Sustainable energy use in 40 houses. A study of changes over a ten-year period

Hiller, Carolina

2003

LUND UNIVERSITY

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

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Carolina Hiller

Report TVBH-3044 Lund 2003
Department of Building Physics

LUND INSTITUTE OF TECHNOLOGY
Lund University

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Carolina Hiller

Licentiate thesis

Department of Building Physics
SP Swedish National Testing and Research Institute
Box 857
SE-501 15 Borås
Sweden

Department of Building Physics
Lund University
Box 118
SE-221 00 Lund
Sweden

ISRN LUTVDG/TVBH--03/3044--SE(103)
ISSN 0349-4950
ISBN 91-88722-29-5

Abstract

In Sweden there has been a number of energy saving measures carried out the last 25 years. From a sustainable perspective it is essential that the energy use stays on a low level the entire lifetime of the building and not only when it is newly built or reconstructed. In order to fulfil the requirement of low energy use over time the factors influencing the energy use need to perform well even in a long perspective.

The main objectives of this licentiate thesis is to enlighten the field of sustainable energy use in general and in particular to verify or reject the *hypothesis* that the energy use increases over time in modern single-family houses in Sweden.

The houses studied are a group of 38 modern nominal identical houses, where their energy data have been analysed for more than 10 years. This has been carried out in three major steps. In the first step corrections have been made in order to be able to compare the energy use between different years. The next step involved structured interviews with six house owners in order to relate activities that have occurred over the years, to their energy use. In the third step measurements of the specific heat loss were carried in two of the houses in order to relate it to their actual energy use. Comparisons were also made with theoretical values calculated in Enorm.

No general trend over time of the energy use has been able to be identified. The average energy use for the group of houses is very stable over the years. However, for individual houses the energy use can both increase and decrease over the years and show sudden dips and peaks from one year to another. If this is a correct conclusion is impossible to say due to that factors influencing the energy use have not been identified and consequently the appearance of the energy use could not be related to certain activities. Instead the interviews highlighted the difficulties with using a retrospective technique. The measurements of the specific heat losses of two houses indicated that the residents have a decisive role regarding the amount of energy used as the house with the highest energy use had the lowest specific heat loss. The Enorm calculations most probably did underestimate the energy use of the house with the highest energy use. The specific heat losses for both houses were also underestimated in Enorm.

Key words: single-family houses, sustainable energy use, changes over time, trends, energy data, degree day method, residents, specific heat loss, energy calculation, Enorm, HEAT2

Preface

This licentiate thesis is part of the project ”Sustainable energy use in houses”. The first publication within this project was a literature study and sensitivity analysis in Enorm[1]. The work was initiated by Professor Arne Elmroth at the Department of Building Physics, Lund University and Eva Sikander at SP Swedish National Testing and Research Institute.

The project is financed by the by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS), the Swedish National Energy Administration (STEM) and SP.

The study has developed through many, and sometimes long discussions, with Professor Arne Elmroth and Professor Ingemar Samuelson at SP. They have given me many valuable inputs. Professor Jesper Arfvidsson at the Department of Building Physics, Lund University has been joining the recent meetings and I am looking forward to work with him in the future. Dr. Per Ingvar Sandberg at SP has been guiding me through my work with the simulations and measurements, where Roland Löfström at SP has technically assisted me. Lilian Johansson at the at the Department of Building Physics, Lund University and Carina Johansson at SP have been there for me whenever I needed some assistance regarding the aesthetic and layout of the report.

I would like to thank the residents of the houses who have participated in my study. Without their co-operation this study would not have been feasible.

I would also like to mention all my colleagues at SP whom I like having around me during my every day life. And my colleagues at the Department of Building Physics, Lund University that I have around me too seldom.

A warm thought goes to my family. Especially to Christian for giving me the time and support to finish my thesis. And to Hannah, my little daughter, for being my sunshine even on the cloudiest days.

Carolina Hiller

Borås, November 2003

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[1] Hiller, C. (2003). *Sustainable energy use in houses - Will the energy use increase with time? Study of literature and computer estimations*. Lund: Department of Building Physics, Lund University. (Report TVBH-3041)

Contents

Sammanfattning

I Sverige har de senaste decennierna ett antal energisparåtgärder genomförts, både i den befintliga bebyggelsen och i nyproducerade hus. Ur ett hållbarhetsperspektiv är det av vikt att energianvändningen i våra småhus är låg och förblir låg under husens hela brukstid. Den teknik som tillämpas måste vara hållbar över tiden och fungera väl när den används av brukarna. För att uppfylla kravet om låg energianvändning över tiden måste således de faktorer som har en påverkan på energianvändningen även bibehålla en god funktion ur ett långtidsperspektiv.

Huvudsyftet med projektet är att belysa hållbar energianvändning i bebyggelsen generellt och specifikt att utröna om hypotesen om att energianvändningen i våra moderna småhus i Sverige ökar med tiden är sann.

Energianvändningen för 38 moderna, nominellt identiskt byggda, småhus analyserades över en period på drygt 10 år. Projektet har utförts i tre huvudsteg. I första steget, kapitel 5, korrigerades energianvändningen med avseende på utetemperaturen för att kunna göra en jämförelse mellan de olika åren. I nästa steg, kapitel 6, intervjuades sex husägare enligt ett frågeformulär angående energirelaterade aktiviteter/händelser som hade ägt rum bakåt i tiden. I det tredje steget, kapitel 7, utfördes mätningar av förlustfaktorn i två av husen för att relatera den till husens faktiska energianvändning. Jämförelser gjordes även med teoretiskt framräknade värden på energianvändningen och förlustfaktorn med hjälp av Enorm.

Ingen generell trend över tiden vad det gäller energianvändningen för grupphusområdet har identifierats. Medelenergianvändningen för husen har varit stabil från år till år. Däremot har energianvändningen för individuella hus både ökat och minskat över åren och dessutom uppvisar den ibland plötsliga ”berg” och ”dalar” från ett år till ett annat. Om det är en korrekt slutsats att energianvändningen inte uppvisar någon markant ökning eller minskning över åren är omöjligt att säga eftersom faktorer som har en påverkan på energianvändningen inte har fastställts och således har man inte kunnat relatera utseendet på energianvändningen till specifika aktiviteter. Snarare påvisade intervjuerna svårigheterna med att använda en retrospektiv teknik. Mätningarna av förlustfaktorn för två hus visade på att de boende spelar en avgörande roll vad det gäller nivån på energianvändningen eftersom huset med den högsta energianvändningen hade den lägsta förlustfaktorn. Beräkningarna av energianvändningen tyder på att Enorm underskattade energianvändningen för det huset med högst energianvändning. Beräkningarna av förlustfaktorn för de båda husen var också underskattade.

1 Introduction

The residential, commercial service sector etc. used in 2001 156.2 TWh energy, which stands for almost 39 % of the Swedish total energy use. (After making corrections for the climate conditions of 2001 the amount is 159.4 TWh.) The total temperature-corrected use of energy in this sector has remained relatively stabled between 1970 and 2001 (Swedish National Energy Administration, 2002). This trend can be explained by that energy savings made have been “eaten up” by the increased heated area. Even though the total energy use has been on approximately the same level the last 30 years the energy sources have changed dramatically, especially at the end of the 70’s and beginning of the 80’s. For single-family houses the change has mainly been from oil dependency to a dependency on electric heating, Figure 1:1.

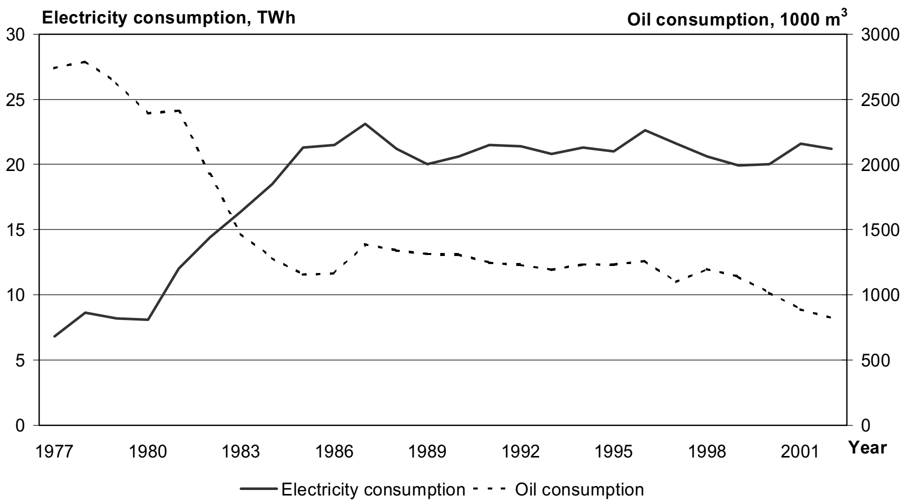

Figure 1:1 Electricity and oil consumption from 1977 to 2002 in single-family houses in Sweden[2, 3]

[2] Comments to Figure 1:1.

- The consumption has not been corrected with the outdoor temperature.
- The energy used for electric heating includes both houses, which have electric heating only, as well as houses with bivalent systems (except for the year 1977). In addition the household electricity is included.
- The oil consumption includes both houses heated with oil only as well as houses with bivalent systems.
- Possibly is the oil consumption underestimated for the years 1985 and prior.
- In 2000 the definition of one- and two-dwelling buildings is somewhat widen.

The trend in energy per square meter and year have been analysed in a report by Carlsson (1992) and the total annual gross (bought) energy use[4] in single-family houses was in 1970 350 kWh/(m^2·year) and in 1990 207 kWh/(m^2·year). For multi-family houses the corresponding figures were 340 kWh/(m^2·year) and 226 kWh/(m^2·year). These figures have been corrected with the outdoor temperatures of the years in question and show a trend of decreased specific energy. In a recent study (Nässén and Holmberg, 2003) it was shown that this trend has ceased during the nineties and that the new building stock does not become more and more energy efficient, at least this is obvious for multi-family houses. If there will be a boost in the construction of new buildings it will result in an increased energy use for the sector.

There are many burning issues in the field of energy both within Sweden as well as international. When the EU directive on the energy performance of buildings (Commission of the European Communities, 2002), which came into force on the 4th of January 2003, will be implemented focus will be put on how energy efficient buildings are and must be accounted for e.g. in a buying-selling situation. In Sweden a law came into force this spring regarding electricity certificate. This implies that a certain amount of the electricity bought must be from renewable energy sources. The purpose of the law is subsequently to increase the share of the electricity that is produced from the sun, wind, water and biomass. Moreover, the Swedish parliament has decided that the electricity should be read off the meter at least once a month, compared to today when it is done once a year. One of the purposes is that the users should be more aware of their consumption since they will be billed the actual cost and not an estimated one, resulting in a decreased electricity consumption.

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[3] Statistics Sweden (1978-2003). *Energy statistics for one- and two-dwelling houses in 1977-2000* found in Statistic Bulletins Bo 1978:17, Bo 1979:12, Bo 1980:20, E 1981:13.2, E 1982: 12.1, E 1983.14.1, E 1984:17.2, E 16 SM 8504, E 16 SM 8601, E 16 SM 8702, E 16 SM 8801, E 16 SM 8902, E 16 SM 9003, E 16 SM 9102, E 16 SM 9302, E 16 SM 9305, E 16 SM 9403, E 16 SM 9504, E 16 SM 9603, E 16 SM 9703, E 16 SM 9801, E 16 SM 9901, EN 16 SM 0003, EN 16 SM 0101, EN 16 SM 0201 and EN 16 SM 0302.

[4] The gross (bought) energy is defined as: i) the energy distributed to the house in the case of electric heating, district heating and natural gas and ii) the theoretical energy contents (i.e. the primary energy) in the case of wood and oil furnaces. In other words, no losses in the heating system are taken into consideration.

2 Definition of problem

There has been a number of energy saving measures carried out the last 25 years, primary in the newly built housing stock. In a sustainable perspective it is of great importance that the energy use stays on a low level the entire lifetime of the building and not only when it is newly built or reconstructed. In order to fulfil the requirement of low energy use over time the factors influencing the energy use need to perform well even in a long perspective.

There have been many energy saving housing projects, but few of these have been followed up after some years in operation. An interesting question is if the energy use has remained on a low level. To study the long-term energy use of these low-energy projects is of importance, especially in regards to the implementation of energy saving measures to the ordinary housings stock.

Three projects, where the performance of low-energy single-family houses after some years in operation has been studied, have been found. The results were that after 7-10 years the energy use had increased with 13 % (corresponding to 1500 kWh) in one study (Weber, 1996). In another project the increase was after 10 years up to 40 % (corresponding to 4000-5000 kWh) (Berggren et al., 1997). In the final study the increase after 5 years was 5 % (corresponding to 900 kWh) (Nilson and Uppström, 1997).

The findings give indications of that the energy use might increase or at least vary over time, which is of interest to study further by conducting investigations of a larger number of "normal" houses.

In a previous report (Hiller, 2003) a literature study of the durability of energy-related parameters, associated with the building and building services, as well as the influence of the residents on the energy use was compiled. The findings were that in general there seems to be a lack of research, especially field research, on the topic of durability and performance over time for a number of building-related parameters. Some of the findings in the literature studied are: The air tightness of the building and parameters affecting it do not show any major deterioration over time. There seems to be a general tendency of a reduction in the airflow in the ventilation systems. Inspections of loose fill insulation materials show that there is a problem with settlement some years after installation. Gas leakage in insulation and other kinds of deterioration might also be a problem. There seems to be a gap to fill concerning the research of ageing of windows, long-term performances of heat pumps and control systems. Regarding the household electricity, no investigations on the long-term performance of electrical appliances and lighting have been found.

The residents of the house influence a number of parameters significant to energy use. The greatest contribution from the residents is the variations in the energy use between one household and another. The literature points towards that the habits of the residents are of great importance to these variations. The investigations do not agree when it comes to relationships between the size of the household, the age, the social status, the activity, the life style etc. and the amount of the energy used.

Long-term changes in energy use related to the residents are very briefly brought up in two studies, where changes in the size of household and the age of the children are possible explanations. These changes are unfortunately not discussed in more details.

3 Objectives

The main objectives of this licentiate thesis is to enlighten the field of sustainable energy use in general and in particular to verify or reject the *hypothesis* that the energy use increases over time in modern single-family houses in Sweden.

Issues that will be discussed are:

- How the energy use in single-family houses changes with time
- How different parameters of the building and building services as well as activities of the residents, can affect the energy use, especially changes in the energy use
- The building and the building services contra the residents' behaviour
- How to interpret energy data

The study can be valuable in the discussions of possible problems with the analysis of energy data, in particular regarding fair comparison between different houses and between different years. In the long run the study can be useful in the choice of techniques and also in the planning phase of buildings.

The houses in question are ordinary *modern* single-family houses, built after the Swedish energy conservation codes were introduced (1977), that have been in operation at least 10 years and the focus will be on some common constructions and service systems. The aim is that the project will differ from the previous studies by investigating a larger number of houses and making a more thorough investigation.

4 Methodology

To verify the hypothesis and identity any trends in the energy use as well as to how factors that influence these changes the project is divided into three major parts, Figure 4:1.

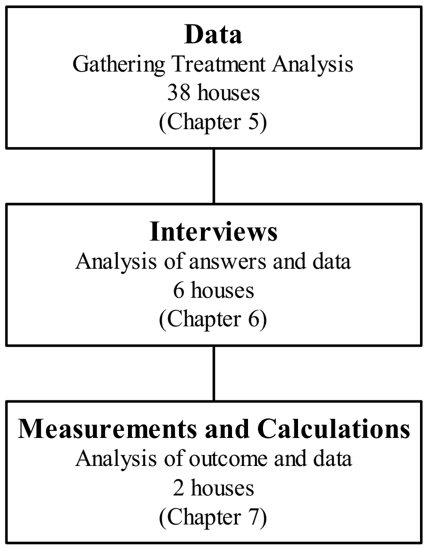

Figure 4:1 The three major parts in the project

In the first step energy and water data is gathered for a group of nominally built single-family houses. The data are corrected for the number of days in a year so that it corresponds to the energy use of 365 days. The data are also corrected for the outdoor temperature. The degree-day method is used for the second correction.

The next step involved structured interviews with six house owners on the housing estate. The questions concerned activities and events, having an influence on the energy use, that have occurred over the years. The interview was supplemented with questions and discussion regarding the house owner's energy use. The answers were thereafter analysed together with the energy use.

In the third step measurements were carried out in order to identify the specific heat loss of two of the houses. The measurements involved participation from the residents. Input data was gathered in order to use the PC-program HEAT2 (version 5.0) to calculate the two-dimensional transient heat losses to the ground from the houses. Additionally, input data was needed for the calculation of the energy use with the energy calculation program Enorm 1000 (version 1.10) as well as a theoretical heat loss factor.

5 Analysis of energy data for a housing estate (38 households)

In this chapter the energy and water data for 38 houses are analysed as a group in regards of trends in energy use over time. Individual houses' energy use are also demonstrated. In addition, how the variance changes over time is studied. The chapter ends with a discussion of how the electricity price has varied over the years and its possible impact on the energy use. To be able to make comparisons between different years, the energy use is corrected for the number of days of the year as well as the outdoor temperature. Different approaches are made concerning the correction with degree days (outdoor temperature).

The purpose is to identify any general trends in the energy data over a time period of more than 10 years and how the study should use the results. The problem with the analysis of data will also be discussed. Any change in the variance of the data over the years will also be analysed as well as the electricity prices.

The chapter begins with a description of the choice of housing estate and the technical characteristics of the houses.

5.1 Description of the houses

5.1.1 The choice of houses

The criteria for the houses of interest were the following:

- The construction of the houses and the building services should be known and generally used.
- The houses should be part of a group of houses that are nominal identical built.
- The houses should be modern houses built after 1977, the year that the new Swedish energy conservation codes were introduced.
- Energy data should be available for at least ten years back in time for the houses.
- Climate data should be available for the location where the houses are situated.

The houses in question have not been randomly chosen from all the houses in Sweden that fulfil the criteria stated above. A suitable housing estate were found in Borås near from where the author works, which made it possible for frequent visits to the houses.

5.1.2 Technical description of the houses

The housing estate constitutes 41 houses built in the mid 80's (energy data were available for 38 of the houses). The houses were identically built at the site, but over the years the residents have made changes to the houses, e.g. extended the houses and installed tiled stoves.

The houses are detached single-family houses with conventional heating and ventilation systems, namely electric boiler with waterborne heat and exhaust air ventilation. Some of the houses, according to the energy supplier 9 houses, have installed an exhaust air heat pump. The exact figure of the number of houses with heat pumps might be incorrect as it is dependent on the house owners to notify the supplier about any changes made to the systems. At least one case where the supplier has incorrect information about the heating system is known to the author.

The houses have wooden framework and the foundation is slab on ground. The windows consist of sealed triple-glazed units. The houses have originally one floor area of just above 104 m^2, but more than half of the houses have made extensions to their houses and some have built a second floor. These extensions appear to be very different from one another and they might not have the same constructions as the original building and have most probably been built by different building companies. This means that the initially nominal identical buildings after some years of operation can be very different from one another.

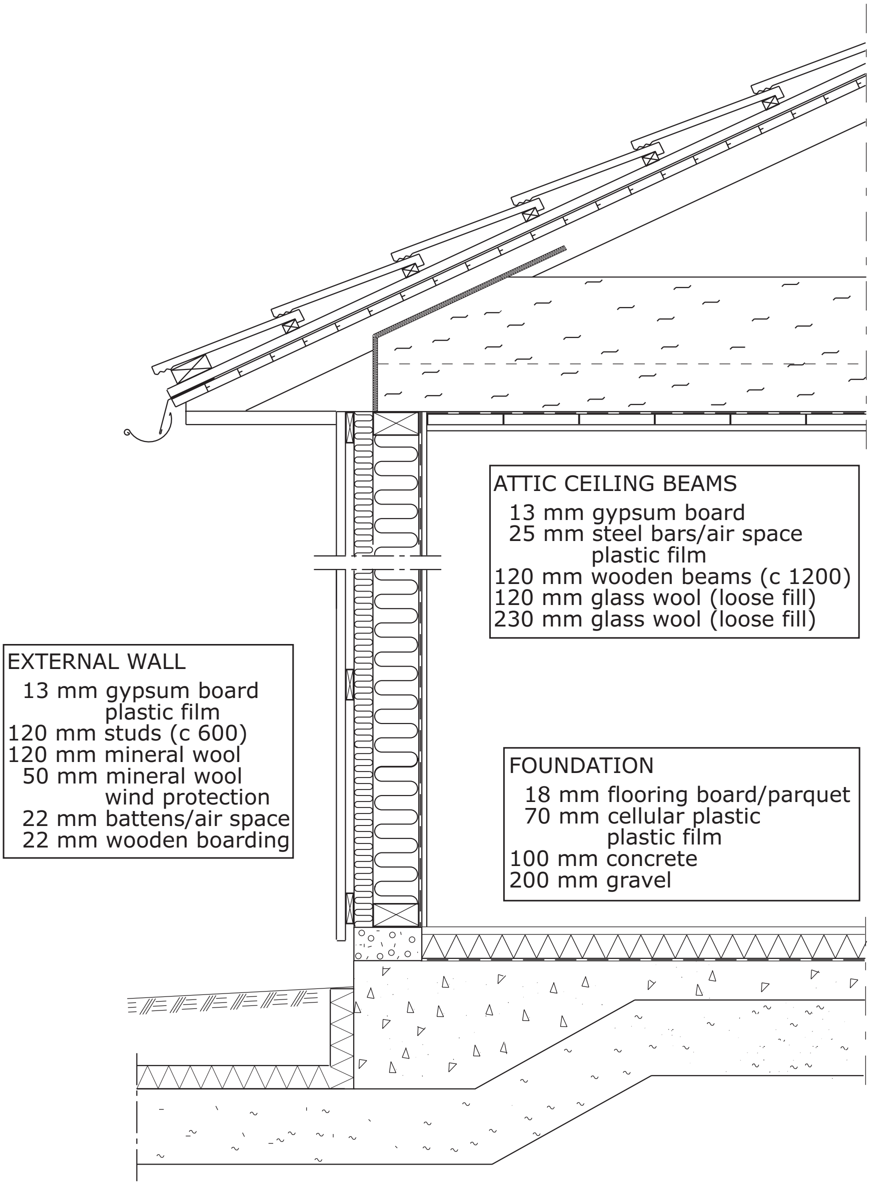

Figure 5:1 The construction of the original houses

Figure 5:1 shows the construction for the original building. The houses have a fairly common construction typical for the 80's.

A remark is here in place regarding the difficulty in getting the correct information about the construction. The residents did not have complete information about their houses, especially not detailed facts on dimensions and type of materials. Maybe this is “typical” for owners of single-family houses. The town planning department[5] did have some drawings of the houses but not on the extensions. These had not been handed in to them. The building company that had built the houses was contacted in order to get some details on the construction. However, some changes had been made to the original plans. Neither the residents nor the town planning department had updated documents on the houses in question.

5.2 Data gathering

The energy and water data was gathered from the local energy supplier. The data was easily available for the latest owner of the houses or at least five years back in time. In other words, changes in ownership have not occurred in most cases, unless it happened during the past five years. The data was only available for 38 of the houses for time periods of 6 to 12 years. The years in questions were 1988/1989 to 2000/2001. The readings of the electricity and water meters were mostly done at the end of May/beginning of June every year.

The energy data is the total bought energy where the energy for the household electricity, hot water production and the space heating are included. As already mentioned some houses have installed heat pumps, if the heat supplier is correctly informed.

The water data includes the total water consumption, i.e. both the cold and the hot water usages.

5.3 Treatment of data

Listed below are some problems that make the treatment of large quantities of data somewhat time-consuming and might introduce some uncertainties in the data:

- The meter readings do not occur with exactly one-year intervals.
- The energy and water readings do not always occur at the same time.

[5] The town planning department plans the housing environment and the land usage in the municipality. They file building related documents such as building permits and drawings of constructions.

- There are cases of several readings occurring during a particular year.
- There are cases with two meters or change of meters.
- The meter changes to zero at certain values

In Section 5.3.1 it is described how the deviation from one-year intervals is corrected. The second issue listed above have been overlooked due to that all data, both energy and water data, are treated on a yearly basis counted from the difference of two dates that are the closest to 365 days. As most readings, both of the water and energy meter, takes place at the end of May/beginning of June a particular year of energy use and water consumption usually correspond to the same days more or less. The third, fourth and fifth items have been taken into consideration in the data handling.

5.3.1 Method for the corrections of the number of days

Firstly, the data have been corrected with the number of days of a year, in such a way that all the energy and water usages correspond to what is consumed in 365 days.

$$\begin{array}{l} \textit{Energy/Water} \\ \textit{use} \\ \textit{(yearly)} \end{array} = \begin{array}{l} \textit{Energy/Water} \\ \textit{use} \\ \textit{(reading)} \end{array} \times \left(\frac{365\ \textit{days}}{\textit{No. of days between readings}} \right)$$

The starting point for the corrected energy and water usage is the date when the actual reading took place and the interval ends 365 days later. This new date, when the interval ends, is usually not the starting point for the consecutive year's data.

Furthermore, this method of correction assumes that the real energy and water use for the days that deviate from the 365 is equal to an average daily energy use. If this is a good assumption when it comes to the water consumption depends on if the residents' usage is an average usage these particular days or not. For the energy use the correction would imply that the outdoor temperature does not differ over the year, which of course is not true. The readings in this study take place at end of May/beginning of June. At this time of the year the average monthly temperature is higher than the average yearly temperature, which means that the correction above generally results in a slightly too high value if the period between two consecutive readings is less than 365 days and in a slightly too low value if the period between the readings is more than 365 days. The above statement is true if the outdoor temperature for the deviating days is "normal". Greatly deviating outdoor temperatures during these days are not at all compensated for.

5.3.2 Method for the corrections of the outdoor temperature

The energy data has thereafter been corrected with the outdoor temperature data to enable a comparison from one year to another for a particular building. The method used is the correction with degree days for the time period and location in question. This steady-state method is appropriate if the building use, including indoor temperature and internal heat gains, and the efficiency of the heating and ventilation systems are constant.

The degree days states how much the monthly temperature deviates from the normal temperature for a particular location. The correction is applied on the climate dependent part of the energy use. Note that this method does not take into consideration the type of building.

The method with degree days is commonly used even though it has its limits. The degree days were purchased from the Swedish Meteorological and Hydrological Institute (SMHI). Details of the calculations and usage of the degree day method are given in appendix A.

An extended method to the degree days is the energy index where not only the outdoor temperature but also the solar and wind data is taken into consideration together with the location of the building, type of building and application of the building[6]. The energy index is available from 1998 and could therefore not be used for the analysis in this study as a time period from 1988 and forward is studied.

The number of degree days for a "normal" year is calculated from data for the period 1961/62 – 1978/79. From January 2003 this period was changed to 1971-2000. This is due to that the ten-year-period 1991-2000 was exceptionally warm[6].

[6] Information about the degree day method is available from http://www.smhi.se/ (the Swedish Meteorological and Hydrological Institute)

5.3.3 Calculations of corrected energy data

In this chapter a number of different diagrams are presented where corrections with degree days have been made with different assumptions of the hot water fraction and household electricity.

The starting points are Equations 5.1 and 5.2 below.

$$E_{corr} = \left(E_{year} - E_{indep}\right) \times \left(\frac{DD_{normal}}{DD_{actual}}\right) + E_{indep} \qquad [\text{kWh}] \qquad (5.1)$$

where

$$E_{year} = E_{read} \times \left(\frac{365}{D_E}\right) \qquad [\text{kWh}] \qquad (5.2)$$

where

E_{corr}	corrected energy use with degree days [kWh]
E_{year}	corrected energy use with the no. of days of the year [kWh]
E_{indep}	part of the energy use that is independent of the outdoor temperature [kWh]
E_{read}	energy read of the meter [kWh]
DD_{normal}	no. of degree days during a normal year [K·day]
DD_{actual}	no. of degree days during the actual year in question [K·day]
D_E	no. of days between energy readings [day]

The part of the energy use that is independent of the outdoor temperature is the household electricity and the hot water production (Equation 5.3). The total water consumption for each house is known. After correction with the number of days of the year (Equation 5.5), the hot water fraction and the temperature rise (ΔT) are assumed and the energy for the hot water production is calculated (Equation 5.4).

$$E_{indep} = E_{el} + E_{ww} \qquad [\text{kWh}] \qquad (5.3)$$

where

$$E_{ww} = W_{year} \times f \times \rho c_p \Delta T \qquad [\text{kWh}] \qquad (5.4)$$

where

$$W_{year} = W_{read} \times \left(\frac{365}{D_W}\right) \qquad [\text{m}^3] \qquad (5.5)$$

where

E_{el}	household electricity [kWh]
E_{ww}	energy for the hot water production [kWh]
W_{year}	corrected total water consumption with the no. of days of the year [m^3]
W_{read}	total water consumption read of the meter [m^3]
f	fraction of hot water ($W_{hot\ water}$ / W_{year}) [m^3 hot water/m^3 total water]
ρc_p	amount of energy needed to heat 1 m^3 1 K [7] [kWh/(m^3·K)]
ΔT	temperature rise [K]
D_W	no. of days between water readings [day]

E_{el} is put to 3000, 4000 or 5000 kWh. These figures are arbitrary chosen. General figures for the amount of household electricity are usually 4000-5000 kWh. For the best available technology the value can be down to almost 2000 kWh (The Swedish Consumer Agency, 2002). On the other hand there are also households that can have much larger consumption than 5000 kWh (NUTEK, 1994).

There are different ways that the energy use for the hot water production can be calculated. One option is to consider the total water consumption and the amount of energy needed to raise the water to the waste water temperature. This means that ΔT is equal to the difference between $T_{waste\ water}$ and $T_{into\ the\ house}$. An average temperature of 30ºC can be used for $T_{waste\ water}$ (approximately this figure have been estimated in Gaunt (1985) and she also refers to previous studies with similar estimations) and $T_{into\ the\ house}$ can be put to the average yearly outdoor temperature, which for Borås and the time period 1988-2001 is 7.0ºC. Equation 5.4 can then be written as

$$E_{ww} = W_{year} \times 27 \qquad \text{[kWh]} \tag{5.6}$$

Another option is to consider the fraction of hot water and the amount of energy needed to raise the water to the tap hot temperature. This means that ΔT is equal to the difference between $T_{tap\ hot\ water}$ and $T_{into\ the\ house}$. An average temperature of 55ºC can be used for $T_{tap\ hot\ water}$. 55ºC was measured as the average tap hot water in the study by Gaunt (1985). This figure seems reasonable considering the requirements on the hot water stated in SBN 80 (Statens planverks författningssamling, 1981), namely that the water from the tap should be 45ºC or more, but when used for personal hygiene not more than

[7] Data for water (disregarding any temperature dependencies): $\rho \approx 1000$ kg/m^3 and $c_p \approx 4.2$ kJ/(kg·K) ≈ 1.2 Wh/(kg·K).

65ºC. $T_{into\ the\ house}$ is the same as before. The fraction of hot water, f, is set to 20 or 30 %. These values were arbitrary chosen after conversation to the water supply and sewerage department at Borås municipality[8]. If the first option with a water temperature of 30ºC is recalculated to a tap hot water temperature of 55ºC this correspond to a fraction of hot water of 48 %. These figures will be used here forth.

The combinations of the different corrections have been summarised in Table 5:1.

Table 5:1 The combinations of different values of the hot water fraction, f, and, the household electricity, E_{el}

Hot water fraction as percentage, f [m^3 hot water/m^3 total water]	**Household electricity, E_{el} [kWh]**	**Corrected energy use with degree days, E_{corr} (f, E_{el}) [kWh]**
20%	3000	E_{corr} (f = 20%, E_{el} = 3000 kWh)
20%	4000	E_{corr} (f = 20%, E_{el} = 4000 kWh)
20%	5000	E_{corr} (f = 20%, E_{el} = 5000 kWh)
30%	3000	E_{corr} (f = 30%, E_{el} = 3000 kWh)
30%	4000	E_{corr} (f = 30%, E_{el} = 4000 kWh)
30%	5000	E_{corr} (f = 30%, E_{el} = 5000 kWh)
48%	3000	E_{corr} (f = 48%, E_{el} = 3000 kWh)
48%	4000	E_{corr} (f = 48%, E_{el} = 4000 kWh)
48%	5000	E_{corr} (f = 48%, E_{el} = 5000 kWh)

In addition a correction is studied that does not take into consideration the part of the energy that is independent of the outdoor temperature (Equation 5.7).

$$E_{corr,\,tot} = E_{year} \times \left(\frac{DD_{normal}}{DD_{actual}} \right) \quad \text{[kWh]} \tag{5.7}$$

[8] Department of water supply and sewerage, Borås municipality, phone call 2001-05-30.

Lastly, the average yearly temperatures have been calculated by taking the average monthly temperatures for Borås from June to May in order to use data corresponding to the same period as the energy and water data.

5.3.4 Analysis of corrections

The different assumptions and calculations are shown in Figures 5:2 to 5:7 for a period of 12 years.

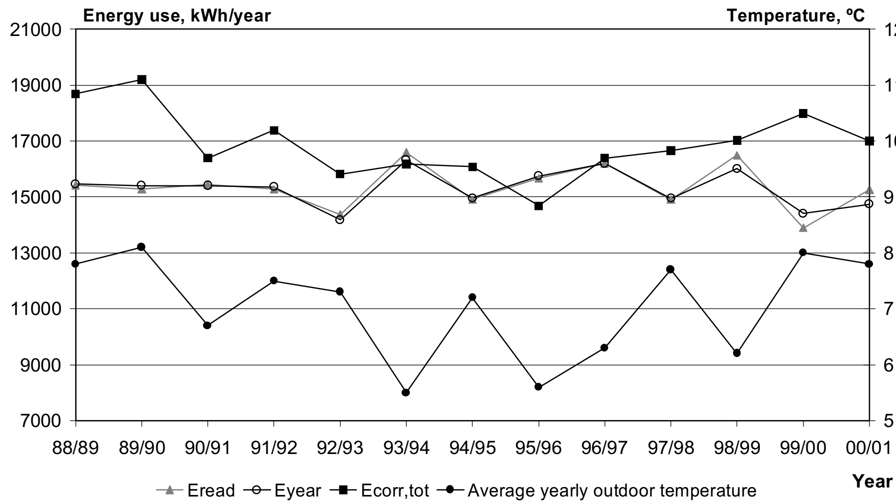

Figure 5:2 Yearly energy use (read of the meter and corrected) and average yearly temperature from 88/89 to 00/01, House VI

In Figure 5:2 the energy use (E_{read}, E_{year} and $E_{corr,tot}$) are shown as well as the average yearly outdoor temperatures for Borås. The temperatures are demonstrated in order to be able to make a visual comparison with the outdoor climate for a particular year.

Firstly, the correction with the number of days in a year can be discussed, i.e. the graphs E_{read} and E_{year}. The number of days between the readings does not seem to differ much from 365 for most years. For the last years the difference are +11, -13 and +13 days, which results in slightly larger corrections. As discussed above, the compensations are probably a bit exaggerated as the temperatures in May and June normally are higher than the yearly average.

When comparing $E_{corr,tot}$ with E_{year} and the average yearly outdoor temperature the diagrams visualise how the correction with degree days appears. If the actual energy use (E_{year}) is not decreasing when the temperature is higher a particular year, the corrected energy use ($E_{corr,tot}$) is increased or vice versa if there is a temperature drop. Generally it can be seen that the $E_{corr,tot}$ lays on a higher level than E_{year}. This is due to that the 90's was exceptionally warm but the period that the degree days for a normal year (DD_{normal}) has used is 1961/62 to 1978/79. As already mentioned this period has now changed to 1971-2000, which would mean a general lower $E_{corr,tot}$.

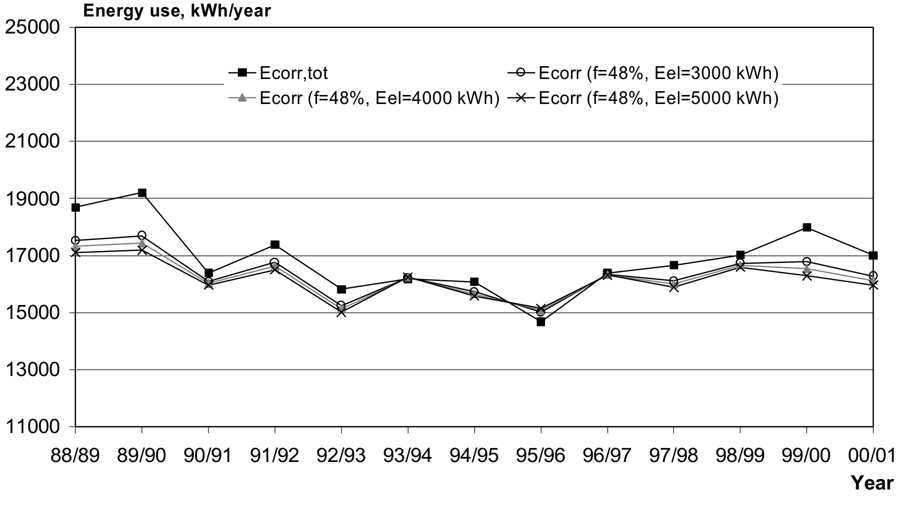

Figure 5:3 Yearly energy use differently corrected ($E_{corr,tot}$ or f = 48% and E_{el} = 3000, 4000, 5000 kWh) from 88/89 to 00/01, House VI

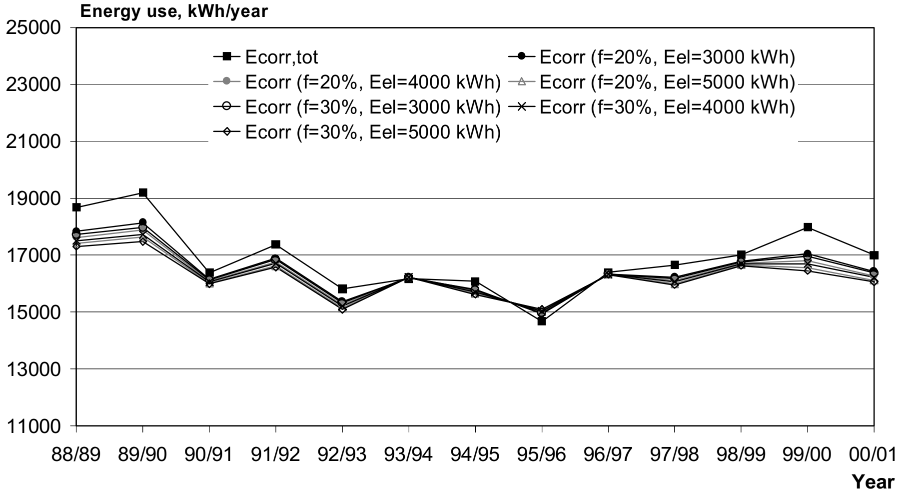

Figure 5:4 Yearly energy use differently corrected ($E_{corr,tot}$ or f = 20%, 30% and E_{el} = 3000, 4000, 5000 kWh) from 88/89 to 00/01, House VI

As seen in Figures 5:3 and 5:4 the different corrections does not seem to make a large difference on the energy use. The difference between the corrections a particular year is never more than 500 kWh (Figure 5:3) or 700 kWh (Figure 5:4). Similar circumstances seem to be the case for the other houses on the studied housing estate.

To analyse this the energy use that is dependent on the climate ($E_{corr,dep}$) and the energy used for the hot water production (E_{ww}) are plotted separately, see Figures 5:5 and 5:6 below.

$$E_{corr,\,dep} = \left(E_{year} - E_{indep}\right) \times \left(\frac{DD_{normal}}{DD_{actual}}\right) \quad \text{[kWh]} \tag{5.8}$$

where

$E_{corr,dep}$ part of the energy use that is dependent of the outdoor temperature and corrected with degree days [kWh]

When $E_{corr,dep}$ and E_{ww} for the different cases are plotted it can be seen that $E_{corr,dep}$ varies to a greater deal more than E_{ww} does. This means that it is $E_{corr,dep}$ that primarily contributes to the appearance of the different corrections (E_{corr}). One exception is the year 89/90 when the water consumption was much higher than most of the other years. This is clearly shown in Figure 5:5. This implies that it does not matter how the presumed values on the household electricity

(E_{el}) are chosen. The variations in the outdoor-temperature-dependent part of the energy are predominating. Unfortunately no actual data on the amount of household electricity is available for the studied houses. House II has also been studied and the appearances of the graphs are similar.

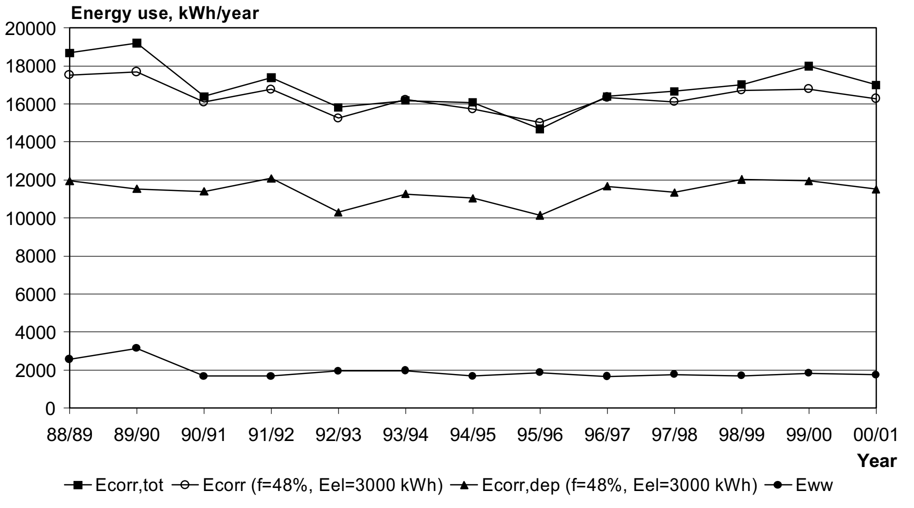

Figure 5:5 Yearly energy use, total or fractions, from 88/89 to 00/01, House VI

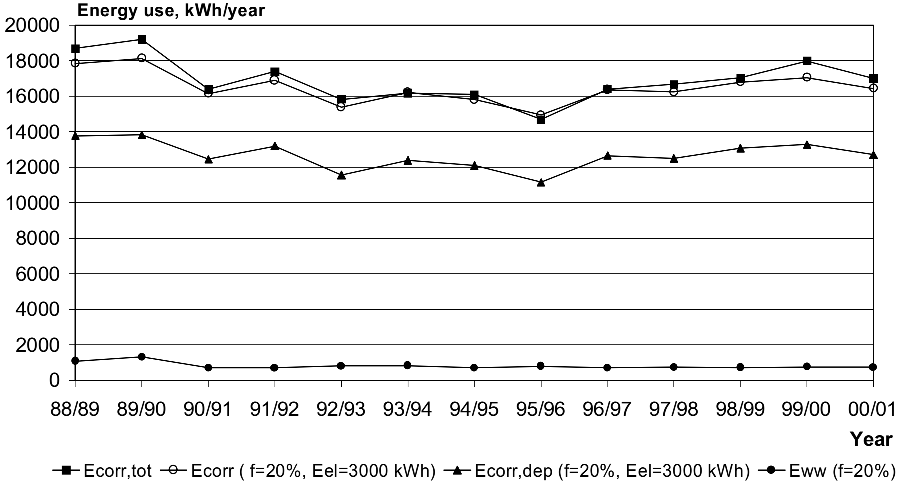

Figure 5:6 Yearly energy use, total or fractions, from 88/89 to 00/01, House VI

5.3.4.1 The normal period

During the project the "normal period" used for the SMHI's degree day method has been changed from the period 1961/62 – 1978/79 to the period 1971 – 2000. The reason being that the outdoor temperature the last decade has been much warmer than previous years. In order to study the effect of the changed normal period the degree day method with the two different reference periods have been applied on one house, Figure 5:7 (note, that the last years energy data have been added).

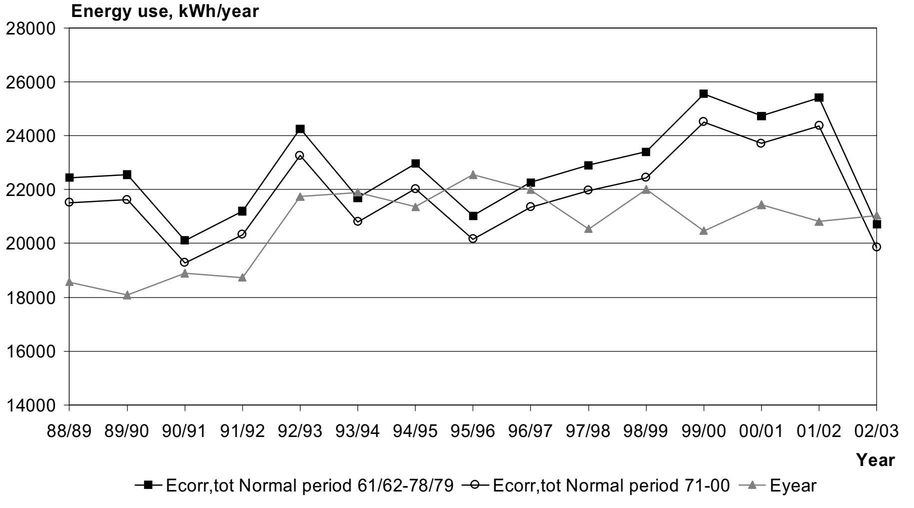

Figure 5:7 Yearly energy use corrected with different normal periods from 88/89 to 02/03, House II

The corrected energy use is with the normal period 1971 – 2000 obviously lies lower than with the correction using the period 1961/62 – 1978/79 and from the graphs it seems like the differences from one year to another are fairly constant (the differences varies between 830 to 1050 kWh). The energy use only corrected with the number of days in a year (E_{year}) still generally lies below the $E_{corr,tot}$ (normal period 71-00), which of course is due to that the time period studied (1988 - 2003) was generally warmer than the period 1971-2000.

5.4 General trends in the energy use

In this chapter the general trends in the energy use over more than a 10 year-period are analysed and discussed. This is both done on an individual level as well as on a group level. The standard deviations are also calculated for each year as a measure of spread. Lastly, the variations over the years in the price of the bought energy will be brought up.

5.4.1 Trends for individual houses

Below, in Figures 5:8 - 5:13, the energy use, E_{year} and $E_{corr,tot}$, are shown for six of the houses on the housing estate. Only one ($E_{corr,tot}$) of the corrections with degree days were chosen due to that the different corrections showed similar appearance. The linear regression line for the $E_{corr,tot}$ is also demonstrated. First of all it can be difficult to plot one trend line for all the years as the energy use suddenly can change direction, like in the case of House III and VI. The energy use can also vary greatly from one year to another, like in the case of House IV where there is a sudden dip 92/93. Furthermore, it is remarkable that the level of energy use can differ so greatly from one house to another like in the case of House I and VI where the difference is generally more than 10 000 kWh for E_{year}.

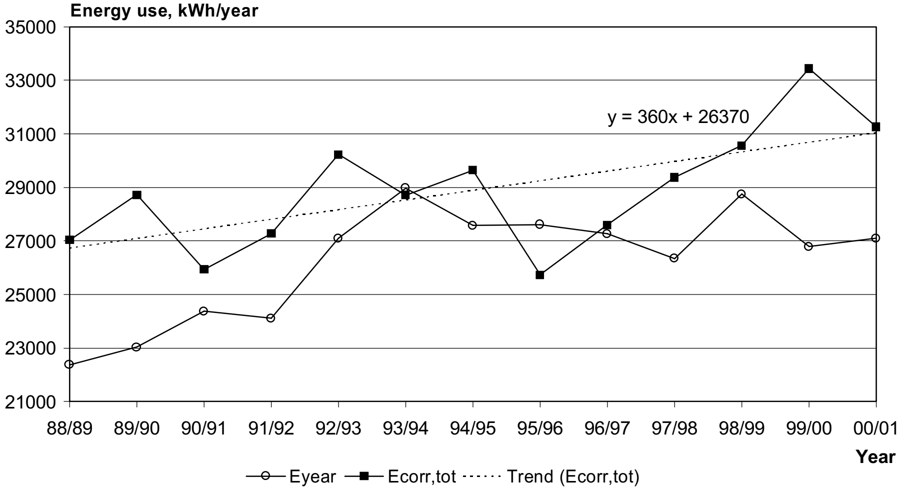

Figure 5:8 Yearly energy use and energy trend from 88/89 to 00/01, House I

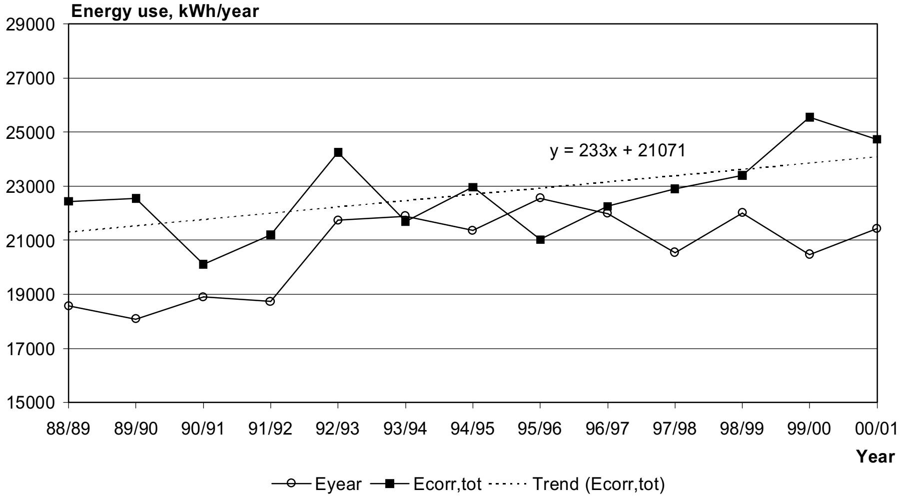

Figure 5:9 Yearly energy use and energy trend from 88/89 to 00/01, House II

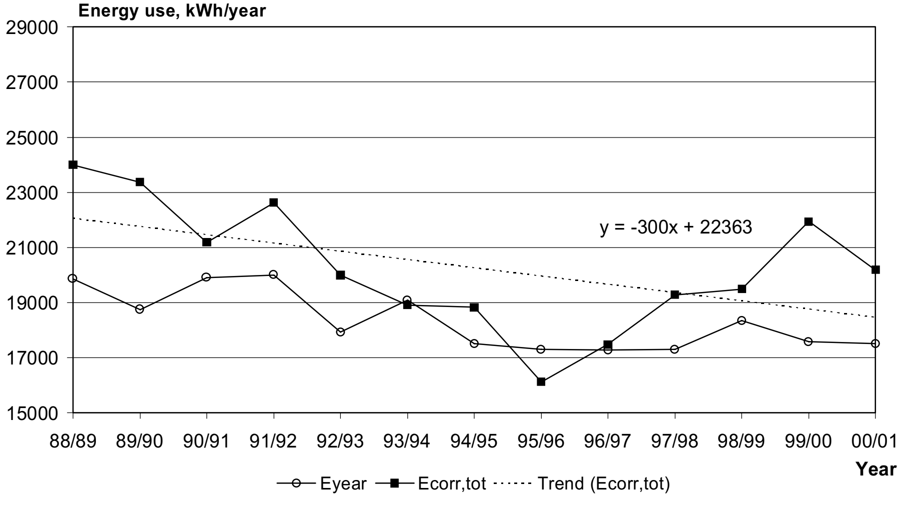

Figure 5:10 Yearly energy use and energy trend from 88/89 to 00/01, House III

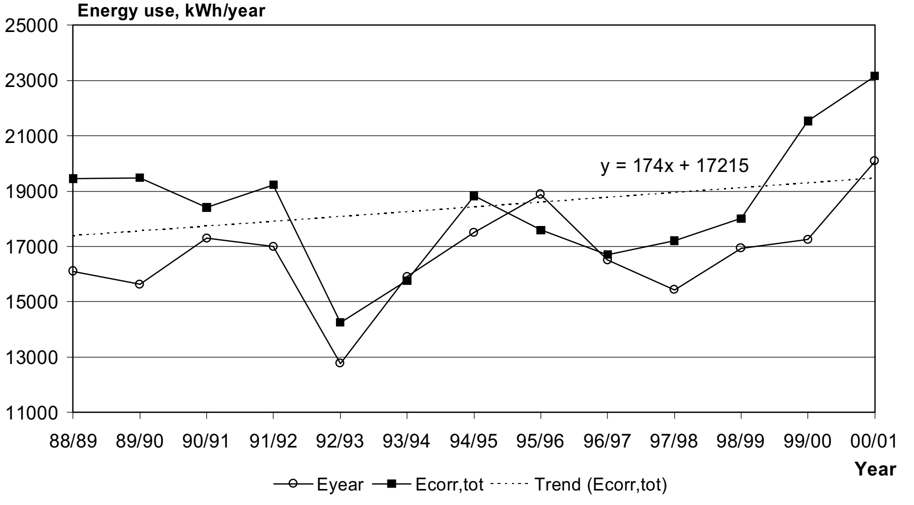

Figure 5:11 Yearly energy use and energy trend from 88/89 to 00/01, House IV

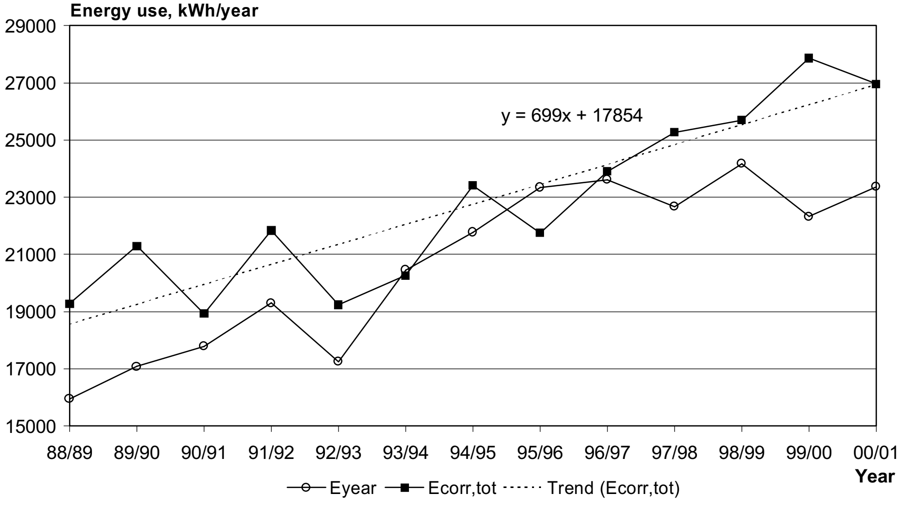

Figure 5:12 Yearly energy use and energy trend from 88/89 to 00/01, House V

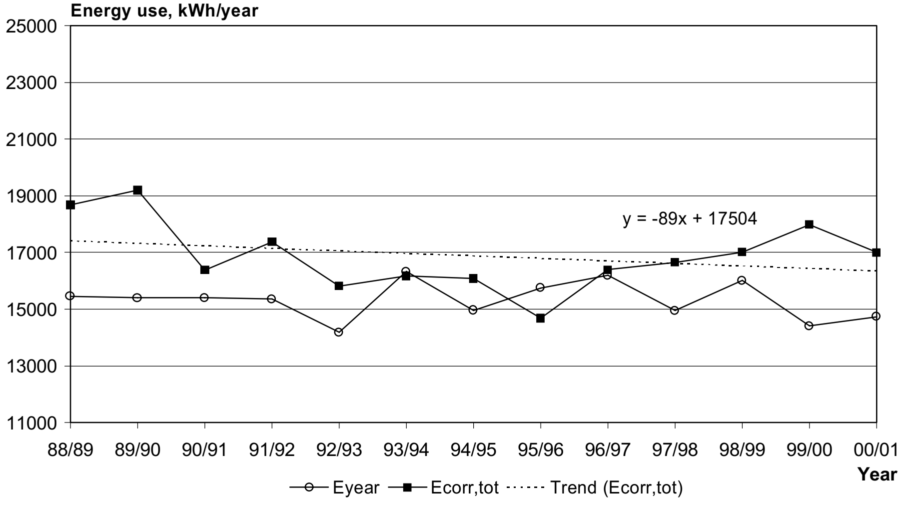

Figure 5:13 Yearly energy use and energy trend from 88/89 to 00/01, House VI

5.4.2 Trends for a group of houses

In Figures 5:14 and 5:15 the energy use for the 38 houses are presented. Each dot corresponds to one house's energy use a particular year. Note that data for all years were not available for all houses. For example, in year 88/89 25 houses' energy use are shown, while in year 94/95 38 houses' energy use are presented. No adjustment has been made to the data other than those described above. To analyse the data when extreme values are removed or large corrections for the number of days in a year were taken into consideration could be of interest.

As seen, no general tendency for an increase or decrease in the energy use can be identified, not even when the energy has been corrected with the outdoor temperature ($E_{corr,tot}$). A small difference between the slopes of the two graphs can be noted, where the slope for the average $E_{corr,tot}$ is less than a third of the slope for the average E_{year}. Other factors that can have changed over the years, and that have an influence on the energy use (also called "noise"), e.g. the heated area, the size of the household, are not known to the author. If they were known and also to what extent they influence the energy use a correction could be made to find out if there is an underlying trend.

A model for the connection between the energy use and the time period can be expressed in the following way:

$$E = \alpha + \beta + \gamma + ... + ct + \varepsilon \qquad \text{[kWh]} \qquad (5.9)$$

where

E	the energy use [kWh]
$\alpha, \beta, \gamma, ...$	the noise that could be identified [kWh]
c	the connection between E and t [kWh/year]
t	the time period [year]
ε	the unidentified noise [kWh]

If $\alpha, \beta, \gamma, ...$ can be identified the equation becomes

$$E - \alpha - \beta - \gamma ...... = ct + \varepsilon$$

and c could thereafter be obtained.

The level of the energy use varies greatly from one household to another, even when the houses were quite newly built. This is no new finding. It has been studied, analysed and discussed in previous reports, e.g. (Värmekostnadssakkunniga[9], 1942; Gaunt, 1985; Lundgren, 1989; Lundström, 1982; Palmborg, 1986; Socolow, 1978; Jensen and Gram-Hanssen, 2000) and the impact on the energy use caused by the residents seems to play a decisive role in these great variations between nominal identical houses.

The average energy use for each year is also shown as linear graphs in the diagrams below (Figures 5:14 and 5:15). As already discussed no general trends can be recognized and for E_{year} the average varies between 19 000 - 20 000 kWh and for $E_{corr,tot}$ it lies around 21 000 - 22 000 kWh.

[9] Proposed Swedish strategy regarding the heat cost investigation.

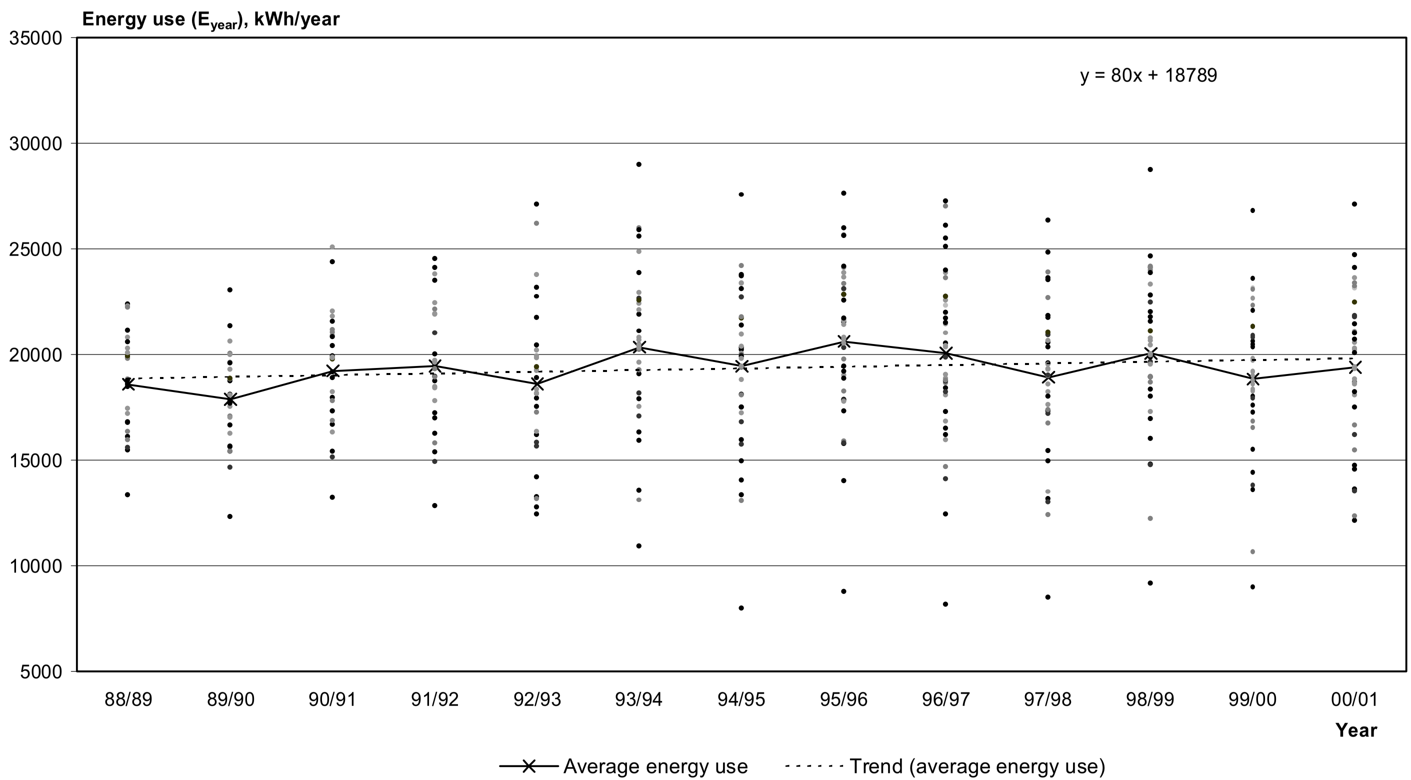

Figure 5:14 Yearly energy use (E_{year}) for 38 houses including average energy use from 88/89 to 00/01. Each dot corresponds to one house's energy use a particular year (note that the number of dots varies from one year to another).

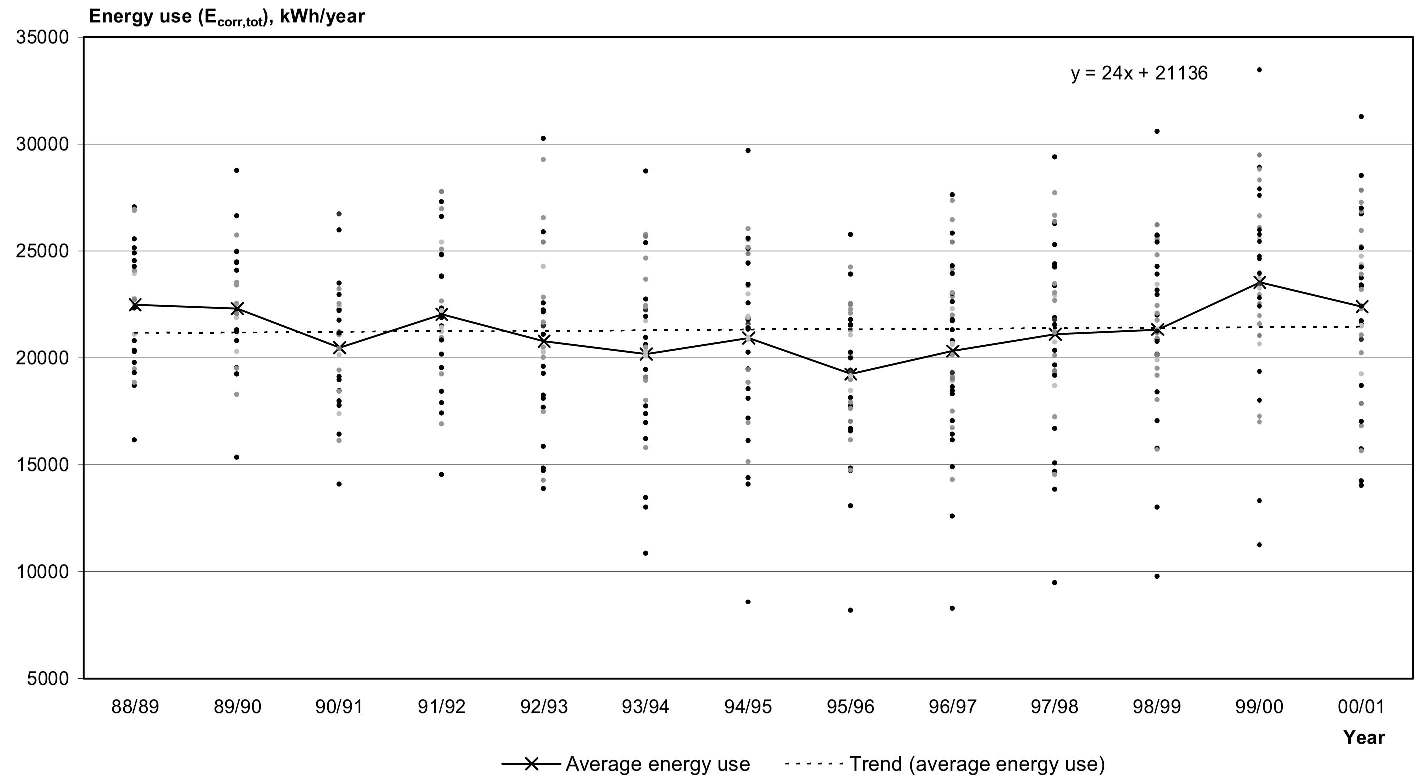

Figure 5:15 Yearly energy use ($E_{corr,tot}$) for 38 houses including average energy use from 88/89 to 00/01. Each dot corresponds to one house's energy use a particular year (note that the number of dots varies from one year to another).rends in variance (spread)

In addition, the standard deviation (variance) of the values for each year are calculated for E_{year} and $E_{corr,tot}$ for the 38 houses[10]. In Figures 5:16 and 5:17 the mean value (η), the standard deviation (σ), which are given above the curve, and the values $\eta+\sigma$ and $\eta-\sigma$ are demonstrated. Figures 5:18 and 5:19 show that the standard deviation has increased somewhat (a bit more than 1000 kWh) over the years. Note that predominately the increase occurred in 91/92 for E_{year} and 91/92 and 92/93 for $E_{corr,tot}$. The explanation behind this is not known to the author.

The sizes of the houses might have an effect on the results regarding how the variance changes with time. The houses in question have originally one floor of 104 m^2. The average floor space (living area) or total heated floor space for single family houses in Sweden were in 2002 approximately 120 m^2 respectively 144 m^2. Consequently, one can speculate that the number of extensions on a building estate where the houses have larger living spaces than 104 m^2 might have been fewer and therefore also lead to that the variance of the houses had changed less over a time period of 12 years.

The houses have originally one floor area of just above 104 m^2, but more than half of the houses have made extensions to their houses and some have built a second floor. These extensions appear to be very different from one another and they might not have the same constructions as the original building and have most probably been built by different building companies. This means that the initially nominal identical buildings after some years of operation can be very different from one another.

A number of activities resulting in a decreased energy use must also have occurred, as the average energy use is pretty much unchanged. One such factor could be the installation and usage of cast iron/tiled stoves.

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[10] The standard deviation is calculated by $\sigma = \sqrt{\Sigma(y-\eta)^2 / N}$, where y is the energy use for a particular house a particular year (kWh/year), η is the mean value of the energy use a particular year and N is the number of values (houses) a particular year. It is assumed that the population is approximately normal distributed and the values are independent of each other.

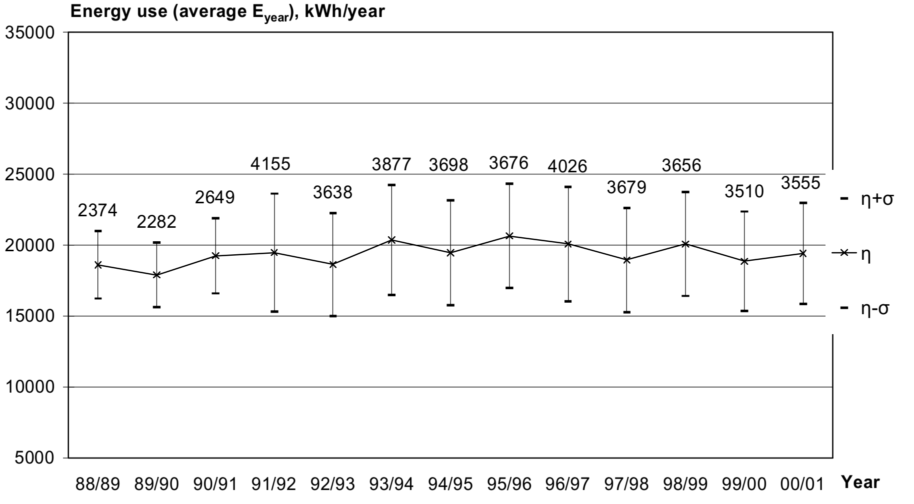


Figure 5:16 Mean (η) energy use of E_{year} and standard deviation (σ) for 38 houses from 88/89 to 00/01

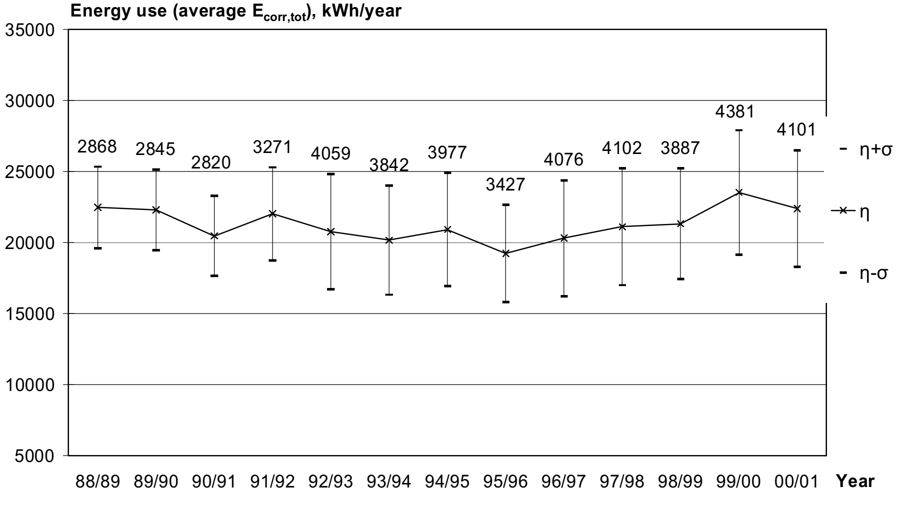


Figure 5:17 Mean (η) energy use of $E_{corr,tot}$ and standard deviation (σ) for 38 houses from 88/89 to 00/01

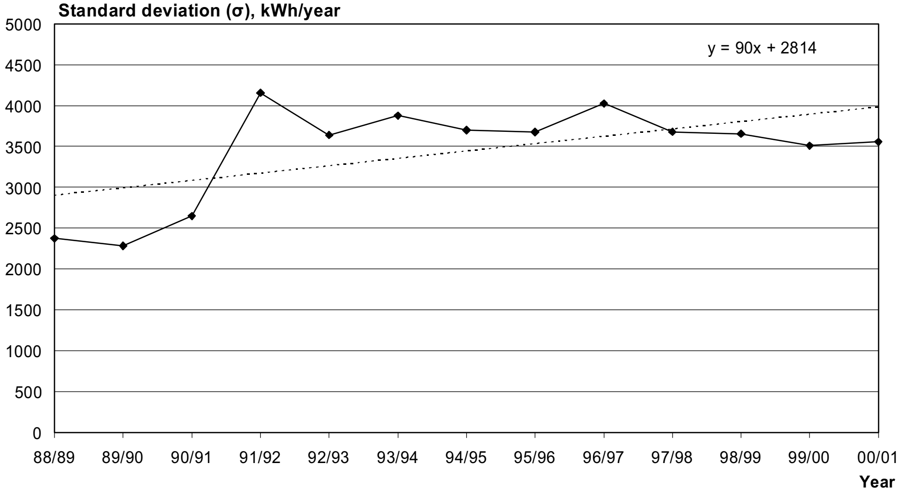


Figure 5:18 Trend of standard deviation (σ) calculated from E_{year} for 38 houses from 88/89 to 00/01

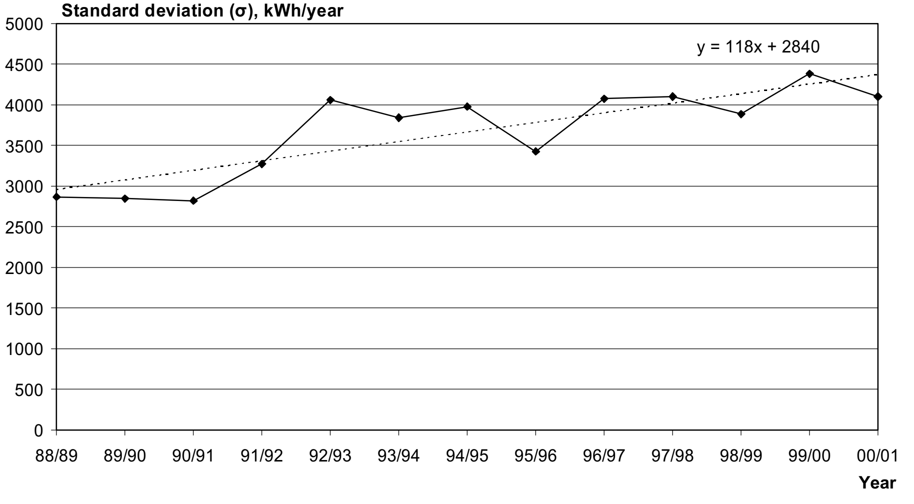


Figure 5:19 Trend of standard deviation (σ) calculated from $E_{corr,tot}$ for 38 houses from 88/89 to 00/01

5.4.3 Trends in the electricity price

Furthermore, it is of interest how the price of the electricity has varied during the period of 1988 to 2001 and whether this can have had any impact on the energy use. First is should be explained that the Swedish energy market was deregulated in 1996 which meant that the electricity service was divided into supply and distribution. The deregulation involved that the consumer freely could choose the power supplier but not the distributor. Additionally, there are different alternatives when it comes to the type of contract. One could choose to have a fixed price, to have a price that follows the spot price or to keep the old price (the result of “nothing has been done”). Lastly, different tariffs over the year or over the day can be chosen (Dalén, 2001).

The choice of supplier, contract and tariff for the studied houses are not known. Electricity prices from 1988 and onwards was provided from the local energy supplier. They represent the situation described above as “nothing has been done” and only includes the variable part of the price regarding both the supply and distribution as well as taxes and a VAT (value-added tax) of 25 %, i.e. the price that the consumer has paid regarding the variable costs.

In order to be able to compare prices between different years they will be corrected by the Consumer Price Index (CPI). This index is the mostly used measure of the development of the prices and shows how the consumer prices changes on average for the private domestic consumption and results in the prices that the consumers actually pay.

The electricity prices and the consumer price indexes have been recalculated to correspond to the same yearly time periods as the energy use (i.e. from June year 1 to May year 2). Thereafter the corrected yearly electricity prices, in the value of the year 00/01, have been calculated using the year 88/89 as the base year.

The results are shown in Figure 5:20 below.

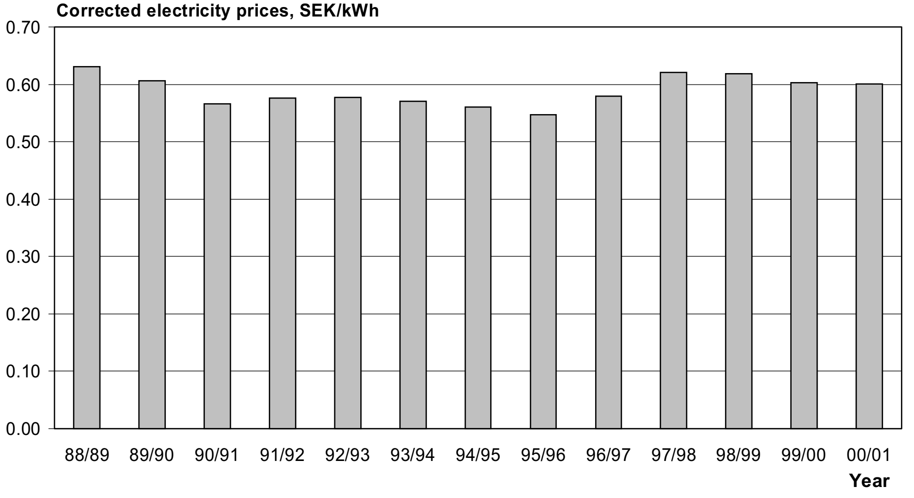


Figure 5:20 The electricity prices (only including the variable part) corrected with the consumer price indexes for the time period 88/89 to 00/01[11]

Looking at the average energy use of the houses, there is nothing indicating that there are a relationship between the electricity price and the energy use. If this is a correct conclusion is impossible to say due to many reasons. Other factors like the extensions of the houses, the residents' energy related habits etc might have greater impacts on the energy use than the electricity prices. Some residents might not be affected by these prices as they can have changed supplier, signed a contract and have certain tariffs.

5.5 Summary of analysis of energy data

The analysis of the energy data has been carried out for a group of houses, from the beginning identically built (nominally). The houses are modern with conventional constructions and heating and ventilation systems. It turned out to be difficult to easily obtain the correct information about the houses. The house owners are not always acquainted with details concerning the building. It has also been realised that the information that the town planning department and the local energy supplier have might be out of date mainly due

[11] Statistics Sweden (2003). *Konsumentprisindex (KPI)* [online] Available from http://www.scb.se/statistik/pr0101/pr0101.asp [2003-03-17]

to that the house owners have not informed them of changes made regarding the houses and the building services.

A substantial number of house owners have made extensions to their houses. This introduces a large uncertainty in the comparison between the houses' energy use. Factors like the type and construction of the extension as well as the workmanship (especially if the building company differ from the one that built the original house) might differ significantly from one house to another.

To have access to raw data is an advantage cause one has control of the different steps of treatment of the data that are taken. On the other hand, the treatment of raw data can be somewhat time-consuming when the data is not presented in an easy and useful way.

That the intervals between two readings are not exactly one year brings in yet another uncertainty in the data where a correction can be made in different ways. If the correction is done with the average daily energy use, as has been done in this report, the uncertainty depends on the time of the year of the readings (the energy use in October is probably closer to the average than the energy use in January). If the actual energy use during these missing/extra days differs significantly from the normal values the uncertainty is even larger. For the houses in this study the readings are done at the end of May/beginning of June, which means that the correction will be somewhat too large. The effect of these corrections is considered to be marginal.

The attempts to correct the energy use by separating the energy use into one part that is dependent and another part that is independent on the outdoor temperature does not have any major effect. This is of course due to that the general figures, used for the household electricity and the fraction of hot water, are the same from one year to another. The variations in the total water consumption (both cold and hot water) are taken into consideration to a certain extent, as the amount of hot water used is a percentage of the total water consumption. The variations in the total water consumption from one year to another does not seem to have any major impact on the total variations of the energy use, when the above stated assumptions have been made.

The normal period chosen as a reference does have an impact on the corrected energy use in the sense that the level of energy use, presented in Figure 5:7, is lowered. The appearance of the graph with the peaks and dips is uninfluenced.

The energy usages for individual houses show that the energy use can increase, decrease or be pretty much unchanged over the years. It can sometimes be difficult to plot a trend line as the energy use show sudden dips and peaks from one year to another.

Any general trends in the energy use can be difficult to find and on a group level the average energy use seems pretty stable over the time period studied. The measure of spread, the standard deviation, has increased somewhat over the years. This implies that some houses have made changes that increase the energy use, such as the building of extensions, and others have made changes that decrease their energy use, such as the installation of tiled stoves.

If factors, like the extensions of the houses, were known some sort of correction could be done to the energy use in order to find any underlying trends of the energy use over time.

The electricity price (the variable part) for the time period studied has not changed significantly or at least not so that it seems to have an impact on the energy use on a group level. If this a correct conclusion one can argue as the supplier, contract and tariff chosen for the studied houses are not known.

6 Interviews with 6 households

The diagrams presented, analysed and discussed in Chapter 5 are somewhat difficult to interpret. In an attempt to get some answers to the appearance of the graphs, especially some of the sudden peaks or dips in the energy use, a pilot study were carried out. After a request was sent out to all the households on the housing estate, six households were selected to be interviewed.

6.1 Contact with the residents

In January 2003 a letter was handed out to the 41 houses on the estate. The letter described the project "Sustainable energy use in houses". The residents were asked to return a slip where they were asked to state whether they were interested to take part in the project and if they were willing to answer some questions concerning their energy use.

Totally 23 households answered, 16 yes and consequently 7 no. Some of the households that firstly returned their slips and where energy data were available, were contacted in order to organise a time and date for an interview. Interviews were held with six of the households.

The interviews should be seen as a pilot study where a retrospective method carried out as structured interviews supplemented with "open discussions" with the house owners were tested. The intention was to find explanations to the appearance of the energy use for the different houses.

6.2 The interviews

The interviews were primary carried out as structured interviews where the interviewer (Carolina Hiller) followed a questionnaire (see Appendix B). The questions concerned activities and events, which could have occurred over the years, and that have an influence on the energy use. Also general background questions were asked. The interview was supplemented with questions and discussion regarding the house owner's energy use. Particularly, sudden peaks and dips were pointed out and the residents were especially asked if they could remember any incident that could serve as an explanation.

An enquiry was put to the residents whether they would participate in a next step involving measurements. In the end two households were willing to take part, see Chapter 7.

The information that derived from the interviews are illustrated and analysed by adding the answers to the graphs showing the energy usage (Chapter 6.3).

Generally it can be said that the residents have had some difficulty in remembering *when* certain activities and events have actually occurred. If evident were available, in the form of receipts, notes or other documents, the first "guess" disagreed in most cases with the actual date.

Furthermore, the peaks and dips were also difficult to relate to certain events.

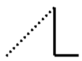
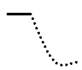
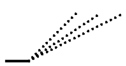
6.3 Analysis of interview answers

In Figures 6:1 to 6:6 the interview answers together with the energy use are shown. First of all it should be pointed out that the approximate dates are *very* approximate as they are "guesses" from the residents without any evident. As discussed in Chapter 6.2 it turned out that it was very hard to remember *when* events had happened. Deviations equal to several years from the true date was not unusual.

An explanation is in order of the different phrases used in the diagrams. When the word "new" is used, e.g. in the case of House II "1993 Nov: New washing machine", a new one is bought and the old one has in one way or another worn out. When the word "bought" is used, e.g. in the case of House III "Approx. 1996: Bought tumble dryer", a new one was bought and the household did not own one before. When "teenager" is used it refers to a child who turned 13 years of age. The reason for pointing this out is that teenagers are supposed to do a lot of energy-extensive activities.

To analyse the graphs together with the information from the interviews is not straightforward. Clear connections between certain activities and their effect on the energy use are not easy to recognise. Different types of impacts are illustrated in the diagrams by symbols, explained in Table 6:1. Furthermore, some years many activities occur, which makes the analyse even more difficult. The uncertainty of many of the dates makes the task even harder.

Table 6:1 Explanations of symbols used for different types of impacts on the energy use

Symbol	Explanation
	The change/activity results in an instantaneous and lasting decrease in energy use.
	The change/activity might have been preceded by an increase in energy use.
	The change/activity could decrease the energy use, but it is dependent on the usage of the installation.
	The change/activity results in an instantaneous and lasting increase in energy use.
	The change/activity could increase the energy use but it is uncertain to what degree and when it starts having an impact.
	The change/activity could increase the energy use, but it is dependent on the usage of the installation.
	The change/activities could affect the energy use either way.

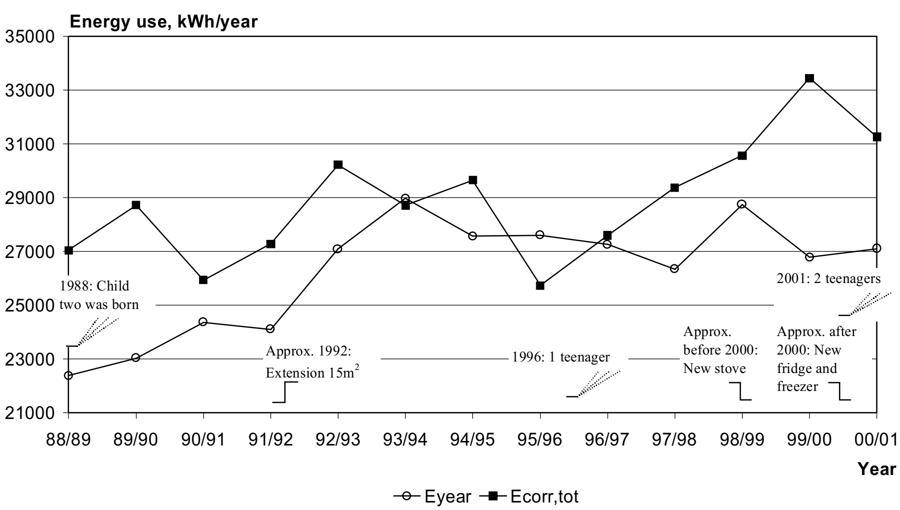


Figure 6:1 Interview answers (including symbols) and yearly energy use from 88/89 to 00/01, House I

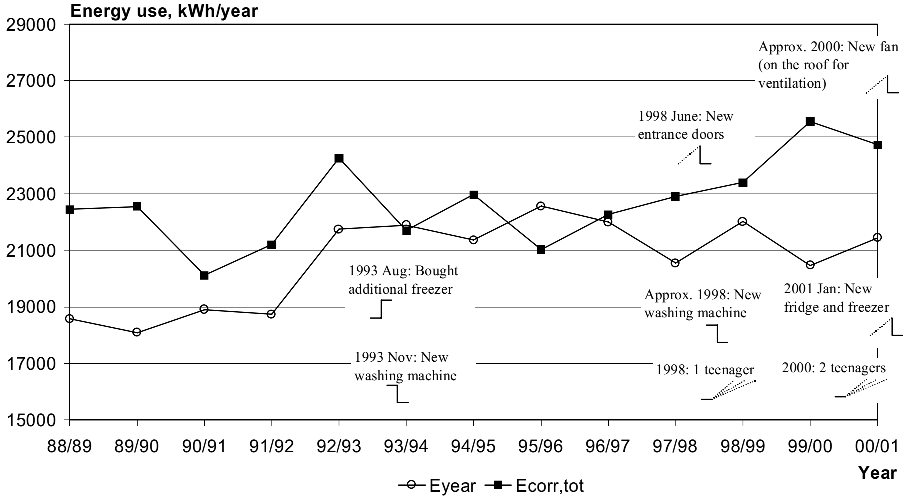


Figure 6:2 Interview answers (including symbols) and yearly energy use from 88/89 to 00/01, House II

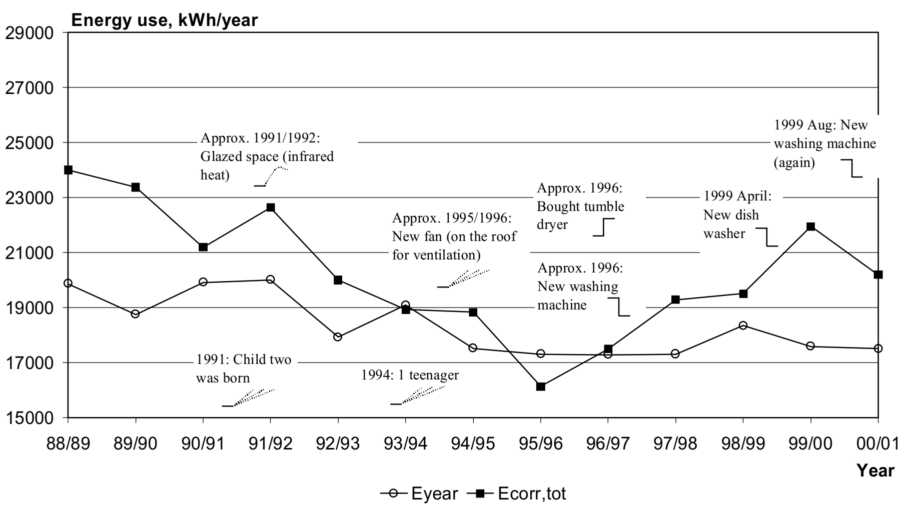


Figure 6:3 Interview answers (including symbols) and yearly energy use from 88/89 to 00/01, House III

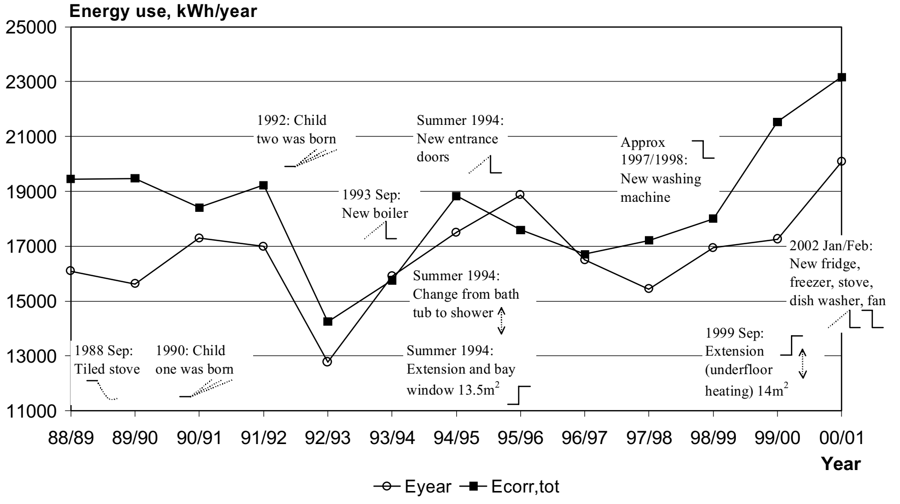


Figure 6:4 Interview answers (including symbols) and yearly energy use from 88/89 to 00/01, House IV

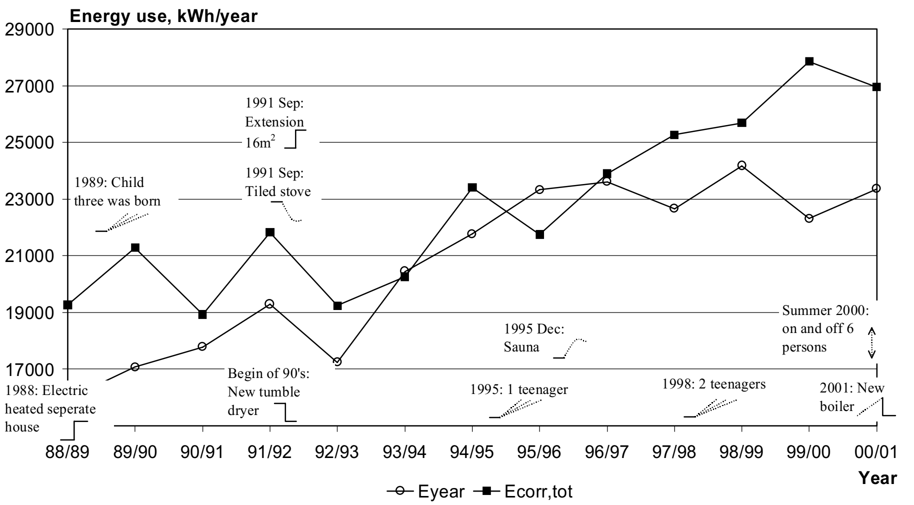


Figure 6:5 Interview answers (including symbols) and yearly energy use from 88/89 to 00/01, House V

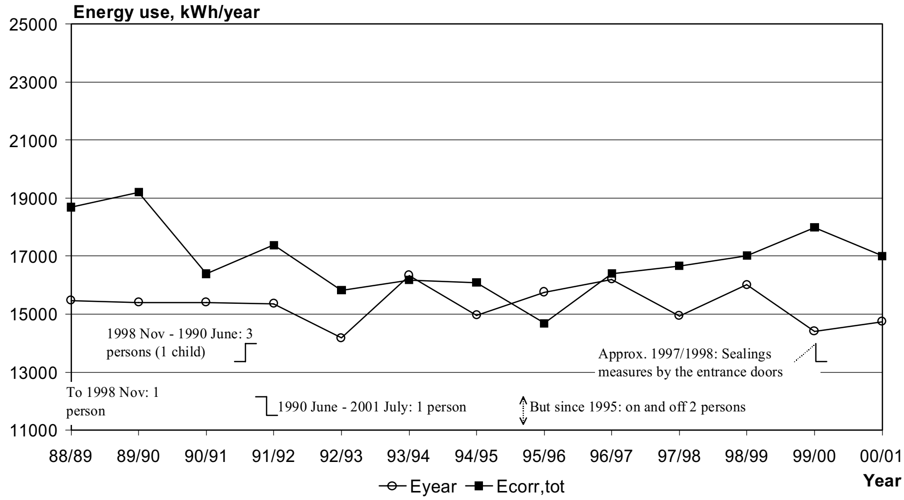


Figure 6:6 Interview answers (including symbols) and yearly energy use from 88/89 to 00/01, House VI

Still, an attempt to analyse the diagrams are made here. The analyse refer primary to the corrected energy use with degree-days ($E_{corr,tot}$).

Extensions (additional heated area) have been made at five occasions (in house I once and in houses IV and V, in both cases twice). One of these happened 1988, which means that there is no preceding data to compare with. The other four resulted in a higher energy level than the previous year, but note that the date for when one of these extensions occurred is very unsure. In two cases the energy use the following year is decreased. Has this to do with that activities leading to less bought energy also were made at the time of the extension? These activities were: a tiled stove was installed in the additional room that was built (house V), a change of entrance doors (house IV) and a change from bath tub to shower (house IV). A tiled stove decreases the bought energy use, but exactly how often it is used is not known. (According to the house owner it is now used three times a week during cold periods.) In this particular case the stove is not centrally placed in the house and the owner did not think the heat was spread in the rest of the house to any great extent, which could mean that the amount of energy bought is unchanged.

Changes in the household (number of persons and age of persons) over the 12-year period occurs in all houses. In most cases it is caused by the births of children and children becoming teenagers and eventually leaving home. To what extent and when a child "significantly starts" to affect the energy use is impossible to say and this is shown in the diagrams. The belief that teenagers do more energy-intensive activities may be verified by the graphs. There is of course no definite age when these energy-intensive activities starts but the findings from house I, II, III and V suggest that the there is a gradual increase in the energy use. However, one should ask the question if this increase would have occurred regardless of the number of teenagers in the household. The corrected energy use for the remaining houses (IV and VI) shows that there is an increase during the period in question (approximately from 95/96 and onwards). Does this indicate that the increase, at first sight due to the number of teenagers, would have taken place anyway? Another example is when the number of residents has changed over the years (house VI). When the household consisted of three persons the energy use was approximately 2500 kWh more than when the household only consisted of one person. During the period studied above (from 95/96 and onwards) the household consisted of two persons on and off and the energy increased again. If these are true conclusions or not are impossible to know by only looking at the diagrams.

Other activities that theoretically would *decrease* the amount of bought energy are: the purchase of new more energy efficient white goods, the installation of tiled/cast iron stoves, the purchase of new boiler or fan (presuming that they are more efficient than the old ones) and new entrance doors (or sealing measures by the entrance doors). There are many uncertain dates regarding the purchase of new white goods, but the energy use are mostly going up the year the white goods were procured. The dates for the installations of new fans are also uncertain, so if these are disregarded the consequences of the other activities seems to be an increased energy use.

Activities that theoretically would *increase* the amount of bought energy are: the installation of infrared heating, purchase of additional white goods and installation of a sauna. The dates of installation of infrared heating and of one purchase of additional white goods are unsure. The installation of the sauna and the purchase of another white goods result in decreased energy use, which the next year is increased.

Activities that could be *either way* (either require a larger or a smaller amount of energy) are: underfloor heating and change from bathtub to shower. The installation of the underfloor shows an increase in the energy use and the change from bathtub to shower shows a decrease, followed by an increase. The year that the bathtub was installed a number of other activities occurred that might be of more importance.

Three of the houses had done measures concerning the entrance doors (either installed new ones or made sealing measures). This is no coincident. According to many of the residents the doors that were installed initially were of bad quality and the residents experience draught due to them.

There are a number of activities in certain houses that are not shown in the diagrams due to that owners could not specify the time it occurred, not even approximately.

In addition, three of the houses (I, II and III) have had problems with the control system of the heating system. For house I the outdoor temperature sensor has broken and the house owner has tried to adjust the electric heating manually. For house II and III the thermostats have not worked satisfactory.

The house owners were asked to particularly think of what could have caused certain dips and peaks in the energy use. For example, house IV has a considerable decrease in the energy use 92/93. From the interview answers there are not anything that clearly can explain this behaviour. The discussion with the residents lead to a number of “guesses”, such as that the mother stayed homed with the children during this/these years and at that time she used the tiled stove to a great extent, but this is only speculation.

In the diagrams of the houses I, II, III, V and VI there is a dip in the corrected energy use ($E_{corr,tot}$) 95/96 and thereafter there is an increase. For house IV there is a dip 96/97 and thereafter an increase. Possibly part of the explanation can be found in the activities described above but it seems to be a general trend for these houses and for the majority of the other houses on the housing estate. Therefore one might believe that there are some common factors that influence the appearance of the energy graph.

Taking a look at the average yearly outdoor temperature, the average outdoor temperature between October and April (the heating season) and the degree day correction factor (DD_{normal}/DD_{actual}) in Figure 6:7, it is clear that the dip 95/96 is due to cold weather that is compensated for by using more energy, but not as much as “is allowed”. The successive years are warmer. The year 99/00 the average outdoor temperature is particularly high and in most cases it results in a lower energy use but the decrease in the energy use is not as much as it “ought to be”.

The year 93/94 the average yearly temperature is as low as for 95/96, but this does not have the same affect on the energy use as the average temperature during the heating season is not as low as 95/96, Figure 6:7.

To conclude, the discussion in this chapter can exemplify the difficulties with connecting certain activities with a certain amount of energy. There are many factors that influencing the energy use at the same time and consequently it is impossible with only the diagrams described in this chapter to draw any definite conclusions. The retrospective method of asking the residents to remember what has happened in the past proves to be a less valid technique. The analysis results in more questions than answers. In order to be able to make a better analysis a more valid method should be used to get better data/information that will be treated with a statistically correct method. More frequent energy data would probably also be required in order to make a more appropriate analysis.

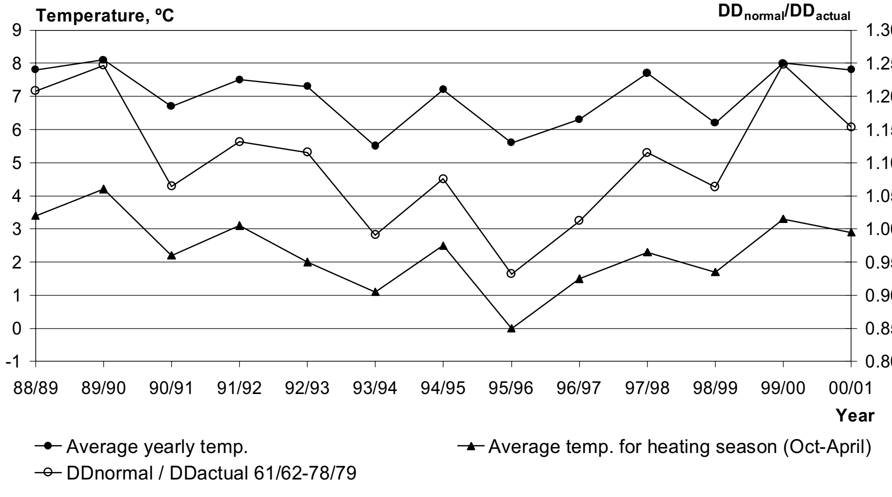


Figure 6:7 The average temperature (yearly and heating season) and degree day correction factor (DD_{normal}/DD_{actual}) for the time period 88/89 to 00/01

7 Measurements and calculations (2 households)

In order to investigate if the different levels of the energy use is due to the house (the building itself) and its building services or if it is due to the residents, a method for the measurement of specific heat loss is applied to two of the houses (II and VI). The owners of these houses were willing to participate in the measurements, which implied rather active roles for the residents.

Furthermore, the PC-program HEAT2 (version 5.0) has been used to calculate the two-dimensional transient heat losses to the ground from the houses. Additionally, the theoretical energy use was calculated with the energy calculation program Enorm 1000 (version 1.10).

First, some further details on the energy use of the houses II and VI.

7.1 Energy use of the Houses II and VI

That the two households have rather different energy use (see Figure 7:1), even if they did not stand for the largest differences between houses on the studied housing estate, can be seen in Figure 7:1. The diagram has been completed with the last years' energy data. Possible explanations to the sudden increase 01/02 for house VI is that an extension of 26.7 m^2 and with large window areas was built during the summer/autumn of 2001. A cast iron stove was also installed, placed in the extension, during this period. In addition, there were two persons living in house VI instead of one from July 2001. Some activities that have happened for House II from July 2001 and onwards is that the second half of 2002 the tumble dryer broke (and it has not been fixed or replaced) and the water heater broke. The drop 02/03 seems to be temperature related with a particular cold heating season. One can also speculate if the energy price (in this case electricity price) has an influence on the amount of energy use as it increased (the "nothing has been done" price from the local energy supplier as well as the spot price on the energy market) during this period. As discussed previously in Section 5.4.1 the type of contract with the energy supplier is decisive if a shift in the energy price has any effect on a household's energy bill or not.

It can also be added that the building company that built the original house also built the extension.

Figure 7:1 Yearly energy use, E_{year} and $E_{corr,tot}$, from 88/89 to 02/03 for Houses II and VI

Some general explanations to the difference in the energy use for the two households could be the number of persons and the indoor temperature. During the whole period the number of persons living in house II has been four. For house VI it has varied but for a large part of the period it has been only one person. The indoor temperature for the whole period is not known, but if we assume that the measured temperature in February (approximately 23.0ºC for house II and approximately 19.5ºC for house VI) reflects the magnitude of the indoor temperature of the whole period this also contributes to the difference in energy use for the two houses. Additionally, house VI lowers its indoor temperature during the night.

7.2 Measurement of specific heat loss

In this chapter the method of the measurement of specific heat loss is described together with the application in and the results from house II and VI. The specific heat loss is a measure of the energy performance of the house and its building services. The influence of the residents and solar insulation is minimised. The question of interest is if the house with the highest energy use also has the highest specific heat loss and vice versa. If this is confirmed it would indicate that the level of energy use could be linked with the building and its building services rather than the residents.

7.2.1 Description of method

The method gives a momentary value of the situation at the time of measurement, consequently no changes over time can be analysed. The purpose of the method is to calculate the specific heat loss of a house. Below a description of the methods is presented. The interested reader is referred to the following literature (Jahnsson, 2000; Sandberg and Jahnsson, 1995; The Swedish Consumer Agency, 1995).

The definition of the specific heat loss, F_T [W/K], is the sum of the transmission and ventilation losses per degree of temperature difference. The ventilation losses include both mechanical and natural ventilation. The temperature difference is calculated from the average indoor and outdoor temperatures. The transmission and ventilation losses are assumed to be equivalent to the supply of energy, obtained from the energy meter. Corrections are made for heat given off by the residents and heat storage of the building and interior. The later one leading to indoor temperature fluxes. The average power demand is calculated by Equation 7.1 (Sandberg and Jahnsson, 1995).

$$Q_{averge} = \left(E_{read} + E_{person} \pm E_T - E_{fan}\right)/\, t \qquad \text{[W]} \tag{7.1}$$

$Q_{average}$	average power demand [W]
E_{read}	energy read of the meter [Wh]
E_{person}	energy given off by persons [Wh]
E_T	energy correction for indoor temperature fluxes [Wh]
E_{fan}	energy used for fan (mechanical ventilation) [Wh]
t	length of measurement period [h]

More details on how E_{person}, E_T och E_{fan} have been calculated can be found in Appendix C.3 (Equations C.1, C.2 and C.3).

The measurements and readings of the indoor and outdoor temperatures and the energy use are made for a number of nights. The reason for that the measurements are carried out at night is that the influence of the residents and the solar insolation should be minimised. The average power demand during each night is plotted in a diagram against the average temperature difference between the outdoor and indoor temperatures. The heat loss factor is calculated by linear regression analysis, which means that it is assumed that the heat loss to the ground is constant and that and that the transmission and ventilation losses are proportional to the difference in indoor and outdoor temperatures, Equation 7.2 (Sandberg and Jahnsson, 1995).

$$Q_{average} = A + B \times \Delta T \quad \text{[W]} \tag{7.2}$$

where

A	heat loss to the ground [W]
B	factor that describes the other heat losses [W/K]
ΔT	difference in indoor/outdoor temperatures (average) [K]

As an approximation, no correction has been made to that the heat losses to the ground are related to the temperature difference between the indoor air and the ground. One could adjust the temperature by a factor γ, which gives the following weight temperature difference:

$$\Delta T' = \gamma \times \Delta T \quad \text{[K]} \tag{7.3}$$

where

$\Delta T'$	weighted temperature difference [K]
γ	correction factor [-]

With the weighted temperature difference the average power demand can be expressed as:

$$Q_{average} = F_T \times \Delta T' \quad \text{[W]} \tag{7.4}$$

where

F_T	specific heat loss of the building [W/K]

The specific heat loss of the building, F_T, could be calculated using Equations 7.2 to 7.4 in the following way:

$$F_T = \frac{A + B \times \Delta T}{\gamma \times \Delta T} \quad \text{[W/K]} \tag{7.5}$$

Assuming that $\gamma \approx 1$ reduces the equation to:

$$F_T \approx \frac{A}{\Delta T} + B \quad \text{[W/K]} \tag{7.6}$$

The assumption that $\gamma \approx 1$ is implies that heat flow to the ground is independent on the temperature difference of indoors and outdoors. This is reasonable for houses with slab on ground and when the measurements take place in a limited period and consequently the heat losses to the ground do not vary significantly.

The method is applicable for detached wooden-framed houses with electric heating and mechanical ventilation. In Sweden the method should preferable be applied between the 15th of November and the 15th of February due to that long nights, limited insolation and a large temperature difference between the indoor and outdoor temperatures are all beneficial (Sandberg and Jahnsson, 1995).

The advantage with the method is that it is simple since it requires no complicated or expensive equipment and no specialised knowledge. The residents of the house are capable to make the readings. Furthermore, the house can be occupied at the time of the measurements and the ventilation and heating system should operate at normal conditions. The disadvantage is that it accuracy is limited. The measurement error, including the systematic and random errors, has been estimated to up to 10 % for the specific heat loss. As already mentioned the method can only be applied to wooden-framed detached buildings (Sandberg and Jahnsson, 1995).

A list of the most important preparations and restrictions of the method as well as different steps of the treatment of the data/information from the residents can be found in Appendix C.

7.2.2 Measurements and treatment of data

A few days prior to the measurements, which were carried out for ten nights during the 3rd and 13th of February 2003, the two houses were visited to mount the temperature sensors indoors and outdoors. The residents were instructed on how to do the readings and keep a record of the readings (see Appendix C.2) as well as the restrictions and preparations to be followed (see Appendix C.1). At the time of the visit the ventilation flow was also measured.

In Appendix C.3 the different steps of the treatment of the data (from the record kept by the residents) are listed. Equation 7.6 above is used to calculate the heat loss factor from the graphs. Moreover, the average power demand has been calculated including only the transmission losses. The correction for indoor temperature fluxes has been varied between 15 Wh/(m^2·K) and 60 Wh/(m^2·K) in order to find out if this would have any effect on the results.

7.2.3 Results

If all the preparations are done and all the restrictions are followed by the residents is impossible to know. One visit was paid to the houses during the measurement period in order to check that the measurements and readings went according to plans. No major deviations were noticed at the time of the visit.

In Appendix C.3 a number of requirements on the data are listed. For house II the requirements are fulfilled in all cases except for one measurement period (the night between the 5th and 6th of February) where the maximum allowed outdoor temperature difference between the evening and morning values is exceeded. For house VI this value is exceeded for the same night but the requirements are also not fulfilled on five other occasions. In Figures 7:2 and 7:4 below all the nights are shown and in Figures 7:3 and 7:5 only nine nights are plotted (the night between the 5th and 6th of February is excluded).

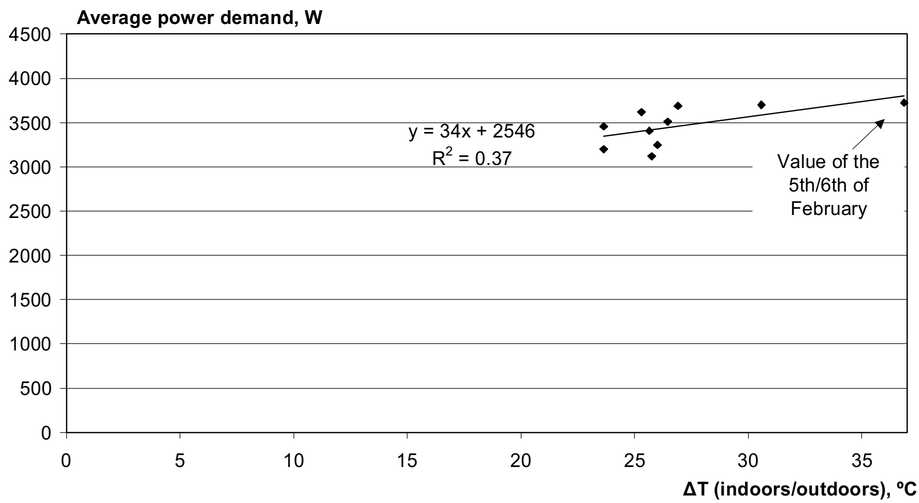


Figure 7:2 Average power demand plotted against temperature difference indoors/outdoors for *ten* nights, House II

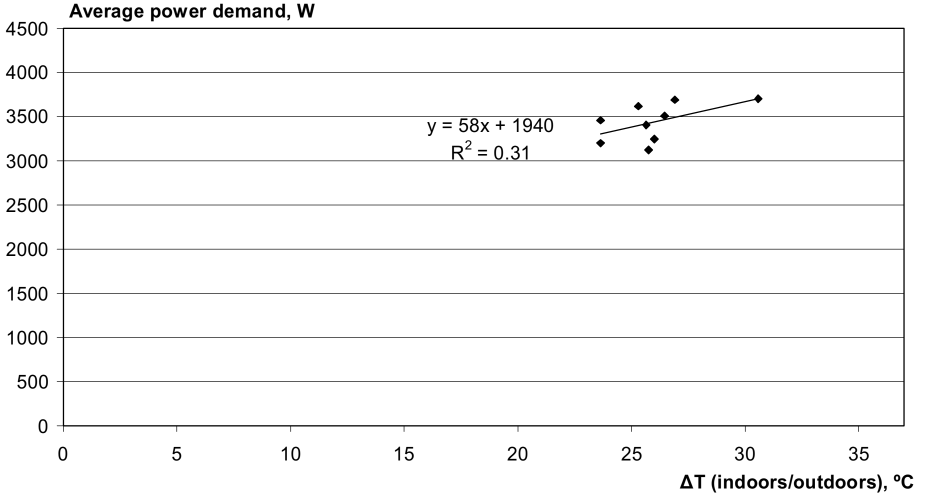


Figure 7:3 Average power demand plotted against temperature difference indoors/outdoors for *nine* nights, House II

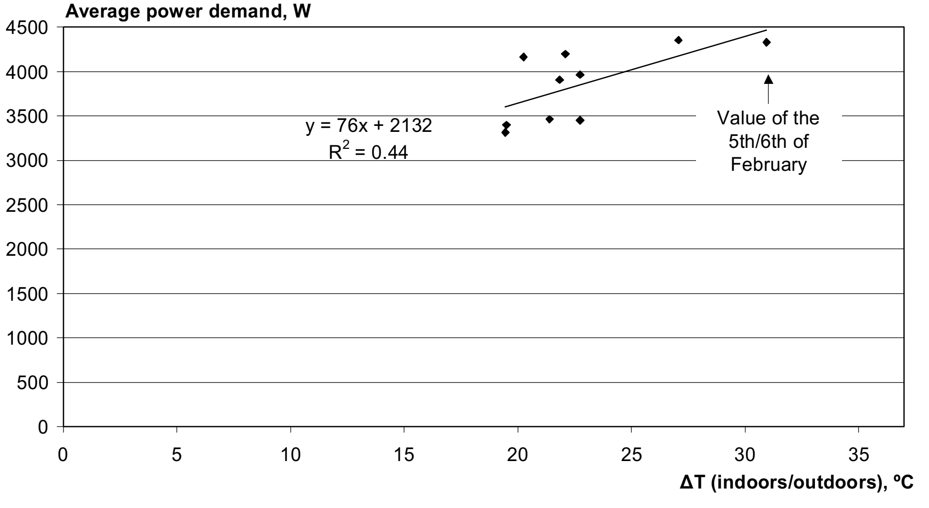


Figure 7:4 Average power demand plotted against temperature difference indoors/outdoors for *ten* nights, House VI

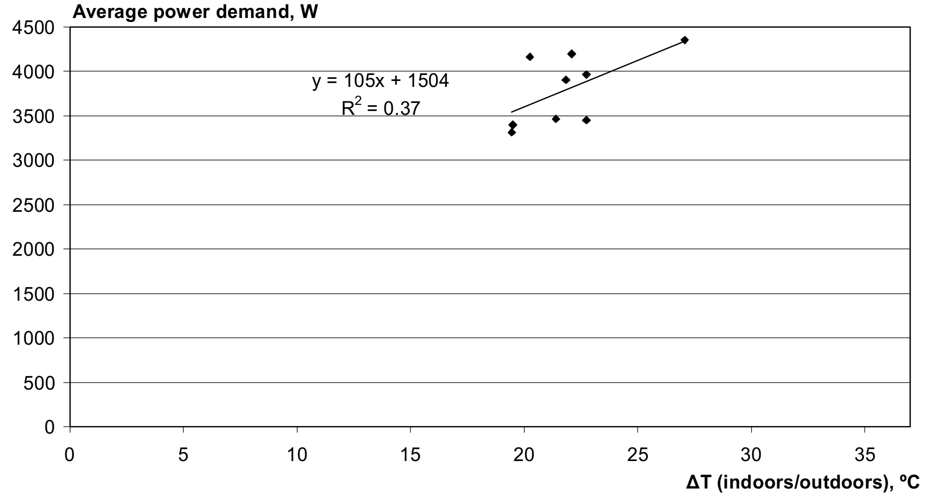


Figure 7:5 Average power demand plotted against temperature difference indoors/outdoors for *nine* nights, House VI

Generally, it is difficult to draw any definite conclusions from the regression analysis as the linear model can be fitted quite arbitrarily. The coefficient of determination, R^2, which is a measure of how well the linear equation represent the values plotted, can be seen in the previous diagrams. The coefficients are in all cases very low.

Nevertheless, the Equation 7.6, where the average temperature difference between outdoors and indoors is used for ΔT, gives the following specific heat losses, F_T:

Regression analysis with	House II	House VI
- 10 nights (Figures 7:2 and 7:4)	128 W/K	169 W/K
- 9 nights (Figures 7:3 and 7:5)	132 W/K	174 W/K

As clearly seen the specific heat loss is larger for house VI. The withdrawal of the results from the night between the 5th and 6th of February makes a marginal difference. For house VI it was also tested to disregard some of the other nights where the requirements were not fulfil. The effect on the specific heat loss was even less than for the night between the 5th and 6th of February.

The calculation of the average power demand including only the transmission losses resulted in that the specific heat losses for the two houses were reduced with about the same quantity. This is due to that the ventilation flows were similar in the two cases, namely 33.3 l/s and 31.9 l/s. This means that the difference in the total heat loss factor (including both transmission and ventilation losses) between the two houses is mainly caused by a difference in the transmission losses.

The variation of the correction factor of indoor temperature fluxes only showed marginal effect on the specific heat loss factor.

In order to investigate if the linear model could be less arbitrary, the heat losses to the ground, represented by the value of the average power demand when $\Delta T = 0$, will be simulated by the heat loss calculation program HEAT2.

7.3 Calculation of the heat losses to the ground (HEAT2)

In this chapter the usage of the heat loss calculation program HEAT2 (version 5.0) is described. An estimation of the heat losses to the ground for house II and VI have been done.

The program simulates the two-dimensional heat flow, in this case, through the foundations. Materials, dimensions and thermal data are chosen as well as indoor and outdoor temperatures. Here, the outdoor temperature is allowed to vary periodically, hence a transient calculation has been made. More details can be found in Appendix D or in the manual of the program (Blomberg, 2000).

Lastly, the results from the HEAT2 simulations are used together with the data obtained from the measurements of the specific heat loss. The average power demands are plotted against the temperature differences in the same way as in Figures 7:2 and 7:4. However, the difference is that the intersections with the y-axes (i.e. when $\Delta T = 0$) are set to fixed values, that is the heat losses to the ground calculated in HEAT2. In Figure 7:8 below the average power demands are represented by one value (an average value) for each house.

7.3.1 Results

The results for the different alternatives i and ii, described in Appendix D.2, for the two houses II and VI are summaries in Table 7:1.

Table 7:1 Results from calculations of the heat losses (W) to the ground using HEAT2

Alternative		**House II**	**House VI**
i		425 W	442 W
ii	Lined area uses calculation 1	474 W	485 W
	Lined area uses calculation 2	489 W	518 W

The results show that the rather coarse approximation of alternative i gives lower values than alternative ii. The way the lined area is calculated in alternative ii only seems to have a small effect on the heat loss for house II. For house VI the difference is little bit larger. Which value that is nearest to the real value is impossible to know but most probably all the values are an underestimation of the real values as no consideration has been taken to all the corner and edges of the houses. There are also a number of uncertainties, such as the ground conditions. Additionally, only the two-dimensional flow has been calculated. Consequently, the calculations should be seen as coarse estimations that indicate the magnitude of the heat flow. For the further analysis the values 550 W and 600 W are chosen.

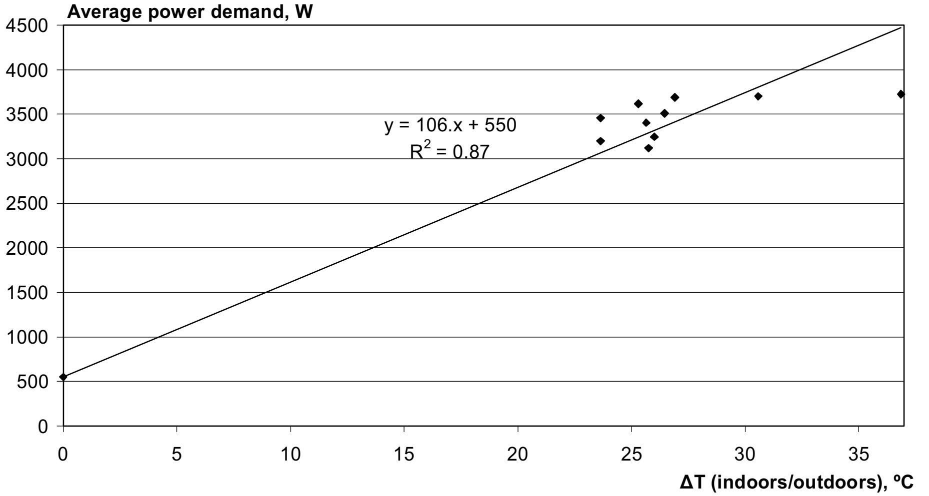


Figure 7:6 Average power demand plotted against temperature difference indoors/outdoors for ten nights including calculated heat loss to the ground, House II

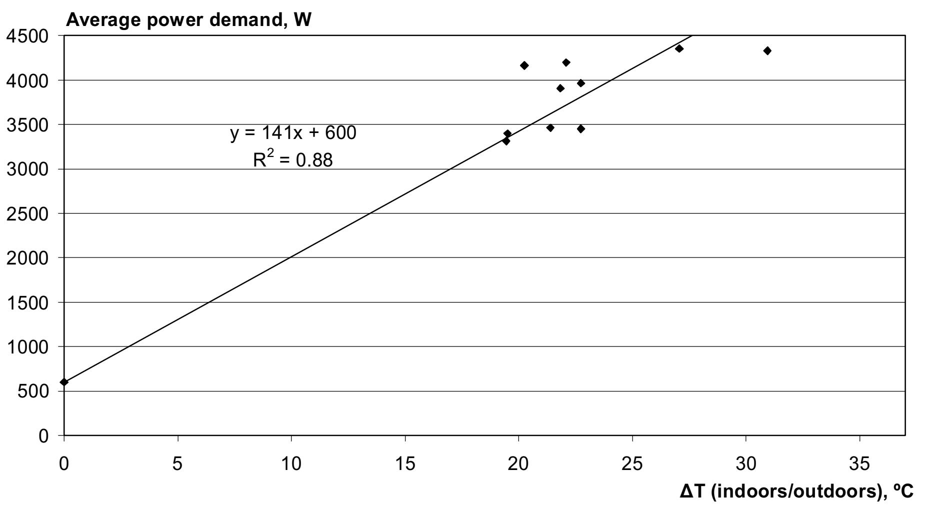


Figure 7:7 Average power demand plotted against temperature difference indoors/outdoors for ten nights including calculated heat loss to the ground, House VI

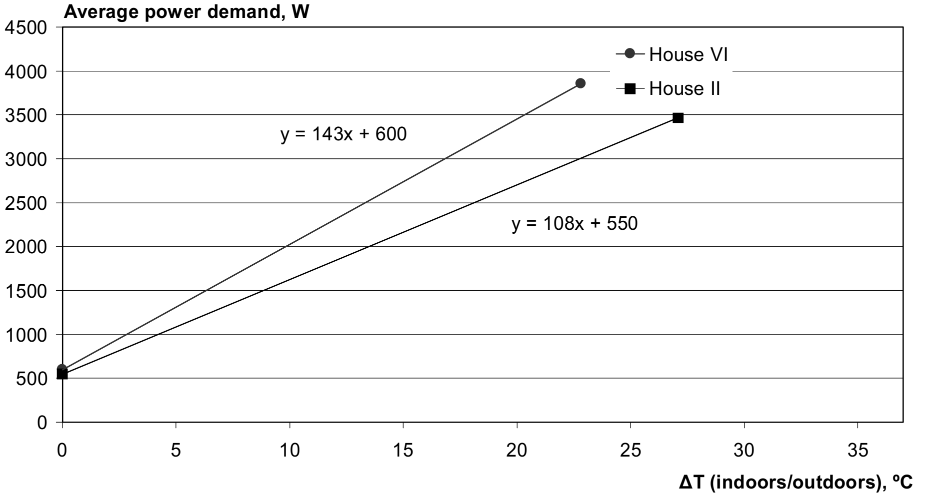


Figure 7:8 An average value of measured power demands plotted against an average temperature difference (indoors/outdoors) including calculated heat loss to the ground, House II and VI

The Equation 7.6, where the average temperature difference between outdoors and indoors is used for ΔT, gives the following specific heat loss, F_T:

	House II	House VI
- 10 nights (Figures 7:6 and 7:7)	127 W/K	168 W/K
- Average value (Figure 7:8)	128 W/K	169 W/K

The results are almost identical to the previous results given in Section 7.2.3. The coefficients of determination, R^2, are now of course considerable higher.

7.4 Calculated energy use by Enorm

In this chapter the energy calculation program Enorm 1000 (version 1.10) is used to calculate the theoretical energy use as well as the specific heat loss. The results will give an indication of what the theoretical value of an "ideal house" would be. The purpose is to get an estimate of the magnitude of the energy use and the heat loss factor.

7.4.1 Description of the Enorm program

Enorm seems to be the energy computer program most widely spread and used in Sweden. It can be used to check the energy performance of a building in relation to the Swedish building regulations (BBR), comparing different buildings, etc. The program calculates the energy use for each day of the year. The characteristics of the building must be known in order to give correct input data to the program. The agreement between the calculated and the actual energy use is strongly dependent on the type of building and the activities inside the building. For example, Enorm does not calculate accurately for buildings with great window areas or great heat storage capacities. Furthermore, the conditions are assumed to be constant over the day and night and the solar energy and waste heat is assumed to be fully used, subsequently the program does not correspond well with actual values for buildings with great changes in operation. The knowledge about the studied object must be detailed in order to give correct input to the program. The interested reader is referred to Enorm's manual[12] for more information on how the program is built up and operated. In the next chapter a few examples are brought up regarding how different calculations are made in Enorm.

7.4.2 Input data and calculations in Enorm

A complete list of input data of house II and VI, together with comments and explanations, can be found in Appendix E. In Table 7:2 the main items of the input data are listed. Some examples of the calculations made in Enorm are also described below.

[12] Svensk Byggtjänst (1996). *Enorm 1000 Manual*. Stockholm: AB Svensk Byggtjänst.

Table 7:2 Main input data to Enorm for the Houses II and VI

Input data	**House II**	**House VI original**	**House VI extension**
Heated floor area	104.2 m^2	104.2 m^2	26.7m^2
Air leakage (at 50 Pa pressure difference)	0.642 l/(m^2·s)	0.662 l/(m^2·s)	
Geographical location (outdoor temperature)	Borås, Sweden (6.1ºC)	Borås, Sweden (6.1ºC)	
Indoor temperature	23.0ºC	19.5ºC	
Area of:			
Ceiling	104.2 m^2	104.2 m^2	29.4 m^2
External walls	98.9 m^2	88.9 m^2	26.7 m^2
Floor	104.2 m^2	104.2 m^2	26.7 m^2
Windows	12.6 m^2	10.6 m^2	15.4 m^2
Doors	4.6 m^2	5.2 m^2	
U-value of:			
Roof construction	0.219 W/(m^2·K)	0.219 W/(m^2·K)	0.162 W/(m^2·K)
External walls	0.321 W/(m^2·K)	0.321 W/(m^2·K)	0.321 W/(m^2·K)
Floor	0.130 W/(m^2·K) (Multiplied by 0.75)	0.130 W/(m^2·K) (Multiplied by 0.75)	0.101 W/(m^2·K) (Multiplied by 0.75)
Windows	1.9 W/(m^2·K)	1.9 W/(m^2·K)	1.9 W/(m^2·K)
Door	0.8 W/(m^2·K)	0.8 W/(m^2·K)	
Type of heating	Electric boiler	Electric boiler	
Type of ventilation	Exhaust	Exhaust	
Basic vent. flow	120 m^3/h	113.1 m^3/h	

Every day the program calculates the heat balance for the building (including both space and hot water heating), where you on the heat loss side have losses due to transmission, ventilation, air leakage and waste water losses. On the supply side you have heat from solar insulation, persons, appliances and heating system (Svensk Byggtjänst, 1996).

The total bought energy is the sum of the bought household electricity, the bought electricity for fans and pumps, the bought energy for heating (exclusive losses) and the losses in the heat production, distribution and control systems (Svensk Byggtjänst, 1996).

The average daily outdoor temperature of the location in question is calculated from SMHI (the Swedish Meteorological and Hydrological Institute) data, taking into consideration the periodic variations of the outdoor temperature.

Air leakage (unintentional ventilation) is calculated according to a general method. The air leakage is estimated through the building envelope according to (Svensk Byggtjänst, 1996):

$$q_{operate} = q_{50} / d \qquad [\mathrm{m^3/(m^2 \cdot s)}] \qquad (7.7)$$

where

$q_{operate}$	air leakage at operating pressure $[\mathrm{m^3/(m^2 \cdot s)}]$
q_{50}	air leakage at 50 Pa pressure difference $[\mathrm{m^3/(m^2 \cdot s)}]$
d	equal to 25 in the case of exhaust air ventilation [-]

In Enorm you can choose different white goods, but Enorm still calculates the household electricity from reference values regardless of the white goods chosen. Instead, the white goods chosen are used to calculate the possible savings made compared to reference values also taking into account the reduction in heat given off to the surroundings if more energy efficient white goods are installed in the building. As a default value Enorm calculates that 80 % of the electricity used in the fridges and freezers are given off to the surroundings as heat during the heating season (Svensk Byggtjänst, 1996).

How the household electricity, the heat gains from persons and the energy for hot water production are calculated as follows:

Household electricity (heat given off is useful)	4.8 + 0.048 × heated area [kWh/day]
Household electricity (heat given off is useless)	1.2 + 0.012 × heated area [kWh/day]
Energy from persons	0.024 × heated area [kWh/day]
Energy for hot water production	5.0 + 0.050 × heated area [kWh/day]

As seen, Enorm uses the heated area in order to estimate these energy usages. The values are derived from a rapport from the National Board of Housing, Building and Planning (Svensk Byggtjänst, 1996).

The last example of the calculations made in Enorm is the calculation of the specific heat loss. Enorm adds up the losses of transmission, ventilation and infiltration (air leakage), and an efficiency of 95 % is used for the heating systems distribution of space heating.

7.4.3 Results

Results from the Enorm calculations are:

	House II	House VI
Total bought energy	21 359 kWh/year	20 397 kWh/year
Specific heat loss	108 W/K	152 W/K

7.5 Analysis of measurements and calculations

The purpose of the measurements and calculations made in this chapter were to investigate if the levels of energy use are due to the building and its building services or if it is due to the residents. A coarse measure of the energy performance of the house is the specific heat loss. The question asked is: Has the house with the highest energy use also the highest specific heat loss?

The specific heat loss, regarding the simulations in HEAT2 or not, were measured to around 130 W/K four house II and to around 170 W/K for house VI. The measurements have an accuracy of roughly 10 % which means that the results could vary between 117 and 143 for house II and between 153 and 187 for house VI.

As the house with the highest energy use has the lowest specific heat loss the results suggest that the different levels in energy use between the two houses are due to the residents rather than the houses.

The calculations in Enorm were made in order to obtain the magnitude of the energy use for the two houses. According to the Enorm calculations house II is suppose to use somewhat more (marginal) energy use than house VI despite that the house has a smaller heated floor area. Regarding the input data consideration has been taking to the different indoor temperatures, the heat generation from persons and the energy used for the hot water production. The household electricity have been assumed to be the same in the two houses, which is probably no the case due to the larger number of persons of household II. The increased window area for the extension of house VI are in the north and west directions. It is difficult to determine the impact of this, but the north windows ought to increase the heat losses from the house rather than increase the solar gains to the house.

Compared to the actual energy use (E_{year}) the results from the Enorm calculations are very precise in the case of house II. For house VI Enorm overestimates somewhat but still the estimate is acceptable. Regarding the corrected energy use (E_{corr}), the Enorm calculations underestimate the energy use for house II for the years 99/00, 00/01 and 01/02. For house VI the corrected energy use for 01/02 was above 22 000 kWh. The Enorm calculations can be regarded as acceptable in this case. An interesting question is if the sudden drop, for both houses, of year 02/03 is temporary or long lasting.

No detailed study of the impacts of the assumptions made regarding the input data in Enorm (such as the air leakage at 50 Pa, the calculations of the U-values, the thermal bridges, the ageing of white goods etc.) or the calculations methods used by Enorm (such as the air leakage at operating pressure, the households electricity, the heat generation from persons etc.) have been made. In this study Enorm is only used to give a “rough” estimation of the energy use of the two houses.

Regarding the specific heat losses calculated in Enorm they are much lower than the measured values, approximately about 20 W/K. The reason for the difference in the results is not known. It might suggest that the houses are not performing as well as they ought to do.

As already mentioned some of the major differences between the two houses are the indoor temperatures, the number of persons and, from 2001, the extension of house VI. Let us take year 01/02 as an example. The actual energy use of that year is for house II below 21 000 kWh and for house VI above 18 000 kWh. A general guideline is that if the indoor temperature is decreased with 1ºC this results in a 5% decrease of the energy demand for heating[13]. This means that a decrease with 3ºC for house II would result in an energy use approximately the same as for house VI. Studying the previous

[13] This is a very rough estimation and originates from the temperature difference (between outdoors and indoors) in the middle of Sweden is around 20ºC during the heating season.

year, 00/01, when the sizes of the heated floor areas are equal, an equivalent decrease in the indoor temperature of house II would not mean an energy use as low as that of house VI. Taking into consideration the estimations of the amount of energy for the hot water production of the two houses (2600 kWh respectively 1400 kWh), the difference is still more than 2500 kWh between the houses. Could the difference lie in the household electricity?

8 Conclusions and discussion

The main objective of this licentiate thesis was to verify or reject the hypothesis that the energy use increases over time in modern single-family houses in Sweden. This task turned out to be complex for a number of reasons, such as difficulties regarding the correction due to the outdoor temperature, great unknown dips and peaks in the energy use, great uncertainties in the energy-related activities that have occurred back in time, difficulties in relating activities to the amount of energy used.

The results from this report could be seen as a description of the situation. To find any explanations to "the situation" are evidently much harder. The attempts made and conclusions that can be drawn are here summaries and discussed.

For a group of modern detached single-family houses, nominally identically built, the energy use was shown to vary a great deal between the houses. This is no new finding and it has been shown in previous reports, but it confirms that the situation is unchanged even for modern built houses. The standard deviation for the group of houses was shown to increase somewhat over the years, i.e. the variations in energy use increased over the years for the houses. Note that the increase mainly was due to an increase over a couple of years. A possible factor behind this could be that many houses on the studied housing estate have made extensions to their houses. The houses have smaller living areas than the average single-family house in Sweden and therefore might tend to increase their living space after some years. There are of course a number of other possible factors that could results in greater differences of the energy usages between the houses, such as the installation of tiled stoves, teenagers etc.

No general trend over time of the energy use has been able to be identified. The average energy use for the group of houses is very stable over the years. However, for individual houses the energy use can both increase and decrease over the years and show sudden dips and peaks from one year to another.

Before any data can be analysed the data might require some treatment such as recalculation and/or correction in order to be able to make fair comparisons between the data. In this study energy data between different years and between different houses are mainly compared. There has been a need to recalculate the energy and water usage so that it corresponds to an actual year's usage. Even though the corrections are somewhat too large due to that the readings usually take place at the end of May/beginning of June, which are usually warmer than the average yearly temperature, the correction is thought to be of minor importance as it usually only involves a few days energy use.

Furthermore, the part of the energy use that is dependent on the outdoor temperature, has been corrected with the degree-day method used by SMHI in order to be able to compare the energy use of different years. In this project this is a very important correction as the purpose is to find any general trend in the energy use from one year to another. Different assumptions regarding the amount of hot water and the household electricity have been made, but the assumptions made no larger difference to the results. The normal period, used as the reference period, has during the course of the project been changed due to that the 90's was an extremely warm period in Sweden. The effect on the corrected energy use is a decrease in the energy use, which is fairly constant from one year to another.

The correction with degree-days can be questioned as an appropriate method for modern airtight single-family houses with a less demand of energy use for heating purposes than older houses. The heat gain from persons, electrical appliances and solar insulation can be used for space heating to a larger extent in these modern houses compared to older ones. As a result, the amount of bought energy for heating can be reduced. The SMHI degree-day method, as it is today, uses a too high balance temperature (17ºC). A lower balance temperature would correspond better to the characteristics of the modern houses where the difference between a comfortable indoor temperature and the balance temperature would be covered by heat from persons, electrical appliances and solar insulation.

The price of electricity has traditionally in Sweden been very low. Sudden peaks in the demand due to cold winters together with dry summers (resulting in low water levels for the water power) has lead to a deficit in electricity and increase in the price. However, as already outlined in Section 5.4.4 this might not affect the energy bill of the individual household straight away as contracts might have been written for a certain period in order to guarantee a fixed electricity price. Nevertheless, the attention in mass media gives a general awareness to the public and a general increase in the electricity price can have long-term effects for all households. A deficit in electricity will probably have the consequence that the amount of energy used more clearly will be linked to the price of electricity than before.

In an attempt to understand the appearance of the energy use for individual households, six house owners have been interviewed regarding the energy-related activities/events that have occurred over the years.

Generally, it was difficult to link certain activities with the amount of energy used, also sudden dips and peaks. This was due to that the residents generally did not remember very well when certain events had happened. This was particularly apparent when there were “evident” in the form of documents showing when a certain activity happened. The actual dates in many cases did not agree with the presumed dates. Additionally, the activities that had occurred in the houses over the years affect the energy use very differently or rather it is difficult to know the impact. In Chapter 6.3 this has been illustrated with different symbols representing certain “types” of activities. For example the extension of the building will increase the energy use instantly, whereas a change of fridge and freezer indicates that the energy use has been affected for many years prior to the change due to ageing.

The fact that many activities occurs the same year makes it even harder to link the impact of certain activities to a change in energy use, especially when the energy data only is given on a yearly basis.

A factor that cannot be studied in this project is the shift in ownership. This is due to that the energy data in most cases only concerns the latest house owner, unless the shift took place during the last five-year period. In a number of previous studies it has been showed and discussed that a change of residents also change the amount of energy used in that particular house (Gaunt, 1985; Lundström, 1982; Palmborg, 1986; Socolow, 1978).

Another interesting finding is that the energy use only seems to follow the outdoor temperature to a certain extent. It appears that the energy use “should” decrease even more when the weather is mild and is “allowed” to increase when it is colder outside in order to keep the same indoor climate. This could mean that the outdoor temperature sensors are not working satisfactorily and it indicates that indoor temperature probably is allowed to fluctuate somewhat.

This impact of the weather can possibly overshadow the affect of certain activities. An example is the number of teenagers that might increase the energy use, but a possible indication of this for certain houses are very uncertain as the appearance of the energy use for the remaining houses, without teenagers, also shows an increase.

Finally it could be said that the retrospective method of asking the residents to remember what has happened in the past proves to be a less valid technique. The analysis results in more questions than answers. In order to be able to make a better analysis a more valid method should be used to get better data/information that will be treated with a statistically correct method. More frequent energy data would probably also be required in order to make a more appropriate analysis.

The main findings of the measurements of the specific heat loss were that the house with the highest energy use has the lowest specific heat loss. The results suggest that the difference in energy use between the two houses is due to the residents rather than the houses themselves.

The Enorm calculations of the energy use are pretty satisfactory for house VI. For house II Enorm underestimate the corrected energy use, except for the last year (02/03) where there is a significant decrease in the energy use, actually to a value near the estimate of Enorm. Additionally, the specific heat losses calculated by Enorm were found to be much lower than the measured ones.

The heat simulation in HEAT2 as well as the energy calculations in Enorm requires a large amount of detailed input data, which turned out to be difficult to obtain. The house owners did not have all the information and the documents they had were not always updated. Neither was the information at the town planning department complete. In addition the energy supplier had not entirely updated information. Most of the details regarding the construction of the houses were obtained from the building company. Thermal characteristics of the materials, used for the simulations and U-value calculations, were set to "standard" values. Similarly, some of the other input data in Enorm was put to standard values or recalculated to suit the houses in question. The lack of easily available correct information about houses can have consequences in the near future, e.g. in regards of the EU Directive on the energy performance of buildings, where energy calculations are suppose to be made. Not having easily available correct information about houses will make this task fairly difficult.

Finally, the purpose with the degree-day corrections done in Chapter 5 was to find the "normal energy usage" for each house. With everything else unchanged, from one year to another, the energy use would be same for all the years. To obtain a normal energy use has not been succeeded in spite of a number of different attempts. Thus, there seems to be a number of factors, other than the outdoor temperature, that changes over the years and that should be taken into consideration. But how should this be done? Part of the answer could also be that the method used to correct for changes in the outdoor temperature, SMHI's degree day method, is unsatisfactory for modern houses as discussed above.

9 Future work

The project so far can be seen as description of the energy use of a group of houses and the obstacles one meet when trying to treat and interpret data in a correct way. To search explanations to the appearance of the energy data and to further investigate the influence of the residents would be of interest. In a literature survey (Carlsson-Kanyama and Lindén, 2002) the knowledge concerning the residents energy behaviour in their homes is highlighted. The authors point out that there is relatively little research regarding the household's energy related behaviours in comparison with research regarding energy efficient technologies.

The future work of this project will subsequently have an interdisciplinary approach with both researchers with technical background as well as a researcher from the environmental psychology discipline.

Three different housing estates are planned to be included in the project; houses with modern conventional technical standard, houses with advanced technical standard and finally houses with somewhat higher technical standard. Here houses with high technical standard are regarded as very energy efficient houses. The houses are preferable modern (built after the energy conservation codes came into force 1977) and situated on an estate with nominal identical houses. A total of 100 to 150 houses will be included in the study.
The different technical standards of the three housing estates give a wider perspective to the project and any differences in the behaviour of the these areas might be recognised. How well the technology operates in the three different areas will also be highlighted.

The everyday habits (behaviour), attitudes and personality traits of the residents in relation to their energy usage will be investigated. The project aims to find explanations to the residents energy related behaviour by keeping a diary, a method that has not been used previously. Using a diary has shown to be a more valid technique than a retrospective method. The energy use will be read frequently of the meter, for most houses every week and in some cases every hour. The behaviour test will be completed with technical measurements and ocular inspections of the houses.

The aim is to investigate the trend of the energy use over time by describing and explaining it in a momentary study. Hopefully the project can be of value in energy planning and the design phase of buildings as well as for a better understanding of the relation between the technology and the behaviour of the users.

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Appendix A The degree-day method

The degree-day method is based on that the number of degree-days is calculated as the difference between the balance temperature and the average daily outdoor temperature. The differences are summed up monthly or yearly (Equation A.1)

$$DD = \Sigma\left(T_{balance} - T_{outdoor}\right) \quad [\text{K·day}] \tag{A.1}$$

The balance temperature, $T_{balance}$, is defined as the lowest outdoor temperature where the internal heat gain precisely covers the heat losses from the building. If the outdoor temperature is lower than the balance temperature, heat from the heating system must be supplied (Abel, 2000). The balance temperature can be written as (ASHRAE Handbook Fundamentals, 1997):

$$T_{balance} = T_i - \frac{Q_{gain}}{K_{tot}} \quad [\text{K}] \tag{A.2}$$

where

$T_{balance}$	balance temperature [K]
T_i	indoor temperature [K]
Q_{gain}	internal heat gains from solar insulation, persons, lighting and electrical appliances [W]
K_{tot}	total heat loss coefficient of the building and building services [W/K]

The balance temperature varies over the year as the internal heat gain varies due to changes in the solar insolation. It can also vary with the activities in the building as well as fluctuations in the indoor temperature. Furthermore, the balance temperature is different for different buildings due to their U-values, air tightness and ventilation flows.

Still, in the steady-state approach a fixed balance temperature is used. For example the Swedish Meteorological and Hydrological Institute (SMHI) calculates the degree days by considering that the heating system needs to supply heat to the building to a temperature of 17˚C ($T_{balance}$).

During spring, summer and autumn the solar insulation is considered to contribute to a larger extent and the calculations are altered. If the daily average outdoor temperature is equal to or higher than the listed temperatures below the contribution is regarded as zero[14].

Month	**Limit for daily average outdoor temperature**
April	12˚C
May, June, July	10˚C
August	11˚C
September	12˚C
October	13˚C

In a report by Schulz (2003) it was pointed out that the above limits are not representative for all kinds of buildings as the internal heat generation can differ greatly.

From the above equations and discussion it can be seen that the degree-day method is not appropriate if use of the building and efficiency of the heating and ventilation systems are not constant. This means that the indoor temperature and the internal heat gain cannot vary and are the same for all households. Furthermore, the degree-days given by SMHI assumes that the outdoor temperature is the same for a whole region in the area of the meteorological (weather) station. The effect of other climate data such as solar insulation or wind is not considered for a particular location.

However, this is a commonly used method and according to ASHRAE (ASHRAE Handbook Fundamentals, 1997) it gives rather correct results for the yearly heating energy for single-zone buildings, which dominating heat losses are through the walls and roof and/or the ventilation.

[14] Information about the degree day method is available from http://www.smhi.se/ (the Swedish Meteorological and Hydrological Institute)

Appendix B Questionnaire

The questionnaire that was used in the structured interviews, described in Chapter 6, included the following questions.

Introduction

Date:	
House number:	
Interview with (the owner):	

General background information (the present situation)

Building year:	
Moved in (year):	
Heated floor area:	
Number of floors:	
The construction and systems	
Foundation:	
Framework:	
Attic:	
Type of windows:	
Heating system:	
Distribution system:	
Ventilation system: (Do you usually alter the ventilation?)	
Solar insulation (south direction):	
The household	
Number of persons (adults and children):	
Ages:	
Others	
Possession of white goods (fridge, freezer, dish washer, washing machine, tumble dryer) and ages:	
Car garage	

Activities/events (important to the energy use) that have occurred over the years

Activity/event	Yes/No	Comments/Details	When (year)
The residents			
Change of owner			
Changes in the family situation			
Number of persons (e.g. birth of children)			
Others (e.g. letting the house, taken in boarders)			
The house			
Indoor temperature			
Change of white goods (fridge, freezer, dish washer, washing machine, tumble dryer)			
Change or adjustments of the heating, distribution and ventilation system*			
Defects in the heating, distribution and ventilation system, etc.			
Rebuilding/extensions (e.g. additional floor, room)			
Reparation			
Major maintenance work			
Other changes (e.g. additional insulation, change of windows, cast iron stoves, sealing measures)			
Other comments			

Appendix C Method of the measurement of specific heat loss

The method of the measurement of specific heat loss in houses is described in Chapter 7.2. Here some of the preparations and restrictions for the residents are listed. This is followed by the record kept by the residents and thereafter a description of the different steps of data treatment. The purpose of this appendix is to give the reader an idea of what the method involves. If the reader wishes more details and explanations to the method he/she is referred to (Sandberg and Jahnsson, 1995).

C.1 Preparations and restrictions

Preparations and restrictions prior to the measurements:

- Disconnection/removal of any night or day lowering of the indoor temperature.
- Constant indoor temperature at least two days prior to measurements.
- No usage of tiled stove, cast iron stove or other fireplace two days prior to measurements.
- Preferable limit the usage of hot water two hours before the measurement period.
- Solar insolation through south and west directed windows should be shielded at the latest 12:00 the day of the measurements.

Restrictions during the measurements (i.e. during the night):

- No hot water usage.
- No usage of hood/forced ventilation
- No usage of outdoor lighting.
- Only blinds in bedrooms are allowed to be used at all times.
- Windows are not allowed to be open.
- Doors (inside the house) should be opened.

C.2 Record of temperatures and energy use

Below follows the record that was kept by the residents of one of the houses. The figures (the temperature and energy readings) were used to calculate the specific heat loss.

Night	Date Evening	Time	Reading energy meter	$T_{indoors}$ °C	$T_{outdoors}$ °C	Date Morning	Time	Reading energy meter	$T_{indoors}$ °C	$T_{indoors}$ Max °C	$T_{indoors}$ Min °C	$T_{outdoors}$ °C	$T_{outdoors}$ Max °C	$T_{outdoors}$ Min °C	Name of persons in house[15]	Between what hours[16]	Comments[17]
1	3/2	21:30	80696.7	19.1	-0.1	4/2	6:00	80725.1	19.3	19.4	19.0	-0.6	0.0	-2.4	2 person		
2	4/2	21:30	80778.1	19.3	-2.3	5/2	6:00	80807.1	19.3	19.4	19.0	-2.1	-1.0	-3.4	2 person	From 23:00	
3	5/2	21:00	80861.0	19.1	-8.4	6/2	6:00	80899.4	19.1	19.6	18.5	-15.6	-8.0	-15.9	2 person		
4	6/2	21:30	80980.6	19.6	-8.9	7/2	6:00	81015.9	19.3	19.9	18.5	-6.6	-6.5	-9.0	2 person		
5	7/2	21:30	81078.0	19.6	-1.0	8/2	6:00	81111.3	19.4	19.9	19.0	-0.5	-0.5	-1.9	2 person		
6	8/2	22:00	81176.2	19.6	0.5	9/2	6:00	81202.1	19.4	20.3	19.0	-0.7	0.9	-1.9	2 person		
7	Went wrong																
8	10/2	21:00	81351.1	19.9	-1.9	11/2	5:30	81384.7	19.5	20.0	19.0	-3.1	-1.0	-3.4	2 person		
9	11/2	21:30	81450.7	19.9	-3.1	12/2	5:30	81479.2	19.2	19.9	19.0	-3.5	-3.0	-3.6	2 person		
10	12/2	21:30	81538.0	19.6	-2.8	13/2	5:30	81565.1	19.6	19.9	19.3	-3.7	-2.6	-3.9	2 person		
	13/2	21:30	81622.2	19.5	-2.8	14/2	5:30	81651.0	19.0	19.9	19.0	-2.6	-2.5	-3.4	2 person		

[15] Name on persons that are in the house during the evening/night/morning (i.e. during the measuring period from the reading in the evening to the reading in the morning). This information is needed in order to calculate the heat given off by persons.

[16] Write down between what hours the person/s are in the house.

[17] Write down any general comments, but most importantly comment on any deviations from the preparations and restrictions listed in a separate document.

C.3 Treatment of data

The list below gives the different steps for the treatment of the data.

1. Corrections of the temperatures according to the calibration of the temperature sensor
2. Check if a number of requirements are fulfilled.
   - Requirements on the maximum and minimum temperature allowed as well as maximum temperature difference between evening and morning readings.
   - Requirement on the length of the measuring period (the night period), which should be at least 8 hours.
   - Requirement on the start and end of the measuring period (4-5 hours after sunset and 1-2 hours before sunrise).
   - Requirements on the wind speed have not been checked.
3. Calculation of the temperature differences between the average indoor temperatures and average outdoor temperatures and check that the differences are larger than 20ºC.
4. Calculation of heat from persons, E_{person}, as follows:

$$E_{person} = \sum_{i}^{n} Q_{person,i}(age; activity) \times t_i \quad \text{[Wh]} \qquad \text{(C.1)}$$

   where

   $Q_{person,i}(age; activity)$ rate of heat generation by person i at a certain age and doing a certain activity [W]

   t_i time period (length) during which the activity is performed [h]

   Data for the heat generation for different ages and for persons sleeping has been taken from the Swedish handbook on building services (Elgestad, 1963). The length of the activity (sleeping) has been approximated with the time spent in the house during the measuring period.

5. Correction for indoor temperature fluxes, E_T, (fluxes in outdoor temperature are neglected). If the indoor temperature has increased during the night E_T is subtracted from the average power demand and vice versa, if the indoor temperature has decreased during the night E_T is added.

$$E_T = X \times A_{floor} \times \Delta T_{indoors} \quad \text{[Wh]} \qquad \text{(C.2)}$$

X correction factor for indoor temperature fluxes (watt-hours per degree temperature difference of the indoor temperature and square meter floor area) [Wh/(m^2·K)]

A_{floor} heated floor area [m^2]

$\Delta T_{indoors}$ indoor temperature difference of evening value and morning value [K]

The correction factor that has been used is 30 Wh/Km^2, which was recommended in the description of the method (Jahnsson, 2000). In order to study the effect of different values of the correction factor, values between 15 Wh/(m^2·K) and 60 Wh/(m^2·K) have been tested.

6. Calculation of the energy used for the fan (mechanical ventilation), E_{fan}. The heat from the fan does not contribute to the heating of the house; hence this value is subtracted from the average power demand.

$$E_{fan} = Q_{fan} \times t \quad \text{[Wh]} \tag{C.3}$$

Q_{fan} power of fan [W]

t length of measurement period [h]

The residents of house II stated that their fan, which was purchased probably in year 2000, had a power of 32 W. The house owners of house VI did not have this information. After discussion with colleagues at SP a reasonable assumption, taken into consideration the building year, would be between 50 and 100 W. For that reason 75 W was chosen for house VI.

7. Energy used during the night (E_{read}) is worked out from the readings in the evening respectively morning.
8. Calculation of the average power demand, $Q_{average}$ (Equation 7.1).
9. Make diagram with $Q_{average}$ and ΔT and the equation for the linear regression line gives the specific heat loss, F_T.

Additionally,

10. $Q_{average}$ has been calculated including only the transmission losses. For this purpose the measured ventilation flows were corrected according to the calibration of the instrument.

Appendix D HEAT2 - Calculations and input data

In Chapter 7.2 the results from an estimation of the heat losses to the ground using the heat loss calculation program HEAT2 (version 5.0) are presented. Here, the calculations are described very briefly as well as the in put data used for house II and VI.

D.1 Description of the program HEAT2
(Blomberg, 2000)

The heat conduction equation in two dimensions for the temperature *T(x,y,t)* that is fundamental for the calculations is:

$$\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)=C\frac{\partial T}{\partial t} \qquad [\mathrm{W/m^3}] \tag{D.1}$$

where

λ	thermal conductivity [W/(m·K)]
T	temperature (at a given point after a certain time) [K]
C	volumetric heat capacity of the material [Ws/(m^3·K)]

Note that, $C=\rho\times c_p$, where

ρ	density of material [kg/m^3]
c_p	specific heat capacity of material [Ws/(kg·K)]

The thermal conductivity, λ, is here assumed to be identical in both x- and y-directions. No internal heat generation is included in this example.

The program solves the heat conduction equation by the method of explicit finite differences, where nodes of temperatures make up the temperature field. The nodes form a mesh of cells, through which the heat flows. The change in temperature, which is dependent on the change in energy, is iteratively calculated at time steps. This is done for all cells.

The construction, including dimensions, materials and material properties, through which the heat flows, is ”drawn” in the program. A mesh is also created. Boundary conditions, initial temperatures, simulation start and stop times, outputs of interests and intervals between screen update are all chosen.

D.2 Input data and use of simulation results

The construction of the foundation has previously been shown in Figure 5:1. Below the “drawings” in HEAT2 are shown for the original building as well as for the extension of house VI (Figures D:1 and D:2). Some general simplifications have been made regarding the interior flooring and distance from the ground to the exterior wooden boarding. Moreover, haunched beams as well as the somewhat different construction underneath the flooring in wet rooms have not been regarded. The material data (standard values) and the boundary conditions are given in Table D:1 respectively D:2.

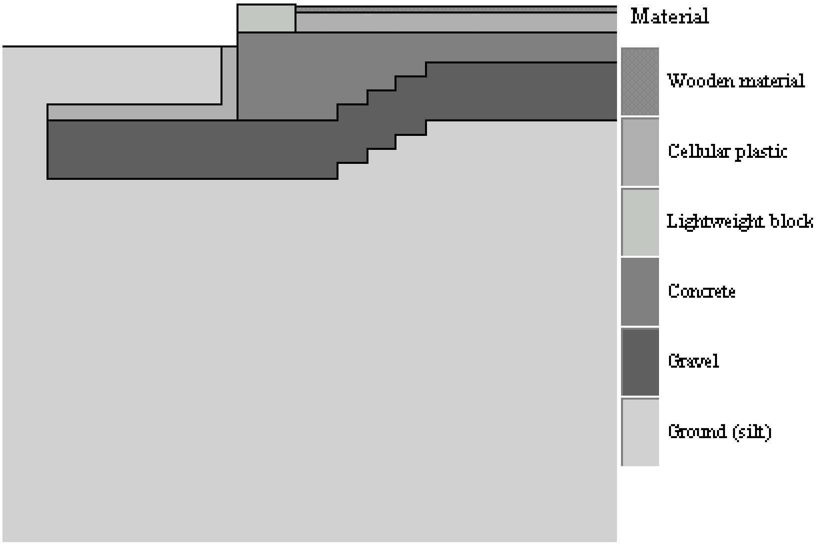

Figure D:1 Drawing/Sketch of the foundation in HEAT2 for the original building

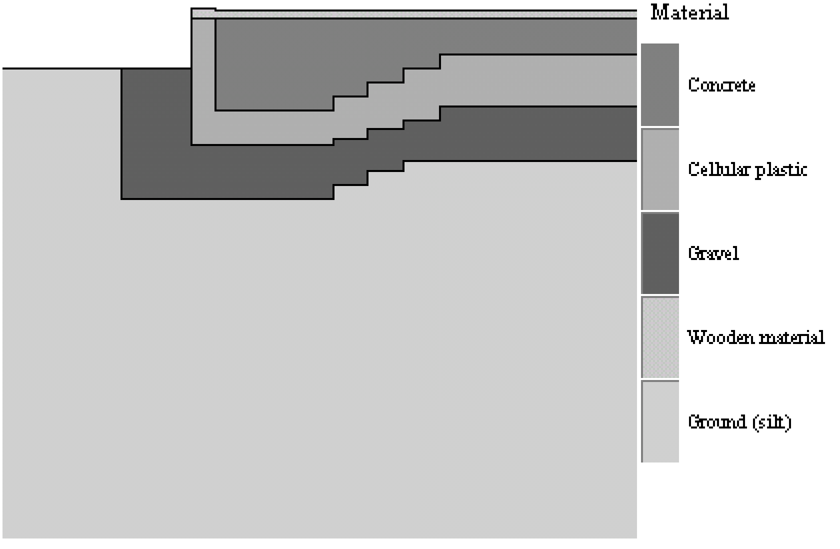

Figure D:2 Drawing/Sketch of the foundation in HEAT2 for the extension of house VI

Table D:1 Material data for the foundations of Houses II and VI

Material	**λ [W/(m·K)]**	**$C = \rho \times c_p$ [MWs/(m^3·K)]**	
		ρ [kg/m^3]	**c_p [Ws/(kg·K)]**
Lightweight block	0.23	C = 0.504	
Wooden material (flooring board and ground plate)	0.14	500	1500 (wood)
Cellular plastic	0.036	30	800 (mineral wool)
Concrete	1.7	2300	900
Gravel	2	C = 2	
Clay or silt	1.5	C = 3	

Table D:2 The boundary conditions used in HEAT2 for House II and VI

Boundaries facing indoors	
$T_{indoors}$(House II) = 23˚C $T_{indoors}$(House VI) = 19.5˚C	The temperatures are taken from measurements carried out in the houses (Chapter 7.2).
R_{si} = 0.17 m^2·K/W (floor) R_{si} = 0.13 m^2·K/W (wall)	
Boundaries facing outdoors	
$T_e(t) = 7.3 + 10.25 \times \sin(2\pi(t_{day} - 106.25)/365)$	For an explanation, see Appendix D.3. (transient)
R_{se} = 0.04 m^2·K/W	
Boundaries at the "edge" of the ground and inside the wall in the vertical direction	
The heat flow is put to 0 W/m^2.	

The main part of the ground is initially set to the yearly average temperature (from February 2002 to January 2003) of 7.3˚C. The remainder of the ground and the construction is set to an initial temperature of 0˚C.

The start and stop times are set to zero respectively 10 years. The 10-year-simulation-period is due to that the temperature variations in the ground shall reach equilibrium where the temperatures are identical at a certain time of the year, year after year.

The output of interest is the heat flow (W/m) through the floor and foundation. This is taken for the same time of year as when the measurements of the specific heat loss (Chapter 7.2) where made, i.e. in February.

Due to that HEAT2 has been used which calculates the heat flow in two-dimensions it is "convenient" if a symmetric line can be drawn in the middle of the house where the dimensions and consequently the heat flow is assumed to be identical on both sides of the line. However, the houses in questions are not symmetrical in this sense. And the extension of House VI has even a somewhat different construction compared to the original building. In Figures D:3 and D:4 the plan for the two houses are divided into sections where symmetric lines are drawn. Separate calculations are made for the different sections.

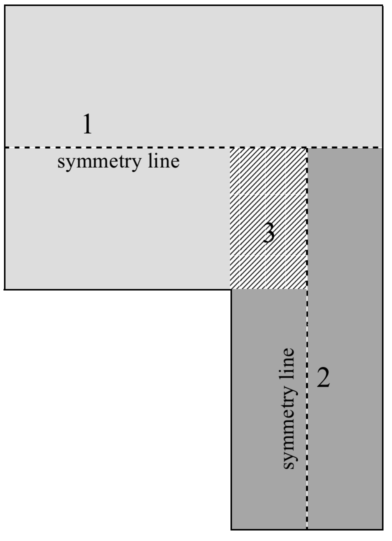

Figure D:3 Simplified plan of house II divided into different sections by symmetry lines
1: Symmetry line 1 and calculation 1
2: Symmetry line 2 and calculation 2

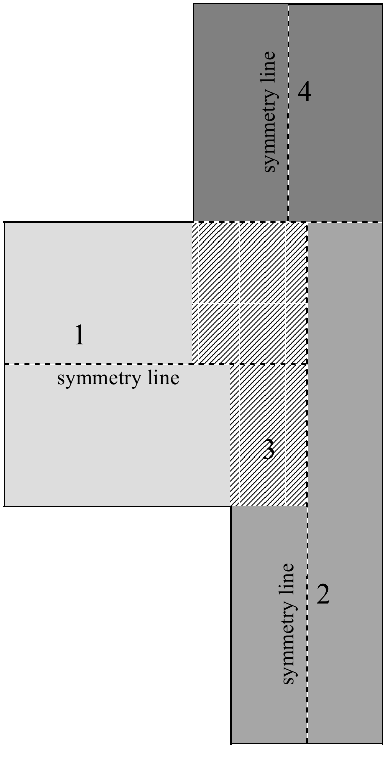

Figure D:4 Simplified plan of house VI divided into different sections by symmetry lines
1: Symmetry line 1 and calculation 1
2: Symmetry line 2 and calculation 2
3: Calculation 3
4: Symmetry line 4 and calculation 4

Two alternative approaches are made:

i. Two calculations are made, one for the original building (number 1 in Figures D:3 and D:4) and one for the extension in the case of house VI (number 4 in Figure D:4). These calculations give the average heat flow through the shaded areas 1 and 4. The calculation of shaded area 1 is used for the whole original building and the calculation of shaded area 4 is used for the extension.

ii. The two (in case of house II) or three (in case of house VI) symmetry lines are used and the calculations 1, 2 and 4 are used around respectively symmetry line. The lined floor areas do not have contact with any outer walls (number 3 in Figures D:3 and D:4) and consequently the heat losses might be lower here than for the rest of the floor. The heat flow thought to be representative for these areas are the heat flow in a point near one of the symmetry lines 1 or 2. Finally, the calculations for the different sections are summed up.

D.3 Periodic variations in outdoor temperature

The original equation is (Hagentoft, 2000):

$$T_e(t) = T_0 + T_{season}(t) + T_{diurnal}(t) + T_{dev}(t) \quad [\mathrm{K}] \tag{D.2}$$

where

T_e	outdoor temperature [K]
T_0	yearly average temperature [K]
T_{season}	seasonal variation [K]
$T_{diurnal}$	diurnal variation [K]
T_{dev}	deviations in temperature due to variations in climate, cloudiness and other disturbances [K]

In most cases a sufficient estimation can be done disregarding T_{dev}. In addition, the calculations in Chapter 7.3 do not take the diurnal variations into consideration. Subsequently the Equation D.2 is reduced to:

$$T_e(t) \approx T_0 + T_{season}(t) \quad [\mathrm{K}] \tag{D.3}$$

The seasonal variations, T_{season}, can be approximated with a sinus function:

$$T_{season}(t) = T_1 \times \sin(2\pi(t_{day} + t_0)/365 \quad [\mathrm{K}] \qquad (D.4)$$

where

T_1	amplitude of seasonal variations [K]
t_{day}	the particular day under consideration (t_{day} = 1 corresponds to the 1st of January) [day]
t_0	time delay (of maximum and minimum temperatures) [day]

For the climate in Borås T_0 has been approximated with the average monthly temperatures between February 2002 and January 2003. The monthly averages have been obtained from the SMHI's (Swedish Meteorological and Hydrological Institute) climate station in Borås. T1 has been approximated with the difference between monthly average temperatures for July and January divided by two. Furthermore, it has been assumed that the coldest day falls in the middle of January and the warmest falls in the middle of July. With the values inserted in the Equations D.3 and D.4, the following periodic variations of the outdoor temperature is given:

$$T_e(t) = 7.3 + 10.25 \times \sin(2\pi(t_{day} - 106.25)/365) \quad [\mathrm{K}] \qquad (D.5)$$

Appendix E Input data to Enorm

Table E:1 Input data for House II and House VI

Page in Enorm	Input data	"Value" House II	"Value" House VI original	"Value" House VI extension	Comments / References
1	Type of building	Single-family house	Single-family house		
	Heated floor area	104.2 m^2	104.2 m^2	26.7 m^2	A total area of 130.9 m^2 for house VI.
	Air leakage (infiltration) at 50 Pascal pressure difference.	0.642 $l/m^2 \cdot s$	0.662 $l/m^2 \cdot s$		Not known According to SBN 80 the air leakage should not exceed 3 airchanges per hour (Statens planverks författningssamling , 1981) were the prevailing Swedish building regulations/codes at the time of construction. The extension of house VI was also built in agreement with SBN 80 according to the contractor. The air leakage is converted to the right unit by using the envelope area[18], see comment 1. It can be added that the house are built on site and sealing measures at the doors or change of doors have been made. No other points of leakage are known.
	Heat capacity	25 $Wh/m^2 \cdot K$	25 $Wh/m^2 \cdot K$		Standard value for wooden houses (Svensk Byggtjänst,

[18] The envelope area is the total area of all surfaces of the building envelope, i.e. the area of the floors, walls and ceilings facing the interior of the building. The building envelope is defined as the boundary or barrier separating the interior heated environment from the exterior environment. The exterior environment could be the surrounding air, the ground, or partly heated or non-heated spaces.

					1996)
2	Geographical location (outdoor temperature)	Borås, Sweden (6.1 ºC)	Borås, Sweden (6.1 ºC)		The average annual outdoor temperature is taken from SMHI, (Swedish Meteorological and Hydrological Institute). Enorm uses statistics from this institute.
	Indoor temperature	23.0 ºC (every day of the week)	19.5 ºC (every day of the week)		These are the indoor temperatures measured in February 2003 (Chapter 7.2) and they were used as the all year round temperatures as it was indicated by the interviews that these temperatures were about right according to the residents. It can be noted that the temperature for House II is higher than the average Swedish single-family houses. The temperature of house VI on the other hand is lower than the average.
3	Area of ceiling	104.2 m^2	104.2 m^2	29.4 m^2	Same as heated floor area except for the extension, which has a sloping ceiling.
	Area of external walls	98.9 m^2	88.9 m^2	26.7 m^2	
	Area of floor (slab on ground)	104.2 m^2	104.2 m^2	26.7 m^2	Same as heated floor area.
	Area of windows incl. frames	12.6 m^2	10.6 m^2	15.4 m^2	The glass panes in some of the doors are also included here, although without frames. As these glass areas only represent a small fraction of the total window area in the house this approximation is assumed to have negligible impact on the result.
	Area of doors incl. frames	4.6 m^2	5.2 m^2		This area excludes the glass panes in the doors. The door in the extension is totally made out of glass and is therefore counted as a window.
4	U-value of roof construction	0.219 $W/(m^2 \cdot K)$	0.219 $W/(m^2 \cdot K)$	0.162 $W/(m^2 \cdot K)$	See comment 2 below.
	U-value of external walls	0.321 $W/(m^2 \cdot K)$	0.321 $W/(m^2 \cdot K)$	0.321 $W/(m^2 \cdot K)$	See comment 3 below.

	U-value of floor (slab on ground)	0.130 W/(m^2·K) Multiplied by 0.75.	0.130 W/(m^2·K) Multiplied by 0.75.	0.101 W/(m^2·K) Multiplied by 0.75.	See comment 4 below. These values are less than for average buildings. The U-values for the slab on ground are reduced with 25 % due to that the heat capacity of the ground means a higher temperature than the outdoor temperature in the winter, which favours a reduction of transmission losses to the ground in the winter.
	U-value of windows incl. frames	1.9 W/(m^2·K)	1.9 W/(m^2·K)	1.9 W/(m^2·K)	The windows are sealed insulating glass units (triple pane). Enorm gives a general U-value for this type of window. Note, that the same U-values have been used for all windows, independent of the size.
	U-value of door	0.8 W/(m^2·K)	1.0 W/(m^2·K)		Not known. Two of the doors of house II have been changed in 1998, which motivate a lower value than 1.0 W/(m^2·K) that is commonly used.
	Regarding thermal bridges, a part from the additional 5 % of wood that Enorm adds for inhomogeneous layers no extra thermal bridges have been considered. The thermal bridges have been assumed to be limited as the houses only have one floor and no balcony.				
5	Solar data	Malmö	Malmö		Enorm only has solar data for the locations Stockholm, Malmö and Umeå.
	Orientation of the “south” wall	South east direction	South east direction		The wall is only slightly to the southeast.
	Share of solar transmittance = 1.0 and Screening factor = 0.75				
	Glass area				The glass panes in some of the doors are also included here.
	- North	4.04 m^2	2.4 m^2	5.7m^2	
	- East	0.22 m^2	1.0 m^2		
	- South	2.32 m^2	2.0m^2		
	- West	1.65 m^2	1.7m^2	5.8m^2	

6	Type of heating	Electric boiler	Electric boiler		
	Production efficiency	100 %	100 %		Calculated by Enorm
	Production losses	0.12 kW, where 100 % is used during the heating season.	0.12 kW, where 100 % is used during the heating season.		Calculated by Enorm
	Heat distribution	Water radiators	Water radiators		
	Basic energy control	Thermostats in rooms and automatic power regulation.	Thermostats in rooms and automatic power regulation.		
	Distribution losses in W/ºC temperature difference heat carrier/indoor air	2.5	3.1		Calculated by Enorm
	Control losses in W/ºC temperature difference heat carrier/indoor air	2.5	3.1		Calculated by Enorm
	Design flow temperature	55 ºC	55 ºC		Not known. Standard value was chosen.
	Power of pumps in the heat distribution system	0.052 kW, where 100% is given off as heat.	0.065 kW, where 100% is given off as heat.		Not known. Standard value was chosen. The fraction of heat given off was given by Enorm.
9	Type of ventilation	Exhaust ventilation	Exhaust ventilation		
	Fan power	0.9 kW/(m^3·s)	0.9 kW/(m^3·s)		Given by Enorm.
	Percentage of energy from the fan that can be useful heat	0 %	0 %		The fan is placed on the roof.
	Ventilated volume	250 m^3	250 m^3	77 m^3	The original building has a height of 2.4 m. The extension has a sloping ceiling with a height of 3.4 m in the middle of the room and 2.3 m at the walls.
	Basic flow	120 m^3/h	113.1 m^3/h		The measured flows of 33.3 l/s (0.32 l/(m^2·s)) for house

	Monday - Friday			II and 31.9 l/s (0.24 l/($m^2 \cdot s$)) for house VI have been used.
	Operational time	24.0 hours per day	24.0 hours per day	
	Forced ventilation flow	0	0	Negligible in residential houses.
10	Basic flow	120 m^3/h	113.1 m^3/h	
	Saturday and Sunday			
	Operational time	24.0 hours per day	24.0 hours per day	
12	In the comparison between the houses II and VI the estimation of these energy usages by using the heated floor area (see Section 7.4.2) might not be an appropriate method. The household of house II consists of 4 persons compared to 2 persons in the case of house VI. Regarding the heated areas it vice versa (house VI has the largest area). Subsequently, the estimations have been altered somewhat.			
	Household electricity (heat given off is useful)	9.85 kWh/day	9.85 kWh/day	The household electricity are set to the same values even though the larger floor area probably do not correspond entirely with the larger number of persons.
	Household electricity (heat given off is useless)	2.46 kWh/day	2.46 kWh/day	
	Energy from persons	3.14 kWh/day	1.57 kWh/day	The approximate ratio between the two households is taken from the previous assumptions regarding the heat generation from persons used in the calculations of the specific heat loss (Equation C.1). Without knowing how often the persons are at home and the type of activities they are performing it is assumed that house II gains twice as much heat from persons as house VI.
	Energy for hot water production	2600 kWh/year (7.12 kWh/day)	1400 kWh/year (3.84 kWh/day)	The total water consumption is about 190 m^3 for house II and about 100 m^3 for house VI. Using Equation 5.4, assuming $f = 30\%$, $T_{tap\ hot\ water} = 45°C$ and $T_{into\ the\ house} = 7°C$, E_{ww} is calculated to approximately 2600 kWh/year and 1400 kWh/year for the two households. Any distribution losses are not regarded here.

13	Type of refrigerator	BOSCH Kyl-Sval KSK 3420 (2001) 361 litres, 168 kWh/year	Husqvarna Grand Menu QR 130 P (1984) 379 litres, 519 kWh/year	The aging has been neglected for the refrigerator in house II. See comment 5 below for how the ageing has been taken into consideration for the refrigerator in house VI. The resulted energy use is rather high for house VI.
	Type of freezer	BOSCH GSD 3201 (2001) 303 litres, 405 kWh/year	Husqvarna Grand Menu QT 105 F (1984) 338 litres, 882 kWh/year	The aging has been neglected for the freezer in house II. See comment 5 below for how the ageing has been taken into consideration for the freezer in house VI. The resulted energy use is rather high for house VI.
	Extra freezer	Philips Whirlpool (1993) 130 litres, 424 kWh/year		The aging has been considered for the extra freezer in house II in a similar way as described in comment 5 below. Some different alternatives have been tested on how to regard this extra freezer in Enorm, see comment 6.
14	Type of dish washer	Husqvarna Cardinal Exclusiv QB 210 W 1984 350 kWh/year	Husqvarna Cardinal Exclusiv QB 210W (approx. 1986) 245 kWh/year	The energy use and the frequency of usages of the dishwashers were not known. Estimations have been done, see comment 7.
	Type of washing machine	BOSCH WFF 1601 700 kilograms/year, (1998) 0.7 kWh/kilogram, 490 kWh/year	Husqvarna QW 810H 350 kilograms/year, (approx. 1986) 0.77 kWh/kilogram, 270 kWh/year	Enorm suggests 700 kg/year, this is reasonable for 4 persons (house II). 350 kg/year has been used for the two-person-household (house VI). Enorm uses 0.7 kWh/kg as a reference value. The manufacture of the washing machine in house VI states that a similar washing machine uses 0.77 kWh/kg. These seem to be reasonable values for the machines in question.

Comment 1 – Calculation of air leakage

Air leakage (according to SBN 80), n = 3 airchanges per hour

	House I	House VI (original building and extension)
Volume, V	250.1 m^3	326.8 m^3
$n \times V$	208.4 l/s	272.3 l/s
Envelope area	324.56 m^2	411.1 m^2
Air leakage, q_{50}	0.642 l/(m^2·s)	0.662 l/(m^2·s)

Comment 2 – Calculation of U-value of roof construction (standard values have been chosen)

Original building

Material	Thickness, d [mm]	Thermal conductivity, λ [W/(m·K)]	Thermal resistance, R [m^2·K/W]
External surface resistance, R_{se}			0.04
Thermal resistance of roof spaces, R_u			0.2
Loose fill insulation (glass wool)	230	0.042	5.476
Beams (45 mm width and c 1200 mm) and loose fill insulation (glass wool)*	120	λ (wood) = 0.14 λ (glass wool) = 0.042	0.857 2.857
Steel bars and air space			0
Gypsum wallboard	13	22	0.059
Internal surface resistance, R_{si}			0.10
U-value (Enorm calculations):		0.219 W/(m^2·K)	

Extension

Material	Thickness, d [mm]	Thermal conductivity, λ [W/(m·K)]	Thermal resistance, R [m^2·K/W]
External surface resistance, R_{se}			0.04
Roofing tiles and battens			0
Tongued and grooved board with sawn face	17	0.14	0.121
Slightly ventilated air space**	25		0.085
Beams (45 mm width and c 1200) and mineral wool*	195	λ (wood) = 0.14 λ (mineral wool) = 0.035	
Battens (45 mm width and c 600) and mineral wool	45	λ (wood) = 0.14 λ (mineral wool) = 0.035	
Tongued and grooved boarding	15	0.14	0.107
Internal surface resistance, R_{si}			0.10
U-value (Enorm calculations):		0.162 W/(m^2·K)	

The weighted U-value for the whole roof construction is 0.206 W/(m^2·K) (used for house VI).

* For inhomogeneous layers the U-value calculations in Enorm adds an additional 5 % of wood.

**Actually, beams and battens (45 + 2x38 mm width and c 1200) and air. The thermal resistance for slightly ventilated air spaces can be found in EN ISO 6946:1996.

Comment 3 - Calculation of U-value of external wall (standard values have been chosen)

Original building and extension

Material	Thickness, d [mm]	Thermal conductivity, λ [W/(m·K)]	Thermal resistance, R [m^2·K/W]
External surface resistance, R_{se}			0.04
Wooden boarding	22	0.14	0.157
Battens / air space			0
Mineral wool	50	0.035	1.429
Studs (45 mm width and c 600) and	120	λ (wood) = 0.14	0.857
mineral wool*		λ (mineral wool) = 0.035	3.429
Gypsum wallboard	13	0.22	0.059
Internal surface resistance, R_{si}			0.13
U-value (Enorm calculations):		0.3213 W/(m^2·K)	

* For inhomogeneous layers the U-value calculations in Enorm adds an additional 5 % of wood.

Comment 4 - Calculation of U-value of foundation (standard values have been chosen)

Original building

Material	Thickness, d [mm]	Thermal conductivity, λ [W/(m·K)]	Thermal resistance, R [m²·K/W]
Ground + R_{se} + R_{si} [1)]			0.70 and 2.20
Gravel	200		0.2[2)]
Concrete	100	1.7	0.059
Cellular plastic	70	0.036	1.944
Flooring board/parquet	18	0.14	0.129
U-value (Enorm calculations):		0.1301 W/(m²·K)	

Extension

Material	Thickness, d [mm]	Thermal conductivity, λ [W/(m·K)]	Thermal resistance, R [m²·K/W]
Ground + R_{se} + R_{si} [1)]			0.70 and 2.20
Gravel	150		0.2[2)]
Cellular plastic	150	0.036	4.167
Concrete	100	1.7	0.059
Flooring board/parquet	18	0.14	0.129
U-value (Enorm calculations):		0.1007 W/(m²·K)	

The weighted U-value for the whole roof construction is 0.124 W/(m²·K) (used for house VI).

[1)] In Enorm it is possible to divide the floor into different areas (in this case two areas), depending on the distance from the external walls, where different thermal resistances are used. The resistances, given in Enorm, include the external and internal surface resistances (Statens planverks författningssamling, 1981).

[2)] For a drainage layer of gravel of 150 mm or more, the thermal resistance 0.2 m²·K/W can be used (Statens planverks författningssamling, 1981).

Comment 5 – Estimation of the effect on the energy use of ageing of the refrigerator and the freezer in house VI

According to Electrolux's customer service[19] the refrigerator was manufactured in 1984 and used 365 kWh/year. The freezer was also manufactured in 1984 but used 621 kWh/year. The ageing of the refrigerator and freezer between the years 1984 and 2003 has been calculated according to a coarse approximation that the energy use increases with 33 % after 15 years in operation[20]. This means that after 15 years the refrigerator and the freezer in question would use 487 kWh/year respectively 827 kWh/year. With the assumption that there is an equal increase per year in energy use, the apparatus would after 19 years in operation use 519 kWh/year and 882 kWh/year.

Comment 6 – Extra freezer in house II

Some different alternatives have been tested on how to regard this extra freezer as it is not straightforward how to consider two freezers of different sizes and usages of energy in Enorm. The alternatives were: i) considering the two freezers in house II as one unit, ii) considering two "average" freezers with the same size and usage and iii) considering the freezer as a chest freezer instead of a cabinet freezer. However, the different alternatives only make marginal or no effect on the total energy use.

[19] Electrolux's customer service, Stockholm, phone call 2003-06-19.
[20] Berit Carlsson, the Swedish Consumer Agency, phone call 2003-06-24.

Comment 7 – Estimations of energy use for dishwashers
The estimations are based on data obtained from the Swedish Consumer Agency's website[21] . Data for new dishwashers of an average energy efficiency class[22] have been considered to correspond to the energy use of older machines. The energy use is around 350 kWh/year calculated with that the dishwasher is used 220 times per year, which approximately correspond to a household of four persons (as in the case of house II). This figure does not include the energy for hot water production. For the two-person-household in house VI it is assumed that they use the dishwasher 30 % less than the four-person-household. This gives an energy use of 245 kWh/year.

[21] http://www.konsumentverket.se

[22] Energy efficiency classes according to the European Standard EN 50242, Directive 97/17/EC regarding energy labelling of household dishwashers.