House Owners' Perspectives on Implementing Energy Efficiency in Existing Residential Areas

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ABSTRACT

There is a significant potential for increased energy efficiency in Swedish residential areas by improving the existing building stock. Energy conservation and changes in the energy supply chain can reduce CO_2 emission and primary energy use by 95% and 70%, respectively, and be cost-efficient from a national economic perspective. However, successful implementation of changes requires them to be sufficiently attractive for consumers to adopt. Here we analyze the economic conditions for house owners to change their heating system and to implement energy-conservation measures in a Swedish context. The basis for the analysis is an electrically heated house, built in the 1970s. The effects of the Swedish customer electricity tax and two recently introduced investment subsides are investigated, and the annual heating cost is compared using two different energy suppliers. However, apart from the economics several other factors affect a house owner's decision to change heating systems. We therefore also examine other factors through two comprehensive surveys and relate them to the house owners' economic situation and to the national economic perspective. The most important factors for house owners were found to be the annual heating cost, the functional reliability, the investment cost and the indoor air quality. The investment subsidies could be useful to break the lock-in effect of resistance heaters, which house owners seemed to experience and the electricity tax made the systems that give effects in line with national goals more competitive. The price differences between energy suppliers had considerable impact on the house owners' economic conditions, and possibly also on their perception of various systems.

Introduction

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. 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, considerable potential lies in improving the energy efficiency of existing buildings. Several studies have concluded that improved insulation is profitable, especially for houses in cold climates (Norrman & Johansson 1995), for houses in need of renovation (Gustafsson & Karlsson 1997), and if the U-value is significantly improved (Erlandsson et al. 1997).[1] 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. Gustavsson and Joelsson (2006) have shown that for an electrically heated detached house, energy conservation measures and changes in the energy supply chain, including conversion to bioenergy systems, can reduce CO_2 emission and primary energy use by 95% and 70%, respectively. At the same time, the changes can reduce the annual cost of heating the house during its remaining lifetime,

[1] U-value=5.682/R-value.

in a national economic perspective. Currently, over a third of all Swedish detached houses are heated with electricity alone and an additional proportion of houses use electricity in combination with other energy carriers. Hence, there is potential to reduce the energy demand by implementing energy conservation measures, and to reduce the primary energy use and CO_2 emission by converting to other heating systems. Swedish energy policy is also 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). Sweden has adopted a national goal of reducing CO_2 emissions by 4% compared to 1990 levels by 2012. However, successful implementation of changes requires them to be attractive enough for customers to adopt.

In this study we investigated the house owners' situation 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 analyzed. We then discussed whether current policy instruments, in the form of investment subsidies and customer electricity tax, encourage homeowners to implement changes in accordance with the goals of decisionmakers.

The house owners' economic situation is analyzed using the same reference house and considering the same measures as those in the national economic study by Gustavsson and Joelsson (2006). House owners' perceptions of different heating systems are discussed based on the results of two comprehensive questionnaires concerning customers' choice of heating system (Gustavsson & Mahapatra 2005; Mahapatra & Gustavsson 2006). These two house owner aspects are then related to the national economic perspective, based on an extension of earlier analyses by Gustavsson and Joelsson (2006). With the comparison of these three different perspectives as the foundation, the two Swedish energy policy measures mentioned above are discussed.

Methodology

House Owners' Economic Situation

An existing detached house built in 1974, and its original heat demand, was the starting point of our analysis. The house is situated in the city of Östersund, in the midwestern part of Sweden, and has two floors with a total heated area of 236 m^2. Half of the lower floor has its walls underground, as a basement. Electric resistance heaters (electric radiators) are used for space heating, and an electric hot-water boiler for tap water. The heat demand was calculated to be 41 MWh per year. Due to the age of the house it was in need of a new drainage system, new end-use heating equipment (resistance heaters and hot-water boiler) and painting of the window frames. The total expected remaining lifetime of the house was considered to be 50 years. The cost calculations included all investments in energy-conservation measures and for installing a new heating system, as well as the cost of purchasing electricity and heat from energy suppliers. Investment costs were annualized, using a 3% real discount rate. The discount rate for house owners after tax adjustments is actually less than 2%, since the current discount rate is low in Sweden. All costs and prices refer to 2006, using an exchange rate of US$1 = SEK7.7 (The Riksbank 2006).

Heat demand and heating system. Three different energy-conservation measures were analyzed: 1) extra insulation consisting of 200 mm blown stone wool in the attic, 2) 100 mm thick expanded polystyrene boards added to the outer basement walls, and 3) replacing the existing windows, with a U-value of 2.7, with new windows with a U-value of 1.2. 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 common in Swedish homes today (Larsson et al. 2003).

The existing heating system (resistance heaters and the electric hot-water boiler) was replaced by a bedrock heat pump, a pellet boiler, or district heating. The installed capacity of the heat pump and the 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 including new windows since the cold draft was reduced. For the 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 actually implemented in the house and a heat pump system was installed.

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 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 house is 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 1 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 larger than Östersund, with three times as many inhabitants.

Table 1. Prices of Electricity and District Heating in January 2006

Electricity Price				**District Heating Price**			
		Jämtkraft	Vattenfall			Jämtkraft	Vattenfall
Production							
Spot price	(¢/kWh)	2.6	3.5	Price	(¢/kWh)	3.7	7.9
Additional charge	(¢/kWh)	0	0.4	Annual charge	($/year)	78	325
Annual charge	($/year)	10.4	34.3	Power charge	($/kWh, year)	45	0
Distribution							
16-amp-fused network (25 amp)							
Annual charge	($/year)	140 (353)	208 (363)				
Price per kWh	(¢/kWh)	1.3 (1.1)	2.1 (2.6)				

Policy instruments. 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 for 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 labor) that exceeds $1300, but is limited to a maximum of $1300. 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 $3900. Both material and labor 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¢/kWh, but since the beginning of the 1980s, the northern part of the country has had a reduced tax, which currently is 2.6¢/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¢/kWh. The customers also pay other state charges to a sum of $7 per year. The value added tax (VAT) of 25% on energy, labor and goods was excluded from all calculations.

House Owners' Perceptions

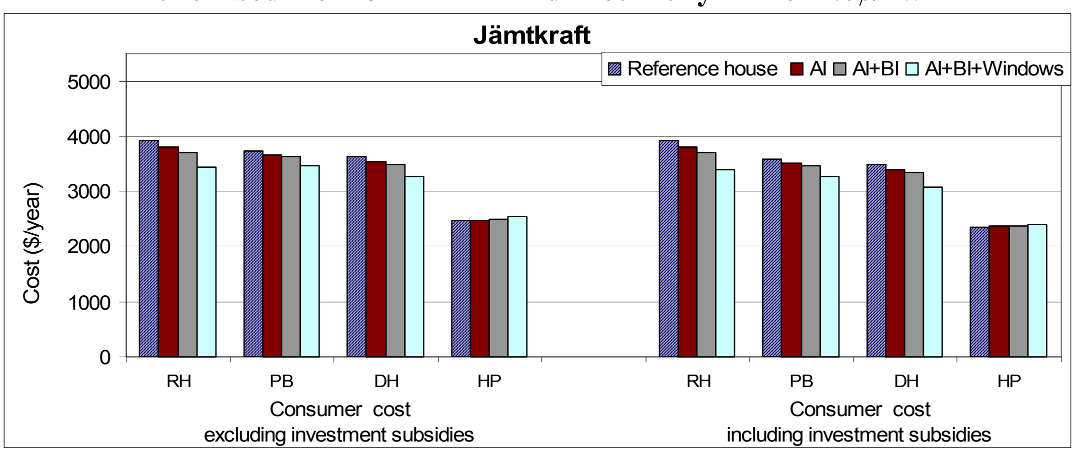
In order to be successful in implementing policies aimed at accelerating the diffusion of certain heating systems and energy-conservation measures, it is important to analyze the factors driving the diffusion. One important factor is customers' perception of the different heating systems. To be able to understand the attitudes of house owners with resistance heaters to different heating systems, 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 which our reference house is located. All the houses in this area were built in the 1970s and are heated with resistance heaters. The response rate of the survey was 59%. We also looked at the results of a survey where the same questionnaire was sent to 1500 randomly chosen house owners throughout Sweden (Gustavsson & 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 occur 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, since this means a change in the customer's routine, which may feel difficult and risky. Before the need has arisen, customers are normally not even open to or affected by information (Gustavsson & 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

House Owners' Economic Situation

Figure 1 shows the customers' costs when purchasing electricity or district heat from the local supplier Jämtkraft, both with and without subsidies. The lower electricity tax of 2.6¢/kWh, applicable to the area of the reference house was used. The figure shows data for the four different end-use systems: resistance heaters (RH), pellet boiler (PB), district heating (DH) and a heat pump (HP), and also the different energy conservation levels: reference, attic insulation (AI), attic and basement insulation (AI+BI) and the insulation measures together with replacement of windows (AI+BI+windows). 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, except when implemented in the heat pump case. For a heat pump system all energy-conservation measures slightly increased the annual cost, even when including the subsidies.

Figure 1. Heating Cost, Excluding and Including Investment Subsidies, With Energy Purchased from Jämtkraft and Electricity Tax of 2.6¢/kwh

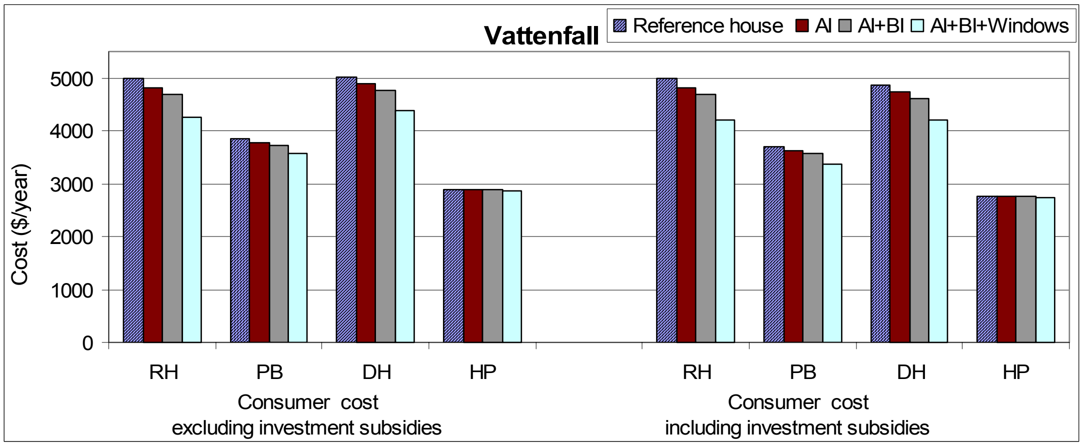


Note: Cost is shown for the four different end-use technologies combined with the energy conservation measures

Vattenfall's significantly higher prices resulted in a higher annual cost (22% higher with resistance heaters, 28% higher with district heating and 14% higher with a heat pump), compared to Jämtkraft (Figure 2). The heat pump system still resulted in the lowest cost, but the pellet boiler system here 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 the house in its original state the real estate tax was $2065 per year.

Figure 2. Heating Cost, Excluding and Including Investment Subsidies, With Energy from Vattenfall and Electricity Tax of 2.6¢/kWh



In Figure 3 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 2.6¢/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 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 energy cost. This explains why the total cost varies 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 the alternative with a heat pump system together with energy-conservation measures. Hence, house owners were exposed to a higher risk in the case of increased electricity prices if they kept the existing system.

Figure 3. Total Cost of Heating the House With Energy from Jämtkraft and Vattenfall: Cost is Divided in Four Parts and Excludes Investment Subsidies

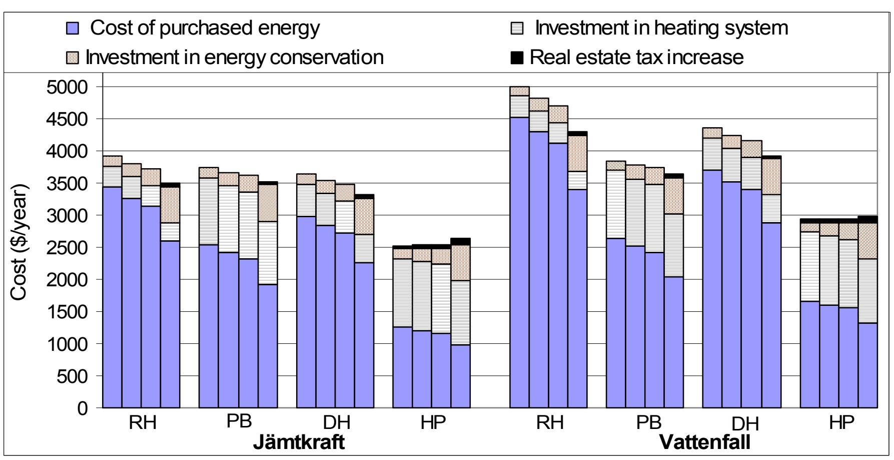
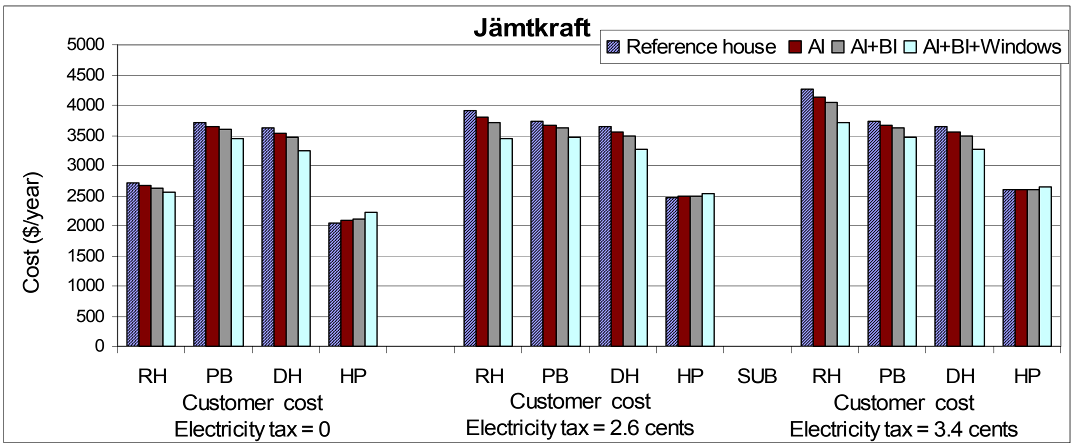


Figure 3 also shows that a low cost of purchased energy resulted in a low reduction of cost of purchased energy due to energy-conservation measures. Hence, the energy conservation measures were not as profitable. This was seen for both a more energy efficient supply system (compare the heat pump with the resistance heaters), and for a lower energy price (compare the heat pump system with Jämtkraft's price to the heat pump system with Vattenfall's price). This was the reason why the energy-conservation measures did not lower the annual cost in the heat pump system case in Figure 1.

The annual cost with three electricity tax scenarios is shown in Figure 4, with the real estate tax and subsidies excluded. The introduction of tax increased the cost of electricity and hence made the pellet boiler and district heating systems 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 is valued higher due to higher energy supply cost.

Figure 4. Total Cost of Heating the House With Energy from Jämtkraft With Three Electricity Tax Scenarios and Real Estate Tax and Subsidies Excluded



House Owners' Perceptions

The results of the Östersund survey showed that 84% of the respondents 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 above, 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 to 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 most dissatisfied.

The performance factors that the respondents ranked as most important were annual cost, investment cost, functional reliability and indoor air quality. These four factors also had the highest rank in the national survey. 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. The respondents' perceived relative advantages of the factors they ranked as important might explain this. 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. Here we found the only major difference with the national survey, in which 54% would recommend a heat pump, and 15% and 10%, respectively, would recommend district heating and pellet boilers.

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 neighbors.

National Economic Perspective

Gustavsson and Joelsson (2006) have previously analyzed the same energy conservation measures and end-use heating systems from a national economic perspective, as here analysed from a customer perspective, although excluding district heating. They evaluated the primary energy use, CO_2 emission and cost, using a system analysis approach. Here we followed their methodology and added a district heating alternative. The system was analyzed through the use of computer simulations and a life-cycle perspective was adopted on the studied energy service. Four variables in the energy chains were changed: the heat demand (as a result of energy-conservation measures), the end-use technology, the fuel used and the technology for large-scale electricity and district heat supply. The CO_2 emission was estimated for each process in the energy system chain, and the energy input and energy efficiency at each stage were taken into account. The CO_2 released from the combustion of biomass was assumed to be balanced by the CO_2 removed from the atmosphere during growth of new biomass. The data input required to perform the analyses are given in the computer software ENSYST, which was used to calculate emission and primary energy for the energy chains (Karlsson 2003).

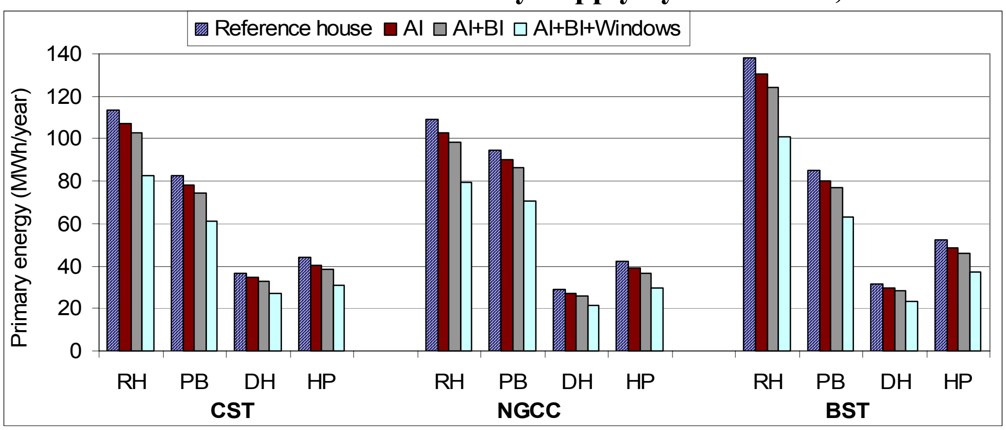
The total cost of heating the house included the costs of investments in plants and end-use technology, fuel, operation and maintenance, power distribution and energy-conservation measures. Investment costs were annualized, using a 6% real discount rate. The external costs were excluded from the analyses, as were domestic Swedish energy taxes, environmental fees and subsidies. All costs and prices refer to 2006, using an exchange rate of US$1 = SEK7.7 (The Riksbank 2006).

Gustavsson and Joelsson (2006) analyzed systems with base-load electricity produced by coal-based, steam-turbine technology (CST), natural gas-based, combined cycle technology (NGCC) or biomass-based steam turbine technology (BST). These systems were assumed to cover 95% of the heat demand, while electricity produced in light-oil-fired gas turbines covered the remaining 5%. The total cost of an electricity supply system included the cost of producing and distributing the electricity. The district heating system analyzed here was assumed to be based on combined heat and power plants, with biomass-based steam turbines (CHP-BST). It was assumed that 15% of the heat demand in the cogeneration system was covered by peak-load production in light-oil-fired boilers. The benefits of cogeneration were credited to the heat production by assuming that cogenerated electricity replaced electricity produced in similar stand-alone power plants using the same kind of fuel. The heat losses in the district heating network were assumed to be 14%.

Results

Gustavsson and Joelsson (2006) showed that 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. Adding district heating showed that this system was the most efficient end-use technology, followed by the heat pump, pellet boiler and finally the resistance heaters (Figure 5). The energy-conservation measures reduced the primary energy use by about 25% when combined, and had a greater impact than the choice of electricity supply system.

Figure 5. The Primary Energy Required to Heat the House With the Systems and Energy Conservation as in Figure 1 -- Here Also Combined with Three Electricity Supply Systems: CST, NGCC and BST



The choice of fuel had the greatest impact on the CO_2 emission, and the differences in emission between the biomass-based systems were small (Figure 6). The CO_2 emission 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 emission by more than 90%.

Figure 6. The CO_2 Emission When Heating the House With the Systems as Defined in Figure 4

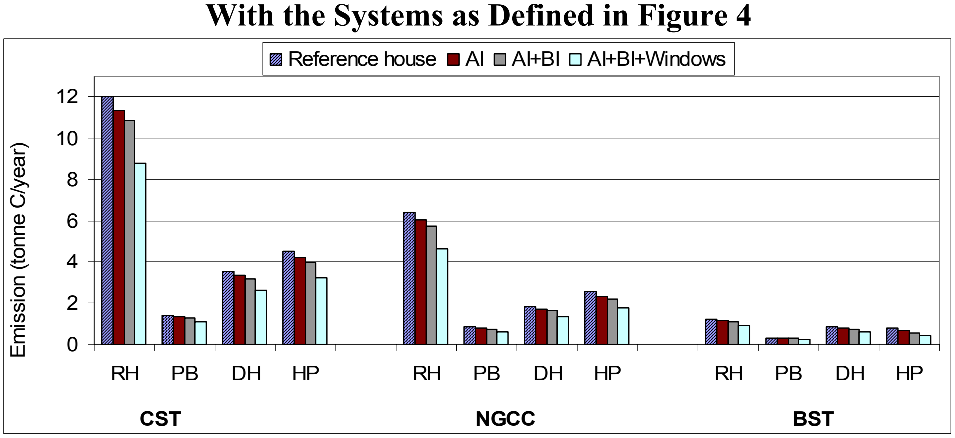
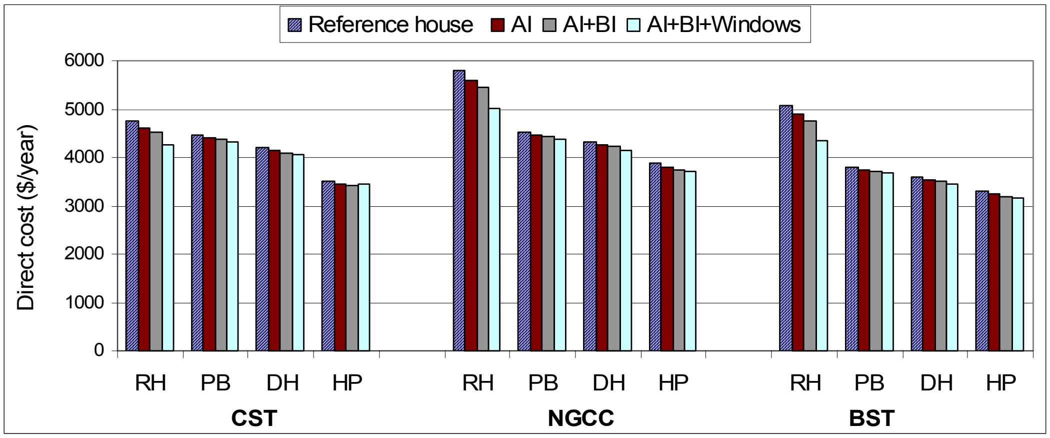


Figure 7 shows that the heat pump system had the lowest cost of the end-use technology alternatives. However, all alternatives had a lower cost than the resistance heaters, irrespective of the choice of electricity supply system.

Figure 7. The Cost of Heating the House With the Systems as Defined in Figure 4, Including Both the Production of Energy and Investment Costs



Comparing the national economic cost with the cost for the house owner, the ranking of the systems was the same for the house owner with Jämtkraft's prices (and shown in Figure 1). However, since Vattenfall's price of district heating is higher in relation to the electricity price than Jämtkraft's price or the production cost, a customer of Vattenfall had a different ranking. In that case the district heating system had the highest cost after a conversion, even higher than retained resistance heaters, if subsidies were not applied (Figures 2 and 7).

Discussion

From a house owner's perspective, the analyzed house 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 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 national policy. It seems reasonable to use economic instruments to promote systems in line with the environmental goals, since house owners gave higher priority to economic aspects than to environmental ones. 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. We have not studied house owners' attitudes to energy conservation-measures, but it is reasonable to assume that it resembles the one for heating systems. The investment subsidy considered here also applies to a house owner changing from an oil boiler to an alternative system (although a smaller sum). The discussion in this paper does not apply to that situation, since the results depend on the reference system and here the reference was resistance heaters (Gustavsson & Joelsson 2006).

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 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 reduced electricity use.

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 was 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.

From a national economic perspective it was cost-efficient to both implement energy conservation measures and to change from resistance heaters to other end-use systems. Pellet boilers, heat pumps and district heating all reduced the CO_2 emission and primary energy use while also reducing the costs. Therefore, 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. To minimize the use of primary energy, priority should be given to district heating and heat pumps where possible. Considering the CO_2 emission, these systems are also competitive with pellet boiler systems if biomass-based supply chains are used. The use of biomass in the production of district heating and electricity is, however, not a customer decision.

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