IEA Heat Pump Programme

Annex 25

Year-round residential space conditioning systems using heat pums

Final Report

Operating Agent: France

IEA Heat Pump Programme Report

Report no. HPP-AN25-1
ISBN 91-85303-03-8

2005

Published by

IEA Heat Pump Centre
Box 857, SE-501 15 Borås
Sweden
Phone: +46 33 16 55 12
Fax: +46 33 13 19 79

Production

IEA Heat Pump Centre, Borås, Sweden

ISBN 91-85303-03-8
Report No. HPP-AN25-1

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

The IEA Heat Pump Programme

The Implementing Agreement for a Programme of Research, Development, Demonstration and Promotion of Heat Pumping Technologies (IA) forms the legal basis for the IEA Heat Pump Programme. Signatories of the IA are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the IA collaborative tasks or "Annexes" in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and workplans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex. The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be benefical.

The IEA Heat Pump Centre

A central role within the IEA Heat Pump Programme is played by the IEA Heat Pump Centre (HPC). Consistent with the overall objective of the IA the HPC seeks to advance and disseminate knowledge about heat pumps, and promote their use wherever appropriate. Acitivites of the HPC include the production of a quarterly newsletter and the webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the IEA Heat Pump Programme and for inquiries on heat pump issues in general contact the IEA Heat Pump Centre at the following address:

IEA Heat Pump Centre
Box 857
SE-501 15 BORÅS
Sweden
Phone: +46 33 16 55 12
Fax: +46 33 13 19 79

TABLE OF CONTENTS

Executive Summary

The objective of this Annex 25 is to define and show the technical feasibility of new packaged systems for year round residential space conditioning using heat pumps. These systems (which include all the components used in a heating / cooling system from the heat pump to the inside unit) target only residential dwellings and use either water or air as energy distribution vector. The work carried out within the framework of this Annex cover low initial and operating costs, comfort provided, suitability to customer demands, design / installation requirements, performances, integration in buildings and aesthetics.

The programme is divided into three parts :

- Task 1: a state of the art study : analysis of existing system, market needs and demand, new concepts
- Tasks 2 and 3: a co-operation with manufacturers on a new concept, demonstration and dissemination.

Canada:

Ductless heat pumps (also known as mini-split systems) function the same as any otherheat pump, except that there is no heating or cooling energy loss in the house's ductworkwhich sometimes traverses unheated spaces. Ductless systems offer energy savings ofas much as 50% over existing electric baseboard-heated homes. The equipment consists of an outside unit, which acts as the condenser in the cooling mode or the evaporator in the heating mode. The indoor unit acts as the evaporator in the cooling mode or the condenser the heating mode and can be located on any nearby wall orceiling. Tubing connects the two units, with the transport medium between the two unitsbeing refrigerant or water. Sometimes a number of indoor units are connected to oneoutdoor unit. This gives the occupants the ability to "zone" different parts of the dwelling.

There are about 3.5 million electric baseboard-heated (ductless) homes in Canada. The convenience of a single appliance that delivers both heating and cooling appeals to a growing segment of builders and homeowners. Ductless heat pumps are ideal for new and retrofit housing and small commercial markets. The target market includes new homes, replacement of older HVAC systems, smaller houses (~93 m2), remote rooms inlarge houses, or houses that have an open floor plan. In addition, owners of electric baseboard heated homes may wish to adopt other heating systems with lower operating costs and/or introduce cooling for total year round comfort conditioning. A difficulty arisesbecause baseboard heated houses have no heat distribution system. In the small commercial market, opportunities for ductless heat pumps exist in motel/hotel complexes and apartment buildings. Even with these advantages, however, many heat pump owners complain about noisy operation and inadequate heating performance.

The objective of this project is to define and show the technical feasibility of single room (ductless) heat pump systems capable of heating and cooling and performing efficiently incold weather.

Canada has a diverse range of climatic patterns. The mini-split heat pumps reviewed in this study tended to be the air source variety manufactured in the “Pacific Rim” countries.The cost of electric energy in Canada is still too low to develop a significant market forthis equipment. The major incentive for ductless split systems is air conditioning ratherthan heating capability in Canada. Potentially long vertical piping runs between theindoor and outdoor units could be attractive to apartment owners interested in upgradingtheir units to air conditioning.

The greatest heating savings occurred when the heat pump was allowed to operate downto its lowest operating point (-8oC for this study). For all climates, simple payback on theincremental cost difference between a split heat pump and equivalent air conditioner wastypically less than 2 years. Since most Canadian climates require supplemental heating, operation of the heat pump down to its lowest cut-off point may not be practical, however. The report identifies a need for an integrated thermostat to control both the existingbaseboard heaters and the heat pump to maximise energy savings.

France:
Up to the late 90's, the French heating market has been mainly dominated by direct electric heating (electric static heaters or electric radiant panels), which equip 42% of new residential dwellings. Moreover, very few dwellings (less than 2%) are equipped with air conditioning. In 1997, EDF decided to launch new commercial offers, including heating and cooling systems using heat pumps, to better respond to customers' needs by improving comfort and operating costs in new and existing houses (better insulation, high performance electrical solutions). Among the different heat pump systems available on the market, four main types were identified to be part and parcel of EDF offers:

- split system,
- heat pump + air distribution
- heat pump + fan coil unit,
- heat pump + floor heating and cooling system.

Heating / cooling floor represents the main system installed in France; it can be coupled to an air-to-water heat pump or a ground source heat pump (30% of the domestic market).

An important work has been carried out by EDF and the manufacturers in order to edit guidelines for each system to properly design, dimension, install and maintain an heat pump installation. Although the development of the domestic heat pump market in France is beginning, the increase is quite significant with 8000 heat pumps sold in 2000 for only 1500 in 1998. A lot of work has still to be done on reliability, technical and economical optimisation but above all on heat pump actors' training.

The French contribution to annex 25 focuses only on hydronic systems. Some works have been conducted to improve the existing systems:

- control strategies of the heating/ cooling floor, more especially in summer to avoid condensation,
- performance analysis of fan coil units in order to develop a new prototype for residential dwellings : silent and small.

People’s needs and expectations were investigated through several market studies and opinion surveys. They lead to avenues for new developments : aesthetics and noise levels are the most important criteria. It has been decided to focus on an hybrid system with heating/ cooling floor and fan coil units on the first storey. Indeed it offers an optimal comfort : a more efficient cooling at the upper floor and the heating/ cooling floor aesthetic and heating comfort is kept on the ground floor.

The Netherlands:

In the 90’s the interest in heat pump technology has regained. This interest was based on high expectations for heat pumps as a mean to achieve a more sustainable energy supply infrastructure. The heat pump programme, carried out by Novem, covers heat pump application in residential buildings, commercial buildings, industry and agriculture. The aim was to achieve a 1.6 PJ energy savings by heat pumps in the year 2000 in residential buildings, through close co-operation with all parties involved (builders, architects, installers, developers, utilities and suppliers). A recent evaluation of the activities carried out thusfar has shown that the energy saving target for the year 2000 will not be reached for the residential building sector. The energy saving up till 1998 was 66 TJ, whereas approx. 1200 heat pumps were installed and 3800 heat pump boilers.

The existing systems encountered can be divided into two categories : heat pump systems with cooling as an extra, and air-conditioning systems with heating as an extra. In the first category no systems have been found that have been operational for any considerable time.

The most important barriers for a large scale application of such systems in the Netherlands are the high investment costs, the integration in the design and building processes, the low price of gas compared to electricity and a possible future limitation to the use of groundwater as a heat source. The possible disadvantages of electric heat pumps, compared to competing options, are largely outweighed by the fact that heat pumps offer a cooling function without extra energy consumption. The most significant market segment for heat pumps is the upmarket, new housing sector. On the basis of this study, the combination that provides heating, hot tap water, ventilation and cooling is the most favourable option for new private housing projects. On-going demonstration projects should help to optimise such a system and to promote heat pumps.

Sweden:
The existing situation shows that the residential sector represents the main market for heat pumps in number of units sold and the forecast for the near future is still promising.

For about 20 years, there are near 300,000 domestic heat pump installations in Sweden. About 45% are exhaust air heat pumps, 25% are ambient air heat pumps and close to 30% are ground-coupled heat pumps**.** Finally, in Sweden, 55 % of the heat pumps installed in single family houses (especially new systems) are integrated systems for both space heating and domestic hot water. The rest 45 % serves only for space heating.

In order to get a complete picture of market needs and demands, the point of view of different groups of people (users, installers and architects) has been investigated. The user's point of view gives information on their opinion on heat pumps, the service demand and pieces of advice to potential heat pump users (technical and economic character). Swedish consumers consider heat pump as a feasible option for heating; this shows clearly that heat pumps have established themselves in the domestic heating market. People who intend to buy a new system seem to apply considerations wider than solely the results of financial calculations: security, flexibility and environmental considerations play also a significant role.

The objective of the Swedish participants within on-going developments concern the improvements and optimisation of the system including the heat pump and the heat distribution. Research and development support is also needed to design efficient, reliable and easy to install systems. Training constitutes another good way to provide skilled heat pump actors.

United-States:
A large survey focused on air-distribution in new constructions in the US has revealed large potential energy savings in residential single family home. The problems with residential ducts are considered to result in substantial amounts of energy usage and poor thermal comfort. The US contribution concerns both new and existing dwellings.

Existing and new duct systems were seen to be an average of 43.5 to 66.2 percent efficient, depending on the climate, duct location, duct leakage and duct insulation levels. The potential heating or cooling savings that would be realised if the standard duct systems were retrofitted range between 0.03 to 0.27 Quads. But they could reach 0.07 to 0.74 Quads[4] if more efficient distribution systems were used. Moreover as the energy use is expected to increase over the next 20 years (7.4% per ten years), thus potential savings from alternative efficient distribution solutions will become even more attractive.

Concerning air distribution, the following improvements have been evaluated : duct sealing and improved installation (proper air flow, proper charge), advanced distribution systems (reduced air flow, high velocity : small ducts). Comparisons have been made between standard air distribution and high-velocity air distribution, completed with field validation.

Two advanced distribution systems, hydronic and high velocity air distributions, are studied and compared by ORNL through modelling and field tests on two houses.

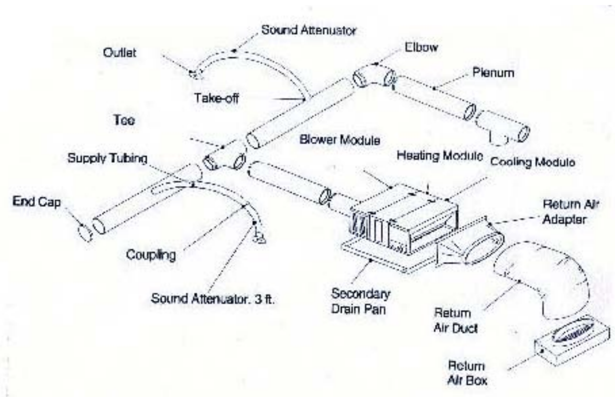


Figure 8.1 : High velocity air distribution system

Tasks 2 and 3: Demonstrations

▪ France:

In this annex, France focuses on hydronic distribution; 2 field tests are presented in this report:

- a 199m² house in Le Cannet (south east of France) with an hybrid system (fan coils + heating/ cooling floor) ;
- - 120 m² house in Avolsheim (East of France : Alsace) with a ground source heat pump for space heating.

▪ **Project in Le Cannet**

The project with the hybrid solution was really satisfying regarding the comfort provided; the ambient temperature in the bedrooms has not exceeded 26°C even

[4] 1 Quad = 1.055 EJ = 1 055.1015 J

during the warmest days (outside temperature around 35°C during several days). The higher cooling power of the fan-coils at the upper floor has been really appreciated, since the house's windows are all facing south.

The users are really satisfied with their system ; they appreciate the hydronic floor for the heating comfort but they prefer the efficiency of the fan-coils during the summer. Another lesson concerns the important consumptions of the circulating pumps (24% of the heating and cooling consumption); regulating these pumps constitutes a major way to improve the installation's seasonal performance. It is especially true for combined solutions that require several pumps. Other field tests (Avolsheim for example) prove that the consumptions of each pumps can be divided by 3 if it is enslaved to the ambient thermostat.

The system working could be improved by:

- enslaving 2 of the 3 pumps ; that would save at least 50% of the auxiliaries consumptions.
- increasing the buffer tank capacity to avoid short working cycle. Also the water temperature could have been lower to increase the performance.
-

▪ **Project in Avolsheim** :

In Avolsheim, the energy consumptions (28 kWh/m²) are really low compared to other field tests with air-to-water heat pumps. Even though this site is located in one of the coldest area in France, the annual heating costs (2.6 Euro/m²) are lower than most of the results on houses located in warmer climates (average between 3 and 4.5 euro/m²). With a COP of 3.2, the consumptions are really competitive compared to any other heating systems. The cost savings were about 30% compared to gas heating.

Regarding global warming effect, the CO2 emissions with the heat pump are 6 times less important than with a gas boiler.

This is due to the good system performance (Heat pump COP = 3.2) and also to the efficient control strategy of the circulation pumps ; the distribution pump is enslaved to the ambient thermostat, which enables to save 2/3 of the consumptions in case of continuous work.

This project has helped to prove that the pump's working enslaved to the ambient thermostat does not degrade the comfort which was a debate between the HVAC actors in France.

The measurements did not show any decrease of the soil temperature around the pipes.

▪ **Conclusion:**

To conclude, we can say that heat pumps systems are a good solution for residential dwellings in France, especially for single houses. The results from the different field tests carried on by EDF since 1998 are really encouraging. They prove the benefits of heat pumps in residential dwellings in terms of energy and costs savings compared to any conventional system using gas or oil and also the reduced impact on the environment due to the low CO2 emissions (especially with the French kWh).

For the future, the main issue to develop the market for heat pump in residential is to strengthen the quality of the installations ; the key to achieve this objective relies on the installers and it is necessary to work on a kind of certification to increase the HVAC actors' competence dealing with heat pumps.

▪ The Netherlands:

Specific measurements are made on attached single houses with the Itho/TNO heat pump system used for heating, cooling (passive or active) and domestic hot water. The heat source consists of a ground source heat exchanger and a solar collector ; during the summer, the soil is regenerated by the solar collector. Moreover, the heat pump capacity can be controlled on 3 steps (33%, 60% and 100%).

▪ System performance

The results are really encouraging; indeed, the hot water can be produced at 62°C without backup heating with an excellent COP of 3. Under normal operation, the average COP reached for the total installation is around 3 to 3.5 (heating + hot water) depending on the house.

The seasonal performance factor (SPF), however, is low (2.25) due to the fact that it was necessary to use the additional electric heater for domestic hot water during the period from February to June 2001.

Due to the free cooling the net extracted heat from the soil is small. The amount of heat extracted is about 5555 kWh and the supplied heat is 3610 kWh.

The hot water temperature (> 60°C) is quite high for a heat pump system.

▪ Users opinion

The end users are very satisfied with the heat pump system. The comfort achieved was very good. They rated the passive cooling of the home as especially important. Due to the high electricity rates (day rate 0.1808 Euro/kWh, night rate (11:00 pm – 7:00 am) 0.1261 Euro/kWh) compared with natural gas (0.3566 Euro/m3 = 0.0365 Euro/kWh), the energy bill was higher than expected. This was partly a result of the use of the electric heater in the boiler during the period from February to June 2001.

▪ Lessons learned

The dimensions of the ground source heat exchanger are very critical. If the heat exchanger is too small, serious problems will arise due to the fact that no additional heater is used and that the heat exchanger is filled with pure water so the minimum source temperature is limited.

- **Possible optimisations**

The solar collector only contributes slightly to the hot water heating. The contribution from the solar collector to the regeneration of the soil, however, is substantial. The energy supplied to the soil is more or less equal to the amount of heat extracted from the house during free cooling in the summer.

- **Non-technical issues**

In the Netherlands, Primary Energy Saving will not necessarily lead to savings in the energy costs. The year-round COP of the heat pump should be at least 2.5 to save primary energy and the year-round COP should be at least 4.2 to save energy costs as well. The calculation of the minimum COP required for saving costs is based on the assumption that 50% of the energy is used during the day period, an efficiency of the reference 97.5% situation (gas-fired condensing boiler) and an efficiency of 39% for the electricity production and transportation.

- ## Sweden:

KTH has measured a ground source heat pump that is replacing a coal/oil burner in a retrofitted house (190m²). The heat pump installation is used for heating (existing radiators + heating floor), domestic hot water and cooling (fan coil). The ground source serves also for the passive cooling which is still quite rare on the domestic market.

A water-to-water heat pump is installed and coupled to a 83m deep bore hole. The heat pump preheats the hot water at 48°C ; then the auxiliary heater is set off to reach 60°C.

The passive cooling has been able to maintain a real comfort in the house during the summer, with an inside temperature around 25°C during the peak cooling loads (brine temperature of 10°C). The regeneration of the soil is quite fast, probably because of the presence of ground water. In May, the soil temperature was nearly the same as at the beginning of the heating season.

The seasonal COP in 2000/2001 reached 3.5 for the heat pump and 2.8 for the system. Hence, the economic savings are about 11.500 SEK/year. This gives us a payback time for the ground-coupled heat pump of 5-6 years.

- **Main conclusions:**

Overall, the results indicate a satisfying operation of the system. The occupants express their satisfaction for the pleasant comfort feeling that the HVAC system provides. Furthermore, the results provide evidence that the design and installation of ground-source heat pumps (GSHPs) do not initiate any kind of difficulties. The GSHPs market is mature and the installers quite experienced in order to deal with problems that might arise.

Whether the GSHPs will maintain their high share in the Swedish market or not in the future is much in the hands of the manufacturers. It is quite likely that the customers will need some extra incentive to overcome the high initial cost associated with GSHPs. In times when company boards seldom approve of investment plans showing pay back times longer than three years, it is not reasonable to believe that individual house owners, in the long run, should allow up to seven years pay back time, which is the current average outcome of such an investment in Sweden.

The main lesson learned under this task-work is that the manufacturers attempt to make the product more desirable and make the customers more willing to accept the long-term investment. Another example of the manufacturers' attempt to make heat pumps more competitive is their great effort to achieve higher performance. This strive is often restricted to improvements within the refrigeration process. These efforts should, by all means, be encouraged, but one should not neglect the potential to enhance performance by improvements of the heat source and heat sink not to forget cost reduction of the same. Little research in these neighbouring fields is carried out from the manufacturers. The heat pump business is in this respect relying on research and development carried out by other national as well as international organizations and research institutes. New promising water driven drill technique currently under development is an example of enhancement in ways to construct the heat source. Initial results indicate that this technique offers reduced energy consumption and doubled drilling speed.

- **United-States:**

Residential ducts have been characterized by major inadequacies that include heat conduction to unconditioned spaces, leakage, and infiltration through supply and return ducts. These problems are considered to result in substantial amounts of energy usage and poor thermal comfort. In addition, distribution problems contribute to high peak electricity demand. Previous research efforts have demonstrated large potential energy savings from distribution system improvements since more than 50% of existing homes have ducted systems. In an attempt to improve distribution system efficiencies, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has undertaken a large research effort to issue Standard 152P, which addresses measurement techniques for determining the efficiency of distribution systems in unconditioned and conditioned spaces.

Presently, the standard addresses forced-air distribution systems (heating and cooling) and hydronic heating systems but (with one limited exception) no cooling. However, one of the next steps in the process is to begin incorporating sections into the standard that can address a broad range of hydronic cooling systems. One of the intended purposes of this field test is to incorporate the results into the ASHRAE Standard 152P writing process. The study is also expected to provide information on the space conditioning equipment/hydronic distribution system energy performance and comfort control to establish a baseline performance and determine areas for future research.

Delivery effectiveness and distribution efficiency were measured to compare the performance of the hydronic distri-bution system to other types of conventional distribution systems. The measured delivery effectiveness values from the field test varied from 81.4% to 92.2% over the range of outdoor temperatures. The distribution efficiency, which includes thermal regain from the distribution losses,
varied from 87.5% to 92.5%, meaning that only 12.5% to 7.5% of the cooling effect that left the space conditioning equipment failed to reach the conditioned space. Measurements for indoor temperature and relative humidity (RH) were also made during the testing to determine the ability of the hydronic system to maintain adequate comfort levels. The results showed that the indoor relative humidity was controlled within a range of 46%-52% RH, while the outdoor relative humidity varied from 25% RH to 100% RH. The study also showed that the indoor temperature/relative humidity combinations were well within the limits of comfort as specified by ASHRAE.

CONCLUSIONS OF ANNEX 25

After 3 years, the annex 25 is now achieved. The results from the different countries participating reveal a great variety, as the situation and the needs are rather different depending on the culture, the climate and the energy politics.

Nevertheless, the same conclusions are brought out from the different contributions:

- the feasibility in residential of such new or improved heat pump systems has been proved; the measurements have confirmed the economical competitiveness of such heat pump solutions compared to conventional heating systems ;
- they enable to reach high performance for both space heating and hot water which represents a considerable amount of energy savings and a great reduction of the impact on global warming,
- finally, the comfort is clearly improved with such systems compared to other conventional heating solutions, especially in summer with limited extra consumptions.

EXECUTIVE SUMMARY FOR THE INTERNATIONAL ENERGY AGENCY

ON ANNEX 25
"Year-round residential space conditioning systems using heat pumps"

Task 1: State of the art study

Participating countries :
France : EDF R&D Division (operating agent)
Netherlands : Novem, TNO
Sweden : Royal Institude of Technology
USA : Oak Ridge National Laboratory
Canada : Ontario Hydro Technologies

Operating agent :
Electricité de France R&D Division (France)
Béatrice Escarnot
Phone: +33.1.60.73.63.75
e-mail: beatrice.escarnot@edf.fr

AIE - Programme Pompe à chaleur / Annexe 25

« Year-round residential space conditioning systems using heat pumps »

Résumé de la tâche 1 : Etat de l'art

SYNTHESE

PARTICIPANTS

- **Canada** : Ontario Hydro Technologies, R and D division[1]
- **France** : EDF, division R et D
- **The Netherlands** : Novem (Netherlands Agency for Energy and the Environment), Building Department
- **Suède** : RIT (Royal Institute of Technology), Dept. Of Energy Technology
- **US** : ORNL (Oak Ridge National Laboratory), Building Technology Center

OBJECTIFS DE L'ANNEXE

Tâche 1: Etat de l'art
Analyse des systèmes existants dans l'habitat individuel
Attentes du marché en matière de chauffage et de rafraîchissement en résidentiel
Définition de nouveaux concepts de système de chauffage et de rafraîchissement

Tâche 2: Coopération avec les constructeurs[2]
Communication avec des constructeurs nationaux
Développement d'un prototype
Préparation d'une opération d'expérimentation

Tâche 3: Expérimentation and communication
Suivis de sites
Communication

PRINCIPAUX RÉSULTATS

Cette note présente les résumés des travaux de la tâche 1 de l'annexe.

PERSPECTIVES

Les tâches 2 et 3 sont déjà partiellement engagées et consisteront essentiellement en retours d'expérience sur sites ; leur contenu reste cependant à préciser et à valider.

[1] Ontario Hydro ne participe plus à l'annexe 25 suite à la dérégulation du marché et à des restructurations des entreprises d'électricité ; la R et D sera à terme externalisée et les pompes à chaleur ne font plus partie de son programme.

[2] Cette phase sera très variable d'un pays à l'autre et, dans certains cas, pourra même être éludée si le système a déjà été développé par ailleurs.

ANNEX 25 : "Year-round residential space conditioning systems using heat pumps"

TASK 1 EXECUTIVE SUMMARIES

1. Annex objectives

The objective of this Annex 25 is to define and show the technical feasibility of new packaged systems for year round residential space conditioning using heat pumps. These systems (which include all the components used in a heating / cooling system from the heat pump to the inside unit) will target mainly new residential dwellings and will use either water or air as energy distribution vector. The work carried out within the framework of this Annex will cover low initial and operating costs, comfort provided, suitability to customer demands, design / installation requirements, performances, integration in buildings and aesthetics.

2. Programme

To reach the annex objectives, the following program has been performed :

Task 1: State of the art study
Analysis of existing systems individual dwellings
Market needs and demands on heating/cooling system for residential dwellings
Definition of new concepts of heating/cooling system

Task 2: Co-operation with manufacturers
Communication with national manufacturers
Prototype system development
Preparation of demonstration project

Task 3: Demonstration and dissemination
On site field tests
Dissemination

The first task is achieved and this document presents each participant's executive summary of their contribution to the task 1.

EXECUTIVE SUMMARY FOR THE INTERNATIONAL ENERGY AGENCY

ON ANNEX 25
"Year-round residential space conditioning systems using heat pumps"

Task 1: State of the art study in Canada

Authors:

W.R. Ruhnke (Ontario Power Technologies, Energy Consultancy Dept.)
C.E. Keyes (Ontario Power Technologies, Energy Consultancy Dept.)

IEA ANNEX 25 STRATEGIC SPACE HEATING SYSTEMS CANADA

OPT Report: 7173-1998-RA-001-R00

December 31, 1999

for
International Energy Agency

W.R. Ruhnke
Project Leader

And

C.E. Keyes
Senior Research Engineer

Energy Consultancy Department

Ontario Power Technologies, 800 Kipling Avenue, Toronto, Ontario, Canada M8Z 6C4

IEA ANNEX 25 STRATEGIC SPACE HEATING SYSTEMS CANADA

OPT Report: 7173 -1998-RA-001-R00

December 31, 1999

for:
International Energy Agency

Prepared by:

W.R. Ruhnke
Project Leader
Energy Consultancy Dept.

C.E. Keyes
Senior Research Engineer
Energy Consultancy Dept.

Peer Review by:

C. McGugan
Senior Research Engineer
Energy Consultancy Dept.

Approved by

J.T. Strack
Acting Manager
Energy Consultancy Dept.

Date: December 23, 1999.

DISCLAIMER

IEA ANNEX 25 STRATEGIC SPACE HEATING SYSTEMS

CANADA

W.R. Ruhnke
Project Leader

and

C.E. Keyes
Senior Research Engineer

Energy Consultancy Dept.

SUMMARY

Ductless heat pumps (also known as mini-split systems) function the same as any other heat pump, except that there is no heating or cooling energy loss in the house's ductwork which sometimes traverses unheated spaces. Ductless systems offer energy savings of as much as 50% over existing electric baseboard-heated homes. The equipment consists of an outside unit, which acts as the condenser in the cooling mode or the evaporator in the heating mode. The indoor unit acts as the evaporator in the cooling mode or the condenser the heating mode and can be located on any nearby wall or ceiling. Tubing connects the two units, with the transport medium between the two units being refrigerant or water. Sometimes a number of indoor units are connected to one outdoor unit. This gives the occupants the ability to "zone" different parts of the dwelling.

There are about 3.5 million electric baseboard-heated (ductless) homes in Canada. The convenience of a single appliance that delivers both heating and cooling appeals to a growing segment of builders and homeowners. Ductless heat pumps are ideal for new and retrofit housing and small commercial markets. The target market includes new homes, replacement of older HVAC systems, smaller houses (~93 m^2), remote rooms in large houses, or houses that have an open floor plan. In addition, owners of electric baseboard heated homes may wish to adopt other heating systems with lower operating costs and/or introduce cooling for total year round comfort conditioning. A difficulty arises because baseboard heated houses have no heat distribution system. In the small commercial market, opportunities for ductless heat pumps exist in motel/hotel complexes and apartment buildings. Even with these advantages, however, many heat pump owners complain about noisy operation and inadequate heating performance.

The objective of this project is to define and show the technical feasibility of single room (ductless) heat pump systems capable of heating and cooling and performing efficiently in cold weather.

Canada has a diverse range of climatic patterns. The mini-split heat pumps reviewed in this study tended to be the air source variety manufactured in the "Pacific Rim" countries.

The cost of electric energy in Canada is still too low to develop a significant market for this equipment. The major incentive for ductless split systems is air conditioning rather than heating capability in Canada. Potentially long vertical piping runs between the indoor and outdoor units could be attractive to apartment owners interested in upgrading their units to air conditioning.

The greatest heating savings occurred when the heat pump was allowed to operate down to its lowest operating point (-8^{o}C for this study). For all climates, simple payback on the incremental cost difference between a split heat pump and equivalent air conditioner was typically less than 2 years. Since most Canadian climates require supplemental heating, operation of the heat pump down to its lowest cut-off point may not be practical, however.

The report identifies a need for an integrated thermostat to control both the existing baseboard heaters and the heat pump to maximise energy savings.

TABLE OF CONTENTS

PAGE

FIGURES

Page

TABLES

Page

To: **International Energy Agency**

IEA ANNEX 25 STRATEGIC SPACE HEATING SYSTEMS CANADA

1 CONCLUSIONS AND RECOMMENDATIONS

Canada has a diverse range of climatic patterns. The mini-split heat pumps reviewed in this study tended to be the air source variety manufactured in the “Pacific Rim” countries. The cost of electric energy in Canada is still too low to develop a significant market for this equipment. The major incentive for ductless split systems is air conditioning rather than heating capability in Canada. Potentially long vertical piping runs between the indoor and outdoor units could be attractive to apartment owners interested in upgrading their units to air conditioning. The greatest heating savings occurred when the heat pump was allowed to operate down to its lowest operating point (-8^{o}C for this study). For all climates, simple payback on the incremental cost difference between a split heat pump and equivalent air conditioner was typically less than 2 years. Since most Canadian climates require supplemental heating, operation of the heat pump down to its lowest cut-off point may not be practical, however. The report identifies a need for an integrated thermostat to control both the existing baseboard heaters and the heat pump to maximise energy savings.

2 BACKGROUND (INTRODUCTION)

There are about 3.5 million electric baseboard-heated (ductless) homes in Canada. This number includes both single residences and multiple unit townhouses and apartment buildings (see Table 1 for breakdown by province). Ductless heat pumps are ideal for new and retrofit housing and small commercial markets. The target market includes new homes, replacement of older HVAC systems, smaller houses (~93 m^2) remote rooms in large houses, or houses that have an open floor plan. In addition, owners of electric baseboard heated homes may wish to adopt other heating systems with lower operating costs and/or introduce cooling for total year round comfort conditioning. A difficulty arises because baseboard heated houses have no heat distribution system. In the small commercial market, opportunities for ductless heat pumps exist in motel/hotel complexes and apartment buildings. Even with these advantages, however, many heat pump owners complain about noisy operation and inadequate heating.

Table 1: Summary of the Canadian Market for Electric Resistance Heaters (Ref. 4)[1]

Utility	Electric Resistance Households
Newfoundland	99,000
Prince Edward Island	--
Nova Scotia	84,000
New Brunswick	154,000
Québec	2,030,000
Ontario	646,000
Manitoba	93,000
Saskatchewan	10,000
Alberta	--
British Columbia	385,000
Total	**3,501,000**

3 PROCESS

The objective of this portion of the project is to define and show the technical feasibility of single room (ductless) heat pump systems capable of heating and cooling and performing efficiently in cold weather.

4 RESULTS

4.1 Review of World Ductless Heat Pump Technologies

Heat pumps suitable for cold climates can be divided into three types based on energy source in the heating mode:

- geothermal,
- air source, and
- bivalent.

Geothermal heat pumps require excavation or drilling to install the ground coupled thermal loop. It has the advantage of providing a stable COP almost independent of external climatic conditions. The disadvantage is high installation cost, which makes these units uneconomical in countries with relatively low energy prices. Although a prototype direct expansion ductless heating only system was developed and tested by Ontario Hydro, commercialized units incorporating air conditioning were not found in the literature search.

Air source heat pumps can be made to operate in cold climates. However, the COP declines in proportion to outdoor temperature. The backup heating system (usually

1 Includes permanently installed baseboard electric heating as well as other types such as floor or ceiling heating wires, in all or most rooms

resistance) takes over when the heat pump can no longer act as the primary heat source.

Bivalent heat pumps introduce a fossil fuel heat source at the outdoor unit to boost the COP at low ambient temperatures and to provide the deicing function at higher source temperatures eliminating the need for a reversing valve. The main disadvantage of the bivalent heat pump is the need to supply a natural gas line to the outdoor unit or where natural gas is unavailable, providing a storage tank of propane.

Due to availability, electric rather than gas driven heat pumps were the only type considered in this report.

4.1.1 The Nordic Heat Pump Competition

NUTEK[2] promoted a Nordic heat pump competition during 1993 – 1996 (Ref. 1) to target a new type of heat pump that would be smaller and less expensive than existing models. Several companies rose to the challenge. Eventually two were selected as finalists. Of the two finalists, one was well suited for homes with electric baseboard heating. The company, Eufor, produced a direct expansion ground-source heat pump, using two condensers to achieve high COPs. The heat pump came with a hermetically sealed system. The indoor unit contains a rotary piston compressor (R407C), air- and water-cooled sub-cooler/condensers, expansion vessel, safety equipment and a sophisticated control/diagnostics unit. The fan-coil was located in the entrance-hall, depending on convection to heat other rooms in the house (necessitating that doors be left open). The installed cost of the equipment including taxes was about $4,700 (US). Estimated annual savings were 8900 kWh. The absence of air conditioning makes the device unsuitable for most Canadian markets.

4.1.2 Ontario Hydro’s Heat Saver

Ontario Hydro designed, fabricated and installed a mini split heat pump in a motel as a trial (Ref. 2). The project involved the installation of six ground-to-water (direct expansion) heat pumps connected to sixteen water-to-air fan coils. Each outdoor heat pump connected to either two or three fan-coils (one fan-coil) to a room. Based on an audit of the site, it was estimated that approximately 40% of the building’s heat loss was displaced by the ground-source systems. So far, this design has not been commercialized and was built as a heating only unit.

2 NUTEK – The Swedish National Board for Technical Development

4.1.3 Ductless Mini Split Air Source Heat Pump

Companies, producing this product, are concentrated in the “Pacific Rim” countries which have a large domestic market already established as indicated in Figure 1. Japan has the largest market for ductless heat pumps. It is often thought of as a warm country but in reality there is a vast difference in the local climates of this string of islands that runs North to South. Many parts of Japan have seasons similar to parts of Canada. Japanese homes were traditionally heated with a centrally placed heater (typically kerosene in modern times). The introduction of the mini-split heat pump was welcomed as it lowered heating costs, required little space (a prerequisite in Japanese homes) and improved comfort levels. To satisfy the local market and branch out to the export market, mini split heat pumps have matured as a product. Heating COP has increased significantly in recent years to models ranging between 3.5 and 5.0[3]. There is a trend to HFC from HCFC refrigerants. However, the cost of HFC (e.g. HFC-410A) tends to be about 20% higher than an equivalent HCFC R22 unit. As well, HFC models require installation work, which use tools and procedures different from those for conventional models. Most of the HFC units are being sold only in the home (Japan) market at this time (Ref. 5).

Multiple split units are popular in Japan, South Korea and China (Ref. 6). This type comprises several indoor units in a building connected to a single outdoor unit. The function of this system has been improved. Enhancements include development of inverter-control methods to regulate performance by varying compressor speed according to thermal load plus the capability of simultaneous cooling and heating functions in a single unit using multiple compressors. The cost of these units remains too high in North America to consider for residential applications at this time.

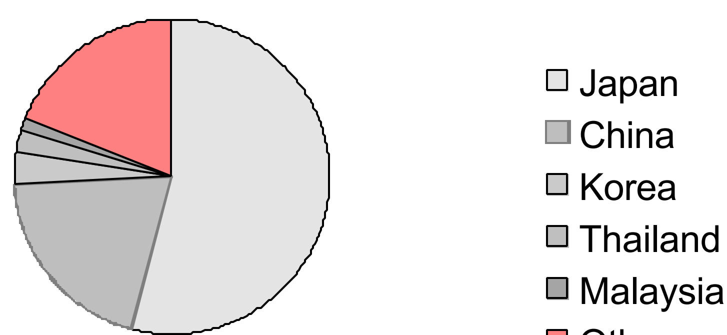


Figure 1: World Production of Ductless Heat Pumps (Ref.7)

3 COP measured at 8.3°C DB

For a “typical” 93 m^2 (1000 ft^2) home, insulated for electric heating, a 1-ton size ductless heat pump was recommended for the Toronto area. This size of heat pump would provide sufficient cooling in the summer months and also displace a proportion of the heating load in the shoulder seasons. From the manufacturer’s literature, the closest model was a unit that provided 12,900 BTU/h cooling and 13,500 BTU/h heating.

4.2 Model “Canadian” Single House

The heating requirement for a house is dependent on a number of factors. Insulation levels, size, layout, orientation and location greatly influence seasonal heating requirements. The lifestyle of the occupants also has a significant effect on the total heating requirement. To standardize the results and allow comparison between different Canadian Regions, data from a “typical” single story house located in the Toronto area was extrapolated to other regions. The size of the electrically home was arbitrarily taken as a 93-m^2 (1000-ft^2) bungalow with a net annual heating consumption of approximately 12,000 kWh (Ref. 3). Connected baseboard heaters are assumed to be a total of 12 kW. Additional specifications for this house are shown in Table 3 in the Appendix.

Figure 2 depicts the range of climate normal extremes for four representative Canadian cities including St. John’s, Newfoundland; Toronto, Ontario; Winnipeg, Manitoba; and Victoria, British Columbia. While this does not provide essential degree-day data for a detailed analysis, it serves to illustrate relative climatic differences for the different regions the cities are representative of.

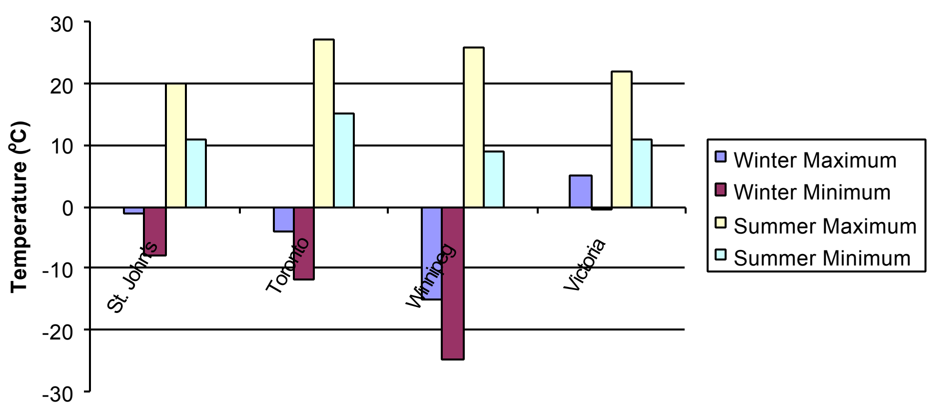


Figure 2: Environment Canada Sample Climate Normals (Averaged 1961-1990)

4.3 Analysis of Heat Pump Retrofit Savings

Table 2 lists typical installed costs for a range of sizes of ductless split air conditioners and heat pumps. The size is expressed in cooling and heating capacities for the sample units. Note that heating capacity (BTU/h) is specified at an outdoor ambient of 8.3 °C.

Table 2: Typical Installed Cost[4]

Size Cooling/Heating kW	Air Conditioning Aprox. Installed Cost ($ US)	Heat Pump Aprox. Installed Cost ($ US)
2.58/3.08	2,000	2,300
3.78/3.96	2,270	3,000
4.28/4.34	2,800	3,270
4.28/5.04	3,000	3,470

Using the model (Table 3) and the simulation program '**HOT*2000*®**' (Ref. 8), energy savings were calculated for two installed heat pump packages plus Coefficient of Performance of 3.5 and 5.0. The higher COP of 5.0 is for HFC units announced recently in Japan but not available yet in North America. The resultant energy savings are depicted in detail in Table 4 and Table 7. Based on these results, simple paybacks based on energy savings alone for representative Canadian cities in Table 5 and Table 7.

4.4 Retrofit Alternatives

Baseboard homes can be retrofitted to forced air. Conventional ductwork can be installed for between $1,700 (US) and $3,400 (US) depending on whether the home is single or multistory. In addition to being disruptive, basements of baseboard heated homes often lack sufficient headroom to accommodate suspended ductwork. Another alternative is small diameter high-velocity ductwork. The cost of this equipment is high (~ $4,300 to $5,000 (US) installed) plus the noise may be objectionable to the occupants particularly if care is not exercised in the installation.

For comparison, paybacks for oil and natural gas retrofits are depicted in Figure 3 for selected Canadian cities. Assumptions for these comparisons are as follows:

- Sized heat pump for optimum savings (3 kW rather than 4kW size) versus forced air gas and oil (where available).
- Fuel prices have been simplified to one value for each type (oil and gas include seasonal efficiency in price) – actual prices fluctuate and can vary from one region to another.
- The cost of a medium efficiency or oil furnace with $2,000 (US) for ductwork plus heating equipment for a total of $3,800 for oil, $3,500 for gas and $2,300 for the 3 kW ductless heat pump.

4 Information supplied by Ontario Based Heat Pump Contractor, March12, 1999

- Pay back in years equal to the retrofit cost divided by the difference in annual heating cost.
- Assumed AFUE efficiencies for gas 80%, and for oil 79%.

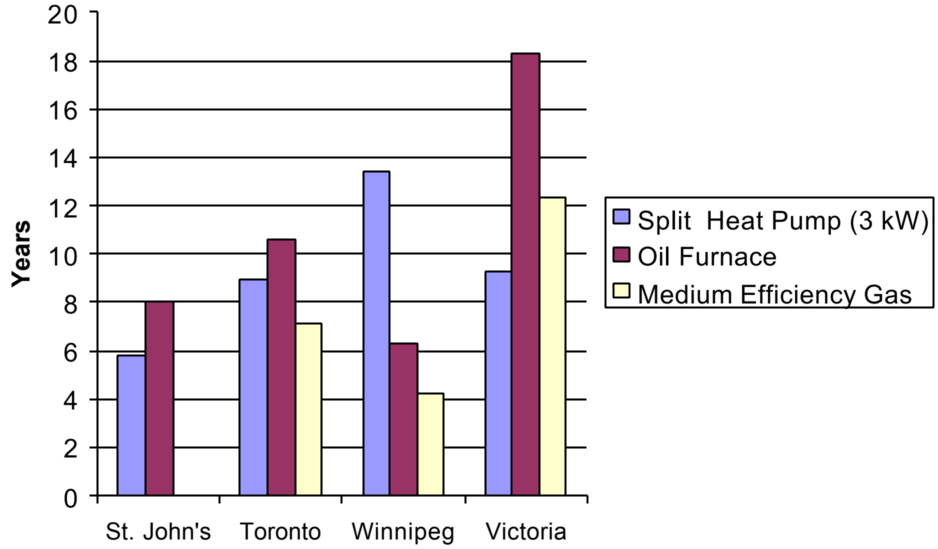


Figure 3: Simple Payback Comparison to Other Fuel Options[5] (Base Case is Electric Resistance Heating)

4.5 The Need for Better Controls in Retrofit Installations

Retrofitting baseboard heated homes in Northern climates with split ductless heat pumps normally requires supplementary heat when the outdoor ambient temperature drops below the balance point of the heat pump. Split heat pumps often incorporate some built-in resistance heating. However, this supplemental heat is intended for intermittent use (i.e. to quickly warm up a room whose temperature was set back). Therefore, the original baseboard heaters usually need to be retained. This often leads to several potential problems. Original electric baseboard thermostats were typically line voltage controls mounted on the individual baseboard heaters or wall mounted. Baseboard-mounted controls are poor at maintaining room temperatures. Cyclic swings of 4^{o} C or more are not uncommon with this type of control since the temperature sensor is too close to the heat source. Wall mounted line voltage thermostats are an improvement. To successfully displace resistance heating using heat pumps, integrated temperature controls are needed which control both the heat pump and the resistance baseboard heaters. OPT is unaware of any product for this application.

5 Assume Electricity $0.06/kWh (US), oil $0.028/kWh (US) and gas $0.0164/kWh (US)
Also assume AFUE efficiencies for gas 80%, and for oil 79%

REFERENCES

1. Per Fahlen ***Cost-Effective Heat Pumps for Nordic Countries***, Swedish National Testing and Research Institute Inc.) Boras, Sweden- Proceedings of Heat Pumps in Cold Climates – Third International Technical Conference August 11-12, 1997 at Acadia University, Wolfville, Nova Scotia, Canada Published November 1997 by Caneta Research Inc., 7145 West Credit Avenue, Suite 102, Building 2, Mississauga, Ontario, Canada L5N 6J7.

2. Lenarduzzi, F.J. ***Monitored Results From the Installation of Six Room-Size Ground-Source Heat Pumps,*** Ontario Hydro Technologies Report No. 3671-010-1997-RA-001-R00***,*** January 23, 1998.

3. ***The Energy Efficiency Potential of the Existing Electrically Heated Housing Stock in Ontario***, Ontario Hydro EnerMark Report, June 1990.

4. Statistics Canada, Household Facilities and Equipment 1997 cat. no. 64-202-XPB, Table 2.1

5. JARN - Japan Air Conditioning, Heating & Refrigeration News, October 25, 1998, Serial No. 357 Volume 30, No. 10, Page 13.

6. Nishimura, Takao*, Regional Reports: "Heat Pumps – Status and Trends" in Asia and the Pacific,* 6th International Energy Agency Heat Pump Conference 1999, May 31-June 2, 1999, Berlin, Germany.

7. JARN - Japan Air Conditioning, Heating & Refrigeration News, November 25, 1998, Serial No. 358-S, Page 25.

8. HOT*2000*® Version 7.10 software program "a comprehensive tool for the design of energy efficient homes and buildings" developed by CANMET/EAETB, Natural Resources Canada, 1995.

9. Energy Statistics Handbook, Statistics Canada / Natural Resources Canada, Ottawa Nov., 1993.

Appendix

Heat Pump Simulation for Energy Savings

"**HOT*2000*^â^**", a software program developed by Natural Resources Canada, was used to simulate a "typical" 1000 ft^2 bungalow. The bungalow was designed for an annual space-heating requirement of 11,000 kWh for Toronto, Ontario that is typical for buildings of similar dimensions and insulation standards. These settings were locked in and weather data for other regions of Canada were substituted for the Toronto data. Arguably, building insulation standards will vary for colder or warmer regions or may not be up to the standards selected for this base case. By keeping these parameters constant, the effect of climate on heat pump performance can be more easily compared.

Two mini-split heat pumps designed to provide cooling and some heating were added to estimate annual energy savings. The heat pumps selected were capable of operation down to -8^{o}C. However, many temperature control schemes only allow one heating system to operate at a time. When the heat pump is no longer able to meet the heating requirements of the home, it is shut down in favor of the baseboard heaters. This cut – off is referred to as the balance point. In other systems, the heat pump works in tandem with the back-up heating system but is arbitrarily shut down at 0^{o}C. All three cut-off points are listed in the table.

The incremental cost of a ductless heat pump over a comparable air conditioner would shorten the simple payback based on net energy savings. However, the sites with the highest potential energy savings would be unlikely to require air conditioning so the heat pump would need to be cost justified on its own merits. Based on the costs listed in Table 2, simple payback based on energy savings only for both total system cost and incremental cost are summarized in Table 5 and Table 7 for COP's of 3.5 and 5. Maintenance is not included in this estimate. Based on previous experience with similar products, the attractiveness of a homeowner product tends to diminish as simple payback exceeds 5 years. An energy cost including taxes of $0.06/kWh (US) was selected for comparison purposes. Jurisdictions with higher or lower energy costs would see shorter or longer paybacks accordingly.

Table 3: “Model” House Specification

House Type	Single Detached
Number of Story’s	One
Wall Construction	Platform Frame, single stud wall
Plan shape	Square / facing south
House Thermal Mass	Wood Frame Construction, gyproc walls and ceiling, wooden floor
Ceiling Insulation	R-value RSI 4.9
Wall Insulation	R-value RSI 1.92 (average)
Basement Wall Insulation	R-value RSI 1.54
Soil Type	Normal Conductivity, dry sand, loam, clay, low water table
Occupants	2 Adults – 50% time 2 Children – 50% time
House Volume	473 m^3
Heating Requirement	21^{o}C
Cooling Requirement	25^{o}C
Design Heat Loss at –17.2^{o}C (Toronto)	13.49 W/m^3 = 6379 W

Table 4: Annual Energy Savings – COP 3.5

Location	Baseboard Only Total Heating Load kWh	Net Annual Savings kWh					
		Heat Pump 1 (3 kW @ 8°C)			Heat Pump 2 (4 kW @ 8°C)		
		-8°C Cut-off	Balance Point	0°C Cut-off	-8°C Cut-off	Balance Point	0°C Cut-off
Saint John's, Newfoundland	14,827	6,658	3,945	3,800	7,267	5,358	3,916
Charlottetown, PEI	13,658	4,886	2,832	2,592	5,346	3,853	2,606
Halifax, Nova Scotia	12,623	5,150	2,848	2,487	5,676	3,908	2,562
St. John, New Brunswick	13,258	4,820	2,956	2,610	5,235	3,911	2,688
Montreal, Québec	13,888	3,997	2,255	2,171	4,398	3,911	2,189
Ottawa, Ontario	13,400	3,746	2,191	1,801	4,108	2,849	1,880
Toronto, Ontario	11,206	4.372	2,531	2,179	4,782	3,230	2,188
Thunder Bay, Ontario	16,214	3,775	2,196	1,801	4,100	2,868	1,816
Winnipeg, Manitoba	18,872	2,910	1,676	1,428	3,199	2,142	1,438
Prince Albert, Saskatchewan	20,154	2,954	2,196	1,571	3,227	2,868	1,589
Edmonton, Alberta	17751	3,395	2,226	1,914	3,877	2,828	1,934
Victoria, British Columbia	6,493	4,179	3,569	3,273	4,203	3,818	3,305

Table 5: Simple Pay-Back (Years) Heat Pump COP 3.5

Location	Heat Pump 1 (3 kW @ 8°C)						Heat Pump 2 (4 kW @ 8°C)					
	-8°C Cut-off		Balance Point		0°C Cut-off		-8°C Cut-off		Balance Point		0°C Cut-off	
	full[6]	D[7]	full	D	full	D	full[6]	D[7]	full	D	full	D
Saint John's, Newfoundland	5.8	0.8	9.9	1.4	10.2	1.5	5.4	1.7	7.3	2.3	9.9	3.1
Charlottetown, PEI	8.0	1.1	13.7	2.0	15.0	2.1	7.3	2.3	10.1	3.2	14.9	4.7
Halifax, Nova Scotia	7.6	1.1	13.7	2.0	15.6	2.2	6.9	2.2	10.0	3.1	15.2	4.8
St. John, New Brunswick	8.1	1.2	13.2	1.9	14.9	2.1	7.4	2.3	9.9	3.1	14.5	4.5
Montreal, Québec	9.7	1.4	17.2	2.5	17.9	2.6	8.8	2.8	9.9	3.1	17.8	5.6
Ottawa, Ontario	10.4	1.5	17.7	2.5	21.6	3.1	9.5	3.0	13.7	4.3	20.7	6.5
Toronto, Ontario	8.9	1.3	15.4	2.2	17.8	2.5	8.1	2.6	12.0	3.8	17.8	5.6
Thunder Bay, Ontario	10.3	1.5	17.7	2.5	21.6	3.1	9.5	3.0	13.6	4.3	21.4	6.7
Winnipeg, Manitoba	13.4	1.9	23.2	3.3	27.2	3.9	12.2	3.8	18.2	5.7	27.0	8.5
Prince Albert, Saskatchewan	13.2	1.9	17.7	2.5	24.8	3.5	12.1	3.8	13.6	4.3	24.5	7.7
Edmonton, Alberta	11.5	1.6	17.5	2.5	20.3	2.9	10.0	3.2	13.8	4.3	20.1	6.3
Victoria, British Columbia	9.3	1.3	10.9	1.6	11.9	1.7	9.3	2.9	10.2	3.2	11.8	3.7

6 Payback based on full installed cost divided by net annual energy savings @ $0.06/kWh (US)
7 Payback based on cost differential of heat pump vs. air conditioner divided by net annual energy savings @ $0.06/kWh (US)

Table 6: Annual Energy Savings Heat Pump COP 5.0

Location	Baseboard Only Total Heating Load kWh	Net Annual Savings kWh					
		Heat Pump 1 (3 kW @ 8°C)			Heat Pump 2 (4 kW @ 8°C)		
		-8°C Cut-off	Balance Point	0°C Cut-off	-8°C Cut-off	Balance Point	0°C Cut-off
Saint John's, Newfoundland	14,827	7,934	4,378	4,706	8,339	5,994	4,718
Charlottetown, PEI	13,658	5,835	3,086	3,145	6,414	4,416	3,139
Halifax, Nova Scotia	12,623	6,150	3,113	3,095	6,814	4,332	3,093
St. John, New Brunswick	13,258	5,774	3,387	3,262	6,295	4,438	3,242
Montreal, Québec	13,888	4,770	2,453	1,632	5,268	3,444	2,637
Ottawa, Ontario	13,400	4,485	2,457	2,273	4,943	3,236	2,269
Toronto, Ontario	11,206	5,024	2,751	2,655	5,519	3,698	2,643
Thunder Bay, Ontario	16,214	4,340	2,484	2,216	4,497	3,249	2,217
Winnipeg, Manitoba	18,872	3,529	1,917	1,758	3,889	2,546	17,752
Prince Albert, Saskatchewan	20,154	3,601	2,041	1,946	3,939	2,662	1,950
Edmonton, Alberta	17751	4,121	2,509	2,427	4,468	3,203	2,378
Victoria, British Columbia	6,493	4,763	4,262	4,402	4,811	4,637	4,055

Table 7: Simple Pay-Back (Years) Heat Pump COP 5.0

Location	Heat Pump 1 (3 kW @ 8°C)						Heat Pump 2 (4 kW @ 8°C)					
	-8°C Cut-off		Balance Point		0°C Cut-off		-8°C Cut-off		Balance Point		0°C Cut-off	
	full[8]	D[9]	full	D	full	D	full[8]	D[9]	full	D	full	D
Saint John's, Newfoundland	5.9	0.8	10.7	1.5	9.9	1.4	5.6	0.8	7.8	1.1	9.9	1.4
Charlottetown, PEI	8.0	1.1	15.1	2.2	14.8	2.1	7.3	1.0	10.6	1.5	14.9	2.1
Halifax, Nova Scotia	7.6	1.1	15.0	2.1	15.1	2.2	6.8	1.0	10.8	1.5	15.1	2.2
St. John, New Brunswick	8.1	1.2	13.8	2.0	14.3	2.0	7.4	1.1	10.5	1.5	14.4	2.1
Montreal, Québec	9.8	1.4	19.0	2.7	28.6	4.1	8.9	1.3	13.6	1.9	17.7	2.5
Ottawa, Ontario	10.4	1.5	19.0	2.7	20.5	2.9	9.4	1.3	14.4	2.1	20.6	2.9
Toronto, Ontario	9.3	1.3	17.0	2.4	17.6	2.5	8.5	1.2	12.6	1.8	17.7	2.5
Thunder Bay, Ontario	10.8	1.5	18.8	2.7	21.1	3.0	10.4	1.5	14.4	2.1	21.0	3.0
Winnipeg, Manitoba	13.2	1.9	24.3	3.5	26.5	3.8	12.0	1.7	18.3	2.6	2.6	0.4
Prince Albert, Saskatchewan	13.0	1.9	22.9	3.3	24.0	3.4	11.8	1.7	17.5	2.5	23.9	3.4
Edmonton, Alberta	11.3	1.6	18.6	2.7	19.2	2.7	10.4	1.5	14.6	2.1	19.6	2.8
Victoria, British Columbia	9.8	1.4	10.9	1.6	10.6	1.5	9.7	1.4	10.1	1.4	11.5	1.6

8 Payback based on full installed cost divided by net annual energy savings @ $0.06/kWh (US)
9 Payback based on cost differential of heat pump vs. air conditioner divided by net annual energy savings @ $0.06/kWh (US)

Table 8: Residential Energy Prices $/kWh Energy Equivalent (Ref. 9)

Province	Nfld.	PEI	NS	NB	Qué.	Ont.	Man.	Sask.	Alta.	BC
Electricity	**0.050**	**0.0761**	**0.0590**	**0.0420**	**0.0429**	**0.0633**	**0.0363**	**0.0497**	**0.0475**	**0.0449**
Natural Gas	-	-	-	-	**0.0190**	**0.0139**	**0.0140**	**0.0109**	**0.0085**	**0.0127**
Oil	**0.0248**	**0.0221**	**0.0224**	**0.0238**	**0.0231**	**0.0233**	**0.0262**	**0.0223**	-	**0.0255**
Electricity Price Ratio (assuming standard heating efficiency) to:										
Natural Gas	-	-	-	-	**1.81**	**3.65**	**2.08**	**3.66**	**4.49**	**2.83**
Oil	**1.59**	**2.72**	**2.08**	**2.89**	**1.47**	**2.15**	**1.10**	**1.76**	-	**1.39**

<u>Notes:</u>

Prices include Federal and Provincial taxes where applicable. Residential electricity price approximations for monthly bills of 2500 kWh.

Fuel Prices assume higher heating values of 10.4 kWh/m3 for natural gas and 10.85 kWh/l for heating oil.

Fuel price ratios assume 80% AFUE for natural gas furnaces and 79% AFUE for oil furnaces.

Prices expressed in equivalent US dollars (1.5 Canadian Dollars = 1 US Dollar).

EXECUTIVE SUMMARY FOR THE INTERNATIONAL ENERGY AGENCY

ON ANNEX 25
"Year-round residential space conditioning systems using heat pumps"

Task 1: State of the art study in France

Authors:

Fabrice Beck (EDF R&D Division)
Philippe Auffret (EDF R&D Division)
Daniel Gautier (EDF R&D Division)
Pascal Girault (EDF R&D Division)
Gilles Guyon (EDF R&D Division)

Co-ordination work:

Fabrice Beck (EDF R&D Division)

EXECUTIVE SUMMARY

1. Introduction

- **Objective**

The objective of Annex 25 is to define and show the technical feasibility of new packaged systems for year-round residential space conditioning using heat pumps. These systems (which include all the components used in a heating / cooling system from the heat pump to the inside unit) target mainly new residential dwellings and use either water or air as energy distribution vector. The work carried out within the framework of this Annex covers low initial and operating costs, comfort provided, suitability to customer demands, design / installation requirements, performances, integration in buildings and aesthetics.

This report is the French contribution, written by the EDF R&D Division, to the first task of this Annex 25 (Task 1 "State of the art study").

- **French background**

Up to the late 90's, the French heating market has been mainly dominated by direct electric heating (electric static heaters or electric radiant panels), which equip 42% of new residential dwellings. Moreover, very few dwellings (less than 2%) are equipped with air conditioning.

But in response to customer dissatisfaction with electric heating (high operating costs or low comfort because of poorly insulated buildings), EDF decided to launch new commercial offers based on:

- effective building insulation,
- high-quality products (convectors, electric floor heating and reversible heat pumps),
- appropriate control systems,
- and services to customers.

Among the different heating / cooling systems available on the market, four main types were identified to be part and parcel of the EDF offers:

- split system
- heat pump + air system
- heat pump + floor heating and cooling system
- heat pump + fan coil unit

This report focuses only on the last two hydronic systems (i.e. **floor heating and cooling system, and fan coil unit**).

2. Analysis of existing hydronic systems

2.1 Heat pump + Floor heating and cooling systems

Control strategies and safety devices in the cooling mode:

For most manufacturers, the inlet water temperature is the only set point with a number of different control variants:

- **Constant inlet temperature:** this minimalist solution consists in keeping a constant inlet water temperature whatever the outside temperature. The level is high enough to prevent condensation, but the cooling capacity is lowered.

- **Floor covering limit temperature**: This method takes into account the floor covering temperature in order to set the inlet temperature so that condensation is prevented.

- **Dew point temperature:** inside temperature and relative humidity are measured and the dew point calculated in order to set the inlet temperature so that condensation is prevented.

- **Outside temperature:** the inlet temperature is set according to the outside temperature, which can be risky because humidity is not taken into account.

To avoid condensation on or under the floor covering, different safety devices are proposed by manufacturers:

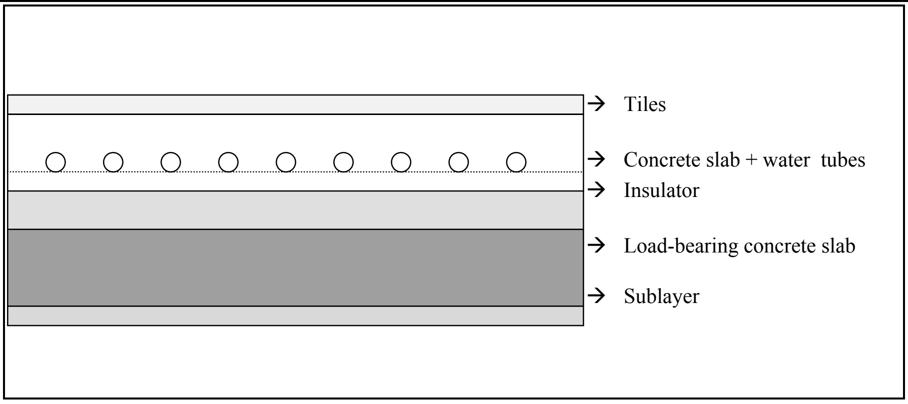
- **In specific rooms with high relative humidity (bathroom, kitchen):** a valve automatically cuts off the water circulation in these rooms when the inlet temperature falls below 20°C (for instance). For higher temperatures it is completely open.

- **Humidity sensor on synthetic tubes:** if condensation occurs on the tubes, it is detected and cooled water production and circulation are slowed down by means of 3-way valves.

Modelling and validation of the floor heating/cooling system

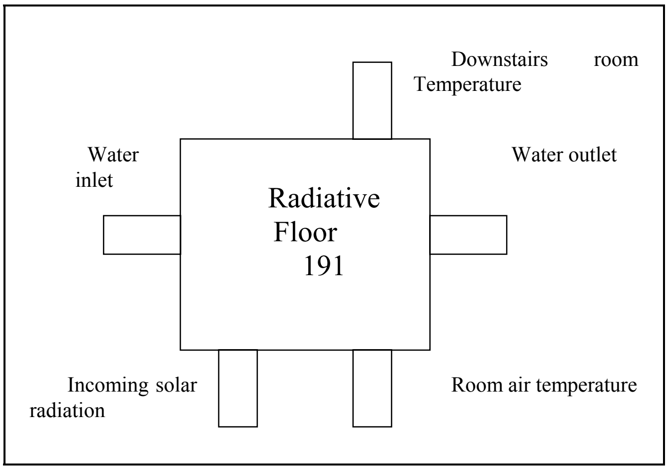
- **Modelling with CLIM 2000**

The EDF R&D division has several building energy analysis tools allowing end-users to study a building with its heating, cooling and ventilating systems and to predict energy consumption. A specific model has been developed in the CLIM2000 environment to represent a radiative floor. This kind of system is dedicated to room heating or cooling. The constituent elements of such a radiative floor are as described in the next figure.



Radiative floor structure

Graphically, the model developed in CLIM2000 has the following graphic appearance.



Formal Type representing the radiative floor.

The main assumptions made during the development of this elementary model are the following:

- the maximum number of layers constituting the floor is limited to 5,
- the analogue model implemented here is derived from a detailed 2D model with a large number of elements. All elements (resistances, conductances and capacitances) have been identified to ensure the same steady-state results,
- the governing equations of heat transfer taking place in water tubes are similar to those used in a heat exchanger,
- the surface coefficients are non-linear and their expressions are adjustable to take account of the two different operating modes: heating and cooling,
- the incoming solar radiation is totally absorbed by the floor. The model does not take into account the first reflection of incoming solar radiation,
- thermal bridges are not taken into account.

- **Model validation**

In 1990, the EDF R&D Division acquired a thermal and aeraulic test laboratory which consists of two semi-detached cells set adjacent to each other and built in accordance with the 1989 French building thermal regulations. This laboratory is called « ETNA » (Essais Thermiques en climat Naturel et Artificiel). The modular configuration of one of the surrounding heat seals means that it can be used for tests performed under natural or artificial climatic conditions.

Picture of the « ETNA » laboratory

During the summer of 1997, a specific experiment in natural climate was carried out to test the efficiency of the radiative floor in real conditions. To this end, one cell was in free floating conditions, i.e. the radiative floor was not in operation, and the radiative floor in the other cell was in operation. The main objectives of this experiment were :

- to evaluate the temperature decrease resulting from the operation of the radiative floor,
- to evaluate the condensation risk on the floor surface,
- to quantify the capacity of the floor to absorb the solar patch,
  to try to improve heat exchange between the air and the floor surface

Each experimental configuration was modelled with CLIM2000. The climate data, guard temperatures, water temperature and water flow measured during the experiment were used as input data.

By comparing the simulations with measurements from two different experimental sequences carried out in ETNA cells, we showed that CLIM2000 and the radiative floor model provide accurate predictions of internal temperature when the room is heated or cooled by a radiative floor. The model can therefore be used in economic studies to predict the energy consumption of such a system and to compare it with other heating and/or cooling systems. The main results of this study are :

- the good behaviour of the CLIM2000 model,
- the radiative floor in cooling mode substantially reduces internal room temperature (2°C), with some peaks of 4°C during sunny days,
- by adding a ventilator inside the room, the efficiency of the radiative floor in cooling mode is improved by 25%.

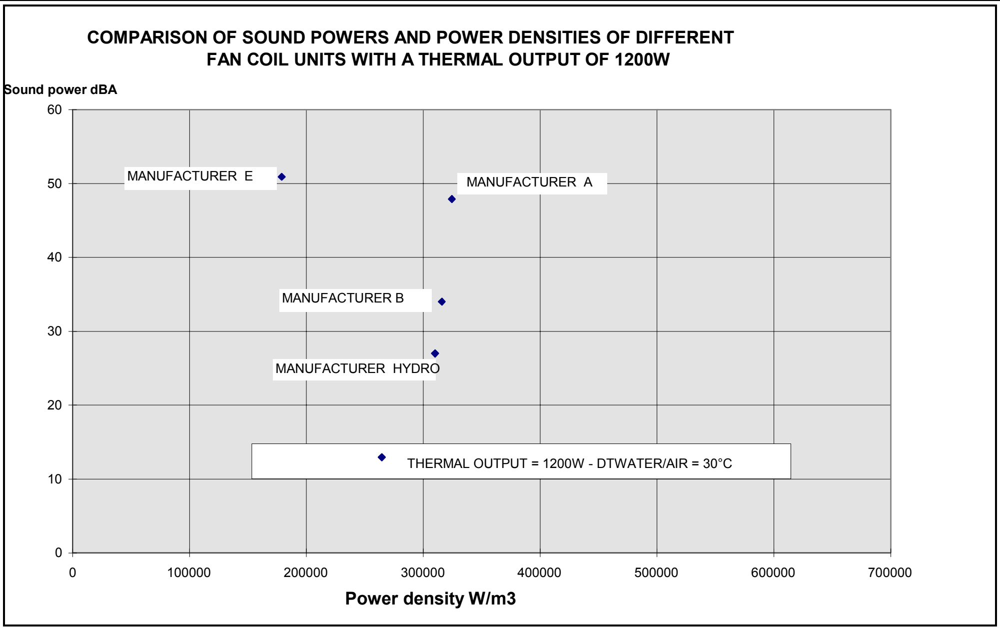
2.2 Performance analysis of a sample of fan coil units representative of the French market

The acoustic tests were performed on the Clamart site of the EDF R&D Division, in an anechoic chamber equipped with a reflective floor. The sound power of the fan coil units was determined by means of pressure measurements on a surface surrounding the source, in compliance with the recommendations of the standard NF S 31-026 (semi-anechoic chamber). The pressure field was measured at 10 points.

These acoustic measurements enabled us to determine the overall sound power and the power by bands of one-third of an octave, for each appliance and for each speed setting. These power levels can be expressed in dB(lin) or in dB(A) (unit most representative of human auditory perception in this range).

To obtain a more realistic comparison, and taking account of the « integration » factor, i.e., appliance bulk is a parameter of equal importance to that of noise level, we thought it would be useful to present, for an equivalent output, noise levels in terms of sound power as a function of the power density[3] of each unit.

[3] Power Density = Thermal output / heat exchanger volume



Relation between power density and sound power at a fixed output.

The acoustic and air flow tests enabled us to assess the fan coil units available on the French market in 1996 and to classify the different appliances. Unit B obtains the best results in terms of noise, taking account of thermal output. Indeed, its performance is very similar to that of an inside split unit, a technology reputed to be more mature, especially in Japan. We note that unit A is the only tested product intended for the domestic market only. Its good acoustic performance is due mainly to a better match between its thermal performance and the needs of this sector, which are lower than in the commercial sector : 1200 W compared to 1800 W in heating mode.

In this context, we note that two different strategic approaches can be adopted to reduce noise from inside units in the domestic sector :

- Exact unit sizing, with a fan which rotates more slowly at maximum speed. This is the strategy adopted by A, and the strategy we will follow for the prototypes to be studied. However, in this case it is impossible to increase output if the heating needs prove to be greater than expected.

- Unit oversizing, with basic thermal output at low fan speeds. The maximum speed, which is noisier, is used only occasionally, during installation startup etc. However, as high noise levels are of short duration and are followed by rapid effects in terms of thermal comfort, this solution should prove acceptable to users.

2.3 Heat Pump systems initial and operating costs

The main conclusion regarding 1998 initial costs in France are :

- in small houses (100m²) : heat pumps are, on average, -5% cheaper than oil systems and +20% more expensive than gas systems,
- in big houses (165 m²) : heat pumps are more competitive, (-10% compared to oil system and +3% compared to gas system) and they provide summer comfort.

The operating cost of year-round residential comfort is in average no more than 4 USD/m² in Paris, and 2 USD/m² in Marseille, with a total operating cost varying between 13 USD/m² and 9 USD/m². The share of heating consumption is, in the worst case, nearly 30% of the final bill, and cooling consumption 10%.

3. Market needs and demand study

In this part, through the results of various market studies on year-round residential air conditioning (opinion poll, definition of people's expectations, etc.) the most advantageous features to be included in new systems are identified.

3.1 Air conditioning market

A survey of HVAC installers was carried out in 1997 to assess the number of air conditioning (AC) system plants installed in France.

	Number of individual RAC installed
1995	178 000
1996	174 000
1997	164 000
1998	195 000

RAC : Room Air Conditioner

Number of individual Room Air Conditioning system installed in France (95-98)

Out of these 147,000 units installed in France in 1997 :

- almost 26% are for residential dwellings (3% for new dwellings, 22% for existing dwellings), representing only2% of total dwellings
- 52% are reversible

3.2 Yearly opinion survey on Air Conditioning in France

Since 1993 every year in august, EDF asks Ipsos (a polling company) to carry out an opinion survey on AC in France. This survey is undertaken on a representative sample of 1000 persons aged 15 or over. The main objective is to obtain a detailed picture of the public's attitude towards AC in their homes, offices and public spaces.

This opinion survey shows that the main advantage is still the comfort provided, and the main barriers the initial cost, temperature difference between outside and inside, impact on health. There is still a lack of information directed to the final consumer (heating performances, initial and operating costs, sales networks, etc.)

3.3 How to overcome barriers against AC systems from the final residential customer

In order to determine the levers and barriers affecting the decision to purchase an AC system, the EDF Commercial services launched a specific study.The methodology used in this survey was the following :

- **a qualitative step :** inventory of the items which could play a role in the decision to buy or not to buy an AC system (level of nuisances, Air Conditioning benefits, purchase trigger, etc.).

- **a quantitative step :** constitution of a panel to determine the behavior of :
  - AC system owners : 400 persons,
  - AC prospects (potential purchasers of an AC system) : 250 persons,

- non-equipped people : 250 persons

Finally, this quantitative step enables us to express the link between the total French population (100%) and the number of 1998 AC owners (2%).

3.4 People's expectations with respect to new year-round space conditioning systems

In 1996, the EDF R&D Division commissioned a sociological survey to assess :

- individual expectations in terms of AC generally speaking,
- people's reactions towards new AC systems.

Focus groups were created in 4 French regions : Paris, Marseilles, Nantes and Strasbourg. Each group was composed of people having AC in their car, in their office, neither in their office nor in their car.

- **Rational and modulated expectations :**

It turned out in this study that AC in the home does not correspond to a clear expectation ; French people like living the different seasons and wish to have a limited [4] « cooling » effect rather than being « chilled ». Therefore, specific rooms such as attic rooms are a prime target for AC because they are very uncomfortable during heat waves.

- **Summer comfort :**

Summer comfort consists for people in creating a « palpable « but limited contrast. Thus, an outside/inside temperature difference of between 4 and 5 K would be ideal.

People have no wish for uniform comfort which will cancel out the seasonal aspect of their lifestyle (i.e. no constant temperature during the whole year).

- **AC perception :**

AC in residential dwellings will have to erase the bad image of AC in commercial buildings : it will have to be silent and invisible, excluding cold air draughts. In their homes, people expect to find a calm, relaxing and non-aggressive atmosphere.

- **Year round space conditioning concept :**

An AC purchase is fully justified only if the device is capable of providing heat as well[5]. This function will have to be given greater place because it takes priority.

- **Ideal system in terms of year round space conditioning :**

The potential user would prefer static cooling (by radiation or natural convection) from the floor or inside unit rather than a dynamic air stream. Moreover, summer control will have to be simple and reliable. The AC should avoid :

- substantial air movements,
- continuous noise,
- an inside unit spoiling the appearance of the room,
- a non-modular installation.

3.5 Avenues for new developments

[4] In time and in space.
[5] In contradiction with the previous study.

Amongst the results of the different studies presented, the following points will direct future product development for France :

- the reversible system will have to « cool » rather than to « chill »,
- the noise level is of major importance : French people are sensitive to it,
- the aesthetics of the inside unit must be « rethought » : invisible or redesigned
- the type of inside unit should depend upon the room,

Emphasis is therefore placed on :

- **Hybrid system :** floor heating and cooling system + fan coil with (or without) air distribution in the upper storey,

- **New fan coil unit for residential dwellings.**

- **Air system (Not described in this report)**

4. Definition of new concepts of heating/cooling systems

By comparing « existing systems » with « people's needs and demands », two kind of new system are defined. These systems may be developed with manufacturers and tested on site during the following Annex 25 tasks.

4.1 Hybrid system : floor heating and cooling system + fan coil or air distribution

Feedback from the field has indicated that the development potential of thermodynamic heating-cooling systems, in this case a water/air heat pump coupled with a heating and cooling floor, is limited for dwellings of more than one storey. Indeed, there are two major obstacles :

- **Loads are higher on the upper floor :**

Loads on rooms under the roof or roof terrace, due to external heat gains in particular (sunlight, conduction through walls), are higher than for rooms on the ground floor.

- **A heating-cooling floor is more difficult to install on the upper floor :**

The construction of this type of floor on the upper floor involves a number of constraints, though the main problem is that builders are not familiar with this type of work. The construction recommendations, are identical to those for a ground floor system, apart from the need to insulate the underside of the slab. The slab is therefore thicker than a standard slab and sufficient heights between slabs must be provided for at the design stage.

Taking account of these criteria, a solution currently being developed by certain manufacturers will make it possible to equip homes of more than one storey. This system comprises a **reversible air/water heat pump** coupled to **a heating-cooling floor on the ground floor** and either to **2-tube water terminal units with or without an air ductwork on the first floor**.

Various techniques that can be used to supply the circuits of the heating-cooling floor and the 2-tube water terminal units will be defined and compared. They must take account of the temperatures and operating conditions of each circuit (comfort, low, frost protection) and the power consumption of auxiliaries, and they must be simple to implement.

Tableau 4.1 : Water inlet temperature in Winter and in Summer for "hybrid system"

Operating conditions	Winter	Summer
heating-cooling floor circuit	T° water from 25°C to 35°C	T° water cstant=18°C
water terminals circuit	T° water from 38°C to 45°C	T° water 7°C

4.2 New Fan coil unit for residential dwellings

On the basis of specifications detailed in this report, 3 prototypes were defined for the residential sector:

- a prototype using a compact exchanger and an optimized tangential fan[6],
- a prototype using a reaction turbine,
- a prototype using a two sets of small axial or tangential fans.

This section presents the experimental results obtained for each appliance prototype and the perception by potential users

- **Thermal and acoustic performance of prototypes**

The results characterizing the performance of the appliances are summarized in the table and figure below:

Tableau 4.2 : Thermal and acoustic performance

PROTOTYPE	HEATING CAPACITY (W)	SOUND LEVEL (pressure)	VOLUME[7] (m3)	POWER DENSITY (W/m3)
Tangential	1200	29.3 dBA	0.00368	326087
Turbine	1200	25.7 dBA	0.00199	603015
2 Tangential	1200	29.5 dBA	0.00209	574163

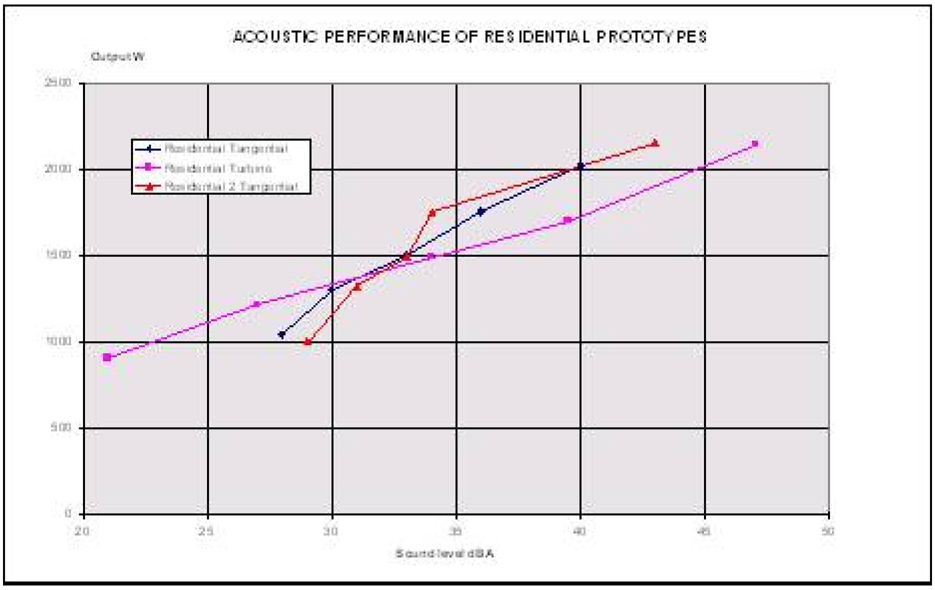


Figure 4-1 : Variation in sound level as a function of output

[6] Tangential fan = "Squirrel cage" fan
[7] Heat exchanger volume

The sound level is not measured in terms of perceived noise (pressure) but in terms of sound power, which characterizes the true quality of the appliance independently of its environment.

- **Perception by the user**

A survey of the general public was performed to integrate the viewpoint of end users. The purpose of the survey was to determine:

- Attitudes towards the principle of the new Heat Pump heating technique after presentation of its technical features,
- Reactions to the three appliance models (see next figure).

Tangential fan: 0.0037 m	Turbine: 0.0020 m	Vertical tangential fans: 0.0021 m
		
- "unsuited to a domestic interior" - "more appropriate for commercial premises"	- "unsuited to a domestic interior" - "concept associated with prestige sites"	- "could suit to a domestic interior" - "modern and non-aggresive appearance"

Figure 4-2 : Synthesis of the users perception

- The conclusions of the survey of potential buyers indicate that commercial development efforts should be focused on the last prototype, which blends more effectively into buildings.
- Efforts will be pursued to reduce volume for the design with natural draught in heating mode and forced draught in cooling mode.
- The results obtained show that the initial objectives in terms of acoustic performance have been reached. Moreover, a technological breakthrough has been achieved, since the power density of the prototypes developed is twice that of appliances currently available on the market.

DRAFT REPORT FOR THE
INTERNATIONAL ENERGY AGENCY

ON ANNEX 25

"Year-round residential space conditioning systems using heat pumps"

Task 1: State of the art in the Netherlands

Authors:
Mr. E. van de Velden (Ecofys)
Mr. T. van Oostwaard (BMT)
Mr. R. Traversari (TNO)

Co-ordination work:
Leon Wijshoff (Novem)

CONTENTS

1. Introduction

1.1 Objective

The objective of the first task, within Annex 25 is to gain insight in the actual experience and market needs for application of year-round residential space conditioning systems using heat pumps, in order to define a programme of demands for these systems in the Netherlands.

This report is the Dutch contribution, written by the Novem, to the first task of this Annex 25 (Task 1 "State of the art study").

1.2 Dutch background

In the 90's the interest in heat pump technology has regained. This interest was based on high expectations for heat pumps as a mean to achieve a more sustainable energy supply infrastructure. However it was recognized that there were no specific activities to support implementation of the heat pump technology. This resulted in the introduction of a heat pump program in 1995 which should help to fill in the ambitious goals of the Dutch Government, energy saving of 50 PJ in 2010 (reference year 1994) by means of heat pump technology. The heat pump program, carried out by Novem, covered heat pump application in residential buildings, commercial buildings, industry and agriculture. The aim was to achieve a 1.6 PJ energy saving by heat pumps in the year 2000 in residential buildings, through close cooperation with all parties involved (builders, architects, installers, developers, utilities and suppliers).

An recent evaluation of the activities carried out thusfar has shown that the energy saving target for the year 2000 will not be reached for the residential building sector. The energy saving up till 1998 was 66 TJ, whereas approx. 1200 heat pumps were installed and 3800 heat pump boilers.

Despite the above heat pumps have gained a lot of interest in the Netherlands, and are still seen as a potential for the future. The knowledge on heat pump technology and application has grown by means of research and development as well as demonstration projects. Also a small supply market has developed. One of the most important experiences in the past years is that the Dutch housing market differs quite a lot, e.g. a wide spread gas infrastructure, low priced condensing boilers, and small houses, from those were heat pumps have become more common. This results in the need for specific heat pumps and knowledge on their application.

In order to improve heat pump application in residential buildings a Covenant is being prepared in which all relevant parties will participate. The Covenant will define the required activities and priorities in order to make the heat pumps a competitor in the field of heating, hot water and cooling. Especially the actual as well as expected increase in cooling demand has been reason to start up activities on heat pump systems which fulfill the heating, cooling as well as hot water function. Therefore the Annex 25 activities are seen as a important area to exchange knowledge gained on an international level. To support these activities on the national level Novem has established a platform, covering suppliers, utilities, consultants and housing developers.

1.3 "State of the art study in Netherlands" contents

The first step in the Annex 25 framework within the Netherlands was planned to be a State of the art study, which would form a base for the further tasks. Starting point within the Dutch activities is the system approach. This means not only focus on the heat pump as a product but look at the total system including source, heat pump and distribution system, as well as the non-technical issues involved as quality, training etc.

Within this state of the art study 3 activities were defined:

- **Inventory of existing systems:**
  This study was meant to collect information and knowledge form existing projects were heat pumps for heating, cooling and hot water were installed.
  ECOFYS
  ir. E.G. van de Velde
  drs. C.A.M. Stap
  September 1999

- **Market study:**
  This part should give insights in the opportunities for heat pumps and year around heat pumps more specific as well as define requirements set by the market.
  BMT
  Drs. Ir. A. van Oostwaard
  December 1997

- **Programme of demands for a year around heat pump:**
  This part would be the compilation of the first two studies and other experiences gained in the field to be the base for product/system development.
  TNO-MEP
  ir. A. Traversari
  September 1999

In the following chapters a short description is given of the work carried out and the results achieved. The first task of the Annex has suffered from insufficient cooperation between various parties involved and insufficient funding which resulted in a delay in the start up of some of the work. Despite this delay the overall planning still seems achievable since some demonstration projects already started and will give earlier results than planned.

2. Inventory of existing systems

Ecofys has made an inventory of existing heat pump systems in Dutch residential building, that provide heating as well as cooling. The underlying thought is that addition of the cooling function to a heat pump system can provide improved comfort, at minimal extra energy consumption (if passive cooling is applied), precisely in modern well-insulated houses that are susceptible to overheating. Because in this way the heat pump system is clearly given an added value compared to a condensing boiler, the residential market for heat pump systems in the Netherlands can be given a strong incentive.

The existing systems encountered can be divided into two categories: heat pump systems with cooling as an extra, and air-conditioning systems with heating as an extra. In the first category no systems have been found that have been operational for any considerable time. For this reason no measurement data or practical experience is available. However, five systems have been found that are supposed to be operational before the end of 1999. Several different configurations have been mentioned by the parties involved, ranging from single houses to a small apartment building with a collective system. Also, different space heating systems are applied, and in some cases preparation of domestic hot water is included.

The most important barriers for a large scale application of such systems in the Netherlands are the high investment costs, the integration in the design and building processes, the low price of gas compared to electricity, and a possible future limitation to the use of groundwater as a heat source.

In the second category (air-conditioners with heating as an extra) there are several systems realised. In all cases, the systems are dimensioned to match the cooling load in the summer, making them unsuited to manage peak loads in heating in the winter. Therefore, a regular central heating system with a boiler has been installed in all cases. This practice forms the most important barrier for future application of such systems in the Netherlands.

Although no suitable information on measured data was found it is recommended that a measurement program be developed for the heat pump systems (using groundwater as a heat source) that will soon be taken into use. Thus, a good feedback can be given to the technical developers of such systems. In such a program however, it should of course be taken into account that on the component level (heat pumps, low temperature space heating/cooling) a lot of information is already available.

3. Market study

Within a cooperative agreement on heat pumps, concluded between Novem (Dutch Agency for Energy and the Environment), SEP (Co-operating Electricity Producers in the Netherlands), EnergieNed (Co-operating Energy Distributors in the Netherlands), NUON, REMU, ENECO and Energie Noord-West (Dutch energy distribution companies), a market study was carried out to provide insight into the market potential for electric heat pumps, as a tool for the development of an effective marketing programme.

3.1 Approach

The starting point in this study was the need to strengthen the relative competitive advantages of heat pumps, as compared to alternative options. In the form of an iterative process, the following steps were taken:

* market trends in the demand for functions offered by climatisation installations and the most interesting market segment for heat pumps in this connection;
* the (manipulable) factors that determine the competitive power of climatisation installations, from the perspective of potential buyers in the most significant market segment;
* the competitive power of heat pumps in the present situation;
* the potentially available marketing instruments;
* the relative competitive power of heat pumps that could be attained in the future through marketing programmes of varying intensity;
* the market potential as a result of marketing efforts in the future (1998-2005);
* recommended steps for the future.

3.2 Relevant market features and trends

The most significant *market segment* for heat pumps is the upmarket, new housing sector.

Major trends in this particular market segment are:

* a rising comfort-level, which means higher demands in the area of climatisation control and hot-water supply and increasing market opportunities for installations that include a cooling function;
* increasing use of sustainable energy which in turn is stimulated by rising demands on actual energy performance and by market incentives.

Air conditioning installations for new private housing projects are currently selected by or on behalf of the prime contractor. This is not likely to change in the future, although contractors will increasingly be confronted with regional regulations on sustainable building and with energy infrastructure agreements, especially when collective facilities are involved. The trend towards more choices for house-buyers will centre on optional extras that can be easily incorporated in existing designs (e.g., kitchen and bathroom set-ups).

3.3 Assessing the competitive power of air conditioning installations

To assess the competitive power of air conditioning installations the point of view of the 'buyer' of the installation: the contractor is taken. Major factors that determine the competitive power are:

* *relative price* (purchase price for the contractor, comprising e.g. hardware, installation costs, margins);

* *relative value* (to be considered specifically as a contribution to 'measurable' values such as desirable functions, energy performance, comfort-level and reliability);

* *relative perceived value* (i.e., the value as the contractor sees it, possibly deviating from the actual value; products that improve the contractor's image and innovative, trendy products are advantageous);

* *switch-over costs* (new installations require the adaptation of, for example, design and building processes; these adaptation costs should be reasonable);

* *tendency towards substitution* (greater among innovative entrepreneurs).

3.4 Competitive power of heat pumps in the present situation

In order to determine the competitive power of heat pumps in the present situation, first the most favorable product types to be used in new private housing projects must be selected. The heat pump system that provides central heating, hot tap water, ventilation and cooling is considered the most promising. The cooling function, especially, which is relatively inexpensive and does not raise energy consumption, offers a major surplus value to both the contractor (buying motive) and to the user (extra comfort without extra energy costs). Under the current circumstances, even the most favourable heat pump system cannot compete with the popular high-efficiency combi-system. The actual heat pump system has several disadvantages that are, from a competitive perspective, unacceptable: high price, limited reliability, and high switch-over costs for the contractor.

Compared to alternative options such as combined heat and power (CHP), solar-gas combinations and gas-fuelled absorption heat pumps, the competitive advantages and disadvantages are less significant. The possible disadvantages of electric heat pumps, compared to competing options, are largely outweighed by the fact that heat pumps offer a cooling function without extra energy consumption.

3.5 Strategic marketing instruments

Strategic marketing instruments aimed at strengthening the competitive power of electric heat pumps must conform to the following guidelines:

* they must be suitable for targeting trade organizations, (umbrella organizations of) energy distribution companies and government agencies, possibly in collaboration with each other;

* marketing tools that are best used on the company level are the responsibility of each individual company and are not considered in this context;

* a distinction is made between instruments that can be used for strengthening the competitive power of sustainable installations in general, and instruments for the exclusive promotion of electric heat pumps;

* the marketing instruments that are used must positively affect those factors that increase the competitive power of heat pumps;

* the effect to be expected must be proportionate to the effort to be made.

As a part of this study, the available strategic marketing instruments were tested for their conformity to the guidelines above. The instruments were generally classified as follows:

I. Financial instruments
II. Regulatory instruments: performance and quality requirements
III. Communication instruments: providing information on the level of decision-makers, designers, builders and installers
IV. Strategic instruments: influencing decision processes

3.6 Competitive power and market potential, period 1998-2005

The competitive power of the electric heat pump has to be increased considerably before it can reasonably compete with the combi-system (high efficiency condensing boiler for heating and hot water) and other new, competitive installations in the period 1998-2002. Such an increase can be realised with the right set of strategic marketing instruments. It is necessary to distinguish autonomous increase from the increase resulting from the use of marketing tools.

3.7 Autonomous

The increased competitive power of heat pumps resulting from the promotion of sustainable options in general, will lead to an expected 50% market share for sustainable options (20,000) in the market segment for more expensive, newly-built private property (40,000 in 2005).

It is estimated that the market share for electric heat pumps within this market segment (20,000) is 20%, i.e. 4,000.

3.8 Instruments for the exclusive promotion of heat pumps

Marketing efforts directed at strengthening the competitive power of heat pumps will obviously result in a general growth of the Sustainable Options' market share (from 50% to 75%). The share of heat pumps within this market segment will rise to 33%. The estimated number of heat pumps sold annually to upmarket, new private housing projects will be 10,000.

It can be realistically expected that after a period of 3 to 5 years, the market for rented houses will follow, with a market potential of 2,500 in 2010. In the long run, the existing real estate will also follow, with the market for major home alterations leading the way.

3.9 Recommended steps for the future

The following steps, to be taken jointly by all parties interested in introducing electric heat pumps into the housing market, will be essential for a successful market result:

1. <u>Selecting the p/m combination with the best market opportunities</u>

It will be essential to make a selection from the many different heat pump types, in order to efficiently develop the product and effectively position it on the market. On the basis of this study, the p/m combination that provides heating, hot tap water, ventilation and cooling is the most favourable option for new private housing projects.

2. <u>Establishing the emphasis of R&D activities and demonstration projects</u>

After the p/m combination with the best market opportunities has been selected, we can further optimise the system by means of R&D and demonstration projects. Activities in this field deserve absolute and immediate priority.

3. <u>Initiating a coherent set of activities</u>

As a preparation for the actual market rollout, the strategic marketing instruments presented in this study must be fine-tuned and supplemented until a coherent marketing programme is produced. This programme can then serve as the foundation for a formal agreement between the parties involved.

4. Program of demands for a year around heat pump

The actual results of this part of the task is a draft version of a program of demands, set up by TNO in close cooperation with a supplier of heat pumps in the Netherlands.

4.1 System description

Discussions have clearly shown that the system must be based on a standard low-temperature heating system. The system design should be such that various heating and cooling devices can be connected to it. The 'plug-and-play' principle will ensure optimum use of these devices both immediately and in the future. The plug-and-play principle is required because the technical life of the heat distribution system involved is about 2 to 3 times longer than that of the device that produces heat and cold. This means that the producing device will have to be replaced during the life of the building and the heat distribution system. A second requirement is that the addition of cooling properties may not cause the system to use more primary energy than it would if it were used for heating only.

These requirements can be met in a system in which the heat pump has a central place. A ground source heat exchanger can then be used as the heat source for the heat pump. During the summer, cooling can be effectuated by connecting the heat distribution system directly to the ground source heat exchanger, thus producing a high-temperature cooling system. The only device required for the actual cooling is a circulation pump. The extra energy consumption can be compensated by the fact that the ground will retain heat produced during the cooling process; this will result in a higher COP during the heating season, so that, in effect, the extra energy used for cooling is recovered later.

It is assumed that the control and the hydraulic coupling for the cooling function are built into the heat pump. Also it is assumed that, if a ground source heat exchanger is used, it is filled with a mixture of water/glycol that must not flow through the heat distribution system. If groundwater is used as a heat source, this separation is also essential.

4.2 Heat distribution system

The heat distribution system should be constructed in such a way that it can be connected to various heating and cooling devices, without the system's functionality (plug and play) being affected by it. Provisions to control the temperature in the heat distribution system and to prevent possible condensation lie within the system limits of the producing device (heat pump). In the development process, the start is made with a floor-heating system for both ground and upper floors. This system is chosen because it is currently not considered feasible to connect standard radiators to this kind of system. Maybe in the future it will be possible to expand the heat distribution system with fan coil units or other new developments.

4.2.1 General requirements

- Maximum supply temperature [°C] 45
- Testing pressure [Kpa] .
- Flow [m^3/s] .
- Resistance of heat distribution system [kPa] .
- Resistance of producing device (heat pump condenser) [kPa] .
- Maximum capacity at heating [W/m^2] .
- Maximum capacity at cooling [W/m^2] .

4.2.2 System structure

The system must not be equipped with mixing controls as the producing device may then reach a higher temperature than strictly necessary for sufficient heat distribution. The ground floor should be insulated from underneath to minimize heat losses. The construction of the floor must be such that condensation in the floor is not possible at a water temperature of 14 °C. The design calculations have been made in conformity with ISSO 10. Pipes, distributors and accumulators on which condensation may occur, must be equipped with moisture-proof insulation materials. Attention should be given to insulation materials being properly installed.

4.2.3 Control

The control in the main room will be integrated in the heat-producing device; other rooms can be controlled by means of thermostat-controlled valves. In this context, however, it should be taken into account that the heat distribution system has water (temperature at least 14 ºC) flowing through it

4.3 Heat pump

Heat pump properties include:

- The generation of heat for domestic hot water preparation and space heating,
- The hydraulic coupling for heating and cooling,
- The control for the heating and cooling functions,
- Separation of the medium in the ground source heat exchanger from the medium in the heat distribution system

The circulation pumps for both feed and distribution have been integrated in the heat pump and are operational only in the event of heat demand or cold demand. The heat pump contains a system that sees to it that during cooling operations the system's feed temperature cannot drop below 14 °C.

4.3.1 Space Heating Performance

The COP of the heat pump must be more than or identical to the values stated in Table 1.

Table 1. Values in conformity with NEN 5128 (Dutch building code).

Heat pump type Source	**Testing condition according to NEN-EN 255**	**Minimum $COP_{NEN-EN\ 255}$**
Earth Brine/water	T1 (B0/W50) T2 (B0/W35) T3 (B-5/W50)	3.03 4.00 2.71
Groundwater Water/water	T1 (W10/W50) T2 (W10/W35) T3 (W15/W50)	3,76 5.08 4.12
Outside air Outside air/water	T1 (A7(6)/W50) T2 (A2(1,5)/W35) T3 (A15(12)/W50) T4 (A-7(-8)/W50)	2.81 2.83 3.19 1.96

4.3.2 7.3.2. Tap Water Performance

- Tap-pattern class 3 (in conformity with NEN 5128)
- COP of at least 2.2 (determined in conformity with the test directive for domestic hot water for heat pumps [1])
- KIWA requirements.
- Continuous 60 [°C] water at the draw-off point guaranteed.

4.3.3 Storage Water Heater

- Flow for heating up [m^3/s] ….
- Minimum contents [l] ….
- Insulation [mm] ….

4.3.4 Sound

Indoor set-ups

If installed in a closed space, the sound pressure level in an adjacent room (in the reverberant field) should be: Lp(A) $\leq$ 30 dB(A)

If the pump cannot be constructed so as to meet this requirement, additional measures can be taken to sound-proof and/or close off the space itself.

Outdoor set-ups

Lp(A) $\leq$ 45 dB(A) measured at 1 m distance.

4.3.5 Measurements

Indoor set-ups

Heat pump: L x W X H = 800 x 800 x 1800 mm

Outdoor set-ups

Heat pump: L x W X H = 800 x 800 x 2000 mm

4.3.6 Control

The control is meant to reach the highest possible COP in a user-friendly way. If the control has a display, the text should be shown in the Dutch language. Parameters that the user may change should be easily accessible. Parameters that only the installer may change are inaccessible to the user. In case of a control based on a heating curve, readjustments must be possible in each room. Whether or not the cooling option is used is up to the occupants; they can turn it on with a switch on the central control. All rooms will then be cooled. The temperature in the main room can be adjusted in the room itself.

4.4 Heat source

The heat sources that appear to be most suitable for this application are ground source heat exchangers and groundwater. The choice for either of these two will vary from one location to another, depending on geological circumstances and costs. In dimensioning the heat source, the regeneration in the summer months may not be considered.

4.4.1 Ground Source Heat Exchanger

Ground source heat exchangers should be dimensioned in such a way that frosts cannot penetrate the ground. They must be guaranteed leak-tight for at least 20 years. The pipes must be placed at a minimum of 120 cm below ground level.

- Testing pressure [Kpar] .
- Flow [m^3/s] .
- Resistance of well system [kPa] .
- Resistance of evaporator [kPa] .
- Maximum capacity [W/m_{buis}] .

4.4.2 Groundwater

Efforts should be made to limit the necessary quantity of groundwater to 10 m^3/h, as dictated by current regulations. Furthermore, if the groundwater quality permits, efforts should be made to use a single separation between groundwater and cooling agent. The well should be constructed by a specialist company, with minimised interflow between extraction well and recharge well. Proper functioning of the well should be guaranteed for a minimum of 15 years.

[1] Test Directive for domestic hot water for heat pumps
TNO report TNO-MEP-R 98/463
A.A.L. Traversari, M.M. van Ingen
November 1998

EXECUTIVE SUMMARY FOR THE INTERNATIONAL ENERGY AGENCY

ON ANNEX 25
"Year-round residential space conditioning systems using heat pumps"

Task 1: State of the art study in Sweden

Author:

Dimitra Sakellari (Royal Institute of Technology, Dept of Energy Technology, Stockholm)

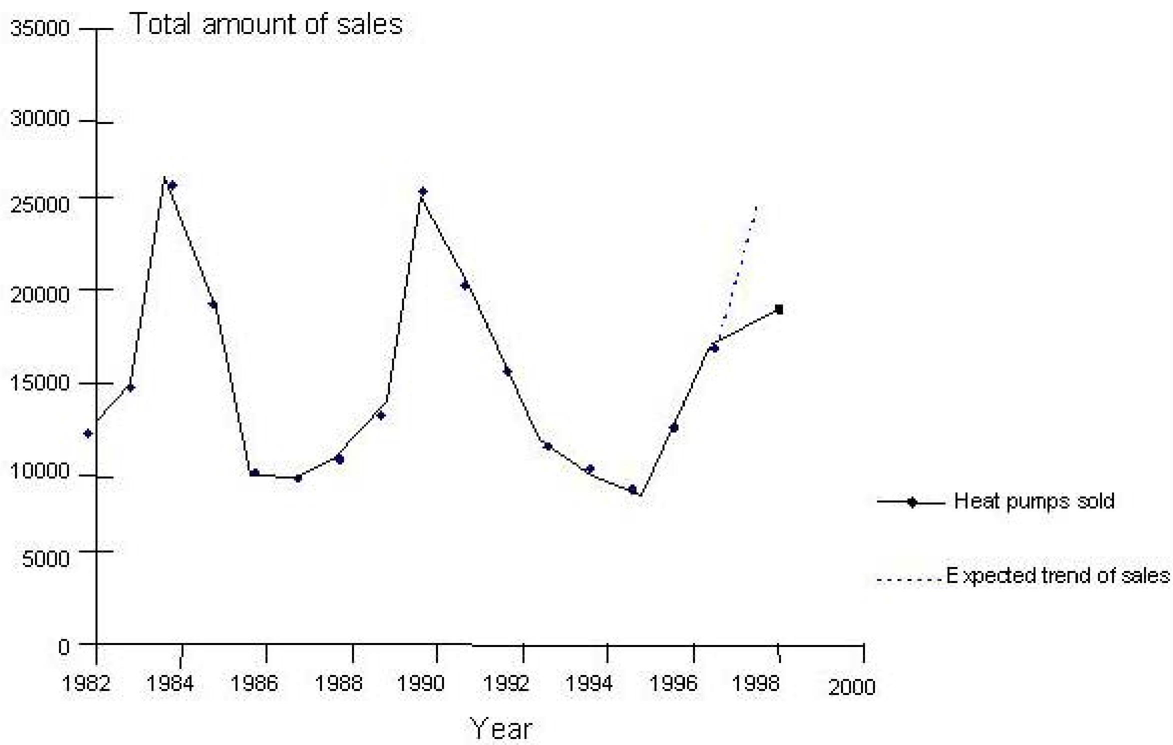
Co-operation work:

Per Lundqvist (Royal Institute of Technology, Dept of Energy Technology, Stockholm)
Martin Forsén (Royal Institute of Technology, Dept of Energy Technology, Stockholm)

1. Introduction

In Sweden, heat pumps have quickly established themselves in a wide range of applications. Today, the total amount of energy abstracted by heat pumps amounts to about 15TWh/year, of which 7-8TWh/year are accounted for large heat pumps supplying heat to district heating systems. Around 5TWh/year provided by heat pumps, are used for covering the heating demand of Swedish single-family houses.

The existing situation shows that the residential sector represents the main market for heat pumps in number of units sold. The diagram that depicts the trend of the heat pump sales from 1983 up to 1998 (see figure 1), shows an upturn in sales for domestic heat pumps after 1995. Some of the main factors that have influenced the sales trend within the years are public subsidies, energy taxes, price-relation between different heating applications, and experience of using heat pumps.



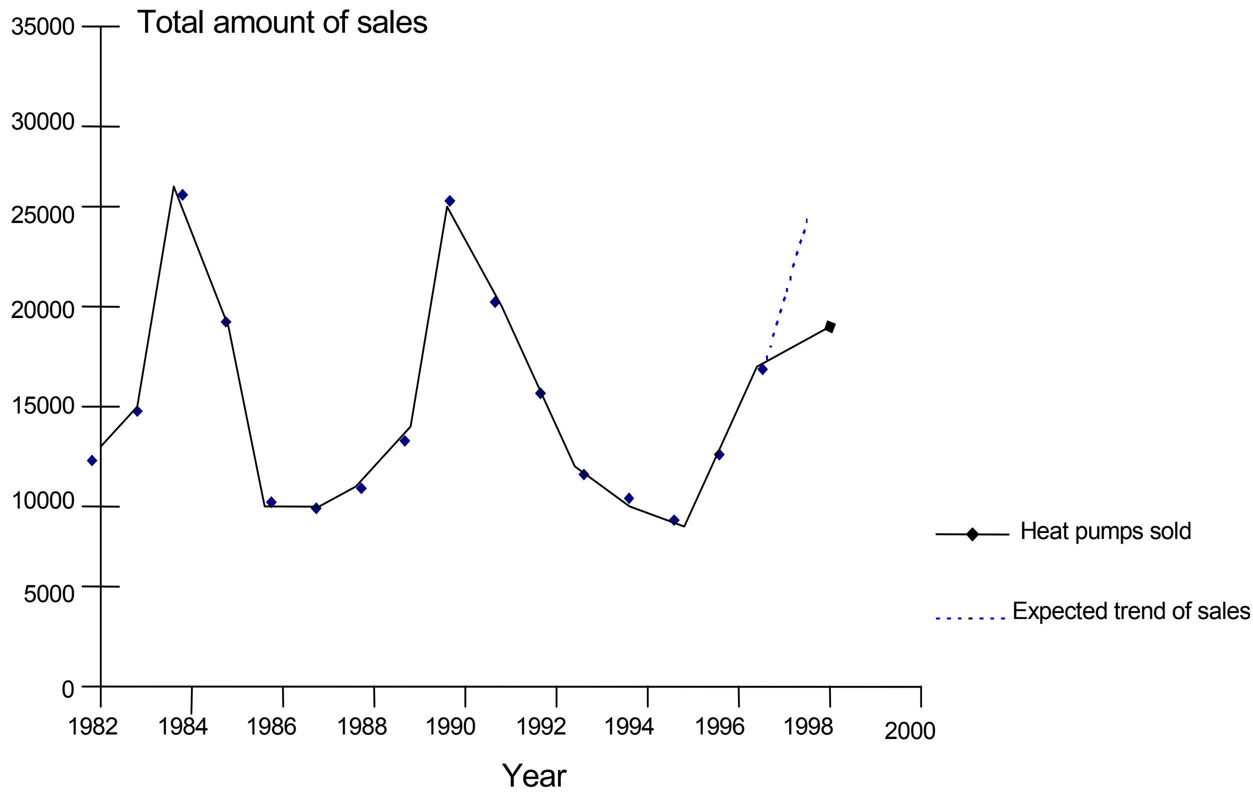


Figure 1: Sales trend of domestic heat pumps in Sweden

Considering the types of domestic heat pumps that are preferably installed or met on the Swedish market today, we find air-to-air, air-to-water, liquid-to-water and ground-coupled heat pumps. From the types mentioned here, the liquid-to-water heat pumps are common for medium and large-scale installations and they are not frequently used for domestic heat pumps. The ground-coupled heat pumps are usually indirect systems having a brine circulating between the heat source and the heat pump evaporator.

For the time being, there are near 300,000 domestic heat pump installations in Sweden. About 45% are exhaust air heat pumps, 25% are ambient air heat pumps and close to 30% are ground-coupled heat pumps. Most of them (85%) use water as the heat sink (hydronic systems). So far, ground-coupled and exhaust-air heat pumps are considered as the best systems for small houses.

Finally, in Sweden 55 % of the heat pumps installed in single family houses (especially new systems) are integrated systems and serve both for space and sanitary water heating. The rest 45 % serves only for space heating.

2. Analysis of existing concepts

2.1. Technical description

In domestic heat pumps the dominant refrigerants are of the HCFC type and especially the hydro-chloro-fluorocarbon R22. The total amount of CFCs in Swedish small-scale heat pumps is low and decreases as the replacement of CFCs continues. In Sweden, the main direction, in the replacement of CFCs and later on (it is on the agenda) of HCFCs, is to develop natural refrigerants. For the time being, chlorine-free substances, the HFCs have been developed and are used for replacing the CFCs and HCFCs in new and existing equipment. The hydro-fluorocarbon refrigerant R134a is the most common HFC refrigerant used for replacing R12.

If we try to go more into details of the technical synthesis of the domestic heat pumps mostly found in existing installations, we notice that the rotary vane, the scroll and the piston type compressors are the most preferable for domestic heat pumps. Reciprocating compressors have been widely applied in small-scale domestic heat pumps but the latest years their applications experience competition due to the increasing employment of rotary vane and scroll type compressors. In domestic heat pumps the evaporator and the condenser can vary a lot regarding the type of the heat source and heat sink. The evaporator type depends as well on whether the systems are direct or indirect. Considering the expansion device, the most popular type is the externally equalized, thermostatic expansion valve.

Taking into consideration the types of distribution systems that are used in domestic heat pump installations, we notice that the heat distribution is dominated by hydronic systems with radiators, especially for heating existing homes. However, when a domestic heat pump is installed, it is usual to complement the distribution system with some air-convectors. For new houses floor heating systems and air convectors are satisfying options. Considering floor heating systems, the floor construction has been improved and simplified a lot the latest years. The most resent developments have minimized the size of the concrete plates that hold the pipes and have led the plate dimensions down to values of 25mm.

Nowadays in Sweden, the heat pump system is not dimensioned for the maximum load. Regarding the yearly heating demand covered by a domestic heat pump, a rule of thumb says that 80-90% of the heating demand should be covered by a correctly sized heat pump. This means that a percentage of 50% of the peak power need must be supplied by the heat pump. In most cases there is another heat source to help heating the building during the coldest days of the year, a so-called supplementary heat source. Oil and electricity are the most popular energy sources used for supplementary heating.

2.2. Performance, Comfort and Costs

As far as the heat pump performance is concerned, the experience changed a lot within the years. Several problems occurred in the early stage of the market development of heat pumps but nowadays there is only a minority of systems with operation and availability problems. Generally speaking, the experience is good in all market segments and the performance has been, in principle, what has been expected. Especially when it comes to new-installed, brine-based units, the experience concerning availability and problems is excellent. Some problems though, still occur in air-to-air heat pumps.

Considering comfort matters, the heat pump does not affect much the different parameters that determine the comfort and 'well-being' of a house. The latest designs of domestic heat pumps are quite silent and they occupy little space. They are less demanding, than oil boilers, in installation requirements but not as simple as electric heating. Considering the heat distribution system, floor heating fulfills comfort standards in a sufficient way. Especially in thermal comfort, floor heating gives good results with even temperature profiles in the room and nice feeling while being bare-footed. However, there are some complains for a draught feeling while standing close to a window (when the window is not tightly sealed).

So far, small-size heat pump applications have been successful in Sweden with more than 300,000 units sold, according to the Heat Pump Association (SVEP). The small heat pumps are manufactured in series by a number of firms, particularly Swedish. In the past, high priority was given to heat pump development and promotion by electric utilities, the government and other players in the energy market. Today no grant/rebate/promotion schemes exist mainly because the Swedish government considers heat pumps as competitive enough.

For calculating the costs, great importance is given in the heat pump costs. The cost calculation method that is followed in this study is the total annual cost method. Furthermore, a comparison is made between a heat pump, an ordinary oil-fired boiler and a common electric heating system in terms of profitability.

An important factor that influences the calculation costs is whether the heating system is converted and upgraded or is a new system. Furthermore, the fact that a back up system is always required, when a heat pump is used, adds complexity and deviation probability from the real costs.

For the time being, the main impediment for wide implementation of heat pumps is high investment costs. However, running a heat pump system gives low operating costs. Therefore, additional heat pump penetration in the market depends strongly on the costs of competing systems. In consideration of maintenance costs, heat pumps have sometimes been questioned as very demanding in terms of service. Generally speaking, maintenance costs for well-designed heat pump installations are low.

At last, as regards the payback time of heat pump installations, the time is quite long and this is a significant factor that makes consumers reluctant to invest their money on a heat pump unit. According to the Swedish Consumer Agency (Konsumentverket) the payback time ranges from 6 to 8 years for three typical installations.

3. Market needs and demands study

In order to get a complete picture of market needs and demands, the point of view of different groups of people is given. The market approach concerns mainly the heat pump although the heat pump is just one part of a heating system, representing the heat generation system. The market investigation is in process with collecting information for the heat distribution system as well.

Starting from the user's point of view, a questionnaire shows mainly the service requirements of domestic heat pumps and indicates in a good manner the heat pump experience in Swedish houses. Consumers' expectations follow with an attempt to display the most significant barriers against domestic heat pumps and floor heating systems. Finally, installers and architects' opinion and expectations help to complete the study for the market needs and demands in Sweden.

3.1. User's point of view

Our department started a survey many years ago in order to find out how domestic heat pumps function in practice, after some years in operation. The questions were aimed in depicting the experience in the performance of domestic heat pumps, the service and cost requirements after many years in operation and the owner's point of view on their heat pumps. The biggest piece of information in the final report (our contribution to the Annex25), as far as market needs and demands are concerned, comes from this survey.

The results from the survey give information in three main sectors:

- owners' opinion on their heat pump,
- service demand,
- piece of advice (from people that already own a heat pump) to those who plan to install a domestic heat pump

Generally speaking, the experience of using domestic heat pumps in Sweden is big and so far quite satisfying. Statistics for properly built and installed units indicate good availability, especially for units that were supplied with complete control equipment from the factory. Service requirements for heat pumps have been considered many times so far and there is information on service demands for different types of heat pumps.

It is worthwhile to mention the advice given by the owners to expected buyers, regarding the purchase of a domestic heat pump. The owners recommend the consumers to choose quality and well-known brands. Moreover, the consumers should go for a contract with big, reliable suppliers, having sufficient competence, including satisfying service coverage and insurance warranty for at least five years. Another advice is to ask information on maintenance provision and quick accessibility to errors and malfunctions, to ask offers from several companies in order to be able to control the installer and to request warranty that the heat pump is silent in operation. Considering advice of technical character, the owners recommend caution against over-dimensioning. They also suggest keeping the old oil-boiler in case of changing the existing heating system. When a rock-coupled heat pump is used they recommend a deeper bore-hole than estimated. Taking advice of economic character into account, owners inform that installation costs are high and suggest accurate and realistic calculations over profitability and savings. Finally, most of the owners point out the fact that the installations give good operation costs but they require a big capital investment.

A general recommendation given by all those who are involved in the heat pump market is that the construction must be authorised before starting the installation (for example by the Environmental Protection Department). Especially rock and ground-coupled heat pumps must get permission as far as the construction of the bore-hole and the ground-coil are concerned. Furthermore, the installer should be authorised.

3.2. Consumer's needs and demands

Consumer's expectations in terms of heating systems concern economic, technical, comfort and security matters. From economic perspective, consumers expect lower initial costs for heating systems that comprise a heat pump and floor heating. From technical point of view consumers prefer a heat pump system that is reliable, easy to run and requires low operating costs. Taking floor heating into account, consumers tend to choose floor-heating constructions that promise less leakage probability and are easy to install.

Interviewing consumers in Sweden for heat pumps has shown that the psychological importance of loans and grants is very important. Favourable public loans for a heat pump are seen as legitimising it, that the society trusts it. Interviews, in the beginning of the heat pump market penetration, showed that many of the owners chose a heat pump for status purposes or as a result of their technical interest. Later on and due to energy and environmental matters, potential buyers began to see the heat pump as a low-energy, non-polluting alternative. From then onwards, the heat pump was sold on its expected economic merits, reinforced by the effects of loans and grants. Nowadays, Swedish consumers consider a heat pump as a feasible option for domestic heating. This shows clearly that domestic heat pumps have established themselves in the heating market and are able to compete with conventional heating systems.

Considering floor heating systems, the main parameters that attract buyers to these systems are thermal comfort and aesthetic criteria. Furthermore, floor heating is favourable for utilising low supply water temperatures and hence it minimises the energy losses. This makes the joining of floor heating and heat pump a good suggestion. For these reasons, further development of floor heating constructions has started and resulted in price reduction and technology improvement. Floor heating constructions have been simplified and optimized a lot the latest years. The probability of errors and malfunctions in floor heating systems has decreased essentially.

At last, it should be mentioned that in Sweden, people who intend to buy a new or change the old heating system seem to apply wider considerations than solely the result of financial calculations. They consider aspects, such as flexibility and security of supply, which can be seen as an attempt to anticipate uncertainty. Finally, environmental considerations play a significant role in the heating market and influence Swedish consumers in their choice.

3.3. Architect's and installer's expectations

In order to define an easy to install system, architects and installers expectations are taken into account. Considering barriers against heat pumps and floor heating, we find that different market forces and trends determine the behaviour and the preferences of installers and architects. Their preferences are affected by consumers' preferences and market conditions and vice versa.

Nowadays, an important trend in the Swedish market is the energy deregulation. Utilities start to offer energy services and they give high priority on energy saving systems. Energy saving and sustainability stands for a domestic heat pump connected to a low temperature heat distribution system. Hence, the impact of energy deregulation on the heat pump market is expected to be rather positive. Generally, the choice of a heat pump combined with floor heating is a possible option when a heating system is to be selected. For several reasons, but mainly because a domestic heat pump is economic feasible, architects recommend a heat pump installation when they see that this choice justifies itself.

According to installer's opinion an easy to install system is not time, space and money-consuming. Several installers define differently an optimal heating system and this is understandable due to the fact that they have different experiences, ideas, and preferences. Moreover, every application is unique and depends strongly on other factors (not only technical). However, all of them agree that the system should be simple, easy-to-run, the connection between the heat pump and the heat distribution system uncomplicated and the comfort provided satisfying.

At the moment, heat pump installer's in Sweden are active in the direction of minimising installations' errors, making the installations properly and quick, and being in contact with consumers and the problems they face with their heating systems. A main trend is that Swedish manufacturers train their own installers and technicians. Companies that construct and promote heating systems based on heat pumps found their own technical schools and offer technical courses (primarily on their own heating systems). In this way, they educate installers and provide them with the technical "know-how" for optimised installations.

4. Technical definition of a new concept

In order to suggest a new heating system consisting of a heat pump and floor heating, we take into account the existing technology, the experience from the field applications and the ongoing R&D in the provinces that are still under improvement. The description of the existing concepts, the experience, the performance analysis, and the study of market needs and demands have already been taken into consideration. What is left, to complete the picture and help us draw conclusions and come up with suggestions, is the ongoing research.

At this point, we should mention that our intention is far away from just giving a strict definition of an optimal system on a purely technical basis. Since, heating systems consisting of heat pumps and floor heating are under development there will always be place for further progress and improvement. Furthermore, even if we succeed in defining technically an optimal system, this is not enough to secure the success of this system in the heating market. The market forces do not depend merely on technical and economical merits.

However, our point is to show the areas, where R&D is active. These areas concern mainly heat pump components. By giving these areas it is easier to realise the trend in optimising heating systems consisting of domestic heat pumps and floor heating. Hence, it is easier to come up with suggestions of systems with sufficient performances.

Much of the research carried out in the last five years has been concentrated on developing and obtaining experience of new, less environmentally hazardous, refrigerants. In Sweden, the trend shows that there is an inclination towards natural refrigerants. This does not necessarily mean that natural refrigerants are the only favourable choice. For the time being, the main options are HCFC or HFC refrigerants.

R&D is still required in order to improve the efficiencies of the electric motor and compressor, radically reduce the temperature difference in the heat distribution system, the evaporator and the condenser and develop low-energy fans. At the same time, heat losses from the warm to cold side need to be minimised. Furthermore, R&D support is needed in order to succeed in the design and production of systems capable of providing a high proportion of the annual energy demand with low costs, without sacrificing reliability or simplicity. Continuous research is required in the areas of thermal characteristics and heat transfer characteristics of pure media and mixtures. Low temperature heat transfer media for use in indirect systems need to be further developed. Also, component development and system design to suit new working media is another working area. Nonetheless, great emphasis is given to measures for energy saving in heat pump systems. Simultaneously, when developing systems towards the target of reduced losses and higher energy savings, it is necessary to remember that the final system must be in a reasonable price or the value spent for the improvement must not be more than the value of the increased savings.

At last, an important objective by the institutes of technology and production companies is to retain and enhance research and training environments. This is the best way to provide industry and society with skilled designers, engineers and installers.

**EXECUTIVE SUMMARY FOR THE
INTERNATIONAL ENERGY AGENCY**

ON ANNEX 25
"Year-round residential space conditioning systems using heat pumps"

Task 1: State of the art study in the US

<u>Authors:</u>
Ed Vineyard (Oak Ridge National Laboratory)

EXECUTIVE SUMMARY ON U.S. TASK 1 ACTIVITIES FOR ANNEX 25

ABSTRACT

Residential ducts have been characterized by major inadequacies that include heat conduction to unconditioned spaces, leakage, and infiltration through supply and return ducts. These problems are considered to result in substantial amounts of energy usage and poor thermal comfort. In addition, distribution problems contribute to high peak electricity demand. Previous research efforts have demonstrated large potential energy savings in the U.S. from distribution system improvements. Recent work in the U.S. has quantified the energy savings from replacing/retrofitting present ducted distribution systems with improved designs or reducing the leakage rate in existing systems. The work has concentrated on the following areas: 1) determining the present stock of existing distribution systems and predicting energy savings from improved efficiency levels; 2) research on hydronic distribution systems; and 3) measurements and computer modeling of forced-air distribution systems.

ENERGY SAVINGS POTENTIAL

A literature evaluation was performed to determine the extent to which residential single-family forced-air distribution systems have been field-measured and quantify their effectiveness. A total of thirty-four studies with sample sizes as large as 820 homes were surveyed. In conjunction with the literature search, data were collected to quantify existing and new construction of homes with forced-air distribution systems. Data were obtained from the National Association of Home Builders (NAHB) Research Center's Builder Practices Report (BPR) for existing homes (1983) and new construction (1983, 1996, 1997, and 1998). Additional data (1984 to 1995) were obtained from the NAHB web site (NAHB.com). The 1998 BPR report projects the rate of growth in new construction to the year 2003. The literature survey revealed large potential energy savings in residential single family homes. Existing and new duct systems were seen to be an average of 43.5 to 66.2 percent efficient, depending on the climate, duct location, duct leakage, and duct insulation levels.

Table 1 reveals the potential energy savings by region if hydronic or high velocity systems are utilized. Data from the Energy Information Administration (EIA) are shown in columns 1 through 3. Based on the EIA data and the average delivery effectiveness, the potential savings for alternative systems were computed. No data was available for the NE and WSC regions; therefore, estimates were made based on regions MA (for NE) and P (for WSC), which have similar duct conditions. The potential heating savings that would be realized using the hydronic system varies from 0.07 to 0.74 Quads and 0.05 to 0.60 Quads if the high velocity system is utilized. The hydronic h_{del} (95%) was extracted from the EIA Core Databook. The high velocity system efficiency (85%) was concluded from a field study. If standard duct systems are retrofitted, potential savings are projected to be 19 percent for all regions, and heating savings range from 0.03 to 0.27 Quads, as shown in Table 1. This percentage was concluded from evaluating field studies. As observed, the hydronic and high velocity systems provide substantially greater savings potential. The greatest heating potential savings occur in the NE, MA, ENC, WNC, and SA regions. The largest potential energy savings for cooling, which is much less than heating savings, occur in the SA region.

Table 1: Energy Consumption (EIA 1999) and Potential Energy Savings

Region	Homes (Millions)			Energy Use (Quads)		Potential Savings (Quads)					
						Hydronic η_{del}= 95%		High Velocity η_{del}= 85%		Retrofit Duct $\eta_{del, improvement}$• 19%	
	Homes	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
NE	5.30	5.20	2.50	0.43	0.00	0.22	0.00	0.18	0.00	0.08	0.00
MA	14.40	14.30	9.70	1.06	0.02	0.55	0.01	0.44	0.01	0.09	0.00
ENC	16.90	16.80	12.40	1.44	0.04	0.74	0.02	0.60	0.02	0.27	0.01
WNC	7.20	7.00	6.30	0.52	0.03	0.23	0.01	0.18	0.01	0.05	0.00
SA	18.70	18.30	17.20	0.51	0.14	0.20	0.06	0.15	0.04	0.05	0.01
ESC	6.30	6.30	6.00	0.22	0.04	0.07	0.01	0.05	0.01	0.03	0.00
WSC	10.80	10.80	10.00	0.36	0.11	0.10	0.03	0.07	0.02	0.07	0.02
M	6.20	6.10	2.90	0.29	0.02	0.09	0.01	0.06	0.00	0.03	0.00
P	15.60	14.90	5.70	0.36	0.02	0.10	0.01	0.07	0.00	0.05	0.00
Total	101.4	99.7	72.7	5.19	0.42	2.3	0.16	1.8	0.11	0.72	0.04

EIA's 1998 Core Databook shows that the total residential energy consumption has increased at an average rate of 15.5 percent per ten year period (1980 to 2000) and is projected to continue to increase at an average rate of 7.4 percent per ten year period (2000 to 2020). Thus, the potential savings noted in Table 4 will become substantially greater, making high velocity and hydronic systems more attractive alternatives.

The major findings from the forced-air delivery effectiveness evaluation are as follows:

– Existing and new duct systems deliver 43.5 to 66.2 percent of the energy to the conditioned space.

– From 1983 to 1998, the number of ducted homes ranged between 70 to 97 percent; 38 to 71 percent of the duct system were located in unconditioned space.

– From 1996 to 1998, greater than 94 percent of homes had duct systems; 47.6 percent of duct systems were in unconditioned space.

– Homes in SA, ESC, WSC, M, and P have the largest percentage of ducts in unconditioned space.

– Potential energy savings for the U. S. (Quads) are :
- 2.30Bheating, 0.16Bcooling (hydronic system)
- 1.80Bheating, 0.11Bcooling (high velocity system)
- 0.72Bheating, 0.04Bcooling (retrofit duct system)

– The greatest potential energy savings for heating occur in the MA, ENC, WNC, NE, and SA regions, accounting for 84.4 percent of the total.

– Potential energy savings for cooling is much less than for heating, with the greatest savings occurring in the SA region.

– Energy use is expected to increase over the next 20 years, thus potential savings from hydronic and high- velocity systems will become even more attractive.

HYDRONIC DISTRIBUTION

A field test was undertaken to investigate the operation of a hydronic system during the cooling season. The information from the study will be used to compare the performance of the hydronic system to forced-air distribution systems. The results from the study included the following measurements: 1) distribution efficiency and delivery effectiveness; 2) parasitic losses (pump and fan power) at different operating conditions to compare them against the fan and blower losses for other types of space conditioning equipment, such as electric heat pumps; 3) energy efficiency of the space conditioning equipment for comparison with equipment used with other distribution system types, such as conventional forced-air and high velocity forced-air distribution systems; and 4) ability of the hydronic cooling system to maintain the relative humidity and dry bulb temperature within the comfort range as specified by ASHRAE.

Hydronic distribution systems have been used for many years in residential applications to transfer energy from the HVAC equipment to the conditioned space. The majority of hydronic distribution systems are located in the northeast U.S. where they are primarily used in radiant floor applications. It is rare to see hydronic systems used for cooling due to perceived problems with condensate removal, noisy and inadequate fan coil designs, and cost. The field test will address these issues by investigating an improved condensate removal system, advanced fan coil units, and a low-cost, easily-installed CPVC hydronic distribution system.

The house used in the field test was a 4300 ft^2 (400 m^2), two-story home with a basement, located in Newark, New Jersey. The majority of the distribution piping is located in the basement with additional piping located in an uninsulated, unvented crawlspace and a garage. The basement ceiling was insulated to R-11. There were eight fan coil units throughout the house consisting of four 3500 Btu/hr (1026 W) capacity units and four 10,000 Btu/hr (2931 W) capacity units. The fan coil units are equipped with variable-speed, brushless-dc motors that consume 8.5 watts (small fan coil) and 15 watts (large fan coil) at the highest speed. The speed is controlled by the thermostat setting. Air enters from the bottom of the fan coil unit and exits though the top of the unit. The distribution piping is 1-inch (2.5 cm) CPVC with R-2.75 closed-cell foam insulation. Condensate is removed from the fan coil units by means of a PVC drain pipe that drains to a common PVC line piped to a drain. The chiller is a 48,000 Btu/hr (14069 W) unit equipped with two variable-speed condenser fans and a pump to circulate the chilled water throughout the distribution system. The chiller also employs a 20 gallon insulated storage tank to reduce cycling of the compressor during periods of low ambient temperatures.

The distribution system, chiller, fan coil units, and house were instrumented to determine distribution losses, equipment efficiencies, and indoor and outdoor ambient conditions. The distribution system losses for the fan coil units with pipes located in the basement were determined by first measuring the distribution loss to the farthest fan coil unit in the system from the flow rate and temperature difference. Next, the distribution losses for the other fan coil units were proportioned to the loss associated with the farthest coil according to their flow rates and piping lengths. Distribution losses for the fan coil units with pipes located in an uninsulated, unvented crawlspace and a garage were calculated in a similar manner as for the farthest piping run. Water flow rates for each fan coil unit were measured using high-precision turbine flow meters with an accuracy of +/- 1%. Temperature measurements were made from thermocouples inserted into the piping. The thermal energy input by the chiller in Btu/hr (W) was measured with a turbine flow meter and thermocouples at the inlet and exit to the chiller. Condenser fan, fan coil units, and pump power was measured with watt transducers to determine the parasitic losses. The fan coil units were also instrumented with RTDs at the air inlet and outlet. Using information from laboratory studies of the air flow rate as a function of energy consumption for the fan coil units, the inlet and outlet temperature measurements together with the power draw enabled a calculation of the sensible capacity for each fan coil unit. Indoor and outdoor temperature and humidity measurements were made at a single point inside and outside the house. The indoor sensor was placed in a centrally located two-story foyer. The outdoor sensor was placed in a shaded area and shielded from rain. The outdoor ambient conditions were compared against airport weather data where the airport was within 8 miles of the home. Data was taken at 30 second intervals and summed over a three-hour period.

Several significant findings were concluded from the field test. It was determined that the distribution efficiency of the hydronic system was quite high, ranging from 87.5 to 92.5%. Typical distribution system efficiencies for residential construction are in the range of 60 - 70%. Thus, the hydronic system is a significant improvement over conventional forced-air distribution systems and would result in large energy savings since the space conditioning equipment would have to provide less energy to meet the building load. In addition, to the energy savings, there would also be a first cost savings for the space conditioning equipment since it could be downsized since less energy input from the space conditioning equipment is required. However, these savings would probably be offset by the higher cost of the fan coil units.

One of the major criticisms for hydronic systems has been the parasitic losses associated with running the circulation pump continuously and having several fans running in the individual fan coil units. The fan coil units and the condenser fans in this study were equipped with variable-speed, brushless-dc motors that enabled the energy consumption to be greatly reduced. Even though the circulation pump was still allowed to run continuously, the high-efficiency fans enabled the parasitic losses to be reduced to a comparable level as those for conventional forced-air space conditioning equipment. Further reductions in parasitic losses should concentrate on using high-efficiency motors for the pump or control strategies for cycling the pump with the compressor. However, cycling the pump could result in higher relative humidity levels in the building.

Measurements for the chiller EER indicated that there is room for improvement to increase the energy efficiency to levels comparable for forced-air equipment. The chiller EER was approximately 9.2 at the 82.0°F (27.8°C) rating point for forced-air equipment. The value is 8.0% below the minimum 10.0 EER for forced-air equipment. The energy input to the hydronic system includes the compressor, condenser fan, circulation pump, and all the fan coil units. As previously mentioned, the fan motors have already been replaced with high-efficiency models. Thus, the only opportunity for improving the EER is to reduce the energy consumption for the pump, improve the compressor efficiency, or improve the heat exchangers to reduce the temperature difference.

The hydronic system did an excellent job of maintaining comfort in the house, even under outdoor conditions of high humidity and low dry bulb temperatures where conventional forced-air systems have trouble. The results showed that the set point temperature could have been raised to further reduce the energy consumption while still maintaining the comfort conditions in the house.

FORCED-AIR SYSTEMS

Activities were conducted toward evaluation of equipment design alternatives to improve field performance in two types of air-to-air-heat pump systems. Both involve air-to-air units operating at reduced airflow per unit capacity. The first activity is the evaluation of design options for better performance in existing unitary air to-air systems under reduced airflow. Evaporator coil designs are investigated that maintain higher air-side heat transfer performance as airflow is reduced. The second effort is a performance assessment and design improvement of alternative high velocity, low-airflow HVAC systems. These indoor unit alternatives are typically designed for half of the usual unitary airflow per ton of capacity. This is to minimize the fan power requirements for the high velocity duct system employed. As the size of these indoor cabinets are quite space restricted, a compact design that provides higher coil performance and lower fan power is needed.

The major efforts to date have been in assembling data sets of evaporator performance in both types of equipment over a wide range of potential airflows and in comparing this data to the coil models of public (the DOE/ORNL Heat Pump Model) and private (from a U.S. coil manufacturer) programs. A related effort has been to upgrade the DOE/ORNL Heat Pump Model to better predict the change in air-side heat transfer coefficients over a wide range of airflows and face velocities. New air-side correlations for flat, corrugated, wavy, louvered, convex louvered, and superslit fins were incorporated into the program. Explicit calculations were also added to account for the increased fin surface area from the enhanced surfaces and to handle fin efficiency calculations in a manner consistent with that used in developing the various correlations.

Data obtained for a conventional unitary design ranged from a design value of 425 cfm/ton (57 L/s kW) down to 125 cfm/ton (16.8 L/s-kW) with a corresponding range in face velocity from 235 to 70 fpm (1.19 to 0.36 m/s). Test data for the evaporator of state-of-the-art high-velocity unit operating with airflow ranged from its rated value of 180 cfm/ton to 400 cfm/ton (24.2 to 53.7 L/s-kW) with face velocities from 275 to 575 fpm (1.4 to 2.9 m/s). These two data sets provide a wide range of face velocities for use in validating the performance predictions of the public and private models used in the analysis.The high-velocity data sets show a slightly smaller drop-off in performance with fixed percentage reduction in airflow as compared to data for the conventional unit. Coil capacity predictions of performance drop off with reduced airflow are compared to these data sets for total, sensible, and latent contributions.

In addition to the modeling work, field measurements were performed on a house located in the southern U.S. to determine the distribution efficiency of a high-velocity forced-air system. The house is a 1680 ft^2 single-story with basement .The cooling ducts are located in the attic. The system has one return in the hall ceiling. The total area of supply ducts was 283 ft^2 with an average R value of 4.4. The total area of return ducts was 44 ft^2 with an average R value of 4.0. These are about 50% to 60% of the default values in ASHRAE Standard 152P (453 and 84 ft^2, respectively). This should help efficiency, as there is less than the usual amount of surface area for heat to conduct through. Supply duct leakage was measured to be 50 ft^3/min (24 L/s) and return duct leakage was 15 ft^3/min (7 L/s). The cooling equipment capacity was 42,000 Btu/hr (12,310 W).

Using the measured information from the house, calculations were performed for the distribution efficiency using ASHRAE Standard 152P. The distribution system efficiency for cooling was reported as 85%seasonal and 79% design. These are significant improvements over conventional forced-air distribution systems and close to the measured efficiencies in the hydronic distribution system field test.

APPENDIX TO THE DUTCH CONTRIBUTION

Is there a market for sustainable cooling?

Market research
for cooling with heat pumps
in newly-built houses

On the authority of Novem, number 345106.9904
P.O. Box 17, 6130 AA SITTARD, Tel. +31 30 4202202
Executed by BMT, Management- en Marketingadviseurs voor de bouw
P.O. Box 1206, 3500 BE UTRECHT, Tel. +31 30 2314714
Authors: Brenda van Rijn, Ton van Oostwaard

Utrecht, 16 September 2004

Summary and conclusions

1. The Market and developments within

Supposing that opportunities for heat pumps used for both heating and cooling initially will lie predominantly in the segment of newly-built owner occupied property, attention is focused on some 60.000 houses per year, whose characteristics are as follows:

- detached/two semi-detached houses: ± 25.000 dwellings;
  * ± 11.000 commissioned by private individuals (in particular detached)
  * ± 14.000 commissioned by property developers
- «more expensive apartments» : ± 10.000 dwellings;
- terraced houses: ± 25.000 dwellings.

After 2002, the annual number of newly-built dwellings is expected to drop. However, the relative demand for more spacious and more luxurious privately owned houses with a strong individual identity (detached or semi-detached) will grow.

The interest in the energy infrastructure at new construction sites has led to the distribution of heat becoming a major issue again. However, as new construction sites become smaller, small-scale concepts in particular gain greater recognition. The number of thermal solar systems and heat pumps, is behind the original objectives. With regard to technical developments, the following preconditions are relevant with respect to future use of heat pumps used for both heating and cooling:

- increased application of floorheating;
- still limited application of air heatingsystems, according to property developers;
- increased application of ventilation systems, including balanced ventilation systems.

Consumers are prepared to invest in durable options. At the same time, the investment should preferably have a reasonable payback time. At present, however, potential house buyers hardly have any choice in this respect, since others make the decisions for them. And once durable options are applied, information directed at consumers is still almost nil. In the light of the expectation that the housing market will shift from a seller's market towards a buyer's market, it will increasingly become more important to take consumer preferences into account.

2. Perception of heat pump systems

According to market parties, tightening the Energy Performance Coefficient (EPC) from 1.2 tot 1.0 will not immediate stimulate the application of heat pumps. However, it will more likely produce an increased use of balanced ventilation.

At the moment the market for heat pumps is largely a push market. Many of those interviewed belong to a relatively small group of innovators and/or motivated to make use of heat pumps mainly on personal grounds (concern about the future). An autonomous market demand for heat pumps for any other reason than the energy-saving potential is hardly noticeable.

With regard to the use of heat pumps, reluctant project developers have various doubts which should be dealt with. They question, for example, the actual return/saving in relation to the investment, the technical performance of the heat pump (in particular with regard to the level of comfort) and the organisation of supply (too many parties involved). Obtaining a Building Guarantee (GIW) for the entire dwelling remains an essential precondition (inspiring confidence).

3. Appreciation of the cooling function

Creating an autonomous market demand requires more than just creating an energy-saving concept. In the context of present energy prices and economic prosperity, an energy-saving technique does not have a great priority with consumers. Moreover, the interests of those who often decide on behalf of the consumers is not focused on the characteristics of this still rather costly energy saving concept.

Providing the cooling function with the heat pump system offers a extra value. But only in the rather limited market segment of (very) expensive private property, at least for the time being. The market sector of turnkey housing (commissioned by private clients) at the moment is an interesting specific market segment with immediate opportunities. The market of expensive housing (detached, two semi-detached, commissioned by property developers or private individuals) also deserves attention, particularly since the cooling function entails little additional costs. The price level, above which property developers would consider offering cooling (without being acquainted with the additional costs) is difficult to establish and mainly depends on the regional situation (tension between demand and supply) or personal estimations.

Market parties would prefer floor cooling systems instead of air-heating systems, at least for the time being, based on technical and economic considerations. With respect to the investment cost, air heating costs are slightly less expensive and already now meets the GIW conditions.

If cooling capacity is offered, performance measurements should be made available. This intrinsic cooling performance, however, is difficult to determine as yet. Whether or not peak cooling will be sufficient cannot be answered because the actual cooling performance of the concept is as yet unknown.

4. Programme of demands

Against the background set out above, a rough specification of requirements can be formulated which a heat pump concept (including cooling function) should meet. These key points have been established under the following assumptions:

- for the time being, the EPC will remain at 1,0;
- fiscal incentives still apply;
- demand and supply should match as much as possible (in the long run an autonomous demand should develop);
- the preferences of property developers and housing corporations deserve particular attention (consultants and contractors have different requirements).

Relative price:

- total cost price (currently some Dfl 30.000,-). Much consideration should be given to lower the costs (caused more by total heat pump concept than by cooling function), by way of:
  * offering more integrated systems (and consequently less labour-intensive)
  * mass-produced source systems
  * mass-produced heat pumps
- a difference in price between a concept without and with cooling is quite acceptable (= added value), but what exactly project developers are prepared to pay varies (partly due to actual performance, contribution to increased comfort, current options/costs, the way prices are established).

Relative importance:

- substantial energy savings (compared with improved high efficiency boiler);
- as yet not clear whether peak cooling is sufficient or total cooling is required, in relation to the performance of the heat pump concept, including cooling;
- minimal cooling in living areas (living room, bedrooms);
- no loss of comfort compared with present level (more in particular with regard to hot-water supply);
- minimise installation space through compact design;
- design must not obstruct flexible lay-out house;
- user-friendly:
  * easy to control
  * pattern of behaviour inhabitants must hardly interfere with performance of system
- no adverse consequences for occupant with regard to interior design;
- noiseless (live up to promised performances);
- possibly join in with other trends (for instance, «remote control»);
- if possible contribute to healthy indoor climate (anti-allergy);
- comply with GIW conditions.

Value perception:

- marketing approach (well-established firms have to adopt the concept);
- one all-in supplier;
- join in with trends (see: relative importance);
- successful demonstration projects:
  * results energy saving
  * performance in actual practice (experience inhabitants)
  * economic assessment: operating examples (in case of leasing)
- effective communication with appealing selling arguments (directed at municipalities, clients and future occupant).

Switch costs:

- quality assurance;
- transfer of knowledge;
- training consultants/contractors;
- if possible further reduction of running costs (in line with cutting back investment costs).

5. Concluding remarks

Heat pump concepts with additional cooling capability offer opportunities in the context of current developments in the housing market. A really big demand for cooling does not yet exist, but as is the case with many products and services, a trend may to a large extent be created. Initially, parties which are enthusiastic and in a position to offer the concept should be approached first (in particular turn-key builders).

Using the programme of demands gives opportunities to broaden the market. Notwithstanding the extra value of cooling, a reduced price as well as lower switch costs are required, with respect to the overall expenditure. Potential additional sales motives should also be looked into. In particular, if any operational profits do not accrue to the investor. In short, it is very much a matter of push and pull marketing. Support by the government, for instance by means of financial incentives and a further increase of the EPC remains a prerequisite for the time being.

Bibliographie

F. Beck, D. Gautier, G. Guyon, P. Auffret, P. Girault. *Report for the Internationnal Energy Agency (IEA) on annex 25 « Year-round residential space conditioning systems using heat pumps ». Task 1 : State of the art study.* Note EDF / Div. R et D HE-12/99/035, HT-34/99/012A, HE-14/99/xx, HE-15/99/019

W.R. Ruhnke, C.E. Keyes. *IEA annex 25 strategic space heating systems. Canada*. Ontario Power Technologies, 31 décembre 99

Dimitra Sakellari. *Final report for the International Energy Agency on annex 2525 « Year-round residential space conditioning systems using heat pumps ». Task 1 : State of the art study in Sweden*. Royal Institute of technology, department of energy technology, Stockolm, décembre 99

INTERNATIONAL ENERGY AGENCY
HEAT PUMP PROGRAMME

ANNEX 25

"Year-round residential space conditioning systems using heat pumps"

Tasks 2 and 3: Demonstration projects

Operating agent :

Electricité de France R&D Division (France)
Béatrice Escarnot
Phone: +33.1.60.73.63.75
e-mail: beatrice.escarnot@edf.fr

Participating countries :

France : EDF R&D Division (operating agent)
Netherlands : Novem, TNO
Sweden : Royal Institude of Technology
USA : Oak Ridge National Laboratory

1. Annex 25 objectives

Participants : France (Electricité de France), US (Oak Ridge National Laboratory), Sweden (Royal Institute of Technology), The Netherlands (NOVEM)

The objective of this Annex 25 is to define and show the technical feasibility of new packaged systems for year round residential space conditioning using heat pumps. These systems (which include all the components used in a heating / cooling system from the heat pump to the inside unit) target only residential dwellings and use either water or air as energy distribution vector. The work carried out within the framework of this Annex cover low initial and operating costs, comfort provided, suitability to customer demands, design / installation requirements, performances, integration in buildings and aesthetics.

The programme is divided into three parts :

- a state of the art study : analysis of existing system, market needs and demand, new concepts
- a co-operation with manufacturers on a new concept,
- demonstration and dissemination.

The state-of-art study is already achieved and a first report summarizes the main results[2] ; the appendix 8. recapitulates the conclusions issued from this task. Thanks to this analysis of the market and of heating and cooling needs in the different countries, each participant has been able to choose a system to focus on.

To fulfil tasks 2 and 3 objectives, demonstration projects have been carried out in 2000 and 2001. The main results and lessons learned are reported in this document.

2. French contribution

2.1 Scope

Annex 25 started in 1998; its objectives are to define and show the technical feasibility of new packaged systems for year round residential space conditioning using heat pumps. These systems target only residential dwellings and use either water or air as energy distribution vector. First, each participating country has produced a state-of-art study which contains an analysis of the existing systems, the market and the users' expectations, in order to define a new concept of heating/cooling system. Then demonstration projects have been launched to prove the feasibility and the performance of these systems.

The french contribution to annex 25 focuses only on hydronic systems. Some works have been conducted to improve the existing systems :

- control strategies of the heating/ cooling floor, more especially in summer to avoid condensation,
- performance analysis of fan coil units in order to develop a new prototype for residential dwellings : silent and small.

People's needs and expectations were investigated through several market studies and opinion surveys. They lead to avenues for new developments : aesthetics and noise levels are the most important criteria. It has been decided to focus on an hybrid system with heating/ cooling floor and fan coil units on the first storey. Indeed it offers an optimal comfort : a more efficient cooling at the upper floor and the heating/ cooling floor aesthetic and heating comfort is kept on the ground floor.

[2] **First report** : IEA – Heat pump programme / Annex 25 "Year-round residential space conditioning systems using heat pmps" – Task 1 executive summary : State-of-the-art study
B. ESCARNOT (EDF), February 2000 (HE-12/00/013)

EDF Research and Development carries out many on-site field tests, in order to validate the systems or to communicate on demonstration projects.
Two of them are presented in this report :

- demonstration project with ground source heat pump in the east of France,
- field test with the combined system (heating/ cooling floor and fan coil units).

2.2 House in Le Cannet (south east of France) with an hybrid system

2.2.1 Description of the project

This field test concerns a single new house in the south east of France, which has a mild climate.

Tableau 2.1 : House characteristics

5 rooms Surface 199 m^2 4 occupants Degree days in winter : 1619 (base 18°C) Heating loss : 6.7 kW	

Tableau 2.2 : description of the installation

Système de chauffage PAC PMER 10 réversible TECHNIBEL Cooling power 9,4 kW (35°C/7-12°C) Heating power 11,1 kW (7°C/45°C) Electrical power 3,62 kW (7°C/45°C) Backup power 3 * 4 kW Buffer tank 60 litres Circulation pump 1 * 132 W électrique Circulation pumps 2 * 93 W électrique **Emiters** Heating/ cooling floor ground floor Ducted fan-coils upper floor **Domestic hot water** : electrical accumulation	 

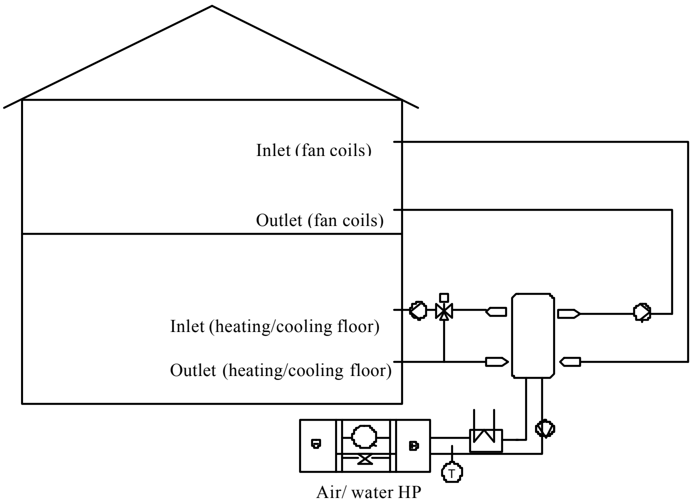


Figure 2.1 : Combined system (heating/ cooling floor + fan coils)

2.2.2 Results

2.2.2.1 Heating comfort

The comfort was very satisfying with a relatively high level of indoor temperature (20°C to 23°C), cf. **Figure 2.2**.

On the graphic, the room temperature declined during several hours, although the outside temperature is picking up. But meanwhile the fan-coils and the heat pump are less working, which probably means that the occupants had switched off the heating in this room.

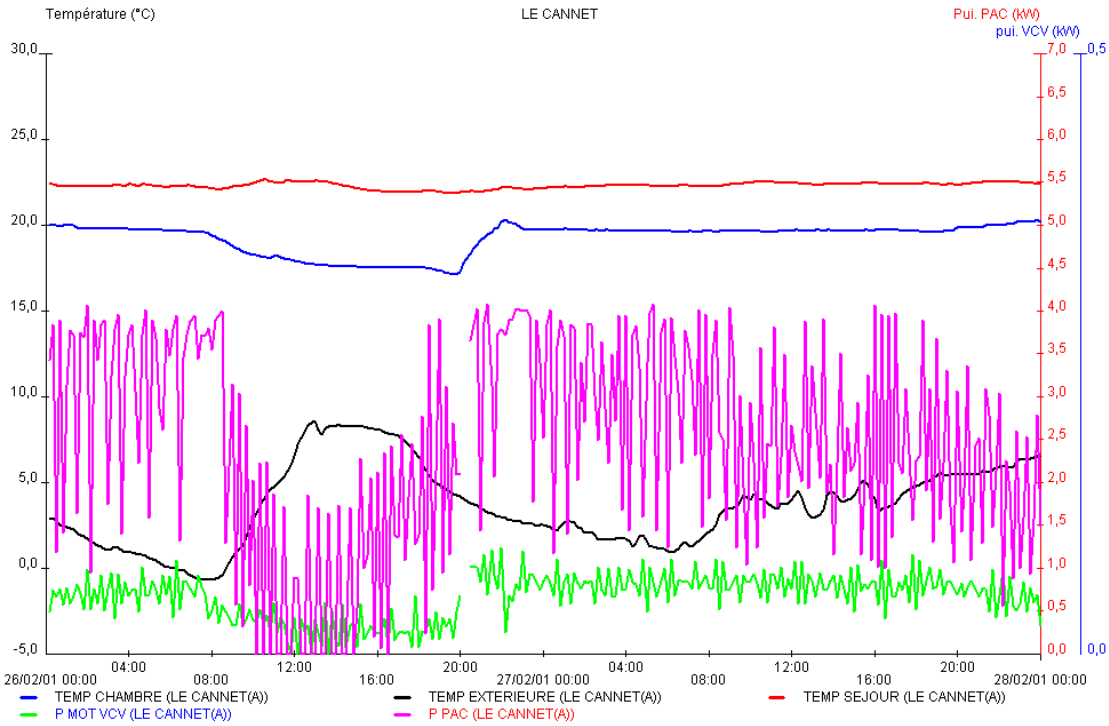


Figure 2.2 : niveau de confort et appels de puissance pendant les journées les plus froides

2.2.2.2 Cooling comfort

The set point in each room is 25°C, except in the living room where it is 27°C (due to a bad calibration of the thermostat).

The temperatures in the living room (ground floor) and in the bedrooms (upper floor) (**Tableau 2.3)** differ of about 3 °C.

This difference is partly explained by the different type of emitters; the fan-coils are far more efficient in the cooling mode than the cooling floor that can deliver a limited cooling power (max 30W/m²) : ***63%*** of the thermal energy is evacuated by the fan coils, and only ***37 %*** by the hydronic floor.

It is also important to note that all windows in the main rooms (32 m²) are facing south which is the worst configuration regarding summer comfort. Netherless, the system has proved its efficiency, especially at the upper floor with a water temperature of 11°C to 15°C, which is higher than usual but favourable for the heat pump performance.

	Min.	Moy.	Max.
T° extérieur	11°C	23°C	35°C
T° chambre	19°C	23.5°C	27°C
Séjour	23°C	26.5°C	30°C

Tableau 2.3: températures intérieures et extérieures au cours de la période de chauffage 2000/2001

During the warmest day in the summer, the outside temperature reached ***35,2 °C;*** **Figure 2.3** shows the efficiency of the fan-coils that were able to maintain 25°C indoor.

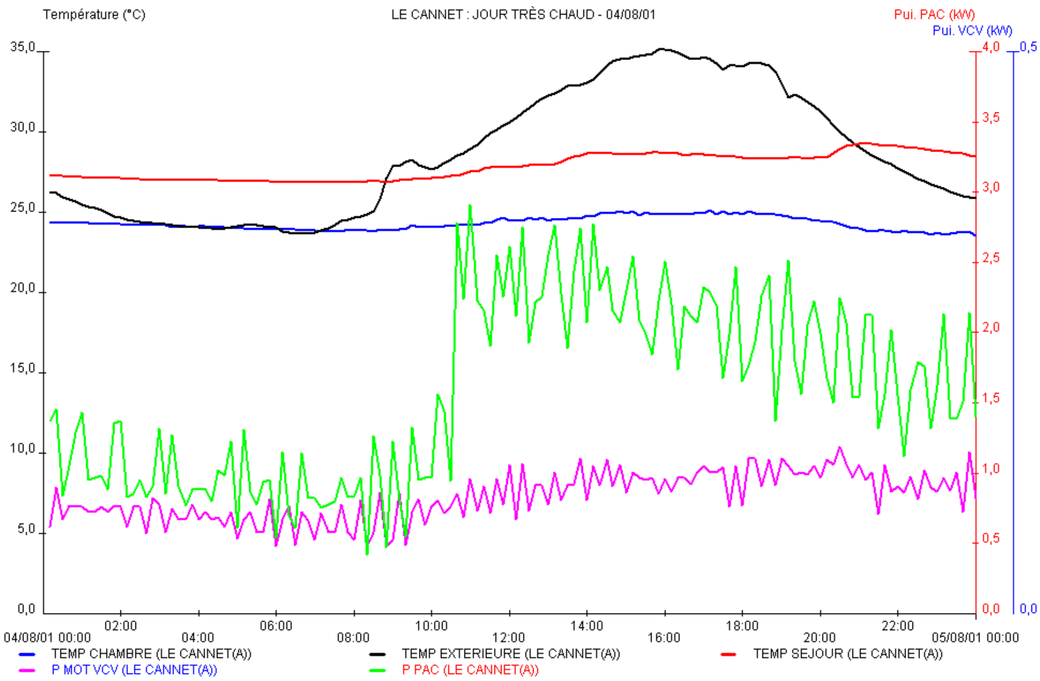


Figure 2.3 : Comfort and power during the warmest day (04/08/01)

2.2.2.3 Consumptions and costs

Heating (Figure 2.4) :
The pumps represent about ¼ of the total heating consumptions, which is too important and is a consequence of their permanent working.
On the contrary, the fans have represent a small percentage of the heating consumptions.

Cooling (Figure 2.5) :

The importance of the pumps consumptions is even higher during the summer as they represent 1/3 of the cooling consumptions.

Enslaving the pumps would be a major improvements of the system performance, especially in cooling mode.

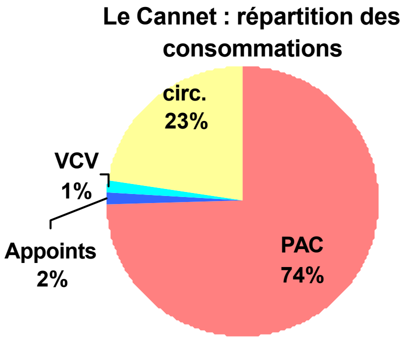


Figure 2.4 : Heating consumptions
(VCV = fan-coils, PAC = heat pump, circ. = pumps, Appoints = backup)

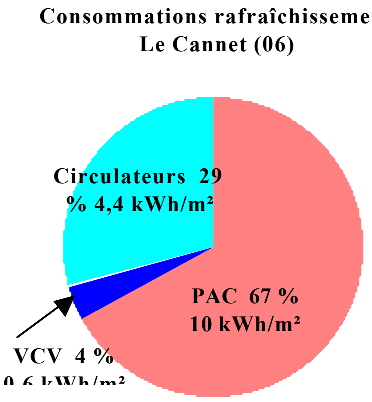


Figure 2.5: Cooling consumptions
VCV = fan-coils, PAC = heat pump, circulateurs = pumps)

Tableau 2.4: Energy and costs

	kWh	Part %	kWh/m²	FTTC	FTTC/m²
HP (heating)	5 233	74	26.3	3 190.4	16.0
Backup heating	113	2	0.6	42.6	0.3
Auxiliaries (heating)	1 686	24	8.5	945.0	4.7
Total heating	7 032	40.3	35.4	4 178.0	21.0
HP (cooling)	2 044	66	10.3	725.3	3.6
Auxiliaries (cooling)	1 060	34	5.3	338.5	2.0
Total cooling	3 104	17.8	10.6	1 113.8	5.6
Heating + Cooling	10 136	58	46.0	5 297.8	26.6
DHW	2 365	13.6	11.9	876 .0	4.4
Other appliances	4 926	28.3	24.6	2 281.4	11.5
tariff	/	/	/	2 285.3	11.5
Total	**17 427**	**100**	**82.5**	**10 735**	**54.0**

Tableau 2.5 : consumptions and costs (1 Franc = 0.15 Euro)

2.2.3 Users opinion

An interview of the users has been carried on.
This heat pump system has been chosen because of its longevity, reliability and safety.
They have appreciated the comfort provided but some changes on the fan-coils have been necessary at the beginning to reduce the noise.
The summer comfort in the bedrooms was excellent due to the fan-coils but by comparaison, they were bit disappointed by the cooling floor. Nevertheless, they have appreciated the comfortable diffusion of the hydronic floor in heating mode.
The investment cost is quite high but the occupants accepted to pay more in exchange of an improved comfort.

2.2.4 Conclusion and lessons learned

This system has been validated regarding the comfort provided in the house in summer and in winter.

But it is important to make an effort on the selection and the installation of the fan-coils regarding the noise level.

The system working could be improved by :

- enslaving the 2 of the 3 pumps ; that would save at least 50% of the auxiliaries consumptions.
- increasing the buffer tank capacity to avoid short working cycle. Also the water temperature could have been lower to increase the performance.

The cooling consumptions (15.6 kWh/m²) are probably the maximum that a house could have in France, as the windows were all facing south and the occupants have never stopped the cooling during the summer (may – September).

2.3 House in Avolsheim (East of France) with a ground source heat pump

2.3.1 Description of the project

A field test consists of a 120 m² single new house in the East of France (cold area) with a ground source heat pump for space heating. This project was included in a program aiming at developing ground source heat pumps with boreholes in France ; this was one of the first installations.

Figure 2.6 : House in Avolsheim

Tableau 2.6 : Building and design values

Location (place, country):	Avolsheim near Strasbourg, France
Year of construction:	1998
Heated floor area (m2):	120
Number of storeys:	2
% of total floor area (%):	100%
Design outdoor temperature (ºC)	-15°C
Design indoor temperature (ºC)	19°C
Degree days	2800
	-15°C
Design heat loss (kW)	6.2

Tableau 2.7 : description of the heat pump installation

Application	Heating		
Heat pump type(s) (eg air-to-air):	water-to-water	Manufacturer :	Waterkotte
Heat pump installed capacity (kW)	conditions	-5°C/-2°C ; 30°C/35°C	
	Thermal power	7.1 kW	
	COP or EFF	3.1	
Heat pump design :	115% of the design heating load		
Refrigerant:	R407c		
Heat source	ground source (borehole)		
Pumping power circulating pumps :	340 W		
Details / control :	240W (ground source, enslaved to the HP) 100W (heating floor / enslaved to the ambient thermostat)		
Borehole depth :	20m	Pipe length:	100 m
Heat transfer fluid:	glycol water		
Distribution : Supply water temperature (ºC): Set point depending on the outside T°C: Supplementary system :	heating floor 35°C YES Complementary electric heater in the bathroom		
Heat pump system completion date :	1998		

2.3.2 Results

The following tables recapitulate the main data collected on this site. The energy consumptions (28 kWh/m²) are really low compared to other field tests with air-to-water heat pump. Even though this site is located in one of the coldest area in France, the annual heating costs (2.6 Euro/m²) are lower than most of the results on houses located in a warmer climate (average between 3.8 and 4.5 euro/m²).
This is due to the good system performance (Heat pump COP = 3.2) and also to the efficient control strategy of the circulation pumps ; the distribution pump is enslaved to the ambient thermostat, which enables to save 50% of the consumptions when it works continuously.

The ambient temperature has remained comfortable (20 to 21°C on average) throughout the winter, even during the coldest days.

Tableau 2.8: Annual energy consumptions, costs[3] and performance

	Heat pump	Auxiliary heating system (Elec)	Auxiliaries: Circulation pumps, fans	Total
Heating				
Energy input (consumption) (kWh/year):	2788	20	583	**3391**
COP or efficiency	3.2	1	n/a	**2.64**
Energy cost (Euro/year) :	261.6	1.5	36	**310.7**
Cost tariff (EURO/kWh) :	0.094	0.076	0.062	**0.091**
Domestic hot water (DHW)				
Energy input (consumption) (kWh/year):		2524		**2524**
COP or efficiency		1	n/a	**1**
Energy cost (EURO/year) :		168.3		**168.3**
Cost tariff (EURO/kWh) :		0.067		**0.067**
Total (Heating, DHW, ventilation, other appliances…)				
Energy input (kWh/year):				**8976**
Energy cost (EURO/year) :				**969.5**

Capital cost (Heat pump system) 14270 Euro

Comparison with a conventional heating system

Type :	Gas boiler	Heating cost	304 Euro
Heat pump system (kg CO2/year):	395	Values for elec. (g CO2/kWh):	89
Conventional HVAC (kg CO2/year):	2370	Values for gas (g CO2/kWh) :	230

Comfort and working conditions	Heating season
Ambient T°C	20 / 21°C
Average source T°C (supply, return)	2°C / 5°C
Average distribution water T°C	30°C

[3] Tax included (32%)

2.3.3 Operating experience and feedback

The pump on the heating distribution is enslaved to the ambient thermostat which permits to optimise its consumptions (30% of energy saving compared to a permanent working).

The reliability is satisfying, as no breakdown has occurred and the heating costs.

With a COP of 3.2, the consumptions are really competitive compared to any other heating systems. The cost savings were about 30% compared to gas heating.

Regarding global warming effect, the CO2 emissions with the heat pump are 6 times less important than with a gas boiler.

Lessons learned :

- This project has helped to prove that the pump's working enslaved to the ambient thermostat does not degrade the comfort which was a debate between the HVAC actors in France. It permits to save 66% of the pump's consumptions.
- The measurements did not show any decrease of the soil temperature around the pipes.

3. Conclusions from the French Contributions

Heat pumps systems are a good solution for residential dwellings, especially for single houses. The results from the different field tests carried on by EDF since 1998 are really encouraging. They prove the benefits of heat pumps in residential in terms of energy and costs savings compared to any conventional system using gas or oil and also the reduced impact on the environment due to the low CO2 emissions (especially with the French kWh).
The project with the hybrid solution was really satisfying regarding the comfort provided. It has been validated through the measurements but also through the users'opinion.

For the future, the main issue to develop the market for heat pump in residential is to strengthen the quality of the installations ; the key to achieve this objective relies on the installers and it is necessary to work on a kind of certification to increase the HVAC actors' competence dealing with heat pumps.

4. Contribution of the Netherlands

Roberto Traversari, TNO Environment, Energy and Process Innovation, The Netherlands

4.1 Scope (General Description of the Project)

During phases one and two of the annex project, Itho B.V. (Schiedam, The Netherlands) and TNO Environment, Energy and Process Innovation (Apeldoorn, The Netherlands) jointly developed a total heat pump system for domestic residences. To collect system data during real operational circumstances, a field experiment was started at the end of 2000. This field experiment was also used during the final phase of the annex.

4.2 The Main Characteristics of the Residences and the Climate

The field test was carried out in two single family houses. According to NEN 5066, the design heat losses were 7860 Watt. The heat recovery unit was included in this calculation. The volume of each home is approximately 350 m^3, with a floor surface of about 135 m^2. The ground floor comprises a living room, kitchen, toilet, entrance, and broom closet (containing the heat pump). The first floor consists of a bathroom, landing and three bedrooms, while the second floor contains the attic. All the floors are heated and cooled by means of floor heating/cooling. The living room is provided with a fan coil unit. Most of the glass surfaces are found on the south side of the house. Figure 4.1 presents the climate data during the measuring period: the average outdoor temperature (on a day basis) and the total global solar radiation per day. Table 1 gives the summarised data.

Table 1. Summarised climate data.

Variable	Average	Minimum	Maximum
Temp [°C]	11.1	-4.8	24.9
Q_{sol} [J/(cm^2.day)]	979	14	3005

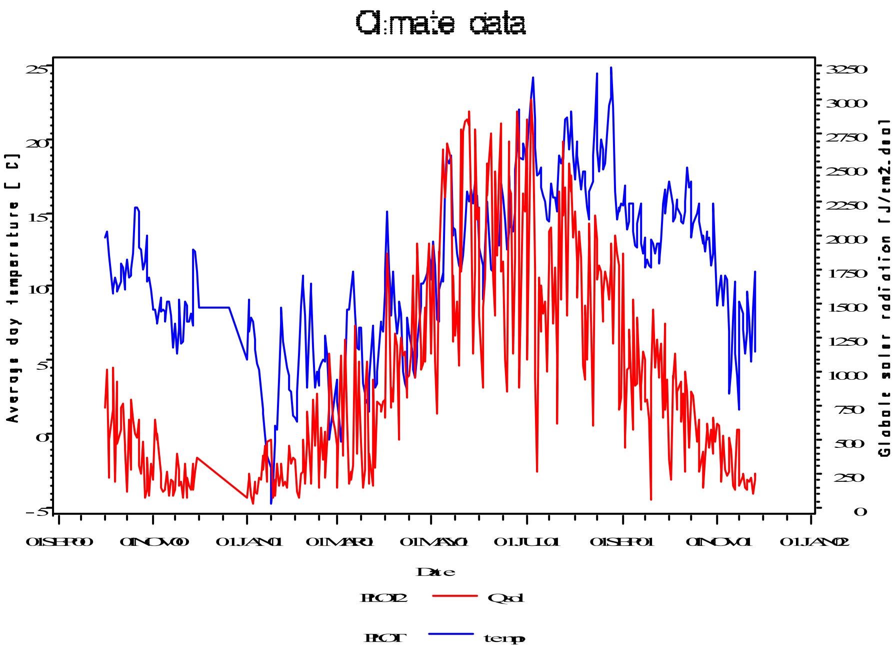


Figure 4.1. Climate data.

4.3 Description of the Heat Pump System

The heat pump system consists of a capacity-controlled heat pump (3 steps: 40%, 60% and 100%), a solar collector, a water-filled ground source heat exchanger and a floor heating/cooling system. The functions of this system are space heating, space cooling (free or passive), and domestic hot water production. Figure 4.2 gives a schematic presentation of the total system.

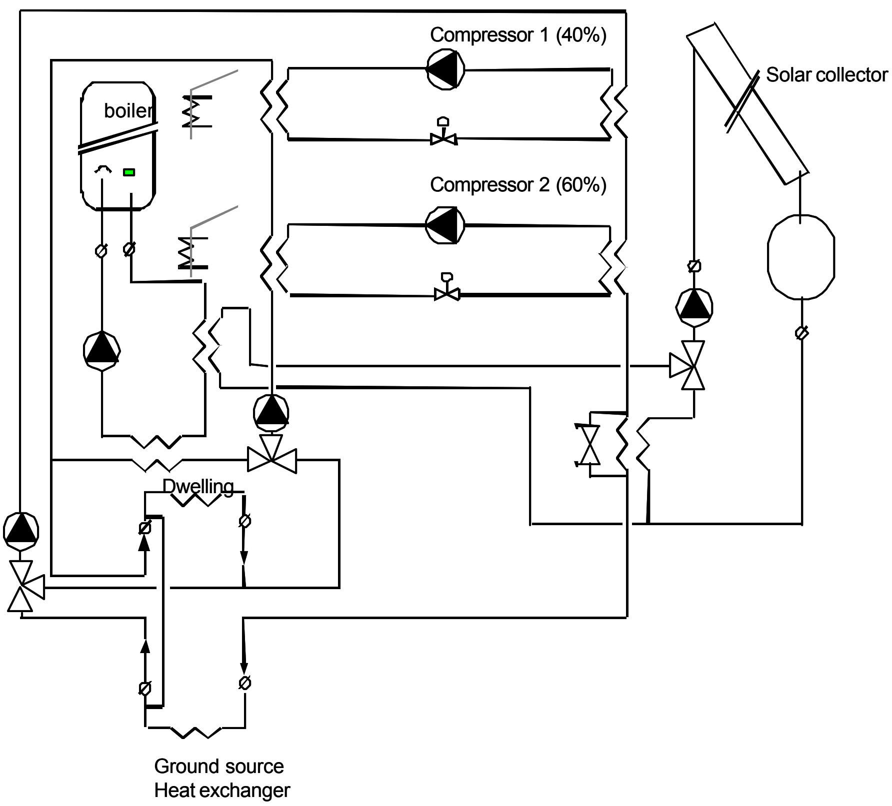


Figure 4.2. Schematic presentation of the total system.

Figure 4.3 and Figure 4.4 show how to install the total system in a home.

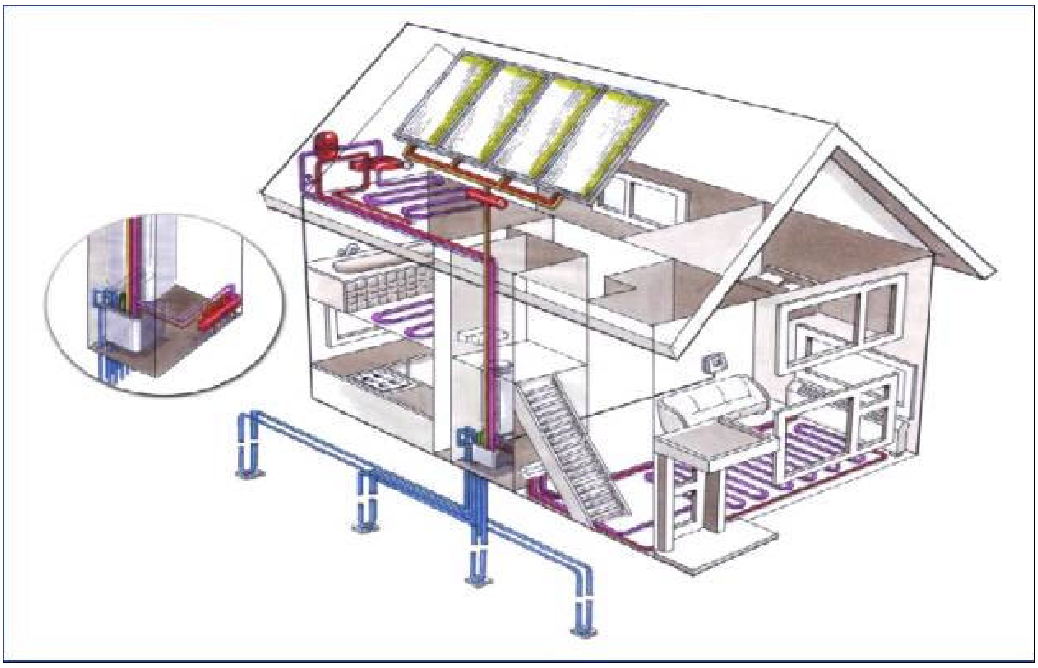


Figure 4.3. Total system installed in a dwelling.

Figure 4.4. Total system installed in a dwelling.

4.4 Results

In the two test houses, a data acquisition system was used to collect the data (every 10 seconds) and to transform the data into 10-minute values. Each month, the 10-minute values were automatically collected by a central computer. With the help of a software programme, the data were converted to information.

4.4.1 Definitions

4.4.1.1 COP

The COP is defined as the thermal energy output of the heat pump divided by the compressor's energy input.

4.4.1.2 SPF

The SPF is defined as the thermal energy output of the system (added to the house) divided by the energy input of the system (compressor, fans, pumps, control, auxiliary heaters, etc.).

4.4.1.3 PER

The PER is defined as the thermal energy output of the system (added to the house) divided by primary energy input of the system (compressor, fans, pumps, control, etc.).

4.4.1.4 Efficiency passive cooling

The "Efficiency passive cooling" is defined as the thermal energy extracted from the house (cooling) through the system divided by the system's energy input (fans, pumps, control, etc.).

4.4.1.5 Carnot efficiency

The Carnot efficiency is defined as the ratio between the COP and the Carnot factor.

4.4.1.6 Carnot factor

The Carnot factor is defined as the ratio between the outgoing water temperature in K (condensing side) of the heat pump and the temperature difference between the outgoing water temperature of the condensing and evaporating side of the heat pump in K.

4.4.2 Monitoring results

The results in the figures are the weekly average values.

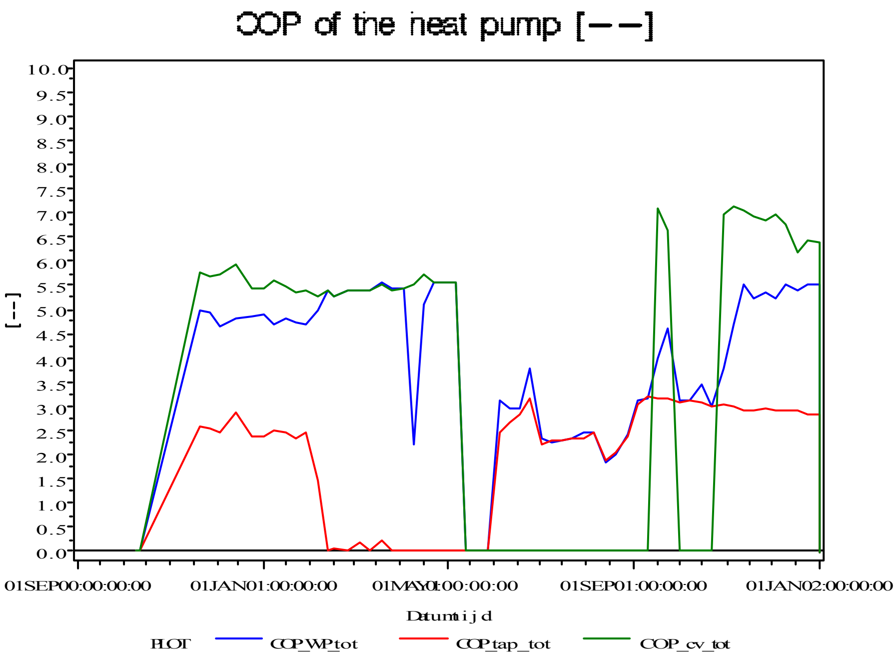


Figure 4.5. COP of the heat pump.

Where:

COP_WP_tot	= COP of the heat pump space heating and domestic hot water
COP_tap_tot	= COP of the heat pump for domestic hot water only
COP_CV_tot	= COP of the heat pump for space heating only

The results show that the COP of the heat pump is quite high (approximately 5.5) for the space heating function. For the preparation of domestic hot water with a temperature of >55°C, the COP is approximately 2.75. The year-round overall COP of the heat pump for both functions is 5.0.

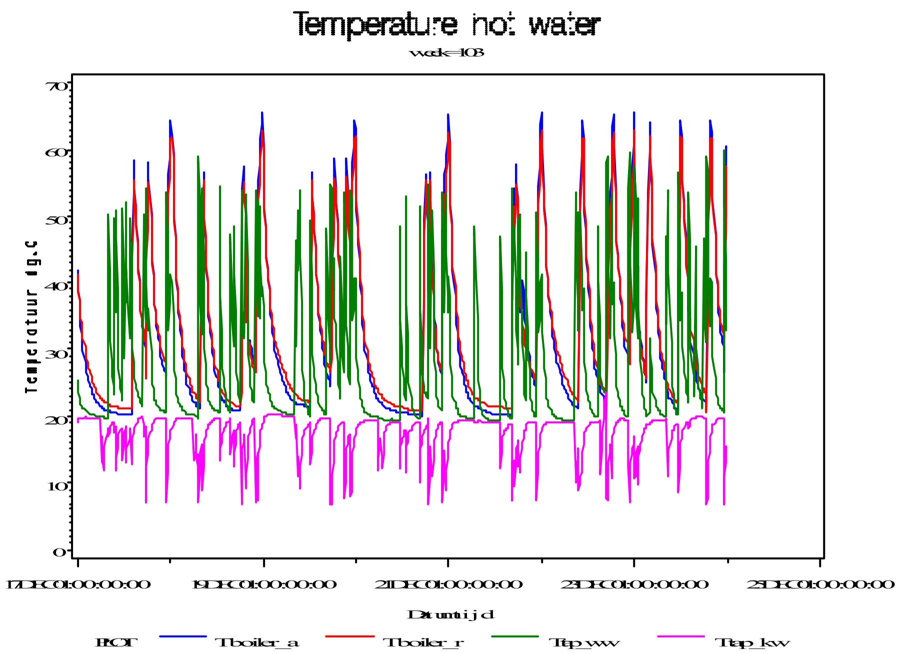


Figure 4.6. Temperature hot water.

Where:

Tboiler_a	= Forward temperature of the hot water during heating up the boiler
Tboiler_r	= Return temperature of the hot water during heating up the boiler
Ttap_ww	= Hot water temperature during draw off
Ttap_kw	= Cold water supply temperature

Tboiler_a	= Forward temperature of the hot water when the boiler is being heated
Tboiler_r	= Return temperature of the hot water when the boiler is being heated
Ttap_ww	= Hot water temperature during draw-off
Ttap_kw	= Cold water supply temperature

Figure 4.6 shows the temperature of the hot water during the heating-up period (Tboiler_a, Tboiler_r) and during the use of hot water. Every evening, the water in the boiler is heated up up to 65°C; during the day it is kept at 57°C.

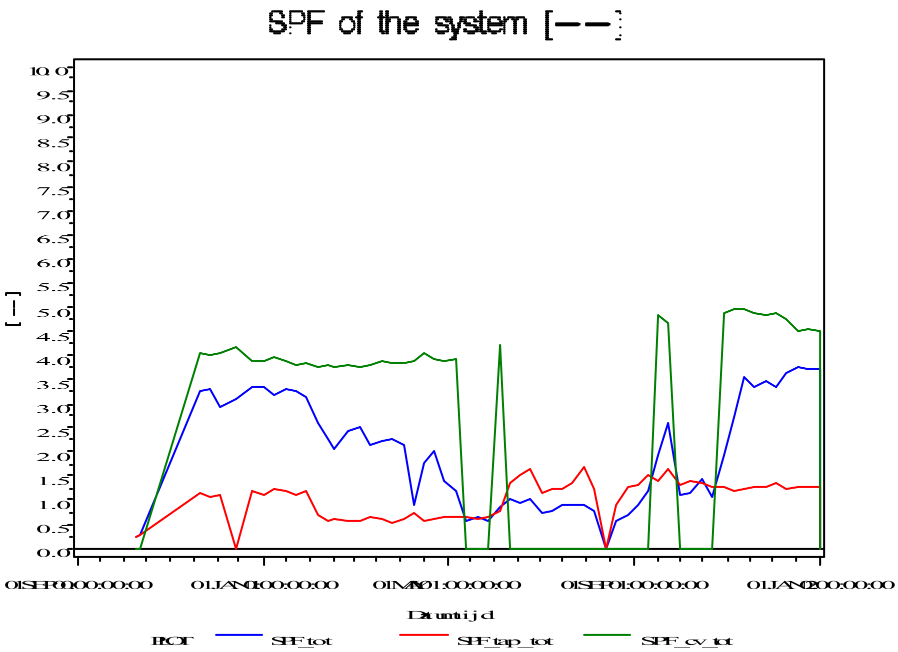


Figure 4.7. SPF of the heat pump system.

Where:

SPF_WP_tot = COP of the heat pump space heating and domestic hot water
SPF_tap_tot = COP of the heat pump for domestic hot water only
SPF_CV_tot = COP of the heat pump for space heating only

Due to the energy consumption of the circulation pumps, controls and energy losses in the boiler, the SPF for space heating is approximately 4.25. The SPF for domestic hot water seems to be quite low. However, this is caused by the additional electric heater that was used from February to June 2001. It was necessary to use this electric heater because of a problem with the capacity (temperature) of the water-filled ground source heat exchanger (Figure 4.11).

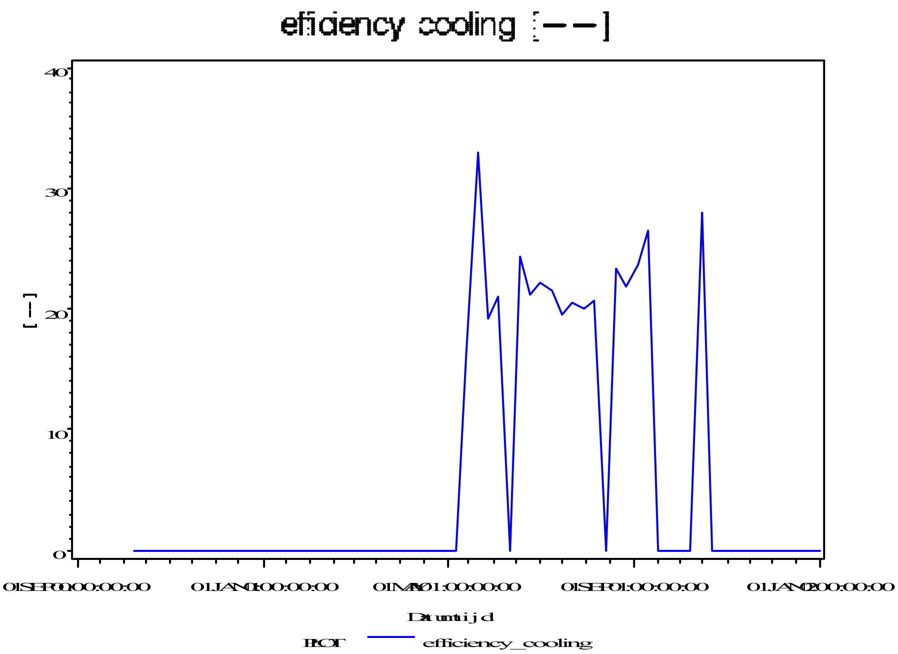


Figure 4.8. Efficiency of passive cooling.

The efficiency of passive cooling is very high, approximately 23. For this type of cooling it is only necessary to use a circulation pump that circulates the water through the floor heating system and the ground source heat exchanger. The disadvantage of this system is that the cooling capacity is limited and it is not possible to dehumidify. Nevertheless, the end users are very satisfied with the system's extra comfort; the efficiency of passive cooling cannot be reached with an active cooling system such as an air conditioner.

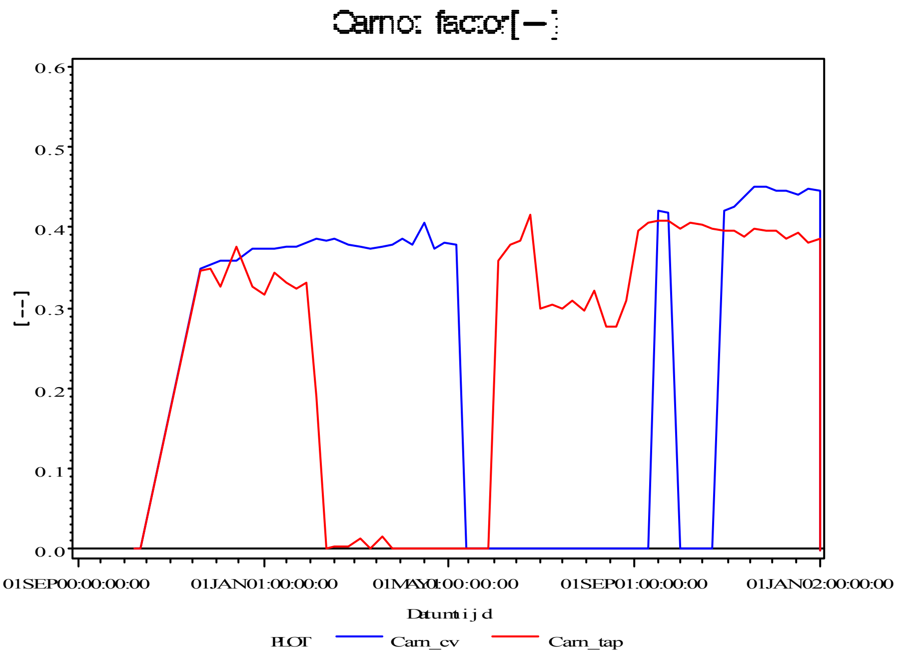


Figure 4.9. Carnot factor of the heat pump based on external temperatures.

Where:

Carn_cv = Carnot factor space heating

Carn_tap = Carnot factor domestic hot water

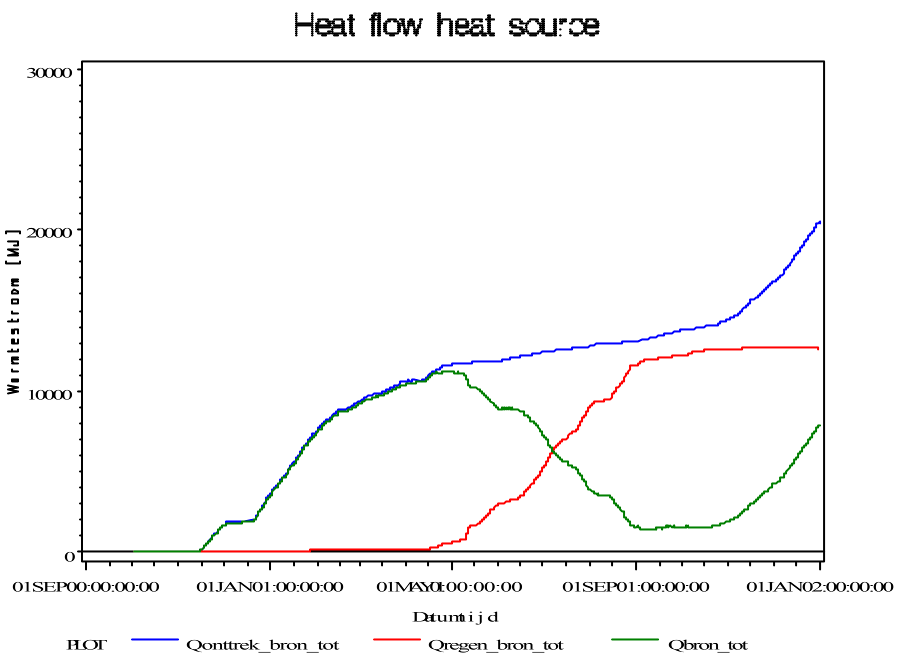


Figure 4.10. Heat flow ground source heat exchanger.

Where:
Qonttrek_bron_tot = total amount of heat extracted from the ground
Qregen_bron_tot = total amount of heat supplied to the ground
Qbron_tot = total amount of heat extracted and supplied from the ground

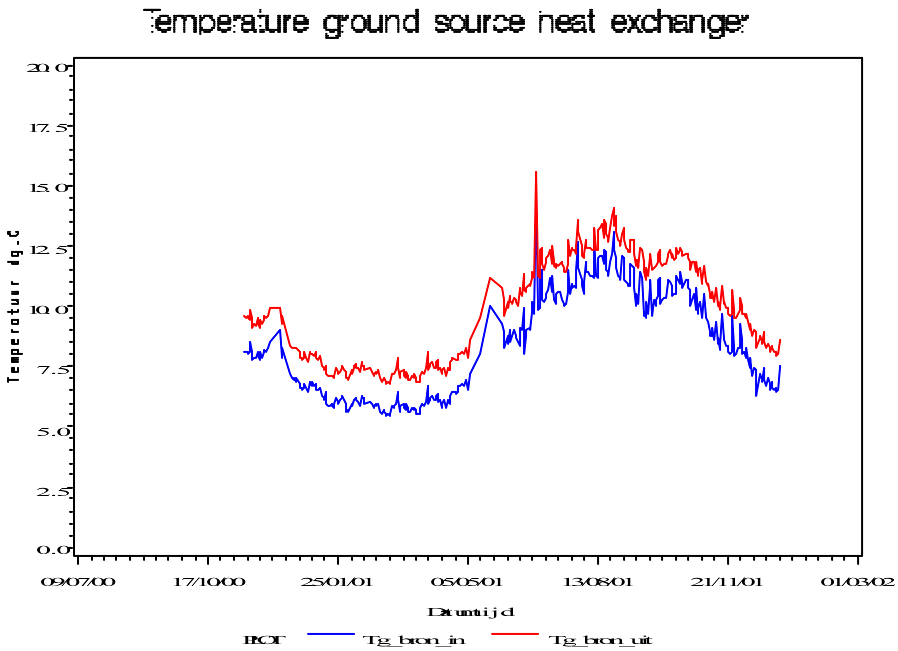


Figure 4.11. Temperature ground source heat exchanger.

Where:
Tg_bron_in = the average weekly ingoing temperature of the ground source heat exchanger
Tg_bron_uit = the average weekly outgoing temperature of the ground source heat exchanger

4.5 Conclusions

4.5.1 System performance

Chapter "Results" shows that the performance of the total system is good. The seasonal performance factor (SPF), however, is low (2.25) due to the fact that it was necessary to use the additional electric heater for domestic hot water during the period from February to June 2001.

Due to the free cooling the net extracted heat from the soil is small. The amount of heat extracted is about 5555 kWh and the supplied heat is 3610 kWh.

The hot water temperature (> 60°C) is quite high for a heat pump system.

4.5.2 Users opinion

The end users are very satisfied with the heat pump system. The comfort realised was very good. They rated the passive cooling of the home as especially important. Due to the high electricity rates (day rate 0.1808 €/kWh, night rate (11:00 pm – 7:00 am) 0.1261 €/kWh) compared with natural gas (0.3566 €/m^3 = 0.0365 €/kWh), the energy bill was higher than expected. This was partly a result of the use of the electric heater in the boiler during the period from February to June 2001.

4.5.3 Lessons learned

The dimensions of the ground source heat exchanger are very critical. If the heat exchanger is too small, serious problems will arise due to the fact that no additional heater is used and that the heat exchanger is filled with pure water so the minimum source temperature is limited.

4.6 Possible optimisations

The solar collector only contributes slightly to the hot water heating. The contribution from the solar collector to the regeneration of the soil, however, is substantial. The energy supplied to the soil is more or less equal tot the amount of heat extracted from the house during free cooling in the summer.

4.6.1 Non-technical issues

In the Netherlands, Primary Energy Saving will not necessarily lead to savings in the energy costs. The year-round COP of the heat pump should be at least 2.5 to save primary energy and the year-round COP should be at least 4.2 to save energy costs as well. The calculation of the minimum COP required for saving costs is based on the assumption that 50% of the energy is used during the day period, an efficiency of the reference 97.5% situation (gas-fired condensing boiler) and an efficiency of 39% for the electricity production and transportation.

5. CONTRIBUTION OF SWEDEN

The main target of this project is to study and visualise the energy savings and the working conditions of a modern HVAC-heat pump application in an old, renovated house. Performance results together with on-site field tests are our main contribution in order to complete the dissemination task of the Annex-25.

5.1 Project description

The air-conditioning system consists of a ground-coupled heat pump, which is connected to a hydronic heat distribution system based on radiators and floor heating. The radiators are placed on the ground and first floor. Their design is quite old with large surface areas. Due to their construction they allow for using a rather low water supply temperature. The floor heating system serves for covering the heating demand of the bathroom and the laundry room in the cellar and it is connected to the radiators' return water with the ability of shunting some portion of the supply water.

The heat pump prepares also hot sanitary water. During summer time the heat source's brine is used for providing comfort cooling via its circulation through the borehole and the two air convectors that are placed on the ground and first floor.

The measurements aim at providing an overall picture of the comfort system and its function. Due to this reason, the measuring techniques are applied on, besides the heat pump, all its surroundings like the heat distribution system, the brine circuit, the outdoor temperature and the inner climate. Moreover, another purpose of the measuring project is to find out any possibility for developing new methods of field measuring by using simple equipment.

In order to allow studies of the dynamic behaviour during compressor start up, the time span between each measurement is kept short (6 measurements/min). The long test period enables observations of differences in operating conditions between seasons. Since the project generates an enormous amount of data, much effort has been put into developing computer programs for automatic data handling and report generation. An HP 34970A is used for data acquisition. This unit is connected to a personal computer (Pentium II 233 MHz, 64 Mb ram) from which a computer program developed in HP-VEE controls all measurements. The monitored data are then saved in a Microsoft Excel file. In order to simplify interpretation of the measurements and for safety reasons, the program creates automatically a new file each day.

All temperatures are measured with calibrated resistance thermometers (PT 100). Mass flows in the cooling and heat distribution circuit are measured by magnetic flow meters (BadgerMeter Magnetoflow Primo). The total electric power input, comprising compressor, brine pump, heat distribution pump and electric auxiliary heater is measured by the test pulse (30720 pulses/kWh) of a modified electric energy meter (ENERMET SK320NXE-100). The compressor power input is additionally measured separately by a meter of the same kind.

5.1.1 Main building characteristics and climatic information

The current project takes place in a detached, one-family house in Katrineholm, situated 170 kilometres southwest of Stockholm. The house consists of two floors each one is 70 m^2, and a furnished, heated cellar of 50 m². It was built in 1938 with a rather practical style. After its construction it has undergone many renovations and the placement of additional insulation has been one of them. The windows are made of two-glass layers. When the house was built it was supplied with a hydronic heat distribution system based on radiators and the water was heated with a multi-boiler designed for burning coal and oil. Afterwards, the boiler was replaced by an electric-boiler. The radiators are of an old type with a relatively large water volume. The dimensioned temperature levels for the system of radiators could not be reached but thanks to the house's extra insulation and the relatively large surfaces of the radiators it was decided that they were suitable to be connected to a heat pump.

The climate is characterised by long cold winters and mild summers. The outdoor design temperature is –20ºC. The heating season lasts 7 months, though the cooling season varies from year to year. The summer can be wet and cool and in such a case there is no need for cooling. However, it can be rather warm also. Then there might be cooling requirement for a period of one-two months.

5.1.2 Description of the system

As already mentioned, the air-conditioning system consists of a ground-coupled heat pump, which is connected to a hydronic heat distribution system based on radiators and floor heating. The heat pump prepares also hot sanitary water. During summer time the heat source's brine is used for providing comfort cooling via its circulation through the borehole and the two air convectors placed on the ground and first floor. Table 1 below shows the main design characteristics of the heat pump.

Table 1. Design specification of the heat pump.

Heat Pump	Thermia VillaClassic 55
Compressor	Copeland Scroll
Refrigerant	1.4 kg R404a
Nominal Heat Output	5.4-5.0 kW
COP (heat)	4.2-2.8
Electric Auxiliary Heat	6 kW
Volume Domestic Hot Water (DHW) Container	150 l
Estimated Maximum Heat Load	8.7 kW
Annual Heat Load	25000 kWh
Annual Heat Load DHW	5000 kWh
Indoor Temperature	20°C
Yearly Mean Temperature (Katrineholm)	6.2°C
Outdoor Design Temperature	-20°C
Calculated Heat Output Heat Pump	22 880 kWh/year
Calculated Total Energy Coverage	91.5%
Balance Temperature	-3.3°C
Calculated Seasonal Performance Factor (SPF)	2.78
Calculated Annual Energy Saving	16 010 kWh
Active Borehole depth	83 m

The supply and the return water temperature of the heat distribution system as well as the outdoor temperature are measured by the internal control system of the heat pump. The heat pump is controlled from curve steering, i.e. every outdoor temperature corresponds to a predefined supply water temperature. Preparation of domestic hot water has priority when there is a simultaneous demand for heating and domestic hot water heating. The heat pump is turned off when the return water temperature exceeds 48°C, in order not to go beyond the maximum operating pressure. Figure 1 that follows shows the schematic layout of the installation.

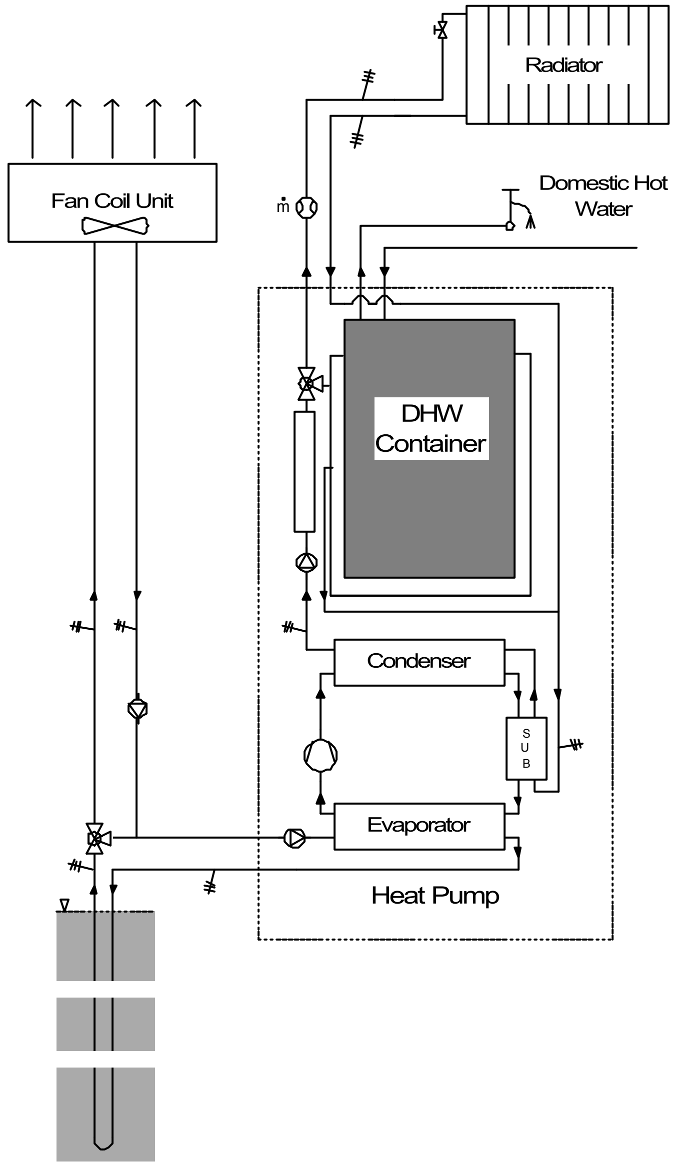


Figure 1. Schematic layout of the heat pump installation.

5.2 Results

Measurements were taken until the end of August 2001 and the preliminary results show that the system is running satisfactory. The system continues its operation until now in an excellent manner with no serious complains by the occupants.

Heating mode: Measured values for a typical operation day and the coldest day in the heating season are shown in figures 2 and 3. The figures show the variation of the supply and return water temperature as well as the compressor power. As can be seen in figure 3, the compressor is required to run about 7h non-stop.

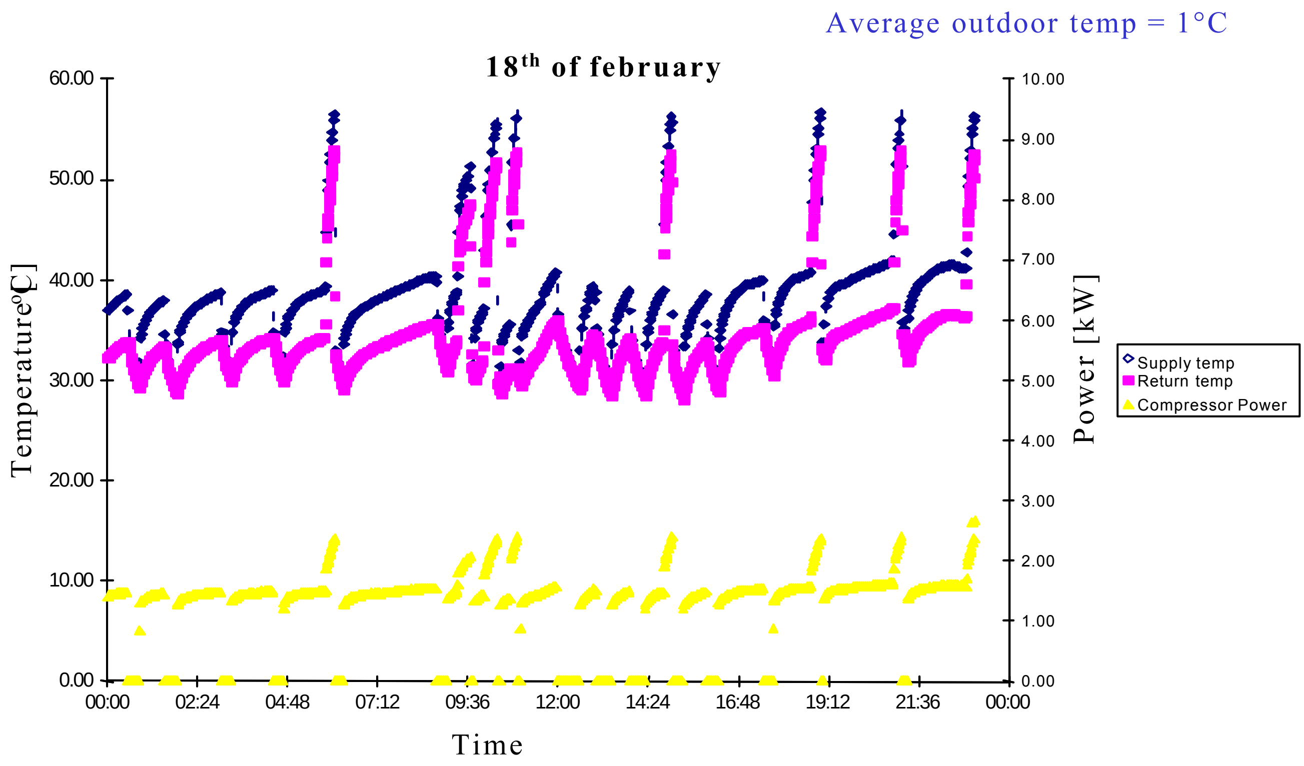


Figure 2. Monitored values for a typical operation day in February.

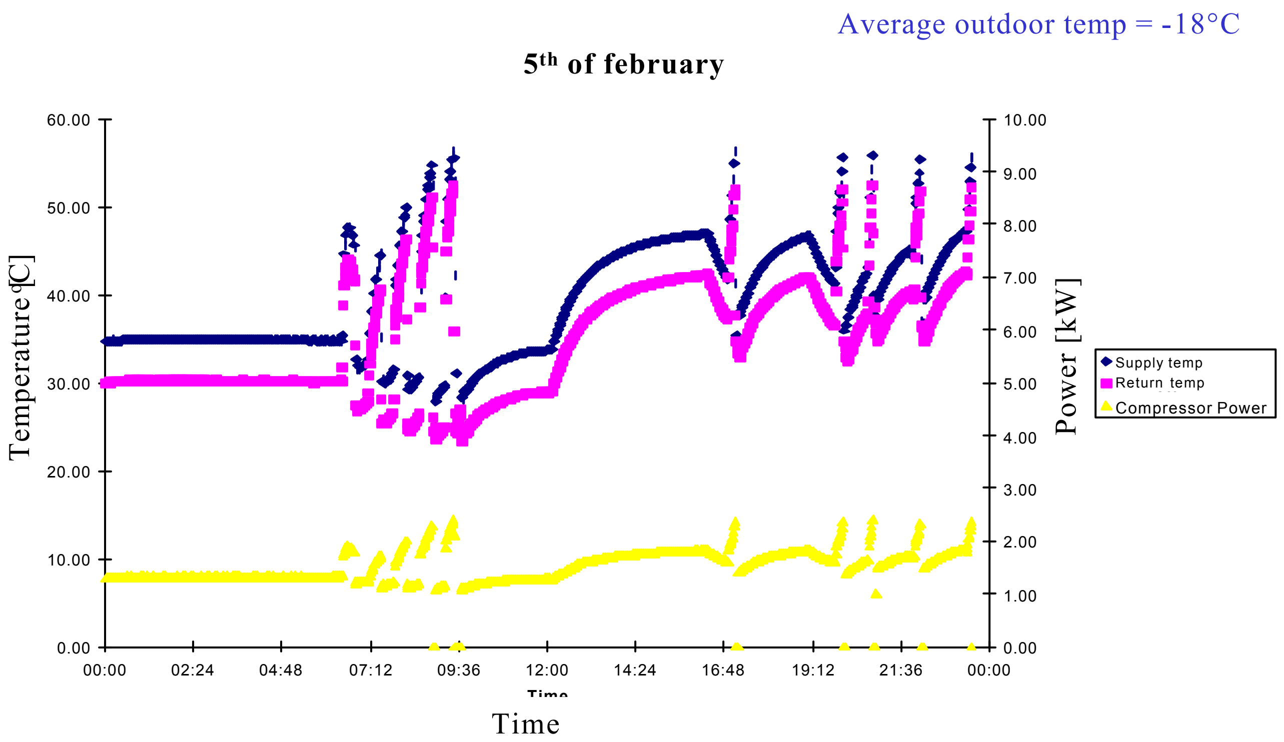


Figure 3. Monitored values for the coldest day in the heating season.

Figure 4 depicts the outdoor temperature in February, which is also the coldest month of the year. The indoor temperature is kept to 20ºC, except the very cold days. These days it decreases slightly and it remains around 18-19ºC. Figure 5 illustrates the temperature of the free water in the borehole from October 2000 to March 2001.

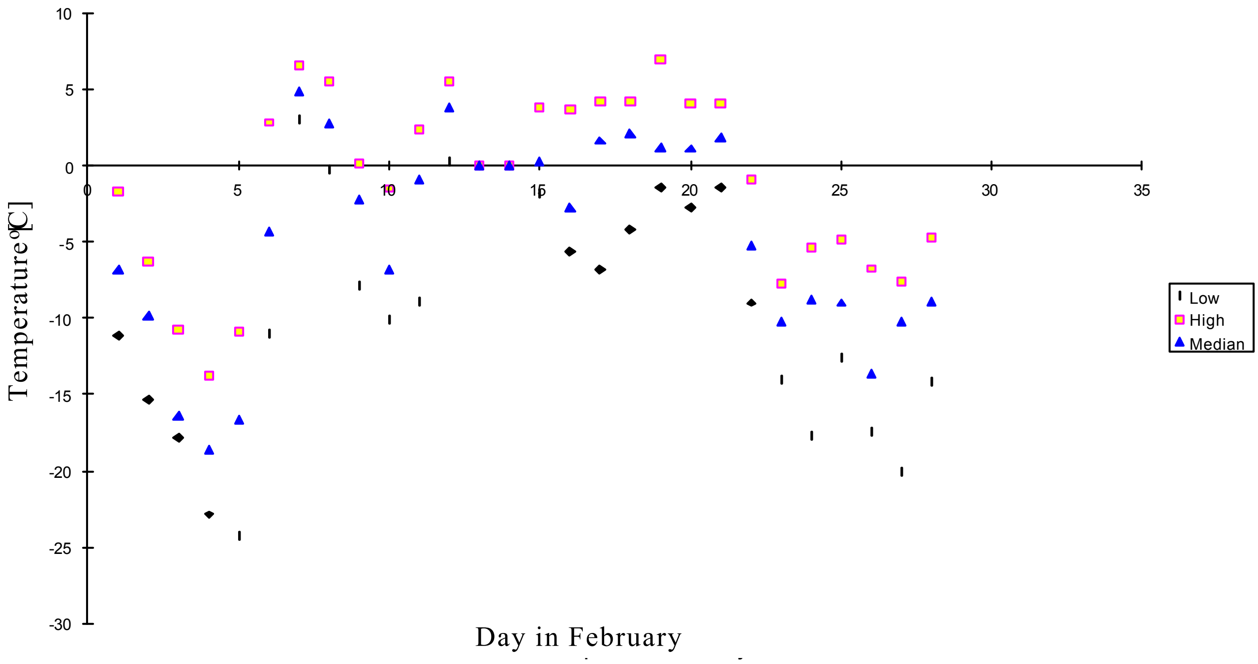


Figure 4. Outdoor temperature in February.

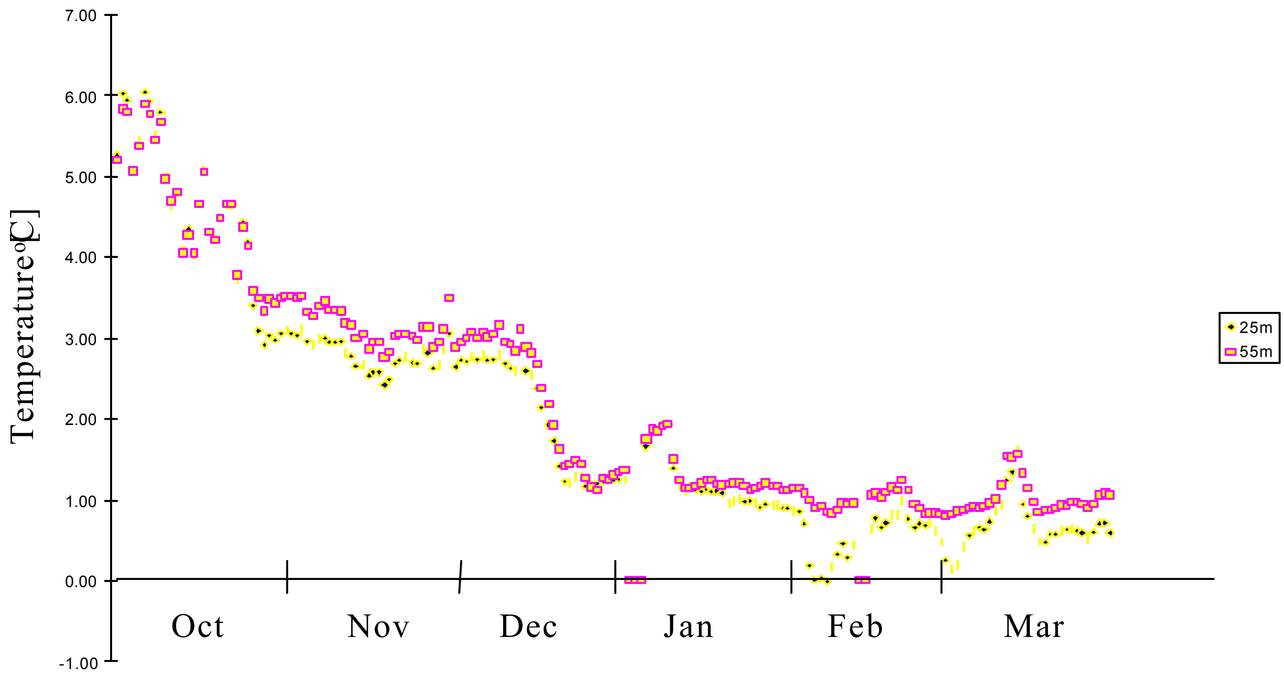


Figure 5. Temperature of free water in the well from October 2000 to March 2001.

Cooling mode: The cooling demand usually occurs during heat waves, which might take place at any time between late May and mid August. The cooling mode was tested in two summers. The first summer was rather wet and cold and there was not any demand for cooling in the house. In fact there was a heating demand from time to time. The cooling mode was activated for a few test cycles to enable checking of instruments and valves in the cooling circuit. The second summer was quite warm and there was cooling requirement in several occasions.

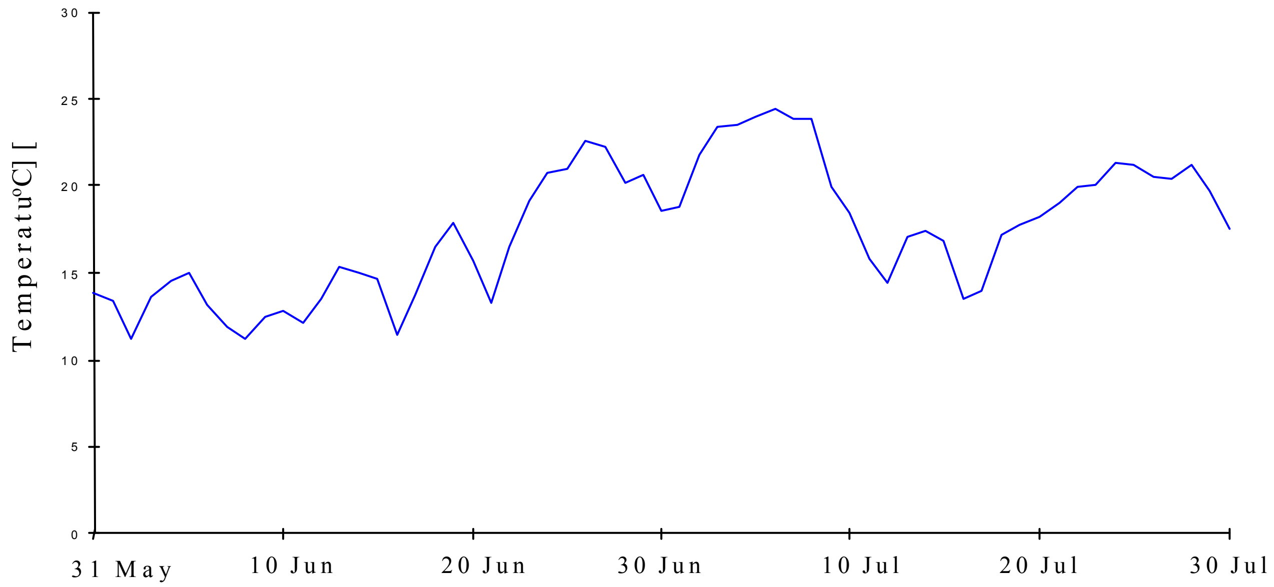


Figure 6. Daily mean temperature in June and July 2001.

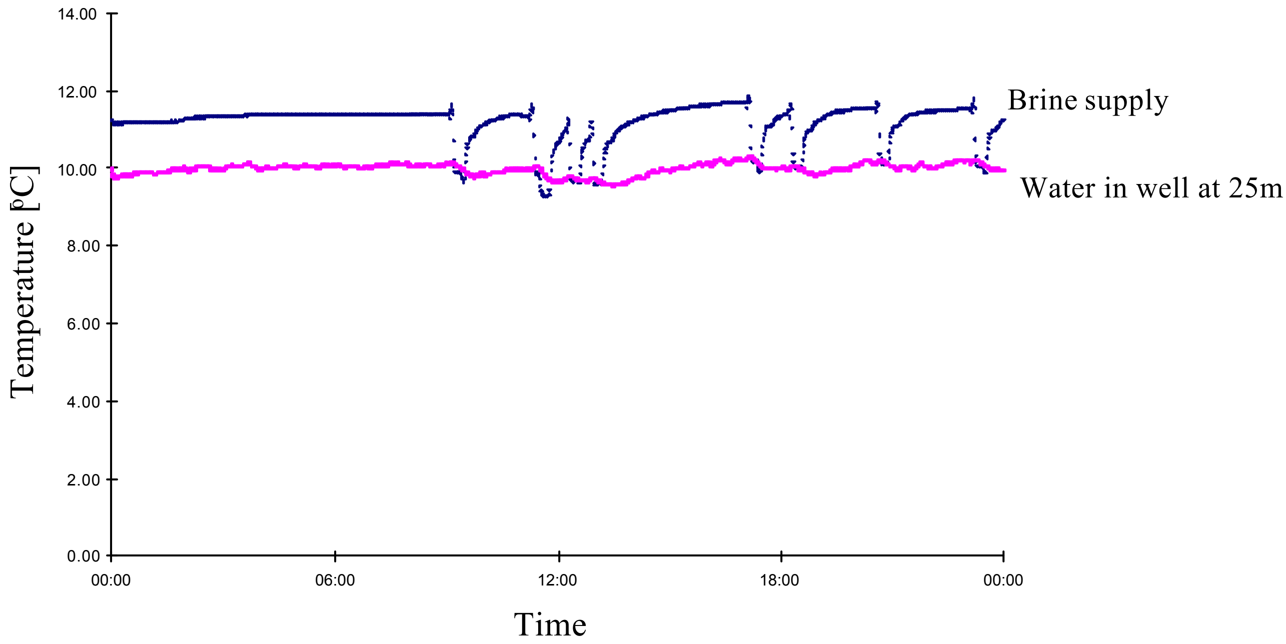


Figure 7. Indoor and outdoor temperature for the 7th of July.

Figure 6, above, shows the daily mean temperature for June and July in the summer of 2001. As can been seen, the daily mean temperature had a peak in the beginning of July and the application was running in the cooling mode during this period. Figure 7 above illustrates the indoor and outdoor temperature for the 7th of July. Figure 8, that follows, shows the supply brine temperature and water temperature in the borehole at 25 m depth for the same date.

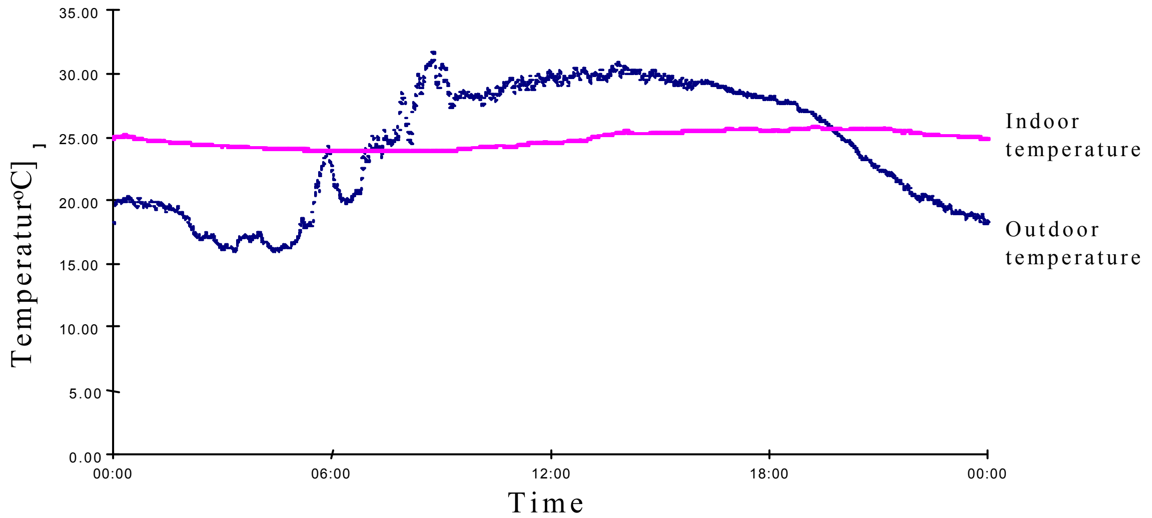


Figure 8. Brine supply temperature and water temperature in well at 25 m depth for the 7^{th} of July.

Annual heating operation: The measurements taken for the first year in operation showed that the total thermal requirement was 24 MWh and 97% of this was covered by the heat pump. Figure 9, below, shows the total energy requirement for the season October 2000-September 2001.

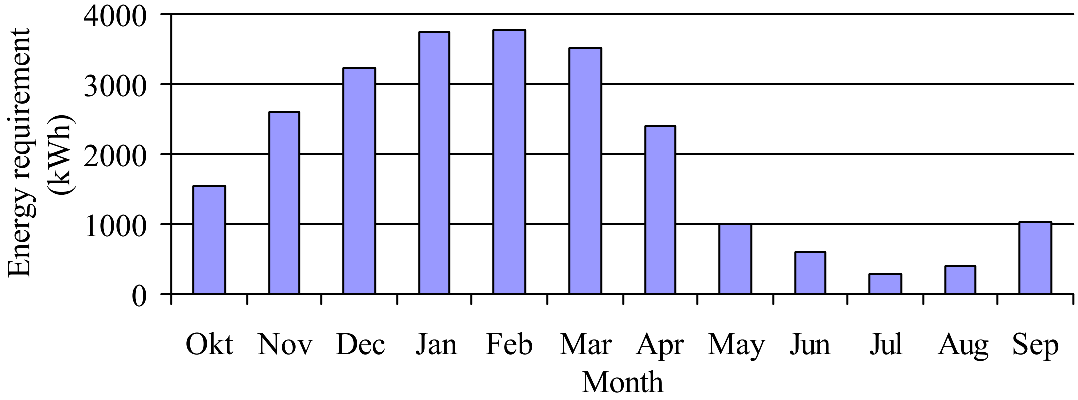


Figure 9. Energy requirement for the heating season October 2000-September 2001.

The auxiliary heating supplied only 564 kWh and it supplemented the heat pump totally 94 hours in the whole heating season. The main reason for the low total thermal requirement is that the winter has been rather mild. According to the yearly reports on the climatic conditions and the corresponding thermal requirement of buildings, the demand in the heating season of 2000-2001 reached only the 87% of the normal annual heating demand.

The total energy demand for running the heating system the first year in operation was about 9 MWh. (table 2). It is worthwhile mentioning the contribution of running the radiator pump, which is 14% of the total energy demand. The SPF for the total heating season was 2,76.

Table 2. Energy demand and COP_1 for the heating season 2000-2001.

Month	Compressor (kWh)	Electricity (kWh)	Heating demand (kWh)	COP1
October	397	475	1.572	3,31
November	693	820	2.648	3,23
December	929	1.086	3.195	2,94

January	1.173	1.377	3.755	2,73
February	1.013	1.640	3.754	2,29
March	1.039	1.407	3.532	2,51
April	613	721	2.424	3,36
May	322	382	974	2,55
June	183	222	605	2,72
July	96	119	274	2,30
August	126	154	385	2,50
September	288	347	1.000	2,88
Total	6.873	8.750	24.117	2,76

Investment and running costs: A simple economic calculation for a heating system with ground-coupled heat pump as in this project is the following.

Investment cost for a heating system based on ground-coupled heat pump in comparison with a new oil boiler:
Ground-coupled heat pump 100.000 SEK (Swedish crowns)
Oil boiler -35.000 SEK
Extra investment cost 65.000 SEK

With a ground-coupled heat pump heating system the energy savings from the running costs are about 60%. For example, in this case for a typical year in operation, the total energy demand is about 35.000 kWh including hot tap water heating. The electric energy demand for running the heating system comes to 1/3 of the total energy demand. Hence, the economic savings are about 11.500 SEK/year. This gives us a payback time for the ground-coupled heat pump of 5-6 years.

5.3 Main conclusions

Overall, the results indicate a satisfying operation of the system. The occupants express their satisfaction for the pleasant comfort feeling that the HVAC system provides. Furthermore, the results provide evidence that the design and installation of ground-source heat pumps (GSHPs) do not initiate any kind of difficulties. The GSHPs market is mature and the installers quite experienced in order to deal with problems that might arise.

Whether the GSHPs will maintain their high share in the Swedish market or not in the future is much in the hands of the manufacturers. It is quite likely that the customers will need some extra incentive to overcome the high initial cost associated with GSHPs. In times when company boards seldom approve of investment plans showing pay back times longer than three years, it is not reasonable to believe that individual house owners, in the long run, should allow up to seven years pay back time, which is the current average outcome of such an investment in Sweden.

The main lesson learned under this task-work is that the manufacturers attempt to make the product more desirable and make the customers more willing to accept the bng-term investment. Another example of the manufacturers' attempt to make heat pumps more competitive is their great effort to achieve higher performance. This strive is often restricted to improvements within the refrigeration process. These efforts should, by all means, be encouraged, but one should not neglect the potential to enhance performance by improvements of the heat source and heat sink not to forget cost reduction of the same. Little research in these neighbouring fields is carried out from the manufacturers. The heat pump business is in this respect relying on research and development carried out by other national as well as international organizations and research institutes. New promising water driven drill technique currently under development is an example of enhancement in ways to construct the heat source. Initial results indicate that this technique offers reduced energy consumption and doubled drilling speed.

Finally, it is worthwhile mentioning the latest trend in heat pump installations in Sweden. It is quite clear that one of the main competitors to the GSHPs comes from the same branch and is the exhaust-air heat pumps (EAHPs). EAHPs gain more space on the market share nowadays. The main reasons are:

- EAHPs and their installations are cheap and fast.
- Tight building constructions with lower transmission losses and higher ventilation losses make EAHPs more favourable.

In general, regarding the different types of heat pumps, within the time one type has the leadership depending on the market trend and circumstances. However, the main point is that the heat pump sector has occupied a lot of space in the heating market and continues being one of the most important players among its competitors.

5.4 Source

Written by Dimitra Sakellari.

Based on:

- Precious material provided by Martin Forsén.
- Published paper in the proceedings of the 4th International Conference "Heat Pumps in Cold Climates", Caneta Research, August 2000, Ottawa, Canada. The paper was written from Forsén M., and Lundqvist P., with the title 'Field Measurements on a Single Family House in Sweden Supplied with a Ground Source Heat Pump for Heating and Passive Cooling'.
- Publications from 'Klimat 21-Effektivare kylmaskiner och värmepumpar', 1997-2000. Final report written from Forsén M., with the title 'Simulering av värmepumpsystem'.
- Final results from the measuring project in Katrineholm.

6. CONTRIBUTION OF THE UNITED STATES

6.1 INTRODUCTION

In an effort to provide information to aid in developing measurement techniques for determining hydronic distribution system efficiencies for ASHRAE Standard 152P, a field test was undertaken to measure the distribution losses associated with the use of a hydronic system during the cooling season. The information gained from the research effort will also be used to (1) determine the energy efficiency of the space conditioning equipment for comparison with equipment used with other distribution system types, such as conventional forced-air and high-velocity forced-air distribution systems; (2) determine the ability of the hydronic cooling system to maintain the relative humidity and dry-bulb temperature within the comfort range as specified by ASHRAE; and (3) measure the parasitic losses (pump and fan power) at different operating conditions to compare them against the fan and blower losses for other types of space conditioning equipment, such as electric heat pumps.
Hydronic distribution systems have been used for many years in residential applications to transfer energy from the HVAC equipment to the conditioned space. The majority of hydronic distribution systems are located in the northeastern U.S. where they are primarily used in convective baseboard and radiant floor applications. It is rare to see hydronic systems used for cooling due to perceived problems with condensate removal and noisy, inadequate fan coil designs.

The field test will address these issues by investigating a hydronic distribution system with an improved condensate removal system and advanced fan coil units. There are two main standards of reporting duct efficiency as outlined in ASHRAE Standard 152P (ASHRAE 1997a). These are *delivery effectiveness* and *distribution efficiency*. Delivery effectiveness is defined as the ratio of the thermal energy transferred to or from the conditioned space to the ther-mal energy transferred at the equipment/distribution system heat exchanger. While delivery effectiveness is an important measure, it fails to fully represent the fraction of the supplied energy that reaches the conditioned space to satisfy the building load. Distribution efficiency, defined as the ratio between the energy consumption by the equipment if the distribution system had no losses and the energy consumed by the same equipment connected to the distribution system, takes into account the effects of thermal regain, the interaction of unbalanced duct leakage with natural infiltration, and the impact, if any, of the distribution system on the equipment efficiency.

Thermal regain accounts for energy lost by the ducts to uncon-ditioned space that is effectively recovered by the building through reduction of losses from the conditioned space to the buffer space due to a temperature change resulting from the duct losses. The interaction of unbalanced duct leakage with natural infiltration changes the building load by either pressurizing or depressurizing the building. This, in turn, results in reducing or increasing the amount of energy that must be supplied by the space conditioning equipment to satisfy the building load (Francisco et al. 1998).

6.2 BACKGROUND

The delivery effectiveness of forced-air heating and cooling systems is greatly affected by the type of distribution system and its location, e.g., attic, crawl space, or basement.

In 1983, 49% of existing residential heating and cooling systems in U.S. households relied on forced-air ducts to supply conditioned air to the building (Andrews and Modera 1991). However, the percentage of homes with ducts is increasing as indicated by more recent information that shows approximately 96% of new construction uses ducted distribution systems (NAHB 1999). Some of the drawbacks of ducted systems are that they require large amounts of space, tend to be noisy, are extremely prone to leakage, and can result in maldistribution of air and large infiltration losses. In addition, dust collection and the growth of mold and mildew inside ducts can cause indoor air quality problems (Kesselring 1993).

Estimates for energy losses for ducts in unconditioned and partially conditioned spaces are 35% and 20%, respectively (Gupta et al. 1995). Further, the problems in ducted distribution systems may contribute to high peak electricity demands. Air leakage from ducts contributes to thermal energy loss and may lead to pressure differences that could cause pollutants such as radon to infiltrate the conditioned space. Hydronic distribution systems are a means of reducing the energy losses associated with forced-air ducted systems and improving the delivery effectiveness of a building's HVAC system (Sarkisian et al. 1990). A hydronic system requires considerably less hydraulic distribution energy than a forced-air system since the working fluid is incompressible. In addition, there are no leaks in hydronic systems to contribute to increased infiltration and thermal losses. The estimated potential national energy savings from all energy sources for reducing distribution losses associated with ducted systems by improving their efficiency to that of a hydronic distribution system is 1.33 quadrillion Btu (Baskin et al.).

Hydronic heating and cooling is also viewed as a technology that could increase the market share for zone control and thus reduce the energy consumption of the system even further by providing conditioned air only to the spaces as needed.

Hydronic distribution systems have individual room control with quick response to thermostat settings and freedom from recirculation of air from other conditioned space. Present zone control techniques for forced-air systems utilize dampers that are cumbersome, unreliable, and costly. With individual fan-coil units in each room, zone control is more easily accomplished, resulting in better air distribution and improved comfort throughout the room.

6.3 METHODOLOGY

The house used in the field test was a 4300 ft^2 (400 m^2), two-story home with a basement located in Newark, New Jersey. The majority of the distribution piping is located in the basement with additional piping located in an uninsulated, unvented crawl space and a garage. The basement ceiling was insulated to R-11. There were eight fan coil units throughout the house consisting of four 3500 Btu/h (1026 W) capacity units and four 10,000 Btu/h (2931 W) capacity units. The fan coil units are equipped with variable-speed, brushless-dc motors that consume 8.5 W (small fan coil) and 15 W (large fan coil) at the highest speed. The speed is controlled by the thermostat setting. Air enters from the bottom of the fan coil unit and exits though the top of the unit. The distribution piping is 1-inch (2.5 cm) CPVC with R-2.75 closed-cell foam insulation. Condensate is removed from the fan coil units by means of a PVC drain pipe that drains to a common PVC line piped to a drain. The chiller is a 48,000 Btu/h (14,069 W) unit equipped with two variable-speed condenser fans and a pump to circulate the chilled water throughout the distribution system. The chiller also employs a 20-gallon insulated storage tank to reduce cycling of the compressor during periods of low ambient temperatures. The distribution system, chiller, fan coil units, and house were instrumented to determine distribution losses, equipment efficiencies, and indoor and outdoor ambient conditions.

The distribution system losses for the fan coil units with pipes located in the basement were determined by first measuring the distribution loss to the farthest fan coil unit in the system from the flow rate and temperature difference. Next, the distri-bution losses for the other fan coil units were proportioned to the loss associated with the farthest coil according to their flow rates and piping lengths. Distribution losses for the fan coil units with pipes located in an uninsulated, unvented crawl space and a garage were calculated in a similar manner as for the farthest piping run. Water flow rates for each fan coil unit were measured using high-precision turbine flow meters with an accuracy of ±1%. Temperature measurements were made from thermocouples inserted into the piping. The thermal energy input by the chiller in Btu/h (W) was measured with a turbine flow meter and thermocouples at the inlet and exit to the chiller. Condenser fan, fan coil unit, and pump power was measured with watt transducers to determine the parasitic losses. The fan coil units were also instrumented with RTDs at the air inlet and outlet. Using information from laboratory studies of the air flow rate as a function of energy consumption for the fan coil units, the inlet and outlet temperature measurements, together with the power draw, enabled a calculation of the sensible capacity for each fan coil unit. Indoor and outdoor temperature and humidity measurements were made at a single point inside and outside the house. The indoor sensor was placed in a centrally located two-story foyer. The outdoor sensor was placed in a shaded area and shielded from rain. The outdoor ambient conditions were compared against airport weather data, where the airport was within 8 miles of the home. Data were taken at 30-second intervals and summed over a three-hour period.

6.4 EXPERIMENTAL PLAN

Since hydronic cooling systems are not presently included in ASHRAE Standard 152P, measurement techniques for determining the efficiency of the distribution system are undefined. In determining the instrumentation requirements for the field test, plans concentrated on the ability to calculate the measures of efficiency that are similar to those for forced-air systems, such as delivery effectiveness and distribution efficiency. This would enable comparisons to the results for forced-air distribution systems and aid in future revisions to ASHRAE Standard 152P. In addition to the efficiency of the distribution system, instrumentation was also included on the chiller to measure the energy efficiency ratio (EER), which is a standard basis for comparison used in rating the performance of forced-air space conditioning equipment.

6.4.1 Delivery Effectiveness

The delivery effectiveness is defined in ASHRAE Standard 152P as the ratio of the thermal energy transferred to or from the conditioned space to the thermal energy transferred at the equipment-distribution system heat exchanger. Accurate field measurements of the energy transferred at each fan coil unit were quite difficult given the uncertainty associated with airflow rate measurements and relative humidity measurements across the coil. In order to more accurately determine the delivery effectiveness, the approach taken was to calculate the distribution losses and subtract them from the energy supplied by the chiller. The distribution losses for the hydronic system are inherently more accurate since they only involve temperature and water flow measurements, which are more accurate than airflow measurements. The distribution loss was calculated for each length of piping in the basement from a common manifold to each fan coil unit and back. As previously explained, the distribution losses associated with the fan coil units with piping in the basement were measured for the farthest run and then proportioned for the other units according to flow rate and piping length. The losses in the farthest run were determined from the following equation :

$Q_{LOSS} = K \times V_{DIST} \times C_p \times (T_{OUT} - T_{IN})$(1)

where Q_{LOSS} is the energy loss in Btu/h (W), K is a conversion constant (500.7 lb_m ×min/gaλ×h [1000 kγ×J/Λ×kJ]), V_{DIST} is the water flow rate through the pipe in gal/min (L/s), C_p is the specific heat of water in Btu/lb_m ×°F (kJ/kγ×K), T_{OUT} is the outlet water temperature in °F (°C) measured at the end of the piping prior to the fan coil unit, and T_{IN} is the inlet water temperature in °F (°C) from the manifold.

In addition to the piping in the basement, there were two additional fan coil units with piping runs through an unvented, uninsulated crawl space and a garage. These were also deter-mined using Equation 1. The distribution losses for all the piping were then summed up to determine the total distribution losses for the system. Next, the energy provided by the space conditioning equipment (chiller) was determined from the following equation :

$Q_{CHILLER} = K \times V_{CHILLER} \times C_p \times (T_{IN} - T_{OUT})$(2)

where $Q_{CHILLER}$ is the energy provided by the space conditioning equipment in Btu/h (W), K is a conversion constant (500.7 lb_m ×min/gaλ×h [1000 kγ×J/Λ×kJ]), $V_{CHILLER}$ is the water flow rate through the chiller in gal/min (L/s), C_p is the specific heat of water in Btu/lb_m ×°F (kJ/kγ×K), T_{IN} is the inlet water temperature to the chiller in °F (°C), and T_{OUT} is the outlet water temperature from the chiller in °F (°C).

The delivery effectiveness was then determined by subtracting the total distribution system losses (as summed from the losses for all the piping in basement, crawl space, and garage) from the total energy provided by the chiller (Equation 2) and dividing by the total energy provided by the chiller (Equation 2) as shown in the following equation :

$DE = (Q_{CHILLER} - \Sigma Q_{LOSS})/Q_{CHILLER}$ (3)

where DE is the delivery effectiveness in percent. The energy terms in Equation 3 are in Btu/h (W).

6.4.2 Distribution Efficiency

The distribution efficiency takes into account the portion of the thermal loss (gain) for the distribution system that is recaptured by the building to reduce/increase the load, depending on its location, e.g., basement, crawl space, etc.

Thermal regain factors for ducts in different locations are shown in Table 1 (ASHRAE 1997a). The distribution efficiency for the hydronic distribution system was determined from the following equation :

$h_{DIST} = DE + ((\Sigma (Q_{LOSS} \times F_{REGAIN}))/Q_{CHILLER})$(4)

where h_{DIST} is the distribution efficiency in percent, *DE* is the delivery effectiveness in percent calculated from Equation 3, Q_{LOSS} is the distribution loss for each section of piping in Btu/h (W), F_{REGAIN} is the thermal regain factor for different locations as defined in Table 1, and $Q_{CHILLER}$ is the energy provided by the chiller in Btu/h (W) calculated from Equation 2. As shown in Equation 4, the distribution losses in each of the different pipe locations (crawl space, basement, garage) times their respective thermal regain factors are summed and divided by the chiller power, then added to the delivery effectiveness to give the total distribution system efficiency.

6.4.3 Equipment Efficiency

In addition to efficiency measurements for the distribution system, measurements were also made to determine the efficiency of the space conditioning equipment. Typically, equipment efficiencies are reported in terms of the EER, which is simply the energy supplied by the equipment in Btu/h divided by the input power in watts. For the chiller, the energy supplied was determined from Equation 2 and the total input power was measured for the compressor, condenser fans, fan coil units, and pump.

6.5 EXPERIMENTAL RESULTS

The field test is designed to assess the performance of the hydronic distribution system and space conditioning equipment under a variety of outside ambient temperatures and relative humidities. Of particular interest is the performance of the hydronic distribution system under the following conditions : (1) low ambient temperatures/high humidities, (2) high ambient temperatures, and (3) low ambient temperatures, regardless of humidity. Forced-air distribution systems can experience problems with maintaining comfort at low ambient temperatures with high humidities. This problem occurs when the space conditioning equipment does not run long enough to adequately dehumidify the air in the building. High ambient temperatures result in a reduced distribution efficiency for forced-air systems in unconditioned space due to high conduction losses from the duct to the ambient air. Finally, low ambient temperatures result in the parasitic losses in hydronic systems becoming a larger portion of the overall power consumption and thus reducing the equipment EER.

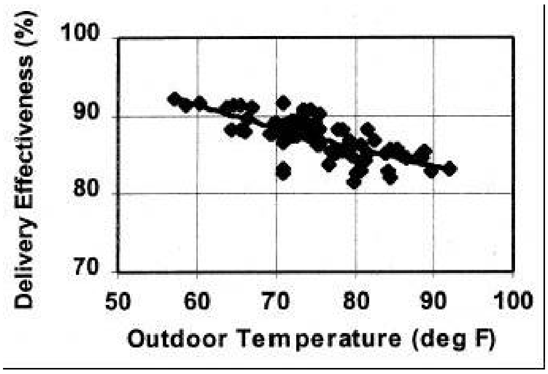
The testing occurred over a period from late July to early September. Two modes of testing were performed. The first mode, which is the one reported in this study, included running all the fan coil units and opening all the doors to the rooms. In the second mode, which will be reported in a later study, some of the fan coil units were turned off and doors to the rooms were shut to simulate zoning.

6.5.1 Delivery Effectiveness

Delivery effectiveness is plotted in Figure 1 as a function of the outdoor air temperature. For the test period, the outdoor ambient temperature varied from 57.2°F (14.0°C) to 91.9°F (33.3°C). As shown in Figure 1, the delivery effectiveness varied from a high of approximately 92.2% to a low of 81.4%. In general, the delivery effectiveness trended lower as the outdoor temperature increased. This reduction in delivery effectiveness occurs as the result of the increased conduction losses (distribution losses) from the higher temperature difference between the water temperature in the pipe and the ambient air temperature surrounding the pipe. As shown in Figure 2, these distribution losses for the piping in the basement, garage, and crawl space increase from approximately 900 Btu/h to 3100 Btu/h (264 W to 909 W) as the outdoor air temperature increases.

TABLE 1
Thermal Regain Factors

Location	Thermal Regain Factor
Garage	0.05
Insulated-ceiling basement	0.30
Crawl space, unvented, uninsulated	0.60



6.5.2 Distribution Efficiency

The distribution efficiency is plotted in Figure 3 as a function of outdoor air temperature. The distribution efficiency ranged from a high of approximately 92.5% to a low of 87.5%. As in the case for the delivery efficiency, the distribution efficiency also trended lower with increasing outdoor air temperatures.

There was a total of 479 ft (146 m) of distribution system piping in the house. The majority of the distribution system piping (74.9%) was located in a basement with an insulated ceiling. From Table 1, the thermal regain factor for this application is 0.30. The remaining distribution losses that were partially recovered were in an uninsulated, unvented crawl space (0.60 thermal regain factor), which accounted for approximately 4.2% of the distribution piping length, and in a garage (0.05 thermal regain factor), where 20.9% of the total distribution piping was located. Comparing the trend lines for the delivery effectiveness and the distribution efficiency, the distribution efficiency decreases at a much lower rate than the delivery effectiveness as the outdoor air temperature increases. This is the result of the second term in Equation 4, the thermal recovery from the distribution losses divided by the chiller energy, increasing as the outdoor temperature increases, as shown in Figure 4. This increased thermal recovery occurs because the distribution losses in the crawl space are increasing at a much higher rate than the losses in the basement and garage as outdoor temperature increases.

Compounding this effect is the fact that the regain factor for the crawl space is much higher (0.60) than that for the basement (0.30) or garage (0.05). At ambient temperatures less than 70°F (21°C), the thermal recovery accounts for less than 2% of the total distribution efficiency. As the outdoor temperature increases above 70°F (21°C), the thermal recovery increases to as much as 6% of the total distribution efficiency.

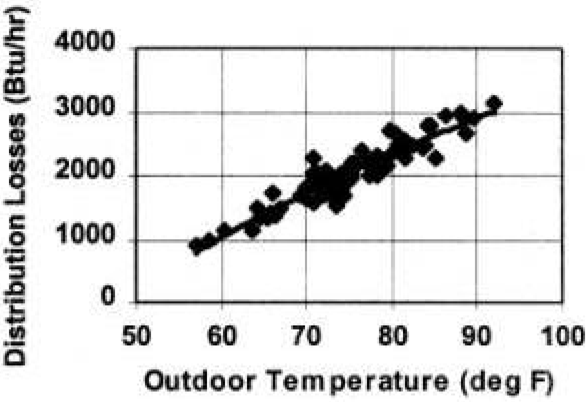


Figure 2 *Distribution losses vs. outdoor temperature.*

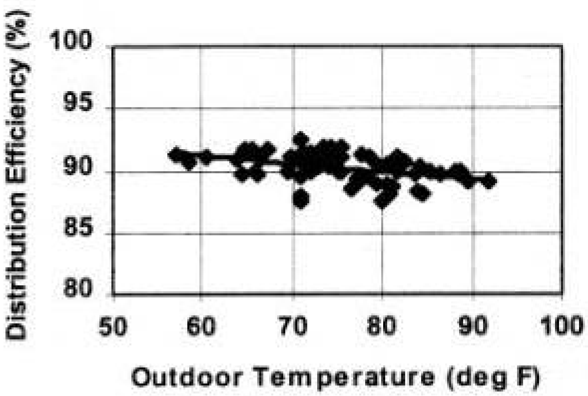


Figure 3 *Distribution efficiency vs. outdoor temperature.*

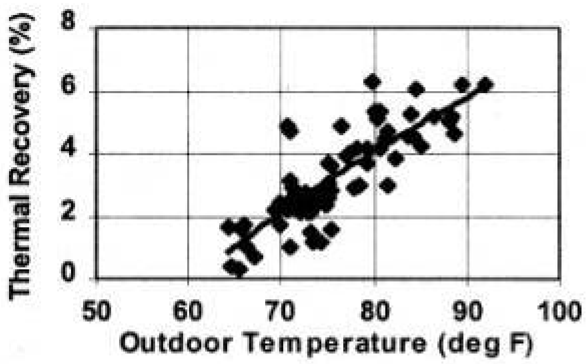


Figure 4 *Thermal recovery vs. outdoor temperature.*

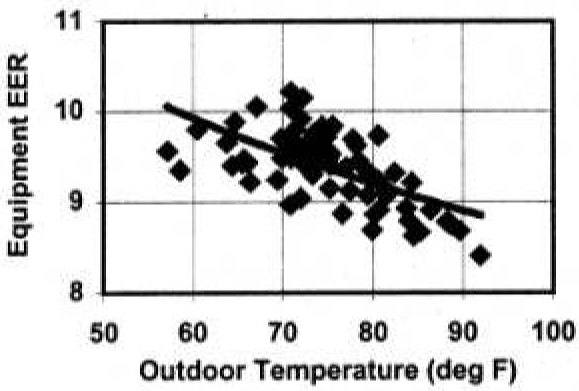


Figure 5 *Equipment EER vs. outdoor temperature.*

6.5.3 Equipment Efficiency

The EER for the chiller was measured to enable a comparison against other types of space conditioning equipment that is used in residential distribution systems, such as electric heat pumps. Electric heat pumps are covered under the National Appliance Energy Conservation Act (NAECA 1987) and are required to meet certain minimum efficiency levels. The typical rating point for electric heat pumps operating in the cooling mode is 82.0°F (27.8°C). At that temperature, the minimum EER for electric heat pumps is 10.0 as mandated by the U.S.

Department of Energy (DOE). Although hydronic heat pumps and chillers are not covered under the DOE standard, it is useful to compare their performance against air-source equipment to evaluate the overall performance of the equipment/ distribution system. The equipment EER as a function of outdoor temperature for the chiller is shown in Figure 5. The EER trends from a high of approximately 10.2 down to 8.4 at an ambient temperature of 91.9°F (33.3°C). At 82.0°F (27.8°C), the chiller EER is approximately 9.2 as estimated from the trend line in Figure 5. Thus, its EER is 8.0% below the minimum efficiency for air-source space conditioning equipment. The lower EER is mainly due to the lower evaporating temperature at which the chiller must operate in order to chill the water down to 45.0°F (7.2°C). Typical entering air temperatures for air-source equipment are approximately 55.0°F-60.0°F (12.8°C-15.6°C), which result in reduced compressor power requirements as compared to the hydronic chiller.

Parasitic losses associated with the condenser fan, fan coil units, and circulating pump have been a concern for hydronic cooling systems. The circulating pump is the main source of parasitic power loss since it operates continuously. For the hydronic system tested, the circulating pump energy consumption was 243 W. By comparison, the total energy consumption of the condenser fans and the fan coil units ranged between 49 W and 134 W, depending on the compressor run time. Figure 6 is a plot of the parasitic losses as a function of compressor run time. The parasitic losses are reported as a percentage of the overall energy consumption of the chiller and fan coil units. As shown in Figure 6, the parasitic losses decrease with increasing compressor run time. The losses, ranging from 16% to 24%, are comparable to those for the blower and condenser fan in an electric heat pump. Thus, even with the circulating pump running continuously, the parasitic losses are not too high. One improvement would be to replace the existing pump motor with a brushless-dc or some other high-efficiency motor to further reduce the parasitic losses.

6.5.4 Comfort

Although energy consumption is the main focus of this study, of secondary importance is the ability of the hydronic system to maintain comfort in the conditioned space. In Figure 7, the indoor relative humidity is plotted as a function of the outdoor relative humidity. Figure 7 shows that the indoor relative humidity remains fairly constant (46%-52% RH) over a wide range of outdoor relative humidity levels (25%-100% RH). Thus, the hydronic system is able to maintain comfortable indoor relative humidity levels over a wide range of outdoor relative humidity levels. To further investigate the ability of the hydronic distribution system to maintain comfort, the indoor relative humidity was plotted as a function of indoor dry-bulb temperature inFigure 8. Using the ASHRAE comfort zone conditions for temperature and humidity, the conditions in the home are maintained in the middle of the humidity range and at the low end of the temperature range (ASHRAE 1997b). The temperatures actually fall within the winter comfort conditions, which suggests that the indoor temperatures could be increased to save energy and comfort would still be maintained. The slope of the trend line in Figure 8 shows that as the indoor temperature increases, the relative humidity is decreasing. From the ASHRAE comfort zone conditions, this is exactly the way a system should control humidity as the outdoor temperature increases in order to reduce energy consumption and still maintain comfort (ASHRAE 1997b). In order to investigate how the hydronic system was able to reduce the relative humidity as indoor temperature increased, a plot (Figure 9) was made of the latent/total capacity of the system as a function of percent run time for the space conditioning equipment. Figure 9 shows that as the run time increased (indicating that the building load is increasing), the latent portion of the total load is also increasing. This indicates that the fan coils are removing more moisture as the system runs longer to meet the building load.

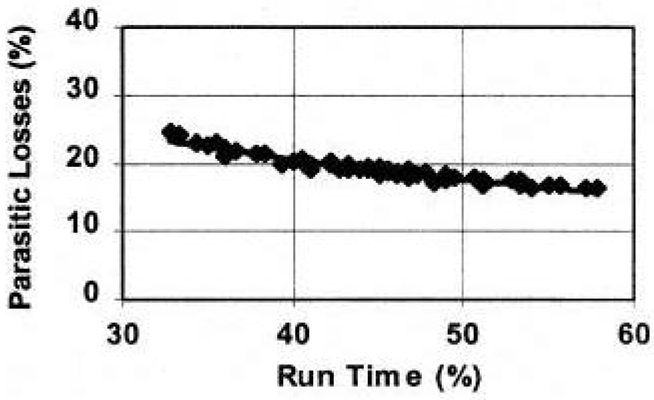


Figure 6 Parasitic losses vs. run time.

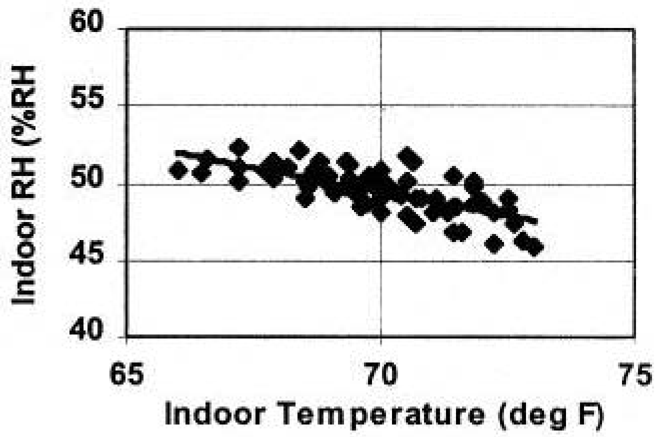


Figure 8 Indoor RH vs. indoor temperature.

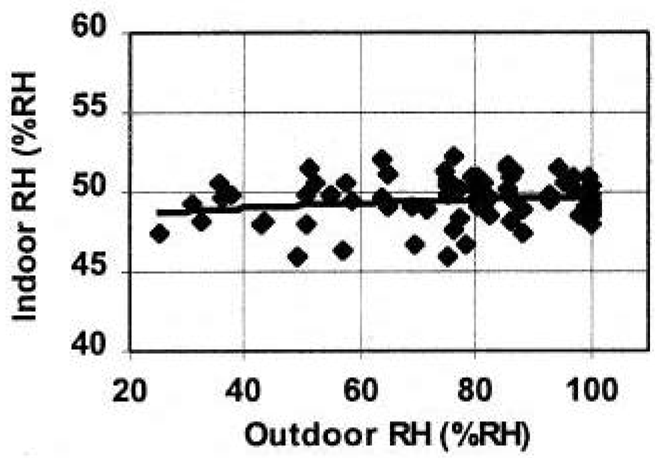


Figure 7 Indoor RH vs. outdoor RH.

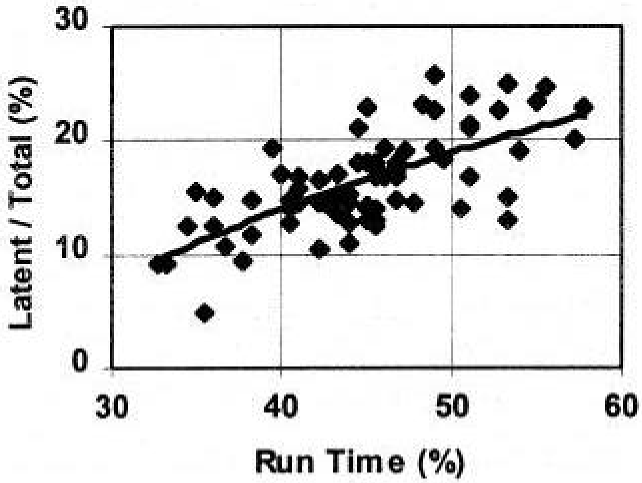


Figure 9 Latent/total vs. run time.

6.6 CONCLUSIONS

Several significant findings were concluded from the field test. It was determined that the distribution efficiency of the hydronic system was quite high, ranging from 87.5% to 92.5%. Typical distribution system efficiencies for residential construction are in the range of 60%-70% (Modera 1993).

Thus, the hydronic system is a significant improvement over conventional forced-air distribution systems and would result in large energy savings since the space conditioning equipment would have to provide less energy to meet the building load.

One of the major criticisms for hydronic systems has been the parasitic losses associated with running the circulation pump continuously and having several fans running in the individual fan coil units. The fan coil units and the condenser fans in this study were equipped with variable-speed, brush-less- dc motors that enabled the energy consumption to be greatly reduced. Even though the circulation pump was still allowed to run continuously, the high-efficiency fans enabled the parasitic losses to be reduced to a level comparable to those for forced-air space conditioning equipment operating with conventional motors. Further reductions in parasitic losses should concentrate on using high-efficiency motors for the pump or control strategies for cycling the pump with the compressor. However, cycling the pump could result in higher relative humidity levels in the building. Measurements for the chiller EER indicated that there is room for improvement to increase the energy efficiency to levels comparable for forced-air equipment. The chiller EER was approximately 9.2 at the 82.0°F (27.8°C) rating point for forced-air equipment. The value is 8.0% below the minimum 10.0 EER for forced-air equipment. The energy input to the hydronic system includes the compressor, condenser fan, circulation pump, and all the fan coil units. As previously mentioned, the fan motors have already been replaced with high-efficiency models. Thus, the only opportunity for improving the EER is to reduce the energy consumption for the pump, improve the compressor efficiency, or improve the heat exchangers to reduce the temperature difference. The hydronic system did an excellent job of maintaining comfort in the house, even under outdoor conditions of high humidity and low dry-bulb temperatures. The results showed that the set point temperature could have been raised to further reduce the energy consumption while still maintaining the comfort conditions in the house.

6.7 FUTURE PLANS

The results of this study were only for the cooling season. Plans are to convert the chiller to a hydronic heat pump and test the hydronic distribution system in the heating mode. In addition, the circulation pump will be replaced with a higher efficiency unit. The test house is presently equipped with a radiant floor heating system. Therefore, tests will be conducted by switching from one system to the other so that direct comparisons can be made for the energy consumption and comfort levels for each type of distribution system. At some point, measurements will be made of temperature stratification in the rooms to determine how well the fan coil units distribute the air throughout the rooms as opposed to the radiant floor heating system.

6.8 ACKNOWLEDGMENTS

This paper is an account of work performed under a cooperative research effort between the Office of Building Technologies, State and Community Programs, U.S. Department of Energy under Contract Number DE-AC05-84OR21400 with Corporation. The authors would like to express their appreciation to David and Jane Sandelman for allowing the instrumentation and monitoring of the hydronic system in their home. In addition, David provided a great deal of useful technical input to the project. Finally, Joe Brana deserves recognition for installing and instrumenting the hydronic system.

6.9 REFERENCES

Andrews, J.W., and M.P. Modera. 1991. *Energy savings potential for advanced thermal distribution technology in residential and small commercial buildings*. Brookhaven National Laboratory.

ASHRAE. 1997a. *ASHRAE Standard 152P, Method of test for determining the design and seasonal efficiencies of residential thermal distribution systems*, draft 2. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1997b. *1997 ASHRAE Handbook—Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Baskin, E., E.A. Vineyard, and E.A. Ibrahim. *Hydraulic-powered fan-coil for advanced hydronic distribution systems, Part 1: Thermal performance and energy characterization of conventional fan-coil units* (submitted for publication to ASHRAE).

Francisco, P.W., L. Palmiter, and B. Davis. 1998. Modeled versus measured duct distribution efficiency in six forced-air gas-heated homes. *Proceedings of the 1998 ACEEE Summer Study*.

Gupta, S., S. Stoltz, and H. Hagen. 1995. *Performance evaluation of the hydronic heat pump system*, vol. 2. TR-104891. Electric Power Research Institute.

Kesselring, J. 1993. Hydronic thermal-distribution systems. *EPRI Journal*.

Modera, M. 1993. Characterizing the performance of residential air distribution systems. *Energy in Buildings*, vol. 20.

NAECA. 1987. Public Law 100-12, March 17 (as amended by National Conservation Policy Act, 9 Public Law 95-619), Part B—Energy conservation for consumer products other than automobiles.

NAHB. 1999. *Builder practices report—Duct usage in new construction 1998*. National Association of Home Builders Research Center.

Sarkisian, P., B. Cohen, and A. Popelka. 1990. *Heat pump thermal distribution systems*. CU-6962, Electric Power Research Institute.