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The Residential Value of Energy Efficient Housing

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Marie H. Wahlström, PhD Student

Institute of Urban Planning and Environment
School of Architecture and the Built Environment
KTH - Royal Institute of Technology
Stockholm, Sweden

Abstract

In line with directives from the European Union, member countries have adopted measures aiming to reduce the energy use in the real estate sector. In Sweden, sellers of residential housing have to provide potential buyers with an energy certificate with detailed information on energy performance and consumption. The idea is to make users more aware of their energy consumption and of different ways to reduce it.

This paper studies to what extent the energy certificates for single-family house owners in Sweden, introduced in 2009, seem to work in the way expected. More specifically, the following questions are addressed:

- What role does preferences and household characteristics play for energy consumption as compared with the energy related attributes of their house?
- What is the price premium for energy efficient housing in Sweden? Are households willing to increase their bids for a given housing alternative, the lower they anticipate their energy cost will be?

An econometric approach is used to address the questions. Energy consumption is related to both housing attributes, including energy-related factors, and household characteristics, including income. A hedonic price model is used to analyze implicit prices for the various attributes. A unique feature is the large set of energy-related attributes included in the database (all single-family houses sold in Sweden 2009-2010), which also comprises individual household data.

Preliminary results show that the energy consumption in a house is partly depending on the building's characteristics, such as vintage, and partly on the household's characteristics, such as size and composition. The hedonic model shows that there is a price premium for energy efficient houses.

1. Introduction

As one of several steps taken to reducethe use of energy and the emission of climate gases Sweden adopted a law on energy performance certification of buildings in 2006.[1] The law, which is based upon European Union directives, prescribes that rental buildings, cooperative buildings and some non-residential buildings must have energy performance certificates from 2009. As for single-family housing each owner has to have the prescribed certificateno later than at the time of selling the house. If the seller does not present such a certificate before the contract of sale is signed the buyer has the right to carry out a certification on the seller´s expense. In this way each potential buyer will have data about the current use of energy as well as about building attributes related to the use of energy. Furthermore, the certificates include expert advicefor reducing the use of energy.

The idea behind the performance certificatesis of course that the added information is assumed to make the owners and users involved more aware of their energy consumption and options to reduce it which in turn should lead to a smaller or at least a more efficient energy use in the residential and commercial sector. That even minor improvements are important is evident by the fact that the energy use in the residential and commercial sector amounts to more than 40 per cent of the final energy use in the European Union (Directive 2002/91/EC) and that 30 per cent of global green house gas emissions stem from the construction and use of buildings (Stern 2008, Kahn 2010).In Sweden the average single-family house consumes 158 % more energy than the average EU household and Swedes use twice as much of their disposable income on energy, compared to the EU average. According to the European commission this cannot be explained by higher electricity prices but rather depends on a larger share of electricity use compared to other types of energy and the comparably cold climate. (European Commission 2011)

A Swedish government study conducted before the law of energy certificates was adopted assumed that the impact would be substantial but also stated that its size would depend upon the development of energy prices, the technical development and the public's attitude concerning global warming and energy consumption (SOU2004:109). Recent studies provide support for the idea that better information and growing awareness will influence the

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[1] Energy consevation requirements for new buildings and carbon dioxid taxes are examples of other poicy measures introduced during the last decades See "Energy in Sweden 2012" at www.energimyndigheten.se.

behaviour. For example, studies of commercial buildings in USA by Eichholtz et al (2010) and Fuerst and McAllister (2011)show that green labelling of office buildings is capitalized into rents. There is less empirical evidence for residential housing but Deng et al (2001) indicate that households are willing to pay a premium for “green” housing and Quigley, Kok and Brounen (2011) that home buyers are willing to pay a premium for homes that have been labeled as more energy efficient or “green”.

In this paper we will make use of the information provided by the Swedish performance certificates to look closer at the energy consumption among owners of single-family housing. We will both look at factors likely to influence their use of energy and at the relationship between the price of a house and its energy performance. More specifically, the following two questions will be addressed.

- What role does preferences and household characteristics play for energy consumption as compared with the energy related attributes of their house? E.g. does energy consumption mainly depend upon technical installations such as heat pumps or is the composition and behavior of the household more important?

- What is the price premium for energy efficient housing in Sweden? Are households willing to increase their bids for a given housing alternative, the lower they anticipate their energy cost will be?

In order to shed empirical light on these questions we have created a database by adding information of household characteristics, neighbourhood attributes and selling price to the corresponding information provided by the single family housing certificates issued in 2009 and 2010. A utility maximization framework and hedonic regressions are used to analyse the resulting database that contains around 80 000 individual observations.

In line with the results Quigley et al derived for the Netherlands, our preliminary results show that the energy consumption in a house is partly depending on the building’s characteristics, such as vintage, and partly on the household’s characteristics, such as size and composition. The hedonic model shows that there is a price premium for energy efficient houses. The main contribution of our research to the existing literature is perhaps the richness of the data set it is based upon.

The paper is organized as follows. The next section provides an overview of previous research and section three outlines the theoretical framework. Section four describes the data and section five presents the econometric model used for our analysis. Section six reports the results from hypothesis testing and finally, in section seven, we will present our conclusions and discussion of the results.

2. Litterature review

The area of sustainable housing is wide and covers a vast range of subjects, of which energy efficiency is one. The literature related to the area of energy efficiency in residential buildings can be summarized in two main categories: residential energy consumption, and the residential value of energy efficiency. This section will briefly review recent literature within these areas.

Residential energy consumption and behavioral pattern

In a recent paper, Brounen et al. (2012) analyse energy consumption, occupant characteristics and dwelling specifications for more than 300 000 households in the Netherlands. They investigate the impact of the physical and hedonic attributes of dwellings on variations in energy consumtion and compare it with the importance of household characteristics. Their results indicate that residential gas consumption is determined principally by structural dwelling characteristics, while electricity consumption varies more directly with household composition, inparticular income and family composition. Finally, they combine their empirical findings with forecasts of changes in household demographics, and conclude that the ageing and increasingly wealthy population will affect significantly the future demand for energy.

In 2011, Costa & Kahn (Costa & Kahn 2011) studied data from the Californian Census from 2000 in order to document the electricity consumption of California homes of different vintages. In particular they seeked to establish how the price of electricity at the time when a home was built determines its later electricity consumption. They estimate a log-linear model where the energy consumption is a function of the price of energy (at time of construction), construction year, house characteristics, socioeconomical & demographical characteristics of the household and geographical fixed effects. They conclude that low electricity prices at the time of construction are an important determinant of a home’s electricity consumption, even

Hanna (2007) studies the relationship between environmentalism and consumer choice through analysing the effect of polluting manufacturing facilities on the economic characteristics of nearby neighbourhoods. The result shows that being a mile closer to a polluting manufacturing plant reduces house values by 1,9 %. Hanna points out that there are good reasons to expect that pollution levels are influenced by neighbourhood incomes. If the willingness to pay for a clean environment is increasing in income, income groups will be sorted into residential locations according to pollution levels, with the rich living in cleaner areas, ceteris paribus.

The residential value of energy efficiency

Laquarta (1986)studies a small sample of newly constructed homes and documents that the Thermal Integrity Factor, a proxy for energy efficiency, has a positive relation to the transaction price. Dinan&Miranowski (1989)found a relation between energy consumption and prices of homes in Iowa, USA. Their data is not very extensive, only 234 detachedsingle-familyhomeswereincluded, but the documentedrelationship is quite precise. One dollar ofenergysavingsleadsto an 11,63 dollars increase in the transactionprice. In another study from the late 80s, Gilmer (1989) concludsthatenergylabelsshortens the search process whensearching for a new home in Minnesota, USA.

The economicvalueofso called green labels on houses has beenresearchedupon in both the Netherlands (Kok & Brounen 2011) and in the US, California (Kok & Kahn 2012). These studies concludedthatbothCalifornian and Dutch homeownersarewillingtopay a premium for homesthathavebeenlabeled as more energyefficient or ”green”.

Both the Dutch and the Californianstudyarebased on large data sets.The Dutch studyinclulds data from 177000dwellings (houses and apartements). Kok&Brounen (2011) concludes that the green labeled homes in the Netherlands sell for 3,7% morethan other homes, ceteris paribus. Further, the study shows a difference inbetween the different green label categories. Homes with the stronges label sell for 10,2 % more, which according to the authors, seem to reflect more than future energy savings alone.

The Californian study covers 1.6 million houses. Through the green label, the residents obtain verification thattheirhomesaredesigned and built touseenergy and otherresourcesmoreefficientlythanprescribed by buildingcodes. Homes with green labelsareclaimedto offer loweroperationalcoststhanconventionalhomes.Kok&Kahn (2012) concludes that the green labeled houses in California sell for 9% more than non-labeled homes. The Californian study further concludes that the premium is positivelycorrelatedto the environmentalideologyof the area, measured by the rate of hybrid vehicles. According to the authorsthiscouldimplythatsomehomeownersmayattributevalue to the moreintangiblequalitiesofowning a green home, such as pride or status. Finally, the Californianstudyverifies the use of a hedonic price model.

In 2011, Deng et. al reported similar results from Singapore's residential sector. Based on data from almost 37 000 transactions, this paper suggests that the economic returns to green buildings are substantial. They used a hedonic price model and added location attributes and Green Mark rating in the second step of the analysis.

Along with the Californian and Dutch studies, Mandell and Wilhemsson (2011) showed that there is a positive willingness to pay for environmental housing attributes and that environmental aware households are willing to pay more than others. Their analysis is based on transaction data and data from a postal survey answered by 618 houses in Stockholm, Sweden. With stepwise regression the hedonic price equation and its parameters are estimated.

Banfi et al (2008) uses a choice-experiment to evaluate residents' willingness to pay for energy saving measures in Switzerland. Their data consists of approximately 300 owners of apartements and houses. The variables in the experimental design are: window insulation, facade insulation, ventilation /air renewal and price. The results show a significant willingness to pay for energy-efficiency attributes, from 3% extra for enhanced insulated facade to 13% extra for insulated windows in old buildings.

Another set of research articlesareconcernedwiththeeconomicimplicationsofenergyefficiency and sustainability labels in the (mostly commercial) real estate sector. Eichholtz et al (2010)study the US office market and findthatbuildingsthatbelongto the top25% (of the most energy-efficientbuildings) have rents thataretwo or threepercenthigher as comparedtoregularofficebuildings. Transaction prices for energyefficientofficebuildingsarehigher by 13-16 percent.

Research questions

Earlier work offer some insights into energy consumption and behavioral pattern as well as residential value of energy efficiency. In this paper we will analyse if the similar relationships can be found among Swedish households. Do they have a corresponding behaviour pattern and preferences as home owners in California, the Netherlands, etc.? Using a rich database, we are able to take an even closer look at the energy consumption among owners of single-family housing. We will both consider factors likely to influence their use of energy and at the relationship between the price of a house and its energy performance. More specifically, the following two questions will be addressed.

- What role does preferences and household characteristics play for energy consumption as compared with the energy related attributes of their house? E.g. does energy consumption mainly depend upon technical installations such as heat pumps or is the composition and behavior of the household more important?

- What is the price premium for energy efficient housing in Sweden? Are households willing to increase their bids for a given housing alternative, the lower they anticipate their energy cost will be?

A main contribution of our research to the existing literature is perhaps the richness of the data set it is based upon. This gives us the possibility to gain further insight to how different energy-related features and information co-vary with household and building characteristics in the complex process of bidding for and buying a house.

3. Theoreticalframework

The hedonic price model is one approach to analyse implicit prices (values) for the various attributes of houses or other goods (Rosen 1974), including implicit prices for environmental attributes (Smith 2011). Following the hedonic housing price model developed by e.g. Quigley &Rubinfeld (1989) we assume that when a household buys a house, it purchases a joint set of attributes at a single price. The attributes can be divided into those providing direct consumer satisfaction, those that are inputs to the production of comfort in dwellings and those that are locational and spatial.

Since we have the corresponding data, a seemingly straightforward way to answer the question about the price premium of energy efficient single family housing would be to estimate a hedonic price function of the following kind.

$$V_j=V(X_{1j}, X_{2j},T_j) \qquad (1)$$

where$V_j$is the value of the house, $X_{1j}$is a vector of variables providing direct consumer satisfaction, X_{2j} is a vector of attributes, including energy consumption, needed to produce comfort and $T_j$represents the outdoor climate.

However, the estimation problem is somewhat less simple than it might seem. A decision to buy a house is presumably preceded by a rather complex evaluation process. Each option considered by potential buyers is characterized by a large set of attributes related to the interior and exterior of the building, the neighbourhood, the accessibility to work places and to different kinds of service and the outdoor climate. As already mentioned a prospective buyer also has to assess the cost of energy for achieving a certain level of indoor comfort, given some technical attributes of the house and the outdoor climate. Another important part when assessing the pros and cons of buying is the income left over for consumption of other goods as a consequence of the price paid. Furthermore, most bidders will probably assess their future income and family situation since it is costly to move, implying that most of them are likely to stay for a rather long time in the house if they buy it.

In spite of this complexity the following utility maximizing frameworkwill be assumed to reflect the most important factors influencing the price bid of a household i for a house j.

$U_{ij} = U_i(X_{1j}, X_{2j}, OG_i, T_j)$ (2)

where X_{1j} is a vector of housing attributes such as living area, interior quality and lot size providing direct consumer satisfaction. The vector X_{2j}represents energy related attributes - including energy use - that creates comfort and $OG_i$is the income left overfor consumption of other goods after paying the annualized cost for the house and for the energy consumed.

One of the difficulties facing any potential buyer of a house for sale trying to maximize his utility is to assess how large his energy consumption will be if buying it. The performance certificate informs him about a number of energy performance indicators and also about the energy consumed by the current owner. He does not know to what extent the observed energy consumption depends upon the habits and preferences of the sellers family and to what extent it depends upon the energy performance indicators but he still has to assess if his own family will need more or less energy in order to have a comfortable indoor climate. The seller if asked will probably tend to exaggerate the role played by the habits of his family.

Whatever the potential buyersconclude it seems likely that some will end up with low bids because they fear that they will need more rather than less energy than the seller. Others might for specific reasons be very keen on having the house and present high bids thinking that they will be able to reduce the observed energy consumption. The budget constraint they all need to consider is given by equation (2) expressing the volume ofother consumption, $OG_{i,}$ as the difference between the income Y_i, the annualized housing cost equivalent to the bid $V_i$and the yearly energy expenditure, E_i .

$OG_i = Y_i – rV_i – E_i$ (3)

where r reflects the capital cost.

The potential buyers might also consider the measures suggested for reducing energy consumption by the expert responsible for the certificate as well as the related estimates of the corresponding cost per kWh saved. Those having a long time perspective and thinkingthat the future price of energy will increase might think such an investment to be worthwhile and bid more than they would do without having the expert advice.

About the only thing we safely can assume about the bidding/selling process is that each house will go to the highest bidder. But the discussion above shows that the relationship between the observed price of a house, its various attributes including the energy consumption and the characteristics of the household selling it is bound to be rather complex. By way of example, a casual interdependence between the price and the energy consumption cannot be excluded.

The role for energy consumption seems easier to assess by means of our data. In addition to the data on energy consumption, energy related attributes and climate, we have information about the income, age and household composition of each seller. Using this information it is possible to relate the energy consumption to family characteristics and attributes of the house. The result from this estimation can also be used to handle or at least ameliorate the problems related to estimating the price premium of energy efficiency. The two-stage econometric approach adopted will be presented after a more detailed description of our data basethat is provided in the next section.

Hypothesis

Based on the literature review and the theoretical framework we formulate the following hypothesis for this paper:

- Household composition is a significant factor, determining energy consumption.
- A household with “green” attitudes and/or behavior, will have a lower energy consumption then households with “non-green” attitudes and/or behavior.
- Households are willing to increase their bids for a given housing alternative if they anticipate a lower future energy consumption.

4. Data and Empirical Starategy

Data and Sample

We have access to a database which holds merged data of the filed energy certifications (mentioned in the introduction section) of all single-family houses sold between 2009 and 2010. In addition to this energy data, the database contains real estate and household statistics from the Swedish Central Bureau of Statistics (SCB). Thus, my data is not a sample in the sense that all sales are included from the two years. The database includes all single- or double family, all-year houses owned by private persons and sold in Sweden during 2009-2010. In total 86162 houses(approximately 40000 from each year).

Variables

For each house, the data base holds information on a total of approximately 200 original variables, related to the following topics:

- House contract price and assessed value
- Building characteristics- interior/exterior
- Energy type, energy consumption, area characteristics
- Climate, politics, population, density, income
- Household characteristics– size, composition, car ownership, income, education.
- Real estate financial characteristics - assessed value, value area for taxation
- Proposed actions in order to reduce the energy consumption and the associated cost

Summary statistics

In table 1 the most important variables are presented with summary statistics.

Table 1: Summary statistics.

Variable name	Binary or category var information		Continuous variable information				
	Variable lables	Column %	N	Mean	Std Dev	Min	Max
Building external attributes							
Property plot (sqm)			85527	1304	3071	1	655055
New construction year			85625	1961	30	1009	2010
Year or reconstruction			12492	1988	14	1840	2009
Floor area (sqm) – temperature-controlled areas			85625	167	58	25	900
Type of building	1 Detached	76,8%					
	2 Semi-detached	11,7%					
	3 Row-house	11,6%					
New façade 2003 or later	3 Yes	1,0%					
New roof 2003 or later	3 Yes	2,8%					
Distance to shoreline	1 Private shoreline or beach	,5%					
	2 0-75 m to shoreline	1,7%					
	3 76-150 m shoreline	3,3%					
	4 More than 150 m to shoreline	94,5%					
Kitchen standard	0 No kitchen equipment	,0%					
	3 Simpel standard	25,4%					
	6 Normal standard	66,6%					
	9 High standard	8,0%					
New kitchen equipment	3 Yes	5,2%					
Open fireplace, electric stove or stove	2 Yes	47,3%					
Living or recreation room in basement	2 Yes	12,2%					
Window standard	0 Other type of windows	3,0%					
	2 Doubled- or trippled glazed windows	97,0%					
Sanitation standard – bath	0 No bathroom or in basement level	4,8%					
	1 One bath room	63,5%					
	2 Two or more bath rooms	31,7%					
Building financial information							
Contract price KSEK			78517	2224	1666	0	35000
Contract price per sqm (KSEK)			78087	18	12	0	242
Sold in year	0 2009	48,9%					
	1 2010	51,1%					

Table 1 (continued): Summary statistics.

Variable name	Binary or category var information		Continuous variable information				
	Variable lables	Column %	N	Mean	Std Dev	Min	Max
Energy information on builiding							
District heating (1)	1.00 Yes	18,1%					
Oiled-fired boiler (2)	1.00 Yes	5,1%					
Gas (natural or town-) (3)	1.00 Yes	1,1%					
Wood (4)	1.00 Yes	21,4%					
Chips, pellets or briquettes (5)	1.00 Yes	5,7%					
Other biofuel (6)	1.00 Yes	,1%					
Electrically heated waterfilled radiators (7)	1.00 Yes	20,1%					
Electric direct heating (8)	1.00 Yes	37,5%					
Airborne electricity (9)	1.00 Yes	2,0%					
Heat pump - ground source (10)	1.00 Yes	12,7%					
Heat pump – waste air source (11)	1.00 Yes	7,9%					
Heat pump – air source (12)	1.00 Yes	17,7%					
Heat pump – water source (13)	1.00 Yes	4,8%					
Solar thermal energy	1 Yes	,7%					
Solar Photovoltaic Systems	1 Yes	,1%					
Ventilation type natural draft	1 Yes	60,9%					
Ventilation type F	1 Yes	15,8%					
Ventilation type FT	1 Yes	2,1%					
Ventilation type FTX	1 Yes	7,7%					
Ventilation type w recycling	1 Yes	5,0%					
Energy consumption kWh per sqm and year			85625	115	52	0	945
Energy consumption in total per year (kWh)			85625	18491	9212	0	109213
Energy consumption per capita (kWh per year)			84710	11001	8590	0	106880
Expected result of suggested action to reduce energy consumption and							
Cost of energy reduction per kWh from action no 1			55809	0	1	0	9,99
Reduction of energy from action no 1			55809	2446	4479	1	553000
Sum of cost of energy reduction			85625	2294	6447	0	386100
Sum of energy reduction			85625	3894	7525	0	553000

Table 1 (continued): Summary statistics.

Variable name	Binary or category variable information		Continuous variable information				
	Variable lables	Column %	N	Mean	Std Dev	Min	Max
Household attributes (seller/current owner)							
Household members =1	Yes	34.93					
Household members =2	Yes	27.84					
Household members= 3-4	Yes	29.99					
Household members= 5 or more	Yes	6.17					
Households with children	Yes	41.71					
Single elderly households (age>65)	Yes	14.99					
Elderly households (age>65)	Yes	27.33					
Higher education (household head)	Yes	36,7%					
Foreign-born or Swedish-born with at least one foreign-born parent	Yes	16,3%					
Number of cars in household	1	88,2%					
	2	10,3%					
	3	1,2%					
	4	,2%					
Number of clean cars in household	0	95,1%					
	1	4,9%					
	2	,1%					
Disp income_hh_cleaned			82440	709687	561164	0	2999406
Disp income_seller_cleaned			82725	568306	494622	0	2999406
Area characteristics							
Climatic zone	1 North	6,4%					
	2 Middle	12,0%					
	3 South	81,7%					
Population – parrish			85625	16803	16407	69	82046
Parrish population per sqm			85625	429	829	0,210	13233,7
Share of parrish population w foreign background			85622	0	0	0,0190	0,8049
Population w higher education– parrish			85624	2513	3099	7	17592
Income (median), KSEK – parrish			85625	235046	30143	52330	319537
Share of votes on MP - municipality			85625	6	3	0,3	16,6

5. Empirical strategy and Econometric model

In this paper, the hypothesis will be tested through statistical hypothesis testing. We do this in two steps. First we estimate the model of energy consumption and after that we estimate the hedonic price model.

Applying a linear log-log model on energy consumption(E), for house i, gives:

$$\ln E_i = \ln\beta_0 + \beta_{1i}h_{1i} + \beta_{2i}h_{2i} + \beta_{3i}h_{3i} + \beta_{4i}Wk_i + \text{region (fixed)} + \varepsilon_i$$

where h_{1i} is a vector of the building's attributes not related to energy, h_{2i}a vector of the energy-related attributes, and h_{3i}a vector of the household characteristics. Finally, $Wk_i$is a vector of the locational and climatic attributes. The vectors include both continuos and binary/discrete variables.The continuous variables will transformed into ln-form before they are included into the regression.

Applying a linear log-log model on transaction price (V) for house i:

$$\ln V_i = \ln\beta_0 + \beta_1 h_{1i} + \beta_5 h_{5i} + \beta_{6i}\ln E(E_i) + \text{region (fixed)} + \varepsilon_i$$

where h_{1i} is av vector of the building's attributes not related to energy, h_{5i} is a vector of the location-related attributes, and $E(E_i)$are the expected energy consumption. Finally, the local housing market is affecting the house price, reflected in the regional fixed effects. The vectors include both continuos and binary/discrete variables. The continuous variables will transformed into ln-form before they are included into the regression.

6. Estimations and Testing of Hypotheses

Estimating the Energy Consumption Function

Table 2: Regression results with Yearly energy consumption per capita, kWh (ln)as dependent. Building characteristics and energy attributes/facilities are independents..

	1 (Building Characteristics)			2 (Building char. and Energy)		
	Coef,		Robust Std, Err,	Coef.		Robust Std. Err.
Construction year 1941-1960	0,631	***	(0,012)	0,458	***	(0,014)
Construction year 1900 or earlier	0,614	***	(0,014)	0,495	***	(0,016)
Construction year 1901-1920	0,601	***	(0,020)	0,500	***	(0,020)
Construction year 1921-1940	0,596	***	(0,013)	0,459	***	(0,015)
Construction year 1961-1970	0,573	***	(0,012)	0,438	***	(0,014)
Construction year 1971-1980	0,392	***	(0,011)	0,325	***	(0,013)
Size of house, sqm (ln)	0,361	***	(0,008)	0,477	***	(0,008)
Construction year 1981-1990	0,271	***	(0,012)	0,201	***	(0,013)
Construction year 1991-2000	0,136	***	(0,015)	0,091	***	(0,015)
Additional insulation recommended	0,108	***	(0,005)	0,039	***	(0,005)
Simple type of windows	0,073	***	(0,015)	0,051	***	(0,013)
New roof 2003 or later	-0,057	***	(0,016)	-0,032	**	(0,014)
One or more floor(s)	-0,061	***	(0,016)	-0,051	***	(0,014)
Two or more bath rooms	-0,064	***	(0,006)	-0,047	***	(0,005)
New facade 2003 or later	-0,091	***	(0,026)	-0,056	**	(0,024)
Semi-detached house	-0,097	***	(0,008)	-0,142	***	(0,007)
New kitchen equipment 2003 or later	-0,196	***	(0,011)	-0,170	***	(0,010)
Row-house	-0,236	***	(0,008)	-0,321	***	(0,008)
Heat pump - ground source				-0,677	***	(0,009)
Heat pump – water source				-0,420	***	(0,012)
Heat pump – waste air source				-0,242	***	(0,013)
Heat pump – air source				-0,222	***	(0,006)
Electric direct heating				-0,076	***	(0,006)
Airborne electricity				-0,015		(0,017)
Ventilation type natural draft, YN				-0,012		(0,007)
Ventilation type F, YN				-0,074	***	(0,009)
Ventilation type FT, YN				-0,042	**	(0,017)
Ventilation type FTX, YN				-0,072	***	(0,011)
Ventilation type Recycling, YN				-0,075	***	(0,015)
Oiled-fired boiler				0,440	***	(0,010)
Chips, pellets or briquettes				0,182	***	(0,011)
Gas (natural or town-)				0,152	***	(0,022)
Other biofuel				0,126		(0,092)
Wood				0,078	***	(0,006)
District heating				0,075	***	(0,008)
Electrically heated waterfilled radiators				0,054	***	(0,007)
Climatic zone: NORTH	0,384	***	(0,015)	0,232	***	0,015)
Climatic zone: MIDDLE	0,229	***	(0,015)	0,163	***	0,014)
Constant	6,697		(0,042)	6,458		0,041)
Number of obs	84146			84146		
R-squared	0,164			0,300		
Root MSE	0,689			0,631		

Significance levels: *** (p<0,01), ** (p<0,05), * (p<0,1)

In column 1-2, table 1, we summarize energy consumption modelled by building characteristics. The result show that house vintage is a strong factor influencing energy consumption per capita and year. Simply put; the older the house the higher is the energy consumption. Houses built before 1980 have a much higher energy consumption compared to new houses (built after 2000). However, the semi-new houses that were built between 1990 and 2000 also have a slightly higer energy consumption (approximately 14%). However, when focusing the analysis on building charactaristics, excluding specific energy attributes and facilities, the vintageeffect is overestimated. I.e. a house built during the 40:s or 50:s seems to consume almost 90% more energy than a newly built house. The reason is that older houses often have weaker energy performance over all. In column 3-4 the energy attributes are introduced into the model.

Size, in square meter (ln), is another strong independent. One percent larger house (about 1,5 sqm on a 150 sqm villa) corresponds to a 0,36% higher energy consumption.

The variable “additional insulation recommended” is a proxy for the house’s insulation quality. I.e. if additional insulation has been recommended by the expert issuing the energy certificate, we assume the insulation quality to be relatively poor. As a result, this recommendation corresponds to approximately 0,11% higher energy consumption. Houses without 2- or 3- glass windows (=*Simple type of windows*) equivalently have a higher energy consumption.On the other hand, a new roof, façade or kitchen equipment has a significant negative effect on energy consumption. The new-kitchen effect seem to be unrealistically high, which could imply that there are other things built into this. E.g. a more comprehensive renovation. Living in a row-house or a semi-detached house is significantly less energy demanding. Less anticipated is perhaps the negative coefficient for of multiple floors and bathroom. There are no noticeable correlations between these attributes and the other independents, but there may be explations outside the model, which is something we have to explore further.

In the model regional fixed effects have been included but omitted from the output. However, the larger climatic zones are listed due to their strong effects. Sweden is a particulary variated country in terms of climate, covering three different climatic zones. In the northest part the energy consumption is far higher compared to the southern part.

In column 2-3 the energy attributes and facilities are introduced into the model, which results in decreased coefficients for the building characteristics (in particular construction year) and climatic zone. Our analysis show that heat pumps in general and ground sourced heat pumps in particular are very strong energy savers. A house with a ground sourced heat pump consumssubstantiallyless energy than a house without such a pump. Houses with modern ventilation systems (e.g. the FTX or recycling type) are less energy consuming than other houses. Houses that uses direct electricity also have a lower energy consumption, which is more difficult to explain. An oiled-fired boiler, gas and bio-fuels all have the opposite, i.e. apositive significant, effect on energy consumption per capita.

Table 3: Regression results with yearly energy consumption per capita, kWh (ln) as dependent. Household characteristics and attitudes/behaviour are independents.

	Regression 3					Regression 4					Regression 5					Regression 6				
				Robust					Robust					Robust					Robust	
	Coef,			Std, Err,		Coef,			Std, Err.		Coef,			Std, Err,		Coef.			Std. Err.	
Age of household head, years	0,003	***	(	0,000	)															
Number of members in household	-0,408	***	(	0,002	)															
Household head is foreign-born or swedish-born with at least one foreign-born parent	0,001		(	0,005	)	-0,021	***	(	0,005	)	-0,016	***	(	0,005	)	-0,014	***	(	0,005	)
Single household						0,681	***	(	0,005	)	0,688	***	(	0,004	)	0,677	***	(	0,005	)
Elderly household(age >65)						0,043	***	(	0,005	)	0,047	***	(	0,004	)	0,032	***	(	0,005	)
Households with children						-0,532	***	(	0,005	)	-0,526	***	(	0,005	)	-0,528	***	(	0,005	)
Disposable income of seller, kSEK (ln)											0,030	***	(	0,002	)	0,040	***	(	0,002	)
Higher education,																-0,011	***	(	0,004	)
At least 1 car																-0,005		(	0,006	)
At least 1 green car																-0,040	***	(	0,008	)
Share of green votes in parrish (ln)																-0,057	***	(	0,005	)
Constant	9,753		(	0,010	)	8,959		(	0,035	)	8,508		(	0,029	)	8,512		(	0,032	)
Number of obs	84510					78001					82433					78296				
R-squared	0,575					0,538					0,551					0,5385				
Root MSE	0,491					0,506					0,504					0,50483				

Significance levels: *** (p<0,01), ** (p<0,05), * (p<0,1)

In table 2 we analyse in what way household characteristics influence energy consumption. The analysis is done in different steps to be able to observe how different characteristics contribute to the energy consumption. As in table 1, the regional fixed effects have been omitted from the output.

In column 1-2 we start the analysis with only a few household variables; age, size and foreign/Swedish background. As expected the size of the household has a strong negative effect on energy consumption. The more people sharing a home, the lower is the energy consumption per capita. The age of the head seem to have a relatively weak but significant positive effect. This would mean that the older the head, the higher the consumption, which we did certainly not expect. In most other studies elderly people have been proven to have a significant lower energy consumption than others. In column 3-4 we separate the elderly households from the single ones, since the correlation between household age and size showed to be substantial. In spite of this we still observe a relatively weak (approximately 4%) but positive effect of elderly households . Households with kids, on the other hand, have a negative effect on energy consumption per capita, which probably goes back to that these households are larger and thus, the consumption is spread out on more persons.

In column 5-6 we add the disposable income, kSEK (ln), to the analysis. The income show to have a significant postitive effect; 1% increase in income corresponds to 3% increase in energy consumption. In other words; the more you earn the more you spend!

Finally, in column 7-8 we add education, car ownership and political environment to the analysis. Education seem to have a significant small negative effect, implying that households with higher education have lower energy consumption. Owning at least one green car seem to have a slightly larger (but still marginal) negative effect on energy consumption and the same goes for the share of green votes in the parrish where the house is located. This last addition to the analysis give us a hint that other, more attitude-/value-related characteristics influence energy consumption. However, their impact is still quite small compared to household composition and income.

Table 4: Regression results with yearly energy consumption per capita, kWh (ln) as dependent. Building characteristics, energy attributes as well as household characteristics and attitudes/behaviour are independents.

	Coef.		Robust Std. Err.
Construction year 1900 or earlier	0,346	***	(0,012)
Construction year 1901-1920	0,335	***	(0,009)
Construction year 1921-1940	0,319	***	(0,009)
Construction year 1941-1960	0,290	***	(0,008)
Construction year 1961-1970	0,252	***	(0,008)
Construction year 1971-1980	0,170	***	(0,008)
Construction year 1981-1990	0,102	***	(0,008)
Construction year 1991-2000	0,057	***	(0,009)
Row-house	-0,217	***	(0,005)
Semi-detached house	-0,077	***	(0,004)
Size of house, sqm (ln)	0,603	***	(0,005)
One or more floor(s)	-0,017	**	(0,009)
New facade 2003 or later	-0,036	***	(0,013)
New roof 2003 or later	-0,027	***	(0,008)
Additional insulation recommended for cealing floors or walls	0,028	***	(0,003)
Other type of windows	0,024	***	(0,009)
Ventilation type FTX, YN	-0,011	**	(0,006)
Ventilation type F, YN	-0,007	**	(0,004)
Ventilation type FT, YN	-0,008		(0,010)
New kitchen equipment 2003 or later	-0,009		(0,006)
Two or more bath rooms	0,000		(0,003)
Chips, pellets or briquettes	0,335	***	(0,006)
Oiled-fired boiler	0,319	***	(0,006)
Gas (natural or town-)	0,206	***	(0,013)
Wood	0,167	***	(0,004)
District heating	0,153	***	(0,005)
Electrically heated waterfilled radiators	0,075	***	(0,004)
Electric direct heating	-0,019	***	(0,004)
Heat pump - ground source	-0,551	***	(0,006)
Heat pump – water source	-0,335	***	(0,007
Heat pump – waste air source	-0,170	***	(0,007)
Heat pump – air source	-0,171	***	(0,004)
Household members =1	0,686	***	(0,003)
Disposable income of seller, kSEK (ln)	0,019	***	(0,002
Households with children	-0,517	***	(0,004)
Households age >65	-0,028	***	(0,003)
Higher education	-0,018	***	(0,003
Foreign-born or Swedish-born with at least one foreign-born parent	-0,014	***	(0,004)
At least 1 green car	-0,002		(0,006)
Share of votes in parrish, % (ln)	-0,010	***	(0,003)
Climatic zone: NORTH	0,154	***	(0,009)
Climatic zone: MIDDLE	0,076	***	(0,008)
Constant	5,606		(0,032)
Number of obs	77769		
R-squared	0.7539		
Root MSE	.36863		

Significance levels: *** (p<0,01), ** (p<0,05), * (p<0,1)

In table 3 we include all relevant variables into the analysis. This means we included the building characteristics, the energy attributes as well as the household characteristics and attitudes/behavious. As in table 1, the regional fixed effects have been omitted from the output, but the climatic zone effects are included.

We made some changes to the model before running this regression. The variable "Ventilation type – recycling" is no longer included, due to strong correlation with the energy attribute "heat pump – waste air source" (r^2=0,65). Further, we exchanged the ordinal variables "Age of household head" and "Number of household members" with the binary variables "Single household" and "Elderly household (age>65)". However, we still have a relatively strong negative correlation (r^2=-0,61) between "Single household" and "Households with kids". "Airborne electricity" , "Ventilation type - natural draft" and "Other bio fuels" was excluded due to insignificancy as well as ownership of "At least 1 car".

In this final regression the strongest variable is "Single household". Living alone in a house generates almost twice the energy consumption per capita, compared to larger households. On the other hand a "household with kids" has even lower energy consumption per capita compared to households without children. Disposible income still has a relatively small positive effect on energy consumption;according to table 3 a household head with 10% larger income has a 0,2 % higher energy consumption. When we control for household characteristics, construction year is not as strong as before, but nonetheless, houses built before 1920 consumes around 40% more energy than newly built houses.

Heat pumps are still strong independents, with a negative effect while "Chips, pellets or briquettes", "Oiled-fired boiler" and "Gas" all have almost as strong positive effect on energy consumption.

Interestingly enough, the variables "two or more bathrooms", "new kitchen equipment" and "at least 1 green car" are no longer significant in the model.

The size of the house has a stronger effect in this final model (table 3), compared to the ones without household and building characteristics (table 1). According to the coefficient in table 3, a house that is 10% larger (e.g. + 15 sqm on a 150 sqm house) consumes about 6% more energy per capita and year.

Estimating the Hedonic Price Function

In the previous section, Estimating the Energy Consumption Function, we concluded that the energy consumption is influenced partly by household characteristics. When we know estimate the hedonic price function we must take this into account. Our hypothesis is that the price is a function of, among other things, the energy consumption during the previous year. The energy consumption in turn is a function of household characteristics, in particular the household size. This endogeneity of energy consumption was also confirmed through a formal test. In order to control for this we perform instrument variable regressions, where the energy consumption per capita is instrumented by the variables "single household", "disposable income" and/or "households with kids".

In the first two regression models (exactly identified 2SLS models), energy consumption per capita was instrumented with "households with kids" and "single household" respectively. Since there was little difference between the two models (in terms of Wald chi2, R-squared and Root MSE) we progressed to an overidentified model, where energy consumption per capita was instrumented with both "households with kids" and "single household". The result is presented in table 4. In order to test whether the instruments are valid or not, we use a gmm estimate.

Table 5: Regression results with Total house price (ln) as dependent. Locational and building charachteristics as well as energy attributes and energy consumption are independents. Energy consumption per capita was instrumented with "households with kids" and "single household".

	Coef.		Robust Std. Err.	
Private shoreline or beach	0,653	***	(0,035)	92,153
0-75 m to shoreline or beach	0,258	***	(0,021)	29,450
76-150 m to shoreline or beach	0,115	***	(0,013)	12,164
Parrish median income, KSEK (ln)	1,774	***	(0,021)	1,774
Parrish population per sqm (ln)	0,249	***	(0,001)	0,249
Construction year 1900 or earlier	-0,213	***	(0,019)	-19,205
Construction year 1901-1920	-0,420	***	(0,015)	-34,295
Construction year 1921-1940	-0,477	***	(0,014)	-37,913
Construction year 1941-1960	-0,542	***	(0,014)	-41,855
Construction year 1961-1970	-0,429	***	(0,013)	-34,852
Construction year 1971-1980	-0,404	***	(0,013)	-33,241
Construction year 1981-1990	-0,263	***	(0,013)	-23,095
Construction year 1991-2000	-0,134	***	(0,014)	-12,561
Reconstructed later than 2000	-0,059	***	(0,006)	-5,708
Semi-detached house	0,025	***	(0,006)	2,569
Size of house, sqm (ln)	0,470	***	(0,008)	0,470
Property plot, sqm (ln)	0,076	***	(0,003)	0,076
New facade 2003 or later	0,105	***	(0,018)	11,087
Open fireplace, electric stove or stove	0,099	***	(0,004)	10,430
Living or recreation room in basement	-0,067	***	(0,006)	-6,503
Kitchen standard - simpel	-0,086	***	(0,005)	-8,224
Kitchen standard - high	0,078	***	(0,007)	8,145
New kitchen equipment 2003 or later	0,059	***	(0,008)	6,038
Two or more bath rooms	0,046	***	(0,004)	4,679
Gas (natural or town-)	0,237	***	(0,013)	26,697
Heat pump - ground source	0,150	***	(0,009)	16,149
Heat pump – water source	0,138	***	(0,010)	14,844
Heat pump – waste air source	0,091	***	(0,010)	9,481
Heat pump – air source	0,014	**	(0,006)	1,430
Solar energy	0,139	***	(0,025)	14,887
District heating	0,105	***	(0,007)	11,021
Electric direct heating	0,069	***	(0,005)	7,100
Airborne electricity	0,033	**	(0,013)	3,304
Electrically heated waterfilled radiators	0,038	***	(0,006)	3,853
Oiled-fired boiler	-0,045	***	(0,010)	-4,390
Chips, pellets or briquettes	-0,052	***	(0,009)	-5,063
Additional insulation recommended for cealing floors	-0,014	**	(0,008)	-1,408
Energy consumtion per capita and year (ln)	-0,078	***	(0,004)	-0,078
Cost of energy reduction per kWh from action no 1 (ln)	0,001		(0,002)	0,001
Reduction of energy from action no 1, kWh (ln)	0,026	***	(0,002)	0,026
Year (1=2010, 0=2009)	0,036	***	(0,008)	3,626
Constant	-17,738	***	(0,265)	
Number of obs	47920			
R-squared	0,6898			
Root MSE	0,40562			

Significance levels: *** (p<0,01), ** (p<0,05), * (p<0,1)

Location seem to be important in several ways. The parrish in which the house is located influence the price through the parrish median income and the density. The denser and richer the parrish, the higher the price. Further, the house's proximity to beach/shoreline is a very strong independent in the model. The price of a house with a private shoreline or beach is almost twice as expensive as a house located more than 150 meters from the shoreline. Even houses within 75 meters from the beach has a strong positive effect on price. Construction year is another strong factor influencing price. Houses built between 1920 and 1960 have the lowest prices, compared to new houses (built after 2000). The effect from recent reconstruction is not as strong, and it actually has a small negative effect on the price. The reason for this could be that the older houses are over represented among the recently reconstructed ones. The size of the house, in terms of temperature reglated area in sqm, is of course a very important factor in the price model. An additional 10% of sqmcorrespond to a price premium of 5 %. E.g. an additional 15 sqm on a 150 sqm villa will yield a price premium of 125 kSEK on a 2,5 MSEK villa, equal to 8 kSEK per extra sqm. The property plot have a much weaker but still positive effect on price.

Other building characteristics with a positive effect on price are: ”New facade 2003 or later”, ”Open fireplace, electric stove or stove”, ”Kitchen standard – high”, ”New kitchen equipment 2003 or later” and ”Two or more bath rooms”. On the other hand a simple kitchen standard as well as a living- or recreation room in the basement both have a negative effect on price. Compared to the coefficient of a high kitchen standard, the coefficient of an open fireplace seem unrationally high. The reason is probably (at least partly) the ”cozyness value” associated with this feature.

Finally, we take a look at the energy-related attributes. Heat pumps in general and ground sourced pumps in particular, have a relatively strong positive effect on the price. According to table 4, a ground sourced heat pump corresponds to a price premium of 16%. On an average 2,5 MSEK villa, this adds up to 400 kSEK, which seems unrealistically high. The reason might be that there are other qualities built into this feature, such as a good standard and energy performance over all. It could also imply that in Sweden, where there is not one standardised green labeling of houses, the heat pump communicate a kind of green lable value.

Gas is another variable with a surprisingly high coefficient. What might be the logic behind a price premium of 26% for houses with gas as energy source?The gas variable is not strongly correlated to any of the construction year variables. However, out of the houses using gas as at least one enrgy source, approximately 50% are built before 1940 or after 1990. In Sweden, very few houses uses gas (approximately 1% of all houses in our database) and when used, it is often a complementary source of energy. Thus, we must look more closely into this matter before drawing conclusions about the price premium of having gas as energy source.

The house’s energy consumption per capita have a negative coefficient, which means houses that have had lower energy consumption in the past sell at a higher price than houses with higher consumption per capita. The price premium is + 0,08 % for 1% lower energy consumption (kWh) per capita. The energy certificates also contains recommendations on how and how much the energy consumption could be reduced. In our model we included two variables corresponing to this information. One of these; the estimated ”reduction of energy from recommended action no 1” has a small but significant positive effect on price. A 1% increase in the estimated energy savings (kWh) corresponds to a 0,03 % increase in price. This is a hint that the recommendations are actually taken into account in the bidding process, even though the influence is quite weak.

The year variable at the very end of table 4, show that the prices were generally higher in year 2010 compared to 2009.

7. Summary and Conclusions

Too be added in time for the conference.

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