

THE HEAT PUMP IN THE REFURBISHMENT OF EXISTING BUILDINGS PERSPECTIVES FROM SWEDEN

Per Lundqvist, KTH, professor
KTH, Energy Technology
Applied Thermodynamics and Refrigeration
President commission E2 IIR

INTRODUCTION

A wide variety of heat pumps has been developed and introduced in the Swedish energy system during the last 20 years. Especially the so-called ground source heat pump for single family houses has been a true success story but also large heat pump delivering district heating in major cities. Today more than 15 TWh of heat are collected from the nature with heat pumps at a value for the tax payers of about 1.3 - 1.5 G€/year¹ (fy 2007). This means that all the money that the taxpayers have “invested” through the governmental financed heat pump research over 30 years is repaid in only 4 – 5 days by free renewable energy.

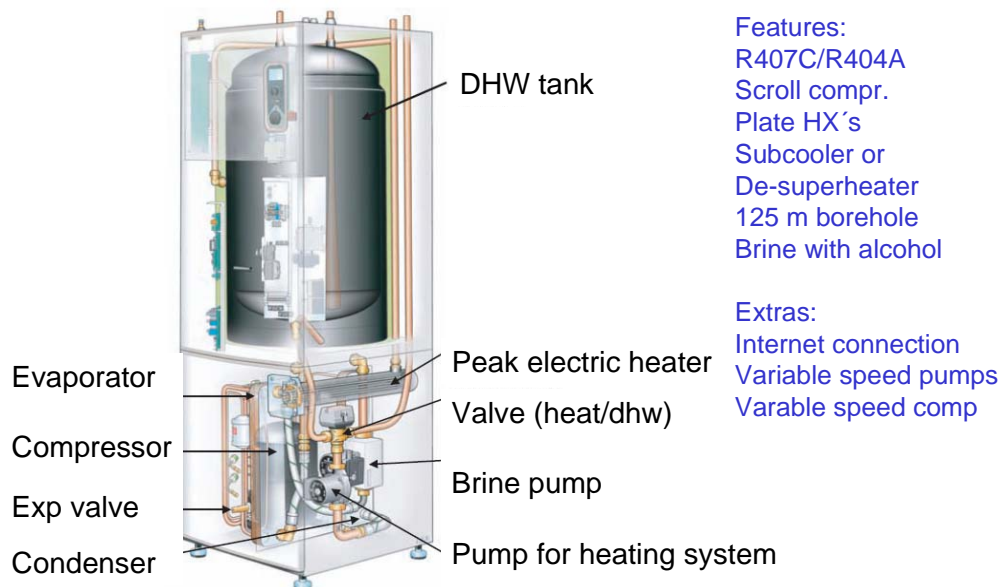


Figure 1. A typical Swedish ground-coupled heat pumps from 2007.

The improvements of components such as heat exchangers, compressors and control systems have been a continuous process as a result of a research and development by heat pump manufacturers in close cooperation with universities and research institutes. The first GSHP with integrated domestic hot water storage was in fact developed as early as 1973 by the company Thermia in Arvika (Thermia 2005). In parallel other types of heat pump systems have been developed over the years such as exhaust air heat pumps for both domestic hot water heating and residential heating and air source heat pumps of various types. One example of more recent product innovation is the IVT495 Twin from IVT in Tranås which combines two heat sources, exhaust air and ground coil in order to overcome the limitation in available energy in exhaust air which is insufficient for a high energy coverage factor (IVT 2007). More recently, variable speed control of compressor and/or circulation pumps has been introduced on the market by several

¹ the value of the free heat is assumed the same as the typical cost for district heating 2008 in Sweden.

manufacturers e.g. the Fighter 1250 (NIBE 2007) by NIBE. The heat pump shown in figure 1 is a generic representation of the typical GSHP in Sweden today.

The general understanding of how heat pump units should be designed to meet customer demands (economy and reliability) and manufacturer's preferences (profit) has thus grown to a mature level although several issues remain to be clarified. Some of these are further elaborated throughout the paper.

THE ROLE OF HEAT PUMPS IN A GLOBAL PERSPECTIVE

There have been many recent attempts to quantify the potential of heat pump in reducing CO₂ emissions as well as in saving on primary energy. IEA Heat pump program, for example, estimates that heat pumps, fully utilized in all sector, can cut global CO₂ emissions by 8% (HPC, 2006). The recent Japanese governmental research program *Cool Earth – Innovative Energy Technology Programme* aims to identify the technologies with the greatest potential to mitigate global warming. The program identified 21 technologies to be developed to cut emissions of GHG's by 50% by 2050. High-efficiency heat pumps is one these 21 technologies along with high efficiency housing and so on (Tanaka, R, 2008). Similar perspectives are put forward in the recent IEA publication: *Energy Technologies Perspectives – Scenarios and strategies to 2050*. The heat pump is highlighted as one of the key technologies to mitigate global warming but also for more efficient fuel utilization in general (OECD/IEA 2008). In the recent IPCC 4th assessment report from WG III heat pumps are also highlighted as an important technology (Barker et.al. 2007). The IPCC reports states:

“Investments in the buildings sector may reduce the overall cost of climate change by simultaneously addressing mitigation and adaptation. The most important of these synergies includes reduced cooling needs or energy use through measures such as application of integrated building design, passive solar construction, heat pumps with high efficiency for heating and cooling, adaptive window glazing, high-efficiency appliances emitting less waste heat, and retrofits including increased insulation, optimized for specific climates, and storm-proofing”

The IPCC report continues:

“Although many practical and cost-effective technologies and practices are available today, research and development is needed in such areas as: high-performance control systems; advanced window glazing; new materials for insulated panels; various systems to utilize passive and other renewable energy sources; phase-change materials to increase thermal storage; high-performance ground-source reversible heat pumps; integrated appliances and other equipment to use waste heat; novel cooling technologies, and the use of community-wide networks to supply heating, cooling and electricity to buildings. Demonstrations of these technologies and systems, and training of professionals, are necessary steps toward bringing those new technologies to market”

It thus clear that the heat pump, as a technology, has an important role to fulfil in the future. One has however to bear in mind that a heat pump always is part of a system. An efficient heat pump unit in a building with unnecessary big heat losses is not a good solution. Thus, failing to make heat pump systems as a whole **efficient enough** must be avoided and some recent attempts to handle this dilemma is given in the new EU directive on renewable energy 2008/0016 (COD). The directive aims to promote the use of renewable energy sources within the framework to achieve the target of a 20% share of renewable energy sources in the final energy consumption by 2020.

The amount of ambient energy captured by heat pumps to be considered renewable energy for the purposes of this Directive, E_{RES} , shall according to appendix VII B in the directive be calculated in accordance with the following formula:

$$E_{RES} = Q_{usable} * (1 - 1/SPF^2) \quad (1)$$

where

Q_{usable} is the estimated total usable heat delivered by heat pumps fulfilling the criteria referred to in Article 5(5) of the directive, implemented as follows: Only heat pumps for which $SPF > 1.15 * 1/\eta$ shall be taken into account.

SPF = the estimated average seasonal performance factor for these heat pumps

η is the ratio between total gross production of electricity and the primary energy consumption for electricity production and shall be calculated as an EU average based on EUROSTAT⁵ data.

This means in practice that for a typical η of 35% (meaning an average efficiency for electricity production of 35%) the SPF should be larger than $1,15 * 1/0,35$, i.e a SPF above 3,3 should be required. The fraction of the supplied energy that is counted as renewable is then calculated as:

$$E_{RES} / Q_{usable} = 1 - 1/SPF = 1 - 1/ 3,3 = 70\%. \quad (2)$$

This may seem like a paradox but the idea is clearly to promote highly efficient heat pump systems. It should be noted that a heat pump with a SPF = 3,3 entirely run on coal electricity produces a substantial amount of carbon dioxide emissions but, according to the proposed calculation procedure, it is 70% renewable energy! A heat pump with a SPF = 3 entirely run on green electricity on the other hand would give 0 % renewable energy!

THE IMPORTANCE OF SYSTEMS THINKING

The heat pump can be viewed from several different system levels and it important to understand that there are different critical issues to consider on each level. The four most obvious levels are:

- The heat pump unit level
- The heat pump system (inkl heat source and sink)
- The building including the users
- The Energy system as a whole

On The *heat pump unit level* we are primarily concerned with issues such as Refrigerants (working fluids), Components, Design (It has to look nice and it should be quit, al least for a single family house model), Duty (DHW and heating and/opr cooling etc). Price and expected lifetime are also important factors but most typically from a manufacturers perspective. Heat pump units are tested for efficiency (COP – see below)) according to EN standards and labelled but for all practical reasons any heat pump may perform good in a well designed system (low temperature lift – see section on heat pump system). The refrigerants have been an issue over the past (ozone depletion, global warming) and several historical considerations can be found in the

² SPF = Seasonal Performance Factor, i.e the total energy delivered by the heat pump system over a year divided by the driving energy including supplementary energy needed on cold days (if applicable).

³ http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1090,1&_dad=portal&_schema=PORTAL

history of Swedish heat pumps later in the paper. Currently the issue is the so-called F-gases such as HFC134a or HFC404A.

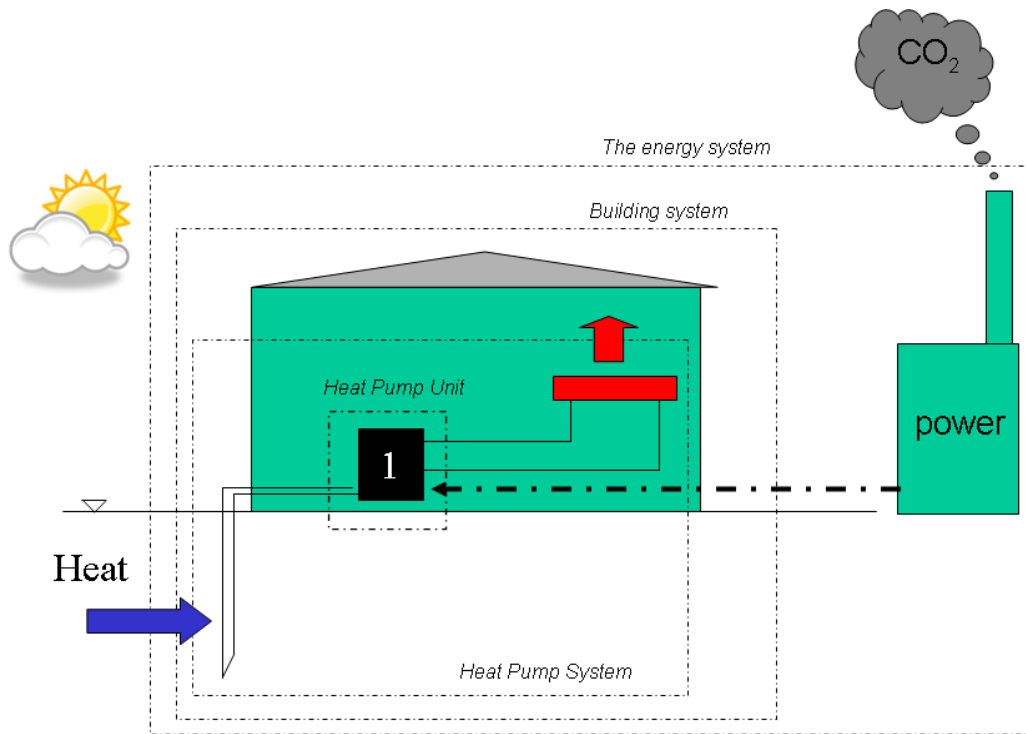


Figure 2. Four different heat pump system levels to consider.

On the *heat pump system level* the COP becomes a relevant concept. COP, or COP_1^4 , means coefficient of performance and it is a measure of how much heat energy a heat pump delivers divided by the required drive energy at a specific operating point. The issue in this system perspective is Temperature levels and type of Heat Source. The thermodynamically ideal value for COP is denoted COP_{1c} and the ratio between actual COP and ideal is sometimes referred to as fraction of Carnot or Carnot efficiency ranging between 0 and 1.

$$COP_1 = \frac{Q_1}{W}$$

$$COP_{1c} = \frac{T_2}{T_1 - T_2} + 1 \quad (3 - 6)$$

$$\eta_c = \frac{COP_1}{COP_{1c}} \quad \text{where}$$

$$0 < \eta_c < 1$$

A heat pump operating between a heat source of 0°C (273K) and a heat sink of 30°C (303K) could therefore theoretically achieve a $COP_{1c} = 10,1^5$. With a 50% Carnot efficiency this should give us a real COP of 5. The influence from the temperature lift is critical. A lower temperature lift gives an even higher thermodynamic potential.

⁴ The subscript 1 means that it is heating COP, compared to cooling COP for refrigeration plants (COP_2).

⁵ $COP_{1c} = 273 / (303 - 273) + 1$

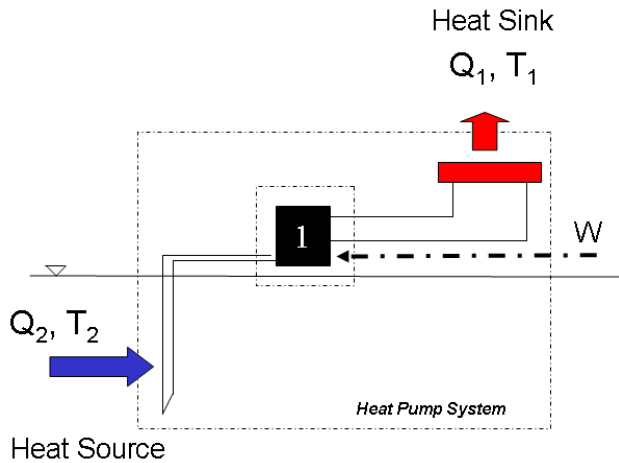


Figure 3, The heat pump system level, the temperature lift is defined as $T_1 - T_2$.

Next level to consider is the building perspective. Of course, the system will now operate under varying, dynamic conditions caused by building type and building behaviour (dynamics), user behaviour, climate etc. Since we now have the user in the system, economy becomes an important factor. The ratio between DHW and Heating duty is important as well. The yearly seasonal performance factor, SPF_y , already discussed determined the economy of the system in relation to other heating methods:

$$SPF_y = \frac{\sum_{year} Q_1 + Q_{extra}}{\sum_{year} W + Q_{extra}} \quad (7)$$

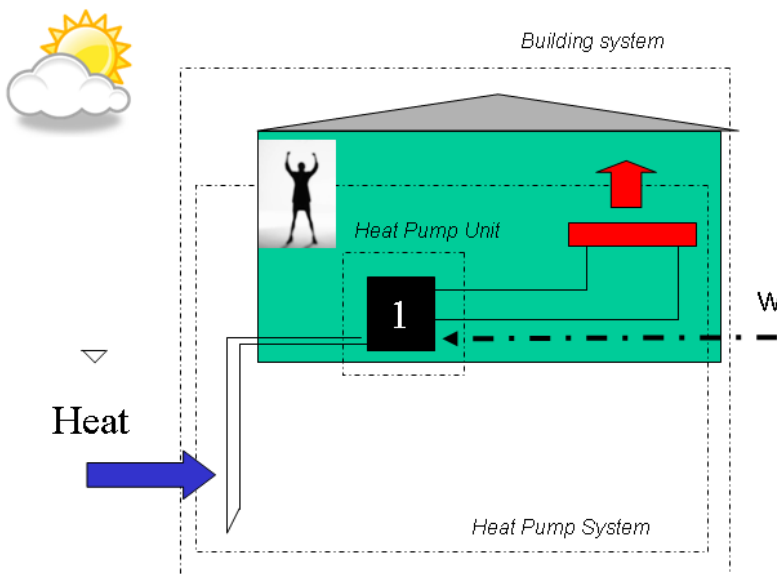


Figure 4, The building perspective, The yearly seasonal performance factor, SPF_y , is the critical performance measure. Another important performance criterion is kWh/m^2 . It has recently been shown that low energy buildings with heat pumps can reach the same performance as so called passive housing.

The last system perspective in this paper is the energy system as a whole. The environmental performance of a heat pump system is largely determined in this system. Two important performance measures are thus emissions (not only CO₂⁶) and more efficient fuel utilization.

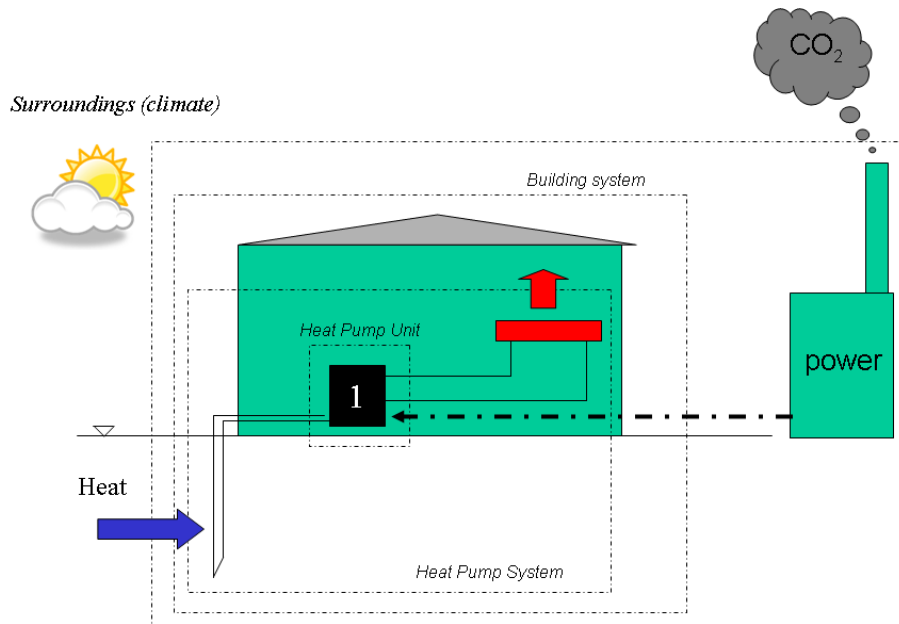


Figure 5 The Energy system perspective. The CO₂ emission from the heat pump systems is indirectly produced in the power plants and through fuel handling. There are several ways to define the carbon content of electricity, typically kg CO₂/kWh_{el} ranging from slightly above 1 to almost zero, i.e. green electricity.

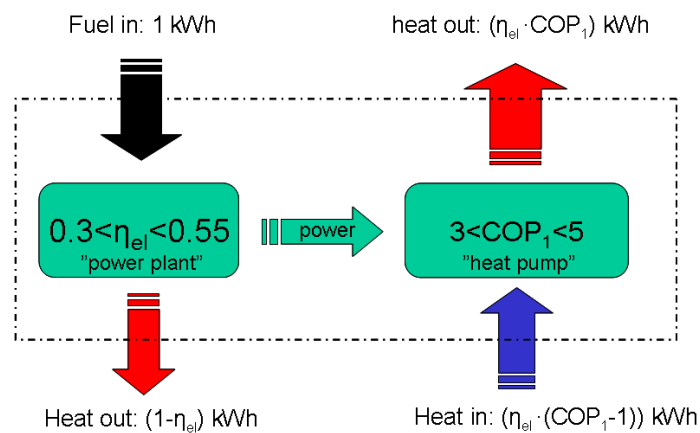


Figure 6, Definition of system for determination of fuel efficiency for an energy system with heat pumps.

We can assume that electricity is produced with a typical efficiency between 30 and 55%, lets say 40%, and that the “waste heat” is fully utilized for district heating. The electricity is used to drive a heat pump with a COP₁ ranging from 3 to 5, lets say 4. This system will lead to “production” of 2,2 units of useful heat (both red arrows) for any unit of heat put into the system (black arrow in figure 6).

The equation determining the fuel utilization ratio, FUR, is easily set up:

⁶ A biomass furnace may yield a vast number of other unwanted emissions with strong local effects. Residential wood combustion emissions could contain sulfur oxides, nitrogen oxides, carbon monoxide and potentially carcinogenic compounds including polycyclic aromatic hydrocarbons, benzene, formaldehyde and dioxins (EPA, 2007)

$$FUR = COP_1 \cdot \eta_{el} + (1 - \eta_{el}) = 4 \cdot 0,4 + 1 - 0,4 = 2,2 \quad (8)$$

A biomass furnace system would under ideal conditions yield 1 unit of useful heat. If the heat from the electric power production is wasted a factor 1,6 is obtained with the proposed system. This clearly show the benefit of using heat pumps for heating provided they are efficient enough...

FIVE PHASES OF HEAT PUMP EVOLUTION IN SWEDEN

1975–1985 Early Pioneering ...

The period can be characterized by different ambitious initiatives and R&D efforts. Also numerous field measurements and evaluations were undertaken. A certain success for shallow ground source heat pumps on the market, often with direct expansion coils. This technology was strongly supported by the Swedish State Power Board's (Vattenfall) research program on Solar Energy and Heat Pumps. Generous governmental subsidies and research grants made available through the Swedish Council for Building Research led to a first "HP-boom" in the early 1980's. In 1985 there were roughly 100 large heat pumps in District heating (MW size) and 110 000 small ones in residential houses. Heat pumps also became a "research issue" at the universities mainly KTH and Chalmers. Ground source systems were analyzed at LTH. A major achievement during the time was the ground-source manual (Claesson 1985) which covers all types of system for heating, cooling and storage in three volumes. The mathematical models of this source-book are still used as the basis for modelling of the heat source behavior in ground source heat pump systems. The largest heat pump in the world was built in Stockholm during the period. It has a heat output of 250 MW and has supplied the district heating network of Stockholm with up to 60 % of the total heat demand during some years. As more than two thirds of the output originates from solar heated surface water – Stockholm has some years been heated by more than 40 % of solar energy! Refrigerants were not an issue: Ozone depletion and global warming were unknown whereas refrigerants were well-known and not considered a problem. A typical choice was either R22 or R502 in ground-source applications. One unique thing was that many systems was monitored right from the beginning through extensive test programs thus leading to experience building.

Typical performance figures of single-family, residential units 1975-1985 (Karlsson 2007)

$\eta_{\text{Carnot}} = 0.4 - 0.57$, SPF = 2.0 - 2.5 (ground-source), 1.5 - 2.2 (outdoor air) and 2.0 - 2.5 (exhaust-air).

1986–1995 Market collapse and refrigerant phase out:

The period started with drastically reduced prices on heating oil coupled with a drastic cut of governmental subsidies and an increase in interest rates. This made the market collapse in a short time. It created large problems for the companies, many of whom went bankrupt. Phasing out CFC-refrigerants added to the complexity for manufacturers. This involved phasing out of the traditional refrigerants, first R12 and R502, later R22. Sweden was thus in the forefront of banning CFC and HCFCs, see table 1, and the first in a series of intensive national research programs, Alternative Refrigerants, for research on alternative refrigerants was initiated. R134a was quickly identified as the alternative for R12, R404a and R507 for R502 and at the end of the period R407C for R22 (Johansson 2001). The period also saw the first experiments with so-called natural refrigerants and propane was tried with excellent thermodynamic performance as an alternative to R22.

In the early 1990-ies however a heat pump competition, supported by NUTEK was announced with a very ambitious time frame. Initially the contest was successful, but large problems arose later for some of the contestants (Fahlen 1995). Even faulty in many respects, the resulting new products reignited the slumbering heat pump market. During this period a relatively large number of air/air heat pumps were also installed. Small series not fully adapted for heat pump operation and larger than intended/expected temperature lifts and frost formation caused malfunction.

⁷ COP₂ of the heat pump unit divided by the theoretical limit based on evaporation and condensation temperatures, i.e not the same as in the example in the previous chapter. This corresponds to a significantly lower number with the other definition

The plate type heat exchanger was introduced during this period leading to a drastic reduction of refrigerant charge and smaller temperature differences in although advanced heat exchanger concepts had been tried earlier, for instance by Thermia in the DUO-series (Fernando 2007). The compressors were becoming increasingly more efficient at pressure ratios more suitable for heat pump applications. This period also saw a reduction of the price for drilling due to market competition and rationalization.

Typical performance figures of single-family, residential units 1986 - 1995 (Karlsson 2007)

$\eta_{\text{Carnot}} = 0.45 - 0.55$, SPF = 2.5 - 3.0 (ground-source), 2.0 - 2.5 (outdoor-air), 2.5 - 3.5 (exhaust-air)

Typical performance figures of district heating units 1986 - 1995 (Ibid.)

$\eta_{\text{Carnot}} = 0.60 - 0.65$, SPF = 2.5 - 3.0 (sewage water ≈ 10 °C, district heating ≈ 80 °C).

1996-2000 Exhaust air and slow recovery

The period can be characterized by a certain recovery of the market, especially with small units like exhaust air HPs. The very complicated machines and installations from the early days were simplified and more or less standardized. Normal HVAC firms, electricians, well drillers and plumbers took up heat pump installation as a part of their normal business. Exhaust air HPs were primarily implemented in new built houses as heat recovery for domestic hot water heating in accordance with the then new building code. As the new building code also enforced thicker insulation the heating demand for smaller residential buildings decreased and the heating capacity of the exhaust air HPs covered typically 30 % of the buildings heat demand resulting in a potential of approximately 50 % energy coverage (the remaining capacity was covered by electric heaters in the liquid heat distribution circuit). Henceforth exhaust air HPs more or less became the standard heating solution for small and medium size domestic houses. Still, a few houses were built using the exhaust air HP only for domestic hot water heating, and direct electric heating for space heating through electric radiators (especially in the slightly lower prize segment).

The research programs Climate 21 and subsequently EffSys 1 were initiated with a stronger focus on efficiency and system issues for heat pump and refrigeration systems. Research was mainly carried out by technical universities (mainly Chalmers and KTH) and research institutes (SP) in close cooperation with manufacturers of heat pumps, heat exchangers, control systems, utilities, and consulting engineers. Projects concerned component as well as system aspects, ranging from heat transfer, refrigerant substitution, charge minimization, variable speed compressors and pumps, recharging of boreholes, combined heating and hot water, integrated control systems etc. to the effect on the national electricity grid by the extensive use of heat pumps (in particular the use of electric supplementary heating).

2001 – 2005 Market take-off and product sophistication

We see an increasing acceptance of heat pumps. Good market, especially for ground source units in relatively large one family houses. Sales are picking up. There are certain governmental support investments aiming for oil reduction and replacement of electrically heated houses. Air/water heat pumps seem to pick up quickly and several new models are appearing on the market due to favourable investment costs and/or less suitable conditions for boreholes. A biased, largely market driven, discussion of the importance of electricity use in heat pump systems was initiated. The competition on the heating market between suppliers of bio-fuels or district heating was more open.

The design of residential units was now more sophisticated with controls that better adapted the heating water supply temperature to the outdoor air temperature and the minimum downtime between starts, incorporated Legionella protection cycles etc. At the end of the period the first GSHPs with capacity control as standard equipment were announced as stated earlier. Plate heat exchangers with narrower channels and thus improved distribution of refrigerant and more efficient heat transfer surfaces were universally used as condensers and evaporators (Claesson 2006). Also, more efficient pumps were incorporated for circulation of brine and heating water. The scroll compressor became a favourite and R407C was selected as the refrigerant.

Performance continued to increase, not by leaps and bounds but steadily:

Typical performance figures of single-family, residential units 1996-2005 (Karlsson 2007)
 $\eta_{\text{Carnot}} = 0.50 - 0.60$, SPF = 2.5 - 3.5 (ground-source), 2.0 - 3.0 (outdoor-air), 2.5 - 3.5 (exhaust-air)

Typical performance figures of district heating units 1996-2005 (Ibid.)
 $\eta_{\text{Carnot}} = 0.65 - 0.70$, SPF = 2.5 - 3.5 (sewage water ≈ 10 °C, district heating ≈ 80 °C),
 SPF = 4.0 - 6.0 (combined heating and cooling).

2006 - A bright future with some surprises

The market value of houses has recently been reported to increase if equipped with an efficient GSHP system thus giving the ground coupled heat pump increased status and a new role. New products with variable speed compressors and/or pumps are gaining market shares. Passive cooling e.g. using the cold from the borehole is becoming more and more popular. Smart and cost effective systems for retrofit of direct electric houses with hydronic heat distribution systems are expected to reach the market if the price of electricity increases. So-called “monovalent” systems with no-peak-electricity will become more common and is likely to be subsidized partly by the electric utility companies. A growing interest for heat pumps in the size 25-40 kW for small multi-family dwellings or offices/industries seems to be a new attractive market for manufacturers and several new models with higher efficiency have recently appeared on the market. Systems are typically installed in parallel to achieve higher capacities. There are now about 100 large ground-source heat pumps for heating and cooling of office buildings with more than 15 boreholes (total borehole depth > 3000 m, heat pump capacity > 200 kW) and about 40 large open-loop systems (groundwater), (Hellström 2007).

THE HEAT PUMP MARKET IN SWEDEN

Statistics for primary energy for heating

The total heating market is the first departure point for a market segmentation of heat pumps. However, this statistical information does not immediately reveal the amount of heat delivered from heat pumps. For instance, a relatively large part of the heat delivered through district heating, approximately 6 TWh, is covered by large electrically driven heat pumps utilizing waste heat in sewage water or sea water. By studying Figure several interesting observations can be made: The use of oil for heating purposes was totally dominant in 1970 with a 75 % share. Since then it has gradually decreased to approximately 12 % in 2005. During 2006 this value has further decreased but since statistical data is not yet available, an estimate could be 6-7 %.

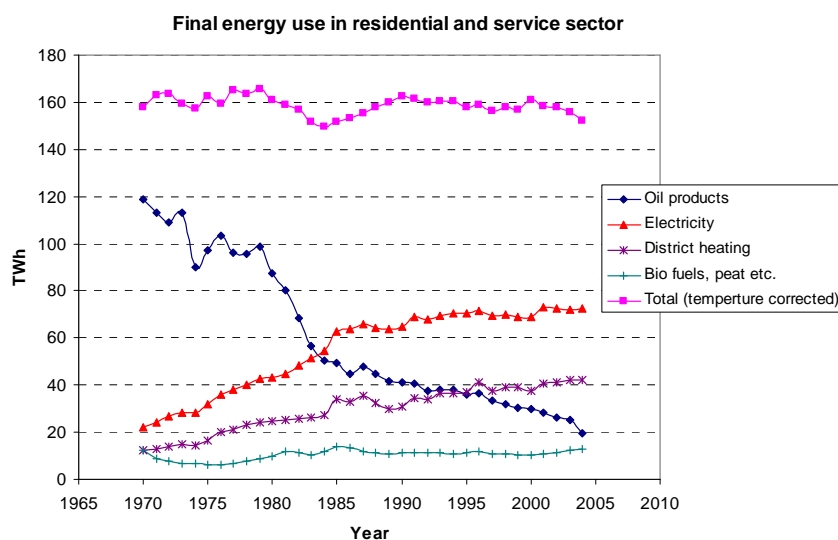


Figure 7: Final energy use in residential and service sector by type (Stem 2005)

The use of electricity for heating was growing rapidly from 1970 to 1990 but this figure is now levelling off. Retrofitting of direct base board heating in houses built during the seventies and early eighties to various combinations of air/air heat pumps/pellet heaters or even retrofit to hydronic heating systems is likely to reverse the trend through the coming years.

The sub-market for heating of residential single-family houses amounts to a total of 40 TWh of which 4.3 TWh has been estimated to be electricity to heat pumps. These heat pumps have been estimated (conservatively) to deliver approximately 8-9 TWh heat, which for obvious reasons does not appear in the statistics. One has to bear in mind that energy use normally is counted as “energy supply”. There is no available statistics concerning useful energy or “heat losses” from buildings.

Primary energy usage for heating of single-family houses in Sweden 2004 (TWh)

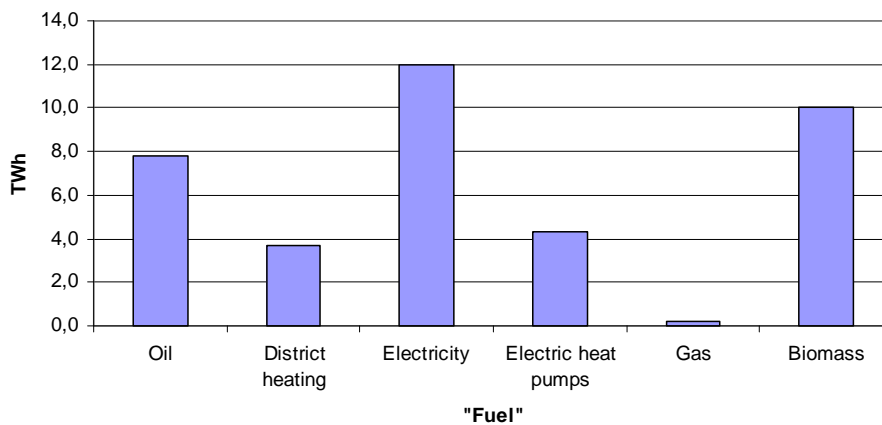


Figure 8: Primary energy usage for heating of single-family houses based on data from Statistics Sweden⁸.

If the total heat delivered by domestic heat pumps is broken down by heat pump type, assuming typical efficiencies, the dominance of the GSHP system is evident (Figure).

Heat delivered by heat pump category

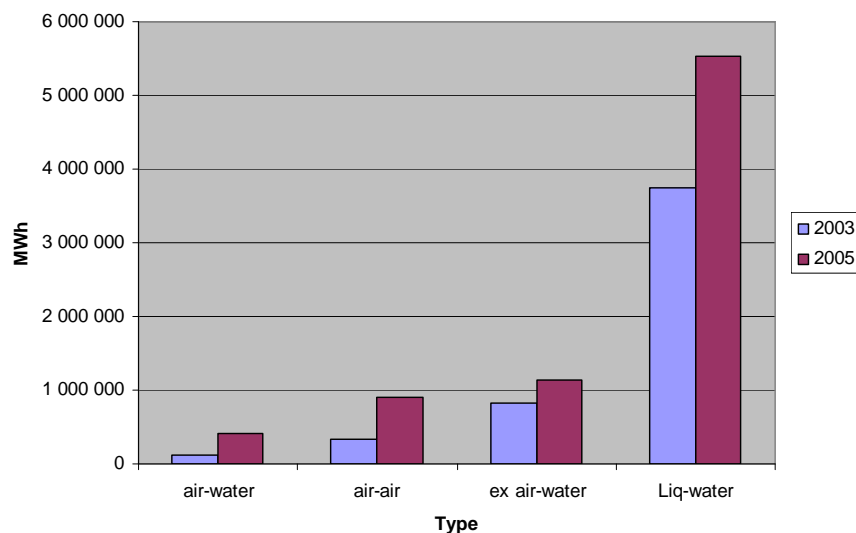


Figure 9, An estimation of heat delivered by heat pumps broken down by category. The diagram is constructed by assuming typical seasonal performance factors and information on heating demand from figure 8 (Forsén 2005)

⁸ www.scb.se

Building size and utilisation

An overview of the Swedish domestic heating market is given in Figure 3 and 4. A relatively large portion of the building stock is quite old. For new dwellings there are two counteracting factors (i) Building heating demand per m² is decreasing due to better insulation standards and (ii) The average size of new buildings are increasing

Interestingly enough similar data for multi-family houses do now show the same clear trend in decreasing energy demand per square meter living area. One may wonder why...

Net energy need for single family dwellings

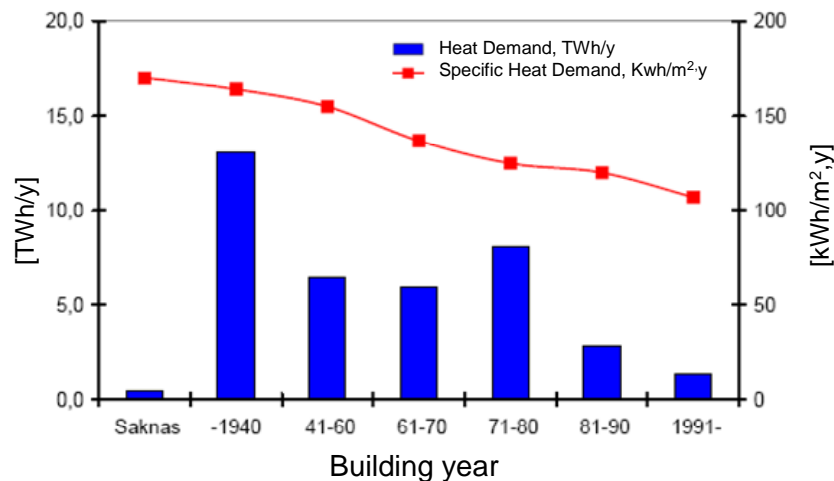


Figure 10, Net annual energy demand for single-family dwellings bundled for 10 years span of erection (left axis). Specific annual heat demand, kWh/m²,year for the periods are also given on the right axis (Dalenbäck 2007)

Heated area, single family dwellings

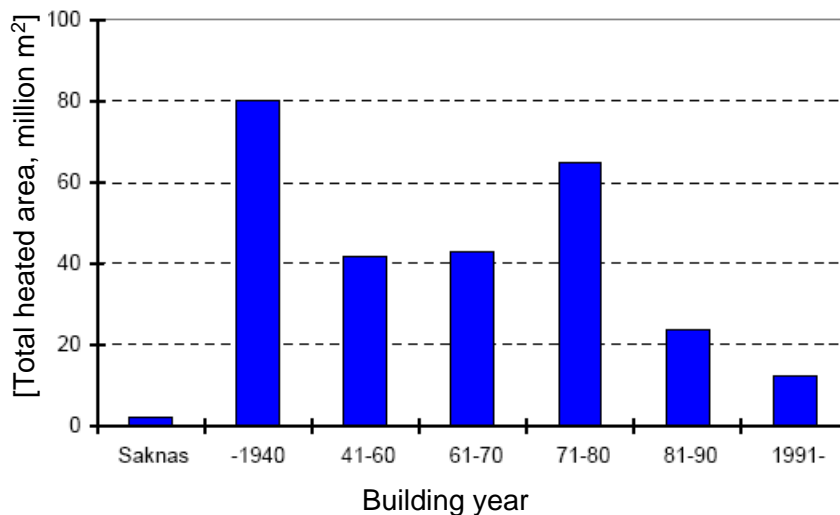


Figure 11, Total heated area single-family dwellings (Ibid.)

Heat Pump Sales

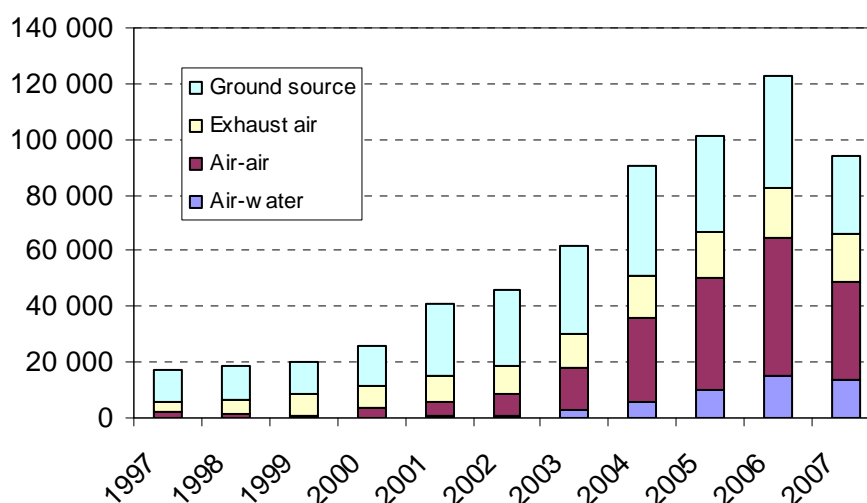


Figure 12, Sales statistics for the period 1997 – 2007. Data is given for air/water (bottom), air/air (second from bottom), exhaust air/water (second from top) and liq/water (top), (Forsén 2008).

CURRENT ISSUES AND TRENDS (ENVIRONMENTAL CONCERN, WORKING FLUIDS, LEGISLATION, PEAK ELECTRICITY)

The heat pump working fluid has been one factor to consider for manufacturers and several attempts have been done to enforce new legislation or labelling promoting increased use of so-called natural refrigerants. Today, the standard choice is typically R407C or other HFC-refrigerants such as R404A, R410A or R134a even though a small number of heat pumps with other fluids such as propane or CO₂ exist on the market (Palm, 2007). Active research to facilitate the use of other fluids such as CO₂, ammonia or propane is undertaken at universities and research institutes with governmental support.

Table 1: Refrigerant phase-out in Sweden (Jobansson 2001)

ASHRAE Number	Primary Replacement	Type of refrigerant	Stop for import or new installations	Stop for refill	Stop for use	Share of the total refrigerant charge in Sweden 1993
R12, R500, R502	R134a R404A	CFC	1/1 1995	1/1 1998	1/1 2000	32% 6%
R22	R407C	HCFC	1/1 1998	1/1 2002	N/A	50%

RESEARCH NEEDS AND ONGOING RESEARCH AND DEVELOPMENT

The research and developments need for heat pump systems can be broken down to heat pump unit issues dealing with the performance of components such as heat exchangers (heat transfer), energy efficient pumps, capacity control, charge minimization, environmentally benign refrigerants etc. Other issues with R&D needs are related to ground coupling of systems (boreholes, collector design, drilling techniques, site-investigation methods, and calculation methods), passive cooling, dual heat sources, techniques for non-electrical supplementary peak energy etc. A complete list is beyond the scope of this brief report.

Ongoing research in Sweden, relevant for the development of more efficient and reliable heat pump systems, is mainly carried out at universities (KTH, Chalmers, LTH and LuTH) and the research institute

SP in Borås and IUC in Katrineholm. Work at the universities are dealing with various issues such as heat transfer and heat exchanger issues as well as improved thermodynamic cycles but also system oriented issues such as control strategies or low temperature distribution systems. Work at Luleå and Lund technical universities has mainly been directed to heat exchange with the ground, evaluation of compact heat exchangers for horizontal installations, characterization of boreholes etc (the well known “Thermal Response Test” for example), completion and maintenance of wells for groundwater applications. A great effort has been put into modelling of heat exchange with the ground, thermal interaction between multiple adjacent boreholes, and hybrid GSHP systems involving solar heat by Hellström at LTH, Lund and Nordell at LuTU, Luleå.

The use of natural refrigerants has been encouraged throughout the last 15 years in research programs and small heat pumps using refrigerants such as propane, NH₃ and CO₂ are being tested and evaluated (Palm 2007). A complete list of ongoing or completed research projects is beyond the scope of this report. The interested reader is encouraged to visit the home page or the different organisations listed at the end of the paper.

A recent effort worth to mention is the new national research and development program EFFSYS2. It is a four year program for applied R&D in Refrigeration and Heat Pump Technology operated by the Royal Institute of Technology Sweden. It was formally started July 1, 2006, and will run up to June 30, 2010. The overall budget is 70 million SEK (about 9 million US\$), of which Industrial Partners are to contribute 60% and Swedish Energy Agency 40%.

The program is a continuation of previous programs: “Alternative Refrigerants”, “Klimat21” and “EffSys”. In total these programs have been running since the start in 1994 until 2004. After an interruption during 2005, the new program, EFFSYS 2 was started, formally July 1st 2006. Generally the experiences of the previous programs have been very positive.

The aim of EFFSYS 2 is to contribute to further strengthen the Swedish R&D community and industry in Refrigeration and Heat Pump Technology. A purpose is to maintain and if possible strengthen the position, nationally as well as internationally. The purpose is to develop more effective systems for refrigeration and heat pumps, reducing the use of electricity and other forms of energy as well as reducing the peak electricity demand. The program focus is on systems, including the building and the energy supply system in general. This does not exclude projects on components, provided that they are important for the system performance.

The vision of the program is to position “heat pumping technologies” as an integral part of an efficient and sustainable energy system of the future. Projects should have practical applications as well as being useful for academic advancements for doctoral students as well as for senior researchers. 16 projects are now ongoing and more information can be found on the program website: www.effsys2.se.

Large development efforts are also undertaken at the different manufacturers and several new initiatives have recently been taken. New R&D laboratories are constructed well integrated with the respective design office in order to develop next generation of efficient GSHP. The reader is encouraged to visit the home page of the various manufacturers to learn more about these activities. Some links are given at the end of the chapter.

Several new EU projects related to heat pump technology have recently been initiated with Swedish participation. One recent example is GROUNDMED a program with a strong focus on ground source heat pumps adopted for the Mediterranean region. Another example is GROUNDREACH involving the Swedish Heat Pump Association. Another activity of interest for heat pump manufactures is the new working party for reduction of refrigerant charge initiated by the IIR and strongly supported by section E2, Heat Pumps and heat recovery⁹.

⁹ www.iifir.org

Table 2: University and research centra in Sweden active in heat pump research

Name	Contact	Tel	e-mail and web
Chalmers TU	Prof. Per Fahlen	+46 31 7721142	Per.Fahlen@chalmers.se www.chalmers.se
KTH TU	Prof. Per Lundqvist Prof. Björn Palm	+46 8 7906000	per.lundqvist@energy.kth.se bpalm@energy.kth.se www.kth.energy.se
Luleå TU	Prof. Bo Nordell	+46 920 491646	bo.nordell@ltu.se www.ltu.se
Lund TU	Dr. Göran Hellström	+46 46 2229091	goran.hellstrom@matfys.lth.se www.lu.se
SP	Dr. Monica Axell	+46 10 5165519	monica.axell@sp.se www.sp.se
IUC	Dir. Jörgen Rogstam	+46 150 57782 +46 768 581545	jorgen.rogstam@iuc-sek.se www.iuc-sek.se

Table 3: Other heat pump related activities

Name	Contact	Tel	e-mail and web
IEA Heat Pump Centre	Dr. Monica Axell	+46 10 5165519	monica.axell@sp.se www.heatpumpcentre.org
Swedish Heat Pump Association	Dir. Martin Forsén		martin.forsen@svepinfo.se www.svepinfo.se
Swedish Energy Agency	Mr Mattias Törnell	+46 16 5442169	mattias.tornell@energimyndigheten.se www.energimyndigheten.se

CONCLUSION AND DISCUSSION

The GSHP has reached a mature status in Sweden; almost 30 % of all single-family houses are now heated with some kind of heat pump system. GSHP is thus today the preferred heating method in single-family houses with a reasonable energy demand. For smaller houses with low energy demand exhaust air heat pumps is the standard solution, but systems utilizing a dual heat source, exhaust air and ground coupling, may become more common thus offering a better energy coverage factor required by the new energy performance directives.

Although large efforts for R&D have been put into HP research many issues remain. A broad competence within academia does exist today and research funding is for the time being relatively stable.

REFERENCES

Barker T., et.al., 2007: Technical Summary. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Claesson, J., et al, 1985. Ground heat - A source-book for thermal analysis - Part I-III . BFR-rapport T16-T18:1985, Statens råd för byggnadsforskning, Stockholm, Sweden (in Swedish)

Claesson, J., 2004. Thermal and hydraulic performance of compact brazed plate heat exchangers operating as evaporators in domestic heat pumps. (TRITA REFR Report No 04/44, pp. 252, Royal Institute of Technology, Energy Technology.) Stockholm, Sweden.

Dalenbäck, J-O. ; Jagemar, L. ; Göransson, A. (2006). Energi- och elanvändning i byggnader. Stockholm: Svenska elföretagens forsknings- och utvecklings Elforsk AB. No. 66925

EPA; 2007, Health Effects Of Breathing Woodsmoke,
http://www.epa.gov/woodstoves/pdfs/woodsmoke_health_effects_jan07.pdf, accessed 2008-12-22

- Fahlén, P., 1985. Laboratory testing of heat pumps - experience 1977-1983 (in Swedish). (Teknisk rapport 1985:05, Statens provningsanstalt.) Borås, Sweden.
- Fahlén, P., 1995. The Nordic heat pump competition - Winners set new standards in performance and price. IEA Heat pump centre Newsletter, nr. 3, September.
- Fernando, W.P.D, B. Palm, P. Lundqvist, E. Granryd 2004. "Propane heat pump with low refrigerant charge: design and laboratory tests", Int. J. Refrig., Vol. 27 (2004), pp. 761–773.
- Fernando, P., B. Palm, P. Lundqvist, E. Granryd, 2007. Performance of a single-family heat pump at different working conditions using small quantity of propane as refrigerant, Experimental Heat Transfer, Taylor & Francis, Vol. 20, no. 1, pp. 57 - 71.
- Forsén, M., Lundqvist, P., 2000, "Field Measurements on a Single Family House in Sweden Supplied with a Ground Source Heat pump for Heating and Passive Cooling", Heat pumps in Cold Climates, Int. Conf, Quebec
- Forsén, 2005, final report for STEM research program eff-Sys
- Forsén, M, 2008, Personal communication
- Hellström, Göran, 2007, Personal communication
- IEA, 2006, "Heat pumps can cut global CO2 emissions by nearly 8%", HPC-BR6, Borås, Sweden (www.heatpumpcentre.org)
- IVT, 2007, http://en.ivt.se/download.asp?pt=pdf&fn=495_EN_Br.pdf (accessed 2007-01-02)
- Johansson A., Lundqvist P., 2001 "Replacement of R22 in existing installations: Experiences from the Swedish phase out", Int. IIR Conference on Refrigerant Management and destruction Technologies of CFC, Dubrovnik
- Karlsson, F., Stenlund M., Axell, M., Lundqvist, P., Fahlén, P., Nordell, B., 2007, IEA HPP Annex 29: Ground source heat pumps - overcoming market and technical barriers - Country report for Sweden, 2007
- NIBE, 2007, <http://www.nibe.se/vvs/produkter/mvp/F1250a.htm> (accessed 2007-01-02)
- Nowacki, J.E., 2007, Personal communication
- OECD/IEA, 2008, *Energy Technologies Perspectives – Scenarios and strategies to 2050*, IEA, Head of communication and information office, Paris
- Palm, B., 2007, Refrigeration systems with minimum charge of refrigerant. Applied Thermal Engineering, Volume 27, Issue 10, July 2007, Pages 1693-1701
- Sakellari, D., Forsén, M., Lundqvist, P., 2006, "Investigating control strategies for a domestic low-temperature heat pump heating system", Int. J Refrig. no 29, pp 547 – 555 (2006)
- Sanyo, 2007, (<http://www.sanyo.co.jp/giho/no73/data-e.html#no05>)
- STEM, 2005, Energy in Sweden
- SVEP, 2006, Swedish Heat Pump Association, personal communication

Thermia, 2005, “Stora Värmepumpboken (The Large Heat Pump Book)”, Thermia, Arvika, ISBN 91-631-7643-2 <http://www.thermia.com/>

Tanaka, R, 2008, Japanese governmental research program *Cool Earth – Innovative Energy Technology Programme*, <http://www.meti.go.jp/english/newtopics/data/pdf/031320CoolEarth.pdf>, accessed 2008-15-15.