Implementing energy efficiency in Sweden's existing housing stock

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Abstract
There is a potential for increased energy efficiency in the existing Swedish housing stock. We analysed changes to building envelopes and to energy supply systems (including power generation and end-use systems as district heating, bedrock heat pumps, wood pellet boilers and electric resistance heaters) and evaluated the impacts on cost, CO_2 emission and primary energy use. We used a system analysis approach and analysed the whole energy system chains, from natural resource to useful domestic heat. The studied houses were from the 1970s and had different size and energy standard, to evaluate how those parameters affect the potential of analysed measures in the building stock. We found that energy conservation and conversion of technology and fuel could reduce the CO_2 emission by 95 % and at least halve the primary energy use, and be cost-efficient from a national economic perspective. We showed that the ranking of the heating systems and the energy conservation measures did not change with house size or energy standard. But the heating systems that had about the same investment cost independently of the heat demand it should cover, were less competitive for the smaller houses. A successful implementation of changes requires them to be attractive for consumers to adopt. Hence, we analysed the economic conditions for Swedish house-owners to implement national economic cost efficient measures, and also what other factors that affect house owners' decisions to adopt new heating systems. We discussed whether policy instruments, in the form of investment subsidies and customer electricity tax, encourage house-owners to implement changes in accordance with the goals of decisionmakers. We conclude that the tax and the currently used investment subsidies in Sweden give relevant incentives to the customers to act according to national policy.

Introduction
A large part of the total final energy use in Europe is used for heat and electricity in buildings. To reduce this energy use and its effects on the climate, several strategies are required, such as energy conservation, increased energy efficiency in supply chains and conversion from fossil fuels. The Swedish building stock was greatly expanded in the 1960s and 1970s and many of these homes were designed for electric heating with resistance heaters (electric radiators). Most of these houses were also built before energy efficiency was emphasized in the Swedish building codes. Since the building stock is renewed at a slow rate, the main potential to improve the energy efficiency is in existing buildings, through energy conservation measures and more efficient end-use heating technology. More efficient conversion technology in district heat and electricity generation, including cogeneration plants will reduce the primary energy use while biomass-based systems instead of fossil fuel systems will reduce the CO_2 emission.

Several studies have concluded that improved thermal insulation is profitable for the house owners (Erlandsson et al., 1997;Gustafsson and Karlsson, 1997;Norrman and Johansson, 1995). Erlandsson et al. showed that the manufacturing, transport, building and demolition of the extra insulation materials had a small pollutant effect compared with the reduction in emissions resulting from the decrease in heating requirements (Erlandsson et al, 1997).

Heat pumps have been identified as a means to improve the energy efficiency in the end-use system and continued technology development is likely to increase their coefficient of performance (COP) (Almeida, 2003; Laue, 2002). District heat produced by combined heat and power (CHP) has a high system efficiency, low emission and a higher degree of fuel flexibility than individual energy systems (Ericsson, 2004;Gustavsson, 2003). There is a also a potential for higher efficiency in biomass-based district heating systems through the commercialisation of the biomass integrated gasification combined cycle (BIGCC) technology (Ståhl and Neergard, 1998).

We have studied detached houses with electric resistance heaters. Options for upgrading the energy efficiency of the energy chains heating the houses were analysed, including changes to the building envelope, end-use heating technology, electricity and heat production technology and fuel. The aim was to show how these different parts of the energy system interact and to evaluate the cost-effectiveness of reducing CO_2 emission and primary energy use by different combinations of changes. In order to find general guidelines for the building stock, we analysed how the size and energy standard of the houses affected the potential for energy conservation and conversion of heating system. No changes to the end-use of household electricity (for lighting, cooking etc) were studied and no comparison of the possible consequences that the analysed changes had on that electricity use was made.

However, successful implementation of changes requires them to be attractive enough for customers to adopt. We hence investigated the house owners' conditions when implementing such energy conservation measures and heating systems that are found profitable from a national economic standpoint. Both the customers' economic situation and their personal perception of different energy supply alternatives were studied. We then discussed whether current Swedish policy instruments, in the form of investment subsidies and customer electricity tax, encourage house owners to implement changes in accordance with the national goals.

Methodology

NATIONAL ECONOMIC PERSPECTIVE

We have used a system analysis approach to study energy system changes and the connection between the supply and the demand. The system boundaries included the energy system chains from natural resource to useful heat service in six reference houses. The total remaining lifetime of the houses in question was considered, and was expected to be 50 years. Four variables in the energy chains were changed: the heat demand as a result of applying energy conservation measures, the end-use conversion technology in the house, the technology for electricity and district heat supply and the type of fuel.

Our starting point was two existing detached houses, both built in the 1970s but with somewhat different construction. House A had 2 floors and half of the ground floor was below ground level, as a basement. House B had 1 ½ floors and no basement. Both used electric resistance heaters for space heating, and an electric immersion heater for tap water. We varied the heated area of the houses by ± 30 % to give six reference houses (3 for each construction) with heated areas between 100 and 306 m^2 and heat demands between 28 and 47 MWh annually. The energy standard of the medium size of house A was varied to simulate the effect of varying energy standard in the building stock. Due to the age of the houses they needed new drainage systems and end-use heating equipment (resistance heaters and immersion heater) and the window frames needed painting. These requirements were included in the reference systems. The reference electricity supply was based on stand-alone steam turbine power plants fuelled with coal. Coal-based electricity is considered to be the marginal electricity production technology in the Nordic countries and steam turbines are still the leading technology used for electricity production in the OECD countries (Swedish Energy Agency, 2002;IEA, 1999).

Primary energy use, CO_2 emission and cost were compared for all energy system chain alternatives. The emission and cost were estimated for each process in the energy chains, and the energy input and energy efficiency at each stage were taken into account. The CO_2 released by burning biomass fuel was assumed to be balanced by the CO_2 removed from the atmosphere during the growth of new biomass. Thus the emission of CO_2 from the biomass-based systems depended on the amount of fossil fuel used in the energy chain, for example in transportation.

The total cost of heating the house hence included the cost of investments in plants and end-use technology, fuel, operation and maintenance, heat and power distribution and energy conservation measures. Investment costs were annualized, using a 6 % real discount rate. The costs were calculated from a national economy perspective and domestic Swedish energy taxes, environmental charges and subsidies were excluded from the analyses, as were external costs. All costs and prices refer to 2006, using an exchange rate of 1 euro = 9.27 Swedish krona (ECB, 2006).

Cogeneration

For the district heating systems analysed, cogeneration plants supplied the based-load demand. When comparing cogeneration with separate production of heat and electricity, both types of energy carriers must be considered. Here the functional unit was the energy needed to heat the house for one year, and hence the main product was heat. As cogeneration produces both heat and electricity we used the subtraction method and assumed that the electricity cogenerated in the district heating system replaced electricity produced in condensing power plants, based on similar technology and the same kind of fuel as the corresponding cogeneration plant (Gustavsson and Karlsson, 2006). This enabled us to carry out the comparison of fossil-fuel based energy chains versus biomass-based chains. We based the underlying assumption of a demand for electricity produced in stand-alone plants on the fact that about 75 % of the power generation in the EU is based on such production (Gustavsson and Madlener, 2003). To emphasize the importance of choice of method when comparing cogeneration with separate heat and electricity production we also performed analyses based on the multifunctional method, where the functional unit included both electricity and heat (Gustavsson and Karlsson, 2006). The functional unit was defined as the sum of heat produced in order to heat the house and the maximum amount of electricity cogenerated by any of the systems when producing that heat. For systems that could not generate the maximum amount of electricity, stand-alone power plants with similar technology and fuel were assumed to cover the electricity deficit.

Heat demand

Energy conservation measures were analysed for three different parts of each construction: attic, windows and basement/foundation. Extra insulation in the attic consisted of 200 mm blown stone wool. Existing windows having a U-value of 2.7 were replaced with new windows with a U-value of 1.2. The new windows were triple-glazed, with two low emissivity coated panes forming a sealed unit and separated by argon. For house A, 100 mm thick expanded polystyrene boards were added to the outer basement walls, and for house B the same type of boards were laid out in the ground horizontally from the foundation. Reference and new U-values are given in Table 1. The different heat demands, as a result of different combinations of the above measures, were estimated using the energy simulation software Enorm 1000 (EQUA 2001), assuming the indoor temperature to be 22 °C, which is usual in Swedish homes today (Larsson et al., 2003).

End-use heating systems

The existing heating system (resistance heaters and immersion heater) was replaced by a bedrock heat pump, pellet boiler, or district heating. The installed capacity of the heat pump and the electrical resistance heaters was adjusted when the energy conservation measures reduced the heat demand. All alternatives included installation of a water-distribution system, and fewer water-filled radiators were installed in the scenarios entailing new windows since the cold draft was reduced. For the wood pellet boiler alternative a chimney and a pellet storage were also included. The investment costs were based on the information provided by Swedish retailers and installers. During 2005, the analyzed energy conservation measures were implemented in house A and a heat pump system was installed.

Electricity and heat supply systems

All end-use alternatives were analysed combined with different electricity supply systems. Besides the reference coal-based steam-turbine technology (CST) we included natural gas-based combined cycle technology (NGCC) and biomass-based integrated gasification combined-cycle technology (BIG/CC). BIG/CC technology is still under development but is more energy efficient than other electricity generating technologies based on biomass (Ståhl and Neergard, 1998;Gustavsson and Joelsson, 2006). These systems were assumed to cover 95 % of the heat demand in the electrical heating systems, while peak production with light-oil-fired gas turbines covered the remaining 5 %. All electricity needed to operate the pellet boilers and district heating systems was assumed to be produced as base load. The district heating system was assumed to be based on cogeneration in combined heat and power (CHP) plants with the peak demand covered by light-oil-fired boilers. Thus the biomass-based supply chains included more fossil fuels than if the peak-load had been supplied by biomass-fuelled hot-water boilers. The economically optimal utilisation time and fraction of cogeneration depends on the fuels used in peak-load and base-load production and on the assumed costs and fuel prices. We performed this design based on oil- and coal prices that included the mitigation cost of switching from the respective technologies to the BIG/CC alternative. When condensing plants were used to cover the deficit of electricity in a system or to be replaced by cogenerated electricity (depending on method) corresponding stand-alone power plants used the same type of fuel. We assumed the electricity distribution losses to be 7 % and the heat losses in the district heating network to be 14 %. All district heating and electricity plants were assumed to have a lifetime of 25 years. The total cost of the district heat and electricity supply systems included the cost of producing and distributing the district heat and electricity. The capacity, efficiency and cost of the power plants described above are given in Table 2.

Fuel chains and fuel prices

The assumptions regarding the production and transportation of fuels for electricity and heat were made according to Karlsson (2003). The biomass fuel used for electricity generation was assumed to be wood chips, produced from logging residues. Crude oil for production of petrol, diesel, and light fuel oil was assumed to be originating from offshore production in Norway, as was natural gas. The coal was assumed to be imported from opencast mines in South Africa, Poland and Colombia, and used in Danish power plants. For the calculations we used mean fuel prices for 2004, when available and the prices are

Table 1. U-values for the medium sizes of the reference houses, new U-values after energy conservation measures were applied and investment costs for implementing the measures in the medium sized houses. For house A, U-values for the 3 energy standards are shown.

	U_{ref} (W/m^2 *K)			U_{new} (W/m^2 *K)			Investment cost (euro)
House A, 236 m^2	A1	A2	A3	A1	A2	A3	
Windows	2.70	2.70	2.70	1.20	1.20	1.20	8736
Attic floor	0.19	0.25	0.49	0.10	0.11	0.15	1265
Foundation	0.31	0.45	0.58				no measure analysed
Basement walls	0.66	0.66	0.66	0.31	0.31	0.31	653
Walls upper floor	0.17	0.23	0.58	0.17	0.23	0.58	no measure analysed
House B, 144m^2							
Windows		2.70			1.20		5616
Attic floor		0.31			0.12		692
Foundation		0.21			0.17		566
Walls		0.36					no measure analysed

Table 2. Capacity, efficiency (η), investment cost (IC), maintenance cost (MC) and assumed annual utilization time (UT) for the analysed power plants (Bärring, 2003;Gustavsson, 1998;Gustavsson, 1992).

	Capacity (MW)	η_{el}	IC (€/kW)	MC (€/MWh year)	UT (hour/year)
Stand-alone power plants					
CST	400	0.47	1 237	5.3	7 000
NGCC	300	0.52	678	2.6	7 000
BIG/CC	100	0.47	1 186	8.6	7 000
Stand-alone, peak- production plants					
Light-oil gas turbine	120	0.27	352	8.9	350
Light-oil boiler	50	0.90	113	1.7	860/900/1540[a]
Cogeneration plants		η_{el}/η_{heat}			
CHP-CST	100	0.34/0.55	1 237	7.4	5 700
CHP-NGCC	50/50	0.44/0.44	773	4.2	5 700
CHP-BIG/CC	60/60	0.43/0.43	1 542	12.3	6 300

[a] For CHP-CST, CHP-NGCC and CHP-BIG/CC, respectively.

Table 3. Fuel prices for fuels used for electricity generation and for pellets in a domestic boiler (Swedish Energy Agency, 2004;Swedish Energy Agency, 2005;SCB, 2005;SCB, 2004;Larsson, 2005).

Fuel	Price (€/MWh, 2004)
Coal	7.3
Light fuel oil	29
Natural gas	22
Wood chips	15
Pellets, residential	33

shown in Table 3. The price of crude oil was at the time US$ 38 per barrel (19 €/MWh).

HOUSE OWNERS' ECONOMIC SITUATION

Cost of electricity and heat

Since January 1, 1996, Swedish electricity is not sold on a monopoly market. Thus, customers can currently choose between more than 30 electricity suppliers, although the three largest companies dominate the market. A large share of the electricity produced in the Nordic countries is traded on the common spot market, Nord Pool. Customers have access to the electricity network through agreements with the network owner in the area. The district heating market is typically local, where one company provides and operates the district heating network within a specific geographical area. We here considered district heating and electricity cost quoted by the energy suppliers Jämtkraft and Vattenfall. Jämtkraft is a local supplier of electricity and district heat in the area in which the reference houses are located and is mainly owned by the local municipalities. Vattenfall is the largest energy supplier in Sweden, and is state owned, with operations also in Finland, Denmark, Germany and Poland. Table 4 presents the electricity and district heating prices used in the study. We applied the district heating tariff that Vattenfall offers its customers in the city of Uppsala, which is three times as large as Östersund.

Policy instruments

Swedish energy policy is aimed at phasing out oil and electric heating, and increasing energy efficiency and the use of energy from renewable resources in the residential sector (Ministry of Sustainable Development, 2005). To promote energy efficiency and to reduce CO_2 emission in the residential sector, two investment subsidies have recently been implemented in Sweden. Between 2005 and 2007 house owners are entitled to a subsidy when replacing old windows with new energy-efficient ones, with a U-value not exceeding 1.2. The subsidy offered is 30 % of the cost (including both material and labour) that exceeds 1 080 euro, but is limited to a maximum of 1 080 euro. Between 2006 and 2010, house owners with resistance heating can obtain a subsidy for installing water-filled radiators, if they at the same time convert to district heating, or install a heat pump (not an air heat pump), or any equipment covering 70 % of the heat demand with biomass as fuel. The subsidy amounts to 30 % of the investment cost, up to a maximum of 3 240 euro. Both material and labour for both the distribution system and heating system equipment can be included in the costs, except in the case of a heat pump, where the cost of the pump itself is excluded. Here, we analyzed the impact of these subsidies.

We also investigated the effect of customer electricity tax. The Swedish electricity tax is 3.4 c/kWh, but since the beginning of the 1980s, the northern part of the country has had a reduced tax, which currently is 2.2 c/kWh. The reason for the reduced tax is to alleviate the burden of taxation in the north where the cold climate leads to higher heating costs (Swedish government, 1981). Here we compared three electricity tax scenarios: no customer electricity tax, the lower tax of northern Sweden and the higher tax of southern Sweden. There is also an electricity certificate system, which obliges consumers to buy a certain percentage of their electricity consumption as renewable through certificates. The suppliers handle the certificates and the price may vary between suppliers. The suppliers investigated here both charged 0.3 c/kWh. The customers also pay other state charges to a sum of 6 euro per year. The value added tax (VAT) of 25 % on energy, labour and goods was excluded from all calculations.

Table 4. Prices of electricity and district heat in January 2006.

Electricity price				*District heating price*			
		Jämtkraft	Vattenfall			Jämtkraft	Vattenfall
Production							
Spot price	(c/kWh)	2.2	2.9	Price	(c/kWh)	3.1	6.6
Additional charge	(c/kWh)	0	0.3	Annual charge	(€/year)	65	270
Annual charge	(€/year)	8.6	28.5	Power charge	(€/kWh, year)	37	0
Distribution							
16-amp-fused network (25 amp)							
Annual charge	(€/year)	117 (293)	173 (302)				
Price per kWh	(c/kWh)	1.1 (0.9)	1.7 (1.7)				

HOUSE OWNERS' PERCEPTION

In order to be successful in implementing policies aimed at accelerating the diffusion of certain heating systems and energy conservation measures, it is important to analyse the factors driving the diffusion. One important factor is customers' perception of the different heating systems. To understand the attitudes towards different heating systems, held by house owners with resistance heaters, we turned to the findings of Mahapatra and Gustavsson (2006). Their study is based on a questionnaire sent to almost 700 house owners in the residential area in Östersund in which our reference house B is located. All the houses in this area were built in the 1970s and heated with resistance heaters. The response rate of the survey was 59 %. We also looked at the results of a national survey where the same questionnaire was sent to 1 500 randomly chosen house owners throughout Sweden (Gustavsson and Mahapatra, 2005). Three main issues were dealt with in the questionnaires. The first one was the house owners' need for a new heating system. A need typically occurs when the customer is dissatisfied with the existing system or has learned that another system has advantages over the old one. Need is one of the major drivers behind the adoption of new systems, and can push someone to overcome the feeling of difficulty and risk, connected to a change in the customer's routine. Before the need has arisen, customers are normally not even open to or affected by information (Gustavsson and Mahapatra, 2005). Secondly, the questionnaire dealt with the sources of information that house owners would consult if they were searching for information about heating systems. This reveals the ways in which the attitudes of the house owners are influenced. The third issue was the perceived performance of the system, for example, technical factors, level of comfort, economic factors and environmental and security issues. The respondents were asked to rank the different systems according to the perceived advantages concerning these factors.

Results

PRIMARY ENERGY USE AND CO_2 EMISSION

The end-use conversion technology had a greater influence on the primary energy use than the choice of electricity supply system or energy-conservation measures. District heating was the most efficient end-use technology, in terms of resultant calculated annual primary energy use per m^2, followed by the heat pump, pellet boiler and finally the resistance heaters. The energy-conservation measures reduced the primary energy use between 20 and 25 % when combined, (depending on construction) and had a greater impact than the choice of electricity supply system. Figure 1 shows the primary energy use of house B for the different combinations of end-use systems and electricity generation technology. Each energy system alternative is shown for the four energy conservation levels: reference, attic insulation (AI), attic and basement/foundation insulation (AI+BI) and the insulation measures together with replacement of windows (AI+BI+windows).

The results in Figure 1 are based on the subtraction method and the efficiency of the power plants from which electricity was replaced was therefore crucial. The lower efficiency of the corresponding BIG/CC condensing plant compared with the corresponding NGCC condensing plant, meant that more primary energy was subtracted from district heating with BIG/CC. The primary energy use of the district heating system was hence lower with BIG/CC than with NGCC. When the multifunctional method was used, the primary energy use was instead slightly higher for BIG/CC than for NGCC (Fig. 2). The differences in primary energy use between the energy systems were overall smaller with the multifunctional method. The two different methods did not change the ranking of the end-use heating systems.

The choice of fuel had the greatest impact on the CO_2 emissions, and the differences in emissions between the biomass-based systems were small (Fig. 3). The CO_2 emissions from biomass-based systems depended on the fossil fuel used in the energy chains. Conversion from coal-based electricity generation and resistance heaters to a district heating system based on biomass reduced the CO_2 emissions by 95 %.

NATIONAL ECONOMIC PERSPECTIVE

Figure 4 shows the annual heating cost of house B for the different systems, in a national economic perspective. The heat pump system had the lowest cost of the end-use technology alternatives. However, almost all alternatives had a lower cost than the resistance heaters, irrespective of the choice of electricity supply system. Conversion to a pellet boiler system was as expensive as retaining the resistance heaters when the electricity supply was coal-based, but changing the electricity supply had a small

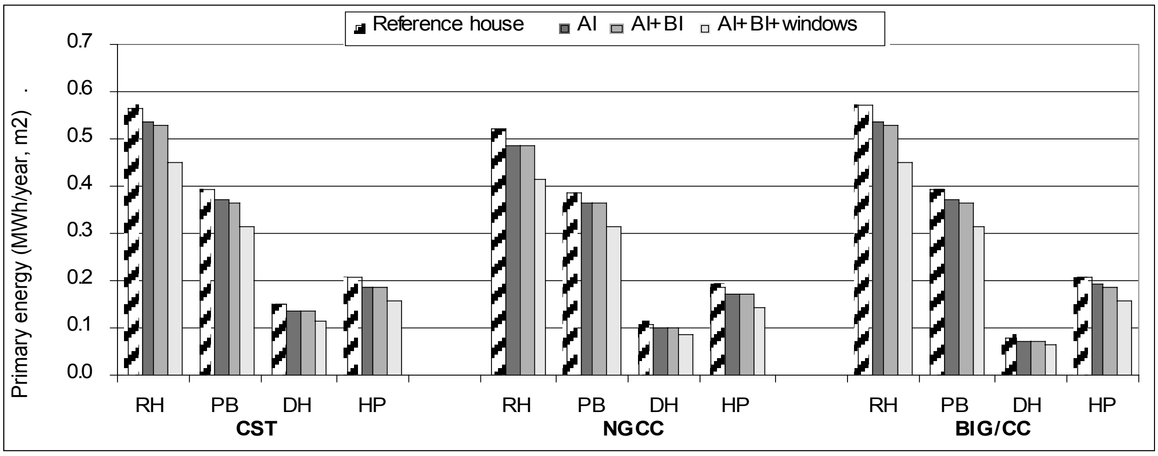

Figure 1. Annual primary energy use of house B. For the four different end-use technologies: resistance heaters (RH), pellet boiler (PB), heat pump (HP) and district heating (DH), combined with three electricity supply systems: coal-based steam turbines (CST), natural gas-based combined cycle (NGCC) and biomass with integrated gasification combined cycle technology (BIG/CC), and with the four different levels of energy conservation.

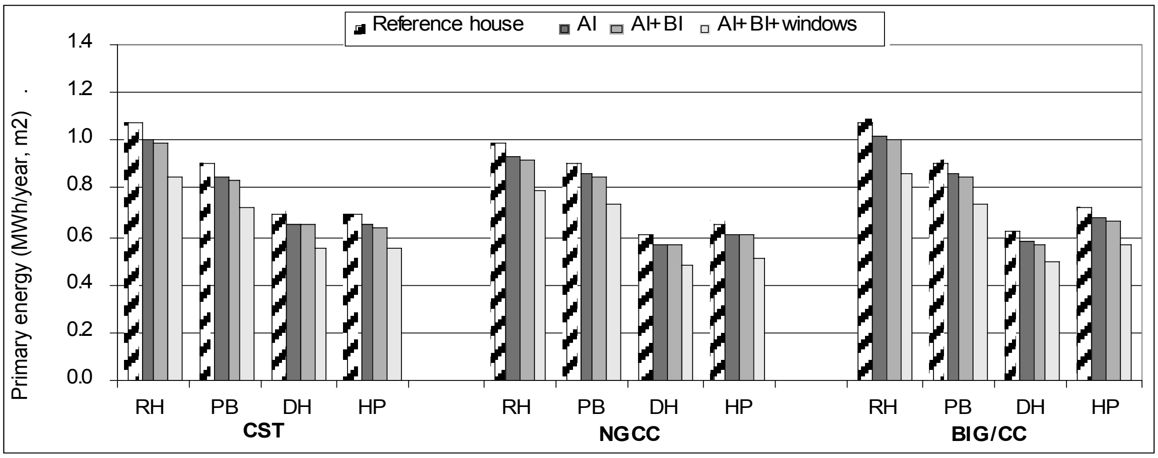

Figure 2. Annual primary energy use of the different systems, as defined in Figure 1. The analysis was here based on the multifunctional method.

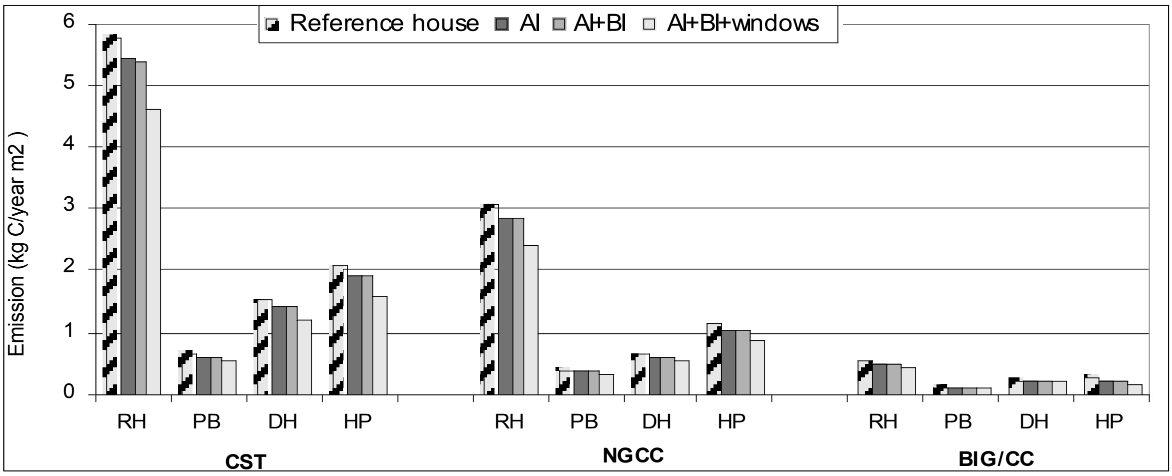

Figure 3. Annual CO2 emission for heating house B with the different systems, as in Figure 1.

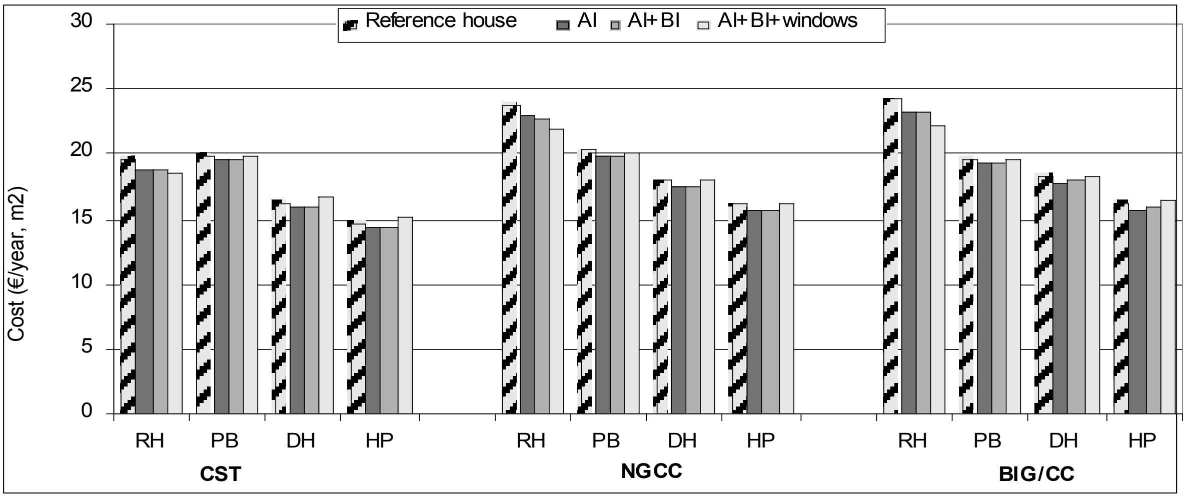

Figure 4. Annual heat cost of house B for the different systems. For abbreviations, see Figure 1.

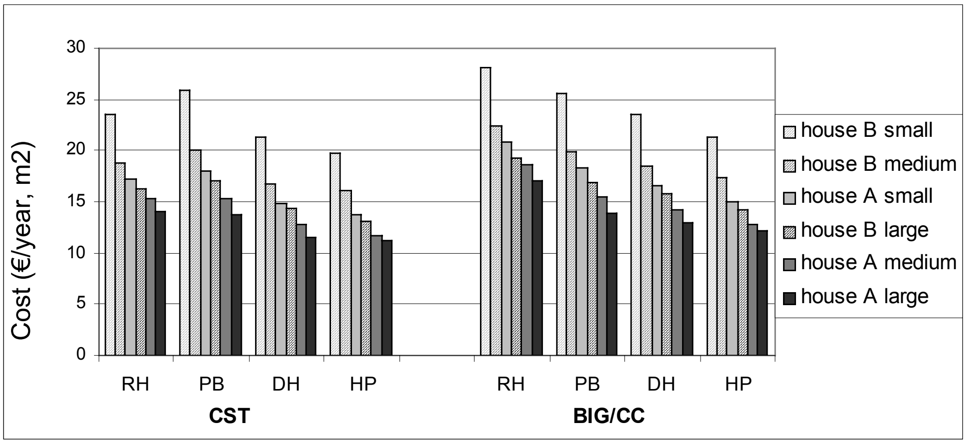

Figure 5. Annual heating cost per m2 for the six house sizes and the different supply systems, with all energy conservation measures applied.

influence on the cost of the boiler systems. As a consequence, retained resistance heaters were significantly more expensive than a conversion to a pellet boiler, when using biomass- or natural gas-based electricity. The insulation measures reduced the yearly cost of all systems, while new windows were not profitable in every case, due to the high investment cost. The differences in cost between conservation levels were small though, and for most alternatives the energy conservation measures changed the annual heating cost by less than 1 euro per m^2.

House size and energy standard

The house size did not significantly influence the economic ranking of the different systems. But the investment cost of the pellet boiler and district heating system was not reduced as much for a lower heat demand as the other systems, which made them less competitive for the smaller houses. This effect was greater when the energy conservation measures were implemented, as shown in Figure 5.

Figure 6 shows the percentage reduction in annual heating cost at conversions from resistance heaters to different end-use heating systems, without the energy conservation measures. The annual cost reduction was highest for implementation of a heat pump and lowest for conversion to a pellet boiler, where it was even negative for smaller houses. For conversion to both pellet boiler and district heating the cost reduction was lower for smaller houses, as the investment costs were not significantly lower for a smaller house.

The energy standard of the house did not alter the relative ranking of end-use heating system either. But the heat cost reduction at a conversion was greater for a house with lower energy standard, as the energy use and hence the energy cost then was greater for the reference system. A lower energy standard also led to a greater heat cost reduction when implementing energy conservation measures, due to a larger reduction in energy losses.

HOUSE OWNERS' ECONOMIC SITUATION

Figure 7 shows the customers' annual heat cost when purchasing electricity or district heat from the local supplier Jämtkraft, both with and without subsidies. The heat pump system showed about 35 % lower cost than the resistance heating system, while the district heating system and pellet boiler system resulted in 5-7 % lower cost. All three energy-conservation measures reduced the annual heating cost (with up to 400 €/year), except

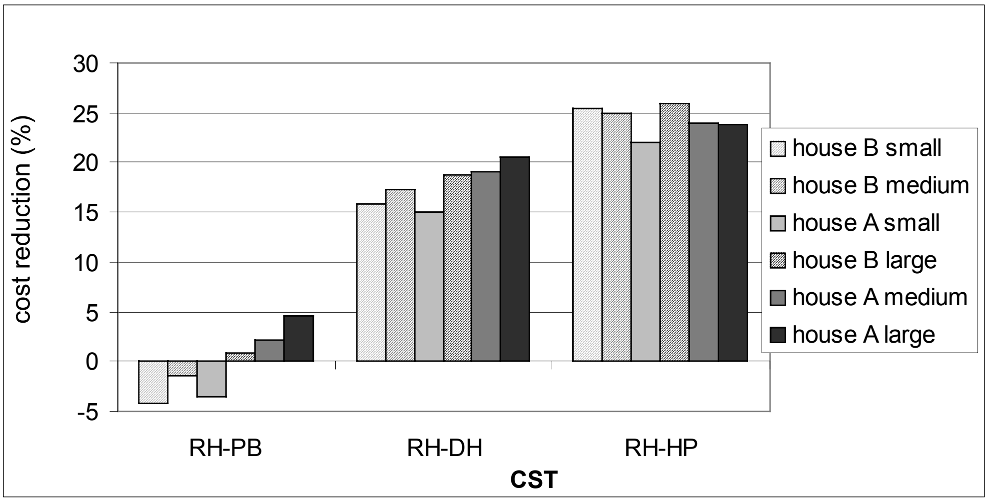

Figure 6. Percentage reduction in annual cost after a conversion of end-use heating system. The electricity used is based on CST.

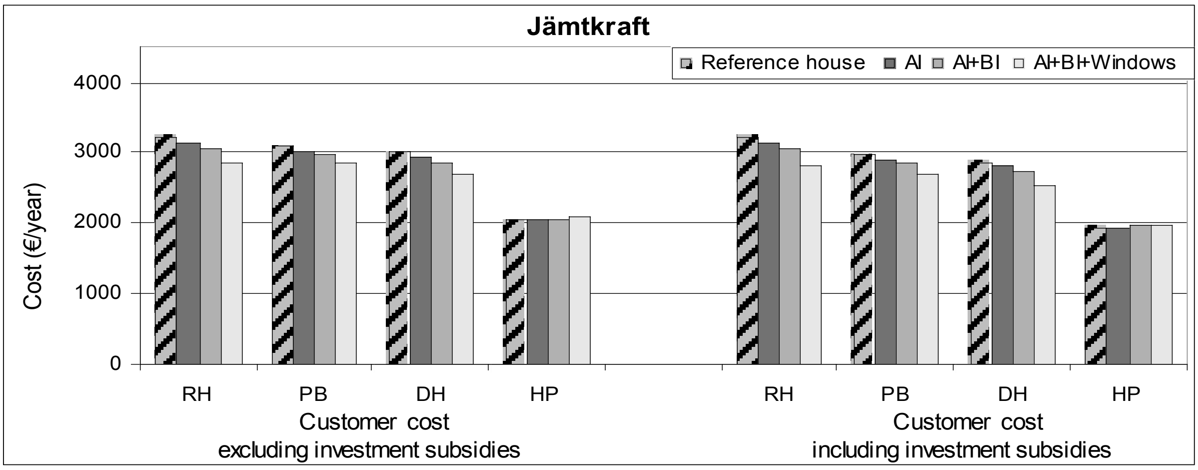

Figure 7. Heating cost of house A, excluding and including investment subsidies, with energy purchased from Jämtkraft and with an electricity tax of 2.2 c/kWh. The cost is shown for the four different end-use technologies combined with the energy conservation measures.

for with a heat pump system. For this system the annual heat cost slightly increased when all energy-conservation measures were incorporated, even when including the subsidies, compared with keeping the original house. This was due to the small reduction in cost of purchased energy (see Figure 9) not compensating for the cost of implementing the measures.

Vattenfall's significantly higher prices resulted in a higher annual cost (22 % higher for resistance heaters, 28 % higher for district heating and 14 % higher for heat pump), compared to Jämtkraft (Fig. 8). The heat pump system still resulted in the lowest cost, but the pellet boiler system became much more competitive compared to the other systems. With the Vattenfall prices all energy-conservation measures decreased the annual heating cost in all cases.

The subsidies did not reduce the annual cost by more than 6 % in any case. In addition to this, the real estate tax increased when installing a heat pump or energy-efficient windows, since the assessed value of the house increased. The increased real estate tax increased the annual heating cost by up to 4 %. For house A in its original state the real estate tax was 1 715 euro per year. In Figure 9 the annual cost is shown for customers of both Jämtkraft and Vattenfall, excluding subsidies. The cost is divided into four parts: cost of purchased energy (including electricity tax of 2.2 ¢/kWh), investment cost of heating systems, investment cost of energy-conservation measures and increase in real estate tax. The investment cost of the heat pump and pellet boiler systems was about twice that of converting to district heating and four times higher than retaining the resistance heaters. At the same time the heat pump and pellet boiler systems had the lowest cost of purchased energy. This explained why the total annual heating cost after a conversion varied less than the cost of purchased energy. The cost of purchased energy was reduced by more than 70 % when converting from the existing system to a heat pump system and implementing energy-conservation measures. Hence, house owners were exposed to a higher risk in the case of increased electricity prices if they retained the existing system.

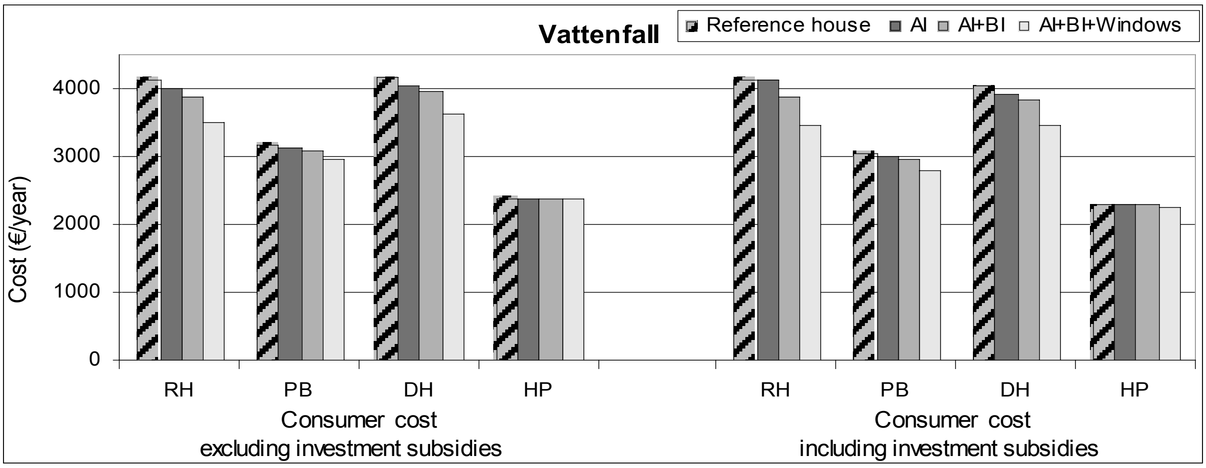

Figure 8. Heating cost of house A, excluding and including investment subsidies with energy from Vattenfall and with an electricity tax of 2.2 c/kWh.

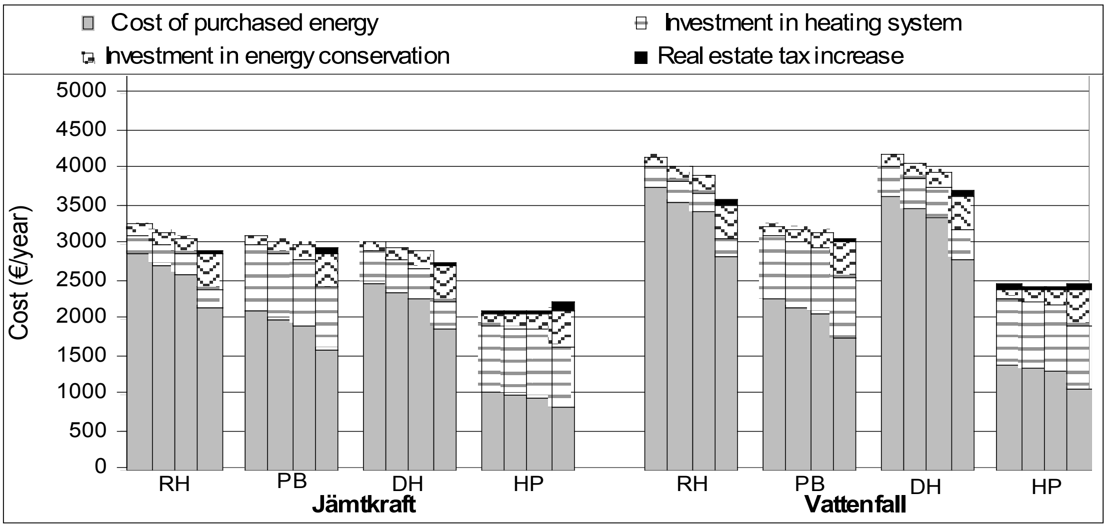

Figure 9. Total cost of heating house A, with energy from Jämtkraft and Vattenfall and an electricity tax of 2.2 c/kWh. The cost is divided in four parts and excludes investment subsidies

The annual heat cost for three electricity tax scenarios is shown in Figure 10. The real estate tax and subsidies are excluded. The introduction of electricity tax increased the cost of the electric systems and hence made the pellet boiler and district heating systems more competitive. When the tax was higher, the introduction of an investment subsidy reduced the annual cost less, in relative numbers than for a lower tax. The opposite was true for the energy conservation measures. They reduced the annual cost by a larger fraction for a higher energy tax, since the energy saving then was valued higher due to higher energy supply cost.

HOUSE OWNERS' PERCEPTION

The results of the Östersund survey showed that 84 % of the responding house owners did not plan to install a new heating system. This high proportion could be explained by the fact that a new system disturbs the customers' daily routine, as mentioned earlier, and the need for a new heating system was not sufficiently high to warrant a change. Dissatisfaction with the old system could be a reason for the feeling of a need of a new one, and a share corresponding to the ones planning a change (12 %) felt dissatisfied with their present system. A reluctance to change could also be explained by the lock-in effect experienced due to high investment cost of installing a water distribution system. In the national survey 80 % stated that they had no plans to change their heating system, and the house owners with resistance heating were less likely to install a new system than those with electric and oil boilers, even though they were among the more dissatisfied.

The performance factors that the respondents ranked as most important for their choice were annual cost, investment cost, functional reliability and indoor air quality. These four factors also had the highest rank in the national survey. People with resistance heaters ranked investment cost higher than others.

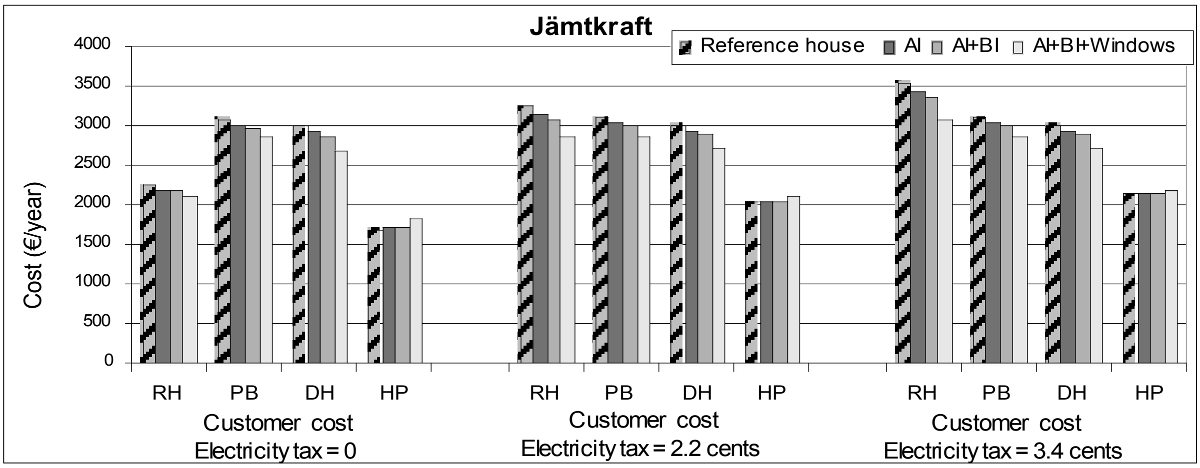

Figure 10. Total annual cost of heating house A with energy from Jämtkraft with three electricity tax scenarios and real estate tax and subsidies excluded

Whether the system was environmentally benign or had low greenhouse gas emissions were ranked much lower, as well as the time required for maintenance of the system.

When the respondents were asked what heating system they would recommend to someone else, heat pump and district heating were the most popular; 41 % and 38 %, respectively, would recommend them. Only 2 % of the respondents would recommend a pellet boiler. Here we found the only significant difference to the national survey, in which 54 % would recommend a heat pump, and 15 and 10 %, respectively, would recommend district heating and pellet boilers. The respondents' perceived relative advantages of the factors they ranked as important might explain their willingness to recommend heat pumps and district heating. They believed that bedrock heat pump systems had advantages over the other heating systems concerning annual heating cost. District heating had advantages with respect to functional reliability and indoor air quality. Pellet heating systems were ranked the lowest of the three, except with respect to investment cost where they were considered to have advantages over the others. If the house owners wanted to obtain information about a new heating system, the majority would turn to installers or sellers. A large group also claimed that they would read the homeowners' magazine "Vi i villa" or talk to friends and neighbours.

Discussion

The end-use heating technology had a greater influence on the primary energy use and heating cost than the choice of electricity supply system or energy-conservation measures. From a national economic perspective it reduced the heating cost of an electrically heated house both to implement energy conservation measures and to change from resistance heaters to a heat pump or district heating. As long as the marginal electricity generation is coal-based, pellet boilers had a higher cost. To minimize the cost and use of primary energy when improving electrically heated houses, priority should hence be given to district heating and heat pumps where possible. Considering the CO_2 emission, these systems are competitive with wood pellet boiler systems if biomass-based supply chains are used. Pellet boilers were also, as were district heating, less economically competitive than a heat pump for smaller houses, since the investment cost of these systems were reduced less than for heat pumps at a reduced heat demand. The conclusions are general across the building stock from the time-period of interest in the sense that the size and energy standard of the houses did not affect the ranking of the end-use systems, neither from a primary energy nor economic viewpoint. We still draw the conclusion that it appears to be justified to promote all three systems, since district heating systems require urban areas with a minimum heat demand per unit area, and heat pumps require a suitable heat source. In a biomass-based energy system the use of district heating with cogeneration was more important for the overall system efficiency than in a natural gas based energy system because of the higher conversion efficiency for natural gas fired condensing plants than for biomass-based ones.

The house owners had a lower annual heating cost for all three alternative heating systems than for resistance heaters. However, since the large majority of the respondents in the Östersund survey did not plan to change their heating system it appears that the economic benefit was not enough to cause the customers to search for and respond to information about new systems. The investment subsidies contributed less than 6 % to the annual heating cost and hence did not affect the customers' economic situation very much. However, since investment cost was ranked as one of the most important factors when choosing a heating system, especially for house owners with electric resistance heaters, the subsidy might help to break the perceived lock-in situation associated with resistance heaters. The economic incentive of a subsidy might also be a trigger for house owners to search for information about new heating systems and energy-conservation measures. Therefore, the analyzed subsidies seemed to give relevant incentives to the customers to act according to the national policy. House owners also gave higher priority to economic aspects than to environmental ones. This indicates that the use of economic instruments would be efficient to promote systems in line with the environmental goals.

The increase in real estate tax when installing new windows or a heat pump was small, but an increase in tax when improving energy efficiency gives a contradictory message to house owners. The electricity tax had a significant influence on the cost of the electric systems. The tax made pellet boilers and district heating much more competitive, and also caused the energy-conservation measures to be more cost-efficient, thereby encouraging house owners to reduce their electricity use. These effects are in line with the national goals. The reduction of the electricity tax in the northern part of the country hence reduced the competitiveness of district heating, heat pumps and pellet boilers and reduced the incentives for energy conservation measures. Here the one political goal of fairness in living expenses counteracts the goal of energy efficiency.

The energy supplier played an important role for the economic situation of the customers. With Jämtkraft's electricity price none of the energy-conservation measures were profitable together with a heat pump, despite the fact that the measures reduced the heat demand and hence the investment cost of the new heating system. However, the differences in annual heating costs with and without energy-conservation measures were very small. The energy supplier may also affect the customer's perception of the systems. The low district heating price in Östersund could be one reason why house owners there were more willing to recommend a district heating system than the average population.

References

Almeida, A. T. D., Lopez, A., Carvalho, A., Mariano, J. and Nunes, C., 2003, Evaluation of fuel-switching opportunities in the residential sector, Energy and buildings, Vol. 36, pp. 195-203.

Bärring, M., Nyström, O., Nilsson, P.-A., Olsson, F., Egard, M. and Jonsson, P., 2003, El från nya anläggningar 2003. Jämförelse mellan olika tekniker för elgenerering med avseende på kostnader och utvecklingstendenser., Report 03:14, Stockholm.

ECB, 2006, Exchange rates, [online], European Central Bank. Available from: http://sdw.ecb.int/browse.do?currentNodeId=2018794, [Accessed December 2006].

Ericsson, K., Huttonen, S., Nilsson, L. J. and Svenningsson, P., 2004, Bioenergy policy and market development in Finland and Sweden, Energy Policy, Vol. 32, pp. 1707-1721.

Erlandsson, M., Levin, P. and Myhre, L., 1997, Energy and environmental consequences of an additional wall insulation of a dwelling, Building and environment, Vol. 32, (2), pp. 129-136.

Gustafsson, S.-I. and Karlsson, B., 1997, Lönsamma energisparåtgärder i 60-talets flerbostadshus., Report LiTH-IKP-R-727, Linköping.

Gustavsson, L. and Börjesson, P., 1998, CO2 mitigation cost - Bioenergy systems and natural gas systems with decarbonization, Energy Policy, Vol. 26, (9), pp. 699-713.

Gustavsson, L. and Joelsson, A., 2006, Energy conservation and conversion of electric heating systems in detached houses, Energy & Buildings, doi:10.1016/j.enbuild.2006.06.014.

Gustavsson, L., Johansson, B. and Bülow-Hübe, H., 1992, An environmentally benign energy future for Western Scania, Sweden, Energy, Vol. 17, (9), pp. 809-822.

Gustavsson, L. and Karlsson, Å. 2003, Heating detached houses in urban areas, Energy, Vol. 28, (8), pp. 851-875.

Gustavsson, L. and Karlsson, Å. 2006, CO2 mitigation: On methods and parameters for comparison of fossil-fuel and biofuel systems, Mitigation and Adaptation Strategies for Global Change, Vol. 11, pp. 935-959.

Gustavsson, L. and Madlener, R., 2003, CO2 mitigation costs of large-scale bioenergy technologies in competitive electricity markets, Energy, Vol. 28, pp. 1405-1425.

Gustavsson, L. and Mahapatra, K., 2005, Swedish house owners' perception of pellet heating systems, 2nd European Pellet Conference, Wels, Austria, 2-4 March 2005.

IEA, 1999, Electric power technology. Opportunities and Challanges of Competition, Paris.

Karlsson, Å. 2003, Comparative Assessment of Fuel-Based Systems for Space Heating, Ph.D., Environmental and Energy systems studies, Lund University, Lund.

Larsson, B., Elmroth, A. and Sandstedt, E., 2003, Västra hamnen. Bo01 - Framtidsstaden. En utvärdering, Gothenburg.

Larsson, M., 2005, Prisblad för biobränslen, torv m.m nr 3/2005, Eskilstuna.

Laue, H. J., 2002, Regional report Europe: "heat pumps – status and trends", International Journal of Refrigeration, Vol. 25, (4), pp. 414-420.

Mahapatra, K. and Gustavsson, L., 2006, Diffusion of Energy-Saving Innovative Heating Systems in Sweden - A Consumer Survey Approach, ACEEE Summer Study, Monterey, California, USA, August 13-18, 2006.

Norrman, S. and Johansson, P., 1995, Energihushållning: ekonomisk utvärdering av energisparåtgärder i småhus, Karlskrona.

SCB, 2004, Peat 2003. Production, use, environmental impact, MI 25 SM 0401,

SCB, 2005, El- och gaspriser jan 1997–jul 1995, [online], Statistics Sweden. Available from: http://www.scb.se/statistik/EN/EN0302/2005H02/Internettablåer.xls, [Accessed January 1 20052005].

Ståhl, K. and Neergaard, M., 1998, IGCC power plant for biomass utilisation, Värnamo, Sweden, Biomass and bioenergy, Vol. 15, (3), pp. 205-211.

Swedish Energy Agency, 2002, Marginal elproduktion och CO2-utsläpp i Sverige, Report ER 14:2002, Eskilstuna.

Swedish Energy Agency, 2004, Energy in Sweden 2004, Report ET19:2004, Eskilstuna.

Swedish Energy Agency, 2005, Energiförsörjningen i Sverige, Report ER 2005:20, Eskilstuna.

Swedish government, 1981. Bill number 1980/81:118.