

# TEN YEARS OF SWEDISH RESEARCH AND DEVELOPMENT IN HEAT PUMPING TECHNOLOGY

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The Swedish Energy Agency, (STEM), together with Swedish industries and organisations, has for the last ten years been financing a large number of research projects with focus on heat-pumping technologies. This all started already 1994 with the first program “Alternative refrigerants”, followed by “Climate 21”. The third programme, “eff-Sys” (short for “More efficient heat pump and refrigerating systems”), has just finished. Common for the 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.

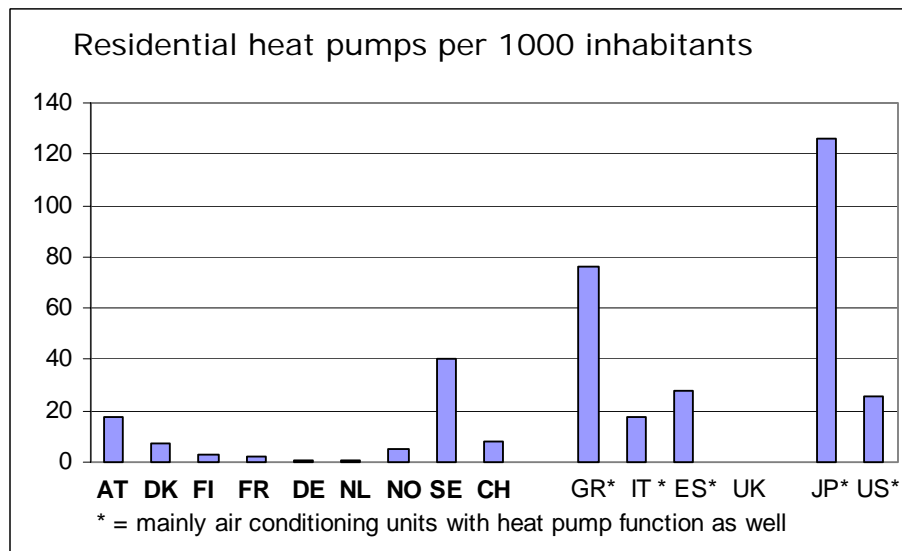
The three research programmes have had a common objective – to strengthen Swedish industry on a long-term basis through co-operation between universities and the industry, which leads to mutual exchange and transfer of knowledge. Focus has widened during the past ten years – from refrigerants via components to complete systems.

But Swedish research in heat pumping technologies is older than that. A strong support with research grants during the earlier years has lead both to a build-up of knowledge at the universities and to Swedish participation in IEA and other international research projects.

**Key Words:** *research, heat pumps, industrial cooperation.*

## 1 INTRODUCTION

Compared to other European countries Sweden is a large user of heat pumps relative its population. It has a leading position when it comes to heat pumps for cold climate and heating purpose only.



**Fig 1. Heat pumps for heating only are very common in Sweden**

One important reason for this dominating role of the heat pumps in Sweden is that the research in heat pumping technologies has been supported both by the government and by the industry. The paper identifies some of these actors and describes how the research and development performed in an active

cooperation between the researchers at the universities and the users of the research results in the industry.

The heating demand is large but varies substantially between different parts of Sweden. The country stretches from 55° 20' N to 69° 4' N and the winter heating conditions vary from design outside temperature of -14°C in Malmö in the south to -30°C in Luleå in the north and with heating degree days of 3,200 to 5,300 respectively. The need for finding substitutes for imported oil was thus great.

## **2 REFRIGERATING PLANTS AND HEAT PUMPS IN SWEDEN**

Refrigerating plants and heat pumps in Sweden are practically all driven by electricity and use totally a significant part of all electric energy used in the country. The only exception is a small number of heat-driven absorption units in special applications. The connection between reduced use of energy and heat pumps is obvious and generally the energy saving potential of heat pumps is the factor that motivates the interest shown. The efficiency is therefore an important factor that obviously has a great influence on the profitability but there are also a number of other elements that have to be considered. The relation between refrigerating plants and energy saving is for some reason not as obvious. Most of the owners and users want to get the usefulness of "cold" as cost efficient as possible. In spite of this even many qualified plant owners lack the practical possibilities to measure and follow-up the real efficiency of their plants.

The refrigeration and heat pump sectors show a considerable potential to make the energy use in Sweden more effective by:

- conversion of private houses with direct acting electric heating to heat pump systems
- streamlining refrigerating and cold storage plants
- developing more efficient heat pumps and by making them attractive both for new installations and for replacements.

More than for most other technologies the results of heat pumps and refrigeration systems are highly connected to how they are applied in the systems they serve and how these systems are designed. All parts of a system must be designed, dimensioned, and brought into operation in such a way that they work well together. Merely a good design of the equipment is not enough for a good total result.

The relative large extent of imported units and components to Sweden together with the fact that our conditions often differ from the optimization criteria that have been set at the manufacturing, often results in the acceptance of less efficient solutions as a consequence of the lack of technically better and more competitive alternatives. There is thus a need for components, units, and systems better adapted for a colder climate.

The refrigeration technology is, generally speaking, widely spread over the world but has its centre of gravity in countries with partially other conditions than those prevailing in more northerly regions. The long-standing work in Sweden with refrigeration technologies and the large interest for heat pumps during the last decades has lead to a considerable knowledge among different Swedish actors, both in the industry and at the universities. One problem is that knowledge and experience are spread on many hands and that the companies are small and have very limited resources for development.

Experience and results from other adjacent research and development programs run together with the industry show that – if properly used, systematized and developed further – they form a good basis for a target-oriented research and development program with object to considerably improve the total efficiency of refrigerating and heat pump systems. As pointed out above the potential for a subsequent streamlining of the energy use is considerable.

A unified effort in Sweden on development of technology and systems for more efficient use of energy within the refrigeration and heat pump technologies would also result in a higher degree of competitiveness for Swedish industries that otherwise would be difficult to achieve for the individual companies.

### **3 THE TRADE**

The refrigeration trade in Sweden constitutes to a large extent of a number of contractors, many small or very small with limited resources for development. Today the manufacturing of refrigerating compressors is no longer taking place in Sweden. There are however a number of unit manufacturers in the country who, within their respective fields, are leading the world, e.g. Electrolux within the white goods sector. The component sector is otherwise well represented when it comes to heat exchangers, primarily compact heat exchangers, and by a number of manufacturers of control equipment and systems.

The heat pump market for private homes is dominated by a few larger manufacturers in parallel with a number of importers and contractors who like other small companies have limited possibilities to influence the development.

Heat pump plants for large apartment buildings and heat pumps for district heating are built on site with imported components by large contracting companies.

Most of the unit manufacturers in Sweden do not have large enough production volumes to be able to maintain the industrial sized manufacture that is common among the large actors on the market.

Also a large and dominating part of the refrigeration units that are installed in Sweden are imported. A successful development activity could result in a larger share of domestically manufactured units which could lead to larger export possibilities.

### **4 OBJECT AND STRATEGIES**

In the Swedish political decision about energy in 1997 a program for an ecologically and economically long-term sustainable energy system was decided. The main aim and direction was to direct the efforts on research, development and demonstration of new energy technologies on a long-term basis. The aim is that during the next ten to fifteen years increase the electricity and heat production from renewable energy sources and to develop commercially profitable techniques for energy streamlining.

Sweden has today internationally prominent research groups within the domain and an industry that in several segments, e.g. household refrigerators and freezers, refrigerated food storage in supermarkets, and heat pumps for homes. During the earlier programs a close co-operation was built up between the industry and the research institutions which was beneficiary for both parties. The work

has met with great international interest and has e.g. led to considerable contributions from internationally established companies in the refrigerating sector and with activities in Sweden.

## **5 THE EARLY YEARS – RESEARCH BEFORE THE LAST DECADE**

The first oil crisis 1973-1974 started an intensive work in Sweden of getting more independent of imported oil. There was a national political unity of using Sweden's own energy resources as much as possible. Electric energy; hydro and nuclear, was used for heating purposes in parallel with other domestic energy sources. Large RD&D programs were started, some of them with the intention to develop more efficient heating systems.

## **6 MANY ACTORS SUPPORTED THE RESEARCH**

### **The Swedish Council for Building Research, BFR**

The Swedish Council for Building Research, BFR, (replaced 2001 by The Swedish Research Council for Environment, Agricultural and Spatial Planning, Formas) was the main governmental actor for supporting research regarding heating of buildings and e.g. the forming of the Nordic Heat Pump Group. Research results and experience was shared at the Nordic Heat Pump Meetings (later to be combined with refrigeration as The 13<sup>th</sup> Refrigeration and Heat Pump Meeting, Stockholm 1985, sponsored by BFR).

Environmental impact from these large heat pumps was also studied, e.g. noise emission towards the nearby dwellings. It was important to show that this new energy efficient solution was user-friendly – no sulphur or soot emission as from the older oil-fired boiler plants. Noise could be one reason for people to have a prejudice against heat pumps and the adverse NIMBY-effect (Not In My Back Yard). The work was successful and led to the introduction of very large (10 MW and larger) heat pumps connected to district heating systems.

### **The Swedish State Power Board, Vattenfall**

Another very active research supporter and researching organization was (and still is) The Swedish State Power Board, Vattenfall. One area where Vattenfall supported both research and industrial application was that of large heat pumps connected to district heating systems. A series of these large heat pumps were built using different heat sources – ambient air (Fagersjö and Eskilstuna-Hällbybrunn – both 2.7 MW), sea water (Lidingö and Visby) – to mention a few.

Another research area supported by Vattenfall was heat pumps for single family houses using ground coupling or outside air and multifamily houses with pumps e.g. using the extract air from the building as heat source for heating tap water. Another large activity started by Vattenfall at that time was the so called "Solar Energy Program," initiated 1979 and ended 1986.

### **The National Swedish Board for Technical Development (STU) and The Swedish National Board for Technical and Industrial Development (NUTEK)**

Other governmental actors supporting research within this field at that time was The National Swedish Board for Technical Development (STU) mainly responsible for new innovations in different technical sectors. STU was later transformed and renewed in The Swedish National Board for Technical and Industrial Development (NUTEK).

### **Nuclear ban speeds up the need for new solutions**

A referendum in Sweden formed a basis for a parliament decision 1980 to phase out the Swedish nuclear plants, the latest 2010. This fixed year was however abolished in 1997. One consequence of the referendum was that it started a still more intensive work on environmentally accepted energy supply and efficient use of energy – and to intensified heat pump research.

One action that has played an important role in strengthening the heat pump use in Sweden was a technology competition for heat pumps for single family houses arranged and supported by NUTEK. Many of these houses had been converted from oil to direct electricity heating after the oil crisis and now it was time convert them to a more efficient type of electric heating system! One complication with the competition was that it took place in the same period as the Swedish National Environmental Protection Agency decided to ban CFC refrigerants. The competition rules were thus changed at the last moment and that lead to some trouble for the participants who had difficulties finding components suitable for the new refrigerants.

### **And so does the ban of CFC's**

One consequence of the ban of CFC and of the experience from this heat pump competition was that NUTEK decided to start a research program in 1995 together with Swedish industries “Alternative refrigerants” and this leads us into the heading of the paper – Ten years of research and development in heat pumping technologies – that is the last ten years!.

## **7 THE LAST DECADE – RESEARCH IN CO-OPERATION**

### **A Unique Way of Working Together**

Common for all three research programs that were run in series is the way the research and development projects are started and run.

A prerequisite for a project to start is that there is an interest both from the industry in the future results and from the university to do the research. A large part of the projects are run as postgraduate studies and should end with a thesis which requires both adequate theoretical value and sufficient time for the work to be done, normally at least three years.

Common for most of the projects is that they stimulate 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.

The idea behind these R&D programs is that the universities and the research institutes shall cooperate with the industry in formulating and solving research problems and thus both answering the questions from the industry but also being part of the scientific education of the postgraduate students at the university. “Industry” here means industries manufacturing components, machinery and systems as well as suppliers and contractors, utilities, energy suppliers, consultants, trade associations, large consumers and companies involved in operation and maintenance of these installations.

### **The First Program – Alternative Refrigerants – 1994-1996**

The refrigeration and heat pump industry has during the last years experienced large changes depending on the need to replace refrigerants that are harmful for the ozone layer with more environment friendly alternatives. In 1994 a research and development program, *Alternative refrigerants*, was started by NUTEK together with industries and universities CTH (Chalmers University of Technology), KTH (the Royal Institute of Technology), and LTH (Lund Institute of Technology).

An all-embracing object for the program was to reduce the environmental impact from the refrigeration and heat pumping technology as much as possible. Primarily the work was aiming at studying questions on how the conversion from traditional CFC- (and HCFC-) refrigerants to more environmental friendly working media could be facilitated in existing and new refrigeration and heat pump systems.

The R&D program *Alternative refrigerants* presented important contributions to the progress and to the change-over from CFC-refrigerants to chlorine free working media. The program has also given deeper knowledge of the use of e.g. zeotropic refrigerant compounds and inflammable media from both a thermodynamic and a safety perspective.

### **The Second Program – Climate 21 – 1997-2001**

To continue this work from the earlier R&D program and to widen it a new R&D program, *Climate 21 – More Efficient Refrigerating and Heat Pumping Plants*, was started by NUTEK together with Swedish industries. In 1998 the energy research supporting and other parts of NUTEK was separated and transformed into a new public authority, The Swedish Energy Agency, STEM, who took over and continued the program.

The budget for this widened program was 54 million SEK (approx. 7 MUSD) which was financed to 40 percent by the Swedish Energy Agency and by the participating companies for the rest. For this program a special focus had been on involving smaller and medium-sized companies with a restricted budget for research. As a contrast some of the largest companies in the world within this field who were based in Sweden also participated in the program.

In the *Climate 21* program the complex of problems was widened to how we shall achieve highest possible reduction of energy use by improvements both at component and system level. After the first three-year period some questions still remained e.g. about replacement media for R22 in different system applications and about the use of zeotropic refrigerants with glide. To accomplish more energy-efficient systems it was necessary to study both control systems for components as well as operation optimization of complete systems. Reliable methods for calculating, measuring and presenting the energy efficiency of systems also had to be studied.

### **The Third Program – eff-Sys – 2001-2004**

The R&D program *More Efficient Refrigerating and Heat Pumping Systems, eff-Sys* therefore started as a natural continuation of the earlier programs but with a more clear concentration towards system studies and special applications, e.g. food refrigeration and alternative principles, e.g. free-cooling. Methods for assessment of heat pump performance have been studied in some of the projects.

The purpose with **eff-Sys** has been to maintain this close collaboration between the industry and the universities within the refrigeration and heat pump field in Sweden during the previous R&D programs. The projects in the program have stimulated and strengthened the participating companies' build-up of knowledge leading in the long run to a strengthening of their national and international competitiveness. The purpose has thus been to support the industry with:

- Long-term competence support to the industry
- Long-term competence build-up within the universities
- Solution of problems in co-operation between the universities and the industry
- Compilation of knowledge, synthesis and information

The idea has been that the university, the industry and the group of project partners in collaboration should formulate and solve research tasks that are relevant to the need of the industry and also are part of the education of the postgraduate students at the university.

The overall object with the program has been to build up a competence and a field of knowledge at Swedish universities and institutes that can contribute to a national industrial development within the area and to an increased international co-operation, a progress towards environment friendly refrigeration and heat pump systems with high efficiency and low costs. Knowledge achieved in the program shall result in products and applications that are characterized by robust technologies and system thinking that are well adapted to environment requirements from a Life Cycle Analysis, LCA, and a Life Cycle Cost, LCC, perspective.

The results from participating projects shall also provide a basis for the companies' own development of a new generation of more efficient refrigeration and heat pump systems and form the basis for implementation of energy, environmental and cost effective solutions.

The efficiency of conventional refrigeration systems and heat pumps can be raised partly by more efficient components as compressors and heat exchangers and partly by optimizing the systems in which they work. An important factor is the control of the whole system to prevent the different parts of the system to counteract each other. The knowledge of and the tools for this optimization are important steps to achieve more efficient systems. Through research and development, with active participation of the industry and interested parties, it would be possible to obtain this result in practice

### **eff-Sys – Activities and Scope of Work**

The R&D program **eff-Sys** started in March 2001 by STEM, the Swedish Energy Agency, together with six institutions at four Swedish universities, a research institute and about thirty companies working within the energy field, primarily with refrigeration and heat pumps. During the program period more companies joined the program and totally fifty companies have participated in different eff-Sys projects. **eff-Sys** was originally planned to run for three years and should have ended in February 2004 but was prolonged to the end of 2004.

The total budget for eff-Sys has – like for the previous program Climate 21 – been more than 54 million SEK (approx. 7 MUSD) which was financed on a fifty-fifty basis by the Swedish Energy Agency and the participating companies. The share of the participating companies has comprised of cash, own work and material costs for the projects.

The program research has been done by the following universities and research organizations:

Chalmers University of Technology

- Building Services Engineering
- Heat and Power Technology

The Royal Institute of Technology

- Department of Energy Technology, Div. of Applied Thermodynamics and Refrigeration
- Department of Chemical Engineering and Technology, Div. of Energy Processes

Luleå University of Technology

- Department of Applied Physics and Mechanical Engineering, Div. of Machine Elements

Lund Institute of Technology

- Department of Heat and Power Engineering, Div. of Heat Transfer

SP Swedish National Testing and Research Institute  
– Department of Energy Technology

The Swedish company Vattenfall Utveckling AB

In total, more than fifty companies and organizations had participated in the program.

### **The Program Board**

As for all three programs the Swedish Energy Agency appointed a program board at the start of the program to be responsible for the activities. Together with a secretariat the board has also answered for administrative and economical handling of the program decisions. The board has decided which projects that should be started and have based their decisions on the following criteria:

- Background and motive for the project
- Energy, environmental and industrial relevance
- Purpose and object of the project
- Expected results
- Project plan, education plan and cost plan
- International co-operation
- Relevance for the program

The program board has also been responsible for a continuous evaluation of the results obtained in the different projects and their importance for the participants.

### **The Projects**

The program has financed different types of research projects such as postgraduate appointments, senior researchers, industrial postgraduate students, and also shorter projects of research and development character.

Most of the projects have been organized and pursued in a similar manner. The main part of the grants for research has been used for postgraduate projects where the purpose has been that the results from the project could form basis for an academic doctor's or licentiate's degree. The time used for these projects has thus been long, 3 – 5 years which means that several of the projects started already during the previous program, *Climate 21*. In parallel with these long and extensive projects a number of shorter projects have been carried out by senior researchers at universities and research institutes.

Ultimately responsible for the progress and realization has been the project leader, the senior researcher. For postgraduate projects the project leader has normally been the instructor of the postgraduate student who carried out the main part of the project work. Each project has had between one and up to ten representatives from the industries. Each project group has also had a controller, a member of the program board, acting as an information link between the project and the program board. The controller has followed the project and also acted as a sounding board for the researchers during the progress of the work and supported the contacts between the university and the industry.

## **8 SUBSEQUENT WORK?**

Discussions and contacts with representatives from the industry and with researchers have shown a continuous and increased interest for co-operation in research and development of more efficient heat pump and refrigeration systems, i.e. heat-pumping technologies.



The field is very expansive and Sweden has got a leading role in parts of it. The heat pump market increases every year in Sweden and, for the year 2004 the Swedish Heat Pump Association estimates that 90 000 heat pumps will be sold in Sweden. Furthermore Swedish companies account for half of the European manufacture of ground-coupled heat pumps (2002) and thus for a quarter of the global market. A strong reason for this is the research and development support the industry has obtained through co-operation with universities and research institutes during the past decade.

Sweden's leading role has also been manifested as SP, the Swedish National Testing and Research Institute, has been appointed to act as administrator of IEA's (International Energy Agency) Heat Pump Center.

The research and the build-up of increased knowledge have led to new issues that move the positions and the frontier of research forward. The development of society and political decisions have lead to that earlier solved problems have got a renewed actuality – the first research program in the series, "Alternative refrigerants" was started to find and test alternatives to CFC and HCFC refrigerants with a less damaging effect on the ozone layer. The HFC alternatives that were chosen then now stand in turn to be phased out in order to reduce the greenhouse effect and this will thus require answers to new questions.

Energy streamlining of the systems has stand in focus for the earlier programs and are still of strong interest where the possibilities to reduce the greenhouse effect are large. Heat pumping technologies that can replace other energy systems with higher greenhouse effect will become an increasingly common system solution.

The long-term and powerful climate change that is expected as a result of the greenhouse effect raises new questions about the building as a system – how shall the buildings and the installations that we build and install today and that will be used during many years in the future be designed to be able to cope with future climatic changes with warmer winters and hotter summers?

Limitation of electric power loads has become more important. This has been studied in some of the **eff-Sys** projects but the question needs to receive further support. Energy storage with different technologies and system applications could in combination with heat pump and refrigeration systems contribute to a reduction of the maximum power need both in short (day) and in the long run.

One of the **eff-Sys** projects has demonstrated a large potential for industrial waste heat that with different heat pump technologies can be used in local district heating systems. The technical, economical, and legal obstacles that slow down this development should be studied further together with an additional mapping of systems that are or have been in operation.

The program board is of the opinion that it is important that the activities that have been pursued within **eff-Sys** and that have been proven to be very successful should be continued preferably in a new and widened program. This will however not be the case in spite of the fact that the actions have been aimed at reducing the energy use in the country in different ways and this within an area where the potential for energy streamlining is very large.

The reason for disrupting the activities is that the Swedish Energy Agency has received a substantially reduced budget for the coming seven years in spite of the weight that energy related questions have in the public debate. In December 2004 there was thus no economical scope for deciding upon a new program as a continuation of **eff-Sys** during 2005.

The program board regards this as very unfortunate. The activities that now are concluding, and that have included three different research programs during a ten-year period, have received a very large and active participation from industries and trade organizations that together have covered more than half of the research budget. The co-operation within the projects has lead to a very rewarding two-way exchange of knowledge between researchers at universities and institutes and companies within the very expansive area of heat pumping technologies.

It is now very important to find other forms for a continued collaboration between universities and industry. It has taken a long time to build up the network and to find well-functioning working forms and it would be very unfortunate if this work should go to waste when there is so much left to do within the area.

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