Air source heat pumps and their role in the Swedish energy system

Itai Danielski[*,a], Morgan Fröling*[a]

[a] *Ecotechnology, Department of Engineering and Sustainable Development, Mid Sweden University, 83125 Östersund, Sweden*

[*] *Corresponding author: itai.danielski@miun.se, Tel: +46 (0)63-165416,*

Abstract

Newly produced air source heat pumps can provide heat energy from outdoor air at temperature as low as -20°C. As a result they could be utilized during most days of the year even in the cold Nordic climates. The drawback of air source heat pumps is the reduction in efficiency as the outdoor air become colder, resulting in lower heat supply in times when it is most needed. Despite its inverse relationship between efficiency and outdoor temperature, air source heat pumps were installed in 57000 detached houses in Sweden during 2010 alone, which is 3% of the total detached houses stock. That makes air source heat pumps the most sold heating technology for detached houses in Sweden during 2010, 1.6 times more than the number of installations of ground source heat pump and 3 times more than the number of connections of detached houses to district heating during the same year. Similar trends can be found in other Nordic countries.

This study compares the use of an air source heat pump with other existing commercial technologies in detached houses and analyzes the impacts on primary energy use, on final energy use, on electricity production and on costs benefits for house owners. It was found that converting existing electric heated Swedish detaches houses to district heating with biomass based CHP or bed-rock heat pump could reduce the use of resources, which could benefit Sweden as a society. Converting electric heated Swedish detaches houses to district heating or pellets stove could reduce power demand and level out the power demand load curve. That would benefit utilities of power supply as it could secure power supply. However cost effectiveness in one of most important drivers for house owners of detached houses to choose energy efficiency measures. For that reason house owners may most likely benefit by the installation of air-source heat pumps.

1. Introduction

Large share of the Swedish residential building were built during the 1960s and 1970s with pick of new constructed units ending during the oil crisis in 1973 (Statistics Sweden 2012a). Until the oil crisis fossil fuel and electricity prices were relatively low, and energy conservation in buildings was not highly prioritized. Oil and electricity were widely used as energy source for space and domestic water heating. With higher fossil prices, many of the detached houses converted to biomass and heat pumps. District heating networks were established providing, currently, space and domestic hot water for 92% of the multifamily dwellings and only for 27% of the total 1.9 million detached buildings. The detached houses stock has the highest final energy use in the service sector for space and water heating (The Swedish Energy Agency 2011a) and four fold higher electricity use in comparison to multifamily dwellings (Statistics Sweden 2012). Electricity is still the most common form of energy used for heating and hot water in detached buildings. Gustavsson and Joelsson (2010) found that the choice of end use energy carrier have a greater influence on the primary energy savings than energy conservation measures done on the thermal envelope of the buildings. In addition, the energy conservation measures were less cost effective when converting to more energy efficient heating system.

Heat pump were available since the 70s but they got their large breakthrough only during 2005 (Nowacki 2007) and were installed mainly in detached houses. About 46% of the detached houses in Sweden has some sort of heat pump installed (The Swedish energy agency 2011b). The most common type of heat pump is the air source heat pump, which include mainly air-to-air, air-to-water heat pumps. Since 2005 the selling of air-source heat pumps has accelerated (Nowacki 2007) and reached 57,000 households during 2010, which make it the most sold heating technology in detached houses in Sweden.

Air source heat pumps are consider being one main reason for the large reduction in the average specific final energy use of the entire detached house stock in Sweden; from 170 kWh/(m^2 year) during 1977 to 140 kWh/(m^2 year) today (The Swedish energy agency 2011). However air source heat pumps have major drawback, they provide less heat when it is needed the most, i.e. when the outdoor temperature decreases. During those cold periods, supplement heat from other sources is needed to maintain comfort indoor conditions, in most cases by resistance heaters. Larsson et.al (2006) study the electricity consumption in 437 detached houses and concluded that the impact of detached houses on the Swedish peak power production is significant. It may increase the power production needed by an additional 1 GW in a 20 year cold winter in comparison to normal year.

In this study the impact of the air source heat pump, installed in Swedish detached houses built in the 70s, is analyzed by several parameters: the final energy use, the primary energy use, its cost effectiveness and the impact on the energy system in Sweden as a whole.

2. Methodology

2.1. Case study

The case study is an existing detached house built in 1974. It has two stories and a total heated floor area of 115 m^2 heated by electric resistance heaters. It has a inclined roof with ceramic tiles that consist of 150 mm mineral wool between wooden beams above particle boards panels with U-value 0.29 W/(m^2 K). The external walls consist of 16 mm gypsum board, moisture protection sheet, 120 mm mineral wool between wooden beams, and 20 mm wood panel with total u-value of 0.33 W/(m^2 K). The ground floor consists of 15 mm oak boarding on 20 mm particle board above 110mm mineral wool laid on 200 mm concrete plate and 150 mm macadam and have U-value of 0.2 W/(m^2 K). All the windows and two of the three external doors are double glazed with a total area of 23.7 m^2 and U-value of 2.7 W/(m^2 K).

The indoor temperature is assumed to be constant 20°C. The yearly final energy use for household electricity and domestic water heating are assumed to be 3348 and 3074 kWh/year respectively.

2.2. Technologies and efficiencies

The COP and heating output of the air source heat pump were based on the test results done by the *Swedish energy agency* (2009a) for few outdoor temperatures and compressor output conditions. The results were extrapolated linearly to the entire outdoor temperature range as illustrated in Fig. 1.

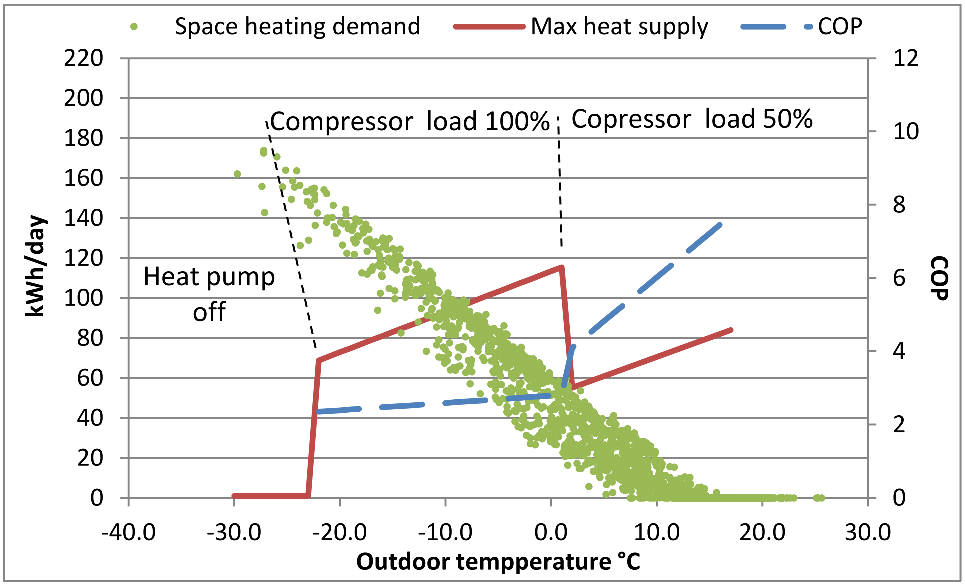

Fig. 1. Data source the Swedish energy agency (The Swedish energy agency 2009)

The air-source heat pump was compared with several commercial technologies, which includes: electric resistance heaters, pellets stove, bed-rock heat pump and district heating. The efficiency of the pellets stove was assumed to be 90% (The Swedish energy agency 2009b). The COP of the bed-rock heat pump was assumed to be 2.6 (The Swedish energy agency 2005).

A dynamic method was used to calculate the primary energy used by a district heating power plant, which include the interaction between the supply and demand sides. The method as well as the reference district heat production system is described in Gustavsson et.al. (2011). The value of cogenerated electricity was calculated using the subtraction method. Where the cogenerated electricity was considered as a by-product and assumes to replace an equivalent amount of electricity produced in a marginal power plant. The marginal power plant assumed to be a coal steam turbine (CST) power plant with 46% efficiency. The distribution losses for district heat and electricity to the building were assumed to be 7% and 11% respectively. The primary energy losses for production of coal and biomass were assumed as 10% and 4% respectively. The electricity and heat used in pellets production were assumed to be 12% and 4% of the total energy embodied in the pellets (Nyström, Nilsson et al. 2011) and assume to be produced in the marginal power plant and in a standalone boiler with 90% efficiency respectively.

The power load demand of the different technologies was compared to the Swedish power demand load that was constructed by hourly data received from the Swedish national grid (2010a) for year 2010.

2.3. Simulation program

The *VIP-Energy* software (Strusoft 2011) was used to simulate the final energy use in the case study. *VIP-Energy* is a commercial dynamic energy balance simulation program that calculates the energy performance of buildings hour by hour. The software was validated by *IEABESTEST*, *ASHRAE-BESTEST* and *CEN-15265*. The case study was simulated in four different Swedish cities representing different Nordic climate conditions as listed in Table 1. The climate data obtained from the Swedish Meteorological and Hydrological Institute for year 2010.

Table 1. Climate scenarios year 2012. Source: The Swedish Meteorological and Hydrological Institute (SMHI)

Climate scenarios (cities):	Malmö	Karlstad	Östersund	Kiruna
Latitude	55°36'N	59°23'N	63°10'N	67°52'N
Average outdoor temperature	7.4°C	4.0°C	1.3°C	-1.5°C
Average daily global solar radiation kWh/(m^2 day)	2744	2,666	2,439	2,178
Average wind speed [m/s]	3.1	3.2	3.9	3.3

2.4. Economy and prices

In this study average values were use for the costs of energy, i.e., electricity, district heating and pellets. The prices for energy systems were obtained by different suppliers and assume to be representative. It is important to note that in reality prices are not uniform and could change with time, by location and differ among suppliers. Large price differences could be found between the values used in this work and real cases but these assumed to be few. The study aims to analyse the driver forces and trends in the Swedish market. The results apply to the prices that are used in this study and should represent the situations in most cases in Sweden.

The total yearly cost was calculated by the sum of the yearly costs for installation, equipment, maintenance (Table 2) and energy costs (Table 3). Eq.1 calculates the yearly cost for installation and equipment (*A*) by multiplying the total costs for installation and equipment (*P*) by the capital recovery factor with interest rate (*i*) of 5% and the expected life time of the products in years (*n*).

$$A = P * \frac{i*(1+i)^n}{(1+i)^n-1} \quad \text{eq.1}$$

Table 2. Prices for equipment, installation and maintenance of different heating technologies

Product	Equipment costs SEK	Installation costs SEK	Maintenance costs SEK /year	Life time Years
Bed-rock heat pump	50,000	5,000	-	15
Borehole	10,000	40,000	-	50
Air-source heat pump	24,500	6,000	-	15
Pellets stove	30,000	2,000	1,000	15
Chimney	20,000	17,000	500	50
District heating	31,100	16,000	-	50
Water based radiator[a]	3,500	2,000	-	50

[a] **Price per unit**

Table 3. Prices for different energy carriers

Energy carrier	Variable price SEK/kWh	Fix price SEK/year
Electricity	0.98-1.15[a]	3206-6900[b]
District heat	0.82[c]	
Pellets	0.6	-

[a] *Depends on the energy tax and power output. Prices are for one year contract (Statistics Sweden 2012)*
[b] *Depends on max power output (Statistics Sweden 2012b).*
[c] *(District Heating in Sweden 2011)*

3. Results

Fig. 2 illustrates the power demand of the case study with different heat sources technologies and with different outdoor temperatures. Air-source heat pump is the most sensitive to variations in outdoor temperatures. The power demand increases exponentially with colder outdoor temperatures until it reaches the power demand of resistance heater. Installing air-source heat pump in detached houses that are heated by resistance heaters will reduce the final energy use but the peak electricity load may remain unaffected.

With connection to the district heating, the peak power demand is the lowest among the different heat source technologies. The variations in power demand are relatively low and are the result of daily variations in household electricity. The amount of electricity, which is co-generated together with the heat at the CHP plant, can be higher than the household power demand load resulting in periods with positive balance of power production. This is not shown in Fig. 2.

The bed-rock heat pump is assumed to cover 100% of the heating demand. Some bed-rock heat pumps may be dimensioned to provide up to 95% (Larsson and Bröms 2007). That will result with higher power demand during low outdoor temperatures if the peak heating load is covered by direct electricity heating, which is usually the case.

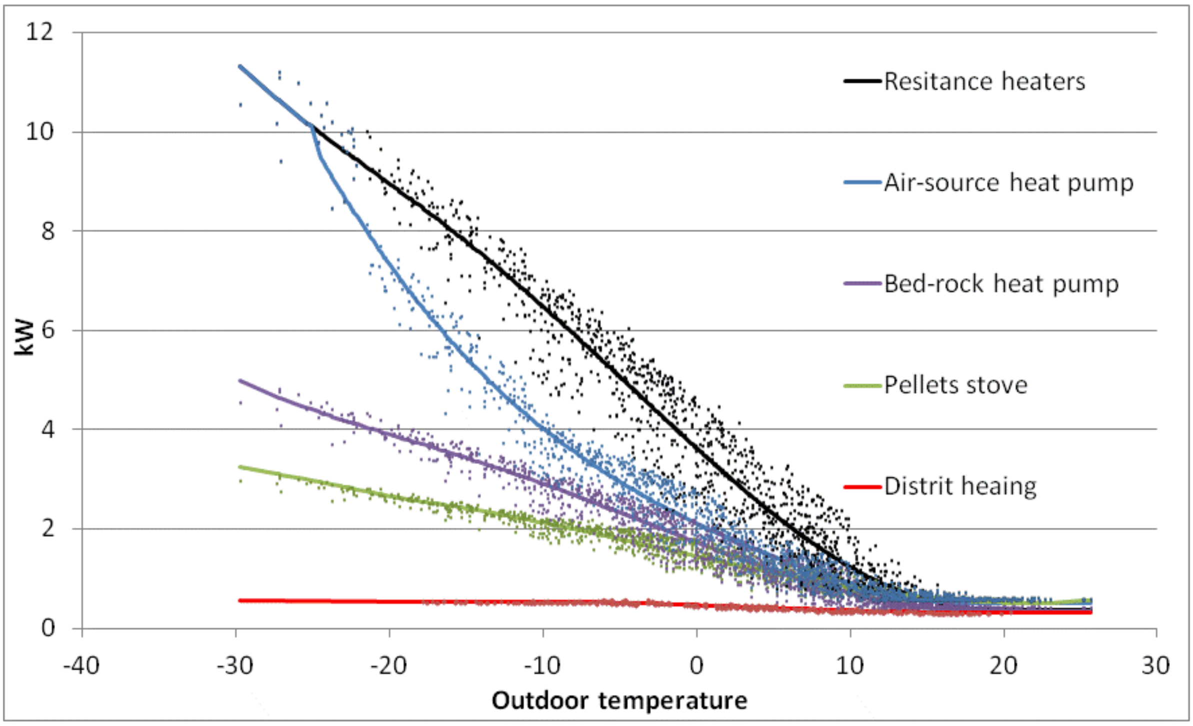

Fig. 2. The electricity production load that is needed to provide similar indoor conditions by different heat source technologies and for different outdoor temperatures in the case study building.

The Swedish power demand curve, illustrated in Fig. 3, was constructed by hourly data received from the Swedish national grid (2010a) for year 2010. Year 2010 was relatively cold year but similar trends are found in previous years as well. The Swedish power demand is sensitive to outdoor temperatures with peak power during the cold periods as a result of electricity heating for space and water heating in the service sector, with the detached houses as the major contributor. According to Fig. 2, resistance heaters and air-source heat pumps may have the largest contribution to the peak load demand. The sensitivity of the industry power demand to variations in outdoor temperatures is marginal (Börgesson, Doorman et al. 2004).

The differences between the electricity production and electricity demand in Fig. 3 shows that Sweden is a net exporter of electricity during low power demand. During high power demand, Sweden has deficit in electricity production that need to be covered by import. Hydro power is the most important regulator between high and low power demand followed by the co-generated electricity produced in CHP plants.

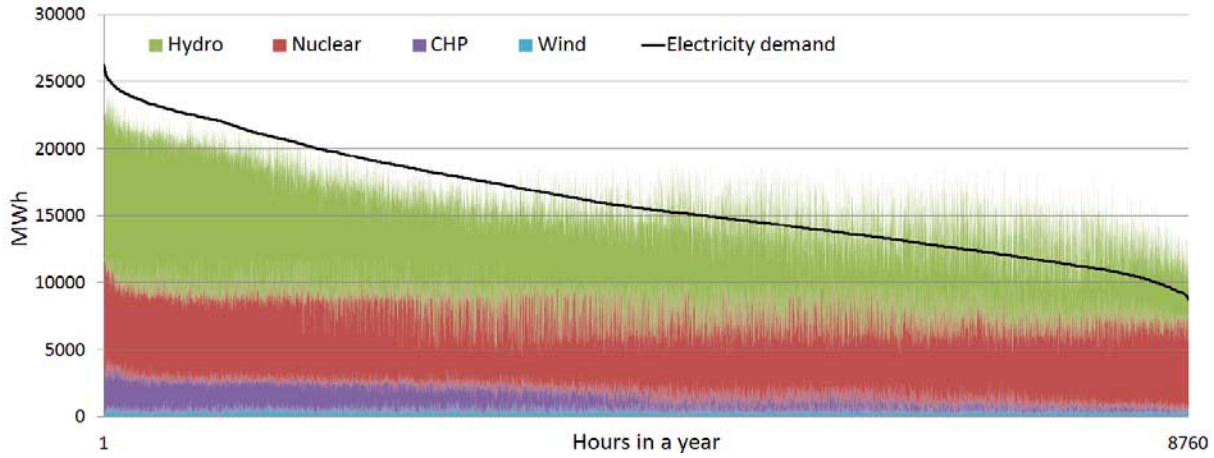

Fig. 3. Electricity load demand curve in Sweden and electricity production by technology for year 2010 (Source of data: The Swedish national grid (2010)).

Converting from the case study building heating system from resistance heaters to air-source heat pump found to reduce the primary energy by 30% to 35% as illustrated in Fig. 4. A pellet stove heating system use slightly more primary energy than air-source heat pump. District heating from CHP production and bed-rock heat pump provide the lowest primary energy use; 30% to 37% lower than air-source heat pump.

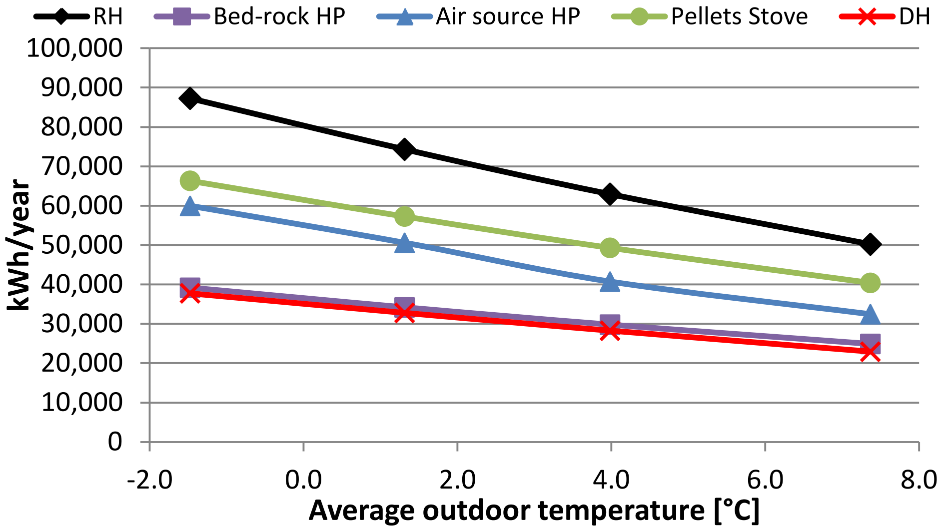

Fig. 4. The primary energy use for different heat source technologies and in different climate conditions

Fig. 5 illustrates the yearly costs of installing and using each heat source technology with and without the Swedish ROT tax. The ROT tax provides 50% tax return on the price of installation and reparation in private houses. The ROT tax favours large installations as bed-rock heat pump and connection to the district heating network. However in both cases air-source heat pumps have the lowest yearly costs for all climates conditions.

The price of electricity includes an energy tax that is lower in north of Sweden with its colder climate as listed in Table 2. Low rate energy tax benefits technologies that consume electricity for heating as heat pumps and resistance heaters. The lower energy tax rate allows bed-rock heat pump to be cost effective as air source heat pump in climate with annual average outdoor temperatures below 0°C. In warmer climates, and higher energy tax, the yearly costs of bed-rock heat pump are higher and district heating may be more comparative. According to Nair et al. (2010) economy is generally the main reason for energy efficiency measures among private house owners. The end user economy is thus most probably an important driver for the increasing number of installation of air-source heat pumps in Sweden.

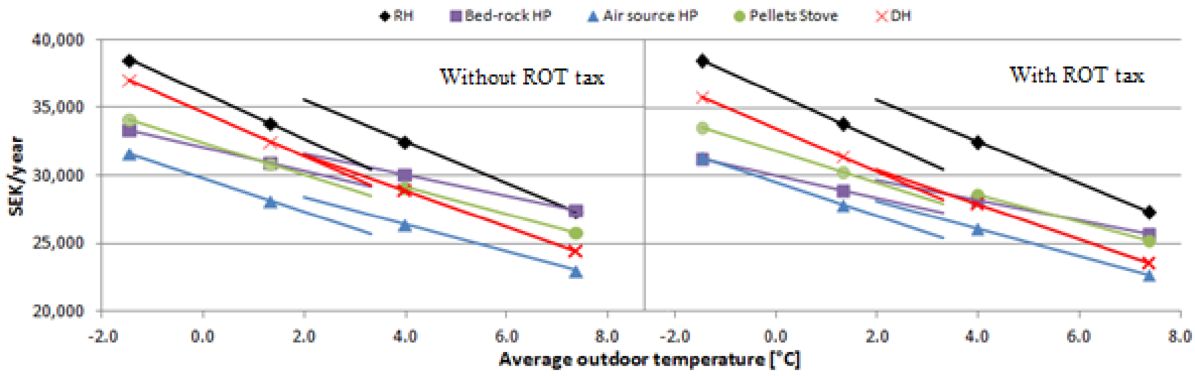

Fig. 5. The yearly costs including material, installation, maintenance, and energy costs for different heat source technologies and climate conditions with and without the Swedish ROT tax.

Air source heat pumps have the lower investment cost among the heat source technologies and lower yearly investment cost per kWh saved yearly in comparison to bed-rock heat pumps as illustrates in Fig. 8.

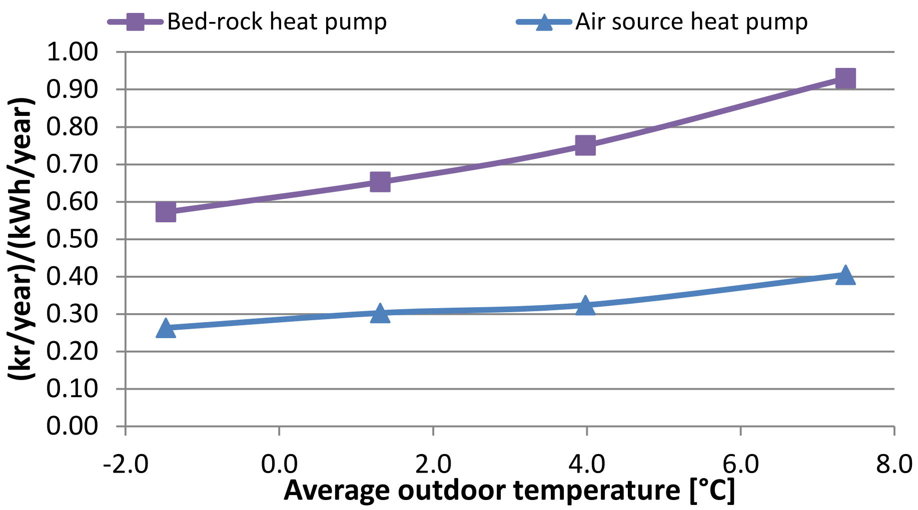

Fig. 6. A comparison of the cost of each unit of final energy saved between air-source and bed-rock heat pumps in different climate conditions.

Air-source heat pumps were found to be cost effective even if they are installed in detached houses that are already connected to the district heating network. The energy costs in detached houses that are connected to the district heating could be reduced by 1500 to 4000 SEK, depending on the climate conditions, if air source heat pump would be installed in addition to the district heating.

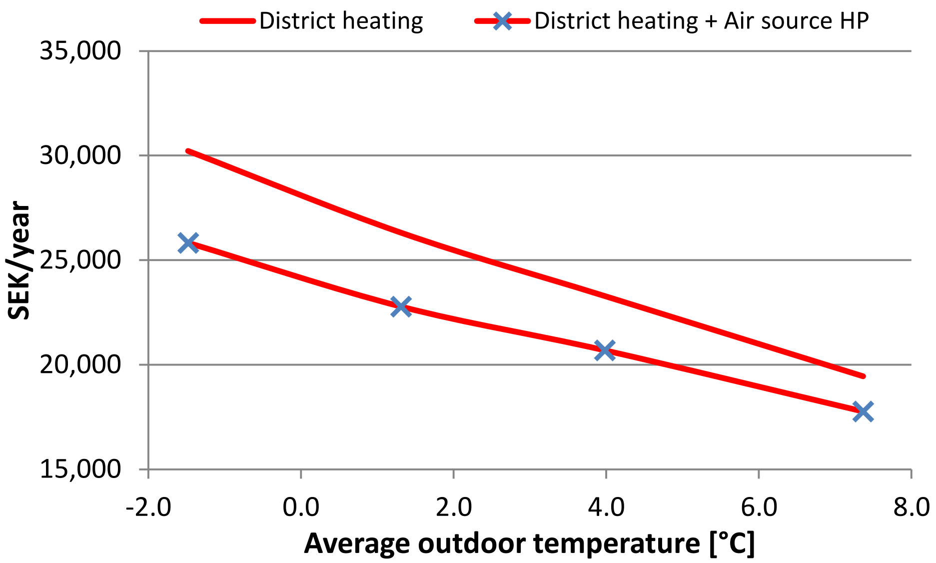

Fig. 7. The yearly costs including material, installation, maintenance, and energy costs for heat supplied from the district heat and heat supplied from both the district heating and air-source heat pump.

Air-source heat pumps provides 35% lower final energy use in comparison to resistance heaters (RH), district heating (DH) and pellets stove (PS) as illustrated in Fig. 7. Bed-rock heat pumps result with even lower final energy use because it covers the total heating demand including domestic water heating.

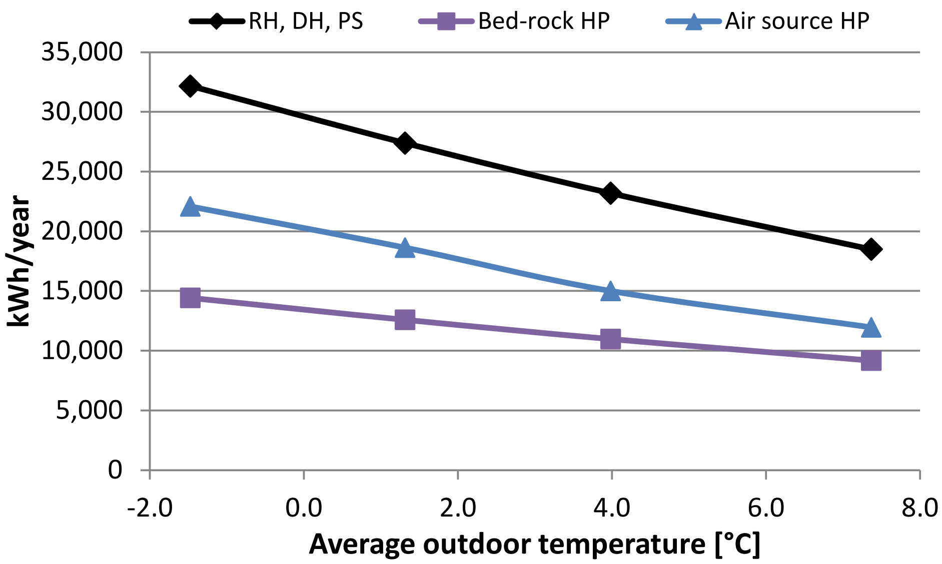

Fig. 8. Final energy use by different heat technology sources and in different climate conditions

4. Discussion

Heat pumps result with lower final energy use than resistance heaters, pellets stove or district heating. Lower final energy is an advantage for labelling in building. The *Nordic Ecolabelled building* provides up to 10 points by reducing the final energy below a certain level, while the minimum amount of points needed to acquire the labelling is 9 out of a total of 22 points that could be gained (Nordic Ecolabelling 2009). Since 2009, an energy declaration is needed for existing detached houses before they are sold, which record the final energy use of the dwelling and give suggestion for cost effective energy efficiency measures. Gustavsson and

Joelsson (2007) found that energy conservation measures were less cost effective when converting to more efficient heating system. The installation costs of air source heat pump are relatively lower than the costs of energy efficiency measures done on the thermal envelop of the dwelling and therefore may be favourable by detached house owners.

Air source heat pumps have lower installation costs and are more cost effective than resistance heaters, bed-rock heat pumps, pellets stove and district heating. Air-source heat pumps were found to be cost effective even if they are installed in detached houses that are already connected to the district heating network. Cost effectiveness may be the main driver for the increasing number of installation of air-source heat pumps in Sweden. In addition, the installation of air source heat pumps is relative simple and quick.

However the efficiency of the air-source heat pumps is reduced with decreasing outdoor temperature. At low outdoor temperatures additional heat source is needed. In most cases direct electricity heating is used, which could be built-in in the heat pump itself or by external resistance heaters. The use of air-source heat pump and direct electricity heating for peak heating load increases the power demand exponentially as the outdoor temperature decreases. District heating provide more uniform power load demand throughout the year followed by pellet stove and bed-rock heat pump.

The Swedish power demand is sensitive to outdoor temperatures with peak power during the cold periods as a result of electricity heating for space and water heating with the detached houses as the major contributor. Sweden export electricity through the Nord pool spot market during low power demand when electricity prices are usually low and import electricity during high power demand with higher prices. During the coldest days in 2010 the spot price of electricity reached a new record of 14 SEK/kWh, which had impact both on house owners and the industries (The Swedish national grid 2010b). Hydro power is used to regulate between periods of low and high power demand. However hydro power is not sufficient during peak power demand and fossil fuel based electricity is used from domestic production and import. Installing air-source heat pump in detached houses with resistance heaters reduces the final energy use but will maintain the high peak power demand during the cold days.

A conversion from resistance heaters to district heating in detached houses will reduce power demand and increase production of co-generated electricity from the CHP plant during peak power demand. Therefore increasing the number of district heated detached houses could reduce the dependency on imported electricity. In addition, replacing imported fossil fuel based electricity from Denmark, Poland and Germany by biomass based CHP production may assist to realize the decision of the Swedish government to break the fossil fuels dependency of the building sector until 2020.

The Swedish ROT tax, which provides 50% tax return on the price of installation and reparation in private houses, increase the cost effectiveness of large installations as district heating and bed-rock heat pump. Higher energy tax increases the cost effectiveness of the district heating in relation to air-source heat pumps. However, for district heating or bed-rock heat pump to be more cost effective than air-source heat pump additional policies are needed.

5. Conclusions

Converting electric heated Swedish detaches houses to district heating with biomass based CHP or bed-rock heat pump could reduce the use of resources, which could benefit Sweden as a society. Converting electric heated Swedish detaches houses to district heating or pellets stove could reduce power demand and level the power demand load curve. That would benefit the power utilities as it would be easier to meet the power demand and secure power supply. However cost effectiveness in one of most important drivers for house owners of detached houses to choose energy efficiency measures. For that reason house owners may benefit the most by the installation of air-source heat pump.

6. References

Börgesson, L., g. Doorman, et al. (2004). Elförbrukningens karaktär vid kall väderlek, Elforsk raport 04:18.

District Heating in Sweden (2011). Fjärrvärmepriser för småhus öre/kWh inkl. moms, 2004-2011 (Excel file).

Gustavsson, L. and A. Joelsson (2007). Energy conservation and conversion of electrical heating systems in detached houses, Energy and Buildings, 39 (6) (2007) 717-726.

Gustavsson, L. and A. Joelsson (2010). "Life cycle primary energy analysis of residential buildings." Energy and Buildings **42**(2): 210-220.

Larsson, L., S. Linskoug, et al. (2006). Elförbrukningens karaktär vid kall väderlek, Elforsk rapport 06:62.

Larsson, S. and G. Bröms (2007). Framtids elvärme och värmepumpar, Elforsk rapport 07:30.

Nair, G., L. Gustavsson, et al. (2010). "Owners perception on the adoption of building envelope energy efficiency measures in Swedish detached houses." Applied Energy **87**(7): 2411-2419.

Nordic Ecolabelling (2009). Nordic Ecolabelling of Small houses, apartment buildings and pre-school buildings.

Nowacki, J. E. (2007). Heat pumps in energy statistics - Suggestions, Nowab.

Nyström, O., P. A. Nilsson, et al. (2011). EL från nya och framtida anlääningar 2011, Elforsk rapport 11:26.

Statistics Sweden (2012). Priser på elenergi och på överföring av el (nättariffer).

Statistics Sweden (2012). Yearbook of housing and building statistics 2012.

Strusoft (2011). VIP-Energy simulation program.

The Swedish energy agency (2005). Årsmätning på fem bergvärmeanläggningar i Sjuhärad.

The Swedish energy agency (2009). IVT Nordic Inverter 12 KHR-N. **2012**.

The Swedish energy agency (2009). Pelletskaminer - Jämförelse

The Swedish energy agency (2011). Energistatistik för småhus 2010.

The Swedish Energy Agency (2011). Energy in Sweden 2011.

The Swedish national grid (Svenska kraftnät) (2010). Elstatistik för hela Sverige

The Swedish national grid (Svenska kraftnät) (2010). Kraftbalancsen på den svenska elmarknaden vintrarna 2009/2010 och 2010/2011.