Load Management in Residential Buildings: Considering Techno-Economical and Environmental Aspects

Abaravicius, Juozas

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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

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Considering Techno-Economic and Environmental Aspects

Juozas Abaravičius

Thesis for the degree of Licentiate in Energy Economics and Planning

Division of Energy Economics and Planning
Department of Heat and Power Engineering
Lund University
PO Box 118, SE-221 00 Lund, Sweden

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by

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juozas.abaravicius@vok.lth.se

Division of Energy Economics and Planning

Department of Heat and Power Engineering

Lund University

PO Box 118, SE-221 00 Lund, Sweden

www.vok.lth.se/~eep

Preface

This thesis is based on research performed by Juozas Abaravicius within the project "Direct and Indirect Load Management in Buildings". This project is however also including research by other members of the research group for DSM and Load Management in Buildings at the Division of Energy Economics and Planning, Department of Heat and Power Engineering, Lund University, Sweden. Besides the subproject presented in this thesis, there are two additional parts:

- Electricity demand variation analyses and the development of new types of contracts and tariffs (Assoc. Prof. Jurek Pyrko).
- Behavioral aspects of energy use in households (Kerstin Sernhed)

Assoc. Professor Jurek Pyrko from the Division of Energy Economics and Planning, Department of Heat and Power Engineering at Lund University has been the project leader and primary supervisor for this thesis.

Assoc. Professor Lena Neij from the International Institute for Industrial Environmental Economics at Lund University has been the secondary supervisor.

This work was financed by the ELAN program- a joint research program on electricity utilization and behavior in a deregulated market. The ELAN-program is financed by the utilities Eskilstuna Energi & Miljö, Fortum, Göteborg Energi AB, the Göteborg Energi research foundation, Jämtkraft AB, Skellefteå Kraft AB, Skånska Energi AB, Sydkraft AB and Vattenfall AB through Elforsk (Swedish Electrical Utilities' R&D Company), project number 4184-LTH, the Swedish Energy Agency and Formas (The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning), project number 2001-1846.

The research group for DSM and Load Management in Buildings is a trans-disciplinary research group, joining the researchers with different backgrounds, such as engineering, economics, social and environmental sciences.

The group is also involved in several other projects, for instance:

- EU project "Pushing a Least Cost Integration of Green Electricity into the European Grid. GreenNet". Working package 5 "Potential and Costs of DSM Measures in Europe" (Jurek Pyrko and Juozas Abaravicius)
- Expansion of district heating to detached house areas (Kerstin Sernhed and Juozas Abaravicius)

Acknowledgements

I would like to express my gratitude to Associate Professor Jurek Pyrko and Associate Professor Lena Neij, my primary and secondary supervisors, for their continuous helpful comments, criticism and assistance of my work.

I would like to thank my colleagues at the Division of Energy Economics & Planning, for the great help and support during my studies. Especially I would like to thank Kerstin Sernhed, for her collaboration in the research, understanding and friendship. Also thanks to Victor, Palle, Tommy and Johanna, my office mates during these years. Special thanks to Johanna, for her help in our project!

My sincere appreciations come to the staff at Skånska Energi AB, especially Lars-Erik Dahlström, Bengt Andersson, Mats Sjöström and Morris Bratt, for providing assistance and practical comments whenever asked.

I'm grateful to my parents, brother and sister, for their continuous emotional support, to all my friends in Lithuania and other countries, for not forgetting me. Thanks to all my friends here in Lund, for these nice moments together.

Finally, my sincerest thanks to my wife Sandra, for her love, encouragement, optimism and being close all the time.

The financial support from Elforsk, Formas and the Swedish Energy Agency is greatly acknowledged. This research would not have been possible without their support.

Summary

Load problems in electricity markets occur both on the supply and demand side and can have technical, economic and even political causes. Commonly, such problems have been solved by expanding production and/or distribution capacity, importing electricity or by load management. Load management is a techno-economic measure for harmonizing the relations between supply and demand sides, optimizing power generation and transmission and increasing security of supply. Interest in load management differs depending on the perspective of the actors involved: from customer, utility, or producer to state policymaker.

The problem of load demand and load management in residential sector is in this thesis approached from different perspectives, i.e. technical, economic, and environmental. The study does not go deep into detailed analyses of each perspective, but rather aims to establish and analyze the links between them. This trans-disciplinary approach is the key methodological moment used in the research work performed by the research group for load management in buildings at the Lund Institute of Technology.

The key objective of this study is to analyze load demand variation and load management possibilities in residential sector, particularly detached and semi-detached houses, to experimentally test and analyze the conditions and potential of direct load management from customer and utility viewpoint. Techno-economic and environmental aspects are investigated.

The study was performed in collaboration with one electric utility in Southern Sweden. Ten electric-heated houses were equipped with extra meters, enabling hourly load measurements for heating, hot water and total electricity use. Household heating and hot water systems were controlled by the utility using an existing remote reading and monitoring system.
The residents noticed some of the control periods, although they didn't express any larger discomfort.

The experiments proved that direct load management might be a possible solution for the utility to solve their peak demand problems. Another solution, considered by the utility and analyzed in this study is a construction of diesel peak power plant. This alternative has negative environmental consequences compared to load management.

The analysis of environmental aspects was extended to national level. To include an environmental perspective is a novel approach, since traditionally, load management evaluation is limited the economic and technical viewpoints. It identifies and discusses the possible environmental benefits of load management and evaluates their significance, primary focusing on CO_2 emissions reduction.

The results show the importance of considering the influence of site-specific or level-specific conditions on the environmental effects of load management. On the national level, load management measures can hardly provide significant environmental benefits, since hydropower is used as the demand following production source in Sweden. Emission reductions will rather be the result of energy efficiency measures, which will cut the load demand as well as the energy demand.

List of publications and drafts

The thesis is based on the following publications and drafts performed within this sub project:

Abaravicius, J. (2004). *Environmental Aspects of Load Management*, Report ISRN LUTMDN/TMHP--04/3012--SE, Division of Energy Economics and Planning, Dept. of Heat&Power Engineering, Lund University, Sweden

Abaravicius, J., Pyrko, J. (2004). *Load Management from an Environmental Perspective*, Division of Energy Economics and Planning, Dept. of Heat&Power Engineering, Lund University, Sweden. (submitted)

Abaravicius, J., Pyrko, J., Sernhed, K. (2004). *Turn Me On, Turn Me Off! Techno-Economic, Environmental and Social Aspects of Direct Load Management in Residential Houses,* Division of Energy Economics and Planning, Dept. of Heat&Power Engineering, Lund University, Sweden. (submitted)

Abaravicius, J., Pyrko, J., Sernhed, K. (2004). *Load Demand Characteristics of Detached and Semi-Detached Residential Houses. Case studies in Southern Sweden*, Division of Energy Economics and Planning, Dept. of Heat&Power Engineering, Lund University, Sweden. (draft)

Contents

1. Introduction

The electricity demand continues to increase all over the world, playing an essential role in economic and social development. The creation of sustainable and stable electricity supply system, able to maintain economic growth and social progress whilst protecting the environment and conserving natural resources, is a strategic issue in almost every country.

Load management (LM) is widely known as a technical and marketing measure for improving the techno-economic performance of the electricity system. Research has mostly been devoted to issues such as harmonizing the relations between supply and demand sides, optimizing the power generation and transmission and increasing the security of supply. These economic and technical effects have the influence on the environmental performance as well.

1.1 Objectives

The objective of this thesis/study is to analyze load demand variation and load management possibilities in residential sector and the techno-economic and environmental aspects of this.

First, the techno-economic aspects of load management are analyzed. This is done through the analysis of load demand and direct load control in 10 selected detached and semi-detached houses in Södra Sandby, Southern Sweden, which have electric space heating and domestic hot water systems. The objective here is:

- to identify and describe the load management needs
- to analyse the collected data on total and partial load demands
- to test the technical possibilities of direct load control
- to estimate load savings
- to estimate the effect on indoor climate and comfort conditions for the customers
- to estimate the effect on hot water availability
- to discuss the technical and economic pros and cons of direct load control from a customer and utility viewpoint

Second, the reduction of environmental impact by load management is analysed. The objective is here to discuss how environmental effects can be reduced, both on a regional level, in Södra Sandby, and on a national level.

1.2 Methodology

Three basic points should be emphasized while defining the methodology of the performed study:

1. *Transdisciplinary research.* It is the key methodological approach used both in this thesis and the research performed by the research group.

"*Research work carried out by our group is explorative in character, which means that we systematically and methodically search for new knowledge but not necessarily by formulating hypotheses to be confirmed or falsified. To identify problems, investigate and describe phenomena gives a new knowledge that gradually can be transformed and applied.*" (Pyrko, 2001)

The problem of load demand and load management in residential sector is in this thesis approached from different perspectives, i.e. technical, economic, and environmental and, to some extent, social. The study does not go deep into detailed analyses of each perspective, but rather aims to establish and analyze the links between them.

2. *Experiments on local level*. The experimental load management works were performed on local (customer-utility) level. Together with our associated electricity supplier Skånska Energi AB we used "real world" lab to accomplish the objectives of the study. It was possible to have access to hourly electricity use data and field-test the available control technique. Ten pilot houses within Skanska Energi service area were selected for the alaysis. All houses are located in Södra Sandby, Southern Sweden. Hourly load data as well as partial load data for heating and hot water for ten selected households was obtained with a help of metering and communication system CustCom, available at the utility. The data collection was carried out for around one year and evaluated continuously. The load management experiment was on/off control of heating and hot water systems at ten selected households.
The interests in load management and the effects both for the customer and the utility are discussed considering different aspects – techno-economic, environmental.

3. Data collection on energy supply was used to analyze the *environmental effects on national level*. This analysis is based on the data obtained from the Swedish Energy Agency, Svensk Energi (Swedish electricity supplier's association) and Svenska Kraftnät (Swedish national system operator). The key focus of the analysis on national level is the variation of CO_2 emissions originated from the Swedish electricity demand, to see how the emission varies with the increase or decrease of electricity use.

1.3 Thesis outline

Chapter 1 is the introduction, defining the objectives and methodology used in this study.

Chapter 2 provides the background information about load demand, load problems on electricity market and analyses the link between load demand and environmental effects.

Chapter 3 presents load management techniques and discusses different perspectives of LM.

Chapter 4 is the analysis of load management experiment in Södra Sandby.

Chapter 5 is the analysis and discussion of the environmental effects of LM on national level.

Chapters 6 and 7 provide the conclusions and recommendations for future research within the field

2. Load Demand

2.1 Electricity market in Sweden

Sweden, as well as other Nordic countries, provides interesting cases for study of load problems due to high consumption of electricity per inhabitant and the effects of electricity market reform. Sweden uses around twice the amount of electric energy per inhabitant than EU average. One of the most important reasons for this is the electricity use for heating requirements (Swedish Energy Agency, 2003).

The production of electricity in Sweden primarily comes from hydro and nuclear power plants (93%). Remaining part comes from wind and thermal power plants, and import (see Table 2.1). The countries that export electricity to Sweden are Norway, Denmark, Finland, Germany and Poland. The Nordic countries have a common electricity exchange known as Nord Pool on which players from Norway, Finland, Sweden and Denmark can trade in electricity (Swedish Energy Agency, 2003).

Table 2.1. *Electricity generated and consumed in Sweden in 2000-2002 and forecasts for 2010, TWh/a (Swedish Energy Agency, 2003, 2004).*

	2000	**2001**	**2002**	**2003**	**2010**
Generation, totally	**142.0**	**157.8**	**143.4**	**132,3**	**147.8**
Hydro power	77.8	78.6	66.0	52,8	68.6
Wind power	0.5	0.5	0.6	0,6	3.9
Nuclear power	54.8	69.2	65.6	65,5	63.6
Conventional thermal power	8.9	9.6	11.2	13,4	11.8
- Combined Heat&Power (CHP) in industry	*4.2*	*3.8*	*4.7*	*5,2*	*4.9*
- CHP in district heating	*4.7*	*5.7*	*6.0*	*7,6*	*6.8*
- Condensing power, incl. gas turbines	*0*	*0*	*0.5*	*0,6*	*0.1*
Consumption	**146.6**	**150.5**	**148.7**	**145,1**	**152.0**
Network losses	11.1	11.6	11.6	11.6	11.4
Imports-exports	**4.7**	**-7.3**	**5.4**	**12,8**	**4.2**

The electricity market in Sweden was deregulated in 1996. Since 1999, all customers are free to choose the electricity supplier. Annual increase in electricity demand in Sweden is around 1-2% (Swedish Energy Agency, 2001).

2.2 Load demand and load problems on electricity market

Energy system has to be designed to meet not only the energy [kWh] but the load demand [kW] as well. Load demand depends on several factors:

- Customer type (household, commercial, industry, etc.)
- Customer's equipment
- Climate (outdoor temperature, light)
- Human factors (consumption patterns, habits, etc.)

The energy demand during specific period of time e.g. day, month or year might be rather constant; however the load demand might vary drastically within a given period. An example of load demand variation in a household during 24 hours is presented in Figure 2.1. This variation affects the environment accordingly to what the production sources are employed.

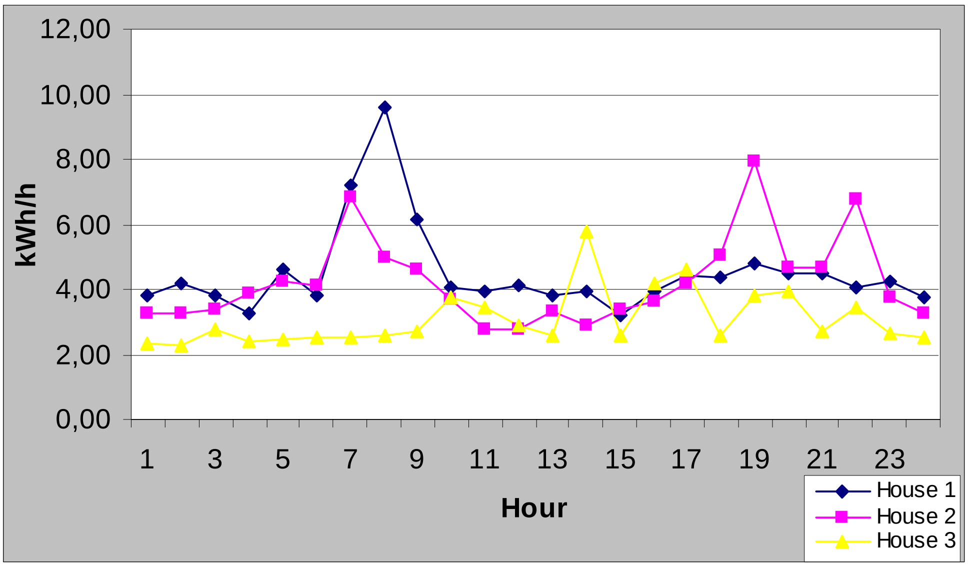

Figure 2.1. *Example of load demand variation in 3 detached residential houses in Southern Sweden during one winter day (Source: Skånska Energi)*

2.2.1 Load demand in Sweden

The load demand situation in Swedish electricity system is presented below. Hourly load data is essential while analyzing load questions. It was obtained from Svenska Kraftnät - the Swedish national grid operator. The data is presented in form of annual hourly load curve in Figures 2.2 and 2.3.

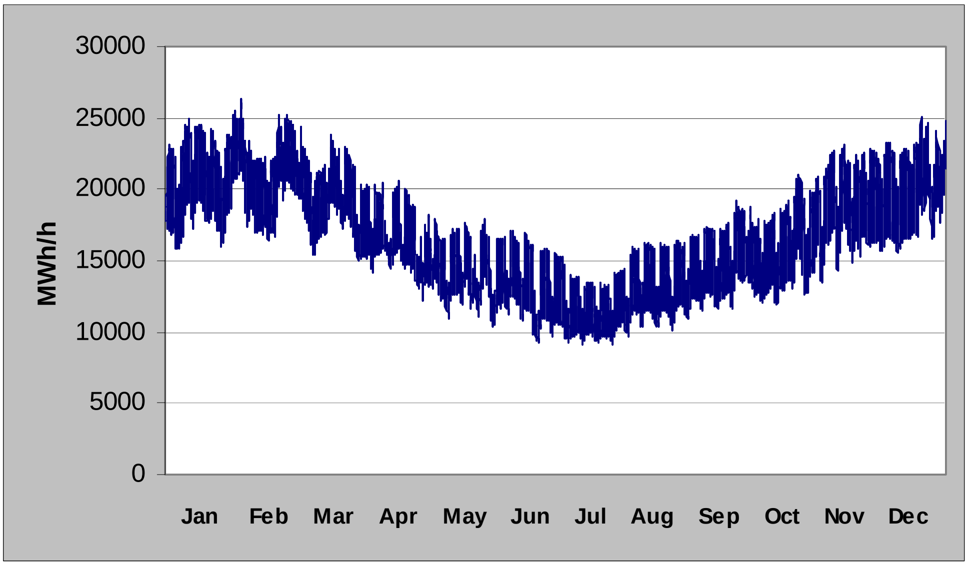

Figure 2.2. *Load curve for Sweden, 2001. (Source: Svenska Kraftnät)*

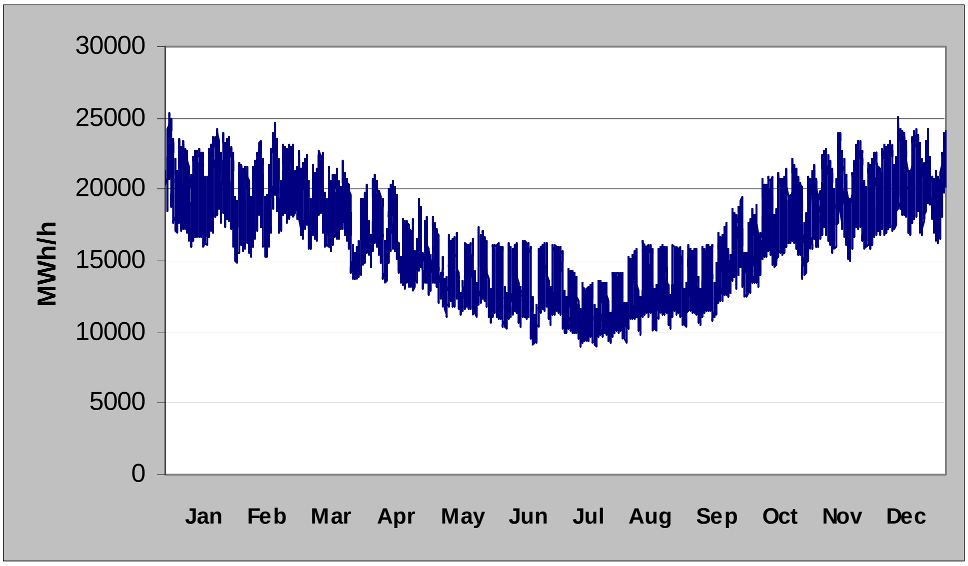

Figure 2.3. *Load curve for Sweden, 2002. (Source: Svenska Kraftnät)*

The curves for both 2001and 2002 show that the highest load demands and thus possible load problems occur in winter season. The key explanation for that is high electricity demand for heating in Sweden. The maximum load demand reached around 27GW and minimum was around 9 GW in 2001. So the difference between minimum and maximum load demand was around 18 GW. In 2002 this difference was approx 16,5GW (around 25,5 and 9 GW respectively).

2.2.2 Production and import sources to meet the demand

The data for the Swedish production mix is available only on weekly basis. The data for imported electricity, specified by the country of origin, is available on hourly basis. Svenska Kraftnät provides this information. Figures 2.4 and 2.5 define the hourly production and import to Sweden during the analyzed years.

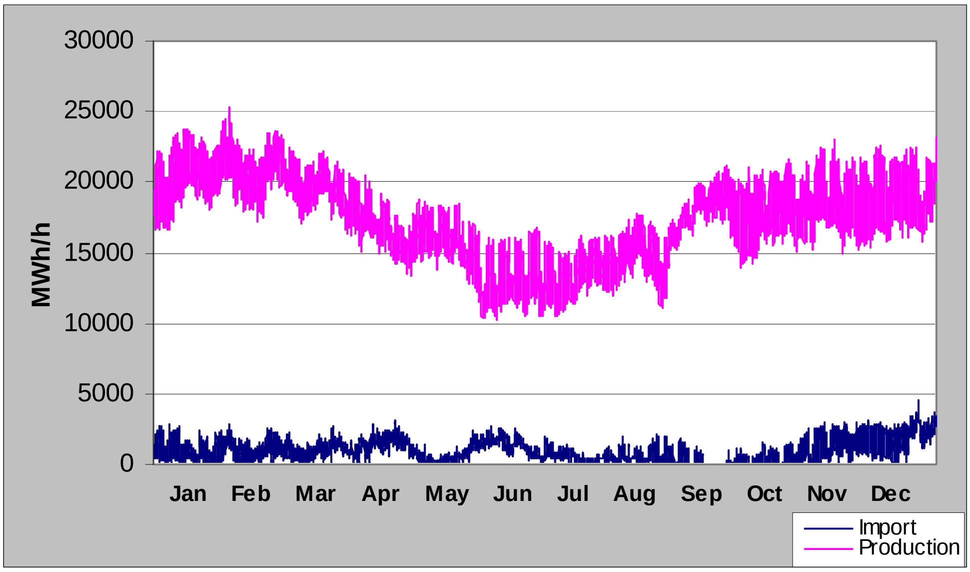

Figure 2.4. *Hourly production and import to Sweden, 2001 (Source: Svenska Kraftnät)*

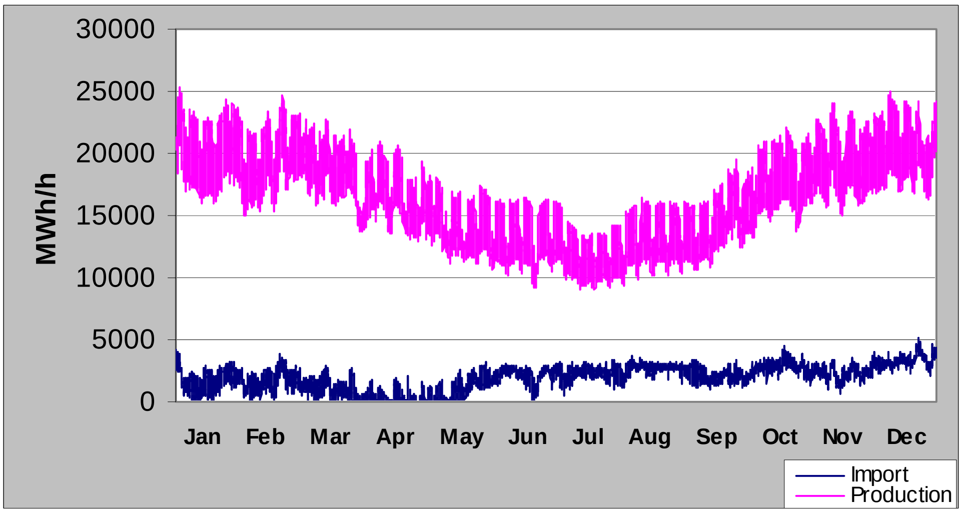

Figure 2.5. *Hourly production and import to Sweden, 2002 (Source: Svenska Kraftnät)*

The peak values during Nov – March can be explained by two reasons: 1 – full production, 2 – outdoor temperature. The bottom values by: 1 – outdoor temperature, 2 – vacations.

Import is higher and more constant during the second half of year 2002. The reason is very dry summer in 2002, which resulted in decreased hydropower availability. A wider discussion on these issues is in chapter 2.4 of this thesis.

Data availability (Sweden)

Since hourly load data is essential while analyzing load questions, different institutions were approached in order to obtain the required data. These primarily are the Swedish Energy Agency, Svensk Energi (Swedish electricity supplier's association) and Svenska Kraftnät (Swedish national system operator). The hourly data on the electricity consumption, total production and import to Sweden was obtained. Furthermore, the import data, provided by Svenska Kraftnät is specified according to the countries the electricity comes from. However the available hourly data does not specify the production sources neither for Swedish side nor the import, therefore it is impossible to say what are the production sources every hour. This kind of statistics is available only on weekly basis. One of the reasons that this kind of detailed statistics is not available is that the electricity producers at the moment are not obliged to provide it.

2.2.3 Load demand in residential sector

The residential, commercial and services sector accounts for half of the total electricity consumption in Sweden (Swedish Energy Agency, 2003). Electric space heating currently accounts for just over 30% of the total electricity consumption in the sector. Approximately 104TWh of heat was used in 2003 to heat homes and premises, of which district heat accounted for 45TWh and electric heating for 21 TWh (Swedish Energy Agency, 2003). High electric load demand variations occur in winter season together with temperature variation.

Detached residential houses in Sweden comprise large part of residential buildings stock. The dominating energy source for heating and domestic hot water for these houses is electricity.

The increased number and the variety of household equipment also cause risks for load shortages if used simultaneously. Even in the households with an alternative heating and hot water systems (district heating or natural gas), hourly load demand reaches very high values. Load demand in residential sector varies significantly during a day and normally has peaks during morning and evening hours.

2.3 Load problems

Inappropriate dimensioning of the network might restrict the possibility to cover momentary demand. For example, the Swedish power network is dimensioned on total energy need, which is not useful if load demand cannot be delivered on a momentary level. This is the most important reason for system blackouts (Pyrko, et al, 2003). Some parts of the network can form "bottlenecks", not capable to transmit the demand required.

As a consequence of the liberalization of the energy market, many energy generation plants have been decommissioned or preserved for economic reasons. One nuclear power reactor (Barsebäck 1) has been decommissioned. The amount of reserve capacity plants has dropped by about 3 GW, resulting in the margin between maximum load capacity and maximum load demand decrease (North, 2001).

Another important problem is uneven generation location. This problem becomes evident when studying the main areas of production and consumption of electricity in Sweden. The highest demand is located in southern Sweden, where the majority of Sweden's population resides. However, the most important areas for energy generation are located in the north of Sweden. This means that it is necessary to transfer electricity from the north to the south and even to buy electricity from other countries. The south of Sweden is highly dependent on load imports. This also causes bottlenecks within the transmission network (Pyrko, et al, 2003).

2.4 Load demand and emissions in Sweden

The aim of the following analysis is to define how (or if) load demand influences the CO_2 emissions in Swedish electricity system and discuss the possibilities of different load management measures to influence, improve the situation. Years 2001 and 2002 are used for the analysis. The analysis is performed in following steps:

- Identifying and defining the demand peaks
- Analysing the CO_2 emissions during the peaks
- Discussing different load management possibilities to decrease the emissions

Identification of the demand peaks

The first step in the analysis is the identification of the consumption peaks. The highest hourly peaks in years 2001 and 2002 are identified. These days and weeks of these days are selected for a further analysis. Load demand, production in Sweden and import according to the countries are defined in Figures 2.6 – 2.9.

According to the data, the highest peak in year 2001 was recorded on Monday, Feb. 5, 2001 (week Feb. 5-11, 2001).

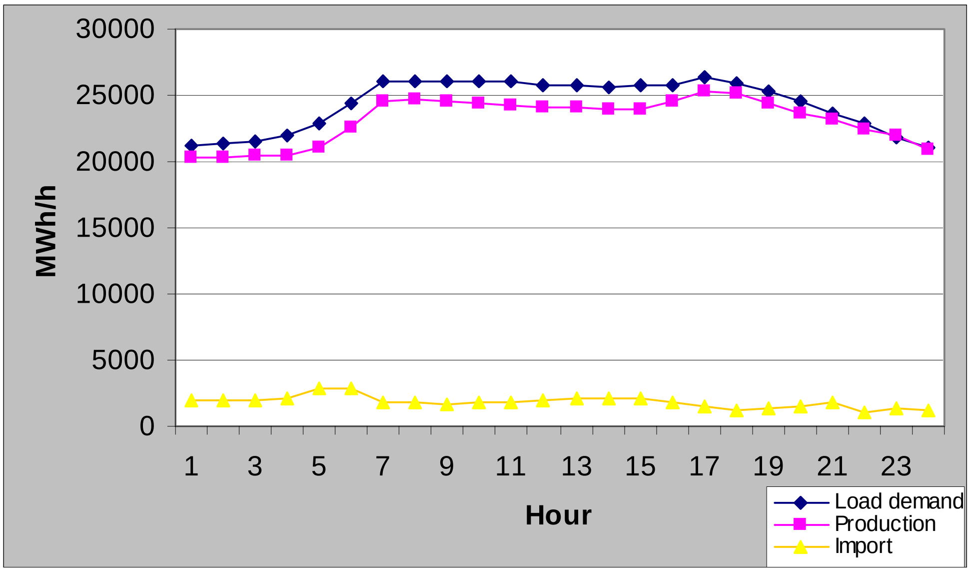

Figure 2.6. *Load demand, production and import to Sweden Feb. 5, 2001* (*Source: Svenska Kraftnät*)

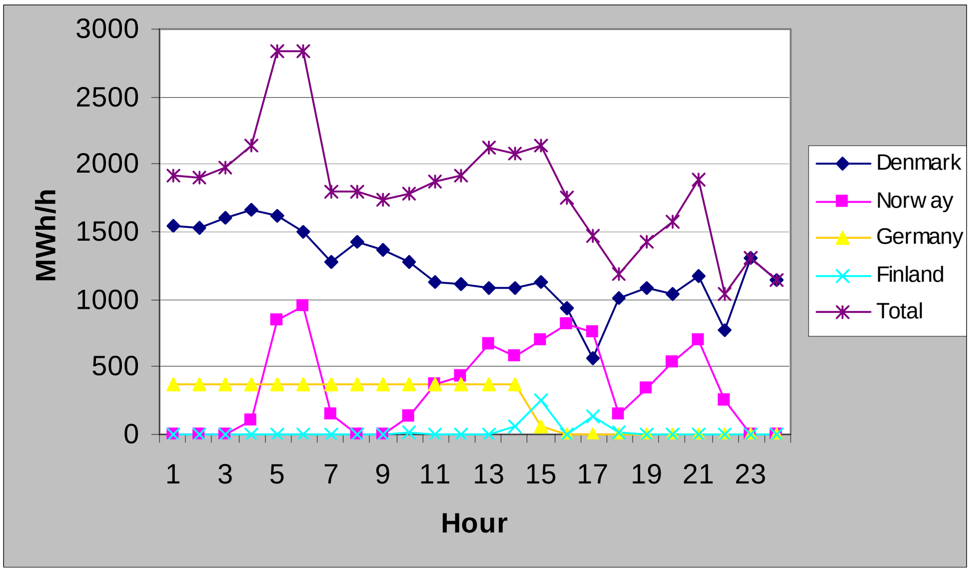

Figure 2.7. *Import structure Feb.5, 2001 (Source: Svenska Kraftnät)*

Figure 2.6 shows that the Swedish production follows the demand but not the import. In other words, import is not on the margin during the analyzed peak period. According to figure 2.7, where the import structure is defined, the import is highest during off-peak hours 3-7. Imports from Denmark and Norway are the major ones. At the beginning of peak period (hour 8) the import from those countries decreases. Import from Germany lasts continuously until the beginning of afternoon peak (hour 15).

One important factor while analyzing load questions is the difference in consumption patterns during weekday and weekend. The previously analyzed peak occurred on Monday.

In order to define the weekly situation the full week analysis is presented in Figures 2.8 and 2.9.

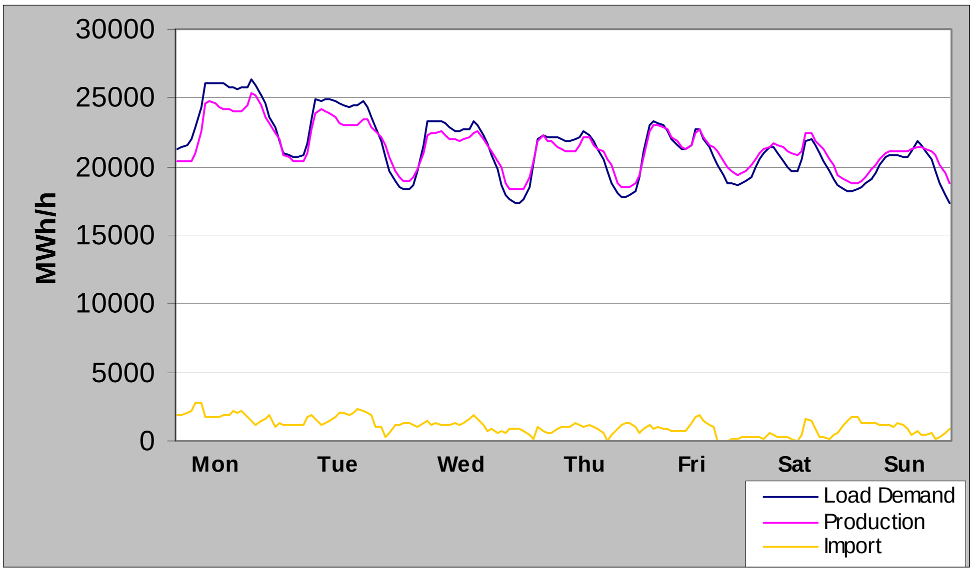

Figure 2.8. *Demand, production and import Monday, Feb. 5, 2001 - Sunday Feb.11, 2001 (Source: Svenska Kraftnät)*

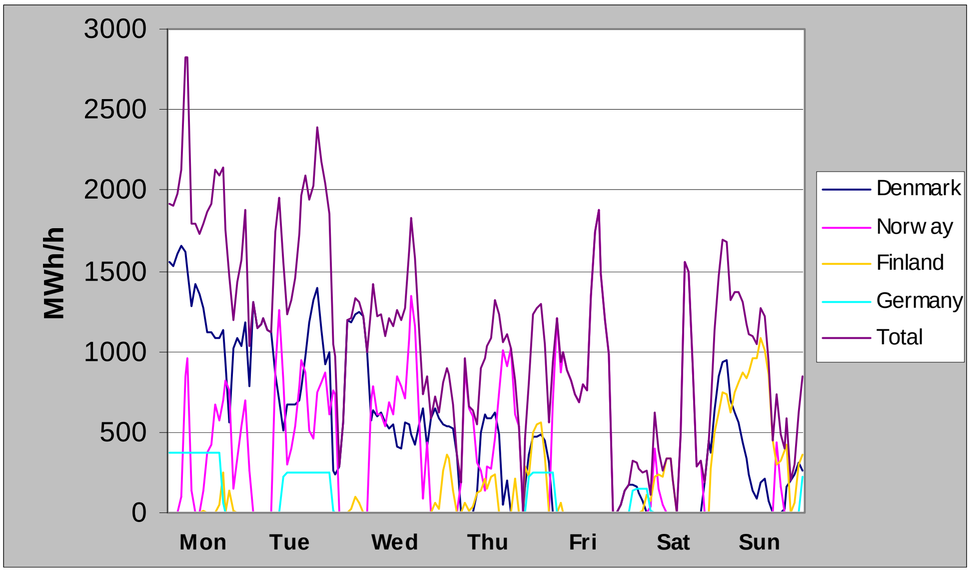

Figure 2.9. *Import structure Monday, Feb. 5, 2001 - Sunday Feb.11, 2001 (Source: Svenska Kraftnät)*

Weekend load shapes are slightly different from the weekday. The total demand is lower. The afternoon peaks compared to morning peaks are higher than on weekdays. Though the import pattern is difficult to compare some differences could be observed as well.

The highest peak in year 2002 was recorded in Wednesday Jan.2, 2002 (Dec.31, 2001-Jan. 6, 2002). The same analysis procedure as for year 2001 is repeated for this peak (as shown in Figures 2.10-2.13)

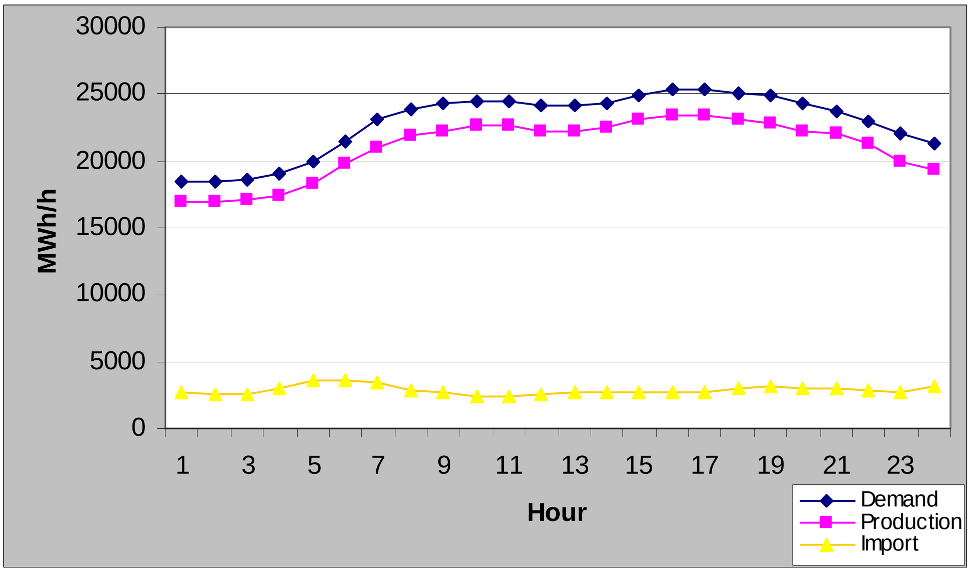

Figure 2.10. *Demand, production and import Jan.2, 2002 (Source: Svenska Kraftnät)*

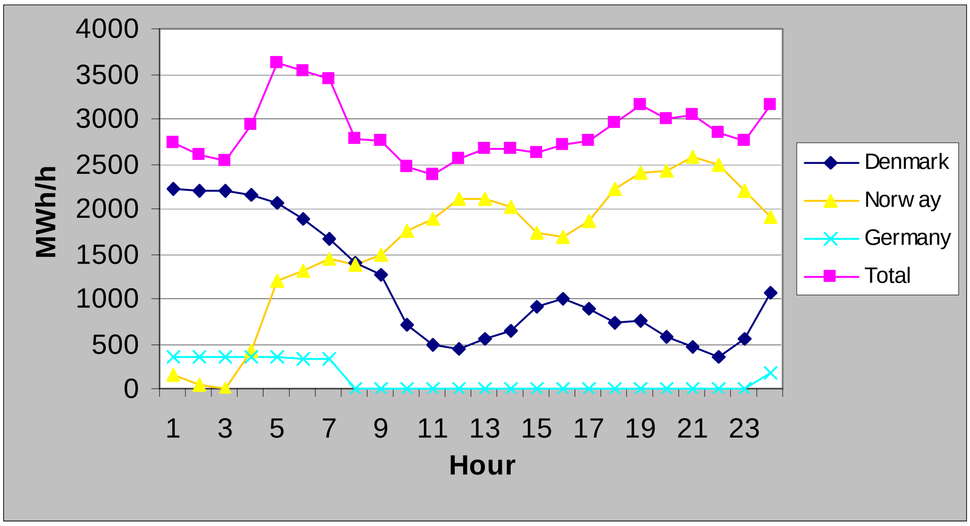

Figure 2.11. *Import structure Jan. 2, 2002 (Source: Svenska Kraftnät)*

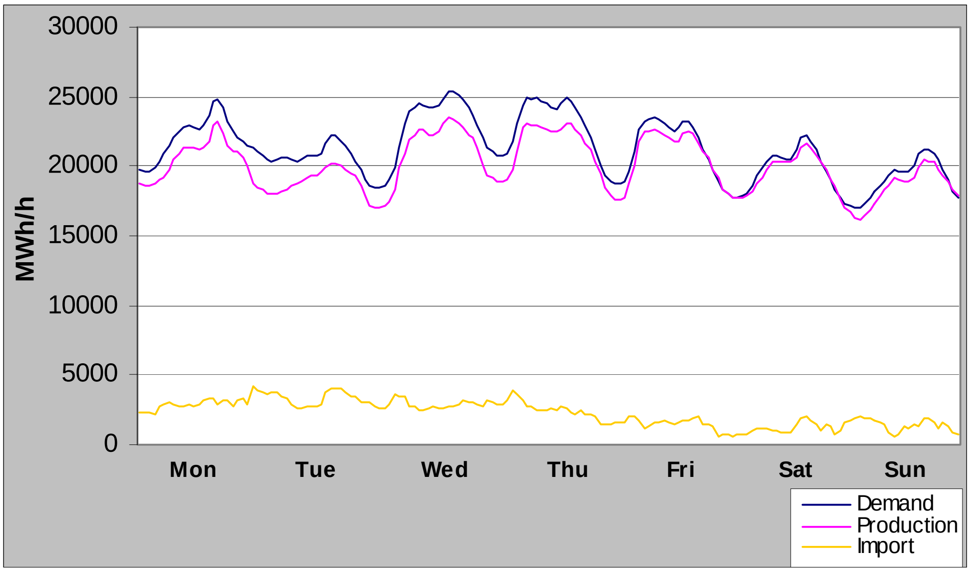

Figure 2.12. *Demand, production and import Monday, Dec. 31, 2001 – Sunday, Jan. 6, 2002 (Source: Svenska Kraftnät)*

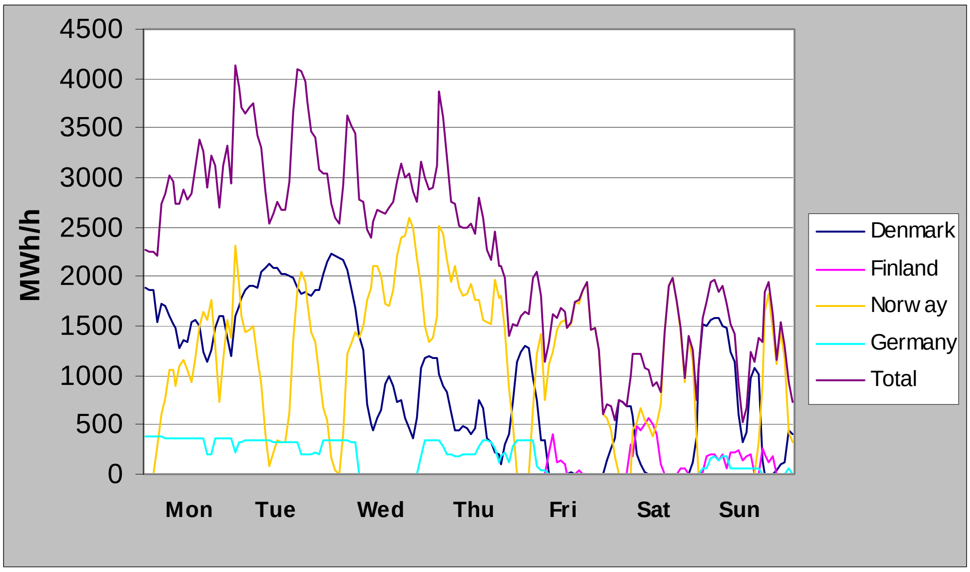

Figure 2.13. *Import structure Monday, Dec. 31, 2001 – Sunday, Jan. 6, 2002 (Source: Svenska Kraftnät)*

The curves in both analyzed peaks show that the import is not following the demand in a short run. The Swedish production is the demand following; the Swedish hydropower units that follow the demand (Swedish Energy Agency, 2002).

The results of this analysis could be compared with the results of the study performed by the Swedish Energy Agency, focusing on marginal power production and CO_2 emissions in Sweden (Swedish Energy Agency, 2002). By analyzing the historical data, the study concludes that in a very short run (hour to hour) hydropower responds to load changes. Hydropower production increases during morning and afternoon peaks and decreases during the nighttime. It is the most flexible technology in the Nordic system. Condensing power plants in Denmark and Finland to some extent also follow the daily demand.

Condensing power supply varies depending on hydropower availability. Hydropower in a longer term (over a year) depends on water availability. In case of dry year, the production in condensing power plants increases. First of all, the increase takes place in Danish power plants, but in Finnish and Swedish as well. The conclusion is that hydropower provides marginal capacity to ensure the load availability and the condensing power provides marginal capacity to ensure energy availability (Swedish Energy Agency, 2002).

CO_2 emissions from electricity production

The next step in the analysis is to define what are the CO_2 emissions per MWh of produced electricity in Sweden and in the exporting countries. Swedish Energy Agency (STEM) publishes the data for Nordic countries (Swedish Energy Agency, 2003). The data for Germany and Poland was received from the corresponding institutions in those countries. All the data is compiled in the Table 2.2. One important shortage of this data is that it is not reported on an hourly basis what production units are employed in each and every country. This is an average annual data. In further calculations it is assumed that every hour the same production mix is used and the emissions are the same

Table 2.2. *Average CO_2 emissions from electricity production (kg/MWh) in Sweden and countries that export to Sweden (sources: Swedish Energy Agency 2003, NAPE 2003, IER 2003)*

Country	Sweden	Norway*	Denmark	Finland	Germany	Poland
CO_2 Emission (kg/MWh)	12	0	361	170	588	1242

*Electricity in Norway is produced entirely in hydropower plants

CO_2 emissions for the analysed peaks are calculated in following way:

$$e_{CO_2} = \sum \left(E_i * e_{CO_2,i} \right)$$

Where:

E_i – production or import of country *i,* [MWh]

$e_{CO2,i}$ – average CO_2 emissions from electricity production in country *i*, [kg/MWh]

During the analysed peaks the following countries contributed to electricity supply in Sweden: Norway, Denmark, Germany and Finland. There was no import from Poland during the analysed peaks. As mentioned previously, electricity in Norway is generated entirely in hydropower plants without CO_2 emissions.

The relation between power consumption and CO_2 emissions during the analysed peaks is presented in the Figures 2.14-2.17:

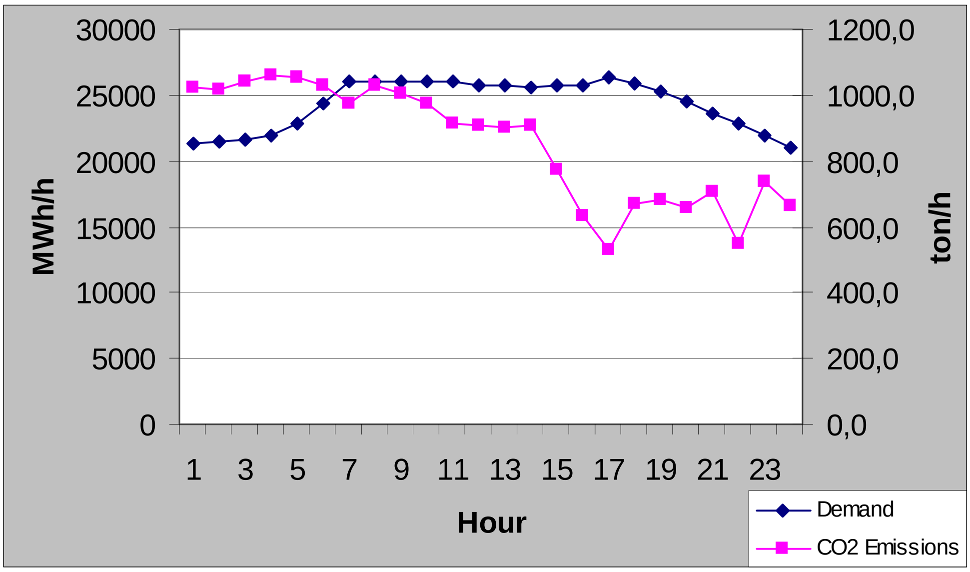

Figure 2.14. *Demand and CO_2 emissions Feb. 5, 2001*

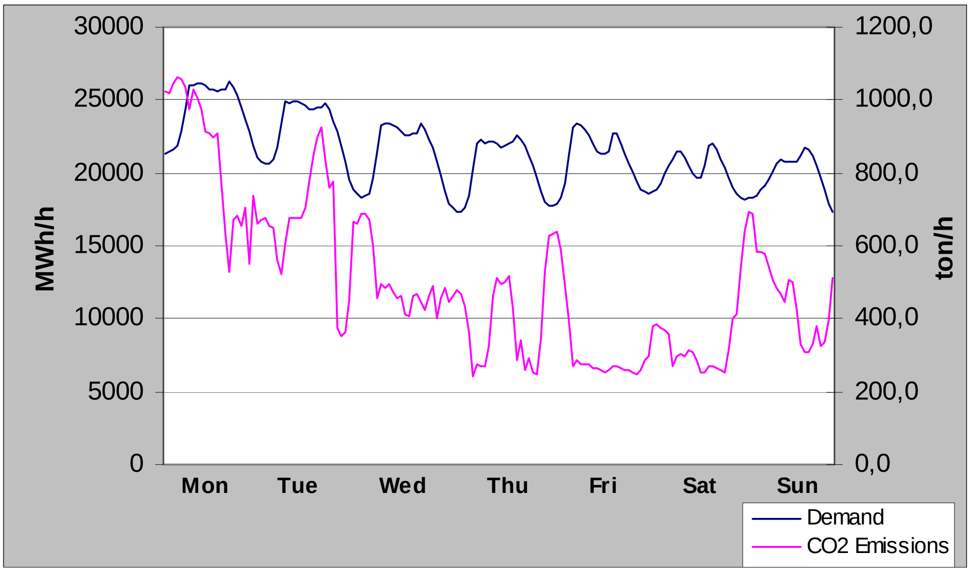

Figure 2.15. *Demand and CO_2 emissions Monday, Feb. 5, 2001 – Sunday, Feb. 11, 2001*

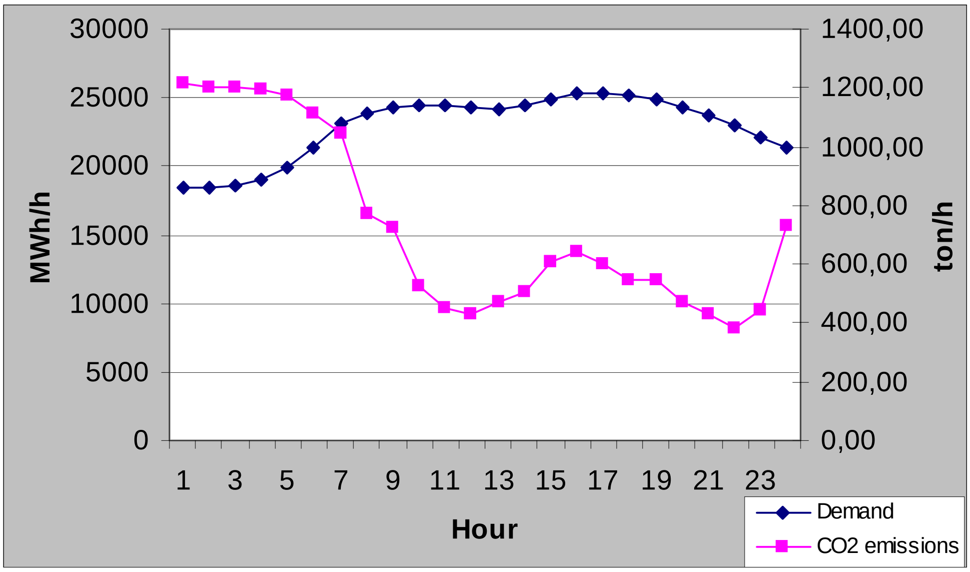

Figure 2.16. *Demand and CO_2 emissions Wednesday, Jan. 2, 2002*

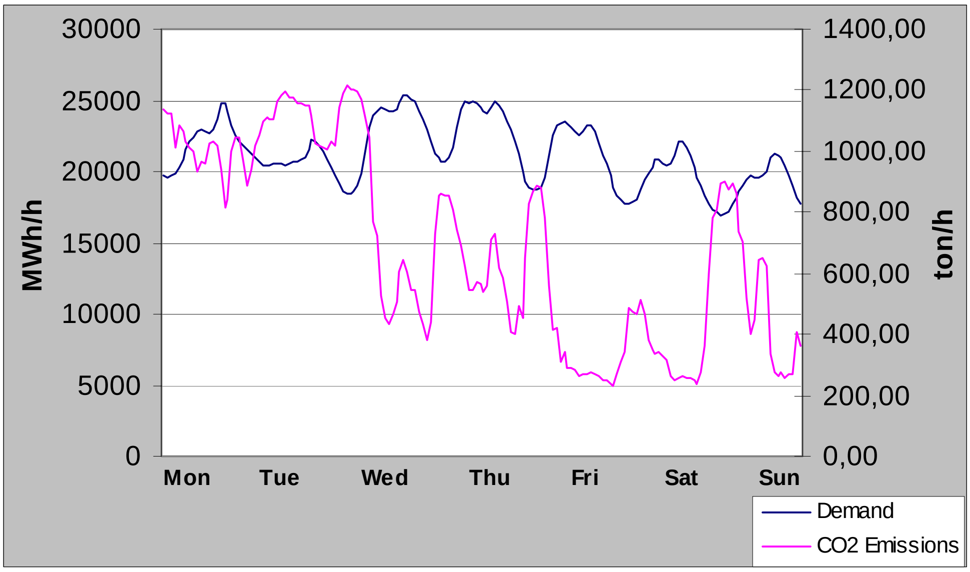

Figure 2.17. *Demand and CO_2 emissions Monday, Dec. 31, 2001 – Sunday Jan. 6, 2002*

CO_2 emissions from the power consumed in Sweden originate in principle from the imported electricity. In Denmark, Poland and Germany, a great part of power is produced in coal condensing power plants. It means that when the import from these countries increases, the CO_2 emissions increases as well (Swedish Energy Agency, 2002).

The main source of CO_2 emissions in Swedish system is from the power imported from Denmark, one of the major exporters of electricity to Sweden. While comparing Figures 2.7, 2.9, 2.11 and 2.13 with 2.14, 2.15, 2.16 and 2.17, it could be seen that CO_2 emissions curves in every case follow the curves of import from Denmark. An obvious way to decrease the emissions seems to be the decrease of import from Denmark.

As the graphs show, there is no direct relation between load demand and emissions. The reasons for that most probably are economic, and the import sources are selected according to the best economic decision. The cheapest power on the market is purchased. During the morning and evening peaks the hydropower is used, which is most flexible technology and at the same time results in no emissions. That is why the emissions are higher during off-peak periods (nights) when more power is imported.

2.4.1 Considering the environment when meeting the load demand

According to Svenska Kraftnät (Swedish national grid operator), 3 basic factors define the nationwide actions when ensuring load demand on peak conditions – price, long term contracts and bottlenecks in the grid. The operator seeks for cheapest sources on the market without considering the type of production. Long-term contracts with other countries oblige to export the electricity even if there is a shortage within the country. That is why sometimes there is both import and export at the same time. Bottlenecks on the grid in peak conditions sometimes restrict the use of desirable source. This problem also often occurs within the country since the major production units are located in the north of the country and the highest demand is in the south (Svenska Kraftnät, 2004).

Thus the economic and energy security factors play the greater role than the environmental when purchasing the electricity. This conclusion could also be drawn from the analysis above. Having a lower load demand, the Danish power is being purchased instead of continuously using the hydropower plants. The latter is preserved for the peak periods when the prices go up.

All Nordic countries levy taxes on electricity at consumer level. The taxes are differentiated for domestic and industrial consumers (Swedish Energy Agency, 2003). However, the taxes are not differentiated according to the power source, i.e. the customer pays for kWh used, without distinguishing the production source.

3. Load management

3.1 Facts, definitions and strategies

Load management is defined as sets of objectives designed to control and modify the patterns of demands of various consumers of a power utility. This control and modification enables the supply system to meet the demand at all times in most economic manner (Paracha, Doulai, 1998). The purpose of load management techniques is to reduce peak demand to level daily, seasonal or annual electricity demand. The techniques help to economize system operation by making best use of its available generation and transmission (network) capacity. Thus it is also divided to **network** and **generation** load management, depending on the prevailing need in a system (SEDA, 2003):

> ***Network Load Management****, includes activities that reduce the peak demand on the electricity network, thereby deferring or avoiding the need to augment the network.*
>
> ***Generation Load Management****, includes activities that reduce the peak demand in the generation market, thereby avoiding the need to call on the most expensive electricity generators and deferring the need to build new power stations.*

Load management does not aim to decrease the overall electricity consumption, rather approaches (or replies to) the consumption pattern. That is the key difference between load management and energy conservation. Load management strategies are designed to either reduce or shift demand from on-peak to off-peak times, while conservation strategies may primarily reduce usage over the entire 24-hour load period (PG&E, 1985). Load management measures could be applied both on energy demand and on supply sides.

The typical and probably the most widely applied load management strategies are peak clipping, valley filling and load shifting. Gellings (1993) and Bellarmine (2000) emphasize 6 load management strategies (see Figure 3.1). In addition to the 3 mentioned there are also strategic conservation, strategic load growth and flexible load shape.

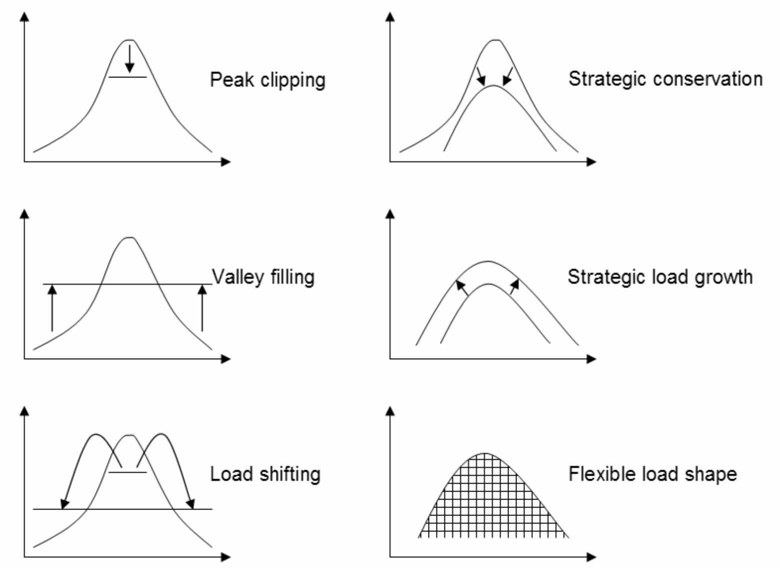

Figure 3.1. *Load control strategies (Gellings, 1993).*

The strategies showed in Figure 3.1. could shortly be described in following way:

- Peak clipping – reduction of load during short usage peaks
- Valley filling - building loads during the off-peak period
- Load Shifting - combines the benefits of peak clipping and valley filling by moving existing loads from on-peak hours to off-peak hours
- Strategic conservation – decreasing the overall load demand by increasing the efficiency of energy use
- Strategic load growth - increased electric energy use either to replace inefficient fossil-fuel equipment or to improve customer productivity and quality of life
- Flexible load shape – specific contracts with possibilities to flexibly control customers' equipment

3.1.1 Load management on supply and demand side

Supply-side load management means the measures taken at the supply side to meet the demand. The concept has been very popular in the seventies of the twentieth century. If the society demanded more power, the power companies would simply find a way to supply users even by building more generation facilities. This was the essence of the concept. However, the supply-side management nowadays also includes energy storage technologies, such as pumped hydro, compressed air energy storage and thermal storage.

Demand-side load management describes the planning and implementation of activities designed to influence customers in such a way that the shape of the load curve of the utility can be modified to produce power in an optimal way. Peak clipping and load shifting from peak to off-peak periods techniques are used to achieve these purposes. Demand side load management includes not only technical or economic but social measures as well, since it is directly related to the behavioral issues.

3.1.2 Load management – direct and indirect

Load management measures are both **direct** and **indirect**. Direct load management (control) is based on technological measures and controls the load demand by directly switching different equipment on or off. Satisfactory service can be maintained without the continuous use of electricity. For instance, water at a satisfactory temperature can be supplied from a previously heated tank.

> *" If the value of the intensive parameter is maintained, e.g. shower temperature, then the consumer is satisfied even if electrical supply is interrupted. Such demand that is satisfied by intermittent power is an interruptible load, also called switchable load"* (Twidell, 2003).

Modern communication technologies are used nowadays to implement load control measures.

Indirect load control is based on economical measures. Different tariffs and pricing mechanisms are introduced in order to encourage customer to optimize load demand. Most common examples could be Time-Of-Use (TOU) tariff, Interruptible Load tariff and tariff with Load Demand Component.

TOU or real-time pricing is designed to reflect the utility cost structure where rates are higher during peak periods and lower during off-peak periods. Both the supplier and the end-user benefit from successfully designed TOU rates.

Interruptible Load tariff offers an incentive rates for the customers, which they get if they interrupt or reduce the power demand during the system peak period or emergency condition. The customers sign an interruptible load contract with the utility to reduce their demand as and when requested by the utility.

Tariff with Load Demand Component is a new electricity tariff with differentiated grid fees based on a mean value of the peak load every month.

3.1.3 Other measures contributing to load optimization

Energy efficiency

Implementation of energy efficiency measures can also contribute to the decrease of demand peaks. For example, use of efficient lighting bulbs would both decrease the energy use and load demand. Energy efficiency measure in this case could be considered as load management measure. Often, when discussing load issues, energy efficiency is named as a strategic conservation. In strategic conservation, utilities adopt focused programs to encourage efficient energy use to reduce demand not only during peak hours, but also at other hours of the day; this can reduce average fuel cost and can postpone the need for future utility capacity addition (Bellarmine G, 2000).

Source switching

Here, a good example could be a conversion from electricity to other heat source, especially district heating. This measure significantly reduces the total electricity use at a household and its dependence on outdoor temperature. Electric heating is the most common source of heat in detached houses, while district heat predominates in apartment blocks. About 8% of the detached houses in Sweden are connected to district heating today (Swedish Energy Agency, 2003).

District heating in detached house areas, is often impaired with problems of low heat density, large heat losses and high construction costs. However, due to the changes on the electricity market (increasing electricity prices), increased environmental concerns and technological improvements, the detached houses' sector is a potential market for district heating.

Distributed Energy Options also contributes to load optimization. The Distributed Energy Options include both supply side and demand side measures. Distributed energy primarily refers to (SEDA, 2003):

- *energy that is generated by or close to the end users of energy within the low voltage distribution network*
- *energy saved by the end user through energy efficiency activities and changes in consumer behavior (load management)*

Many experts forecast a rapid expansion of the Distributed Energy Options in future (SEDA, 2003). This is primarily due to several reasons, such as the development of generation technologies, gradually requiring lower investments, the penetration of IT technologies and energy security.

3.2. Different actors and their perspectives

Customer, utility, producer and state are the main actors involved in load management processes. The aim of the following section is to define what aspects of load management are more or less important for each actor (customer, utility, producer, grid operator and, finally, society).

Customer (residential)
Social and economic aspects are of the major importance here. Load management to some extent means adjusting your behavior to the performance of electricity system, i.e. decreasing or increasing the use of electricity during specific periods. Load management (for exp. time-of-use tariffs) could help to reduce the electricity costs. Decreased fuse level is a

way to decrease network costs, but this, in turn, might limit the possibility to use many of the household's equipment at the same time. From the technical point of view the optimal use of load demand could help to avoid the unexpected fuse problems.

Utility

Since the re-regulation of the electricity market, electricity trading and network services have to be provided by different legal entities. Therefore when trying to identify the interests in load management it is important to consider that these may be different in **retail** and in **network** company.

For a retail company it is principally the economic issues that matter. Everything depends on the contracts the company has with a producer/supplier and with a customer. During high peak periods, in cases when the utility has to purchase power on spot market, there is a risk to get financial losses.

For the network company there could be both technical and economic aspects. As a technical problem it is usually a limited network capacity, occurring during peak demand (Nordvik, Lund, 2003). A typical economic problem could be the penalties for exceeding the subscribed load levels.

Load management also could be a way for a utility to fulfill goals established by environmental certification programs (e.g. ISO 14001)

Producer

Technical, economic and environmental aspects could be addressed with help of load management. Technical, as well as economical benefits of load are the optimal operation of base production units, avoided operation of peak units and avoided (or postponed) the generation capacity addition. By avoiding using peak units, such as diesel generators and gas turbines, which are the most polluting ones, a producer could improve its environmental performance.

Grid operator

National Grid operator is responsible for stable and non-interruptible operation of power system on National level. The operator aims to ensure it with lowest costs. Technical and economic factors therefore are most important on this level.

Society

Society demands to ensure stable and non-interruptible nationwide electricity supply with least adverse environmental, social and economic impact. Therefore in this level all aspects of load management (technical, economic, environmental and social) are important.

Different interests in load management are summarized in Table 3.1. An important conclusion is that the interests in load management differ depending on the perspective of the actors involved. Therefore it is vital to clearly identify these perspectives in order to achieve successful load management actions.

Table 3.1. *Summary of interests in load management*

	Customer	Utility		Producer	Grid operator	Society
		Retail company	Network company			
Technical	Avoiding fuse problems		Avoided network capacity problems	Maximum use of base (and cheapest) production units Avoided production capacity addition	Stable operation of power system on National level	Stable operation of power system on National level
Economic	Lower electricity costs Lower network costs due to lower fuse level	Lower risk when purchasing power on spot market	Lower demand subscription fees. Avoided investments in the network	Lower production costs	Stable operation on lowest costs Avoided/postponed investments in the network	Economically sustainable electricity supply. Maximum reliance on local production
Environmental	Avoiding peak power plants nearby living area	Fulfilling goals established by environmental certification programs	Fulfilling goals established by environmental certification programs.	Avoided use of peak units (e.g. diesel or gas turbines) – which result in high emissions	Avoided new network construction	Least possible environmental effects
Social	Service compatible with the social activities					Power accessibility and equal conditions for all members of the society

4. Direct load management in residential houses

The aim of the following analysis can be divided into 4 parts:

1. To identify and describe the load management needs, prerequisites and possibilities at Skånska Energi AB.

2. To analyze the collected data on total and partial load demands for 10 selected households in Södra Sandby

3. To apply load management in experiments direct load control with the following purposes:
- To test the technical possibilities of direct load control with the system, available at the utility (CustCom) and customers' equipment
- To estimate what load savings could be achieved
- To estimate how would it affect indoor climate and comfort conditions for the customers
- To estimate how would it affect hot water availability

To analyze the results of the performed direct load control experiment at 10 selected households from both households' and utility's perspective (primarily focusing on load savings and effects on households' comfort conditions) and to discuss the technical and economic pros and cons of direct load control.

4. To analyze the reduction of environmental impact by load management

4.1 Skånska Energi and its needs

4.1.1 The utility

Skånska Energi AB is an electricity utility, located in the south of Sweden, Skåne. The utility has 16 500 customers, of which 99 % are residential customers (about 53% of the electricity sale). Skånska Energi also serves industrial companies, agricultural properties and schools (about 47% of the electricity use). About 1700 customers (10%) belonging to this grid area purchase their electricity from other energy utilities.

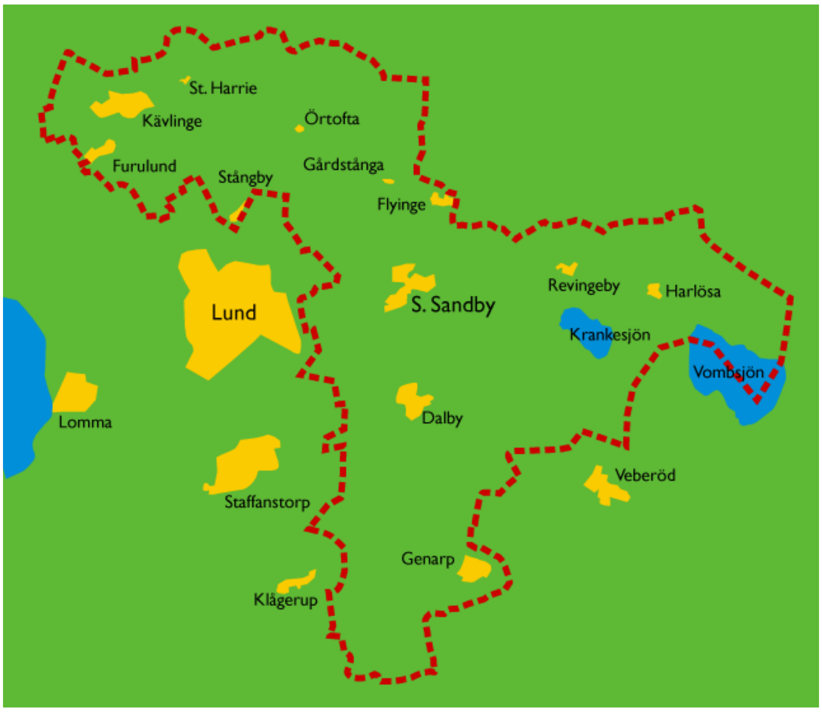

Figure 4.1. *Skånska Energi network area*

Skånska Energi AB consists of two subsidiary companies - the grid company Skånska Energi Nät AB (SENAB) and the trading company Skånska Energi Marknad AB. They are legally bound to be two different entities.

Skånska Energi has adopted a minimal risk policy – it means that the company tries to secure its costs by contracts with fixed prices. Therefore, they choose not to buy electricity on the spot market.

It is also important to mention that Skånska Energi is certified according to ISO 14001 since November 2000 (Skånska Energi, 2004).

Electricity purchases

Historically, Skånska Energi has always had **one** electricity supplier – Sydkraft. But since Jan 1, 2003 the contracts with Sydkraft are gradually being phased out (finished by year 2006) and new contracts are signed with Vattenfall. The different contracts with Sydkraft have different validity, which means that over some period of time, Skånska Energi is having two distributors.

Earlier contracts with Sydkraft have included a fixed price, often based on a season pricing (winter 1, winter 2, summer and so forth – the same as on the spot market). The earlier contracts have worked with a "rubber band" principle; if the electricity demand is larger than the contracted volume, the price for the exceeding part is still the same. If the demand is below the contracted level, the price for the used electricity is also the same.

The reason why Skånska Energi wants to change its distributor is that Sydkraft no longer wants to sign contracts with the “rubber band” principle. Instead, the exceeding amount of electricity would be purchased at the spot market. Vattenfall has nevertheless agreed to sign a contract that guarantees stable, and therefore predictable, electricity prices (“rubber band”).

As Skånska Energi does not purchase power from the spot market, there is no link between spot price and load management. As the Skånska Energi’s power supply contract looks like today, there is no interest for load management from the **electricity trading perspective**. The price of electricity would be the same no matter what the demand is.

Grid contracts

Skånska Energi has to pay high load demand subscription fees to Sydkraft, that owns the regional grid in the area. The contracted load for year 2002 and 2003 was 76 500 kW. There are two tariffs, depending on the connection area - 265 SEK/kW (Furulund area) and 136 SEK/kW (Södra Sandby and Önneslöv areas).

Load tariffs

Customers are paying for the electricity according to their contracts with Skånska Energi. Differentiated tariffs were abolished when the billing system became integrated with the CustCom system (May 2002), i e when customers begun to pay for used electricity instead of preliminarily calculated. Few customers have special contract conditions due to their very specific energy demand during different time periods (e g agricultural customers with crop drying during in summer).

Tariffs with load component are of course of interest for the company, due to previously mentioned load management aspects. Load tariffs should reflect the cost of extra load demand that Skånska Energi has to pay to its supplier. Today, there is no cost for customers to demand higher load from the grid. This cost should be shared with the company, especially in case of load shortages. On the other hand, customers “helping” to avoid load peaks in the grid should be rewarded in some way through the tariff.

An important condition for Skånska Energi to introduce such a load based tariff, is direct load control possibility in the supply system. It has to be secured that the load demand will decrease when needed - to rely on customers' will would be too unreliable.

Other ways to lower the total load demand could be installation of heat storage systems or heat pumps. Those concepts are investigated by the utility.

4.1.2 Load problems

Load problems occur during peaks in winter time. Load demand is especially sensitive for weather changes, as the majority of Skånska Energi's customers have electrical heating. Daily peak demands (during morning and evening hours) together with higher heat demand due to outdoor temperature drop, cause risk to exceed the subscribed load for the company.

In case of exceeding the subscribed load, Skånska Energi has to pay high penalties to Sydkraft, especially on weekdays, when it is the double tariff for every exceeded kW (530 SEK/kW and 272 SEK/kW respectively). Hence, from the **grid cost perspective,** there is an obvious interest in load management for the company - to be able to guarantee not to exceed the subscribed load level.

From technical point of view so far there's no problem with load as the utility's net has a sufficient distribution capacity.

Load management therefore is considered as a solution of economic problem, under current circumstances occurring during heating season. According to SENAB, the problems usually occur on weekday mornings and holiday (weekend) afternoons.

It should be also noted that for a utility it is an average 1 hour load that matters. Momentary load within 1 hour period could be higher, but it is important that the hourly average does not exceed the subscribed load level. The momentary load fluctuations on the higher grid level therefore become very significant at the end and the beginning of every hour when the utilities are applying different solutions in order to stay below the subscribed load level. These fluctuations might cause the stability problems in the national grid.

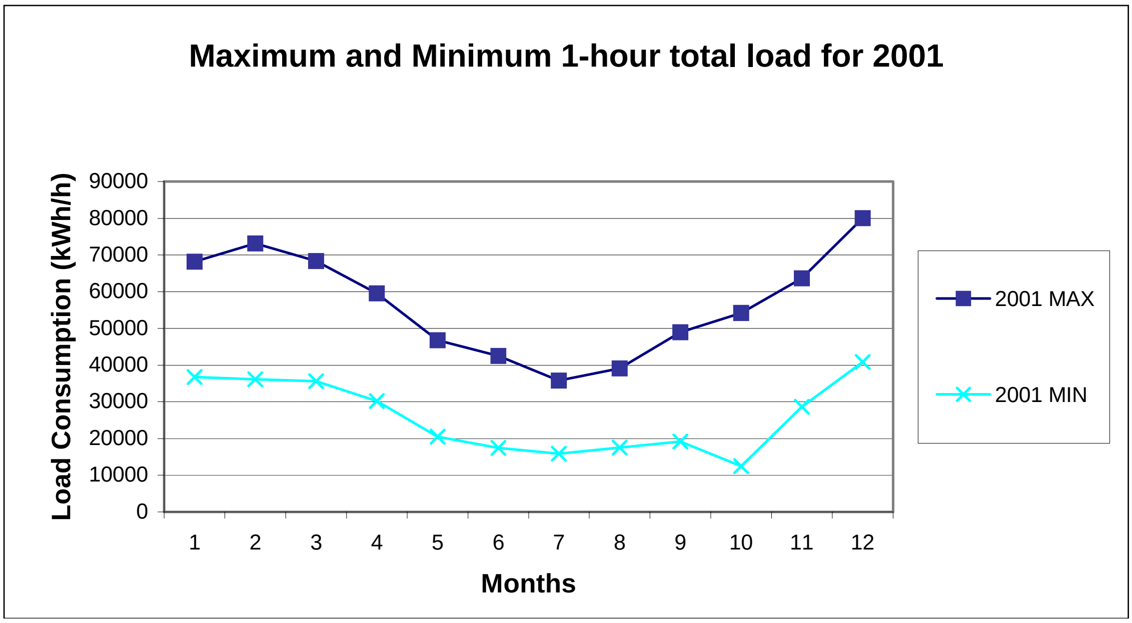

Figure 4.2. *Skånska Energi's load curves - example for year 2001*

4.1.3 Alternatives to solve load problem

There is a clear economic interest in Skånska Energi to decrease grid costs, or at least avoid possible penalties. The utility considers two alternatives:

1. To apply load management

Within this alternative there are two possible solutions:

a) Indirect load management. Skånska Energi has considered introducing an electricity tariff with load demand component. A comparative study was done in order to see what the effects would have been if the tariff with load demand component from another utility would be applied at Skånska Energi (Perez Mies, 2002). The results showed that it could be a way to improve the customers' consumption patterns and some of the customers would have had a better load profile, however, for the utility in general it would not have been a financially beneficial tariff. Higher benefits would have the customers gained. Another disadvantage of this measure is that the utility still cannot be sure that the customer would improve the consumption pattern. It still depends on customers will. Therefore Skånska Energi considers the introduction of direct load control measures as more reliable ones.

b) Direct load control. Direct load control with a help of CustCom system, which is described in chapter 5.1.4.

2. To install diesel peak power plant

Skånska Energi considers the installation of 2-3 generators with a capacity of 4 MW each. The used diesel engines from ships are being considered to drive the generators. The plant has to be located closely to the users. The power plant is planned to be used during peak hours, when a risk to exceed the contracted load occurs. In addition, the utility is going to reduce the contracted load by 6 MW and thus save money.

4.1.4 Load management system

Communication

Advanced metering system "CustCom" is installed to all Skånska's residential customers. The system provides automatic hourly measurements (it can even measure with shorter periods - down to 1 minute), as well as electricity control and information services.

The architecture of a complete system typically incorporates three main items; namely customer based terminals, intermediate stations and a central controlling unit located at the utility. Connecting these items are two-way communication signals, that transmit the information to and from the customer's terminal and the utility by the use of either radio, GSM, fibre or control cable. The information that is transmitted includes meter readings, various control signals and additional features such as alarms. Figure 4.3 shows this arrangement (North, 2001).

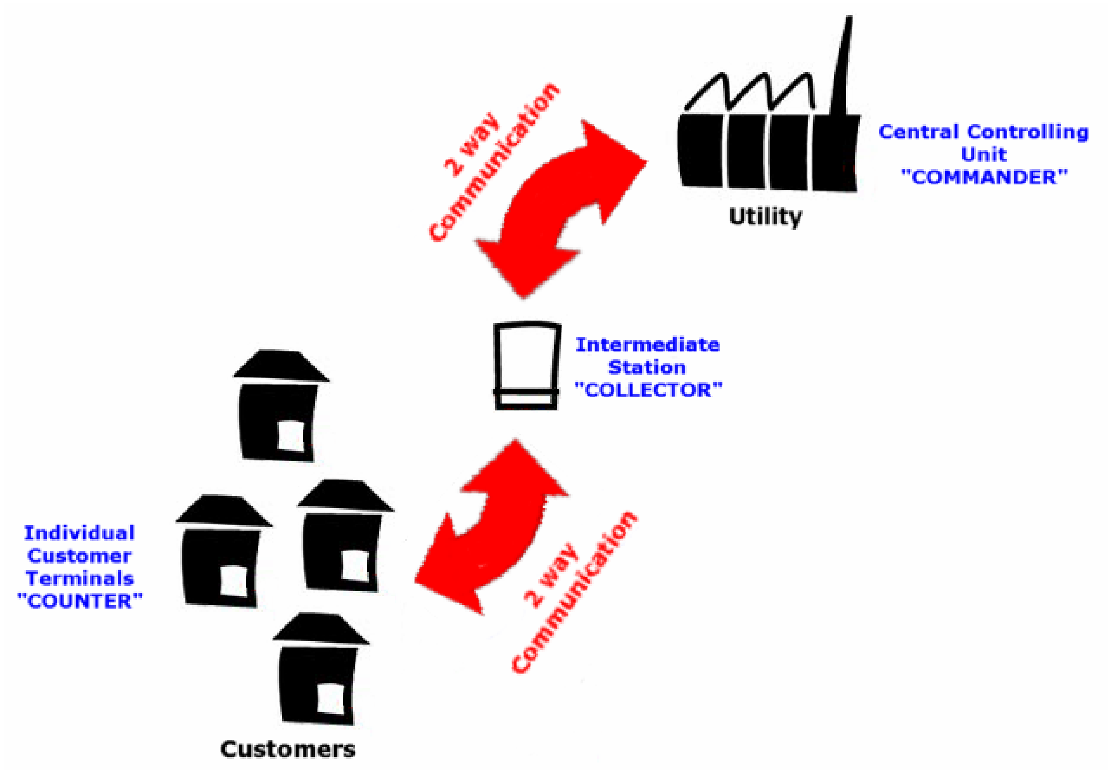

Figure 4.3. *CustCom's Typical System Architecture (North, 2001)*

Control

The CustCom system provides several technical possibilities to control load, such as cyclic control of devices, "object" control, manual "broadcast" control.

Counter 1000, one of the constituent units of CustCom system, could be extended with the additional card, which increases the functionality of the unit and creates the possibility to control load for a specific devices (objects). “Object” control gives the system operator four manual control possibilities (North, 2001):

- Manual “once only” control on a single relay at a single customer site
- Once daily timer control
- Timer (3 events per day) control
- Control signals to mirror the customers electricity tariff changes

This binary relay signal acts on a single fuse of the households electrical system.

A manual “broadcast” control signal gives the system operator the ability to send a binary relay signal to a specific channel, therefore instantly reducing the loading on the electricity network. A channel is defined as a group of customers within the utility that can be any number in size and can be created on demand (North, 2001).

More detailed technical description of the CustCom system could be obtained in the report of the division of Energy Economics and Planning “Residential Electricity Use and Control” by Greg North, 2001.

4.2 Load management experiment objects

4.2.1 10 households

This study focuses on 10 households in Södra Sandby, Southern Sweden. All are the customers of Skånska Energi. The households were selected based on the energy survey, performed by the research group for Load Management in Buildings, division of Energy Economics and Planning in year 2001. The primary idea was to select the identical households, however, the variety of different technical and social aspects made this idea impossible. Customer willingness to participate in this kind of study puts the also limitations to select very similar households. Each household therefore is analysed as a separate case. An attempt to generalize the results is given, however, it is quite complicated due to the variation of such factors as:

- **Demographic composition of the households**
  The composition of five households (H1, H2, H4, H5 and H6) is two persons, the composition of three households (H7, H8, H9) is three persons, one household with four persons (H10) and one household (H3) with one person only

- **Behavioral patterns**
  The occupants are of a different age and background.

The social and behavioral issues are deeply analysed in another part of this project, performed by Kerstin Sernhed.

- **Size and type of the house**

7 of the analysed houses are detached houses and 3 are semi-detached houses. The age of the houses is quite similar, since all were built in the period between 1964-1978. Some of the houses, however, were extended in the later years. The living area varies from 95 m^2 to 300 m^2. The houses are also of different levels (from one to two storeys). One of the houses (H5) have a basement, which is used as living area.

- **Construction of the house**

The dominating construction type of all houses is brick with wooden frame or light concrete frame. In most of the houses the attic insulation was improved after the construction.

- **Type of heating and hot water system**

Four of the houses (H1, H2, H3, H4) have waterborne systems with electric furnaces, while other six (H5, H6, H7, H8, H9 and H10) have direct electric resistive heating. H2 also has a heat pump.
Hot water preparation boilers work as separate units in all of the houses except H2 and H4 where it is integrated in the furnace.

All the households were visited and interviewed.

Installation of meters for heating and hot water loads

Technical possibilities to meter heating and hot water loads are not present in every building. In houses with direct electric heating this is always possible as the heating system is completely separated from hot water preparation system. One meter is installed to measure the load for the heating system, another one to measure the load for the hot water preparation unit.

The situation is different in the houses with waterborne heating systems, where the possibility to measure separate heating and hot water loads is dependent on the boiler type. When the space heating boiler and hot water boiler are separated (H1 and H3), there are no problems to measure the load. Integrated boilers have one common heating element which provides heat for both heating system and hot water system. In such cases (H2 and H4) it is impossible to separate loads as the power is supplied to one common element.

Table 4.1 provides the summarized description of the analyzed households.

Table 4.1. *Description of analyzed households*

Features		H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
Occupants	**Gender and age**	1M26-65, 1F 26-65	1F 26-65, 1M 26-65	1M 26-65	1M 65+, 1F 65+	1F 26-65, 1M 26-65	1F 26-65, 1M 26-65	1M 19-25, 1F 26-65, 1M 26-65	1M 13-19, 1M26-65, 1F 26-65	1M 33, 1F 32, 1baby	1M 45, 1F 44 (1F 16, 1M13 half time)
	Home during daytime?	sometimes	yes (M)	yes	yes	no	no	sometimes	no	yes	no
	Annual electricity use (2003)	20993 kWh	27597 kWh	21254 kWh	21626 kWh	22950 kWh	16528 kWh	15396 kWh	17272 kWh	14019 kWh	18478 kWh
House	**Type**	detached	detached	detached	detached	detached	semi-detached	semi-detached	semi-detached	detached	detached
	Levels	1,5 stories	1 storey	1 storey	1 storey	1 storey + basement	2 storey	2 storey	2 storey	1 storey	1 storey
	Living area	160 m^2	186 m^2	180m^2	145m^2	150m^2 + 150m^2 basement	118 m^2	118 m^2	110 m^2	116 m^2	95 m^2
	Construction year	1968	1951-75	1965	1964	1974	1978	1978	1978	1969	1969
	Construction type	brick with wooden frame	brick with light concrete frame, (60m^2 brick and wood frame)	brick with light concrete frame	brick with light concrete frame, (55m^2 brick and wood frame)	brick with wooden frame	brick with wooden frame	brick with wooden frame	brick with wooden frame		
	Glazing	triple	triple	triple	triple	double and triple	double	triple	triple	double	triple
	Fuse level	20A	20A	20A	16 A (load guard)	20A	16A	16A	16A	20A	20A
Heating system	**Type**	waterborne, electric furnace	waterborne, electric furnace	waterborne, electric furnace	waterborne, electric furnace	direct resistive, electric radiators	direct resistive, electric radiators (oil-filled)	direct resistive, electric radiators	direct resistive, electric radiators	direct resistive, electric radiators	direct resistive, electric radiators (oil-filled)
	Power	13kW	13,5 kW (steps 2,5;4,5;9kW)	13 kW	15,75 kW (9kW limited)	11,4kW + 8,7kW in the basement				8,3 kW	6,5 kW
	Control system	outdoor sensor	outdoor sensor, thermostats	outdoor sensor, thermostats on radiators (not all)	outdoor sensor, thermostats on radiators	thermostats on radiators	"Soft heating" with outdoor sensor, temp. limiter		"Soft heating", temperature sensors in rooms	thermostats on radiators	thermostats, "Soft heating"
	Secondary heating system	open fire (5m^3 firewood/year)	heat pump (2,5kW), floor heating (1,5kW), open fire (2,5m^3firewood/year)			open stove in the basement	floor heating (8m^2)				
Hot water system	**Power**	3kW	integrated in the furnace		integrated in the furnace	3kW				3kW	3kW
	Boiler volume	200 liters	120 liters	200 liters	120 liters	300 liters	300 liters	300 liters	300 liters	200 liters	200 liters
Improved features	**Better insulation**	yes (5cm under windows and gables)	yes (attic)	yes (attic, 150mm)	yes (some of the walls 1964 - 73)		yes (attic)	yes (attic)	yes (attic)		yes (attic 340mm)

1M26-65, 1F 26-65 means: 1 male of the age between 26-65 and 1female of the age between 26-65 (these age ranges are selected primarily to determine the occupants' presence at home during daytime)

4.2.2 Metering and data analysis

Metering

Load (total and partial)

1 hour average load for heating, hot water and total are measured and stored in a database. Remaining household electricity load is calculated by subtracting heating and hot water loads from the total. The data was obtained using CustCom system. Metering of heating and hot water loads for all selected households started on April 1, 2003. Originally it was planned to start metering from the March, but due to the delay of installation of meters it started only from April 2003.

a) b) c)

Figure 4.4. *a) Main electricity meter with CustCom Counter unit , b) extra meters for metering heating and hot water loads, c) CustCom online statistics*

Outdoor temperature

Hourly outdoor temperature data is also provided via CustCom system. As a shortage, could be mentioned that the temperature is being measured in one place, at Skånska Energi headquarters area. Though the examined houses are located relatively close to the headquarters, there might be some variations.

Electricity use characteristics

The data for total and partial loads is analysed for the period **April 1, 2003 – Feb 15, 2004**. (The data is also available for the rest of the heating season, however, as the control measures were performed starting from Feb 16, 2004 it is not reasonable to include it into analysis).

The further analysis is divided into 3 parts – total load, heating load and hot water load.

Total household load

Load curve and load duration curve

Chronological load data for each hour of an analyzed period is required to construct load curve. The Figures 4.5 and 4.6 provide the load curves (kW) and load duration curves for ten selected households during the analyzed period (April 1, 2003 – Feb 15, 2004).

As it could be observed the lowest load variations have H6, H7, H8 and H9. These customers are the most favorable for the utility from that point of view. Remaining households with significantly higher load variations might cause a risk for the utility. On the other hand, the mentioned households have lower electricity consumption.

Load duration curves have similar shapes for all households. The key difference is the highest demand values, which, again, are lower for households H6, H7, H8 and H9.

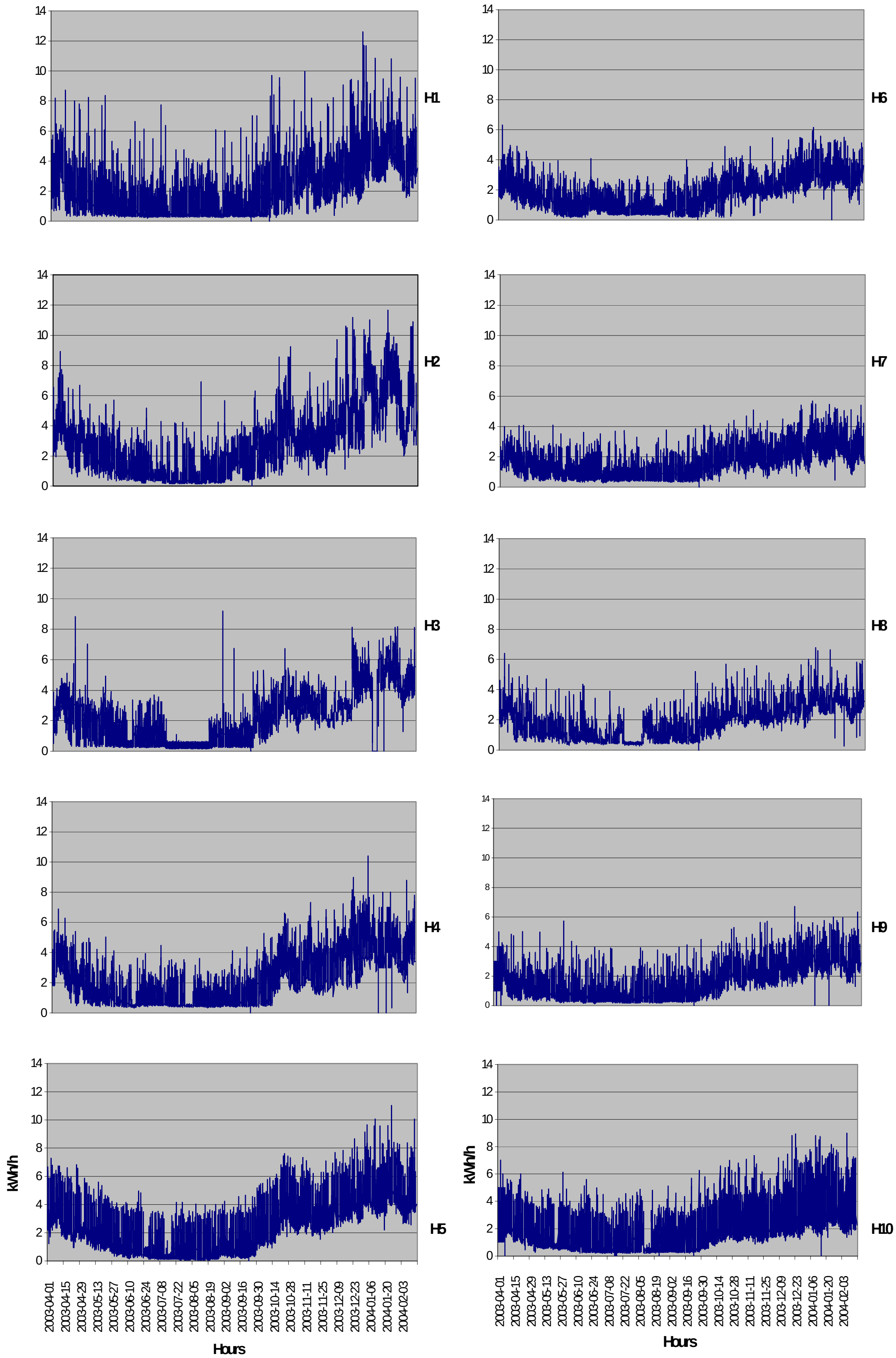

Figure 4.5. *Load curves for the analysed houses*

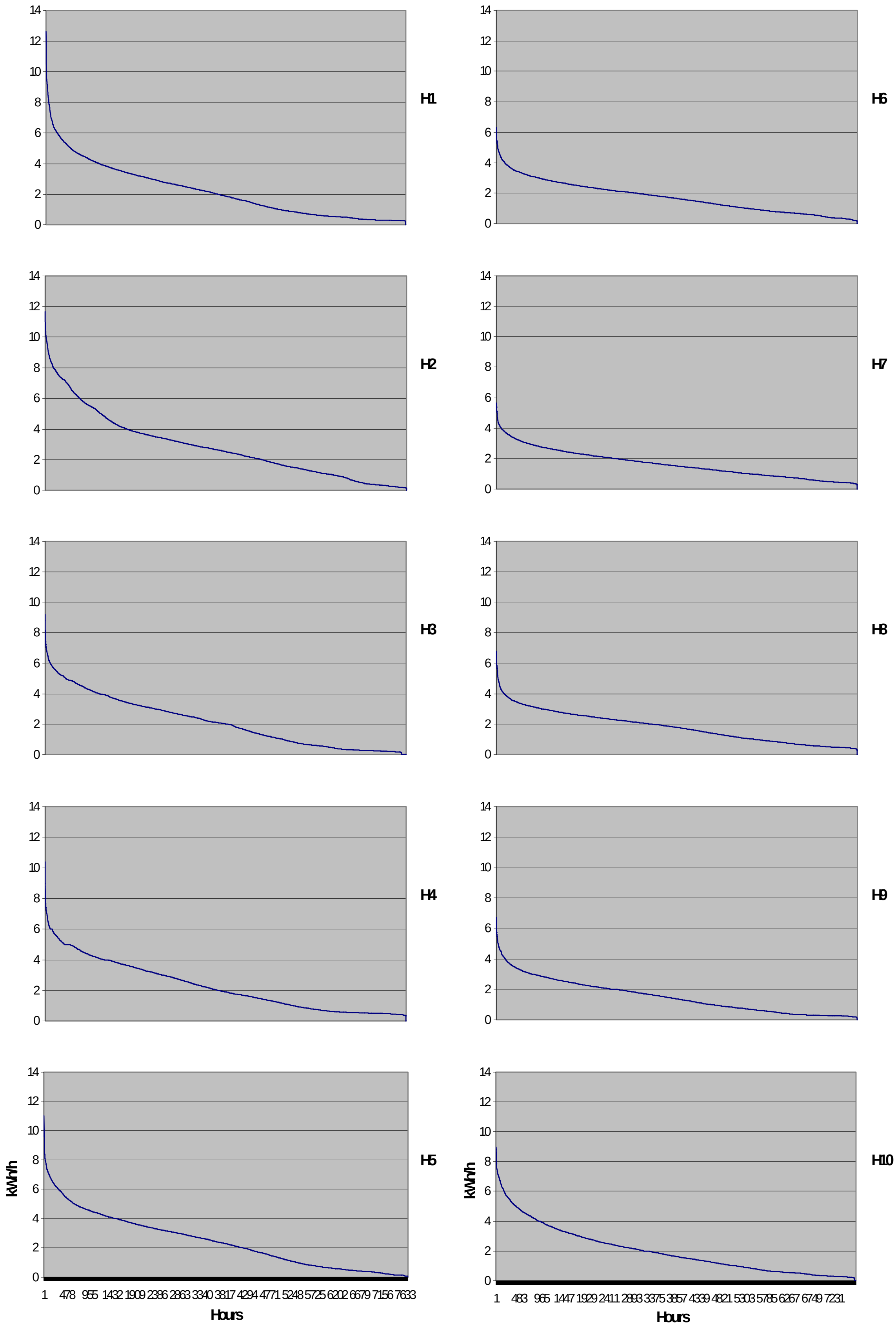

Figure 4.6. *Load duration curve for 10 analyzed households*

Load factor and exploitation time

Load Factor
The load factor is used to demonstrate variations of the household's load curve. This factor can range between 0 and 1, where a value of 1 would indicate that the household load curve was completely flat and no peaks where present. From the supplier point of view, it is preferable to remove peaks and flatten out the load curve, which corresponds to a load factor increase (North 2001).

Load factor is calculated by averaging the annual hourly load data obtained from the metering system and then dividing it with the maximum (peak) load during that period, as seen in equation (1):

$$\text{Load Factor} = \frac{Load_{average}}{Load_{\max}} \qquad (1)$$

Exploitation Time
The exploitation time is also an indication about the shape of the customer's load curve. The time, calculated in hours, represents the required duration of maximum (peak) load needed to correspond to the total actual electricity usage during the same period, which can be represented by the equation (2). A high exploitation time relates to an even load demand – a preferable situation for the utility (North, 2001).

$$\text{Exploitation Time (h)} = \frac{\text{Electricity Consumption}}{Load_{\max}} \qquad (2)$$

A graphical representation of this time is given in Figure 4.7.

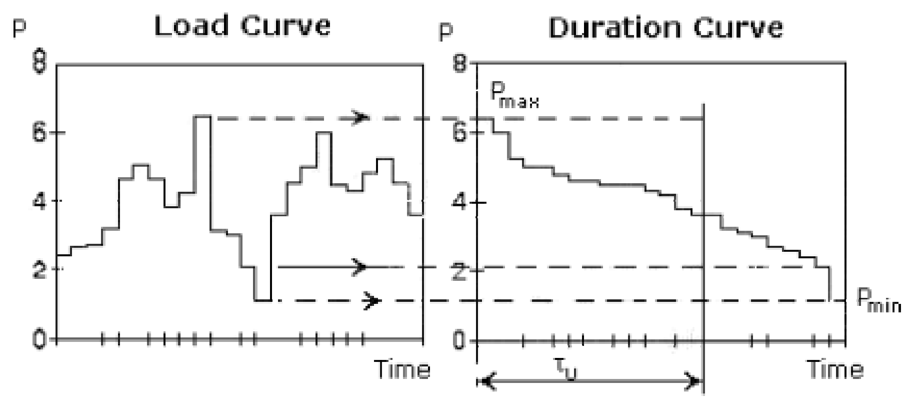

Figure 4.7. *Exploitation time (τ_u) calculation*

Load factor and the exploitation time for the analyzed households is calculated and provided in the Table 4.2. H6, H7, H8 have the highest load factors and highest exploitation times among analyzed households. The calculation refers to the analysis period (April 1, 2003 – Feb 15, 2004)

Table 4.2. *Load factors and Exploitation time*

Household	Total consumption	Total Average	Load Factor	Exploitation time
	kWh	kWh/h		h
H1	16906,14	2,19	0,17	1339,63
H2	21910,06	2,84	0,24	1877,47
H3	16525,07	2,14	0,23	1798,16
H4	17506,58	2,27	0,22	1683,33
H5	18695,68	2,43	0,22	1698,06
H6	13404,73	1,74	0,28	2127,73
H7	12757,15	1,66	0,29	2253,91
H8	13966,44	1,81	0,27	2059,95
H9	11873,99	1,54	0,23	1769,60
H10	15422,34	2,00	0,22	1719,32

Daily load curves

This analysis is performed in order to define the daily load pattern for the analyzed households. This kind of analysis helps to see the load variation every hour of the day during the analyzed period. Since the load demand in winter season is higher and causes load problems, the Figure 4.8 shows the daily load curve for the period from October 1, 2003 until February 15, 2004. The average and maximum hourly load as well as standard deviation is shown.

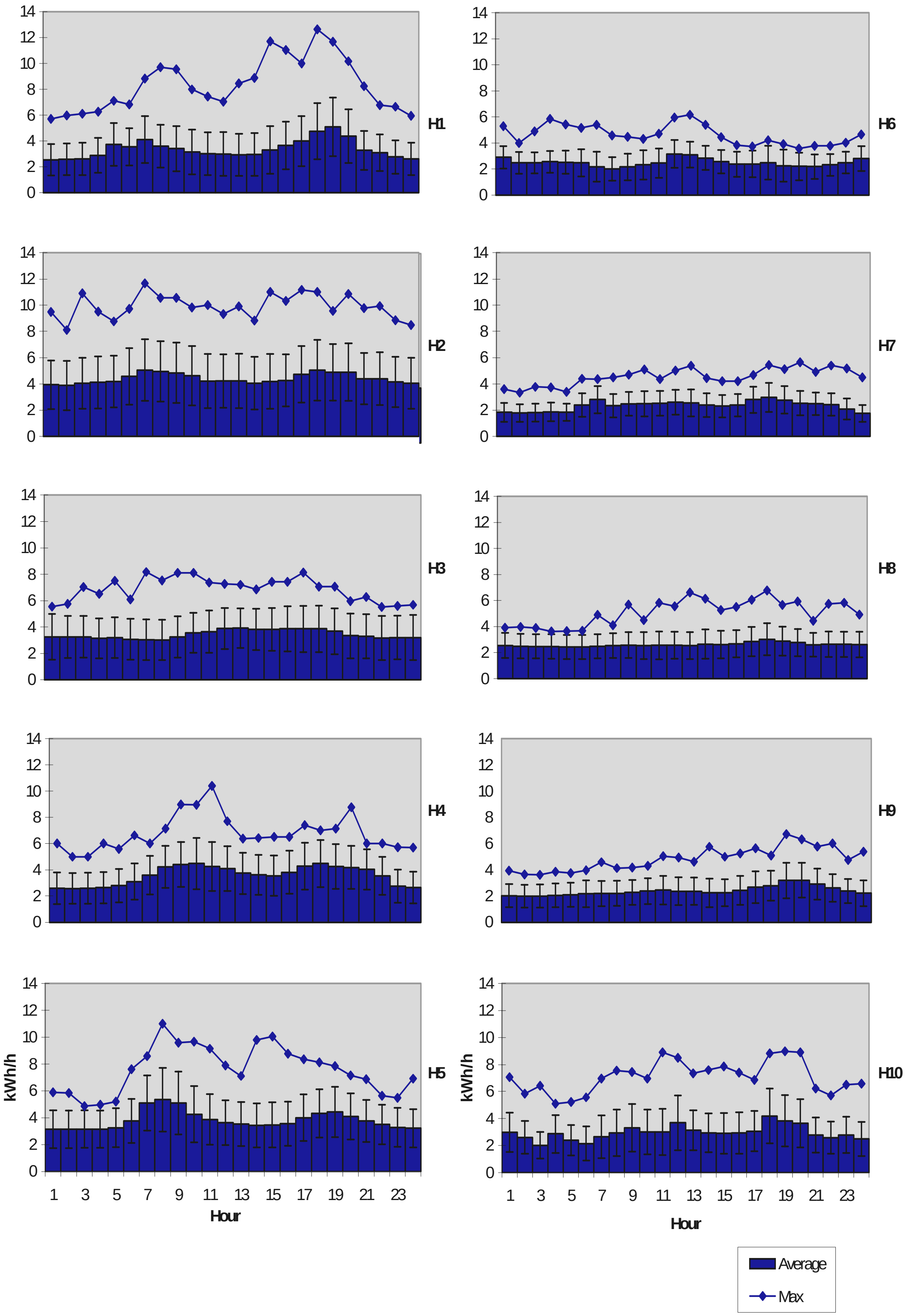

Figure 4.8. *Daily load curve for winter season*

10 highest peaks

Figure 4.9 provides the overview of the average of 10 highest peaks of every household and the peaks' composition. The available metering of partial loads allows seeing the origin of the peaks, i.e. whether it is climate dependent peak or behavior dependent peak. The composition is presented in two ways – in kW, in order to see the peak value and in percentage, to express the share of the end use.

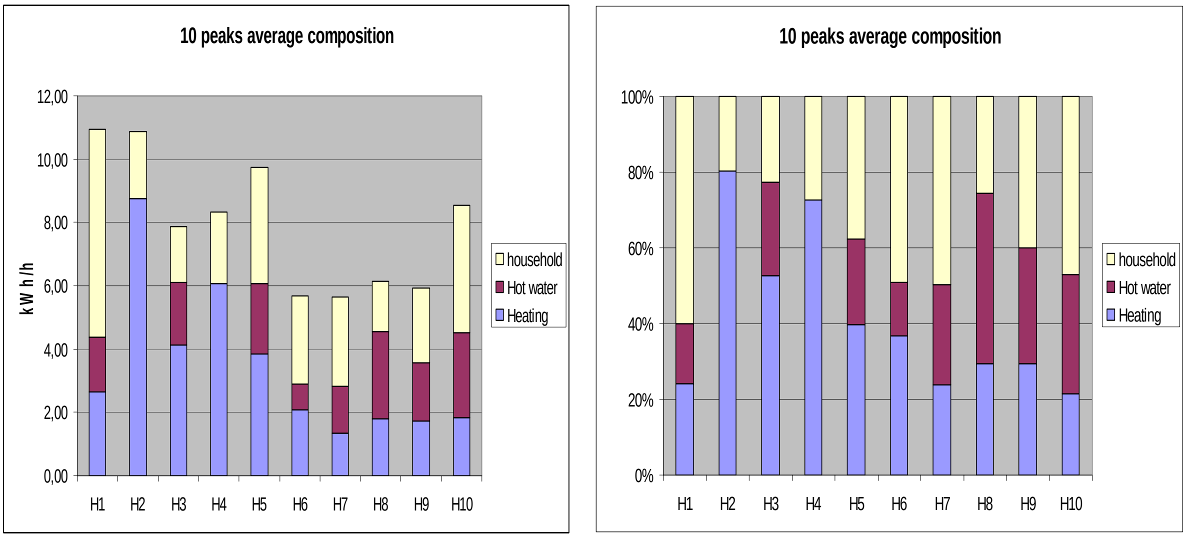

Figure 4.9. *10 highest peaks at the analyzed households*

As mentioned previously, there were no technical possibilities to separate the measurements for heating and hot water at H2 and H4. Therefore they are shown as one (heating) load in the figures.

A very interesting and, in a way, unexpected result in Figure 4.9 is the electricity demand for household needs. The Figure shows that it could be even as high as 60% of the total demand during some periods. Furthermore, these periods are in winter season when one would normally expect the heating demand to take the highest share. The important conclusion therefore is that not only the climate (outdoor temperature), but the behavior related electricity use could be a serious cause of load problems.

Superposition factor

Superposition describes the contribution of partial load to the total load. Superposition factor is the ratio between the partial load demand during the total peak and the maximum partial load during the same time period as it is expressed in Figure (4.10) and equation (3). The range of values that this factor can take is between 0 and 1, where a value of 1 would indicate, that the peak of the partial load coincided with the peak of total load.

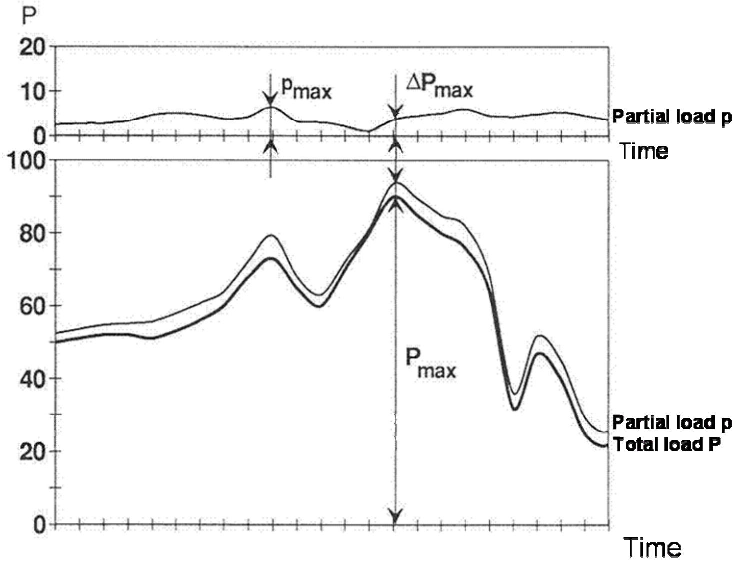

Figure 4.10. *Superposition and superposition factor (Pyrko 2004)*

$$SF = \Delta P_{max}/p_{max} \quad (3)$$

where:

ΔP_{max} = increase of total load peak value due to partial load **p**,

p_{max} = partial load maximum value

Superposition factor analysis was performed for our 10 households in order to observe which of them are mostly contributing to the utility peaks. Ten highest SENAB hourly peaks within the analysed period were selected and the superposition factors for the households calculated. The results shown in Table 4.3 indicate that households H10, H4, H5, H6, H8 were mostly contributing to the selected SENAB peaks.

Table 4.3. *Superposition factor for analysed households*

SENAB 10 peaks												
date	kWh	Out. Temp.,°C	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
2004-01-22 08:00	80387	-15	0,81	0,95	0,81	1,00	1,00	0,65	0,66	0,91	0,81	1,00
2004-01-22 18:00	76400	-9	0,78	0,79	0,89	1,00	0,59	0,70	0,82	0,78	0,89	0,80
2004-01-21 19:00	74019	-8,1	0,69	0,66	0,92	1,00	0,75	0,56	0,74	0,88	0,70	0,73
2004-01-21 08:00	73773	-9,8	0,78	0,86	0,76	0,83	0,99	0,55	0,59	0,86	0,57	0,95
2004-01-26 18:00	72202	-3	0,75	1,00	0,90	0,95	0,81	0,68	0,78	1,00	0,60	0,60
2004-01-27 18:00	71429	-4,3	0,66	0,92	0,82	0,81	0,76	0,64	0,94	1,00	0,56	0,93
2004-01-05 18:00	71128	-7,4	0,81	0,91	0,83	0,59	0,97	1,00	0,85	0,79	0,68	0,93
2004-01-23 08:00	70934	-3	0,88	0,86	0,81	0,86	0,82	0,66	0,55	0,68	0,55	1,00
2004-02-12 08:00	70614	-4,3	0,31	0,80	0,73	0,87	1,00	0,72	0,79	0,53	0,65	1,00
2004-01-02 18:00	69494	-3,9	0,74	0,89	1,00	0,92	0,59	1,00	0,86	0,97	0,71	1,00

Heating load

Figure 4.11 shows daily load curves for heating load during heating season

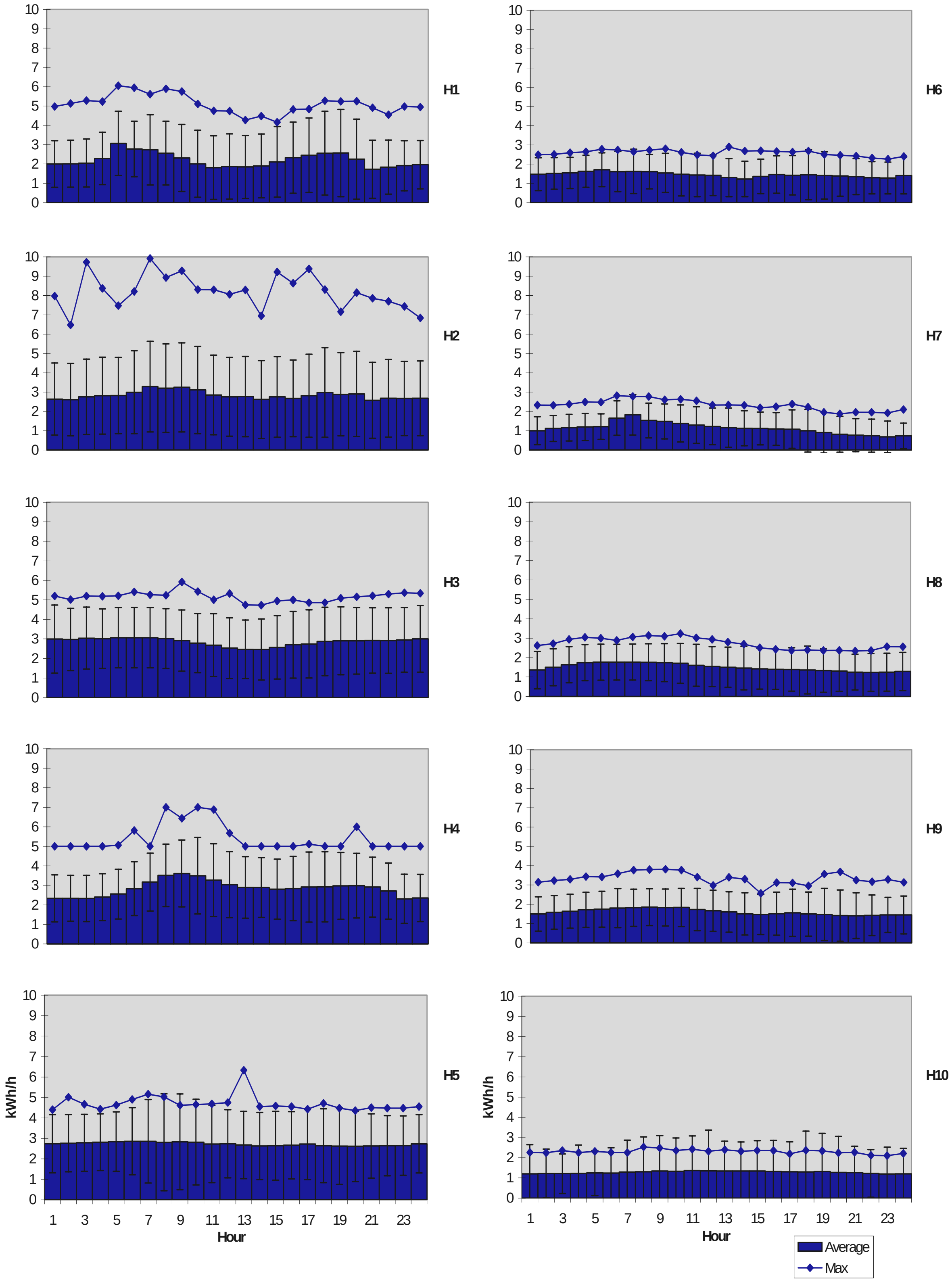

Figure 4.11. *Daily load curve for heating in winter season*

H6, H7, H8 and H10 have the lowest fluctuations primarily due to the presence of “soft electric heating” system. The basic feature of “soft electric heating” system is the pulsing of the electric energy to the specific radiators in specified time intervals. Living area could be divided into different temperature zones and the control system is pulsing energy in turn to the radiators in these zones. Since the pulses are shifted the radiators are never switched on all together, what gives the decrease in load demand (Andersson, 1992).

Other important factor, explaining why the load demand for heating is lower at H6-H10 is the smaller living area.

Outdoor temperature and heating load correlation

The ability to measure load demand for heating provided the possibilities to estimate its correlation to outdoor temperature. The correlation is shown in Figure 4.12.

$$P_{heating} = f(t_{out})$$

Few important remarks regarding Figure 4.12:

As already discussed in this thesis, at H2 and H4 there were no technical possibilities to separate heating and hot water load measurements. That’s why the figures for these households show the correlation between outdoor temperature and load demand for heating and hot water.

In H8 the big amount of data for heating load during May – August, 2003 was not available due to technical communication problem.

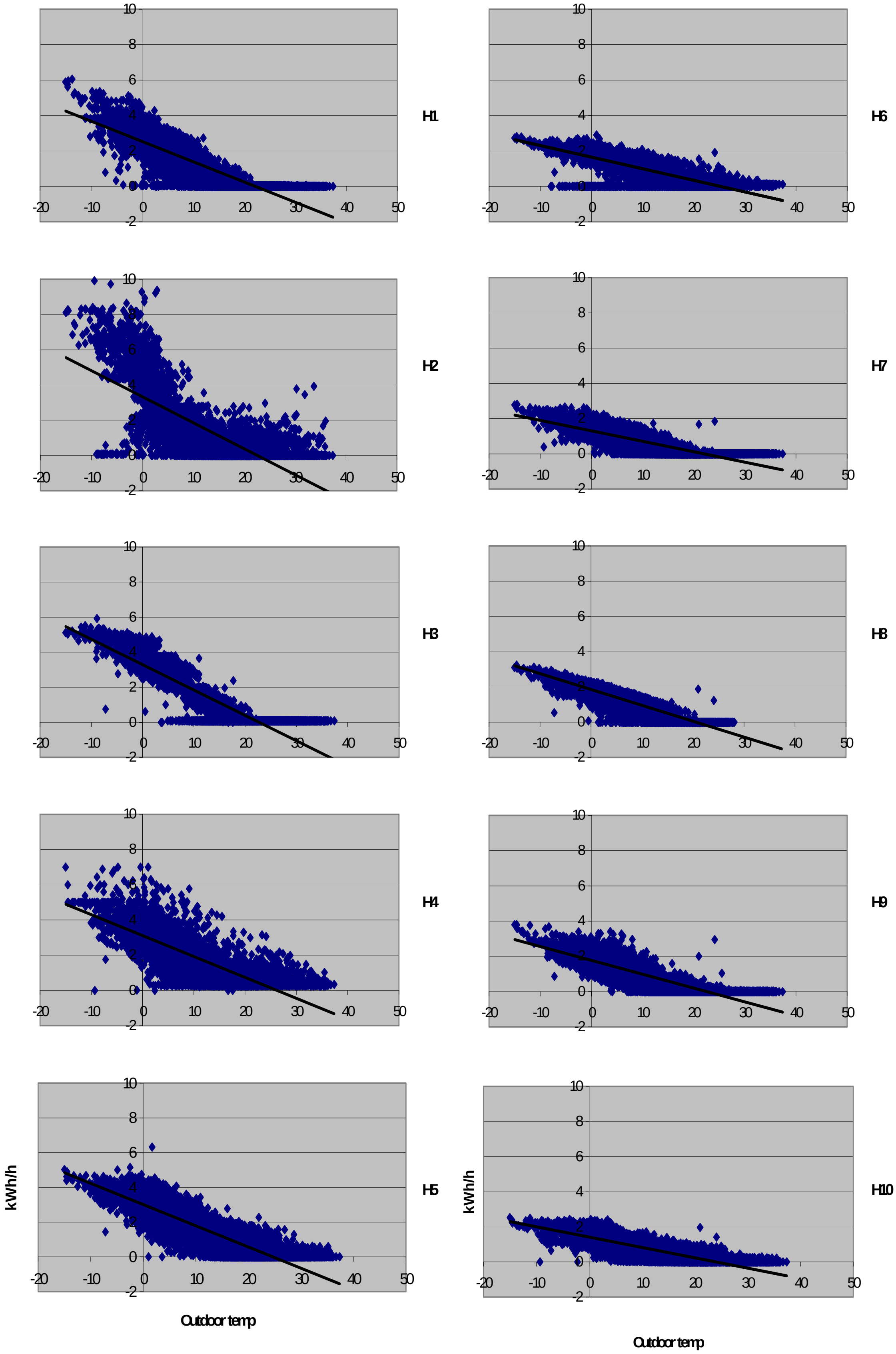

Figure 4.12. *Outdoor temperature and heating load correlation*

The measured data could be extended to -15ºC using the *regression analysis*. The following parameters could be determined:

a – intercept point (load demand when outdoor temperature is 0 ºC)
b – regression coefficient (slope of the line)

r – correlation coefficient (In this analysis it is the heating load dependency on outdoor temperature).

> *A correlation coefficient expresses quantitatively the magnitude and direction of the relationship* (Pagano, 1990). It could vary within the range [$-1 \leq r \leq 1$]

r^2 – determination coefficient (In this analysis it explains what part of the heating load demand data was dependent on outdoor temperature)

> *Determination coefficient (r^2) determines what part of variations in the dependent variable could be explained by independent variable* (Ejlertsson,1992).

Table 4.4. The regression analysis results for the analyzed households

	P = a + bx, (kW)	**r**	**r^2**
H1	P = 2,54 - 0,11x	0,85	0,72
H2	P = 3,34 - 0,15x	0,76	0,58
H3	P = 3,29 - 0,14x	0,9	0,81
H4	P = 3,12 - 0,12x	0,81	0,66
H5	P = 3,02 - 0,12x	0,86	0,74
H6	P = 1,65 - 0,07x	0,82	0,68
H7	P = 1,31 - 0,06x	0,83	0,69
H8	P = 1,86 - 0,09x	0,88	0,77
H9	P = 1,78 -0,08x	0,86	0,73
H10	P = 1,42 - 0,06x	0,84	0,7

The load demand (P) for heating at the analyzed households could be calculated using the equations in Table 4.4 for the outdoor temperature interval -15ºC…+20ºC.

Hot water load

Daily load curves for hot water for the period April 1, 2003 – February 15, 2004 are presented in Figure 4.13. As it could be observed the pattern differs from household to household. Hot water use, however, has a tendency to increase during morning and evening hours in most households and thus contribute to the total load peaks. Similar conclusion could also be drawn from the analysis of probability that hot water boiler is on full power, presented in Figure 4.14.

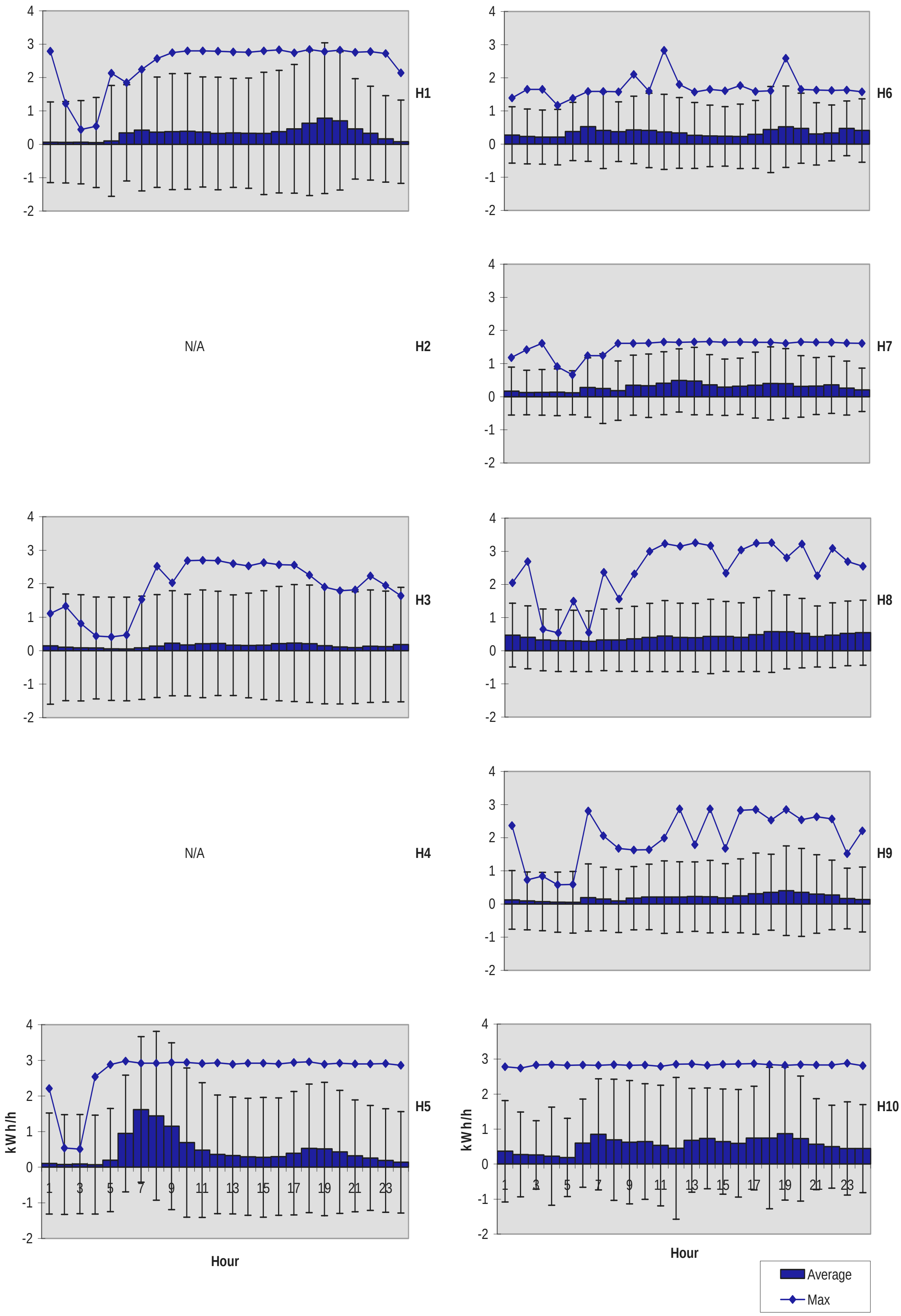

Figure 4.13. *Hot water daily load curves*

Probability that hot water boiler is on full power

An interesting question, when analyzing load demand for hot water, is when the hot water boilers are on full power. Having this knowledge it is easier to create load management strategies, as it gives a suggestion when to control the units in order to get a maximum load savings. Using the daily load curve and the hourly data, the following methodology for finding the probability if the hot water boiler is on full power was developed:

It is assumed that boiler is on full power if it's hourly load exceeds 2,5 kWh/h (exception was H7 , where there is a load limitation. In that case the value assumed is 1,5kWh/h). Every hour of the day through the period April 1, 2003 – February 15, 2004 is analyzed. Number of hours when the load reached this value is divided by the total number of recorded hours.

The results are summarized in Figure 4.14. Values on Y axis show the probability (%) and the values on X axis are the hours of the day (0-24).

Figure 4.14 shows that the pattern of load demand for hot water varies from household to household, principally depending on the behavioral factors. There is a tendency, however, that the highest demand occurs during morning and evening hours, therefore these periods could have the highest potentials for load control.

Remaining household load is normally not subjected for direct load management; therefore it is not analyzed in this thesis. This load is closely connected to the behavioral aspects and is analyzed in another part of this project, performed by Kerstin Sernhed (Sernhed 2004). The study of behavioral questions in her thesis is based both on energy diaries and on measurements, including even 5-minutes data analysis.

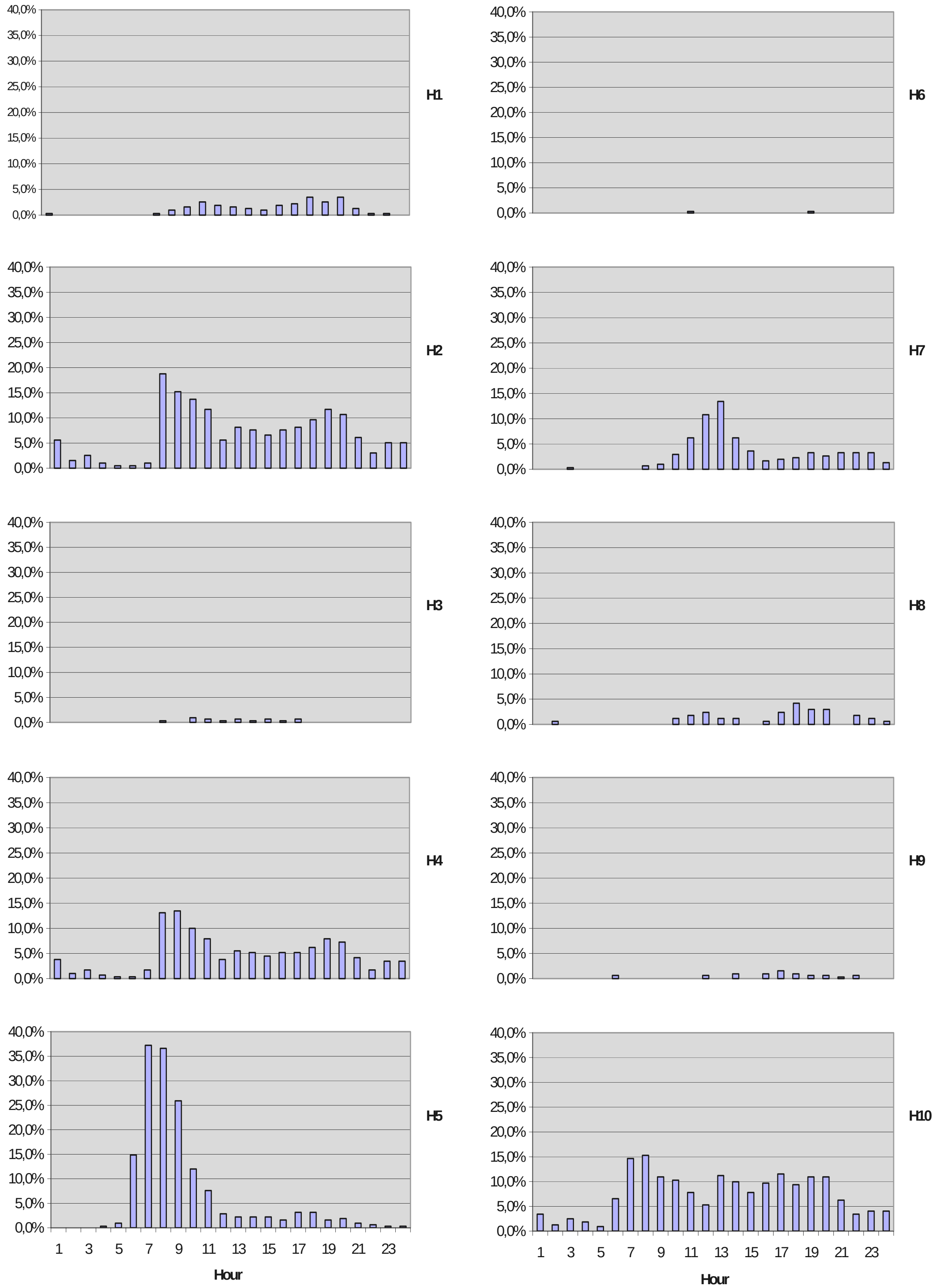

Figure 4.14. *Probability that hot water load is on full power during a day*

4.3 Load management experiment

The experiment strategies were formed based on the analysis of the available measurements from the following two perspectives:

Utility perspective. Load is controlled when utility has problems with peak demand. According to SENAB the problems usually occur on weekday mornings and holiday (weekend) afternoons.

Household perspective. The load is controlled when the customer has peaks, testing the possibilities and effects on the household in order to make load curve as even as possible. The benefit of this perspective would be the view of how load profile could be improved in this kind of household and what consequences would it have.

As it was already mentioned, the main purposes of the experiment were following:

- To test the technical possibilities of direct load control with the system CustCom, already installed at the utility and customers' equipment
- To estimate what load savings could be achieved
- To estimate how load control would affect indoor climate and comfort conditions for the customers

4.3.1 Experiment procedures

Extra control cards and relays were installed at by Skånska Energi in all 10 houses.

Figure 4.15. *Control relay and extra meter*

Experiment was carried out successively during period Feb 16, 2004 – Mar 7, 2004.

The essence of the experiment was on/off control of heating and hot water systems in houses according to the prepared schedule. The schedule was based on the analysis of the total and partial load demand data, as described in part 4.2. It was prepared by the research group and sent to the utility. The utility personnel set the control for the given channels in "CustCom" system.

Load for heating was switched off for the periods of 1, 2, 3, 4 hours.
Load for hot water was switched off for the periods of 1, 2, 3, 4 and 16hours.
The control periods are specified in Table 4.5.

The time, chosen for the experiment was within a statistically coldest period in the region. However, relatively high outdoor temperatures this particular year did not allow to make the tests under most sensitive conditions. Temperatures during control periods are shown in Table 4.6.

Measurements and control costs

The total estimated costs for the installation of the measurement and control equipment is around **10 000 SEK** per household (excluding VAT). This includes:

- extra meter 500 SEK
- terminal 1500 SEK
- control card 400 SEK
- relay box 300 SEK
- installation (material and labor) and other costs 7300 SEK

1SEK is approx 0.12 EUR (December 2004)

Table 4.5. *Load control periods*

Household	Installation	2004 02 16-18 Mo-Wed	2004 02 19-20 Thu-Fri	2004 02 21-22 Sat-Sun	2004 02 24-25 Tue-Wed	2004 02 27 Fri	2004 02 28 Sat	2004 03 02 Tue	2004 03 03 Wed	2004 03 06-07 Sat-Sun
H1	**Heating**	9.00 - 11.00	10.00 - 11.00	10.00-11.00; 17.00-19.00	8.00-11.00	9.00-10.00	16.00-20.00	17.00-20.00	17.00-20.00	16.00-20.00
	Hot water	8.00 - 10.00	9.00 - 10.00	9.00-10.00; 19.00-20.00	8.00-11.00	10.00-11.00	17.00-19.00	07.00-23.00	No control	No control
H2	**Heating + hot water**	No control (family absent)	No control (family absent)	No control (family absent)	8.00-11.00	9.00-10.00	16.00-20.00	17.00-20.00	17.00-20.00	16.00-20.00
	Heat pump	No control	No control	No control	No control	No control	No control	No control	No control	No control
H3	**Heating**	9.00 - 11.00	10.00 - 11.00	10.00-11.00; 17.00-19.00	8.00-11.00	9.00-10.00	16.00-20.00	17.00-20.00	17.00-20.00	16.00-20.00
	Hot water	8.00 - 10.00	9.00 - 10.00	9.00-10.00; 19.00-20.00	8.00-11.00	10.00-11.00	17.00-19.00	07.00-23.00	No control	16.00-20.00
H4	**Heating + hot water**	9.00 - 11.00	9.00 - 10.00	9.00-10.00; 17.00-19.00	8.00-11.00	9.00-10.00	16.00-20.00	17.00-20.00	17.00-20.00	16.00-20.00
H5	**Heating**	9.00 - 11.00	10.00 - 11.00	10.00-11.00; 17.00-19.00	8.00-11.00	9.00-10.00	16.00-20.00	17.00-20.00	17.00-20.00	16.00-20.00
	Hot water	8.00 - 10.00	9.00 - 10.00	9.00-10.00; 19.00-20.00	8.00-11.00	10.00-11.00	17.00-19.00	07.00-23.00	No control	16.00-20.00
H6	**Heating**	9.00 - 11.00	10.00 - 11.00	10.00-11.00; 17.00-19.00	8.00-11.00	9.00-10.00	16.00-20.00	17.00-20.00	17.00-20.00	16.00-20.00
	Hot water	8.00 - 10.00	9.00 - 10.00	9.00-10.00; 19.00-20.00	8.00-11.00	10.00-11.00	17.00-19.00	07.00-23.00	No control	16.00-20.00
H7	**Heating**	9.00 - 11.00	10.00 - 11.00	10.00-11.00; 17.00-19.00	8.00-11.00	9.00-10.00	16.00-20.00	17.00-20.00	17.00-20.00	16.00-20.00
	Hot water	8.00 - 10.00	9.00 - 10.00	9.00-10.00; 19.00-20.00	8.00-11.00	10.00-11.00	17.00-19.00	07.00-23.00	No control	16.00-20.00
H8	**Heating**	9.00 - 11.00	10.00 - 11.00	10.00-11.00; 17.00-19.00	8.00-11.00	9.00-10.00	16.00-20.00	17.00-20.00	17.00-20.00	16.00-20.00
	Hot water	8.00 - 10.00	9.00 - 10.00	9.00-10.00; 19.00-20.00	8.00-11.00	10.00-11.00	17.00-19.00	07.00-23.00	No control	16.00-20.00
H9	**Heating**	9.00 - 11.00	10.00 - 11.00	10.00-11.00; 17.00-19.00	8.00-11.00	9.00-10.00	16.00-20.00	17.00-20.00	17.00-20.00	16.00-20.00
	Hot water	8.00 - 10.00	9.00 - 10.00	9.00-10.00; 19.00-20.00	8.00-11.00	10.00-11.00	17.00-19.00	07.00-23.00	No control	16.00-20.00
H10	**Heating**	9.00 - 11.00	10.00 - 11.00	10.00-11.00; 17.00-19.00	8.00-11.00	9.00-10.00	16.00-20.00	17.00-20.00	17.00-20.00	16.00-20.00
	Hot water	8.00 - 10.00	9.00 - 10.00	9.00-10.00; 19.00-20.00	8.00-11.00	10.00-11.00	17.00-19.00	07.00-23.00	No control	16.00-20.00

4.3.2 Experiment results

The experiment had the following purposes:

- To test the technical possibilities of direct load control with the system CustCom, already installed at the utility and customers' equipment
- To estimate what load savings could be achieved
- To estimate how load control would affect indoor climate and comfort conditions for the customers

From the technical point of view, the system CustCom proved to be a good technical tool to implement load controlled objectives. No serious technical problems occurred during the experiment. However, when it comes to economic issues, the costs for extra equipment for measurement and control purposes (meters, relay, control card, labor, etc.) appeared to be really high, reaching 10 000 SEK per household.

Load demand savings for heating

The heating systems in houses were switched off during periods of 1, 2, 3, and 4 hours. Load savings are calculated in the following way:

$$LS = \frac{P_{bc} + P_{ac}}{2}$$

Where:

LS – Load savings
P_{bc} – load hour before the control period
P_{ac} – load hour after control period (excluding recovery load*)

*** If load control was performed for one or two hours – it is assumed that recovery lasts for one hour, if it was for 3 or 4 hours – it is assumed that recovery lasts for 2h. The assumption is made based on actual readings of load curves.**

The Figure 4.16 summarizes the results for all households.

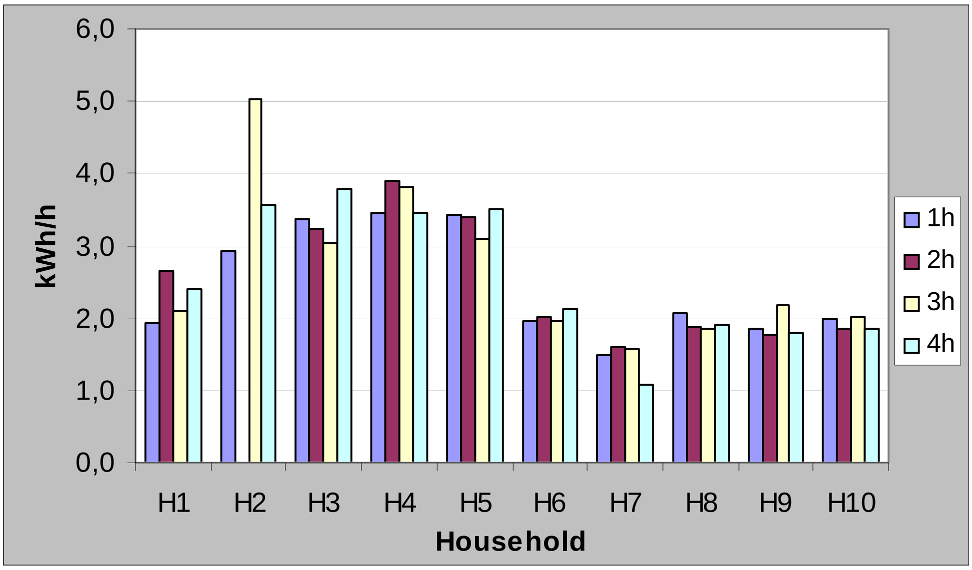

Figure 4.16. *Hourly load savings on heating*

In H2 the 2 hour control was not performed.

Figure 4.16 show that H2 and H4 have highest hourly load savings on heating. It is important to consider, however, that the data from H2 and H4 also includes load for hot water, since these houses have integrated boilers with integrated hot water system. The results for other households show that the savings in principle depend on house area. H3, H5 and H1 have larger living area and gradually the demand for space heating than the remaining ones.

According to the calculations, performed by the chosen methodology, there is no dependency of potential hourly load savings on the control period, i.e. 1, 2 3 or 4 hours.
The potential hourly load savings for heating varies from 1,1 to 3,8 kWh/h per household.

Recovery load for heating

Recovery load occur when the system is reheating the house after the control period. It is an important issue since it can result in another, even higher, peak after control. The further analysis shows the recovery loads for heating after the implemented control periods (during the first hour after the control period).

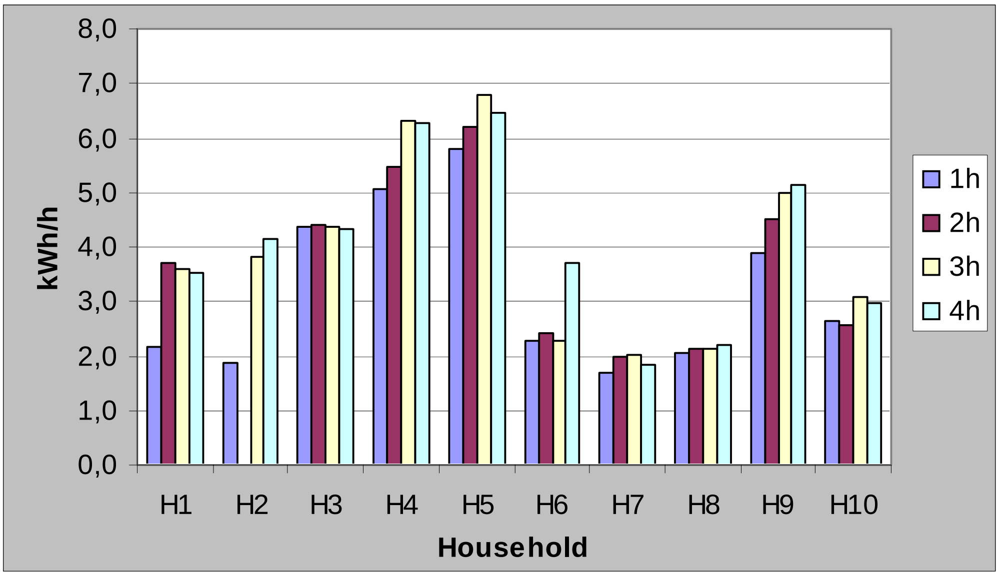

Figure 4.17. *Recovery load for heating*

A dependency on control period can be observed here. Households 6, 7, 8 and 10 have „soft heating" systems and load guards that keep the load demand below a specific level. This system can be recommended as a good solution to protect the grid from high recovery peaks. However, for the household it could mean a longer loss of indoor comfort. In this particular experiment the indoor temperature drops were very small as the outdoor temperature was relatively high.

Indoor climate

Indoor temperature drop

Indoor temperature was measured during the whole experiment period.
Indoor temperature logger was placed in every household in the living room at about 130cm from the floor. Temperature readings were taken every 15 minutes with a precision of 0,5 °C. As a shortcoming could be mentioned that only one logger is placed. Therefore the assumption is made that indoor temperature is the same in all the house.

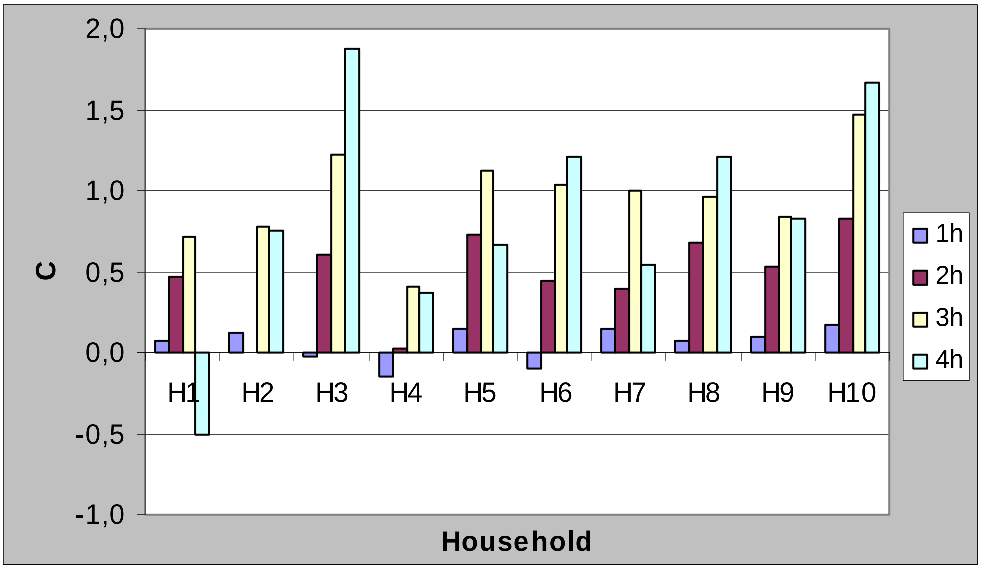

Figure 4.18. *Indoor temperature drop*

Under the weather conditions, which were present during the experiment, no significant negative effects for the customer indoor thermal comfort were recorded as the indoor temperature drops were low, varying from 0 to 1,7 °C. In some cases of 1hour control even a temperature increases were recorded. This is obviously a result of some activities in a household. Average outdoor temperatures during control period are presented in Table 4.6.

Table 4.6. *Average outdoor temperature during control periods*

Control duration, h	Average outdoor temp, °C
1	2,8
2	2,0
3	2,4
4	1,9

Hot water system

Load savings for hot water preparation

Domestic hot water systems have a potential for load savings for 1, 2, 3 or 4 hours control without serious negative consequences. However, to say how big the savings are it is difficult, as the water use measurements were not performed. The systems normally have installed capacities of 3 kW, which actually could be considered as a controllable potential. The full load probability analysis as well as daily load curves shows the pattern of water usage, which could be followed for selecting the control strategy.

The Table 4.7 shows the hot water load during 1st hour after control. It is an attempt to estimate if there was a recovery load after the control periods. Underlined figures in italics indicate assumption that it is a recovery load and that certain load savings were achieved with the control performed.

Table 4.7. *Recovery load for hot water system*

Control duration, hours	Load 1h after control (recovery load), kWh/h									
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
1	0		0		0,79	0,45	0,92	*1,06*	0,73	*1,86*
1	0		0		*1,67*	0,35	*1,26*	0,87	0,04	*2,74*
1	0,64		*1,14*		*2,84*	*1,21*	0,63	0,5	0	*2,71*
1	*1,72*		0		*1,39*	0,56	0,57	*1,02*	0,52	0,61
1	*2,13*		0,36		*2,81*	*1,36*	1	0,6	0,73	*2,67*
1	0,27		0		0,32	*1,15*	0,82	*1,07*	*2,52*	*2,24*
1	0		0,4		0,28	0,54	0,45	0,69	0	*1,57*
										-
2	0		0,39		*2,86*	0,84	*1,19*	*2,41*	0	*2,69*
2	0,25		0,46		*2,84*	0,7	0,63	0,97	0,57	*2,68*
2	0,24		0,43		*2,88*	0,65	0,77	0,75	0	*2,71*
2	*2,75*		0,33		0,41	0,74	*1,04*	*2,57*	0	*2,74*
							-	-		-
3	0,34		0,6		*2,8*	0,95	*1,44*	*1,2*	0,52	*2,71*
3	0		0,34		*2,83*	1	*1,02*	*1,06*	0,88	*2,76*
					-		-	-		-
4	0,2		*2,39*		*2,1*	*2,54*	*1,59*	*1,11*	*1,52*	*2,71*
4	0,11		0,4		*2,8*	*1,74*	*1,57*	*1,17*	*2,71*	*2,69*
					-		-	-	-	-
16	*2,43*		*2,25*		*2,85*	*1,58*	*1,6*	*3,14*	*2,8*	*2,75*

Total load

The question is – did our control periods have the positive effect for the utility? One of the ways to interpret the results from the utility point of view is to look at the superposition factor with an experiment and without it. 10 highest utility peaks within the experiment period were selected for this purpose. According to the data, the control actions matched with 7 of them. (An assumption was made when calculating the superposition factor without the control. It was assumed that load demand without the control would have been equal to an average of the demand before the control and the demand after the recovery hours). Table 4.8 summarizes the superposition factors with and without experiment (underlined italics). The last column in the table also shows what systems (heating – h, or hot water – hw, were controlled at that particular hour.

Table 4.8. *Superposition factors with and without experiment*

Date & Time	2004-02-18 09:00	2004-02-21 19:00	2004-02-22 19:00		2004-02-28 19:00		2004-03-02 09:00		2004-03-06 19:00	2004-03-07 20:00
SENAB top, kWh/h	59764	58659	60188		60204		60742		60683	59606
Out temp, °C	1	-0,1	1,4		-0,8		3,6		0,6	1,2
H1	0,43	0,38	0,07		0,81		0,63		0,29	0,24
	0,43	*0,77*	*0,50*		*0,57*		*0,78*		*0,67*	*0,51*
H2					0,27		0,56		0,37	0,36
					0,60		*0,00*		*0,66*	*0,64*
H3	0,71	0,06	0,21		0,07		0,57		0,05	0,05
	0,70	*0,74*	*0,68*		*0,69*		*0,64*		*0,61*	*0,79*
H4	0,00	0,06	0,12		0,23		0,55		0,13	0,13
		0,70	*0,52*		*0,55*		*0,51*		*0,60*	*0,52*
H5	0,38	0,59	0,22		0,14		0,52		0,22	0,25
	0,74	*0,55*	*0,53*		*0,50*		*0,94*		*0,38*	*0,54*
H6	0,57	0,17	0,48		0,09		0,57		0,06	0,09
	0,57	*0,58*	*0,74*		*0,54*		*0,73*		*0,42*	*0,53*
H7	0,43	0,26	0,41		0,63		0,57		0,30	0,29
	0,61	*0,73*	*0,73*		*0,55*		*1,00*		*0,83*	*0,56*
H8	0,78	0,32	0,43		0,22		0,43		0,21	0,22
	0,87	*0,88*	*0,77*		*0,84*		*0,56*		*0,70*	*0,85*
H9	0,54	0,08	0,27		0,05		0,44		0,22	0,11
	0,50	*0,56*	*0,41*		*0,45*		*0,67*		*0,36*	*0,29*
H10	0,46	0,31	0,25		0,25		0,51		0,29	0,20
	0,67	*0,38*	*0,40*		*0,59*		*0,73*		*0,58*	*0,67*
Controlled	hw	h	h		h+hw		hw		h+hw	h+hw

The table shows that in most cases the control actions decreased the superposition factor i.e. moved the customers' demand further away from the utility's peak.

4.4 Households' experience (response)

The interviews with household members were carried out after the experiment. Aditionally, the household notes on heat and hot water comfort from test period were analysed. According to the interviews and notes, the residents noticed some of the control periods, although they didn't express any larger discomfort. Feedback from the customers also contains opinions on their acceptance of load control, questions about compensation, needs for information and alerts.

How much of comfort can customers "give up"? This is different from customer to customer. According to the interviews, the customers are sensitive to temperature drops even of 1 °C, however it does not seem to be problematic for them. Of course, the customers that have lower temperatures at home (for exp. 19°C) are more sensitive.

What is important for the customers when being controlled? The key problem is that customers usually do not distinguish between load demand and energy use. When it is explained that the issue of load demand is not the same as energy savings but rather the pattern and that gradually there won't be savings the interests become weak.

Being informed about the control is important. Some customers raised an idea that the control could be performed according to a prepared schedule, when they are not at home

An issue of refund is important among younger customers. Older customers even offered to take the actions free of charge in order to help to a local utility.

The extensive analysis of these social aspects is provided in another part of this project, performed by Kerstin Sernhed (Sernhed, 2004).

4.5 Economic considerations

Would it be economic for the utility to implement direct load control? It is difficult to give the exact answers. Here come few rough calculations and assumptions:

There are two reasons to implement load control:

- To avoid penalties

Penalty differs on weekdays and weekends. In S.Sandby and Önneslöv areas it is 272kr/kW on weekdays and 136 kr/kW on weekends and holidays. In Furulund area the penalty is 530 kr/kW on weekdays and 265 kr/kW on weekends and holidays.

If, for instance on weekday morning (a typical time when the utility risks to exceed the demand) a subscribed load demand is exceeded for one hour by 1000 kW in each area, the total penalty for the utility would reach 1 074 000 kr.

In year 2003 there were no exceeding of contracted load. In year 2002 it was 1 hour exceeding with 355 kW.

- To decrease the subscribed load level

Costs for the installation 10 000 kr/house. Average expected load savings – 3 kW/house.
If, for instance, to install it in 1000 households, 3000 kW could be saved. The installation, however could cost around 10 000 000 kr.
Expected savings for decreased subscribed load by 3 000 kW would be 814500 kr/year. An average payback would be around 12 years. Of course, assuming that the system could help to avoid penalty for exceeding subscribed load, the payback period could be shorter and thus the investment more attractive.

An alternative sollution could be an installation of "soft heating" systems with "load guards". The costs per household are approx 6000-7000 kr. This system could allow customer to decrease fuse level and gradually get lower bill.

4.6 Environmental considerations

Load demand peaks create significant economic problems for this specific utility. Both load management and peak diesel plant are the solutions, however, with completely different environmental effects. If choosing load management, the increase in CO_2 emissions, as well as other negative environmental effects can be avoided.

The construction of the peak plant would have negative environmental impacts both on local and global levels. First of all, the plant has to be located close to the users. This might create significant problems in local environment, as the quality of the environment would be decreased both by emissions and possible noise level increases. From the global perspective, the production of electricity using diesel generators would mean high CO_2 emissions. The efficiency of such a technology is low and the resulting emissions are high. Diesel generation normally has the lowest generation efficiency, reaching only around 25% and also one of the highest emissions factors per fuel, reaching 288 kg C/MWh (1056 kg CO_2/MWh) (Meyers, et al). For the comparison – the average CO_2 emissions from electricity production in Sweden is 12 kg CO_2/MWh (see Table 2.2).

As mentioned above Skånska Energi is aiming to decrease the contracted load by 6 MW, from 76.5 to 70.5 MW. From the analysis of hourly load data for Skånska Energi year 2002, it was found out that there were 25 hours when the load demand was higher than 70.5 MW. 47.3 MWh of electricity was consumed during these hours. This resulted in about **0.6** tons of CO_2 emissions. If this electricity was produced by the diesel power plant around **50** tons of CO_2 would have been emitted.

4.7 Discussion on experiment

The objectives of the experimental work, performed in collaboration with the utility were divided into 4 parts:

1. To identify and describe the load management needs, prerequisites and possibilities at Skånska Energi AB.

2. To analyze the collected data on total and partial load demands for 10 selected households in Södra Sandby

3. To perform the direct load control experiment in 10 selected households and analyse the results both from households' and utility's perspective (primarily focusing on load savings and effects on households' comfort conditions)

4. To analyse the reduction of environmental impact by load management

Peak load demand is an economic problem for Skånska Energi resulting in financial losses in case of exceeding the subscribed load level. The risk to exceed this level normally occurs at periods of low outdoor temperature on morning and afternoon peaks.
Direct load management is one of the solutions for Skånska Energi to solve the peak demand problem.

The detailed information about the selected households as well as hourly load demand data and the possibility to monitor partial loads for heating and hot water helps to identify the origins of the peaks and thus to create consequent load management strategies. The parameters as load factor, superposition factor, exploitation time were used to characterize the of households' load demand. These characteristics help to define and compare the load demand patterns for households and thus to define which of them could have highest potentials for load management. Ten analyzed households have different load patterns, however there are the tendencies that could be observed and generalized. Detached houses with larger living area had a worse demand pattern for the utility than the semi-detached houses. On the other hand, semi-detached houses have lower consumption and also have decreased their fuse level, primarily due to installed "soft heating" system with load-guards. Lower fuse level means lower network fee for the customer and at the same time lower income for the utility. Generally, there is a potential to decrease the fuse level at many customers, since the maximum available load is normally not used. This in a way could be considered as load management measure, as there would be a limitation for load demand. Of course, it should be considered that this could cause technical problems when fuse goes off. And, in turn, could create a recovery load problems for the utility. An important factor is also that the utility is not very much interested in decreasing fuse levels for households.
The installed metering and communication system "CustCom" proved to be a good technical tool to control the load demand for heating and hot water in households. However, this technical solution requires extra installations in the household which are quite costly. This solution therefore could be questionable in wider application. Though this experiment did not create significant inconveniences for the household members, it is important to consider

that it was carried out with relatively high outdoor temperatures and this was a limitation to test it under most sensitive conditions.

Domestic hot water systems have a good potential for load savings. Most of the systems have tanks with 300 liters of volume, therefore the interruptions for 1 to 4 hours or even longer does not have serious negative consequences. Domestic hot water load is different from heating load since it principally is not dependent on outdoor temperature. It is dependent on behavioral factors which, under proper conditions, have a potential to be adjusted.

Another solution to solve load problem, considered by the utility, is a construction of diesel peak power plant. This alternative has negative environmental consequences compared to load management. This fact proves that though load management is not energy saving measure, it could be used as a tool to achieve environmental targets.

In order to discuss this experiment in a broader perspective and to get a full picture of what has been done, it is essential to consider the behavioral and social aspects. The extensive analysis of these aspects is performed in other part of the project (by Kerstin Sernhed) (Sernhed, 2004).

4.7.1 Experiences and suggestions

Several suggestions need to be emphasized, which could be helpful when conducting this kind of studies in future research work:

- Closer collaboration within the research group

As this is a trans-disciplinary research, a close collaboration within the group is essential. At the same time it is extremely important to clearly identify the personal responsibilities within the project.
When it comes to presenting the results it probably could have been more convenient to present all the aspects (techno-economic, environmental and social/behavioral) in one report. That would have created a more comprehensive view for the reader and would have better covered the issue as well as better reflected the novelty of the study.

- Closer collaboration with utility

It should have been very useful to have a representative of the utility incorporated in the group. This would have definitely helped to avoid many delays with for example installation of meters, data access, etc. This would have also helped to better follow the utility's point of view and to make a further analysis of the techno-economic aspects.

- More efforts on selection of the pilot households

A suggestion to devote more time and efforts for selecting the pilot houses could be given. From the behavioral point of view it could have been more interesting to have households with more residents and wider variety. From the technical point of view, more similar houses could have given better possibilities for comparisons and generalizations.

4.8 Comparison with other studies

There are several examples of direct load management projects, focusing on residential houses both in Sweden and other countries. Two among the largest Swedish electricity suppliers Vattenfall and Sydkraft have performed similar load management projects in detached houses.

For example, Sydkraft project ToppKap, performed at the end of 1980s and the beginning of 1990s focused on developing an electronic load control system for direct resistive heating. The performed tests showed the possibilities of load decrease of 4 kW per house (at -13C) with minimal comfort losses (Sydkraft, 1989). Vattenfall project Uppdrag 2000, performed in 1990, was focusing on controlling electric boilers in small houses with waterborne heating systems. Achieved load savings on average were 3 kW under cold winter day. Many, problems, however came up with recovery load in those experiments.
There are also many examples from other countries, especially the United States. One of them could be a program for load control of cooling systems in households, performed by Long Island Power Authority (LIPA) (LIPA, 2004).

Of course the scale of this project (study) in Södra Sandby is small comparing to others. For example Sydkraft "ToppKap" estimated control potential was 150MW. LIPA Peak load reduction program – 95 MW. However, this project can do a lot to develop a specific methodology for the complex analysis of load problems in electricity market, which would integrate not only techno-economic aspects but the social and environmental as well.

The results of this study are quite close to the results of the similar studies. The basic value and novelty, however, is that it was performed in a trans-disciplinary manner and it was based on 10 "real world" cases, with explicit and detailed information about households and measurements of partial loads. Both measurements of indoor temperature drops, load savings, recovery load (quantitative data) and customer experiences of load management (qualitative data) are analyzed. Therefore in order to get a full picture of this project, it is essential to get acquainted with the analysis of behavioral and social aspects, performed by Kerstin Sernhed (Sernhed, 2004).

5. Environmental effects on a national level

5.1 Load management and emissions in Sweden

5.1.1 Load management techniques

Can load management decrease the emissions in Sweden? This question is quite complex to answer. It depends on many factors already mentioned and, of course, on a kind of load management measures that are implemented.

Peak clipping

Peak clipping means reduction of load during peak periods to get the load profile as desired by the supply side. This is a direct load control measure, primarily used to reduce capacity requirements, operating costs and dependence on peak units. Since the predominant power source to meet the peaks in Swedish system is hydropower, the reduction in emissions would not be significant. However, the share of import from Denmark and Germany prevails during the analyzed peak periods (see Figures. 25 and 29), therefore, assuming that this share is decreased by load control measures, the decrease in emissions could be achieved.

Load shifting on the daily basis

If load management would be used as a shifting from peak to off-peak use it is hardly to expect clear changes in emissions. The curves in Figures 32-35 show that the emissions do not follow the demand. Load following power source is the hydropower. Import (the principal cause of emissions) structure varies more due to economic (or other) reasons rather than demand and the environmental performance. The results show that the emissions are even higher during off-peak periods. The reason for that is that the cheaper Danish condensing power is purchased during off-peak (night) period and the hydropower is preserved for the peak consumption.

Load shifting on the weekly basis

Load demand could also be shifted from weekdays to weekends. As the curves show, the consumption patterns slightly differ in weekdays and weekends (Fig 33 and 35). As it could be observed, the morning peaks are lower during Saturday and Sunday. Looking at the emissions curves, however the same tendency, as discussed above, could be observed – the emissions are higher during the off-peak period.

5.1.2 Other measures

As discussed in chapter 3.1.3, energy efficiency measures contribute to load optimisation and could be implemented due to that reason. Energy efficiency decreases the energy consumption, consequently reducing the emissions.

Another important case in Sweden could be the switching from electricity to other heating source. The Swedish use of electricity is greatly dependent on the climate and the highest peaks usually occur when the outdoor temperature drops. This is due to the fact that electric space heating currently accounts for over 30% of the total electricity consumption in the residential, commercial and service sector (Swedish Energy Agency 2003). The alternatives to electrical heating and sanitary hot water preparation, such as natural gas, biofuel, district heating etc. are widely discussed.

5.2 Swedish case in European perspective

The situation on the Swedish and Nordic electricity market differs in several aspects from the situation prevailing in the rest of Europe. Huge resources of hydropower make the system less sensitive to load fluctuations, since hydropower is the load following technology in the Swedish system. In a system with less hydro resources it would most probably be gas turbines that would meet the short-term peaks. That technology is the most expensive and polluting one. If that one is used as a peak following technology, the need and results of load management would have been much more important and would have played much more significant role in improving the environmental performance.

Liberalization of electricity markets in Europe creates the possibilities for the consumers to choose their electricity supplier. This choice is usually based on price, but there is a new initiative – environmental labeling which would enable people to decide using the environmental criteria as well (Lane, 2003). Can environmental labeling of the electricity improve the situation? Of course, it greatly depends on the awareness and willingness of the user. If customers purchasing the electricity would see that a significant part of electricity comes from polluting sources they would probably not buy it. This would create a higher demand for renewable energy and could gradually cause a need of load management measures in order to meet the load with a highest possible renewable share. When connecting the issue to load questions it is essential that such information is available on an hourly basis. It is also very important to make this information visible and easily readable for customers. Nowadays, there are the technical possibilities to inform the customer about the usage and price of electricity on an hourly basis. However, the hourly information on what kind of energy is used is not available so far. This kind of information is even difficult to get on a national level, since the producers are not obliged to report it on an hourly basis (Svenska Kraftnät, 2003).

Two other factors that would obviously increase the concerns for load issues are the Swedish strategy to phase out nuclear power and to increase the share of renewable energy. A system of electricity certificates was introduced in Sweden on May 2003 (Swedish Energy Agency 2003). The system determines a certain quotas for the renewable energy (it should be mentioned as well that there are special restrictions for hydropower units to be considered as a renewable energy units and only a very small share meets these restrictions). In year 2003 the renewable electricity quota was 7,4% from the total electricity consumed. In year 2010 this quota will reach 16.9 % (Swedish Energy Agency, 2003). Renewable energy units, such as bio-fuel and wind power normally do not operate as a demand following power sources. This means that during the peak demand hours the dependence on import could increase.

Furthermore, the previously mentioned study on marginal power and CO_2 emissions by Swedish Energy Agency concludes that **in a long term**, natural gas based power production in Norway is considered to be a marginal capacity. It is seen as the cheapest technology while considering the full costs. Due to low natural gas costs in Norway and sufficient power transmission capacities between Norway and other Nordic countries, it should be more economical to import power from Norway than to build natural gas power plants in other countries.

6. Conclusions

The variation of load demand in residential sector could be explained only by extensive analysis and the integration of technical, economic and social factors.

The interests in load management differ depending on the perspective of the actors involved - customer, utility, producer, national grid operator and, finally, society. It is vital to clearly identify these perspectives in order to achieve successful load management actions. Load management effects, in turn, are different on different levels.

In the experimental part of this study, direct load management was tested as one of the solutions for the associated electric utility Skånska Energi to solve peak demand problems - increased fee for exceeding the subscribed load level can be an economic problem for some grid companies.

Thanks to an existing remote reading and monitoring system CustCom the detailed information about 10 electric-heated households as well as hourly load demand data for total load and partial loads for heating and hot water was collected and analyzed. It helped to identify the origins of the peaks and thus to create consequent load management strategies, which were used for the experimental tests.

The on/off load control experiment was carried out in February- March 2004. Electric space heating and hot water systems in 10 analyzed households were controlled by the utility using CustCom system. Hourly load savings for heating varied from 1,1 to 3,8 kW per household.

Under the weather conditions, which were present during the experiment, the residents noticed some of the control periods, although they didn't express any larger discomfort. The indoor temperature drops were low, varying from 0 to 1,7 °C. There were no serious interruptions of domestic hot water supply recorded.

CustCom system proved to be a good technical tool to perform load control actions. The costs for installation of extra equipment for control, however, were really high, reaching 10000 SEK/ household (1 100 EUR). This solution therefore could be questionable in wider application.

As the case of Skånska Energi shows, load management could be an environmentally sound solution to economic problems caused by peak load demand, compared to another alternative - diesel peak power plant – that would have many negative environmental impacts.

When it comes to the analysis of environmental effects on national level, load management measures, such as peak clipping and load shifting can hardly decrease the emissions, as the load following supply source in Swedish system is hydropower. Furthermore, according the national grid operator, responsible for stable load situation on national level, the economic factors (costs, long-term contracts etc) are of greater decisive importance than environmental factors (cleaner production sources) when managing peak load demand problems.

Energy efficiency measures have a potential to decrease emissions and, at the same time, could contribute to the solution of load problem.

One of the key complications for good estimation of the environmental effects is the unavailability of hourly data, divided according to electricity production source.

7. Further research in this field

The experimental works helped to collect many detailed and valuable data about 10 analyzed households. Extending the collected data and experiment results with simulations could help to develop different scenarios and enable the interpretation and application of the results in a wider context.

An important step in continuing the research is an analysis and development of the strategies for expressing the economic benefits of load management actions both for the customer and the utility. A system of refunding the customer for the comfort loss needs to be developed.

A research on environmental benefits of load management on different levels should be continued. An interesting issue is the development of customer information system in order to show the environmental benefits of rational load use.

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