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CHARACTERIZATION OF HOUSEHOLD ENERGY CONSUMPTION IN SWEDEN

ENERGY SAVINGS POTENTIAL AND FEEDBACK APPROACHES

Iana Vassileva

2012

MÄLARDALEN UNIVERSITY
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School of Sustainable Development of Society and Technology

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Akademisk avhandling

som för avläggande av teknologie doktorsexamen i energi- och miljöteknik vid Akademin för hållbar samhälls- och teknikutveckling kommer att offentligen försvaras onsdagen den 12 september 2012, 10.00 i Lambda, Mälardalens högskola, Västerås.

Fakultetsopponent: professor Jenny Palm, Linköpings universitet

MÄLARDALEN UNIVERSITY
SWEDEN

Akademin för hållbar samhälls- och teknikutveckling

Abstract

Energy consumption is on a constant rise with domestic use contributing substantially to the overall consumption. The population growth along with ever increasing comfort levels and daily appliance usage are driving the domestic electricity demand to higher levels. Targeting domestic consumption is thus of great importance if global consumption is to be lowered. This involves understanding and changing consumers' behaviour, awareness and increasing their knowledge on the subject of energy use.

In this thesis various factors determining household energy consumption such as dwelling size, income and number of occupants have been found alongside consumer behaviour to influence consumption the most.

Energy awareness, related interest and knowledge have also been considered when trying to explain differences in household consumption patterns.

Despite all possible characteristics and factors, the largest differences in energy consumption are found between individual households.

Providing feedback and information to households has been proven effective when addressing the issue of reducing domestic energy use. In this thesis, the effectiveness of three of the most popular ways of currently delivering feedback and information on energy consumption (displays, websites and bills) have been investigated by analyzing consumption patterns before and after their implementation. Consumers living in apartments that followed their consumption through the web based feedback were the ones that achieved the greatest electricity reductions (17,5%) when compared to the years before the website.

In order to provide effective feedback, with long lasting results that would keep consumers interested, several parameters have been proposed to be included when developing feedback and information. The type of dwelling (house or apartment), the age of the occupants, their level of education, income and their energy awareness and interest are the main determinants of feedback preferences.

The findings presented in this thesis contribute to a better understanding of households' energy consumption patterns closely related to their characteristics, behaviour, interest and awareness, and also provide ways of improving the development of consumption feedback and information.

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Sammanfattning

Energiförbrukningen ökar kontinuerligt över hela världen och energin som används i hushåll bidrar i allra högsta grad till den totala förbrukningen. Befolkningstillväxt och högre krav på komfort är två anledningar till att användningen av hushållsel ökar. Att fokusera på hushållens konsumtion av energi är därför av stor betydelse om den globala förbrukningen ska sänkas. Detta innebär att förstå och förändra konsumenternas beteende, att öka deras medvetenhet samt att förbättra deras kunskaper om energianvändning.

I den här avhandlingen har flera faktorer som påverkar hushållens konsumtion av energi identifierats, såsom bostadsstorlek, inkomst och antalet boende. För att förstå och bättre förklara skillnader i hushållens konsumtionsmönster har hänsyn tagits till energimedvetenhet, relaterade intressen och generella kunskaper om energi. Även när det finns likheter inom olika egenskaper och faktorer finns det ändå stora skillnader i energiförbrukning mellan enskilda hushåll. Att ge återkoppling och information till hushållen om dess energikonsumtion har visat sig vara en effektiv metod när det gäller att minska energianvändningen. Effektiviteten av tre av de mest populära sätten att leverera återkoppling och information om energiförbrukning (displayer, webbplatser och räkningar) har undersökts genom att analysera konsumtionsmönster före och efter genomförandet av energiinformation. Konsumenter som bor i lägenheter och samtidigt följde sin konsumtion via en webbaserad tjänst var de som uppnått den största reduktionen i elkonsumtion (17,5%) jämfört med innan återkoppling av elförbrukningen lanserades. För att ge effektiv återkoppling med långvariga resultat och för att bibehålla konsumenternas intresse är det viktigt att rätt verktyg används för återkopplingen av energiinformation. I avhandlingen presenteras hur olika parametrar påverkar konsumentens val av återkopplingsmetod. Typ av bostad, ålder, utbildningsnivå, inkomst samt konsumenternas energimedvetenhet är de viktigaste faktorerna som påverkar valet av återkoppling.

Resultaten som presenteras i den här avhandlingen bidrar till en bättre förståelse av hushållens energiförbrukning relativt de boendes egenskaper, beteenden, intressen och medvetenhet. Vidare ger avhandlingen förslag på metoder som kan förbättra utvecklingen av verktyg för återkoppling av och information om energiförbrukning.

Acknowledgements

I am deeply thankful to my main supervisor, Prof. Erik Dahlquist for offering me the possibility of working for interesting projects and also for the support, encouragement, inspiration, patience and his always positive attitude over the years!
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And last but not least, special thanks to Thomas, for being my friend and supportive partner and for bringing light into the long and dark Swedish winters!

List of Publications

This thesis is a comprehensive summary of the following papers, which are referred to in this thesis by their Roman numerals.

I. Vassileva I., Dahlquist E. (2008). Economical savings through lowering energy consumption in rented apartments. A case study in Västerås area. *Journal of Numerical and Applied Mathematics* Vol. 1, (96):234–245.

II. Vassileva I., Lundh M., Dahlquist E. (2009). *Efficiency of interactive information on energy consumption in households in Sweden*. In Proceedings of the International Conference on Applied Energy, January 5–7, Hong Kong.

III. Vassileva I., Wallin F., Dahlquist E. (2012). Analytical comparison between electricity consumption and behavior characteristics of Swedish households in rented apartments. *Applied Energy*, 90:182–188.

IV. Vassileva I., Wallin F., Dahlquist E. (2012). *Understanding energy consumption behavior for future demand response strategy development.* Energy DOI: 10.1016/j.energy.2012.02.069.

V. Vassileva I., Wallin F., Ding Y., Beigl M., Dahlquist E. (2011). *Household indicators for developing innovative feedback technologies.* In Proceedings of the Innovative Smart Grid Technologies (ISGT Europe). 2011 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies – Europe", pp.1–7, 5–7 Dec.; doi: 10.1109/ISGTEurope.2011.6162715.

VI. Vassileva I., Odlare M., Wallin F., Dahlquist E. (2012). The impact of consumers' feedback preferences on domestic electricity consumption. *Applied Energy*, 93:575–-582.

Author's contribution to the papers

Iana Vassileva contributed with ideas, methods, data collection and analysis and manuscripts preparation to all papers. Most of the ideas were discussed with Erik Dahlquist and Fredrik Wallin. The statistical analysis in Paper VI was provided by Monica Odlare.

Other publications not included in this thesis

I. Vassileva I., Bartusch C., Dahlquist E. (2008). *Differences in electricity and hot water consumption in apartments of different sizes*. In Proceeding of the Swedish National Energy Convention 2008 (Sveriges Energiting), 12–13 March, Stockholm, Sweden.

II. Lundh M., Vassileva I., Dahlquist E., Wäckelgård E. (2008). *Comparison between hot water measurements and modelled profiles for Swedish households*. In Proceedings of Eurosun 2008, 7–10 October, Lisbon, Portugal.

III. Vassileva I., Bartusch C., Wallin F., Dahlquist E. (2008). *A simulation model of the interactions between power producers and customers.* SIMS 2008, 7–8 October, Oslo, Norway.

IV. Widén J., Lundh M., Vassileva I., Dahlquist E., Ellegård K., Wäckelgård E. (2009). Constructing load profiles for household electricity and hot water from time-use data-modeling approach and validation. *Energy and Buildings*, 41:753–768

V. Vassileva I., Wallin F., Dahlquist E. (2009). *Consumption patterns today and tomorrow with respect to energy and how the energy system will be affected by this*. In Proceedings for the Swedish National Energy Convention 2009 (Sveriges Energiting), 11–12 March, Stockholm, Sweden

VI. Vassileva I., Dahlquist E. (2010). *Analysis of the effects of individual payment and tenants' behaviour on electricity consumption*. In Proceedings for the Swedish National Energy Convention 2010 (Sveriges Energiting), 17–18 March, Stockholm, Sweden

VII. Vassileva I., Wallin F., Dahlquist E., Roots P. (2010). *The relation between consumption of electricity and hot water and different consumer variables.* In Proceedings for the Practicing Science and Technology, Performing the Social, 2–4 September Trento, Italy.

VIII. Dahlquist E., Vassileva I., Wallin F., Thorin E., Yan J. (2011). Optimization of the energy system to achieve a national balance without fossil fuels. *International Journal of Green Energy*, 8:684–704.

IX. Dahlquist E., Vassileva I., Thorin E., Wallin F. (2011). *How to save energy to reach a balance between production and consumption of heat, electricity and fuels for vehicles.* In Proceedings for the International green Energy Conference, 5–9 June, Eskisehir, Turkey.

X. Bartusch C., Wallin F., Odlare M., Vassileva I., Wester L. (2011). Introducing a demand-based electricity distribution tariff in the residential sector: Demand response and customer perception. *Energy Policy*, 39:5008–5025.

XI. Ding Y., Decker C., Vassileva I., Wallin F., Beigl M. (2011). *A smart energy system: distributed resource management, control and optimization*. In Proceedings for Innovative Smart Grid Technologies, 5–7 December, Manchester, UK.

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Part I: Comprehensive summary

1 Introduction

The increasing energy consumption is one of the most relevant concerns that current societies are facing. With incessant population growth, technological booming, development of societies which strive for having more and the best quality of everything, energy problems are inevitable.

The building sector alone is responsible for 40% of the total energy consumption in the European Union and is continuously expanding. In Sweden, the final use of electricity in 2009 reached 125 TWh of which the residential and services sector (formed by residential and commercial premises, holiday homes and land use) used 73 TWh. The total energy use in the sector was 149 TWh (residential buildings and commercial premises accounting for 87%) or 39% of Sweden's total final energy use. Therefore, households constitute one of the most important groups when addressing energy efficiency, policies and conservation measures in residential buildings.

However, despite all efforts (information campaigns, low energy consuming appliances and increasing the energy efficiency) household energy consumption continues to increase. In Sweden, for instance, the household electricity used for lighting and different electric appliances, has more than doubled between 1979 and 2006 (from 9.2 TWh to 22.1 TWh) [1].

One of the main reasons is the unavoidably increasing number of households worldwide. Another explanation for many researchers is the higher household incomes and consequently the increase of the purchasing power of all income levels of society [2]–[6]. During the last decades a wide adoption of a variety of new household appliances and electronic equipment has occurred, changing consumers' overall routines and lifestyle and raising domestic electricity consumption.

Nevertheless, there are also several ways of reducing household energy consumption. Three of the main methods are mentioned by Wood and Newborough [7]: replacing the existing housing stock with low-energy buildings; promote use of low-energy domestic equipment; and finally, promote energy-conscious behaviour among the consumers. While the first two would be very time and money consuming, changes in the behavioural patterns can save energy without additional investment in infrastructure and the effects would appear quickly [8]. In fact changing occupants' behaviour towards less energy usage already appeared in the mid-1970s probably related to the first oil crisis and it is described by Hayes and Cone [9].

Nowadays, with the introduction of smart meters, monitoring households' consumption has become easier also allowing the development of accurate and detailed information-feedback for the consumers.

1.1 Problem definition and research questions

Since domestic energy consumption is an important part of the worldwide total energy consumed, most of the scientific research, policies, legislation and technological developments are based on developing different energy saving measures. However,

- There are no clearly established parameters to be used when assessing domestic energy consumption in order to acquire more knowledge on consumption and behavioural patterns.
- Little research exists on how different feedback on energy consumption is accepted by the consumers and if it causes the expected effects (e.g. decreased consumption or increased consumers' energy awareness).
- When developing different ways of providing information or feedback to the consumers, their preferences, knowledge and characteristics are not taken into account.

Therefore, the work included in this thesis could be summarized under the following four main research questions:

- **Question 1:** Which are the main parameters affecting domestic energy consumption?
- **Question 2:** How can households' energy consumption be reduced?
- **Question 3:** What are the effects of the installation of smart meters and the provided information/feedback on the household consumption?
- **Question 4:** How feedback could be improved: what information should it include and how should it be delivered to the consumers?

The aim of this thesis is to establish the importance of considering domestic energy consumption as a part of a complex system formed by diverse inter-connected components. The system has been illustrated in Figure 1. Households have been placed in the core since they are the ones stirring the consumption levels by their behaviour, awareness and characteristics. Therefore, in order to change the consumption trends, information and feedback have to be provided to the consumers and target changes in their behaviour, increase their energy awareness and only then energy savings would be achieved.

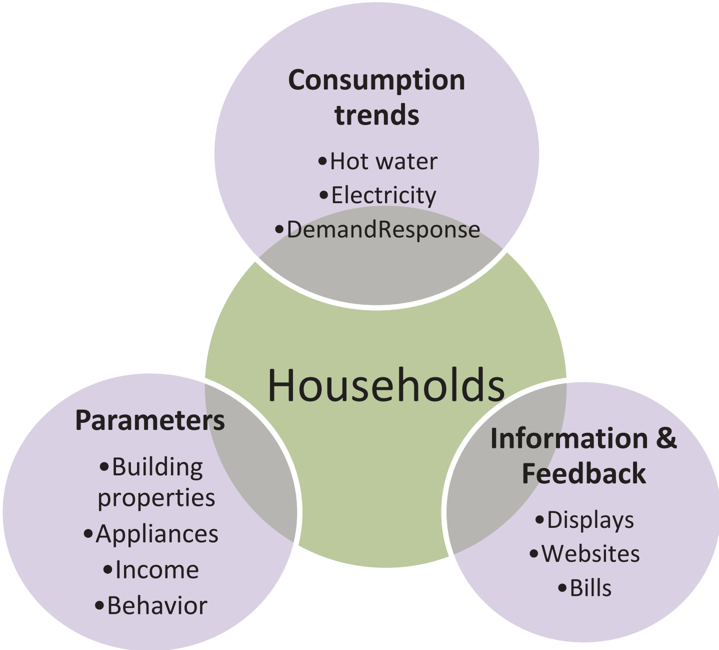


Figure 1. Representation of the main domestic energy consumption interrelated features analyzed in this thesis.

1.2 Contribution of the thesis

Despite all investigations on domestic energy done so far, there is a clear lack of a systematic analysis connecting the need for household energy savings, people's behavioural characteristics, different saving strategies, applicable methods, types of consumption feedback and long lasting results leading to the accomplishment of the targeted issues.

The above interrelations vary significantly depending on the country and region, but also mainly on individual households' characteristics. Closely related to these problems are the following issues that have been addressed throughout this thesis:

- For a full analysis of domestic energy consumption various factors have been proposed: consumers' energy related behaviour, awareness and households' type and structural characteristics. (PAPERS I, III and IV).
- The effects of providing direct feedback have been established through analysis of hourly consumption patterns. (PAPER I and II).
- In order to implement and design more efficient feedback and strategies it is important to analyze the determinants of household behaviour, energy related awareness and current level of knowledge (PAPER III, VI).

- Specific household characteristics that should be analyzed and included during the development of innovating technologies for providing feedback, have been proposed (PAPER V).
- The effectiveness of diverse types of feedback and different electricity payment methods have been determined through examination of household consumption patterns and characteristics. (PAPER VI).
- Different consumption trends and user profiles have been established (PAPERS III and VI).
- The influence on consumers' behaviour of different ways of providing energy consumption feedback, tips and information and their effectiveness has been discussed (PAPER IV).

The connection between research questions and papers can be seen in Figure 2, which will also serve as an outline of the thesis.

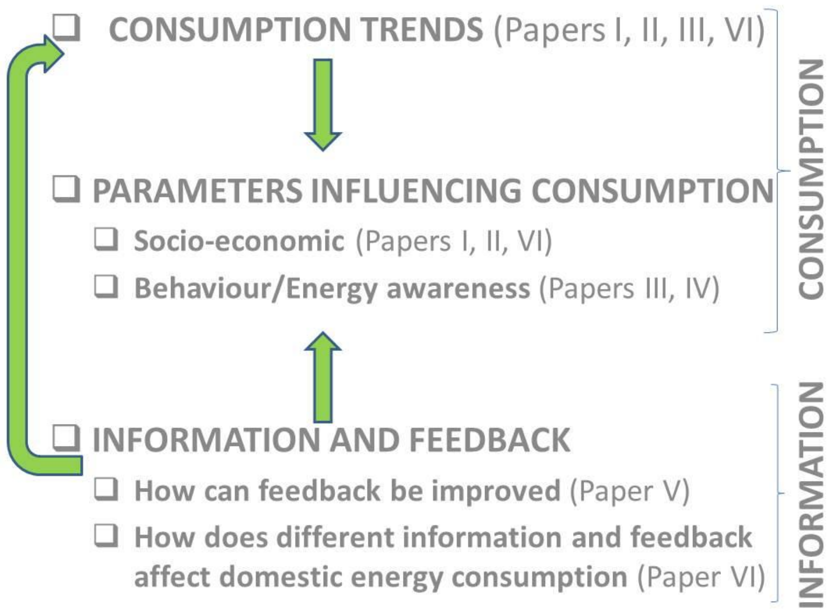


Figure 2. Thesis and papers outline.

Domestic energy consumption trends have been investigated for different types of households in Sweden. The trends have first been analyzed from a "weather-time" perspective (seasonal, hourly, and yearly values) showing the importance of these variations. Further research has been carried out on the possible parameters influencing the consumption patterns (related to households' characteristics, behaviour and energy awareness). Finally, the last part of the research is based on the description and improvement of information feedback which is believed to cause a significant impact on the overall household energy consumption and would lead it to large savings.

1.3 Methodology

The proposed methodology for this thesis consists of collecting and analyzing hourly, daily, monthly and yearly energy consumption data sets (hot water and electricity) and indoor temperatures. In order to correlate socio-demographic characteristics and consumption data, user profiles were created to identify energy awareness and feedback preferences. To obtain the required econometric information (user consumption patterns and feedback preferences), a questionnaire was designed and sent out to the demographic groups of interest.

1.3.1 Papers evolution

The purpose with the first paper was to estimate how much the selected 24 households were paying for their electricity and hot water based on a 2-year hourly consumption data. Low electricity prices were found to be the explanation for high electricity consumption in these households. It became necessary to determine if economic penalties might increase household energy awareness.

The aim of the second paper was thus to analyze this effect of economic penalties on energy awareness. The majority of the households in the study in-fact maintained their indoor temperatures regardless of the extra economic penalties which applied. These results lead to the foundation of the further research on consumer behaviour.

Paper III included the results from a questionnaire survey intending to justify the 6-year consumption patterns by behaviour, use of appliances, households' characteristics, level of education and so on.

In order to see if the findings could be generalized, a similar approach was adapted on a larger scale (2000 households) in Paper IV. Apart from intending to find common behavioural patterns another objective with the questionnaire sent out to 2000 households was to investigate the possible impact on consumption and behaviour after the introduction of web based feedback. In order to explain why some households did not visit the website, the investigation was directed towards finding common factors determining the preference for different types of feedback.

Paper V presents several indicators attributed to households' characteristics and preferences that are suggested to be used when developing future feedback and information.

The last paper aims at comparing the consumption patterns of three different households groups which received information through different feedback methods (website, bill, display). The information presented on a website resulted as the one that achieved the major electricity savings during the studied period.

1.3.2 Demographic group of interest

Three different groups of households with different socio-economic characteristics were selected, in order to obtain contrasting consumption patterns and econometric data correlations.

The first group was formed by 24 apartments from a high-income area in Västerås, Sweden. The group consisted of two multi-family houses (12 apartments each) built in 2001. This group had the following characteristics:

- Homogeneity: This first group had almost equal characteristics: same number of occupants per apartment, no children, infrequent changes of the household owners and same building insulation. In this way the comparison of the different consumption patterns was highly dependent on personal energy usage rather than the households' characteristics.
- Advanced Metering Infrastructure (AMI): These apartments were provided with smart meters and hourly measurements of hot water and electricity were available for 2+ years. Moreover, electricity values were presented in small displays in each apartment, providing instant feedback on consumption to the household members, helping increase their energy usage awareness.
- Demand Response: A demand response scheme was implemented by penalizing the occupants with extra payment for each indoor temperature degree over 21 ºC. The traditional billing scheme required consumers to pay for their exact heating consumption.

The second group was formed by 80 apartments located in low-income areas in Västerås and Eskilstuna. This group had the following characteristics:

- Heterogeneity: Opposed to the first group, this one had contrasting characteristics; different cultural backgrounds, occupant's age, family structure and very varying household energy consumption data. The buildings containing these apartments were older than the ones from the previous group and did not have any major energy efficiency upgrades.

- Lack of detailed metering infrastructure: The apartments from this group situated in Västerås, have never paid specifically for electricity consumption, since it was aggregated to their monthly rent. The ones located in Eskilstuna have been paying for their consumption every three months on estimation-based rates because the meter reading only occurred twice a year. This group started paying for their actual consumption in 2008, after the installation of smart meters.

The third and largest group of interest consisted of 2 000 households (1 000 houses and 1 000 apartments) located in the city of Växjö. The local power supplier provided them with a web based feedback on energy consumption.

The website was launched in 2008 accompanied by a large advertising campaign. The web based feedback was advertised in newspapers, television, radio, cinemas and the electricity bills. Houses and apartments were selected from random areas in the city although households in apartments were further divided into different groups according to their monthly income. For this group, only households with complete consumption values sets were used for analyzing consumption patterns.

Table 1. Summary of characteristics of all households groups.

	Group I	Group II	Group III
Location	Västerås	Västerås/Eskilstuna	Växjö
Income area	High	Low	Low/Moderate/High
Type of households	Apartments	Apartments	Apartments/Houses
Important aspects	Same characteristics; high income	Different characteristics; low income	Large information campaign; different income
Total households	24	80	1 000/1 000
Total responded questionnaire	19	10	197/432
Main type of feedback	Display	Bills	Web

1.3.3 Questionnaire design

A questionnaire was designed with the objective of obtaining behavioural patterns of different groups of households that were going to be studied as a whole. These questionnaires have had different structures and contained different questions depending on the type of household they were addressed to (apartment or detached house), the purpose of the study and the location of the households (see Appendix).

This questionnaire based approach (also used in, [6], [8], [10]–[12]) was chosen to favor a higher relationship between what the respondents answered and reality. The work follows the hypothesis that many factors considered together affect the final total energy consumption. There are two types of questions included in the survey: one includes a qualitative approach, where respondents have to evaluate their behaviour, level of knowledge, etc. The other type of questions requires quantitative.

Other types of survey approaches such as time diaries, phone interviews or focus groups were considered, but found unsuitable for the present research, because even though they provide high-detailed behavioural data, only do it for a very short time-span. The proposed methodology was aimed at analyzing a greater number of households with larger historical energy consumption data sets, in order to analyze consumption patterns that could include seasonal changes and temperature effects.

Furthermore, it is also considered that using less direct-personal observation approach participants will not feel observed and the different behaviour due to the awareness of being observed, known as the Hawthorne effect (also mentioned in Wilhite and Ling, [13]) will be minimized.

1.3.4 Software

Several commercial software packages were used throughout the research process. For analysis and organization of the received data (consumption values and responses received from the questionnaires) Microsoft Excel was mainly used. For the scientific and statistical analysis of the thesis, more specialized software packages such as SigmaPlot, SPSS and The Unscrambler were used. Significant effects between the different factors were evaluated by one-way ANOVA followed by Tukey's HSD multiple comparison test using the computer software package SPSS 19 (SPSS Inc., Chicago, IL, USA.). The Unscrambler (2011, CAMO Software) was used for performing PCA (Principal Component Analysis) in order to confirm the influence of income and other parameters on the households' final electricity consumption. The PCA analysis allows the study of all measured variable simultaneously capturing the most important data set information in the first components revealing patterns and structures not always revealed by classical statistical methods.

2. Background

20 181 TWh of electricity were produced in the world in 2008; more than three times the electricity produced in 1973. 13 675 TWh, 67% of the total production, came from burning fossil fuels, contributing heavily on the overall CO_2 and greenhouse gases emissions [14].

Many different Directives, policies and research programs worldwide have targeted energy consumption reductions. The European Union, particularly, has been driving very important programs on energy efficiency, increased use of renewable energy and CO_2 emissions. The associated formulated policies have been based on competitiveness, sustainability and security of supply.

2.1 Electricity consumption

2.1.1 Electricity consumption in Europe

Europe contributed to 3 170 TWh of the electricity production in 2008; 54% from burning fossil fuels, but what is more important, most of these fuels were imported (83.5% oil and 64.2% gas), increasing the supply dependency of the European Union [15].

In order to overcome this and to mitigate the EU's impact on greenhouse gas emissions, it has been the leading party in many international negotiations regarding climate changes. Two of the most remarkable treaties are the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and the Kyoto Protocol in 1997.

The United Nations Framework Convention on Climate Change was created in order to "achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic (originating in human activity) interference with the climate system" [16].

The governments of the countries that ratified the Convention are committed to exchange information on their greenhouse gas emissions, national policies and practices. The governments are also responsible for introducing different strategies limiting greenhouse gas emissions and preparing for the possible impacts originated from the climate change.

Linked to the Convention, the Kyoto Protocol is one of the major international agreements on committing the participating industrialized countries to reduce their greenhouse gas emissions. In order to reach the targeted emission thresholds, the countries are conceded with three different types of mechanisms [17]:

- Emissions trading: where countries with an excess of emission capacity sell emissions to countries without a surplus.
- Joint implementation: enables countries to earn emission reduction units (ERUs) from an emission-reduction/removal project in another Kyoto participating country. The ERUs can be used towards meeting a country's own Kyoto target. The ERUs are each equivalent to one tonne of CO_2.
- Clean development mechanism: is used by countries to obtain emission reduction credits by implementing emission-reduction projects in developing countries. The first country is given certified emission credits, each equivalent to one tonne of CO_2.

With regard to the Convention and the Kyoto Protocol, in 2009 the European Commission adopted the so called 20/20/20 Climate strategy. This climate package focuses mainly on emission cuts, renewable energy and energy efficiency. The policy targets a 20% cut in emissions of greenhouse gases by 2020 (with respect to 1990 levels); a 20% increase in the share of renewables in the countries' energy mix; and finally a 20% cut in energy consumption.
In addition to the previously mentioned objectives, in the new strategy adopted by the European Council, in June 2010, energy, efficient use of resources and innovation are the main new areas complementary to the 20/20/20 targets.

In order to fulfill these targets, incentive mechanisms have been created decreasing the costs of the technical solutions, land and capital, including reduction of the CO_2 taxes, lower interest rates or simply reduced taxes.
Moreover many Directives originated by the European Union are trying to direct and encourage the transition towards more sustainable and efficient use of energy and the expansion of renewable energy sources in the residential sector.

Additionally, the European Union is also striving to extend the use of energy from renewable sources in the Directive 2009/28/EC. The Directive includes legally binding national targets such as reaching the 20% of renewable energy by the year 2020 and provides the countries with different help measures in order to achieve the targeted limits. The results show a positive trend, being the renewable energy 62% of the total energy generation investments in the EU during 2009. The European Union expects the increase of the use of renewable energy to reach 217 Mtoe by 2020 (gross final energy consumption), 45% of which would be constituted by the electricity sector [18].

In order to fulfill the 20/20/20 goals, increased use of renewables alone are not going to be enough to meet the EU´s consumption requirements, therefore the final use of energy in every sector must be more efficient.

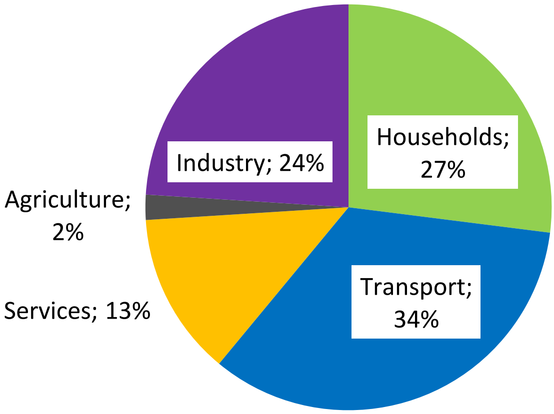


Figure 3. Final energy consumption by sector in 2009 [19].

As presented in figure 3, households alone, account for more than a quarter of the EU's total energy consumption. If all the office buildings' energy consumption is included, the building sector accounts for 40% of the total energy consumption in the Union. In order to reduce their energy footprint, a revised Directive concerning the Energy Performance of Building presented in 2010, established that from 2020 all new buildings must be close to zero energy buildings [20].

There are differences between the EU Member States with regard to their targeted building energy efficiency levels. The Netherlands for instance, will try to reduce their energy consumption by 25% by 2011 and by 50% by 2015 (compared to previous standards) while in Sweden buildings are planned to be consuming 20% less energy by 2020 and 50% by 2050 (compared to 1990 levels).

Moreover, the methodologies for determining buildings' energy efficiency and the standards on the energy performance of new buildings have been compiled in the Directive 2002/91/EC on Energy Performance of Buildings [21].

In relation to the previously mentioned Directive and the improvement of energy efficiency, the Directive 2006/32/EC claims that “improved energy end-use efficiency will make it possible to exploit potential cost-effective energy savings in an economically efficient way”. The energy efficient use would consequently allow the Community to reduce its dependence on energy imports and also to reduce CO_2 and other greenhouse gas emissions. The main aim of the Directive is to create stronger incentives for the demand side. The final consumers should be provided with information (comparative final consumer profiles, energy efficiency improvement measures, etc.) and should be encouraged to check their meter readings regularly. The Directive thus considers that energy efficiency improvement could be achieved by technological, behavioural and/or economic changes. [22].

2.1.2 Electricity Consumption in Sweden

Electricity consumption in Sweden was 138.3 TWh in 2009; 4% lower than the electricity consumed in 2008. The major consumption reduction was in the industrial sector, reducing its electricity use by nearly 12% - the lowest electricity use by the industrial sector since 1986 -. The sector involving residences, and services, however, increased its electricity consumption by nearly 3 percent to 71.3 TWh [23].

Moreover, Swedish local electricity production has also decreased: its production in 2009 was 133.7 TWh, 8% lower than in 2008. Hydropower fell by nearly 5% and total nuclear energy produced was only 50 TWh, 18% lower than in 2008 and the lowest since 1984. Wind power, however, showed an increase of 25%, to 2.5 TWh. Finally, conventional thermal generating stations (and the most expensive ones) increased their production by 11% to 15.9 TWh. To compensate the production-consumption deficit, Sweden had to purchase approximately 4.7 TWh for 2009. In 2008 Sweden was a net exporter of 2 TWh.

These changes have affected the local electricity market and Sweden experienced a considerable price increase in the electricity spot price. On February 22nd, 2010, at 8 am, the electricity spot price was 1400 EUR/MWh, about 25 times higher than the average price. During the rest of the year, the mean spot price in Sweden was 54.48 EUR/MWh, the highest annual mean price even recorded [24].

In 2009 a joint climate and energy policy was approved establishing targets and strategies for future development. Some of the targets include reaching the 50% of renewable sources of the total energy supply by 2020, in line with the previously mentioned EU Directive No. 2009/28/EC. A new 40% reduction in greenhouse gas emissions by 2020 in comparison with 1990 has also been established in the new policy. Regarding the use of energy in residential and commercial buildings, it must be reduced by 20% by 2020 and by 50% by 2050 in relation to 1995 level. Regarding the current situation of energy provided by renewable sources in Sweden, they amounted to 44.7% in 2009 (while in 1990 it was only 33.3%). The main contribution was made by electricity production of which a major proportion was provided by hydro power. Sweden is also the country with highest proportion of renewable energy used in relation to final energy use when compared to the rest of countries in the entire EU [23, 25].

Bearing in mind that the rate of new building in Sweden is only 1% of the total building stock per year, in 2006 the Agency started the so called Energy, IT and Design program [26] focused on influencing consumers' everyday habits, values and behaviour. The program, intended to end by the end of 2012, is aiming at making it easier for the households to control their consumption while transforming the energy consumption into a more efficient one. The targets would be achieved by the creation and design of different technical methods oriented towards changing end-users' behaviour.

The Swedish Energy Agency through this program considers that residential energy consumption could be reduced by focusing the strategies towards three different areas: the building, the technical equipment in the buildings and buildings' users. However, highly efficient buildings do not assure that their occupants have the knowledge of how to use them.

Furthermore, in order to promote the most cost-effective production of renewable electricity the Swedish Government in 2003 introduced the Green Electricity certificate. The Certificate is a market-based support system to assist expansion (by 25 TWh by 2020) of electricity production in Sweden from renewable sources and from peat. Its target defines the amount of new renewable electricity production that should be developed by a certain date [23]. Electricity certificates for every MWh of produced electricity is given to the producers and subsequently sold for an extra income in addition to the sale of electricity. This system has proved to be highly effective and therefore, has been extended to 2030.

Another important step within the Swedish energy policy, was the deregulation of the electricity market in 1996 ensuring competition and consequently lower prices. Household customers were given the opportunity to choose to sign contracts with whichever of the electricity suppliers connected to the grid. One of the next steps was the introduction in 2003 of monthly meter readings affecting 5.2 million customers. This system also ended an era characterized by payment for estimated values of electricity consumption, and electricity being included in the rent for some of the customers. One of the negative effects was the increase of the electricity prices. During the first ten years after the deregulation, a report from the Swedish Energy Markets Inspectorate states that the total electricity costs for a typical apartment household increased by more than 50% [27].

With increasing customers' participation in the power system and capacity adjusting to changing demand conditions, the so called demand response has been on focus when aiming to reduce supply uncertainty and utilities' exposure to price risk. These reductions can be achieved by switching demand from peak to off-peak usage times or by generally lowering the total demand. Both utilities and consumers are required to follow several actions such as increasing energy efficient behaviours and changing the pricing systems. Financial incentives and penalties are the main ways used to achieve lower seasonal and daily peaks although results have proven them not so effective: in 2008 peak load reductions in European countries reached an average of just 2.9%.

2.2 Smart grids

The basic architecture of today's electric grid has almost not changed since it was designed over 100 years ago. However, our current societies and economies are in need of a 21st century grid to provide more cost effective, efficient, reliable and cleaner electricity [28].

With the liberalization of the electricity systems in many countries, the access to transmission and distribution grids has become more accessible. Simultaneously, there has been a rapid increase in the development of renewable energy technologies and co-generation and energy resources and storage. Consumers have been pressured to increase their participation in all energy related aspects, as end-users, power producers, and so on.

The introduction of smart grids has meant the integration and improved relationship between power generation, transmission, distribution, consumers, markets and finally, service providers.

There are many different ways of defining 'smart grids' and probably the most official one is given by the European Technology Platform: 'electricity networks that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies' [29].

The main advantages with smart grids are the integrations of supplying power together with information and intelligence, by better planning and running existing electricity grids, increasing the energy efficiency and enabling new energy services.

From the consumers' point of view, which is of interest for the research in this thesis, the installation of smart meters is beneficial for providing information and options for choice of supply and allowing them to participate in the operating of the system. The provided bills will be based on real consumption and will be received more often. Historical data will be also provided with the bill allowing customer to compare their current consumption with the one from past years. Smart meters would entail other advantages such as: the possibility of installing micro generation measures; time sensitive pricing, allowing them to purchase electricity when costs are lower; and the possibility to reorganize consumption patterns in order to take advantage of time of use tariffs [30].

Another new term included in smart grids, connecting consumers and smart grids, is demand response. Demand response is primarily an electricity tariff or program created in order to increase the changes in households' electricity consumption, reducing the electricity used when market prices are high or with grid reliability problems. In this way, end-users become involved in a process that traditionally was a producer's responsibility. By changing their behaviour and routines, they can shift their electricity usage from peak to off-peak time periods, reducing network congestion.

The main benefits of demand response have been summarized by Kim and Shcherbakova [31]: lower risk of power interruptions from lower peak loads; improved operating conditions for utility firms from increased peak-time rates, reduced marginal costs of lower peak power quantities and ability to postpone infrastructure investment; cost savings for end users from a combination of reduced off-peak tariffs and a greater awareness of one's level and pattern of power consumption; increased spread of energy-efficient appliances; and a general increase in responsibility and prudence with regard to electricity use.

From all the European countries, Italy is the country that stands out for globally leading the development of smart grids. By the end of 2009, around 85% of the Italian homes could monitor their consumption thanks to smart meters. The main driving force was the major utility in Italy, Enel. Already in 2001 Enel, started a 5-year project for installation of smart meters in 40 million homes and businesses. The utility's customers are given the possibility to have a greater control over their electricity bills and reduce them almost by half with only changing their habits from high peak (with high prices) to low peak periods [32].

However, a report elaborated by the International Energy Agency, states that despite all efforts and investments made the scale of demonstration and deployment coordination still has to be increased. The report concludes that collaboration between governments and private sectors is vital in order to achieve the goal of modernizing the electrical systems [33].

2.3 Current situation in Sweden

The results from all these reforms are still hard to evaluate and cannot be conclusive since the current period is of a transition and adaptation.

Regarding smart metering, there is a need for changing the current regulations and also the infrastructures used for data collection and the reporting of the measured values. The hourly based tariff prices have to be used and made understandable for the customers.

Regarding the deregulated electricity market, in Sweden the outcomes are being debated in different reports and have not been very positive. An evaluation of 1200 apartments and houses in Sweden showed that only 20% of the consumers see deregulation as something positive and 30% of the households had switched electricity supplier during the last 5 years. The main reasons for not changing suppliers were mainly the costs (time) for searching for information to change electricity suppliers being too high [11].

In a later study carried out in the end of 2009, including 2 000 households (evaluated in Paper IV), occupants living in houses were more active when it comes to changing electricity supplier, 28.5% of the total changed it during the last four years, while only 15.5% of the occupants living in apartments changed it. On the other hand, from the total Swedish households, the numbers can significantly vary among the different years. In 2008 the monthly average households that changed their supplier was 33 224; in 2009 it was 43 356 and 35 634 in 2010 [34]. One of the main explanations for these variations could be the varying electricity prices, especially during the winter periods. Time constraints, attention, resources and the ability to process information are considered important obstacles to reach higher consumer participation.

Additionally, for most of the consumers, the introduction of smart meters, new ways of payment, large amount of not tailored information and the deregulation of electricity markets have mainly translated into an increase of their electricity bills. This is partly occurring due to the lack of dynamic pricing designs and implementation even in countries with advanced metering infrastructure already installed. On the other hand, the adoption of dynamic tariffs would be very low if customers are the ones in charge of making the switch, rather than having a dynamic tariff as the default [35]. Higher adoption of dynamic tariffs could be achieved by increasing customer participation, stressing out the environmental benefits and financial rewards and offering them a lower flat tariff in return for choosing an automatic demand response.

What is clear is that more attention needs to be paid to making customers understand how crucial their participation in the energy system is and to in-form them about the consequences that their every-day practices have from the global energy perspective.

Therefore, it is of great importance, to first better understand households' consumption patterns, to try to develop different information techniques, policies and other regulations and to consider the end-users' preferences and interests in order to achieve great energy savings.

The integration of all these matters (households' consumption patterns, interests, knowledge, preferences and reactions towards different feedback) are included in the following sections of this thesis.

2.4 Previous research

If the increased blackouts during peak-time and the unreliability of the electricity supply characterized the conventional grid used in the past century, the customer-side constitutes one of the cores of the smart grids. Consumers are expected to make more informed decisions, to increase their participation in the electricity market and to generally change their behaviour and adapt to new pricing systems, policies and perhaps the automated use of some of their appliances.

While most of the focus relied on hardware upgrades of the grid, software, control systems and policies are still in progress [36]. Reports and studies started addressing the consumers' side only a few years ago. The most cited ones could be divided into two groups according their main objectives: energy consumption patterns and different types of feedback.

Within the first group, Sardianou, analyzed the energy conservation in 500 Greek households using face-to-face interviews with one adult from each household [37]. The author determined that the energy-saver consumer has a high income, owns the house and is a member of an extended family core.
On the other hand, the number of rooms, size of the dwelling, the sex, educational level and marital status cannot be predictors of energy conserving behaviour.

Ndiaye and Gabriel, conducted a similar study in Canada including 221 phone surveys and 1-year electricity consumption data [38]. Amongst the 60 variables that were included in their principal component analysis, the number of occupants, the home ownership and the vocational period were selected as the main energy consumption predictors.

In Sweden, Ek and Söderholm, analyzed 564 questionnaires concluding that price incentives, information and environmental moral concerns are necessary to promote less electricity use [10].

Research should also focus on people's day-to-day actions and how they vary depending on physical, economic and moral-based contexts. On the other hand, a more recent study, performed by the University of Gothenburg, used data of 4 000 Swedish households collected by the Society, Opinion and Media Institute for studying patters of energy savings [39]. The most prominent socio-economic factors affecting energy consumption were found to be: age, housing type and household income. The authors found that environment-related attitudes had weaker effects on saving energy in owner-occupied detached houses. Homeowners seemed to react better to economic incentives. Households with higher incomes and living in non-detached houses (and apartments) were more sensitive to environmental attitudes. The study recommends that policy measures should be tailored to fit household preferences depending on income and housing forms.

A number of researchers point out that behaviour (as the action taken by the households in their use of energy at home) plays a major role in determining energy consumption [40]–[43]. It seems therefore logical to target different behavioural aspects when attempting to increase energy awareness and savings. This could be mainly achieved by providing feedback and information. These tools would also make the electricity more visible, especially important in countries like Sweden, where until recently many households had their energy consumption included in their rent.

In one of the most cited reports where energy saving through feedback has been analyzed, it is concluded that direct feedback (in-home displays) could save up to 15% electricity, while indirect feedback (bills) would only achieve reductions of 10% [44].

In another report, written by Fischer [45], where 21 original studies were analyzed, from 10 different countries, savings achieved about 20%, although, depending on the nature and frequency of the feedback. Providing the households with a frequent feedback and over a long period improves its effectiveness. The author concludes also that the information has to be presented in a clear and appealing way, preferably by interactive tools.

The effects of direct feedback was also analyzed Hargreaves at al., in 12 households in the UK [46]. The authors found out that the monitors needed to look good to fit in with the wider household and also that the information they provide needed to be clear, transparent and flexible. In some of the analyzed cases, the devices were giving the participants sense of control and empowering them to take stronger action to reduce their consumption, to discuss energy issues with their family and friends and to seek further information and tips.

However, very few authors consider the preferences of the consumers when it comes to receiving feedback and the type of information they want to receive. In a recent study, Karjalainen [47] presented different information prototypes to 14 households in Finland. After interviewing them, the conclusions he obtained were that people preferred visualizing the costs of their consumption and also presented in kWh instead of simply the power (W);

the appliances specific breakdown was also important in order to understand the amount of electricity consumed by the different appliances; and finally, a historical comparison of the consumption was also preferred by the consumers. Similar results were obtained in the UK, after examining 240 questionnaires regarding householders' awareness of energy issues, attitudes to energy savings and energy behaviour in general. 73% of the consumers considered that better information should be provided by the utilities when it comes to the energy consumed by the different appliances. Also the most preferred ways for receiving such information were the energy bills and the newspapers (chosen by 35% and 25% of the participants, respectively) [43].

After reviewing the previously mentioned reports and many other research papers, several gaps have been found between the different approaches taken. Very few authors have analyzed the effects of different types of provided feedback on the actual electricity consumption (followed up for several billing periods after the introduction of the feedback). Just a limited number of authors have combined consumption-related behavioural patterns, energy consumption and the provided feedback.

Moreover, there is not much information available on consumer's preferences regarding types of information and desired energy usage visualization formats.

All these issues are considered throughout this thesis and are essential for further policy development in the public sector and increased consumers' awareness and control over their energy consumption; a very important topic for utilities interested in deploying large-scale demand-response. Also, In order to design appropriate demand response programs, accurate energy demand-consumption models should be developed to simulate different household scenarios. This can only be achieved by further understanding consumer's behaviours and preferences in order to have a deeper understanding of the smart grids' performance with the consumer as the "smart" component of it.

3. Results and Discussion

Household energy consumption is affected by many different factors such as building and appliances efficiency, location, occupants' behaviour and socio-demographical characteristics (income, age, occupancy patterns, etc.). In this thesis research has been directed at analyzing the relation between these factors and energy consumption patterns investigated in the first place.

Additionally, domestic energy consumption and some of the previously mentioned factors (as the type and use of appliances) could be modified by changing occupants' behaviour, decisions and daily routines. Different behaviour modifications techniques have been found to achieve energy reductions by 10 – 30% [48, 44]. Therefore, in the second part of this section, the effectiveness of several ways of providing feedback have been evaluated and different ways of improving consumption feedback in the future have been proposed.

The Results and Discussion part of the thesis has been divided into two main sections (following the outline presented in Figure 2):

3.1 Domestic energy consumption patterns and influencing parameters

3.2 Information and Feedback

These two sections are followed by:

3.3 Conclusive Discussion

3.1 Consumption: Trends and influencing Parameters

(Papers I, II, III and VI)

Analyzing electricity consumption patterns (magnitude and time of peak loads) constitutes an important part of a better planning of the electrical grids. Investigating domestic energy consumption would also be necessary for the improvement of forthcoming information, feedback and policies.

Many different factors affect the final household energy consumption. In the beginning of this work attention was mainly paid to non-behavioural consumption analysis. Therefore the first part of the thesis tries to answer: which are the household characteristics that influence consumption the most?

Throughout this thesis, electricity and hot water hourly measurements were collected and analyzed for different periods of time: daily consumption (weekdays and weekends) would give us more information on peoples' daily routines; monthly data is used in order to find seasonal variation and yearly consumption is used for investigating how households' consumption varies in a more global perspective.

Furthermore, several households' characteristics (size, number of occupants and the monthly income) were related to the consumption pattern analysis in order to observe their effects on the final consumption.

With the help of questionnaires, occupants' behaviour and energy awareness were included in the investigations in order to explain the consumption variations that could not be explained by the non-behavioural characteristics.

3.1.1 Seasonal, hourly and yearly variations
(Papers I, II, III, VI)

Seasonal changes in the domestic energy consumption are common in the Nordic countries and have been reported by many authors [49, 7]. Electricity consumption is usually higher during the winter in comparison to the summer period, especially in countries that, as Sweden is, are characterized by long and dark winters.

Seasonal variations of domestic electricity consumption for a long period of time have been analyzed in Paper III and are presented in Figure 4.
The total electricity consumption per month for 19 apartments from group I for a six-year period, shows overall stable levels with approximately 2 500 kWh of difference between some of the years.

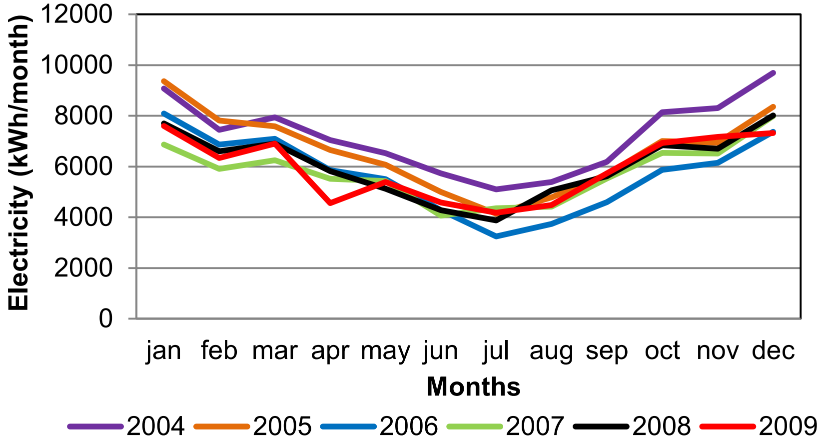


Figure 4. Total monthly electricity consumption for the apartments from group I (N=19).

The results showed large differences between summers and winters, reaching up to 5 000 kWh difference in the year 2006 for instance. Such large fluctuations demonstrate the necessity of adding specific tips about winter savings to the information/feedback given to the occupants.

On the other hand, the total electricity consumption during the month of January for the 5-year period has been further compared to the average temperature for the same period finding no relevant effects of outdoor temperature on the consumption (Table 2).

Table 2. Total electricity consumption and average temperatures in Västerås for the month of January (2005-2009), group I (N=19).

Year	Electricity (kWh/month)	Outdoor Temperature-January (ºC)
2005	9 365	0,47
2006	8 095	-4
2007	6 866	-0.9
2008	7 697	1.7
2009	7 598	-2.3

The fact that the highest consumption level was reached in a year which January's average temperature was not the lowest of the period investigated indicates that the outdoor temperature is not the only driving parameter of electricity consumption during the winter. The observed seasonal differences however, are mainly explained by the fact that occupants spend more time at home during the winter, and consequently use their appliances and lighting for longer periods of time.

Similar results have been obtained when analyzing hot water consumption levels: lowest consumption was reached in July for years 2008 and 2009. Relatively higher measurements were recorded during the year 2008 especially during the cold months (October-February). If related to weather conditions, according to an analysis of the outdoor temperatures recorded by the Swedish Meteorological Center, the temperatures during 2008 were 14% higher than a normal year. Therefore, it could be concluded that there is no clear effect of the outdoor temperatures on the household tap hot water consumption.

In conclusion, this part of the study shows that there is no direct influence of outdoor temperatures on domestic electricity or hot water consumption. The winter-summer consumption variations are attributed to holiday periods (households away from their homes during summer time and spending more time at home during the winter time) and excessive usage of electricity (especially for lighting) during the winter periods. During the colder months, Swedish energy consumers tend to spend more time at their homes consequently leading to higher consumption of both, electricity and hot water. It is therefore, important to analyze the daily/hourly variations in order to better understand peoples' routines.

At the same time, hourly measurements are also giving us important information that is necessary for predicting future electricity demand and consequently create demand response measures [50]. In this thesis hourly measurements were only available for households from group I. The average hourly load curves of weekend days and week days are presented in Figure 5. These curves reflect the average consumption per apartment for group I.

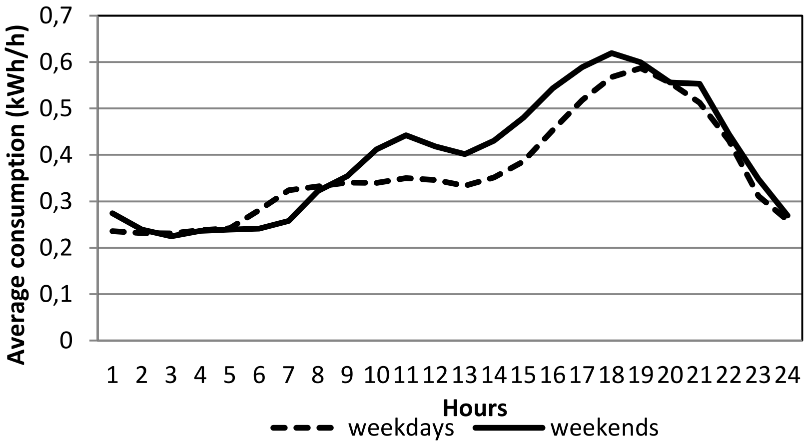


Figure 5. Average hourly electricity consumption per apartment for the month of January, 2006.

Clear peaks can be observed in the evenings, between 5 pm and 7 pm in the weekdays that become higher during the weekend days also starting earlier in the evening. These evening peaks are linked to the use of appliances (for cooking, washing or entertainment) after the occupants are back from work.

There is also clear evidence of the morning use of appliances although peaks are not as pronounced as in the evenings. Morning peaks are produced later during the weekends than during the weekdays. The difference in the morning peaks is explained by the occupants staying in bed longer during weekends since they do not have to go to work.

The weekends' consumption levels are generally higher than those reached during weekdays, especially between 9 am and 5pm. This tendency is explained by the occupants dedicating more time to cleaning, cooking, washing and using all of their appliances more.

The electricity used was measured during the month of January, 2006, being one of the coldest years investigated in this thesis. However, despite the low temperatures reached that year, the peak loads are not very different from a warmer January, confirming again the lack of influence of the outdoor temperature on electricity usage.

Lastly, analyzing the variation of electricity consumption between different years is important for various reasons:

- First, it is interesting to analyze how the electricity consumption evolves with time in order to understand different household energy-use patterns and also for creating more personalized energy use information.
- Moreover, the comparison of yearly values is used for examining if the provided energy saving measures (new meters, feedback, etc.) are causing the expected effects.

- A third reason for investigating yearly consumption is the possibility to compare households of different cities or countries, or even within the same city and get a more general and "long-term" idea of the energy situation.

Yearly consumption patterns have been investigated and used as a base for comparison of all the households groups considered in this thesis:

- Apartments and buildings with very similar characteristics and same locations.
- Apartments with Houses.
- Apartments with different geographical locations.
- Apartments and houses with different income-areas.

The overall results show that 5% of the apartments from group III reached higher electricity consumption levels than the established by the Swedish Energy Agency (40 kWh/m^2) while 50% of the apartments from group I reached levels beyond the average for Sweden [23]. On the other hand, households from group II, located in the same geographical area as group I, had the lowest consumption when compared to groups I and III.

From these results, it was concluded that there is a large saving potential existent amongst Swedish households and within the selected groups investigated in this thesis. The largest variations were found between individual households rather than between different groups.

Therefore, the approach taken in the following part of the thesis is to address the influence of different parameters that could explain the consumption levels of individual households.

3.1.2 Socio-economic parameters influencing consumption

(Papers II, III, VI)

In this section of the thesis, several socio-economic parameters will be analyzed in order to investigate their influence on households' energy related behaviour and consumption.

The effects of the size and number of occupants on domestic electricity and hot water were investigated throughout Papers I, II and III. Also in Paper III, the monthly income was proposed as the predominant parameter that best explained the electricity variation between apartments from group I.

In order to investigate more in detail the effects of the previously mentioned factors on different households groups, consumers living in houses were divided into three different income groups and presented in Fig 6.

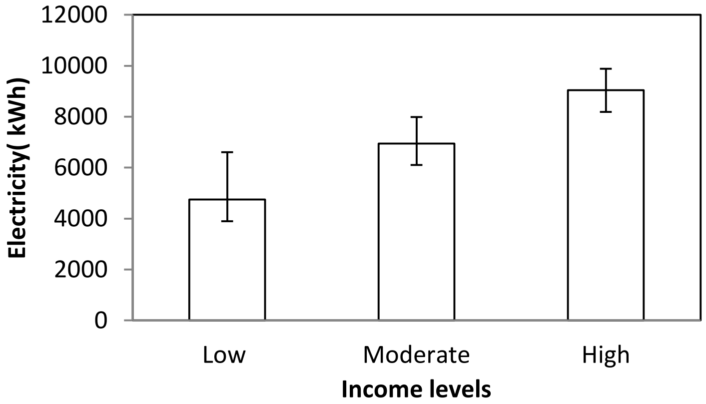


Figure 6. *Average electricity consumption for year 2010 and confidence intervals for the different income-levels grouped houses from group III.*

The confidence intervals that are not overlapping, show that the income plays a significant role on the electricity consumption, but only for households with low (below 20 000 SEK/month) and high (more than 40 000 SEK/month) income levels.

These results suggest that low income consumers are more aware about their consumption and strive to reduce it, whereas the high income consumers lack the economic pressure and therefore, have little incentive to lower their energy usage. This explains the lower consumption levels of households from group II, located in low-income areas.

Similar results have been described in Paper IV where the analysis of the questionnaire responses showed people with low income and living in apartments located in low income areas are the most striving ones to reduce their electricity consumption (67%) in comparison to moderate and high-income areas (45 and 57% respectively).

Electricity and hot water consumption levels of households from group I for the years 2005 and 2006 were examined and presented in Figure 7. The apartments were grouped into size groups with eight apartments each (62, 79–80 and 92 m^2).

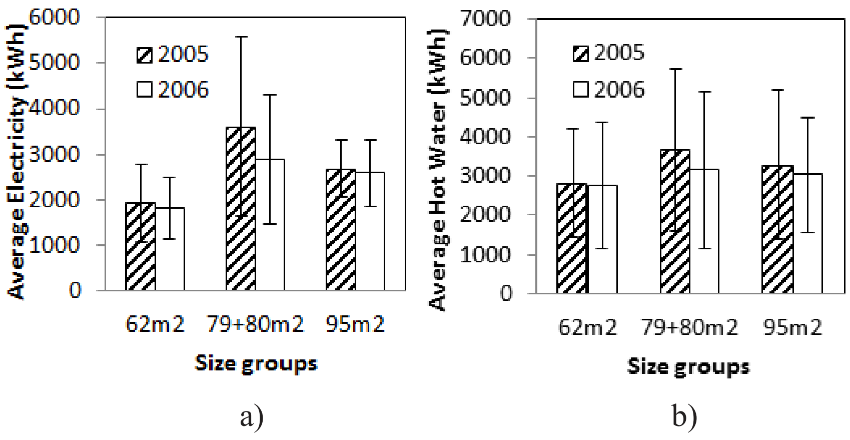


Figure 7. *Average a) electricity and b) hot water consumption and confidence intervals per group (N=8) of apartments from group I (N=24), for the years 2005 and 2006.*

Despite the almost equal characteristics of the households, clear differences in the electricity consumption levels between the different groups can be observed especially between the middle size group and the other two, 62 and 95m^2. The confidence intervals analysis shows that even if the effect of the size is not statistically significant, large variations in the consumption levels can be found between individual households within the groups, for both electricity and hot water. These differences in electricity consumption between individual households have also been presented in Figure 8.

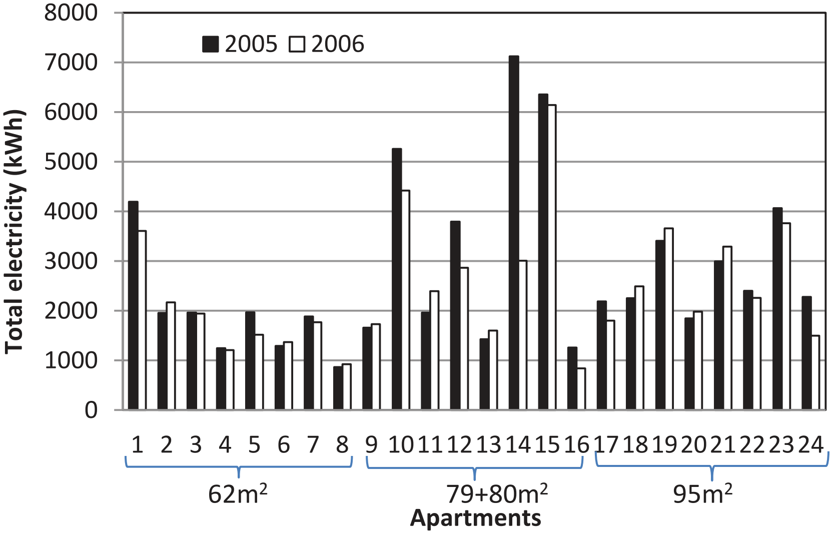
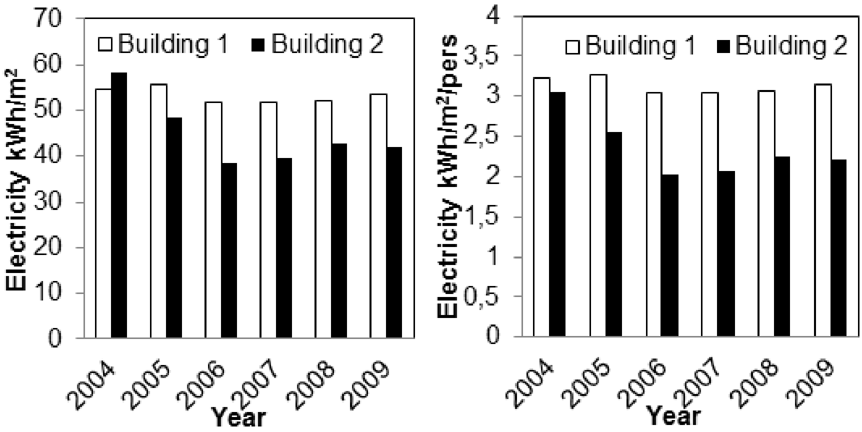


Figure 8. *Total electricity consumption of 24 apartments (group I) for the years 2005 and 2006, divided according their sizes.*

The explanation for the dramatic yearly variation in the consumption levels for some of the apartments is the change of occupants between the two years. Only behavioural and energy awareness characteristics could however, explain the large differences between the households (bearing in mind that households' structural and building properties are the same for all apartments).

Analysis of the effects of the size on the electricity consumption of the households from group III carried out in Paper VI, confirmed that size only plays an important role in some cases, and it cannot be therefore considered as the only factor determining consumption levels.

However, when investigating and comparing overall energy consumption levels it is important to consider them in relation to the households' surface area and also the number of occupants as households' electricity tends to increase with the number of occupants [51]. The results presented in Paper III, of a 5-year electricity consumption period per apartment size and per person for households from group I can also be observed in Figure 9 a) and b).



a) b)

Figure 9. Total annual electricity consumption a) per floor area and building and b) per floor area, person and building (group I).

The large differences perceived between the two figures, and despite the almost equal characteristics of both buildings, demonstrate the great importance of considering the number of occupants when analyzing electricity demand. When including the number of people per apartment in Fig. 9 b) the highest consuming building in 2004 becomes Building 1 instead of being Building 2 when only the consumption per m^2 is considered, as seen in Fig. 9 a).

On the other hand, when comparing the consumption values to the average 40 kWh/m^2 suggested by the Swedish Energy Agency mentioned earlier, it can be observed that the electricity consumed is above the average, especially for apartments from Building 1.

In conclusion, this part of the thesis shows that three parameters have considerable influence on the domestic energy consumption. The number of occupants and the size of the house or apartment are essential when investigating or comparing the consumption levels of different households.
Also the occupants' income plays a determining role especially in low and high income areas, influencing the consumers' way of using energy, their awareness and even the number and frequency of use of their appliances.
These are however not the only defining factors of consumption, as personal behaviour and energy awareness ultimately have an impact on the overall consumption of a particular household. The behaviour-awareness factors will be examined in the following section of this thesis.

3.1.3 Behaviour and energy awareness
(Papers II, III and IV)

Data on occupants' energy (electricity and hot water) related behaviour and awareness has been obtained from the analysis of responses to some of the questions included in the questionnaires sent out to all households groups.

These questions target the understanding of the attitudes that the households have towards energy use and savings. Consumers' knowledge on their own consumption and on how to reduce it, and the willingness to increase such knowledge also formed part of the behavioural analysis. The effects of imposed economic penalties on extra energy consumption – through indoor temperature regulation, and the reaction of the occupants affected have also been examined and it has been considered as part of the behaviour/awareness section.

3.1.3.1 Regulation of indoor temperature
(Paper II)

The effects of administrative measures imposed by the housing company in order to reduce the use of district heating in the households from group I have been analyzed. The results are of interest since they could be considered as a demand-response measure (paying economic penalties for extra comfort) and show how certain households groups would react when introducing electricity demand response based tariffs.

Even if outdoor temperatures showed no influence on domestic electricity and hot water usage, in general outdoor and indoor air temperatures play a significant role on the comfort and health of the occupants. In general high indoor temperatures are indicators for a need for a high comfort which is especially understandable in cases where households are occupied by old people, or simply a wasteful energy behaviour [52].

The 24 apartments comprising group I were equipped with thermostats allowing the occupants to regulate their indoor temperatures. Furthermore, occupants with indoor temperature higher than 21ºC were economically penalized.

The overall results did not show a positive influence of this energy saving measure during 2006, since in most of the apartments the indoor temperature was maintained above 21ºC during January, one of the coldest months in Sweden, as seen in Fig. 10 a) and b). This could be due to generally lower outdoor temperatures during the winter of 2006 when the average temperature during January was –4ºC. With higher average outdoor temperature of 0.5ºC in January 2005, the number of apartments with an indoor temperature higher than 21ºC decreased to 13 as seen in Fig. 10 b). The warmest apartments are approximately 2.4ºC and 2.3ºC warmer than the coldest apartments in January 2005 and 2006, respectively. This difference in the registered level of thermal environment can be attributed to the consumer behavioural activities such as the opening/close of windows, the use of appliances, the time spent at home, etc.

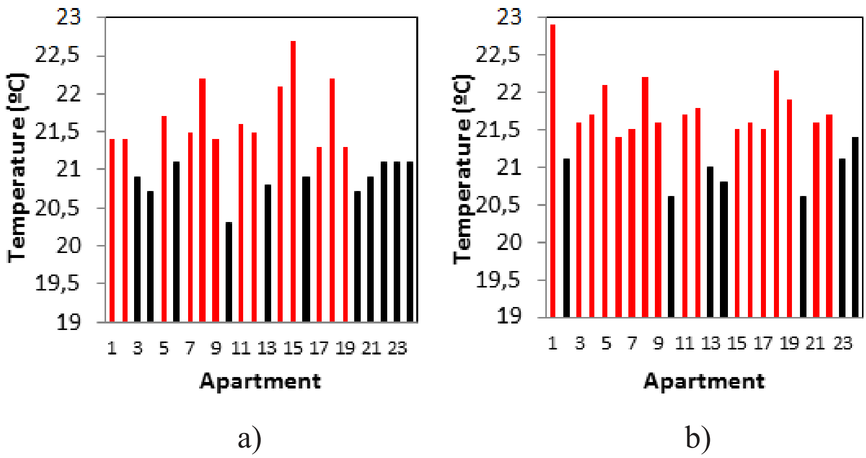


Figure 10. Average indoor temperature from group I (N=24) during a) January 2005 and b) January 2006 (red bars are for temperatures above 21°C).

As seen in the previous section, the income of households comprising group I was high in comparison to the other groups, which explains the unsuccessful results of the implemented measure: people with high income mind less paying extra money for comfort.

3.1.3.2 Use of appliances

(Paper III)

Although the introduction of highly efficient technologies into modern societies could lead to energy reductions, their increasing number in the households leads to lower prices causing the opposite effect. This is known as the "rebound effect", used to describe how the increase in the supply of energy services followed by a decrease in the effective price and leading to an increase in demand [53].

It is estimated that in Sweden of the total annual electricity demand of 3000 kWh per apartment, about 23% is used for lighting and about 24% is used for refrigerators and freezers [54].

The impact of electric appliances on the household final electricity consumption has been discussed by many authors. The analysis of 1 000 similar houses in Denmark, with large variation in energy consumption showed that the energy efficiency of household appliances did not contribute to the differences in consumption. However, the number and use of appliances did correlate to the number of people living in the house. One third of the variation in consumption could be explained by households' income and size [55].

Domestic appliances are divided into cold (refrigerators and freezers), wet (dishwashers and washing machines) and lighting. Several energy saving solutions could be suggested for each one of them: locating the cold appliances away from hot sources (oven); lowering the wash temperature or increasing the washing load of the wet appliances; and finally using more efficient light bulbs or installing occupancy sensors.

A lot of time and energy are also involved in the cooking process and therefore there are many ways of reducing them by using microwave instead of oven, use kettles for boiling water or making a more effective planning, among others. However, all these measures are dependent on the users' energy saving awareness and commitment [7].

Another way to increase energy awareness among the end-users is by presenting feedback with the appliance-specific breakdown and has been considered by some researchers as one of the main ways of improving consumption behaviour [44, 47, 56]. Unfortunately, the technique is not cost effective yet and therefore it has not been implemented by most of the feedback providing tools. This type of information was however, presented in a simple way to households from group I. The small displays showed the instantaneous power consumed in the apartment, meaning that whenever the occupants made use of their appliances, they could observe the change in their electricity consumption due to the corresponding appliance. The information was however, not further used to provide the consumers with a specific advice or information together with their electricity bills or web based interfaces.

In this thesis the appliances usage in the different households has been examined by asking the consumers about the time they spend making use of a group of appliances. Questionnaire surveys were preferred instead of, time diaries due to the aim of the investigation being to obtain a general view of some of the most electricity consuming domestic appliances.

The results collected from the households from group III, have been divided into apartments and houses in order to detect differences due to home type, and can be observed in Figure 11 a) houses and b) apartments.

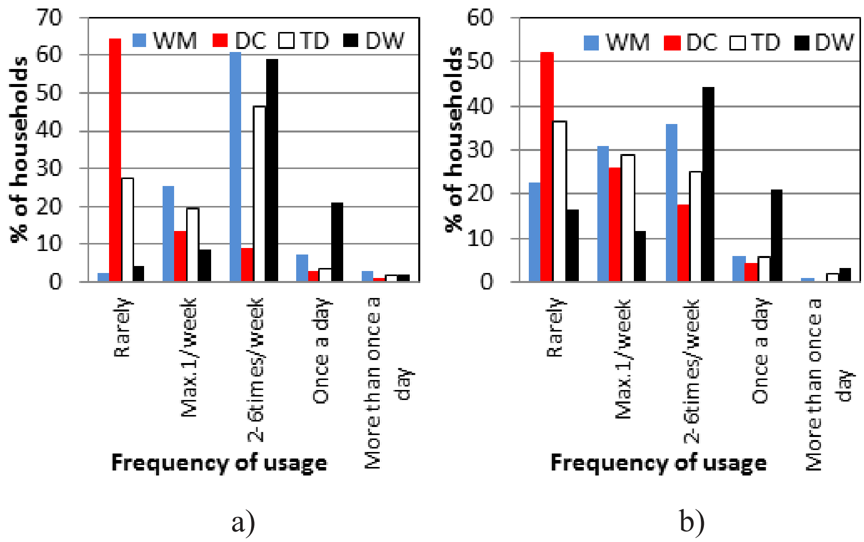


Figure 11. Frequency of usage of domestic appliances in a) houses and b) apartments. (WM= washing machine; DC =Drying closet; TD=Tumble drier; DW=Dishwasher).

Comparing both types of dwelling, a general trend of lower frequency of appliances usage in apartments than in houses is observed. There are more households in apartments that responded that they use their appliances 'rarely' in comparison to consumers living in houses.

During the last few years, the private ownership of washing machines and tumble drier has increased. This process, occurring mainly due to changes in the social structures, as women's higher participation in the labor market and the increased economic growth, is occurring in most of the Nordic countries [56].

Higher frequency of usage of the same appliances was found in the apartments from group I. Households comprising group I use their appliances more often than the apartments and houses from group III. These results explain the higher electricity consumption levels reached by group I in comparison to groups II and III.

In relation to the use of appliances and the increasing use of standby electricity of most of the domestic appliances, households from group III were asked if they believed this type of electricity consumption was influencing the total household electricity bill. More than half (53%) of the occupants from both apartments and houses answered standby consumption had no influence at all on the overall electricity consumption. Therefore, special attention should be paid on the information and communication technologies (computers, Internet, mobile phones and plasma screens among others) due to their major contribution to standby consumption and the increased use made of them in our daily routines. Internet and computers are nowadays included in all type of activities: communicating with friends and family, work, entertainment, etc. The number of devices per person is also increasing. Different use patterns vary depending mainly on age, gender, education and income [57]. There is also a group of extra devices used in combination with the previously mentioned: webcams, headsets, hi-fi sound systems, external disks, projectors, home servers, IP telephone connections and others that also contribute to the monthly electricity bill.

Results from the frequency of use of some of the information technologies and entertainment used by the 19 households in Västerås, are presented in Figure 12.

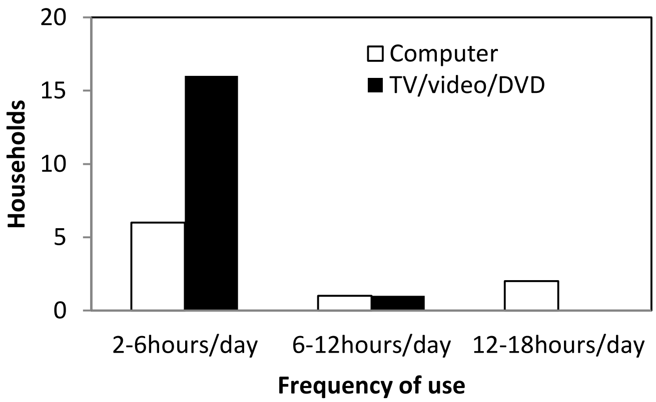


Figure 12. Frequency of use of computers and TV/Videos/DVD per household (N=19).

Computers are used between 12 and 18 hours/day although only by 2 of the households while TV/Video/DVD are used by 16 households between 2 and 6 hours/day.

In a recent study, including 12 countries within the EU where 500 questionnaires were sent per country and 11 500 households' appliances were analyzed, it was concluded that through behaviour changes, energy savings of 1 300 kWh per household per year could be achieved. In the same study the authors considered that apart from behaviour, if cold appliances, lighting and computers were changed, they would become the major electricity saving appliances (with 26.8%, 23.6% and 10.8% respectively) [58].

Therefore, targeting behavioural change and increasing energy awareness by different strategies and measures is believed to help achieve great energy savings. The final section of this thesis includes an investigation on different consumption feedback and also on how they affected the final domestic consumption.

3.2 Information and feedback

(Papers IV, V and VI)

Providing consumers with the possibility to securely access their own energy consumption has become one of the most challenging and fast growing concerns of current societies.

Feedback in this thesis refers to the method of providing information, knowledge or contributing in any other ways to changing consumers' behaviours and energy consumption habits.

The main objectives when providing feedback are the following: feedback should enable and motivate households to conserve energy and increase their awareness; it should improve consumers' satisfactions; and it should lead to load shifting [45].

The effectiveness, persistence and the way feedback should be delivered to the households has been widely analyzed in many reports and publications. Most of the studies conclude that it is possible to decrease energy consumption through feedback and information although the effects are impossible to predict due to human factors [59]. However, very few of these studies examine the long-term effects and how did the households react to the feedback. Additionally, in most of the cases where feedback was provided, no previous studies on the consumption trends nor the behaviour and people's preferences were carried out.

In one of the most cited studies in this area feedback is classified as: direct, as the 'raw' one provided from a meter or a display monitor; and indirect feedback, which has been processed before reaching the consumers (i.e. bills, displays separate from the meter or web pages). The reported energy savings are between 5–15% in cases where direct feedback is applied and 0–10% for indirect feedback, although depending on the context and quality of the information offered [44].

The information provided to the consumers should be easy to understand. Consumers are not always familiar with scientific units and not always understand how their electricity consumption is connected with CO_2 emissions. Householders are also less interested in feedback that only includes economic or environmental impact. Therefore, presenting the energy costs, the appliance-specific breakdown and historical comparison are the main aspects selected to be included in the information/feedback given to the consumers [44, 55, 47].

However, despite of general tips and indications to save energy being usually available, these recommendations hardly catch the attention of the consumers [60]. Households do not apply tips provided with general information campaigns since they do not relate themselves to the provided tips. Tailoring the information to the situation and characteristics of the household is one of the solutions proposed by many researchers although it has not been generally applied yet [44, 47, 61].

The way of delivering the feedback to the consumers is another important aspect discussed by some researchers. There are three main ways of providing feedback: displays (displaying direct or indirect consumption information), electricity bills (improved by the installation of automatic meter reading systems and more detailed and frequent measurements), and websites (delivering different types of indirect information).

Therefore, in order to obtain the desired effects with the provided feedback, it is essential to firstly investigate what type of communication technology would be more suitable for the different households. The most preferred methods for providing feedback for the EU countries have been analyzed by the TNS/ Future foundation research. All Nordic countries, The Netherlands and France chose displays as main way of receiving feedback, while Germany, Great Britain, Spain and Portugal selected bills as most favorite [62].

So far, some of the most essential feedback related findings have been summarized in the Smart Metering Guide [30] elaborated by the European Smart Metering Alliance, and are the following:

- Adding a high but reachable targets could save up to 3% extra energy.
- Providing historic feedback has been proven more effective than comparative one.
- Direct displays providing immediate feedback give more energy savings than delayed feedback.
- Consumers are not willing to pay extra for feedback devices.
- Negative feedback ("your energy consumption is higher than the target") has been proven as ineffective.
- Internet is not the most preferred medium for providing feedback.

In Sweden, the Swedish Energy Agency plays an important role in providing information, employing many different channels and working with a large number of different parties ensuring the delivery of the information to the targeted groups. The Agency has even financed special energy advisors that work for the local authorities and are trained by regional energy offices to provide information, tips and help to customers in need [1].

The three earlier mentioned ways for providing feedback have also been offered to Swedish households. Most of the local power suppliers (Mälarenergi, Vattenfall, Göteborg Energi, etc.) have created websites where their customers can visualize their consumption and also receive general energy saving information. Other households have also been provided with similar services received on their mobile phones, or displays although these methods are not very spread. The electricity bills have been improved and in some cases they even include graphical presentation of the monthly consumption.

However, it is interesting to note that even in the Scandinavian countries, where the access to Internet is widespread (80% of users in Sweden [63]), and where web based feedback is the most used communication technology, it is not the most preferred one by the households. This could be considered as one of the main reasons for the low percentages of website visitors that some of the studies carried out in Sweden show [49].

The advantages, disadvantages and effectiveness of displays, websites and bills are further analyzed below.

3.2.1 Displays

One of the most frequently mentioned advantages of using displays, is that it allows the consumers to have a better control over some of the appliances used (by connecting and disconnecting them, they can see how much the overall consumption has changed).

Furthermore, displays have been demonstrated to be the easiest to access if compared to websites since the consumer has to have a specific need or interest to use the computer and browse the website [64].

In a project where Mälardalen University participated in 2008, two displays (touch screen panel PC) were developed showing household's electricity consumption in different forms (diagrams, comparisons with previous months, current consumption and also the price to pay in the end of the month-according the electricity tariff that the household had). The default screen had an intuitive design in the form of a visual fire place where the flames' intensity corresponded with the households' current consumption. A low, typical and high consumption was represented by low, medium and high intensity of the flames respectively. The display was connected wirelessly (via Bluetooth) to the smart meters situated in the basement of the buildings where the display were tested. The testing of the displays was carried out during the summer of 2007 among households from Eskilstuna (group II, described in the Methodology). A total of 12 different apartment households volunteered to participate in the study. Each household could keep one display for one month as maximum.

The feedback obtained after interviewing the participating households, was positive. Most of the users (of different background, age and characteristics) found them easy and interesting to use and also challenging since some of them decided for instance to buy more energy saving appliances in order to reduce their monthly bills.

Displays can also present other useful information as for instance: instantaneous levels of electricity use; the daily electricity use (in kWh, monetary cost or CO_2 emissions); monitoring when appliances, boilers and radiators are on and for how long have they been on [46].

Households from group I, located in Västerås and previously analyzed in this thesis, have been provided with small and simple displays showing only numerical information on electricity consumption and also the indoor temperature. The displays were individual for each apartment and were directly connected to the smart meters situated in the stairwell.

Consumption patterns have been discussed in the previous section of this thesis and show the tendencies for high consumption of most of the apartments and especially when compared to apartments and houses from groups II and III.

The elevated electricity consumption levels could show the ineffectiveness of the direct feedback at least in this group of households. On the other hand, the high income and the low awareness of the occupants could also lead to the current situation.

3.2.2 Websites

Web based feedback has been the most widely adopted way of providing information and feedback on energy consumption. For the utility, the web based presentation of electricity consumption constitutes an improved communication between the company and the customers and also transforms electricity into a “visible” product for the users.

However, customers do not seem to be very active in following their consumption on the web. When consumers use the web based consumption information means that they do it because they are very interested in doing exactly that which makes the information to be better assimilated. The main reasons found among Swedish households for not using the provided web based feedback are: time constraints and problems concerning the use of the website [65].

On the other hand, most of the websites were very similar in content and form, despite the different actors that created them (municipalities, companies, authorities, etc.). It is believed that consumers’ knowledge needs to be increased through, for example discussions concerning energy reduction in relation to the consumption society where consumption patterns and lifestyle are also included [66]. Also the websites have to include continuous and direct feedback and it has to be frequently renewed [67].

The households from the third group analyzed throughout this thesis, that have visited the provided web based feedback at least once, have been divided into houses and apartments and their consumption differences with respect to previous years have been analyzed (Paper VI).

The highest reductions in electricity consumption were reached the year after the website introduction (2008). Consumers living in houses reduced their consumption with respect to 2008 levels, with 8.3%, while those living in apartments did it with 6.4%.

However, the greatest reductions were achieved with respect to 2007 levels. The biggest savers were the occupants living in apartments, who reduced their electricity consumption with 17.5%.

The overall lower consumption could be an indicator of the effectiveness of the web based feedback: households that have made use of it achieved greater reductions than the group as a whole (the percentage of all the households that visited the website was 27%).

There are few results published on how web based feedback affects the final household consumption. Smart meters/automatic meter readings in Sweden were only generally introduced in 2008 and therefore the outcomes of the feedback have not yet been very clearly established.

3.2.3 Electricity bills

Already in 1988, Owens and Wilhite presented the results of a Nordic Council of Ministers project on the evaluation of electricity bills in the Nordic countries. The results presented in the report show the difficulties that consumers encountered with the electricity bills. Increasing the number of bills per year, including previous periods' consumption, reducing the information provided and including energy saving tips are the main proposals for making bills easier understandable for the consumers and obtain energy savings [40].

The information provided with the electricity bills has improved during the last few years. With the introduction of smart metering systems and hourly or monthly readings, bills have the possibility to become more informative than ever. They can include graphs showing how consumption has changed in comparison to the same month of previous years. Although some studies show that households do not like to be compared to others, bills can also include a comparison between the households' consumption with the one of a different household with similar characteristics [68]. Bills can even provide the consumers with valuable energy saving tips (different with each bill and specific for each household or period of the year).

In an experiment carried out in Sweden [64] customers experience with graphs presented with the bills was very positive, especially among households living in houses. Graphic presentations would be even preferred by households with non-Swedish backgrounds (or with difficulties with understanding the language). The graphs should be presented in the same time-period as the bill is received (often monthly).

In this way, households from group II studied in this thesis, which received improved bills, did not achieve the expected effects since their consumption increased with almost 20%. This increase, however, could be due to lack of energy awareness amongst the consumers. Those households, who had their electricity included in the rent before the installation of the new meters, could have realized that what they usually consume does not cost them a lot decreasing their energy awareness even more. Another reason is that the collected data from the meters is not used to generate tips that are specific for the different households.

3.2.4 Conclusions about information and feedback

The main conclusion made after the analysis of all the different cases, is that the way of increasing the effectiveness and longevity of the energy consumption feedback is to first identify the possible households where most savings could occur. Studying consumption patterns and investigating households' characteristics are the main approaches to consider.

Some of the most relevant households' characteristics determining the grade of energy improvements are: income, home ownership and the family size (energy saving activities increasing with the number of family members) described the typical energy-saving consumer [40, 69]. These findings agree to some extent with Vringer et al., (2007) statement in their analysis of consumer specific information: high-energy households require 70% more energy (electricity and gas) than low-energy households having also about 10% more appliances [70].

Taking consumers' individual preferences into account is therefore, another essential step to examine before developing feedback technologies. Large differences in the preferences obtained from the households from group III, located in Växjö, have been found (Papers IV, V). From the 660 households (provided with web based feedback) that responded the questionnaire, it could be concluded that the level of knowledge on their own consumption, the occupants' age and income, the energy awareness and behaviour and the type of the dwelling play a significant role in the manner in which the occupants respond to the feedback.

The results discussed in Paper V and VI show that the feedback provided to households with high income (group I) has not been as effective as the provided to households with moderate income, for instance. Low income households (group II) have not decreased their consumption levels either, although this fact could be due to having much lower consumption anyway when compared to the rest of groups. Income was shown to cause more impact on the electricity consumed by households with high and low income but not within the moderate one. This could also explain the effectiveness of the provided feedback: high income is linked to high consumption and less energy awareness in general; while low income is linked to low consumption and therefore, low savings potential.

The analysis showed that the most preferred ways of receiving feedback by the youngest group of occupants (18–24 years) is display, followed by mobile phone applications and e-mail. Websites and e-mail were the selected ones by the three following age-groups, while the oldest occupants preferred letter as a main way to receive feedback on their consumption.

On the other hand, displays were the most preferred ones by 33% of the respondents living in apartments, while 27% of the consumers living in houses preferred e-mails, followed by websites, 26%. That could explain why only 23.5% of the total households living in apartments have been visiting the website provided by the electricity supplier. These differences in preferences can be due to possession (or lack of it) of computers/Internet. The respondents living in apartments might not have computers/Internet and therefore, prefer having in-home displays. On the other hand, if relating preferences to age as seen earlier, apartments are usually occupied by young people who prefer displays as main way of receiving feedback.

3.3 Conclusive discussion

Individual differences have been found to have greater importance than bigger groups of households. It is therefore that consumers need to be interacted with using a more personal approach in order to ensure effective consumption reduction.

The individual characteristics need to be addressed to provide relevant methods to lower energy usage. The individual approach also involves targeting energy usage on a more specific level, through paying more attention to hourly/daily consumption. Behaviour and activities influencing this type of consumption should be targeted since it would help changing the energy consumption in the long term.

Displays and SMS (or through smart phones applications) would be in that case the most appropriate ways of providing feedback since the instantaneous changes in the consumption can be delivered to the interested consumers. Providing web based information and feedback has been proven effective in some cases although that occurs when consumers have high energy awareness or interest and time to browse the website. Therefore, web based solutions should not be the only ones offered to the consumers, as those without the necessary time or interest will might fail to take advantage of the service.

Effective reductions in consumption cannot be achieved through solely imposing dynamic pricing and demand-based tariffs, as these would not change the behaviour and daily activities of occupants with high incomes, for instance, and people that do not care that much about saving money, especially when that entails reducing their comfort. The best energy saving strategy is the consideration of consumers' interest, opinion and preferences.

People should first be given the possibility of choosing their way of reducing consumption: different tariffs, information and feedback or a combination of different measures. If however, their consumption levels still remain high, then the new technological advances in the field (automatic lighting, temperature regulation, etc.) should be applied.

The consumers' involvement in the process is important in increasing their awareness and creating sustainable long term reductions in their energy use. The main challenge and a key area for future research is on finding a way to keep consumers interested in the goal of keeping consumption low and continuing to find ways to further reduce it.

Our research results showed very high interest levels in energy saving techniques and technologies during the beginning stages of implementation. These levels decreased significantly as time went on. It is evident that consumers lose interest once the novelty and curiosity wears off. The long term energy saving awareness could be reached through making energy saving measures second nature to consumers. This could possibly be achieved by forming good energy habits through various short-term motivating programs (feedback and incentives).

4. Conclusions

Which are the main parameters affecting domestic energy consumption?

The first step considered to compare different patterns, was the analysis of household energy use to identify consumers with high saving potential (based on consumers' characteristics, knowledge, awareness, etc.) to improve the effects of the provided feedback and therefore, increase the energy consumption reductions.

Seasonal and hourly variations showed high impact on energy use (as discussed in Papers II and III), especially in Sweden where winter periods are long and dark, increasing the time spent at home with intense use of appliances.

Furthermore, according to the findings described in this thesis, hourly, daily and monthly differences between different years were strongly influenced by the occupants' habits, knowledge level and energy-use awareness. As explained in paper III, electricity-use behaviour and income level were the only parameters that could explain why apartments with same physical characteristics and same family structures had large differences in their consumption patterns. Moreover, other factors, such as size and number of people per household showed to have an important impact on the overall household energy consumption, and consequently should be considered when performing any type of energy consumption assessment.

How can households' energy consumption be reduced?

Based on the previous findings, aside from the energy-efficiency technological upgrades in appliances, the main efforts should be focused on targeting consumers' behaviour and increasing their energy-use awareness and knowledge. Greater reductions of electricity consumption can be achieved by changing people's habits and usage patterns.

Behavioural change is a highly complex task but can be induced by providing the consumers with tips, information, comparisons, discussions and incentives. The results presented Papers V and VI showed that all these measures have to be specifically-targeted for each household-type, depending on their preferences, knowledge and disposition. As discussed in Paper I and II, energy prices and financial penalties did not affect the high-income group but it was relevant for people with lower incomes.

Households from the high-income group did not complain about their electricity bills and consumed much more electricity than the rest of groups (including houses, as compared in Paper VI). Consequently, it is necessary to target high income groups by providing them with more detailed information and to take a different approach more than just the financially related saving opportunities (Paper I).

What are the effects of the installation of automatic meter readings and the provided information/feedback on the household consumption?

In order to provide the users with relevant energy-use information, the first step is to compile enough knowledge on their consumption trends and their individualities. This can be partly achieved by the recently installed new metering systems. The new meters allow utilities and policymakers to propose the necessary and specific energy saving measures to the corresponding households. However, the large amount of consumption data accumulated by the utilities is not always used to give the consumers specific and personalized advice.

The results presented in Paper VI established that changing the energy-use awareness and the daily routines is possible through information and feedback (advertising to increase the use of web based energy information systems resulted in users reducing up to 18% in their electricity bills). However, the results also showed that this is only valid for households where energy-related awareness already exists and for those who preferred receiving information through web based interfaces.

The instantaneous measurements obtained by the new meters were especially helpful in those cases where households have had their electricity and hot water consumption included in the apartment’s rent for years, because before, they had limited to none information about the energy consumed by their appliances (Paper VI). Electricity bills based on estimated consumption were also eliminated allowing the consumer to have a better control over their energy usage. Having access to instantaneous measurements allowed new energy information channels to be used, such as SMS, displays and TV interfaces.

How could feedback content be improved, what information should it include and how should it be delivered to the consumers?

From the analyses of the questionnaires used in this thesis, it was concluded that future information campaigns must include clear and simple messages, specifically targeted for each household based on their knowledge, preferences and characteristics.

For instance, consumers that did not visit the provided web based energy information system, preferred receiving feedback through other methods (letters, displays, etc.). On the other hand, the group with high energy usage that had displays showing their consumption had higher incomes and needed a different motivation to save energy (for instance, detailed energy consumption per appliance). When developing policies and other energy saving measures, the preferences of the households, their incomes, age and the areas and the type of dwelling where they live should be also taken into account.

These parameters (age, income, type of dwelling and level of energy related interest) are chosen after analyzing and comparing a large set of feedback preference data and are highly recommended in future development of policies and feedback strategies.

The higher energy saving rates reached in the first year after the introduction of the website and following stabilization, demonstrates that it is equally important to provide the consumers with frequent and interesting and relevant information and feedback in order to keep them interested and prolong the behavioural changes.

In order to change energy consumption on a global scale it is important to change individual behaviour. This is most effectively done by a more personal approach and adapting the measures to specific cases.

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Appendix I – Questionnaire

Akademin för hållbar samhälls- och teknikutveckling (HST)
Department of Sustainable Society and Technology

Frågeformulär till hushåll i Växjö
September 2010

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1. When did you move into the apartment?

Year: …………………… month (if possible): ……………………

2. What is the apartment's size?

m^2: ……………………

3. How many people live in the apartment during most of the year?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 or more

children in the age of 0-6 years: ………… 7-12 years: ………… and 13-17 years: …………

4. Time that the occupants spend at home during weekdays:

Adults spending time in the apartment:

All days:………… half days: ………… only evenings and nights: …………

Children spending time in the apartment:

All days:………… half days: ………… only evenings and nights: …………

5. Do the household members have any electricity consuming hobby?

☐ yes → which? ……………………………………………………………

☐ no

6. Which is the occupants' education level?

Adults (older than 18) that have completed

elementary school: ………… persons
high school: ………… persons
university: ………… persons

7. What is the households' total income per month?

Income (gross) per months: …………… SEK/month

8. What is the frequency of usage of the following appliances in the household?

	Year	Rarely	Max. once week	2-6 times/ week	once/day	>once/day
☐ Washing machine	………	☐	☐	☐	☐	☐
☐ drier (with heat)	………	☐	☐	☐	☐	☐
☐ tumble drier	………	☐	☐	☐	☐	☐
☐ dishwasher	………	☐	☐	☐	☐	☐
☐ fridge	………					
☐ freezer	………					

		Estimated hours of use per day (in case of several appliances, add the total of hours)
☐ stove/oven	………	………… hours/day
☐ microwave	………	………… hours/day
☐ computer	………	………… hours/day
☐ tv/video/dvd etc	………	………… hours/day
☐ large screen TV	………	………… inches

amount: estimated hours of use per year

☐ extra radiator ………… ………… hours/year

☐ infrared heater ………… hours/year

Frequency of use/ Hours of use per year

☐other electricity using devices → which? ....

9. How many incandescent light bulbs are used in the household?

Total: ……………………

10. How many LED and low energy light bulbs are used in the household?

Total: ……………………

11. Have the occupants use "EnergiKollen" to follow up the energy consumption?

☐ yes → Mark the most suitable option: Once, Every year, Every month, Every week, Every day

☐ no → go to question 13

☐ do not know

12. Is the information provided by the "EnergiKollen" easy to understand?

☐ ☐ ☐ ☐ ☐ ☐ ☐

yes, very interested no, not at all

13. Which of the following options do the occupants consider interesting for improving the control of the energy consumption?

	Yes, very interested						No, not interested at all
Letter	☐	☐	☐	☐	☐	☐	☐
Website	☐	☐	☐	☐	☐	☐	☐
E-mail	☐	☐	☐	☐	☐	☐	☐
Mobil - SMS	☐	☐	☐	☐	☐	☐	☐
Mobil - MMS	☐	☐	☐	☐	☐	☐	☐

Mobil - WAP	☐	☐	☐	☐	☐	☐	☐
Mobil – Apps*	☐	☐	☐	☐	☐	☐	☐
Display	☐	☐	☐	☐	☐	☐	☐

*Mobil Apps programs that can be downloaded on your phone (App = Application).

Other solutions ……………………………………

14. Is the household interested in energy related questions?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Yes, a lot no, not at all

15. Do the occupants strive to reduce the electricity consumption?

☐ ☐ ☐ ☐ ☐ ☐ ☐

yes, always no, never

16. Is the household aware of the steps that can be taken to keep low electricity consumption?

☐ ☐ ☐ ☐ ☐ ☐ ☐

yes, very aware no, not at all

17. Is the household interested in increasing their knowledge of actions that can be taken to keep low electricity consumption?

☐ ☐ ☐ ☐ ☐ ☐ ☐

yes, very aware no, not at all

18. Is the household aware of their own electricity consumption?

☐ ☐ ☐ ☐ ☐ ☐ ☐

yes, very aware no, not at all

19. **Do the household members turn off the lights in rooms with no presence?**

☐ ☐ ☐ ☐ ☐ ☐ ☐
yes, always no, never

20. **Is the household's total electricity consumption affected by the stand-by consumption?**

☐ ☐ ☐ ☐ ☐ ☐ ☐
yes, a lot no, very little

21. **Do you usually fill the washing machine completely before each use?**

☐ ☐ ☐ ☐ ☐ ☐ ☐
yes, always no, never

☐ do not have a washing machine

22. **Do you usually fill the dishwasher completely before each use?**

☐ ☐ ☐ ☐ ☐ ☐ ☐
yes, always no, never

☐ do not have a dishwasher

23. **Is it the energy efficiency or the price the most decisive factor when buying new home appliances?**

☐ ☐ ☐ ☐ ☐ ☐ ☐
Efficiency Price

24. **Do the occupants strive to limit the heating consumption?**

☐ ☐ ☐ ☐ ☐ ☐ ☐
Yes, always No, never

25. Do the occupants strive to limit the hot water consumption?

☐ ☐ ☐ ☐ ☐ ☐ ☐
Yes, always No, never

26. How often do the occupants take a shower (as an average in the household)?

☐ 1-3 times a week ☐ 4-6 times a week

☐ 7 or more times a week

☐ Never/there is no shower in the apartment → go to question 28

27. For how long do the occupants take shower (as an average in the household)?

☐ max. 5 minutes ☐ 5-15 minutes
☐ 15 minutes or longer

28. How many times do the occupants take a bath (as an average in the household)?

☐ 1-3 times per year ☐ 1-3 times per month ☐ 1-3 times a week

☐ 4-6 times a week ☐ 7 or more times a week
☐ Never/there is no bathtub in the apartment

29. Has the household change the electricity supplier for the last 4 years?

☐ yes → How many times? ....

☐ no

☐ Do not know

30. What do you think about the electricity bill?

☐ ☐ ☐ ☐ ☐ ☐ ☐
Very high Very low

31. Which is the main motive (for the household) to save energy?

☐ ☐ ☐ ☐ ☐ ☐ ☐
Environment Money

32. Which from the following claim(s) are suitable for describing how the questionnaire was answered?

☐ All household occupants answered together

☐ The adults living in the apartment answered together.

☐ The person that answered is the responsible for paying the household's energy/electricity bills.

☐ The person that answered is the most interested in energy questions.

Thank you for your collaboration!