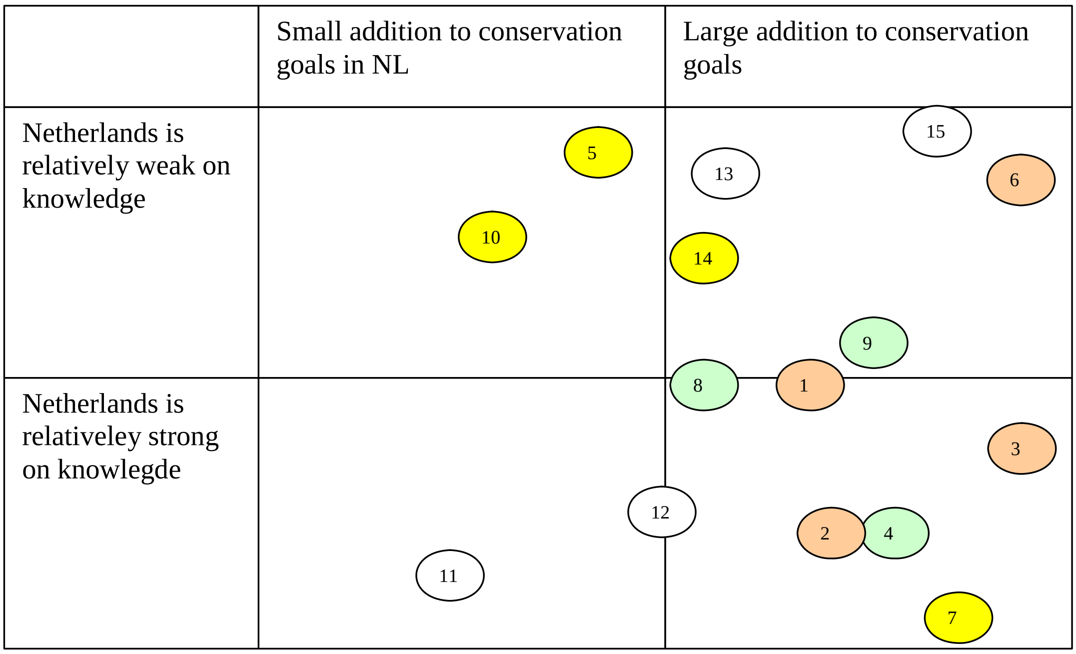
Larger systems

For larger systems, most heat pumps applied are air source heat pumps in HVAC systems.
The performance figures for commercial buildings are significantly lower than for domestic systems. In commercial buildings and greenhouses the heat pump has been tailor made based upon air-air heat pumps in air-conditioning systems and chiller systems. Manufacturers are mainly American and Japanese. Some Dutch companies like KODI and ETP adapt their

machines to dedicated ground source systems. Their adaptions are very succesfull, and KODI and ETP sell high grade heat pumps ranging from 250 – 1000 kW's with a COP of 5.0 and more for the Dutch market. This research is doen by these companies in collaboration with institutes such as TNO.

Unique experience has further been built up in the Netherlands with open-source systems, in combination with cold storage. These are applied for commercial as well as domestic buildings. With regard to quality in relation to regulations a lot of knowledge has been gained that is important for the development of future European regulations. Large aquifer based systems have also been standardised to a high COP for heating, allowing Dutch suppliers to be competitive at European level in future.

Strenght and weakness analysis
The strength and weaknesses of running technological developments in the Netherlands compared to running developments in other countries can be summarized in this matrix.



1. Small domestic heat pumps for new buildings
2. Large electric heat pumps for commercial sector and greenhouses
3. Medium to small sorption heat pumps for retrofit
4. Large sorption systems for collective retrofit
5. Compression heat pumps with CO_2 as refrigerant for domestic hot water
6. High temperature compression heat pumps with CO_2 as refrigerant for space heating
7. Open ground sources and aquifer based storage systems
8. Closed loop ground source heat exchangers
9. Quality control and system integration in buildings
10. Industrial heat pumps
11. High termperature industrial heat pumps
12. Large compressors with natural refrigerants
13. Compact chemical storage
14. Compact heat exchangers
15. Components for heat pumps

The main topics for R&D are dictated from need and experiences from the market. Thus installers, energy companies and consultants are the main parties involved in the development of heat pump systems. This type of development is focussing on application of existing basic technology and optimising this for the local situation and market. As the only Dutch heat

pump manufacturers are using component integrating these into a product for the Dutch market no real fundamental technology or components are under development.
Except for Grenco in refrigeration technology and in the field of gas research where with the knowledge built up in the development of high efficiency gasboilers, the development of applicable and practical sorption technology bears fruit. Also some manufacturers in the field of refrigeration and heat exchangers are active.
The state of the art of heat pumping technology and running research in the Netherlands is extensively described in 'Ontwikkeling en toepassing van warmtepomptechnologie in Nederland in de internationale context' [1].

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The main running research at this moment is:

- ***Improvement of heat sources***: The practical research is mainly focussed on a more effective/efficient use of open ground sources and optimisation of the models for closed ground source loops. Important partner in this field are IF-Technology and TNO-NITG for open sources and Groen Holland and Installect for closed loop systems. TNO Built Environment and Geosciences is the main partner in technical research for air source heat exchangers supporting local manufacturers and active in the European project Miniref.
- ***Improvement and development of heat pump technology***. There is a small but growing number of heat pump manufacturers. Inventum and ITHO are active making heat pumps for the specific Dutch market. They have been investing in research and are active on monitoring practical applications. Techneco has also developed a special heat pump for the Dutch market and together with ROBUR have developed sorption technology up to a level of dedicated application in heating mode. KODI has re-engineered existing GRASSO ammonia chillers into dedicated heat pumps for application in the commercial and greenhouse sector. These developments are mainly for new building projects. For the existing market in retrofit situations only the gas-absorption heat pump has been developed for collective systems by ROBUR together with Techneco, Gasunie and KIWA. For retrofit replacing individual gasfired high efficiency boilers in individual domestic heating systems research is being done on commercial basis by KIWA, TNO Built Environment and Geosciences. Also on the same basis research on heat pumps with CO_2 as refrigerant and thermo-magnetic technology is undertaken by the same institutes. At ECN research on heat pumps for industrial application is undertaken based upon thermo-akoestic and thermo-chemical reactions. Basic knowledge is used from within international networks of these institutes, where specific knowledge on gas-technology is sought by interntional companies with institutes like KIWA and Gasunie.
- ***Improving systems for heating***. This research is mainly on applied research on heating systems in buildings where the focus is on integration in the building structure and procedures. This research mainly is being done at this moment without much participation of the heat pump network. But increasingly as seen in the developments with companies like ITHO the involvement of manufacturers in building systems is growing.
- ***Testprocedures for heat pumps***. These testprocedures have been developed in Netherlands by TNO Built Environment and Geosciences together with the Dutch Society for Quality Assurence on Heat Pumps (Stichting Kwaliteitszorg Warmtepompen) and are used for setting standards of perforamnce and servicing. These quality standards will be extended toward system quality and will be matched to DACH from 2006 onwards.

- ***Refrigeration technology***. Developments on refrigeration technology especially on heat exchangers and CO_2-technology are leaning towards heat pump technology. It is noticible that the attention of trade associations like NVKL and NVVK and their magazines publish more on running developments in the field of applied heat pump technology. Industrial developments tend towards smaller and more effective heat exchargers with smaller refrigeration charges. An important project in this field is Miniref run by TNO Built Environment and Geosciences. Also larger manufacturers like GRASSO and Verhulst are active in developing technnology with new refrigerants.
- ***System integration and building concepts***. Zero-energy and autark concepts are being developed by building constructors (BAM, Pepping, Vos) and heat pump based heating systems are integrated as a long term development strategy together with energy companies (NUON, ENECO) and institutes (TNO, ECN). The Association for Building Research (SBR) is involved in this.

4 Activities other countries

4.1 Introduction

The most important countries with heat pump research relevant for the Netherlands are Switzerland, Sweden, USA, Japan and China. But also in Germany, Austria and Norway are interesting individual research projects.

Most of the succesful research programmes were based upon focussed projects in which industry, institutes and universities work together. Common success for these programmes is that they have stimulated the development of state of the art technology for heat pumps and refrigerating systems that utilize energy very efficiently and are commercially and environmentally viable.
Some of these programmes were governmental driven (like in Switzerland, Sweden and Japan) and some of these were set up by market organisations with institutes and supported by government (USA). Information is widely available on the Internet, at least for pre-competitive research.

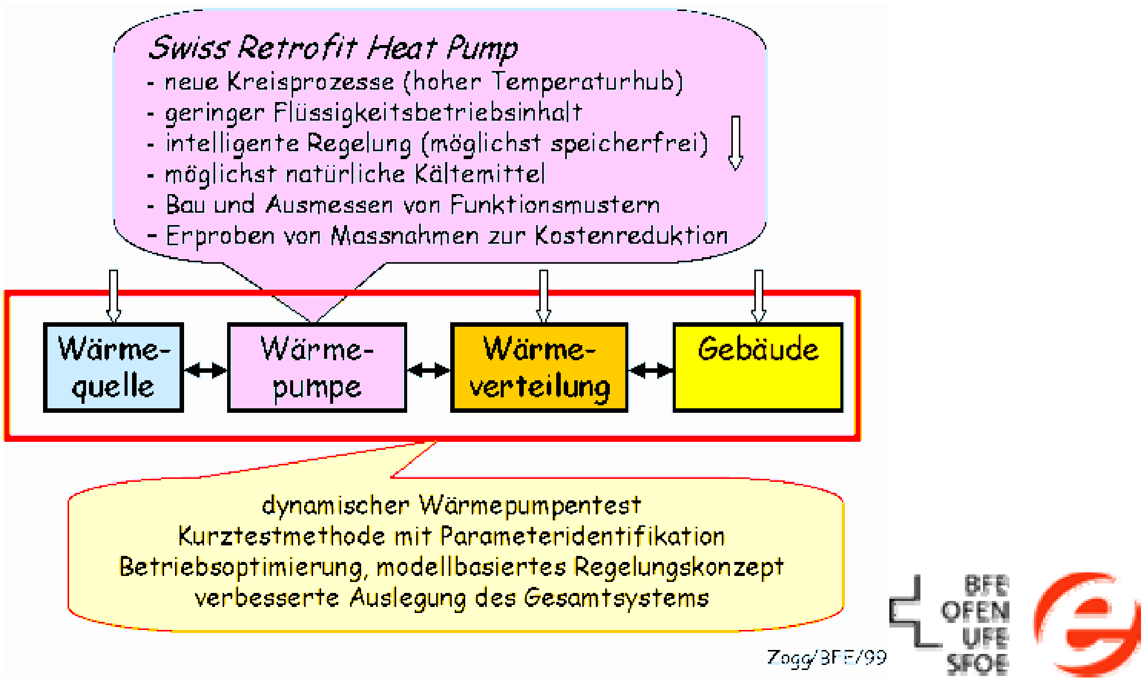
4.2 Switzerland

Although there is a remarkable number of oil-fired systems for heating purposes in Switzerland, there is also an increasing amount of heat pumps. 60 % of new built residential houses are equipped with a heat pump. Compressor heat pumps with electric drives are mainly sold. Recent years have seen an increase of air to water heat pumps compared to earth probe heat pumps. Until 2003, 85,000 heat pumps were running: 59.5 % air to water, 37.3 % brine to water and 3.2 % water to water.

4.2.1 Research Strategy

The CO_2 problem and technological emissions to the environment as GWP and ODP guided the strategy of Swiss research politics in heat pumping technologies (www.heatpump.ch). Every four years, a research activity master plan is made by the Bundesamt für Energie (BFE) after intensive discussions among manufacturers, energy suppliers, installers, research and energy specialists. Since about 1990, the main areas of research in heat pumping technologies have been:

- Development of retrofit heat pumps to replace oil and gas burners
- Screening and improvement of heat source such as air coolers, earth probes and waste water channels
- Development of heat pumps with natural working fluids especially ammonia and CO2
- Improving components such as compressors, heat exchangers and other equipment
- Improving the integration of the heat pumps in existing buildings incl. improvement of control equipment and control strategies
- Investigation and improving methods to measure and calculate coefficients of performance and seasonal performance factors



At present, 15 research projects are ongoing. 60% of them are cooperations between industry and research institutes. The projects ranges from SF 40,000 to SF 550,000 per project and last from one to three years.

4.2.2 Research Projects

A range of focussed research projects are running in dedicated institutes:

a. Development of heat pump for retrofit

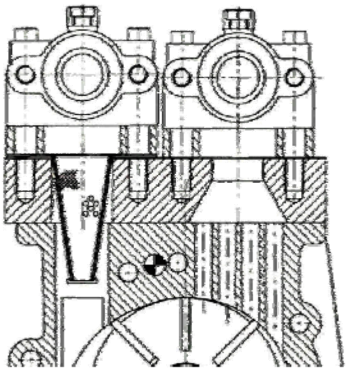
Retrofit - Heat Pump In 1996, the SFOE launched a 'Swiss Retrofit Heat Pump' competition to develop an air to water heat pump with high temperature rise to replace oil and gas burners. The thermal capacity should be 15 to 20 kW with an air temperature of – 12 °C and a water temperature of 60 °C. Four project teams started their planning. End of 2002, the SFOE could officially close this competition and declared the SWISSTOP heat pump as the winner. Unfortunately, this heat pump is not on the market yet, because the manufacturer decided to improve some internal elements	

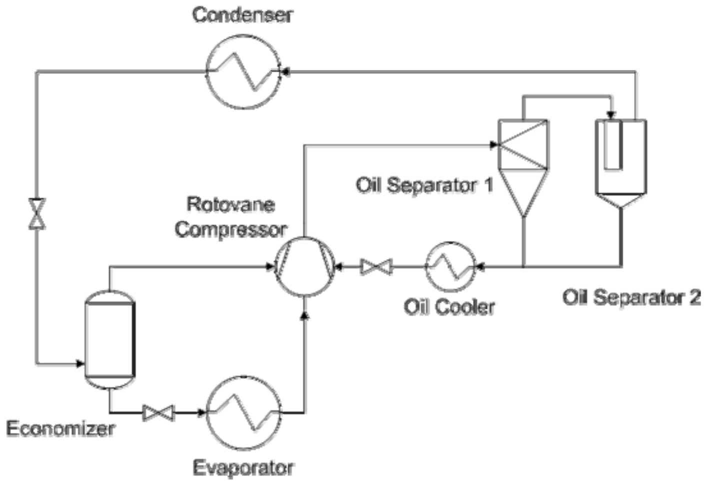
b. Improvement of Components

- *Air Sources* Ambient heat can be collected from outside air, from ground and ground water and from waste water. It is easiest to use air to gain heat from the environment. Two main practical problems are tackled in the ongoing research:
  - State of the art analysis of outside air coolers: The results showed that the ventilator had a poor efficiency of 14 %, and the pressure drop in the circulation loop of the working fluid was four times higher than in the air cooler itself. This means that existing air coolers in the refrigeration market are not optimized for heat pumps.

        - Antifreezing Surface Treatment Air coolers are freezing on the surface and therefore the heat resistance increases and the performance drops, thus a need for de-icing exists.
        - LOREF Improvement of Air Coolers for Retrofit-HP. SFOE initiated a new competition ‘improvement of air coolers for retrofit heat pumps’ in 2003. The project is now in phase 2 where several air coolers with optimised fin geometry are engineered, fabricated and tested.
    - *Ground Sources* The technology to increase the possible drilling depth is well established and does not require anymore research. Probe depths in Switzerland are 150 to 500 meters. Usually, double U-probes are installed. Glycol filled earth probes have the disadvantage of additional friction in the glycol loop. A recent project investigated natural flow convection in the probe with CO_2 as working fluid. Also, there has been research to utilise underground waste water system as a heat source. The temperature of the waste water is about 15 °C.
        - Pumpless Ground Probe Phase 1: Potential and Feasibility Study. A recent project investigated natural flow convection in the probe with CO_2 as working fluid. It was shown that for the depths needed in Swiss installations, a probe length of 75 m, as seen in Austrian probes, is not sufficient. The overall results were showed that free conventional CO_2-flow needs diameter of 40 mm if depth is 350 m.
        - Heat from Waste-Water Systems (Waste-Water Channels) Temperature of waste water in waste water channels is around 15°C. In Switzerland, there are about 1000 possible locations for such waste water channel heat exchanger systems and several exchangers have been built. Fouling of the surfaces is not the same on each installation and can lower the heat transfer capacity to 50 %. So the conditions for prevention of fouling and the behaviour of the sewage treatment plant were investigated with a pilot scale heat exchanger in a small waste water channel. The best antifouling effect is attained by regular short term increase of the flow velocity. Other measures as coating or obstacles in the channel had less influence. The measured heat transfer capacity could range from 60 % without any measures to 83 % with intermittent flushing compared to 100% for clean surface. The sewage treatment plant is not harmed when proper dimensioning rules are followed.

c. **Heat Pumps with Natural Working Fluids**. Due to ODP and GWP, the Swiss government and the SFOE decided to support research projects with natural working fluids. Propane, ammonia and CO_2 are considered as natural working fluids at the moment. Some heat pumps which were refilled with propane instead of R22 were sold also in Switzerland, but caused severe problems due to failures of lubrication in compressors. Therefore there is no great interest in propane nowadays. Ammonia is common for larger refrigeration plants in the food and beverage industry and in ice rinks also in Switzerland.
    - NH3-Heat Pump with Rotovane Compressor. An ammonia heat pump with a thermal output of 17 kW (with Tin -12°C, Tout 60°C) was equipped with a rotating blade compressor Rotovane.





- o NH3-Heat Pump with Two-Stage Compressor, an oil-free two stage compressor is tested. Suppliers have limited experience with ammonia and there are not enough components on the market, especially for lower size application.

d. CO_2 as natural working fluid (by Awtec(CH) and Stiebel-Eltron(D) and Pac- CO_2 (www.pac-co2.com). Much is expected from CO_2 as natural working fluid. There are two projects currently running:

- o Development of a heat pump with CO_2 for space heating and water heating. A transcritical CO_2 heat pump prototype for a combined space and hot water heating system for residential European-style low-energy-houses has been designed, built and tested. The goal of the project was to verify the potential of the CO_2-heat pump process in such an application and to gain experience with the CO_2-heat pump for later commercial realisation.
- o 60 kW CO_2 air-to-water heat pump with 2 m^3 hot water storage at Locle Hospital. *(Installation d'une pompe à chaleur air/eau, d'une puissance de 60 kW, utilisant du CO2 (R 744) avec ballon d'eau chaude de 2'000 litres pour les expériences et mesures , qui sera exploitée sur le site de l'Hôpital du Locle (NE), sur une période de 2 ans. Préparation d'eau chaude sanitaire à des témpérarures de 60 à 80°C, avec température d'eau froide de 10°C)*

e. Small turbo-compressor for two-stage heat pumps. Exergetic analyses show clearly that the compression is still the element where most improvements are possible. In the project ‘Small turbo compressor for two-stage heat pumps, the research team plans, builds and investigates a turbo compressor for a heat pump with R134a.

f. Control systems. Heat pump with frequency control PIONEER (1 of 2). Special focus is given to the effect of speed variation in the compressor and in the ventilator for the air cooled evaporator. Speed of the compressor can be varied from 17 to 117 Hertz. By this strategy, the heat for the building can be accurately supplied in function of seasonal demand.

g. Building Integration

- o Pulse-Width Modulation, Phase 4**.** Special activities were made to study the method of pulse-width modulation where heat packages are delivered to the building via the ordinary hydronic system. Frequency and duration of heat pulses are varied according to the ambient outside temperature.