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ENERGY PROFILING OF SINGLE-FAMILY HOUSES BUILT BEFORE 2010

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ENERGIAPROFIILIEN LUOMINEN ENNEN VUOTTA 2010 RAKENNETUILLE OMAKOTITALOILLE

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Opinnäytetyön aiheena oli energiankulutusprofiilien muodostaminen omakotitalouksille, joiden omakotitalo on rakennettu ennen vuotta 2010. Tämä vuosi valittiin sen vuoksi, että vuonna 2010 rakennusmääräykset muuttuivat huomattavasti rakennusten energiatehokkuuden suhteen. Tässä opinnäytetyössä kerättyjä energiankulutustietoja ja niistä muodostettuja energiaprofiileja hyödynnetään Satakunnan ammattikorkeakoulun SmartSolar-projektissa. Energiankulutusprofiilit muodostettiin omakotitalouksille siten, että aluksi luotiin kyselylomake jossa kysyttiin tietoja itse rakennuksesta ja asukkaiden energiankulutustottumuksista. Tämän jälkeen osallistujien energiankulutustietoja kysyttiin heidän energiayhtiöltään tuntipohjaisina mahdollisimman pitkältä ajanjaksolta. Tuntipohjaiset kulutustiedot edellyttävät etäluettavaa mittaria ja tämä on vanhempien rakennusten ja asuinalueiden kohdalla ongelma, koska energiayhtiöt ovat siirtyneet etäluettaviin mittareihin monilla alueilla vasta vähän aikaa sitten. Kyselylomakkeen täytti 17 taloutta ja kolmelletoista näistä talouksista muodostettiin kulutusprofiili.

Rakennusten energiankulutus on merkittävä osa koko maailman energiankulutuksesta, Euroopan unionin alueella noin 40% kulutetusta energiasta kuluu kotitalouksissa ja liikerakennuksissa. Energiaprofiili on hyvä väline kotitalouksien energiankulutuksen ennustamiseen ja tätä ennustusta voidaan käyttää paikallisen energiantuotannon optimointiin ja tätä kautta hiilidioksidipäästöjen vähentämiseen.

Tutkimukseen osallistuneissa rakennuksissa oli suuri hajonta rakennusvuodessa, vanhin oli rakennettu 1800-luvun lopussa ja uusin vuonna 2008. Tästä johtuen suuria eroja oli myös eristyksessä. Suurimmassa osassa talouksia oli päälämmitysjärjestelmänä sähkö, mutta myös öljyä, puuta ja kaukolämpöä käytettiin lämmitykseen. Eri lämmitysjärjestelmien vertailu oli hankalaa. Energiayhtiöltä saatiin tieto sähkönkulutuksesta, mutta jos öljyä on käytetty lämmitykseen, niin tämä energiankulutus ei näy kulutusprofiilissa. Myös veden lämmitykseen kuluvan energian osuutta oli vaikea arvioida koska ei ollut tarkempia tietoja sen osuudesta vedenkulutuksesta, joten käytetään yleistä arviota, että lämpimän veden osuus on kolmasosa vedenkulutuksesta.

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The aim of this thesis was to create energy consumption profiles for single-family households, whose house has been built before 2010. The reason why this year, 2010, was chosen was that the building regulations changed significantly regarding buildings energy efficiency. Energy consumption data that has been collected and the energy consumption profiles created from that data for this thesis are utilized in the Satakunta Univercity of Applied Sciences SmartSolar-project. The energy consumption profiles were created to the single-family households in such a way that first a questionnaire was made. It included questions about the building itself and the energy consumption habits of the inhabitants. After that the energy consumption data of the participants were asked from their energy company in hourly basis from as long as possible time. Hourly based energy consumption data requires remotely readable electricity meter, and this is a problem with older buildings and neighborhoods, because the energy companies have changed to the remotely readable meters in many areas only recently. 17 households filled the questionnaire and for thirteen of them the energy profile could be made.

Energy consumption of buildings is a major part of the whole world's energy consumption, in European Union about 40% of the used energy stems from residential and commercial buildings. Energy profile is a good method for prediction of households energy consumption. This prediction could then be used to optimize local energy production and in that way to reduce carbon dioxide emissions.

There were large difference in the building year between the buildings that participate to this survey. Oldest building was built in the late 1800s and the newest 2008. This resulted in big differences in insulation. Most of the households used electricity as main heating system, but also oil, wood and district heating were used. Comparison between different heating systems was difficult because the energy company gave electricity consumption data but for example if oil was used in heating, that energy consumption did not show in the profile. Also the amount of energy used for heating domestic hot water was difficult to estimate because there were no exact data of what is the portion of hot water from the total water consumption. So the amount of hot water is estimated to be one third of the total water consumption.

CONTENTS

1 INTRODUCTION

This thesis is made for Satakunta University of Applied Sciences for the SmartSolar project. In this work the energy profiles are made for single-family houses that have been built before 2010. The year 2010 was chosen because there were big changes in the building regulations then. Because household consumption is one of the major forms of energy consumption globally, energy profiling is a good method to estimate and predict energy consumption of the given household within the given timeframe, month, week or day. In this work the energy profile is more correctly electricity consumption profile, because if electricity was not used for heating the consumption profiles do not show the energy used for space and water heating.

About 80% of the global population has access to electricity. This percentage has been increasing in the last decades as the population is more and more concentrated to cities. There is however huge variation of electricity consumption between households in different parts of the world. On average the consumption is roughly 3500 kWh/a in year 2010. In figure 1 household electricity consumption data for different countries is presented. (Website of Shrink that footprint 2013)

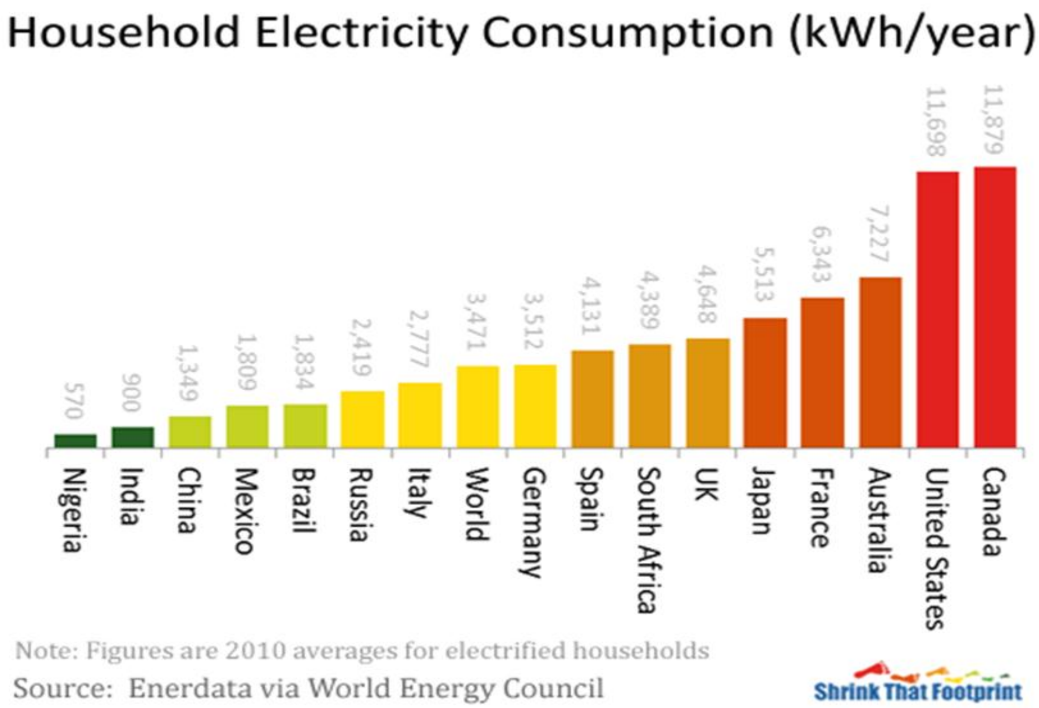

Figure 1. Household electricity consumption figures in 2010 for some countries (Website of Shrink that footprint 2013).

Finland has really high electricity consumption, on average 8371 kWh per household in 2013 (Website of World Energy Council 2015). Electricity production is major source of greenhouse gas emissions, about 30,6 gigatons of carbon dioxide was released to atmosphere in 2010 due to electricity production (Website of Bloomberg 2014).

Energy profiling is useful tool when local electricity production is planned using small power plants or the production is optimized. With energy profiling the base consumption and peak consumption times could be seen clearly and by using this data the electricity consumption can easily be anticipated. Also the information about the base consumption of a household can be utilized when households plan to produce the electricity they need with for example solar panels. With energy profiling it is easy to plan such a system in such a way, that it produces at least so much electricity that the base consumption is.

2 ENERGY PROFILING

It is more and more important in Europe and in the whole world to increase the energy efficiency of buildings. Both the existing building stock that is going to undergo renovation projects and also buildings that are going to be build need to be as energy efficient as possible. In Europe, many different policy tools have been adopted to increase this energy efficiency issue as a part of the plan, which aims a low carbon economy. (Beccali et al 2013. 284)

Currently, about 40% of the total final energy use in the European Union, stems from residential and commercial buildings. This energy usage corresponds to a bit over one third (36%) of the total CO_2 emissions in EU area (Hiller 2012. 376). In 2007 the European council adopted energy and climate change objectives for 2020. These objectives require that greenhouse gas emissions in the EU area will be declined by 20%, compared to the level in 1990. Also the use of renewable energy should be increased to 20% of the total energy usage and the overall energy efficiency should be increased by 20% by the year 2020. Further the dependency of fossil fuels shall not exist and the share of renewable energy use shall increase continuously. (Hiller 2012. 376) Load data is crucial for planning electricity distribution networks and optimal production capacity. Accurate knowledge of the household consumer loads is important, when small scale distributed energy technologies are optimally sized into the local network or local demand side management measures are planned. This knowledge is also useful for planning medium and low voltage networks in residential areas. (Paatero & Lund 2005. 273)

Several studies are made about energy profiling. For example in Sweden between November 2005 and February 2006, a survey was made where measurements were made for three four day periods in three different housing areas. Measurements were made from Wednesday evening to Sunday evening. In this project similar Swedish houses, total 57 households, on three different housing areas were chosen so that the constructions and building services of the houses were quite similar, so that the effect of residents and their habits could be seen from the data. This projects goal was to use the information gathered to contribute the reduction of energy use in the residential sector in the long run. The parameters measured in this study were: total energy use, indoor temperature, water use and outdoor temperature. The main conclusions from this project were that the differences between households' total energy use of similar houses are large, and that the load curves for groups of households clearly vary between weekdays and weekends. Another founding was that water use differs even more than the energy use for different households. (Hiller 2012. 376-385)

One study was made in arctic Greenland where the building regulations and the buildings energy consumption were measured. In this study an estimation of the energy savings and thus reduction of greenhouse gas emissions in detached and semi-detached houses in Greenland was made. Result from this study was that the more energy efficient the building is the less heating energy is needed. Main improvements regarding energy efficiency of buildings in Greenland relate to the insulation, air tightness of the buildings, super efficient windows and well implemented heat recovery system. (Bjarløv & Vladykova 2011. 1525-1536)

There is also created some mathematical models for energy profiling. Typically the data that the electrical companies have on domestic electricity consumption is not detailed. Usually the data is aggregated consumption of multiple households and it does not contain detailed information of the individual houses. The electricity demand models are often used in order to forecast demand at the utility level. These models are used when there is none or very little information of the appliances and other root level consumer details. The alternative for traditional demand forecasting is to use end-use models that represent a bottom-up demand modelling approach. The accuracy of these models depends greatly on the availability of the consumption details and the typical limitation for these models is the extensive need of data about the consumers, their consumption habits, appliances they use, and about the apartment in general. (Paatero & Lund 2005. 274)

One example of bottom-up energy consumption model is presented in figure 2 (Paatero & Lund 2005. 277).

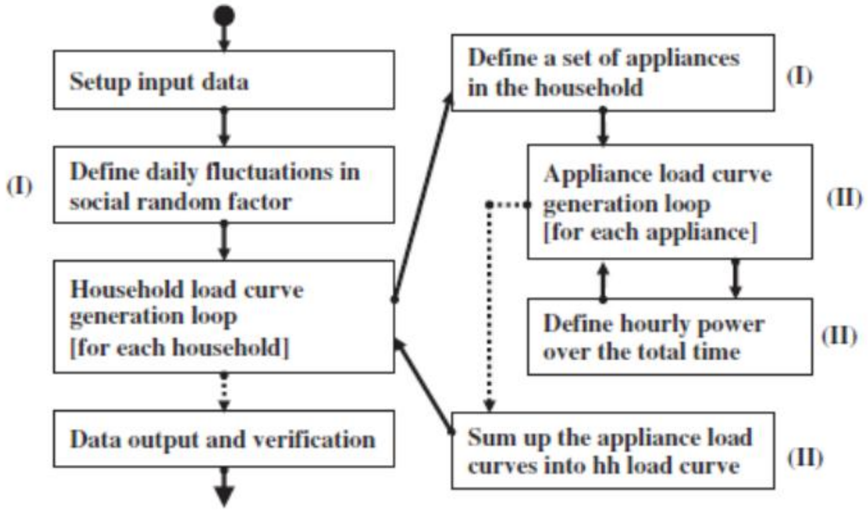

Figure 2. Diagram of a two component bottom-up model for household electricity consumption (Paatero & Lund 2005. 277).

Model accuracy is better, when the input data is more detailed.

3 BUILDING REGULATIONS

Building regulations in Finland are binding and their purpose is to guide towards good building quality and to good energy efficiency. Aim of the regulations is to cut off bad and inefficient solutions and to give minimum required level for insulation and energy efficiency. Traditionally the Finnish single-family house builders have insulated their houses a bit better than the regulations require. In addition of regulations building authorities give instructions, they are not binding so also other solutions than those that are in accordance with the instructions can be used if they fulfill the set regulations. (Website of Energiatehokaskoti 2013)

Finnish building regulations are quite flexible regarding energy economy and give architects possibilities to implement building also in other ways than those ways given in regulations. This can be done for example so that the heat losses through the wall are higher than the benchmark values given in regulations if the building is otherwise implemented in a way that fulfills the total requirements. (Website of Energiatehokaskoti 2013)

Building regulations changed significantly in Finland at the beginning of 2010. New regulations required new buildings to be more energy efficient than before, the regulations tightened about 30%. The most important changes were that the requirement for annual benefit for the heat recovery of the air conditioning rose from 30% to 45%, requirement for air tightness, (so called n_{50}-number), tightened from 4,0 1/h to 2,0 1/h. Third important change was that the flexibility of designing was improved in a way that if the insulation in some part of the buildings outer sheath is weaker than the reference level, it can be compensated with better heat recovery from air conditioning or better insulation in other parts of the outer sheath. This flexibility increased from 20% to 30%. (Website of Energiatehokaskoti 2013)

Energy efficiency has to be taken into account also in building renovation projects that require construction permit. Some renovation projects also in single-family houses require this permit. Typically permit is required when the use of the building changes, load-bearing structures are touched or fire departments are changed. Also actions that have effect on the inhabitants' safety and health need permission. Such actions are for example renovations affecting to the heating system or air conditioning in a major way. Also building expansion needs always construction permission (Website of Neuvoo.fi 2014). The requirement for construction permissions in cases of renovation projects has however quite large variation amongst Finnish municipalities, some have much stricter requirements than others (Website of Korvo.fi 2014).

4 ENERGY POLICY AND ENERGY PRODUCTION IN FINLAND

4.1 Energy policy in Finland

Finland's energy policy is based on long-term approach and predictability. In the last decades Finland has been one of the leading industrial countries using renewable energy and in particular bioenergy. Also in the last 20 years the aim has been to product as big portion of the electricity in the combined heat and power plants as possible. Finland has managed to create exceptionally diverse and decentralized energy production network.

Finland's energy policy has three basic premises: energy, economy and environment. Main points are ensuring the availability of energy, competitive pricing of energy and fulfilling the energy and environment objectives that have been set in the whole EU. European Union has made in December 2008 decision to reduce greenhouse gas emissions by 20% before 2020. Also in the same time energy efficiency should be increased by 20% and rise the renewable energy's portion of the total energy consumption to 20%. Finland aims to raise the portion of renewable energy by 38%. (Website of Työ- ja elinkeinoministeriö 2014)

4.2 Electricity production in Finland

Electricity is produced from many different sources and ways in Finland. Electricity production in Finland is fairly distributed compared to many other European countries. This diversity and distributed structure in electricity production increase the security of electricity supply (Website of Finnish Energy Industries 2014). Main energy sources are nuclear energy, water power, coal, natural gas, wood and peat. Wind powers share is small, about 0,9% of the total energy consumption in Finland 2013, but it is growing (Website of VTT 2013). Solar energy has also been growing in the last years, when the potential of solar energy has been noticed (Website of Aurinkoenergiaa.fi 2014).

About 120 companies produce electricity in Finland with about 400 power plants, over 50% of these plants produce electricity from water. Because Finland buys part of the used electricity from abroad, big part comes from the Nordic markets where the electricity is mainly produced from water in Sweden and Norway. Water powers' share and thus also the share of fossil fuels in electricity production vary greatly depending of these Nordic markets and the electricity price there. (Website of Finnish Energy Industries 2014)

Almost one third of the electricity is produced combined with heat, so that fuel's energy content could be utilized as complete as possible. In some combined heat and power plants up to 90% of the energy content of the fuel could be transferred to heat and electricity. In figure 3 is presented the energy production by source in 2013 (Website of Finnish Energy Industries 2014).

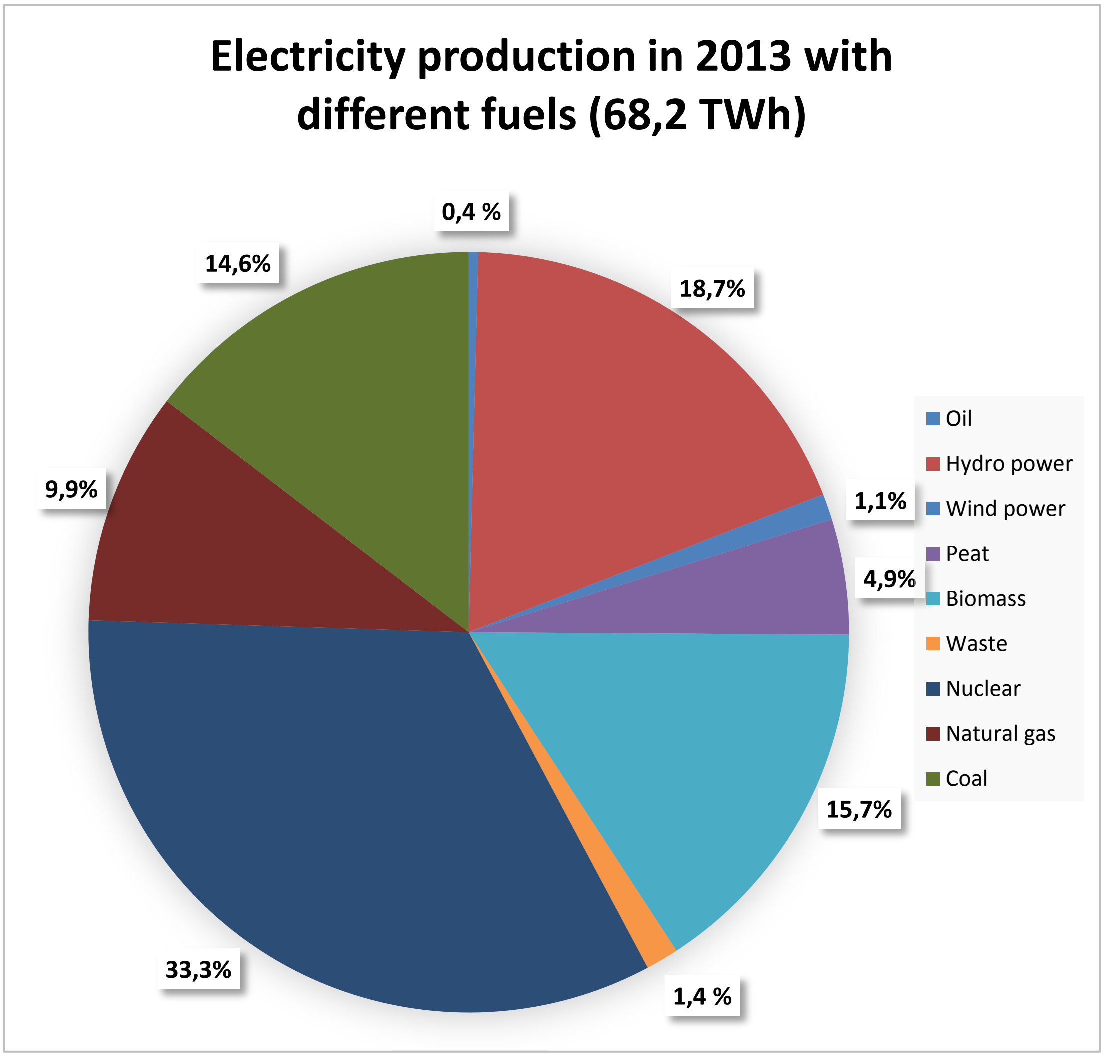

Figure 3. Electricity production in 2013 with different fuels (Website of Finnish Energy Industries 2014).

In figure 4 is presented Finland's electricity acquisition in year 2013 divided to different fuels, also the electricity import is taken into account in this figure (Website of Finnish Energy Industries 2014).

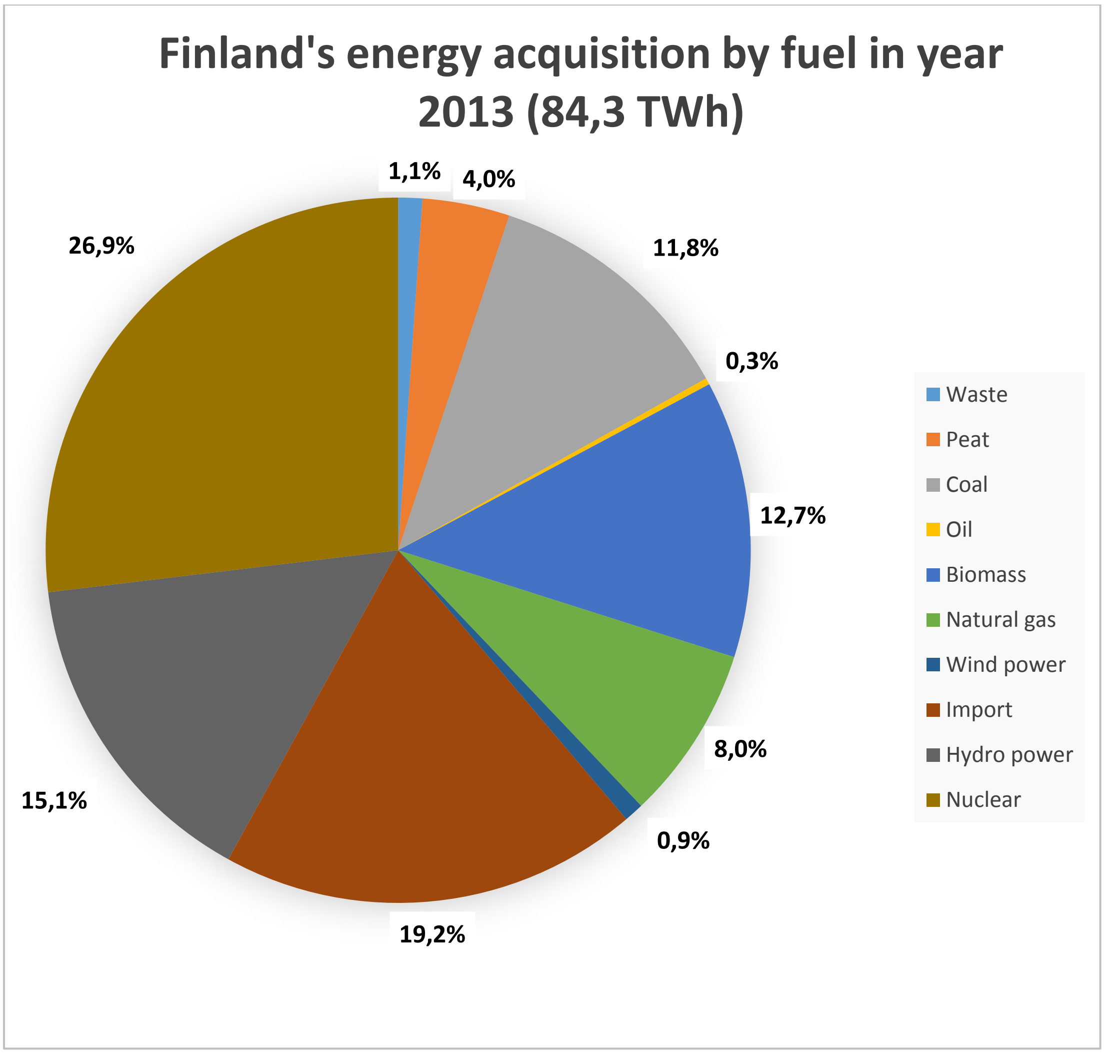

Figure 4. Finland's energy acquisition by fuel in year 2013 (Website of Finnish Energy Industries 2014).

5 ENERGY CONSUMPTION

5.1 Total energy consumption

Total energy consumption in Finland was 1392 PJ (petajoules) in year 2011 and the total consumption in 2012 was 1362 PJ regarding to the preliminary information given by the Finnish Bureau of Statistics. These numbers are given without taking into account the losses occurring due to the energy transportation and transformation from one form to other. This energy consumption in 2012 is about 251 gigajoules/capita. As it could be seen from the numbers, energy consumption decreased about 2 percent from year 2011. This decrease was due to decrease in the energy consumptions of industry and traffic. Energy consumption needed for the heating of buildings increased by 6 percent. (Website of Motiva 2014)

When the energy losses have been taken into account, the preliminary information of the total energy consumption in Finland 2012 was 1118 PJ, meaning about 207 GJ/capita. End use of energy increased by one percent compared to the year 2011. Industry used 46% of the energy, decreasing by one percent. Heating of buildings required roughly one fourth of the end use, increasing 6 percent from previous year, resulting from colder weather. Traffic used a bit less energy. In figure 5 the energy end division in 2012 is presented. (Website of Motiva 2014)

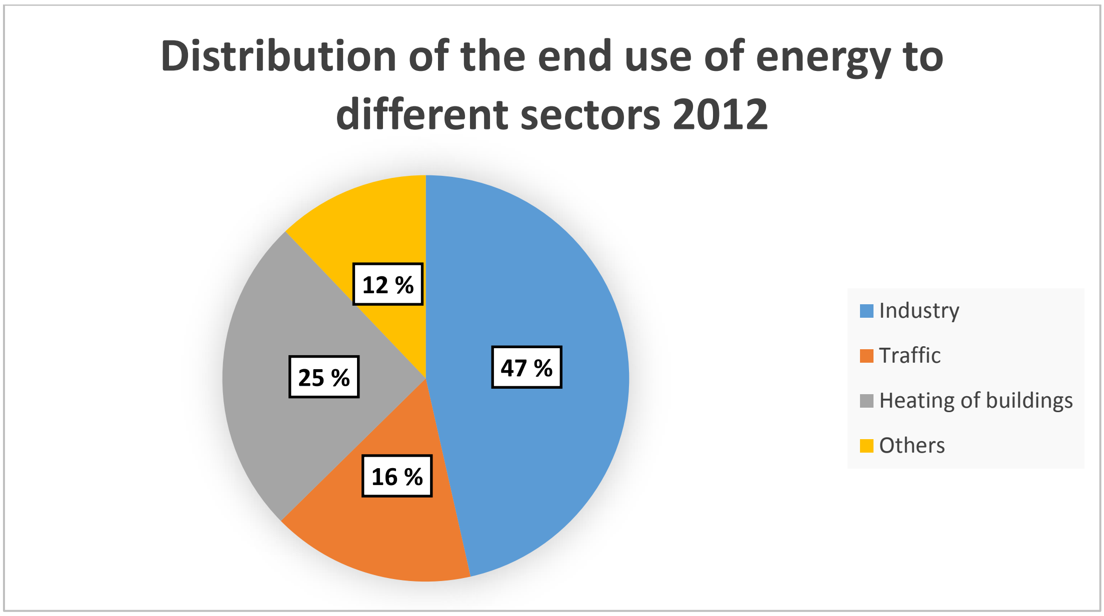

Figure 5. Distribution of the end use of energy to different sectors (Website of Motiva 2014).

When pure electricity is considered, the total electricity consumption in Finland in 2012 was roughly about 15,7 MWh/capita. Total energy consumption increased slightly, 1,1 percent from the previous year.

5.2 Water consumption

Water consumption is one of the major sources of energy consumption. Warm water consumes significant amount, about one fifth, of the total energy requirement of residential houses. Water consumption varies greatly between different households. Typical water consumption in Finland varies from 90 to 270 liters/day/capita and average consumption is about 155 liters per person per day. About 40-50 liters of the used water is warm water. In figure 6 is presented roughly how the water consumption is divided per person during one day (Website of Motiva 2014).

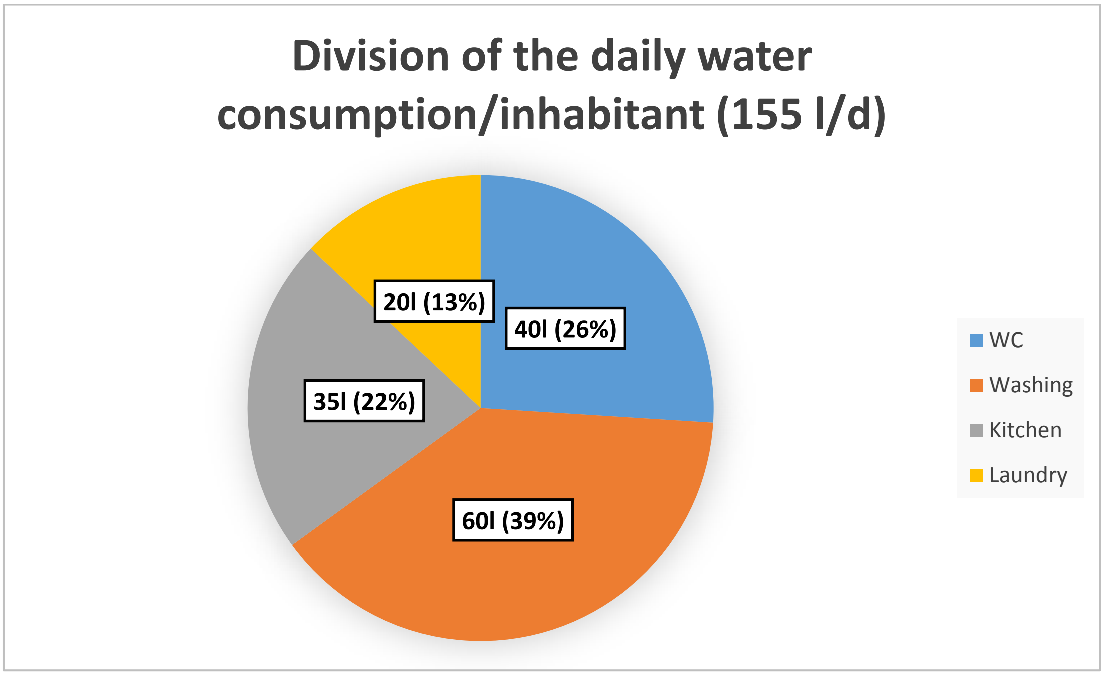

Figure 6. Rough division of the daily water consumption (Website of Motiva 2014).

Water consumption is greatly affected how aware the residents are about their consumption habits. For example 5 minutes shower consumes roughly 60 liters of water and taking a bath takes 5 times more water. Water fittings and their condition has significant effect on the water consumption. It is wise to invest to the modern technique with these water fittings, for example with the modern single lever mixer the full flow of water can be restricted to four liters per minute (Website of Motiva 2014).

5.3 Electricity consumption

In table the distribution of Finnish households is presented. Households are distributed by the apartment type and the number of inhabitants (Kotitalouksien sähkönkäyttö 2011, 12).

Table 1. Finnish households, distributed by the apartment type and number of inhabitants (Kotitalouksien sähkönkäyttö 2011, 12).

Inhabitants	Single-family house [%]	Terraced house [%]	Apartment house[%]	Other [%]	Total [%]
1	8	6	25	1	40
2	15	5	13	1	33
3	7	2	3	0	12
4	7	1	2	0	10
5+	4	0	1	0	6
Total [%]	41	14	43	2	100

At the end of year 2011, there were about 2836000 apartments and about 280000 of those apartments were without permanent inhabitants. A research report was published at February 2013 about the Finnish households' electricity consumption. Between 2006 and 2011, electricity consumption in Finnish households' has increased almost 2 TWh (Terawatt hours) and this increase is, as a whole, electricity consumption that is associated with heating homes. In figure 7 is presented the distribution and the changes in distribution, of heating systems in Finnish single-family houses built between 2006 and 2011 (Website of Motiva 2014).

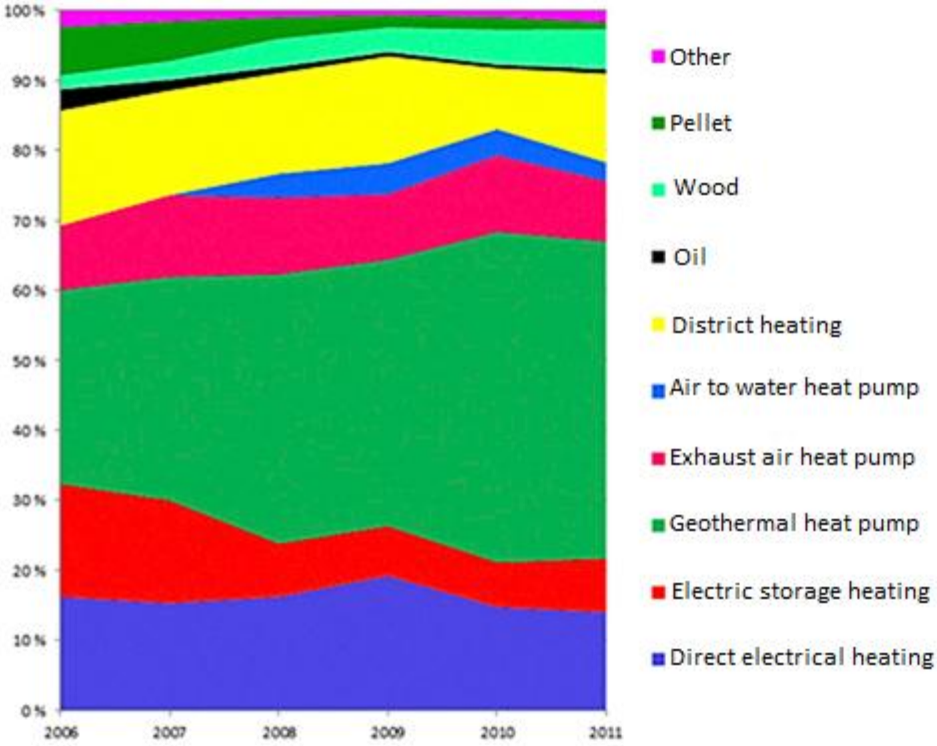

Figure 7. Distribution of heating systems in Finnish single-family houses built between 2006 and 2011 (Website of Motiva 2014).

According to the new statistics treatment heating, domestic hot water and air conditioning require about 60% of the buildings electricity consumption and in this group the annual increase in the energy consumption is a bit over 4%. Traditional electricity heating and domestic hot water requires roughly 70% of the electricity that is used for heating and from the total electricity consumption this share is 42%. Electricity usage for heating is slightly decreasing. There is instead strong increase in the usage of electrical floor heating and air source heat pump as secondary heating equipment. Heat pumps are also becoming more common as main heating system in both new construction and in renovation projects. This results increasing electricity usage in heating because in renovation projects oil heating is more and more commonly replaced with heat pumps. There are two main reasons behind the decrease of electricity as main source of heating. First, about 40% of the in-room electrical heating systems has air source heat pump and secondly, in about 75% of the cases also wood is used as secondary heating form. (Kotitalouksien sähkönkäyttö 2011, 5)

Electricity consumption due to home appliances and lighting has not increased as whole between 2006 and 2011. The amount of appliances has increased, but at the same time the need of electricity from single appliance has decreased. In 2011 the three main appliance groups, in regards of electricity consumption are lighting, home electronics and refrigeration equipment. (Kotitalouksien sähkönkäyttö 2011, 5) In table 2 is presented typical distribution of electricity consumption in Finnish households, space heating and domestic hot water are not taken into account in this distribution (Website of Otaniemen ympäristöseura 2014).

Table 2. Typical distribution of electricity consumption in Finnish households (Website of Otaniemen ympäristöseura 2014).

Lighting and other consumption	28%
Food storage	26%
Laundry	8%
Dishwashing	8%
Food preparation	17%
Entertainment	12%

In table 3 is presented the prevalence of some appliances in Finnish households in 2006 (Kotitalouksien sähkönkäyttö 2006, 31).

Table 3. Prevalence of some appliances in Finnish households in 2006 (Kotitalouksien sähkönkäyttö 2006, 31).

Appliance	Percentage [%] (2006)
Refrigerator	60
Freezer	66
Refrigerator-freezer combined	54
Microwave oven	90
Electric stove/oven	99
Dishwasher	54
Washing machine	88
Dryer	14
Drying cabinet	3
TV	>100

In table 3 the prevalence of TVs is over 100%, meaning that many households have more than one television. Between 2006 and 2011 the only group in household appliances that has increased its electricity consumption is IT-equipment. The consumption within this group is doubled in five years, because the equipment has become more common fast, the number of computers has increased by 29% and fewer and fewer households are without computer and broadband connections. For lighting the electricity consumption has dropped about 50%. Modelling of lighting has changed to be more accurate in the statistics. Also the proliferation of energy saving lamps has dropped the consumption. (sähkönkäyttö 2011, 5)

6 RESEARCH

In this study, energy profiles were made for single family houses that were built before 2010. For the study 17 households were interviewed about their residence and energy consumption. Interviews were made so that the participants filled a questionnaire that contained such questions that gave as detailed information about the household's energy consumption habits. Questions asked from the households included questions about the building, inhabitants, heating solutions used in the building and how the inhabitants use energy/electricity during the day.

Questions related to the building and inhabitants were for example when the building was build, how big floor area it has, how many inhabitants and the age of the inhabitants. Also the main and secondary heating solutions were asked. When either the primary or secondary heating solution was not electricity and was something with easily measured volume (oil, wood) the estimation for yearly consumption was asked. Some questions were asked about the habits of electricity usage, like what are the peak hours of electricity usage, how many hours per day at least one person is at home, are the lights always on or only when someone is in the room and how many times a week the sauna is warmed up and how many hours the heater is on (if the heater used was electrical one). The whole questionnaire is presented in appendix 1.

The problematic question about the building itself proved to be the question about the insulation used in the building. The material used for insulation was asked and also the thicknesses of material layers in floor, ceilings and roof was asked. These questions were challenging because with the older buildings, the current owner had not necessary made any renovations to the house and it was not known exactly what material was used to insulation and how thick the layers were. Because of this challenge, the owners were asked what they think insulation material to be and to give estimated thickness for the layer.

Another problematic question was the one about the water consumption of the household. It came clear that people had difficulties to estimate yearly consumption. Some knew it, from bills, but others just gave some assumption. It was also asked how the water consumption divides during the year, is it steady all year or is there clear differences for example in summer and winter time. This question about the division of water consumption could not be answered; those that answered to this were only dividing the yearly consumption evenly for each month.

In order to make the energy profiles for the households, the energy consumption data was collected from the energy companies, the participants gave letter of attorney to the company so that they could give the information for the research, and the data had to be on hourly basis. This meant that the household needed to have remotely readable electricity meter. The energy consumption data should be from as long time as possible so that the effect of the seasons could be seen from it. This proved to be quite a big problem because the energy companies have only in the resent years started to change electric meters in single-family houses to remotely readable meters. Because of this the questionnaire was answered by 17 participants and for 13 of them the energy profiles could be made. For one participant the remotely readable meter had only been about three months so the amount of data was not sufficient. For three participants although they gave the letter of attorney that was delivered to the energy company, that company never sent the consumption data back.

6.1 Energy profiles

In table 4 is presented some chosen information about the households that participated to this research.

Table 4. Information about the households that participated to the research. Targets marked with asterisk have not energy profile made.

Target	Municipality	Inhabitants	Year of construction	Main heating system
25	Luvia	2	1895	electricity
26	Noormarkku	4	1989	combined boil-er (oil/wood)
27	Pori	3	1984	electricity
28	Ulvila	2	1980	electricity
29	Pori	3	1997	electricity
30	Ulvila	7	1974	air source heatpump
31*	Luvia	1	1950	electricity
32	Lohja	3	1972	oil
33	Lappeenranta	4	1987	district heating
34*	Luvia	1	1992	electricity/wood
35*	Luvia	1	1962	oil
36	Rauma	3	1937	electricity
37	Keuruu	5	2002	electricity
38	Nakkila	2	1985	wood
39*	Pori	3	1981	electricity
40	Pori	2	2001	geothermal
41	Pori	4	2008	electricity

For making profiles two weeks were randomly selected from each season: winter, spring and summer and one week for autumn. These same weeks were used to make all profiles. For these weeks average total consumptions were calculated for each hour, weekends and weekdays were calculated separately because in weekends the residents are more at home and the energy consumption therefore is a bit higher in weekends. Also if possible the profile was made for Christmas week 2012 (20.-26.12.2012) because at Christmas time the whole family is more likely at home and there is probably higher energy consumption than normally because of the Christmas preparations. Energy profiles for targets 25, 26, 30 and 33 are looked in more detail. These targets are chosen for more detailed inspection because of two reasons: firstly they all have different main heating system and secondly they all have detailed data from energy consumption in weeks 5, 10, 15, 20, 26, 30 and 40. Target 25 has also detailed data from week 45, for others the consumption data from the electricity companies were delivered so early that they did not contain information of the week

45. Targets 25, 30 and 33 have also consumption data from the Christmas week and target 25 has this data also from Christmas week 2013.

6.1.1 Target 25, house in Luvia

In table 5 is presented information about the house in Luvia.

Table 5. Information about the house in Luvia.

Municipality	Luvia
Year of construction	~ 1895
Living area	120 m^2
Frame material	Log
Residents	2
Main heating system	Electricity
Secondary heating system	Fireplace
Ventilation	Gravitational
Energy consumption peaks, week days	6-8 and 16-18
Energy consumption peaks, weekends	6-8 and 16-18

This house is situated in Luvia. It has been built over one hundred years ago, about 1895. Building has two floors and two residents with about 120 m^3 of living area. Building frame is made from logs. Really old building so over the years some renovations have been made. In the last years, the renovation projects that have had influence to the energy efficiency have been changing of the roof, addition of more insulation material to walls, roof and floors. Also windows have been changed to triple-glazed windows. Main heating system for the house is electricity, secondary heating is provided by three fireplaces. The energy consumption peaks mentioned in the table 5 are times that the residents of the household estimated to have the highest consumption of electricity. In figures 8, 9, 10, 11, 12 and 13 are presented the weekly energy consumption profiles for year 2012.

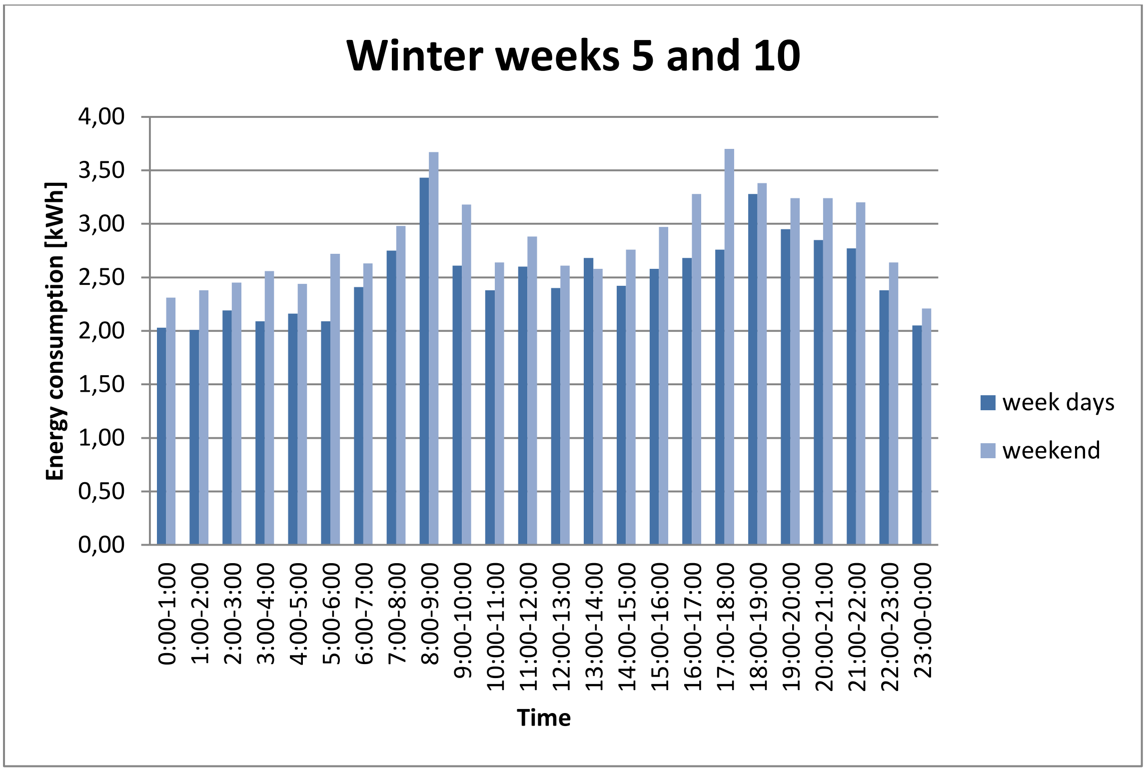

Figure 8. Awerage energy consumption for winter weeks 5 and 10.

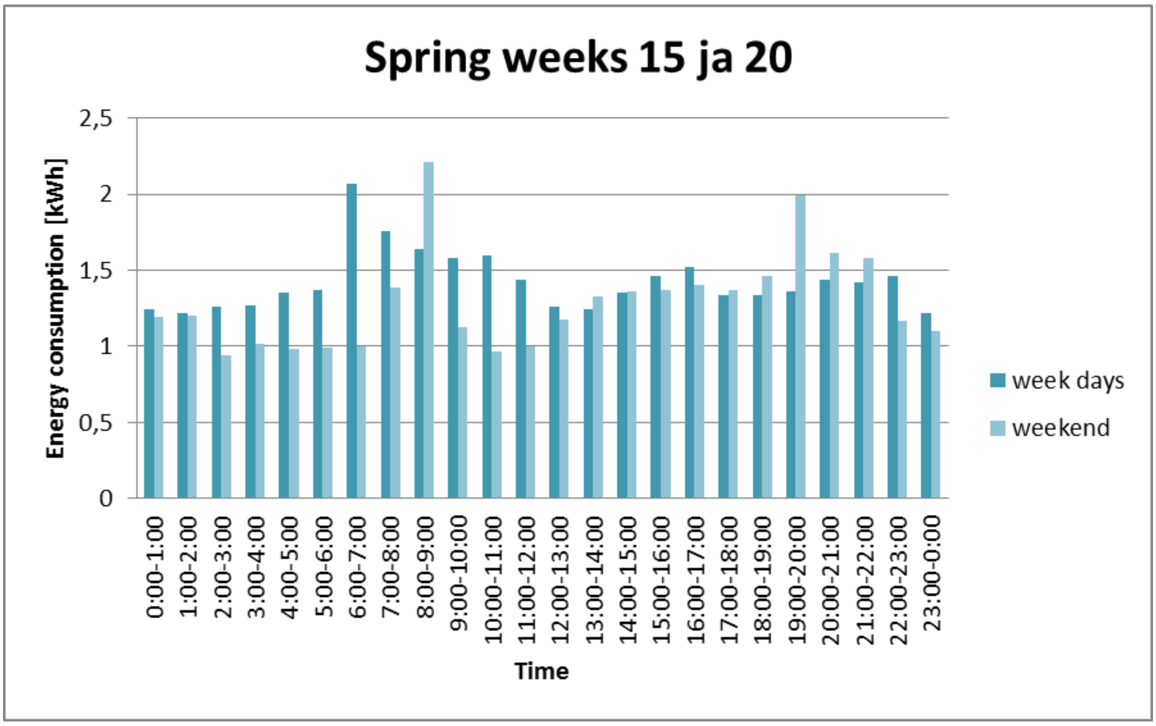

Figure 9. Awerage energy consumption for spring weeks 15 and 20.

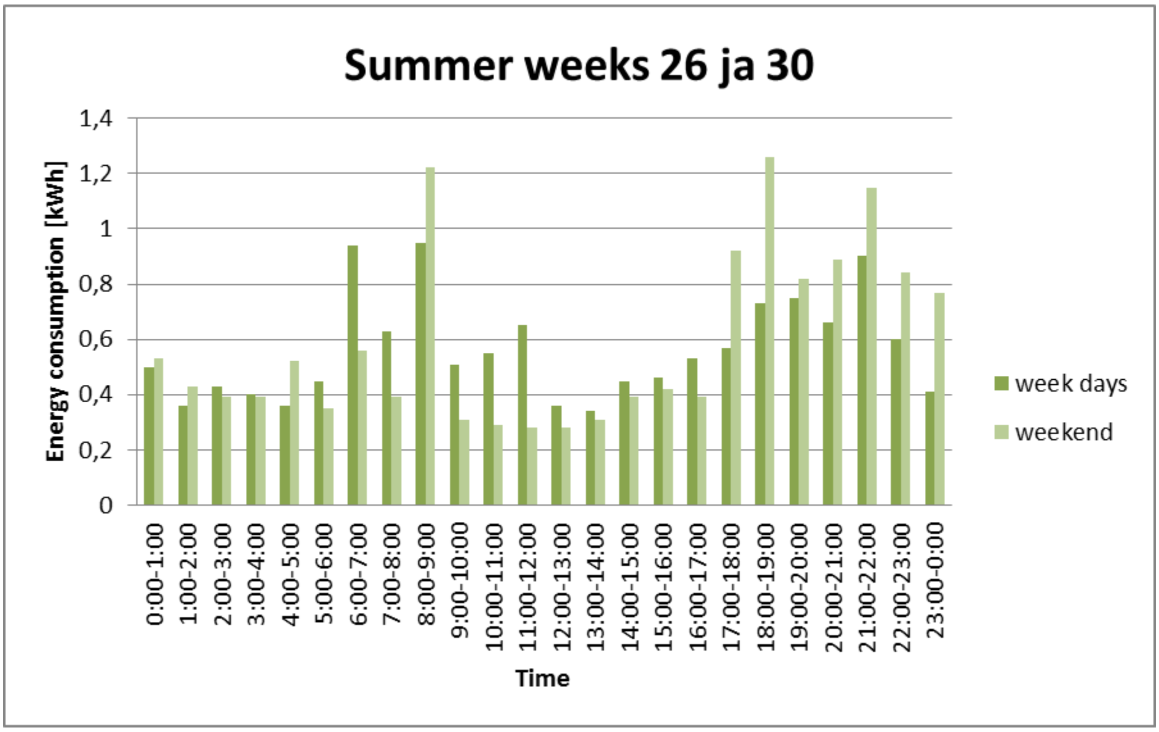

Figure 10. Awerage energy consumption for summer weeks 26 and 30.

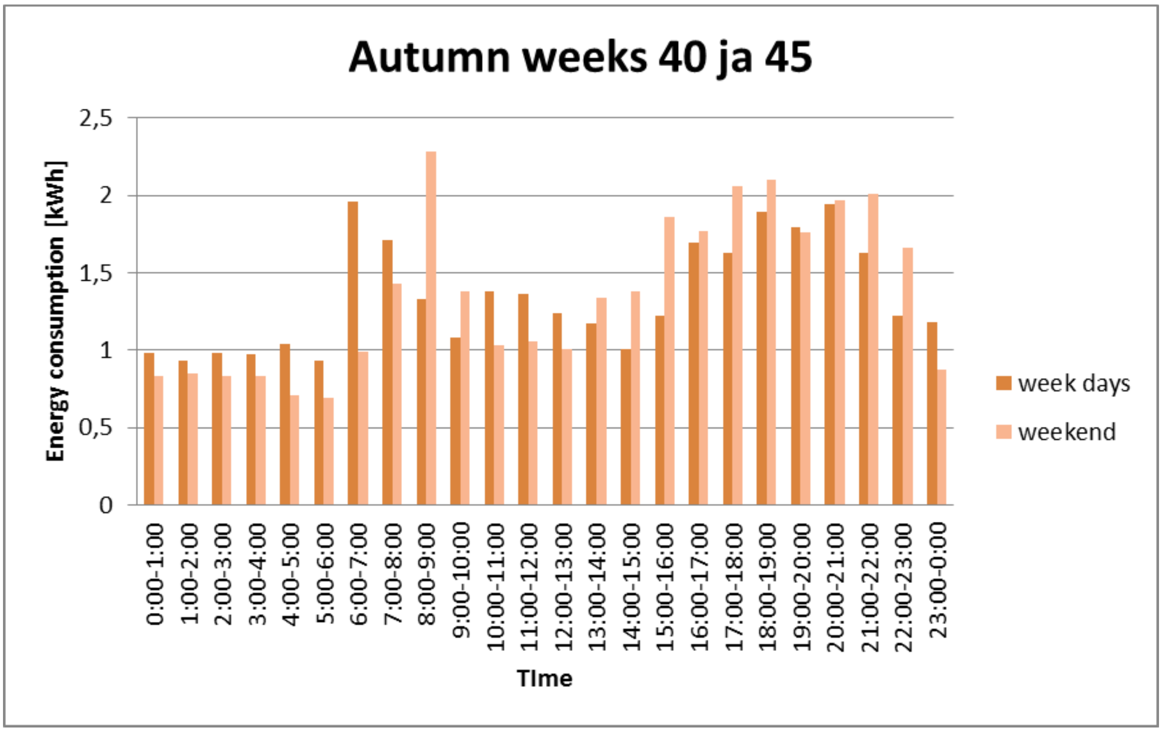

Figure 11. Awerage energy consumption for autumn weeks 40 and 45.

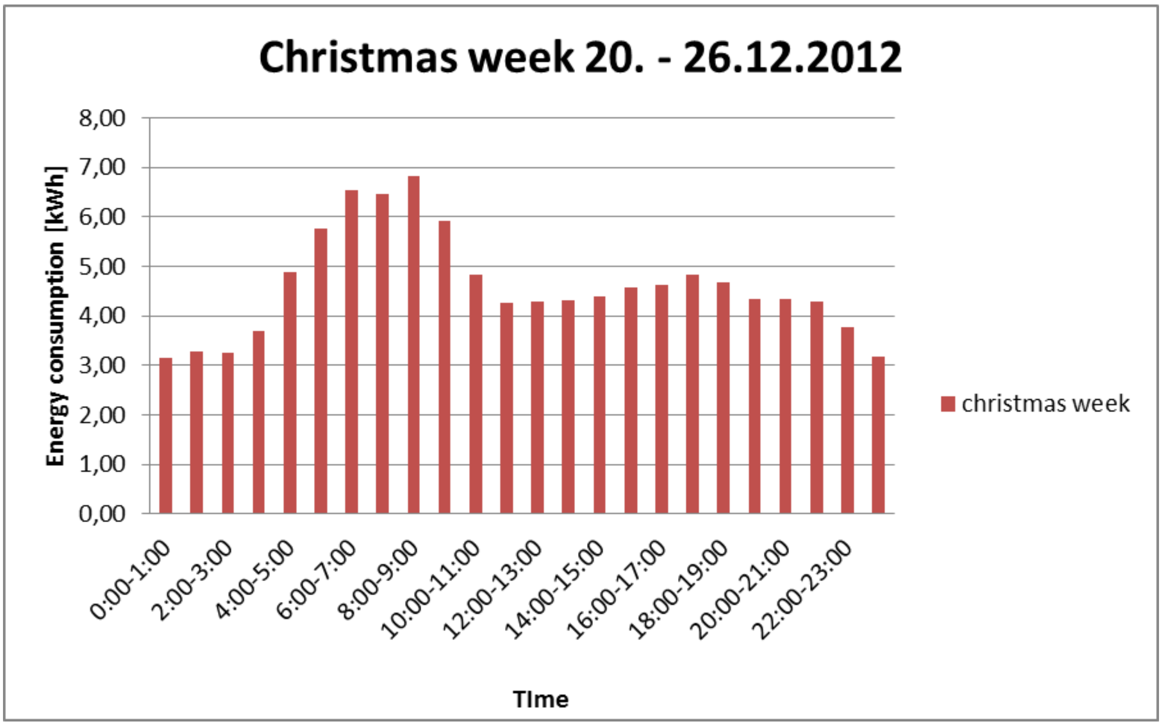

Figure 12. Awerage energy consumption for Christmas week 2012.

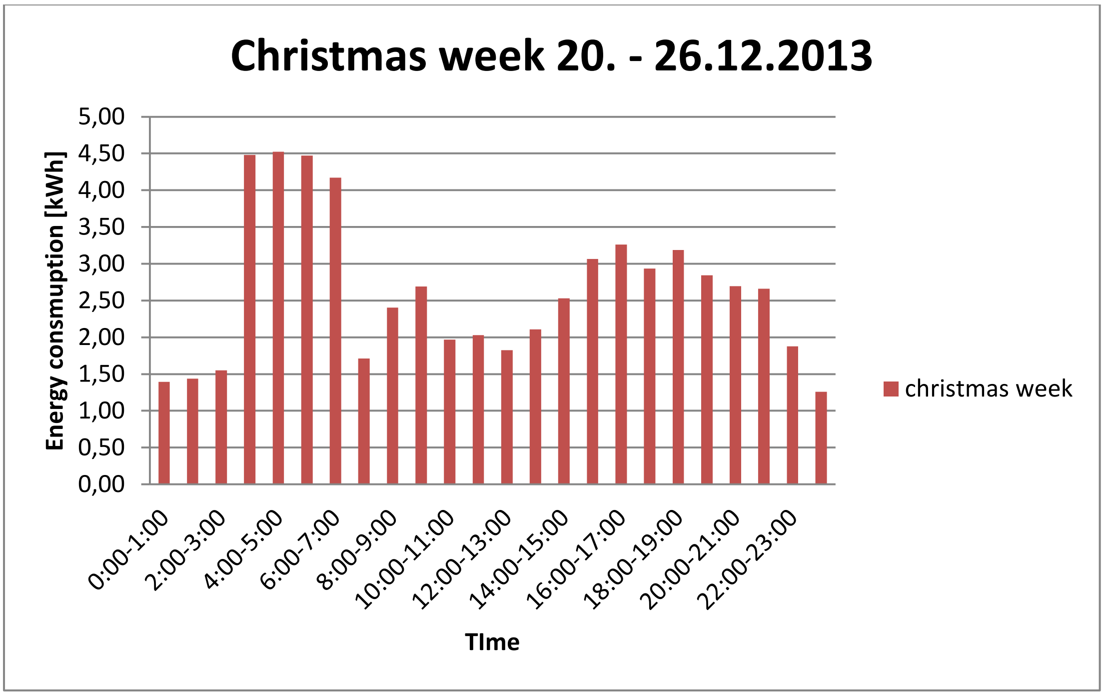

Figure 13. Awerage energy consumption for Christmas week 2013.

From these figures can be seen that the average energy consumption in winter weeks varied from quite steady 2,5 to peaks of a bit over 3,5 kWh, peaks matching the estimated consumption peaks given by the residents. Consumption in weekends is a bit higher than in week days. At spring weeks the average consumption is lower than in winter varying from about 1,2 to peaks of bit over 2 kWh and resulting most probably from higher outside temperatures and thus lower heating demand, week days have higher average consumption than weekends. From the summer consumption can clearly be seen that there is no need of heating so the consumption is resulting from the use of household appliances and there can be seen clear spikes when more of the appliances are used simultaneously. In autumn the average energy consumption starts to rise because of the need of heating, also there is during the day clear times when the energy consumption is higher than the base level. Christmas week 2012 has clearly higher energy consumption average than Christmas week 2013, most of the difference resulting probably from the differences of outside temperatures during those weeks.

6.1.2 Target 26, house in Noormarkku

In table 6 is presented information about the house in Noormarkku.

Table 6. Information about the house in Noormarkku.

Municipality	Noormarkku
Year of construction	1989
Living area	170 m^2
Frame material	downstairs: concrete, upper floor: wood
Residents	4
Main heating system	Combined boiler: oil/wood
Secondary heating system	fireplace
Ventilation	gravitational
Energy consumption peaks, week days	16-18
Energy consumption peaks, weekends	10-12 and 16-18

This house is situated in Noormarkku. Build year is 1989, it has two floors, 170 square meters of living area and 4 occupants, 2 adults and 2 kids. One of the kids is in school, the other is in day care. The house is built to hillside, so that half of bottom floor is excavated to the hill. Bottom floor has concrete frame and the second floor has wooden frame. No renovations effecting energy efficiency have been made. Main heating is provided by combined boiler for oil/wood, oil is main fuel. Secondary heating is provided by fireplace and in wet areas have underfloor heating with electricity. Electricity is not much used for space heating and the father of the family follows closely electricity consumption so that there is no lights in a room when there is no-one, rest of the family is a bit more carefree about that issue. From the whole electricity consumption data can clearly be seen holiday weeks when the house has been empty. From that data can be clearly seen how much electricity house appliances use. In figures 14, 15, 16 and 17 are presented the weekly energy consumption profiles for year 2012.

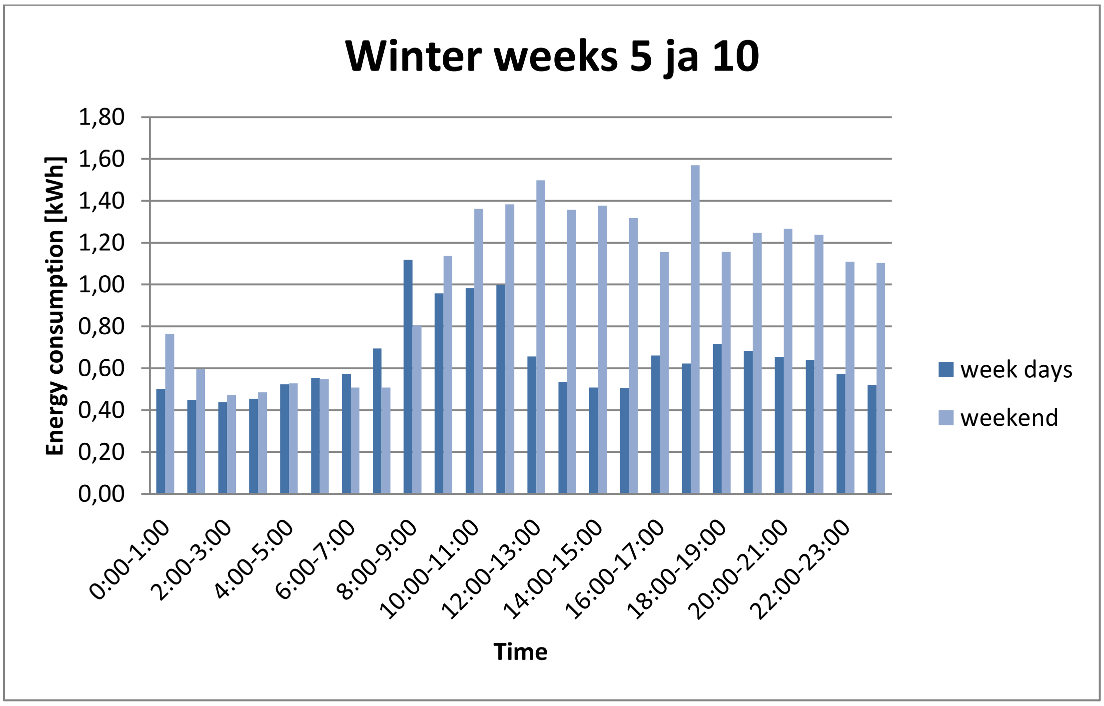

Figure 14. Awerage energy consumption for winter weeks 5 and 10.

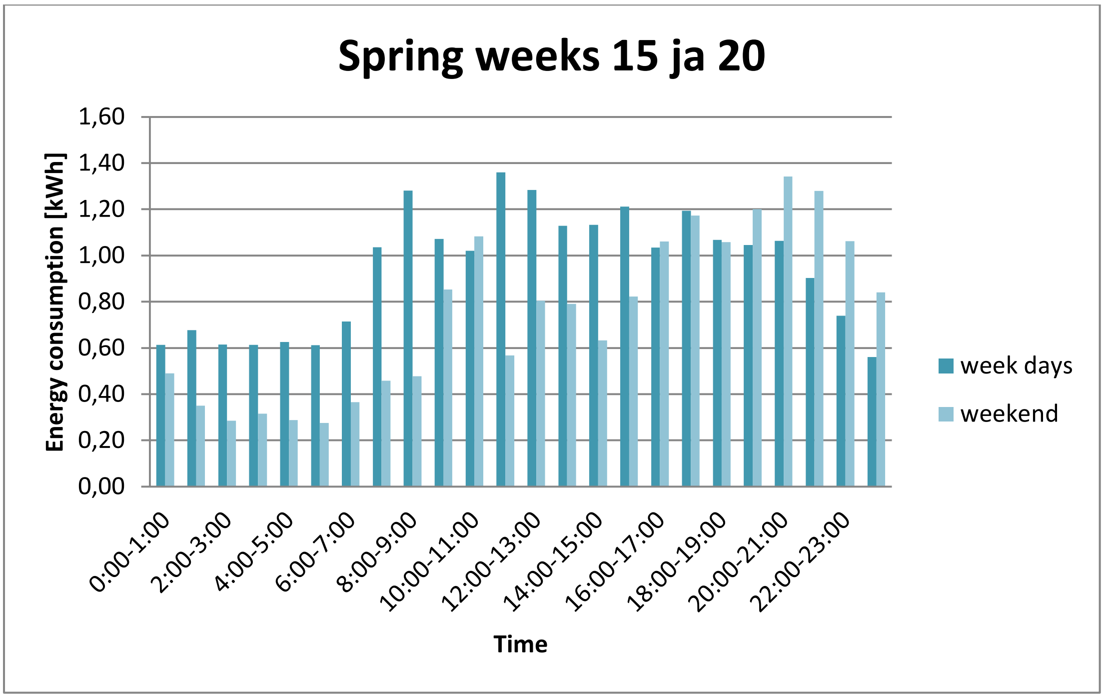

Figure 15. Awerage energy consumption for spring weeks 15 and 20.

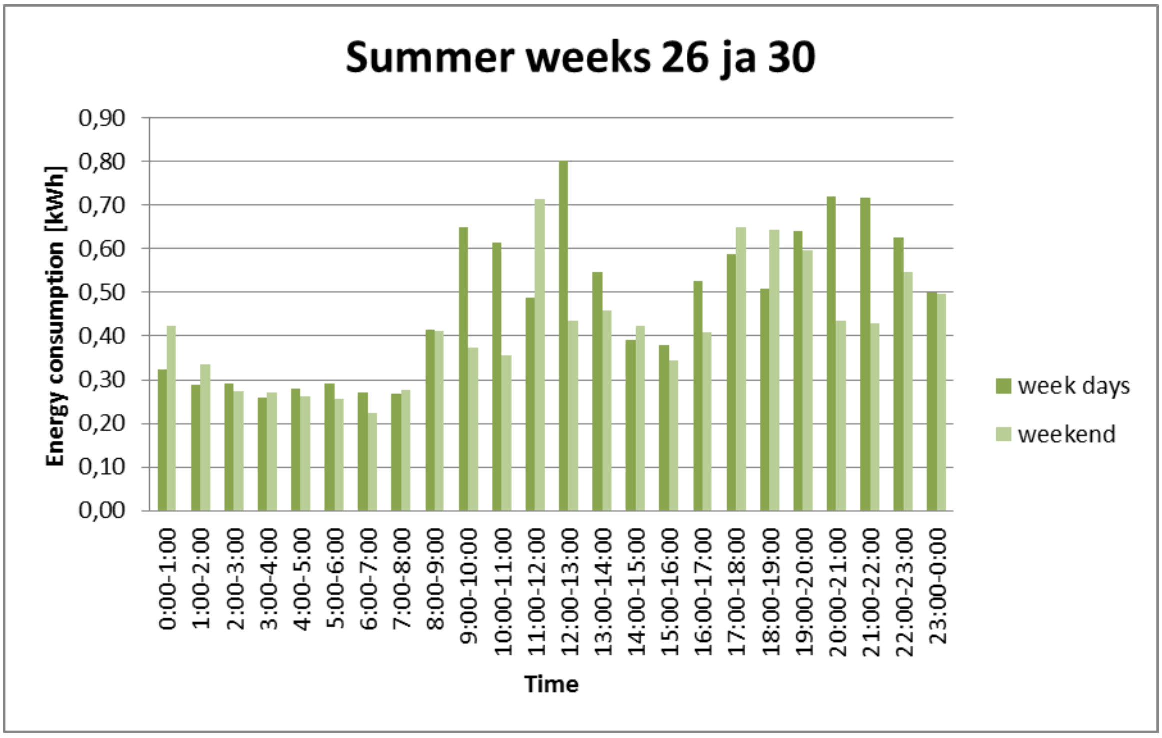

Figure 16. Awerage energy consumption for summer weeks 26 and 30.

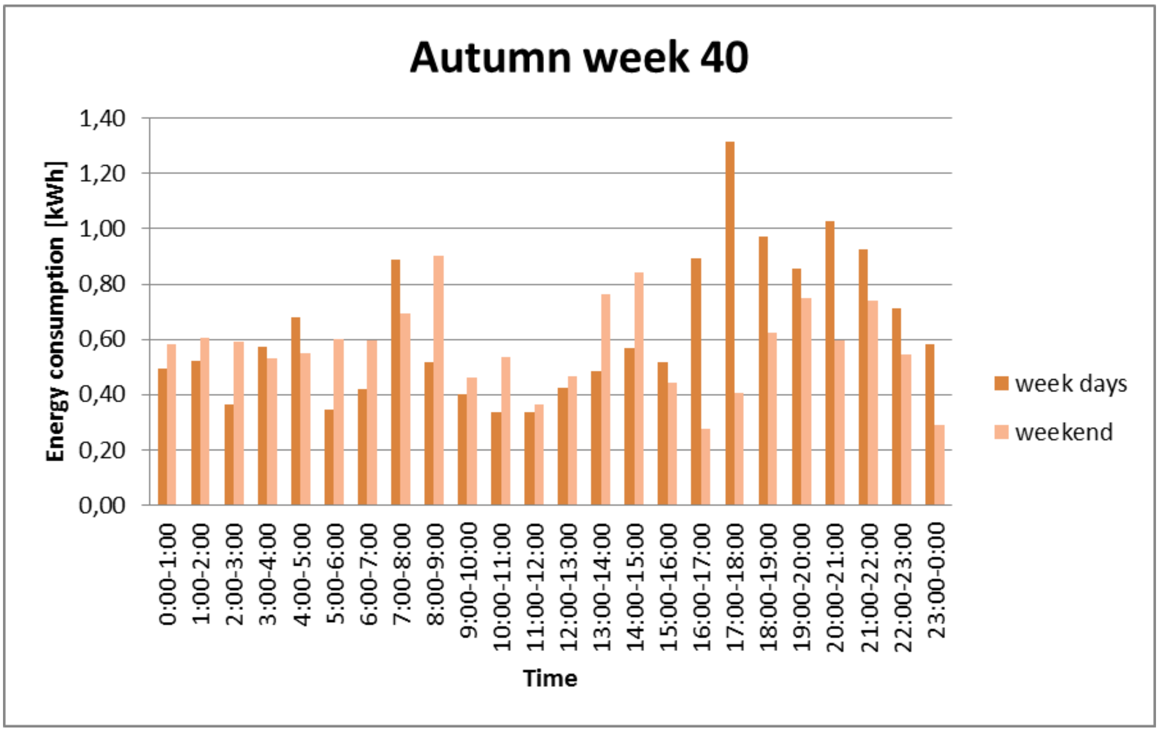

Figure 17. Average energy consumption for autumn week 40.

The main heating for this house is provided by combined boiler for oil and wood, oil being the main fuel. Only the wet spaces have floor heating using electricity. That electricity is not used for space heating can clearly be seen from the weekly energy consumption profiles. The average consumption during every other season than summer is clearly lower than in households that use electricity in heating. Only other household reaching as low average energy consumptions is the one using district heating as main heating system. Problem with the district heating is that the energy used for heating with it does not show in the profiles.

6.1.3 Target 30, house in Ulvila

In table 7 is presented information about the house in Ulvila.

Table 7. Information about the house in Ulvila.

Municipality	Ulvila
Year of construction	1974
Living area	240 m^2
Frame material	wood
Residents	7
Main heating system	air source heat pump *3
Secondary heating system	fireplace
Ventilation	mechanized with heat recovery
Energy consumption peaks, week days	12-14 and 20-22
Energy consumption peaks, weekends	12-14 and 20-22

This house is situated in Ulvila, 2 adults and 5 kids live in there, age of the kids varying from 1 to 16 years. House is built 1974 and has wooden frame material. Main heating system for the house is air source heat pumps, three pumps with input power of less than one kW are used simultaneously. Secondary heating is provided by fireplace. From the four houses viewed more closely this is the only one where gravitational ventilation is replaced with mechanized ventilation with heat recovery. No other renovations having effect on energy efficiency have been made. In figures 18, 19, 20, 21 and 22 are presented the weekly energy consumption profiles for year 2012.

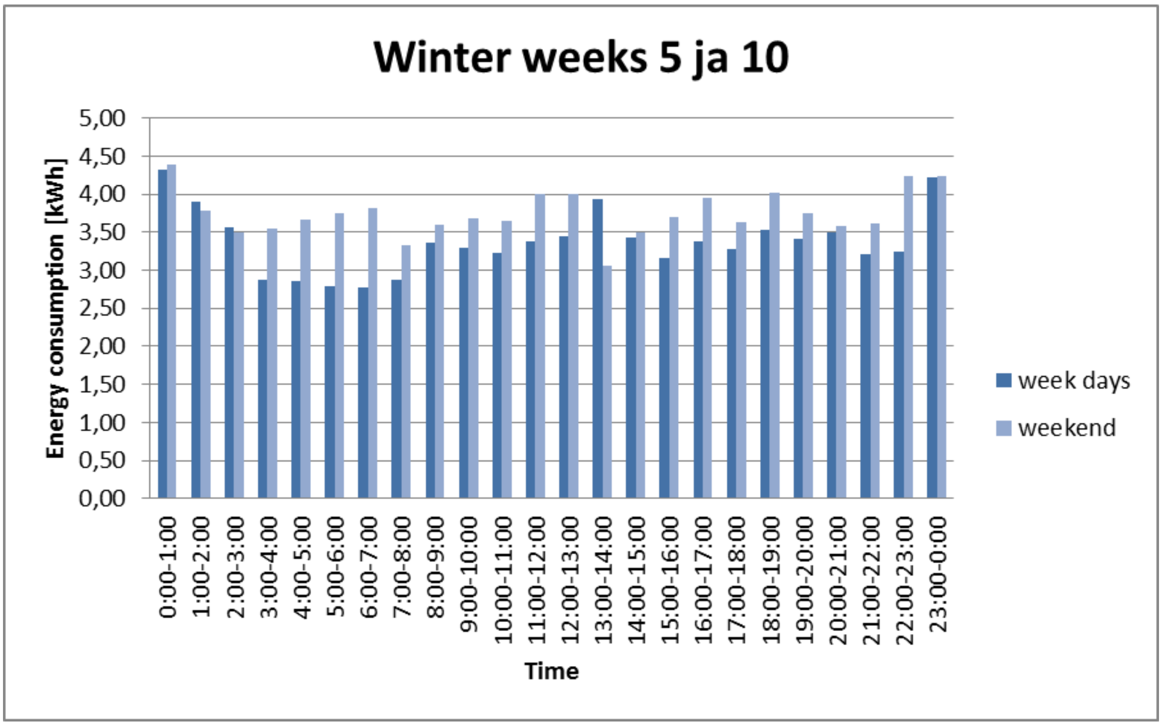

Figure 18. Awerage energy consumption for winter weeks 5 and 10.

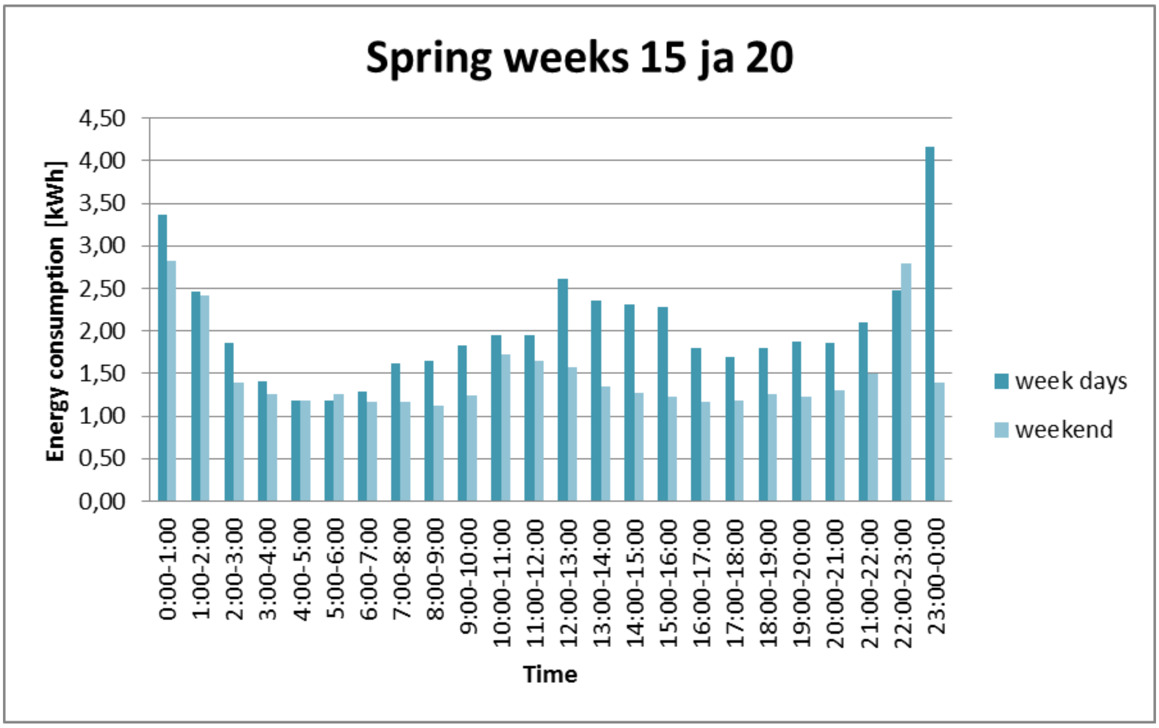

Figure 19. Awerage energy consumption for spring weeks 15 and 20.

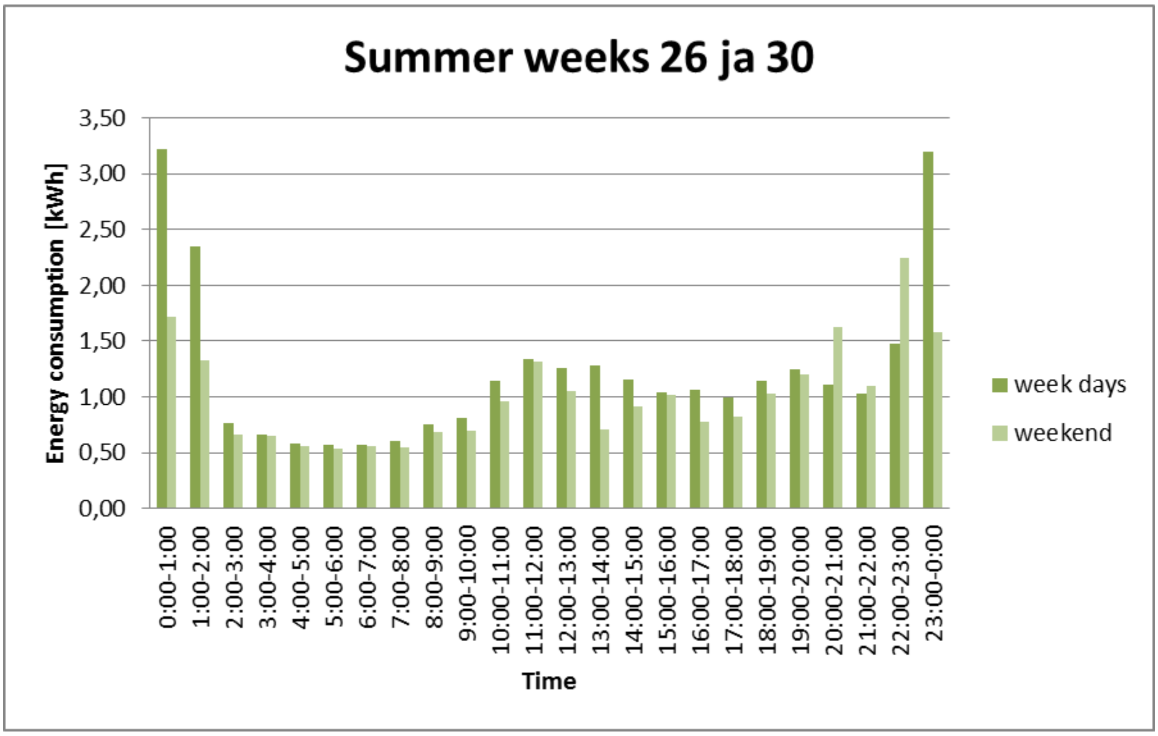

Figure 20. Awerage energy consumption for summer weeks 26 and 30.

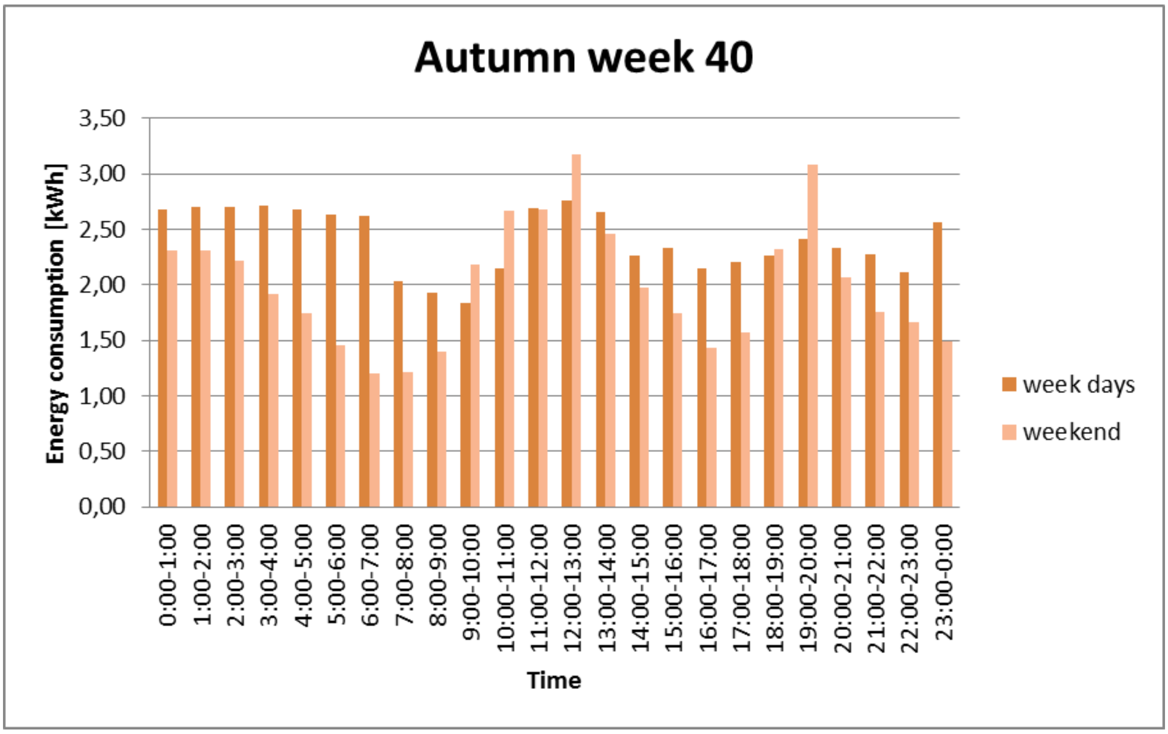

Figure 21. Awerage energy consumption for autumn week 40.

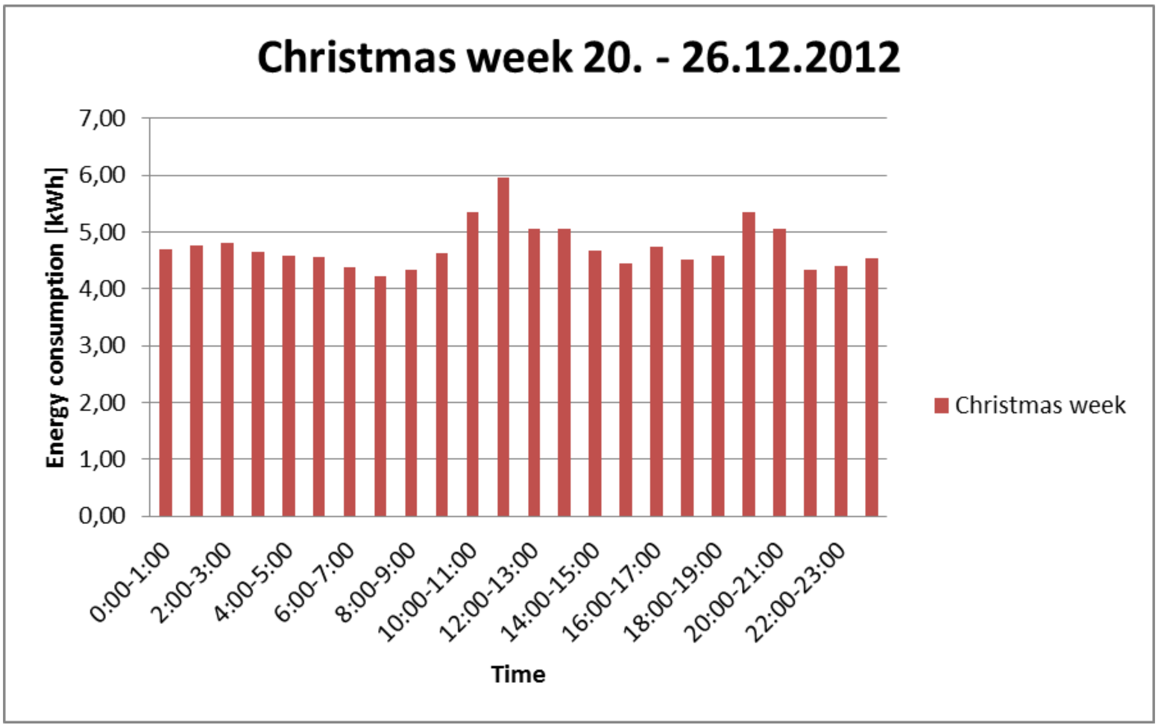

Figure 22. Average energy consumption for Christmas week 2012.

Average energy consumption in winter and autumn weeks and also Christmas week is higher than with the other heating systems that are looked more closely in these profiles. Summer consumption is at the same level than others and spring is at the same level as with electricity. In spring and summer weeks there are clear consumption spikes at the middle of the night.

6.1.4 Target 33, house in Lappeenranta

In table 8 is presented information about the house in Lappeenranta.

Table 8. Information about the house in Lappeenranta.

Municipality	Lappeenranta
Year of construction	1987
Living area	138,5 m^2
Frame material	wood
Residents	4
Main heating system	District heating
Secondary heating system	fireplace and air source heat pump
Ventilation	gravitational
Energy consumption peaks, week days	10-12 and 16-20
Energy consumption peaks, weekends	10-12 and 16-20

This house is situated in Lappeenranta. Four residents live in the house, 2 adults and 2 kids, both kids under school age. 138,5 m^2 living area. House is built 1987. Frame material for the house is wood. Main heating system for the house is district heating, so also the warm water is heated with it. Secondary heating is provided by fireplace and air source heat pump. No renovations having effect on energy efficiency have been made. In figures 23, 24, 25, 26 and 27 are presented the weekly energy consumption profiles for year 2012.

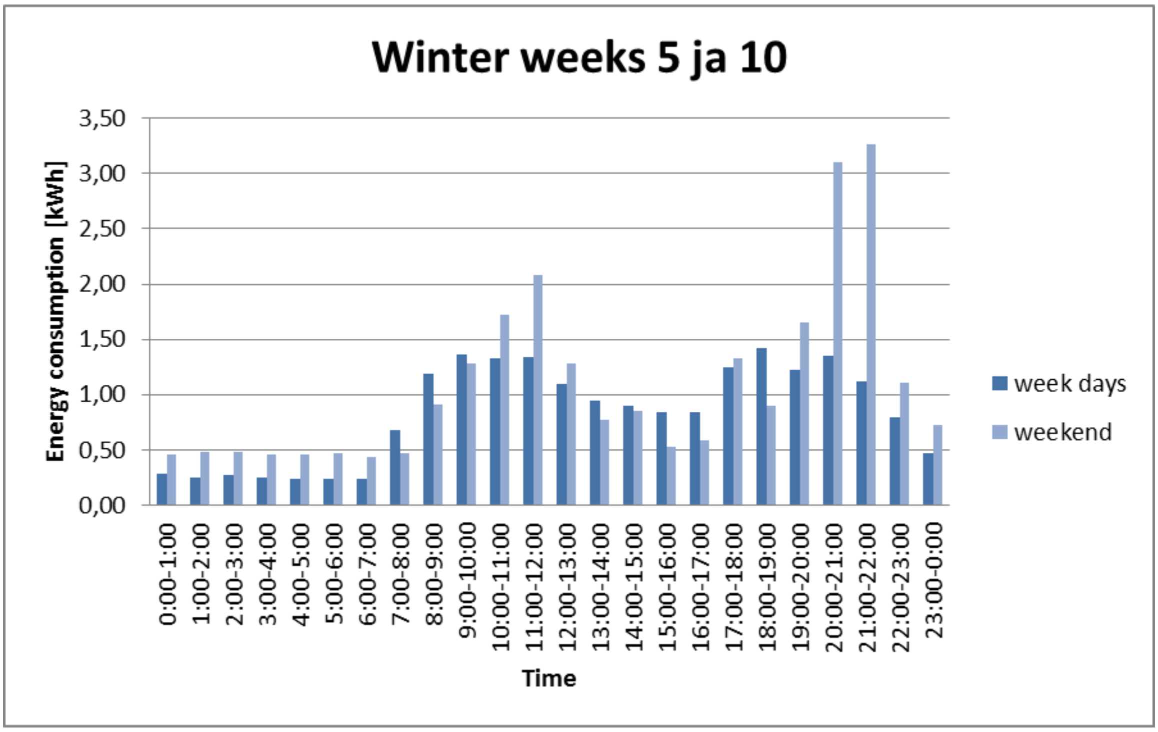

Figure 23. Awerage energy consumption for winter weeks 5 and 10.

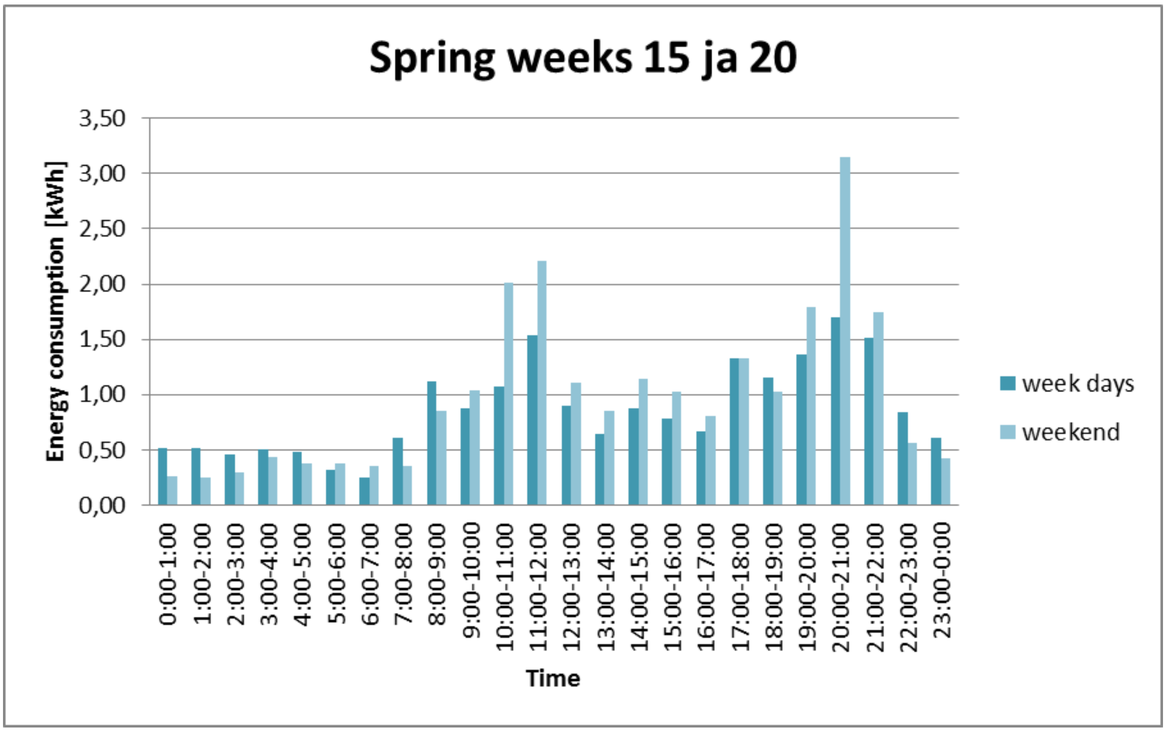

Figure 24. Awerage energy consumption for spring weeks 15 and 20.

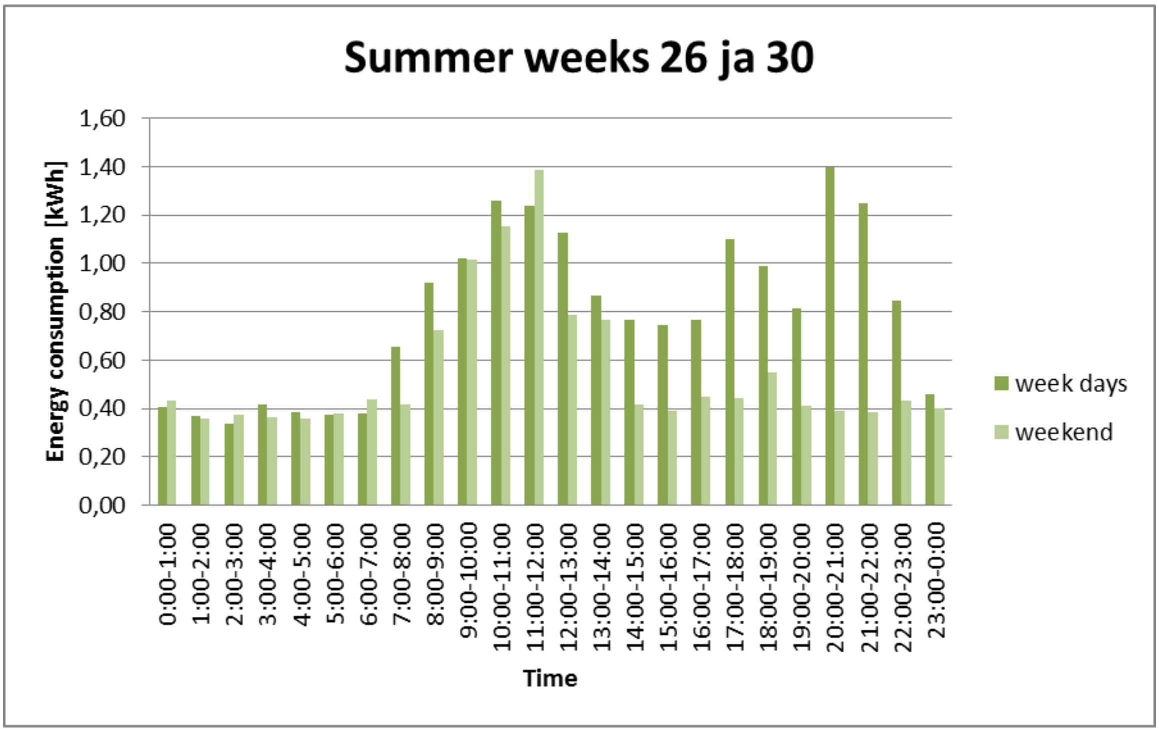

Figure 25. Awerage energy consumption for summer weeks 26 and 30.

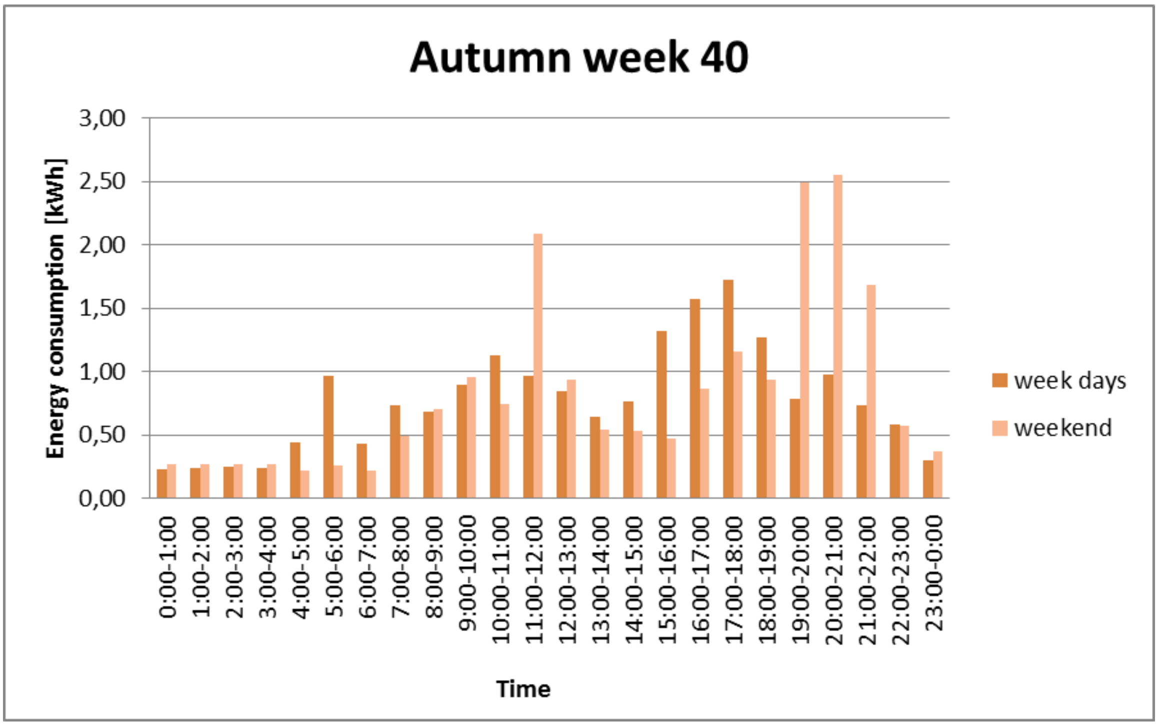

Figure 26. Awerage energy consumption for autumn week 40.

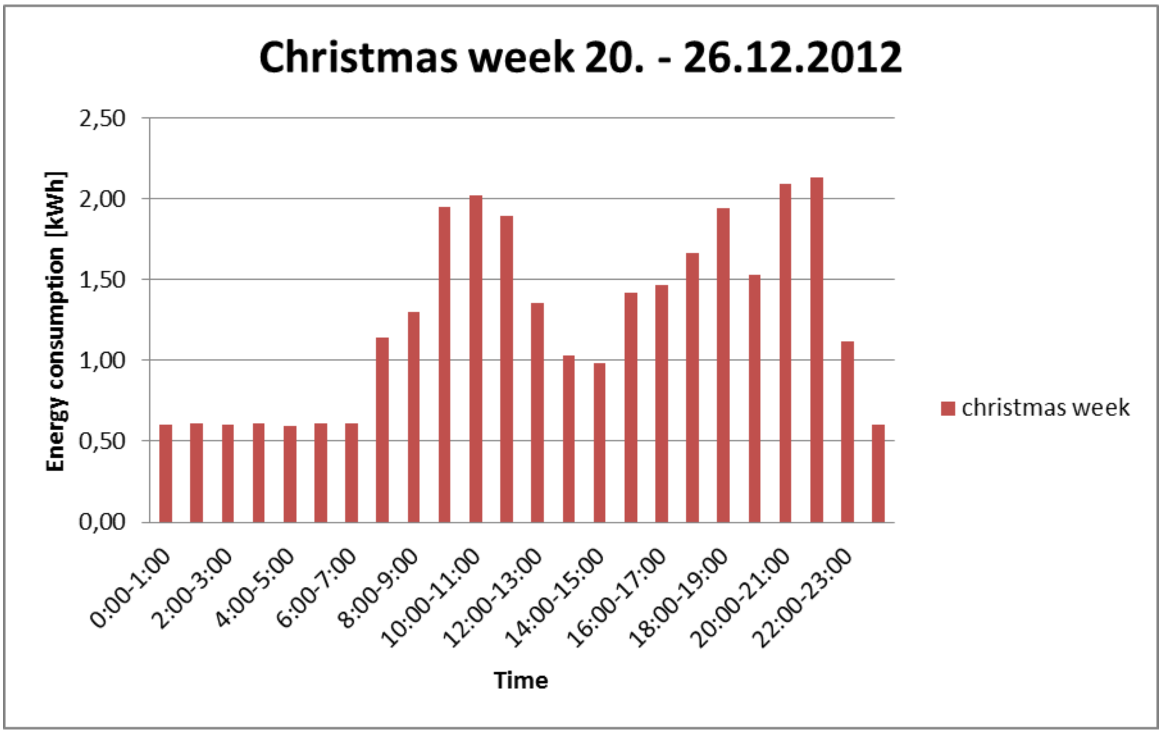

Figure 27. Awerage energy consumption for Christmas week 2012.

The main heating method for this household is district heating, so both the energy used for space heating and for the heating of domestic hot water are not showing in these weekly profiles. From all of these profiles presented in figures 23-27 can be seen that during the night hours are quite stable and resulting probably only from the household appliances that are on the whole day. During day and evening the energy consumption rises so there are more appliances used at a given time.

When the annual energy consumptions of these profiles are compared there are clear differences to be seen. Targets 25 and 30 have electricity as main heating system, target 30 is marked as having heat-pumps as main heating, but they operate with electricity. For the target 25 the total energy consumption is 14000 kWh between 1.1. - 31.12.2013, and for target 30, the total energy consumption is 15200 kWh between 1.1. - 15.10.2013. Target 26 has wood/oil combined boiler and target 33 district heating as their main heating method, so in these both cases the space heating and domestic hot water are provided with these methods and therefore energy used for these is not seen in their total energy consumptions. For target 26, the total energy consumption was 5250 kWh between 1.1. – 17.10.2013 and for target 33 it was 5700 kWh between 1.1. – 28.10.2013. From these consumption figures can be seen that with direct electrical heating the annual energy consumption is almost three times larger than with combined boiler or district heating.

With both targets, 26 and 33, where electricity consumption results only from household appliances, the base electricity consumption load is quite stable throughout the whole year, a bit under 0,5 kWh per hour. With target 25 the base load varies between seasons, in winter the base load is about 2 kWh/hour, in spring and autumn it is roughly 1 kWh/hour and in summertime 0,5 kWh/hour. Biggest variations with base consumption load is with target 30, in wintertime the base consumption is about 3 kWh/h, spring and summertime it is roughly 1 kWh/h and in autumn a bit under 2 kWh/h.

With both profiles 25 and 26, the electricity consumption spikes occur at morning and evening when the hourly electricity consumption is 2-3 times higher than the base load. The consumption spikes are generally bigger in weekends than in week days. With profile 30, there are not so much consumption spikes in winter and autumn, slight variation, but not so clear spikes. In the spring and summer though there are clear spikes in consumption in the middle of the night, probably caused by the heating of the domestic hot water. These spikes are in spring 3 and in summer almost 6 times higher than average daily consumption. From these profiles, profile 33 has the clearest spikes at midday and evening, at summertime these consumption spikes are broader. These spikes are 4-5 times higher than the base consumption.

7 CONCLUSIONS

From every profile can be seen that the form of the main heating source has clear effect on the energy consumption profiles that were made during this research. The problem was that when the main heating was not electricity, the amount of energy used for the space heating was not seen in the profiles, at least not all of it. Another problem was that the portion of household energy consumption used to heating of domestic hot water is so high that it should be taken into account in the profiles more clearly. The amount of energy used for water heating can be roughly calculated from the water consumption by assuming that one third of the water used is hot water, but in this research the water consumption was one of the hard questions for the participants so there is no certainty if the given water consumption readings are correct or not. Another way to roughly calculate energy needed to water heating is that it corresponds about 20% of the total energy consumption. As an example for the target 25 the estimation of energy needed for water heating is calculated to be:

$$0{,}2 * 14000\ kWh/a = 2800\ kWh/a$$

where 0,2 is the 20% of the total energy consumption and 14000 is the total energy consumption.

Also from the profiles can clearly be seen how the energy consumption varies during the day and certain consumption peaks could be seen almost from every profile. Those peaks result more from the different energy consumption habits of the participants than real differences between different building materials or heating methods.

What would be interesting is a larger research about the energy profiles so that the effect of different heating methods could be seen clearly.

REFERENCES

Beccali, M., Cellura, M., Fontana, M., Longo, S. & Mistretta, M. 2013. Energy retrofit of a single-family house: Life cycle net energy saving and environmental benefits. Renewable and Sustainable Energy Reviews 27. 283-293.

Bjarløv. S.P. & Vladykova. P., 2011. The potential and need for energy saving in standard family detached and semi-detached wooden houses in arctic Greenland. Building and Environment 46 issue 8. 1525-1536.

Hiller, C. 2012. Influence of residents on energy use in 57 Swedish houses measured during four winter days. Energy and buildings 54. 376-385.

Kotitalouksien sähkönkäyttö 2006. Tutkimusraportti 2.10.2008. Referred 10.10.2014. http://www.motiva.fi/files/1353/Kotitalouksien_sahkonkaytto_2006_-raportti.pdf

Kotitalouksien sähkönkäyttö 2011. Tutkimusraportti 26.2.2013. Referred 7.10.2014. http://www.motiva.fi/files/8300/Kotitalouksien_sahkonkaytto_2011_Tutkimusraportti.pdf

Paatero. J.V. & Lund. P.D., 2006. A model for generating household electricity load profiles. International Journal of Energy Research 30 (5). 273-290.

Website of Aurinkoenergiaa.fi 2014. Referred 16.9.2014. http://www.aurinkoenergiaa.fi/

Website of Bloomberg 2014. Referred 24.9.2014. http://www.bloomberg.com/

Website of Energiatehokaskoti 2013. Referred 2.10.2014. http://www.energiatehokaskoti.fi/

Website of Finnish Energy Industries. Referred 16.9.2014. http://energia.fi/

Website of Korvo.fi 2014 Referred 3.10.2014. http://www.korvo.fi/

Website of Motiva 2014. Referred 11.11.2014. http://www.motiva.fi/

Website of Neuvoo.fi 2014 Referred 3.10.2014. http://www.neuvoo.fi/

Website of Otaniemen ympäristöseura ry 2014. Referred 5.11.2014. http://oys.ayy.fi/ymparisto/energia/energia.html

Website of Shrink that footprint 2013. Referred 25.9.2014. http://shrinkthatfootprint.com/

Website of Työ- ja Elinkeinoministeriö. Referred 15.9.2014. http://www.tem.fi/

Website of World Energy Council. Referred 15.5.2015. http://www.wec-indicators.enerdata.eu/household-electricity-use.html

Website of VTT 2013. Referred 16.9.2014. http://www2.vtt.fi/

APPENDIX 1

Questionnaire of household energy consumption for the solar energy projects of Satakunta University of Applied Sciences

Please, answer for the following questions as precisely as possible. You can leave those questions empty that in your opinion do not apply for your property.

Information about the residents of the property

1 Names of the owner/owners of the property

____

2 Street address, postcode and post office of the property

____

3 Number of residents living in the property ________________

4 Years of birth of the residents living in the property

____

5 Can your name be published in the webpages of Satakunta University of Applied Sciences in connection with the SmartSolar-project as survey participant?

□ Yes

□ No

6 Can we be in touch to you later relating to a solar energy project that is done in spring 2014 by students? In the project solar energy system is designed to selected properties without any charge.

□ Yes

□ No

APPENDIX 1

Information about the property

7 In what year the building of the dwelling house is completed ______________

8 Living area of the dwelling house ____________m^2

9 Total area of the dwelling house ____________m^2

10 Ceiling height in the dwelling house ____________m

11 Number of layers ________________

12 Location, city/neighborhood

---

13 Positioning of the dwelling house in the site

Windows facing south

- □ Number ________________
- □ Surface area ____________m^2

Is there any trees in the site that are shading the dwelling house?

- □ Yes
- □ No

14 Frame material

- □ Stone/Concrete frame
- □ Wooden frame
- □ Timber frame
- □ Metal/Steel frame

15 Insulation

	Wall	Base floor	Roof
Mineral wool	□	□	□
Rock wool	□	□	□
Eko wool	□	□	□
Polyurethane	□	□	□
Sawdust (cutter chips)	□	□	□
Peat	□	□	□
Linen	□	□	□
Felt disc	□	□	□
Styrofoam	□	□	□

Some other, what?____

16 Insulation thick-ness,approximation__________mm______________mm________________mm

17 Is the foundation of the dwelling house

□ Basic wall and slab-on-grade base floor

□ Basic wall and slab-on-grade base floor, basement

□ Basic wall and load-bearing base floor, crawl space

18 Total area of the exterior doors of the dwelling house

19 Total area of windows in the dwelling house ____________m^2

- ◻ Double windows
- ◻ Triple windows
- ◻ Fourfold windows

20 Has there been any renovation projects for the dwelling house that have improved the energy efficiency of the building? (look point 21)

- ◻ Yes
- ◻ No

21 If you answered yes to the previous point, then what following renovations have been made and when?

	Year
◻ Windows replaced	__________
◻ Added heat insulation	__________
◻ Roof renovated	__________
◻ Heating system renovated	__________
◻ Ventilation renovated	__________
◻ Something else, what? (answer below)	__________

____

____

____

22 If there have been added insulation for the dwelling house, what material is used and how much it is used?

---

23 If there have been changes in the heating system and/or in other building services (eg. ventilation), what have been done?

Information about the energy company and energy consumption habits

24 Energy company

□ Pori Energia Oy

□ Fortum

□ Vattenfall

□ Koillis-Satakunnan Sähkö Oy

□ Kokemäen Sähkö Oy

□ Tampereen Sähkölaitos Oy

□ Vatajankosken Sähkö Oy

□ Rauman Energia Oy

□ Some other, what?____

25 How many months before moving in to the building the electricity contract has been made? This question concerns buildings that have been built after 2010 (construction time) _________months

26 Main heating system

□ Electricity

□ Geothermal

□ District heating

□ Wood

□ Pellet/Wood chips

□ Oil

□ Solar collectors

□ Other heatpump, what?______________________________________

□ Combined boiler, what?______________________________________

27 Technical details of the heating system, brand of the device, size/power?

____

____

28 During a year, how many months you are using the main heating system?
___________months

29 Heating systems that are used in addition to the main heating system

□ Fireplace or other hearth

  □ Heat storaging

  □ Non-heat storaging

□ Air source heat pump

□ Other heat pump, what? ________________________________

30 Heat distribution system, mark all systems that are in use

  □ Radiant floor heating

  □ Electric underfloor heating

  □ Hydronic radiator heating

  □ Electric radiator heating

  □ Ceiling heating

  □ Air radiant heating

31 Estimation of fuel consumption needed for heating (wood as stack cubic meters/pellet/oil)

Main heating system ___________ m^3/a

Additional heating system __________ m^3/a

32 If you can estimate the monthly fuel consumption, how it is divided between different months during the last year (October 2012 - September 2013)?

October	___________	April	___________
November	___________	May	___________
December	___________	June	___________
January	___________	July	___________
February	___________	August	___________
March	___________	September	___________

33 If wood is used for heating, has it been

□ Birch

□ Conifer

□ Mixed species

34 Is the heating system same, as main heating system, in all of the floors of the dwelling house?

□ Yes

□ Some other, what?_____________________________________

35 Room temperature normally

□ 18 - 20 °C

□ 21 - 23 °C

□ 24 °C or over

36 Do the dwelling house have

- ◻ Mechanical ventilation with heat recovery
- ◻ Mechanical ventilation without heat recovery
- ◻ Natural ventilation

37 Do the dwelling house have

- ◻ Cooling in connection with ventilation
- ◻ Cooling implemented with heat pump

38 Is there any outbuildings within the property that are heated?

- ◻ Yes ___________m^2 ___________m^3
- ◻ No

39 Is the heating system in the outbuildings same as in the dwelling house?

- ◻ Yes
- ◻ No,what?____

40 Temperature in the outbuilding

- ◻ 10 - 14 °C
- ◻ 15 - 19 °C
- ◻ 20 °C or over

41 Time spend at home on average when at least one person is present ___________h/d

42 At what time of day most persons are at home between 6 - 24? You can choose several options.

Weekday		Weekend	
◻	at 6 - 8	◻	at 6 - 8
◻	at 8 - 12	◻	at 8 – 12
◻	at 12 - 16	◻	at 12 - 16
◻	at 16 - 20	◻	at 16 - 20
◻	at 20 - 24	◻	at 20 - 24

43 At what time of day the household appliances load the electricity consumption roughly the most (eg cooking, sauna heating)? You can choose several options.

Weekday		Weekend	
◻	at 6 - 8	◻	at 6 - 8
◻	at 8 - 10	◻	at 8 - 10
◻	at 10 - 12	◻	at 10 - 12
◻	at 12 - 14	◻	at 12 - 14
◻	at 14 - 16	◻	at 14 - 16
◻	at 16 - 18	◻	at 16 - 18
◻	at 18 - 20	◻	at 18 - 20
◻	at 20 - 22	◻	at 20 - 22
◻	at 22 - 24	◻	at 22 – 24

44 Sauna heating ___________times/week

- □ Electrically heated
- □ Immediately ready
- □ Wood heated

45 If sauna is electrically heated, how many hours it is on per time?___________

46 Size of the hot water heater ___________l

47 Heating of the hot water heater

- □ Electricity (day/night) (circulate the used one)
- □ District heating
- □ Geothermal
- □ Air-/water heat pump
- □ Some other, what? ___________________________

48 Annual water consumption on average ___________m^3/a

49 If you can estimate the monthly water consumption, how it is divided between different monthsduring the last year (October 2012 - September 2013)?

October	___________	April	___________
November	___________	May	___________
December	___________	June	___________
January	___________	July	___________
February	___________	August	___________
March	___________	September	___________

50 Mark what following household appliances your household has. If there are more than one piece of a single appliance, mark also how many there are.

		Pcs
□	Refrigerator	___________
□	Freezer	___________
□	Microwave	___________
□	Electric stove/-oven	___________
□	Dishwasher	___________
□	Washing machine	___________
□	Dryer	___________
□	Drying cabinet	___________
□	TV	___________
□	Computer/game consoles	___________
□	DVD-player	___________
□	CD-/record player	___________

51 Estimate your indoor lighting habits on the basis of the following claims. Circulate the best option in your opinion. (1 = does not describe at all, 2 = describes in some way, 3 = does not decribe well, nor poorly, 4 = describes fairly well, 5 = describes well)

While being at home lights are on in those areas, where people stay	1	2	3	4	5
Lights are switched off always when leaving room	1	2	3	4	5
Lights are not much used by daytime	1	2	3	4	5
Most of the lighting is implemented with LED-lights	1	2	3	4	5
Lights are controlled by motion detectors (swithc on/off when someone enters/leaves the room)	1	2	3	4	5

52 Number of outdoor lights in the property (electric) ___________pcs

53 Estimate your outdoor lighting habits on the basis of the following claims. Circulate the best option in your opinion. (1 = does not describe at all, 2 = describes in some way, 3 = does not describe well, nor poorly, 4 = describes fairly well, 5 = describes well)

Atleast one outdoor light is on also at daytime	1	2	3	4	5
All outdoor lights are always on in at dusk and dark	1	2	3	4	5
Lighting time is adjusted with dusk/time switch	1	2	3	4	5
Only part of the outdoor lights are continuously used	1	2	3	4	5
Outdoor lights are always switched off during night	1	2	3	4	5
Outdoor lights are only switched on when outdoors (motion detector)	1	2	3	4	5

54 Do you use interior or engine heater in your car?

□ Yes

□ No

55 If yes, how many cars are heated? ___________pcs

56 On average, how long the heating is on each time? ___________h/car

57 Additional information

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