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Analysis of electricity consumption patterns in Hungarian households

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT OF THESIS submitted by:
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This work presents the results of the analysis of electricity consumption patterns in Hungarian households using data collected by REMODECE project (Hungary). High-resolution data (10-min records) from individually monitored appliances and light sources in 75households between 2006 and 2008 was processed. The obtained annual electricity consumption of the average Hungarian household was 2117kWh/year (present state). Cold appliances (44%), lighting (18%) and home entertainment (11%) are the end uses with the highest share. These end uses are in general, characterized by appliances with both high electricity consumption and high penetration in households. The analysis of the typical day (24-period) revealed two main patterns: appliances with defined periods of high consumption (e.g. TV sets between 20:00 and 00:00) and appliances with relatively constant electricity consumption during the day (e.g. modems and set top boxes).

ICT equipment was selected to analyze power consumption in different modes: LP1 (off mode), LP2 (standby) and normal mode. For TV sets and computers up to 45% of the electricity consumption in a typical day occurs in LP1 and/or LP2 modes. For the rest of appliances it is above 90%. The combined share of LP1 and LP2 in the final electricity consumption of the average household was 3.2% (66.5kWh/year). This value is lower than the obtained in previous studies. Potentials for electricity conservation were identified and assessed comparing the consumption in the present state with the one using energy efficient equipment. Savings of up to 946kWh/year were obtained (46% of the consumption of the average household). Freezers, fridges and lighting were the appliances with the highest potential for electricity conservation. This savings can represent a reduction of up to 1618Kt of CO_2/year.

Keywords: Appliances, Electricity, Households, Monitoring, Power levels, REMODECE.

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LIST OF ABREVIATIONS

BAT	Best Available Technology
EIA	Energy Information Administration
EU	European Union (also EU27)
EU15	European Union (Germany, France, United Kingdom, Italy, Spain, Portugal, Greece, Sweden, Austria, The Netherlands, Finland, Belgium, Ireland)
EU27	European Union (All the 27member states as of May 26th 2010)
GWh	Gigawatt hour
kWh	Kilowatt hour
HEEP	Household Energy End-use Project
ICT	Information and Communication Technology
IEA	International Energy Agency
Int.	Intermediary values between LP1, LP2 and normal modes
Int.1	Intermediary power values between 0W and LP1
Int.2	Intermediary power values between LP1 and LP2
Int.3	Intermediary power values between LP2 and Normal mode
KSH	Központi Statiztikai Hivatal (Hungarian Central Statistical Office)
LCD	Liquid Crystal Display
LP1	Low Power 1 (off mode)
LP2	Low Power 2 (active standby)
NMS	States that joined the EU in 2004 (Hungary, Czech Republic, Slovenia, Slovakia, Poland, Lithuania, Latvia, Estonia)
OECD	Organisation for Economic Development and Cooperation
PC	Personal computer
PR	Penetration rate
RECS	Residential Energy Consumer Survey
REMODECE	Residential Monitoring
Wh	Watt hour

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1. Introduction

1.1 Background

The residential sector is one of the largest consumers of the electricity generated in the world. In the EU27 alone, it constitutes the second largest consumer with 28.1% (800.7TWh) of the final electricity consumption while in the US the share reaches 37% (EC JRC 2009, Hutts 2009). Although there has been improvements in the energy efficiency of the main domestic appliances (e.g. fridges, washing machines, light sources) the electricity consumption shows an upward trend. According to Bernoldi and Atanasiu (2007), the electricity consumption in the residential sector of the EU25 grew 11% between 1999 and 2004. Similarly, the most recent report by the Joint Research Centre (JRC) of the European Commission shows that between 2004 and 2007 the electricity consumption increased by 2.1% (Atanasiu and Bernold 2009). Some of the factors behind this trend include a higher penetration of appliances (e.g. more TV sets with bigger sizes), an increased use (e.g. users watching TV for more hours), increase in the area and number of households, among other factors (Firth *et al.* 2008, Fonseca *et al.* 2009). As these variables are expected to continue driving the increase of the consumption in households, the demand for electricity will grow.

As electricity generation in several countries depends on the combustion of fossil fuels, an additional demand implies a potential increase in greenhouse gas (GHG) emissions (IEA 2008). In 2006 alone, 41% of the world's electricity was produced using coal (IEA 2009). In 2004, the combustion of fossil fuels was responsible for 57% of the total GHG emissions worldwide. Electricity generation plants were the largest individual sources of GHG emissions with 10GT CO_2 (IPCC 2007). However, it is important to mention that the energy sources used to produce electricity vary among countries. For instance, in a country such as Norway more than 90% of the electricity is generated by hydropower (considered as a clean energy source). In contrast, in the Netherlands 90% comes from fossil fuels (coal and natural gas) (UNDESA 2007). In the case of Hungary, 38% of the electricity is produced using gas while and 19% by using coal (IEA 2008). Considering the above, electricity conservation in households can have a positive impact in reducing emissions where fossil fuels are used for electricity generation.

Although the connection between electricity savings and reduction of GHG emissions appears trivial, a context-based knowledge on potential electricity savings in the residential sector is in general, scarce. Reliable information on how electricity is used in households is required for the development of policy recommendation aimed at saving electricity (Cogan *et al.* 2006). The approach to analyze electricity consumption must be integral considering both users-consumers and appliances (Fonseca *et al.* 2009, Zimmermann 2009). One of the ways to determine potentials for electricity conservation is the analysis of appliance use patterns. There are basically two ways: in the first, electricity consumption from appliances is estimated using reference values such as the household electricity consumption and data gathered from surveys (USDOE 2009). The surveys provide information on socioeconomic aspects, use patterns (behaviour), along with information on brands, power among others. The estimation is made using statistical tools relating data on consumption (reference values) with information from the surveys. As no measurements on appliances are made, the process reduces costs and time (Larsen and Nesbakken 2002). One example of this type of approach is the residential energy consumption survey (RECS) in the US. The information gathered by RECS is used to estimate the electricity use from the main end uses in households. It is also used as input for modelling scenarios about the future energy demand (USDOE EIA 1998US, DOE EIA 2005). The methodology has been also used outside the US to analyze residential energy use (CLASP 2009).

Another way consists in measuring electricity consumption from individual appliances. The measurements are recorded using devices installed on individual appliances in selected households (Sidler *et al.* 2002). Along with the measurements, a survey is applied to gather information on socioeconomic and behavioural aspects. Usually, the measurements are recorded every 10 minutes during intervals that can go from 1month to 12 months (Fonseca *et al.* 2009, Zimmerman 2009). In Europe the most relevant projects analyzing electricity consumption in households include EURECO (households monitored in four European countries between 2000 and 2001), REMODECE[1] in 13 European countries including Hungary, between 2006 and 2008 (Sidler 2002, Fonseca *et al.* 2009). Additionally, there are two projects that are probably the most comprehensive carried out for particular countries to date: the improved energy statistics in buildings project by the Swedish Energy Agency SEA (hereafter, SEA Sweden project) and the Household Energy End use Project (HEEP) in New Zealand (Bennich *et al.* 2009, Camilleri 2009). Unlike the previous ones, the measurements on appliances took place in statistically selected households (representative samples) (Bennich and Person 2006, Camilleri 2009). This is, the results can be directly generalized for the entire country. However, these studies are complex

[1] The data used in this research was gathered as part of this project between 2006 and 2008 in Hungarian households.

(national, supranational scales) and expensive (logistics and monitoring devices). This can explain the relatively few number of projects of this type worldwide (Darby 2006).

The first approach is convenient to reduce time and costs and it is convenient when these resources are limited. However, a monitoring process can provide a more accurate picture of how appliances are really used in households, since the collected data correspond to the actual consumption of the appliance in normal operating conditions. As presented in Isaacs *et al.* (2006), the usefulness of large scale monitoring projects is not recognized until the data is analyzed and the results show relevant context-based findings. For instance, according to the SEA Sweden project, the end use with the largest consumption is lighting (Zimmerman 2009). This makes sense considering the duration of the night during the wintertime in this Scandinavian country. In the case of HEEP, 75% of the households use electric water heaters, which is probably de highest rate in the world (Camilleri 2009). The EURECO project found an increasing penetration of air conditioning devices in southern European countries such as Greece and Portugal. It also found, that energy efficient cold appliances in Denmark dominate the stock in households (Sidler *et al.* 2002, ENERTECH 2006). In this sense, the understanding of how, when and where energy is used in households contributes to identify the best (appropriate) opportunities for electricity conservation.

The analysis of electricity consumption patterns allows determining the main end uses in particular contexts. For instance, in the US, heating, ventilation air conditioning –HVAC- accounts for up to 31% of the final electricity consumption in the residential sector (EIA 2005). In Europe, space heating accounts alone for up to 18.8% of the final electricity consumption in household (Bertoldi and Atanasiu 2009). In general, after HVAC cold appliances (refrigerators, freezers) and lighting are, the main consumers of electricity. In Europe, cold appliances and lighting consume 15.3% and 10.8% of the final consumption in households respectively (EUROSTAT 2007). In Japan, refrigerators and lighting are responsible each for 16% of the final electricity consumption in the residential sector (JICA 2006). Information and communications technologies –ICT- are becoming more important in the final electricity consumption in households. There are two main reasons for this: a higher and diverse number of appliances and standby consumption (Hutts 2009). In the case of standby, the share in the final electricity consumption of households is far from being uniform. In OECD countries it has been estimated in 3% of the final electricity consumption in households, while in countries such as Australia it can be around 10% of the final consumption in the residential sector (Benoit et *al.* 2000, Harrington *et al.* 2007). In European households measurements revealed shares between

4% an 11% (Siderius *et al.* 2006). In 2007, the calculated share of standby in the final electricity consumption of the EU27 was 5.9% (JRC EC 2009). Without measures, by 2030 up to 15% of the final electricity consumption in households of the EU27 can be attributed to standby consumption (IEA 2003).

The above studies on electricity consumption in residential sector consider both measurements with behavioural aspects. This is certainly an indication that the analysis of electricity consumption in households requires an integral approach. As presented in Isaacs *et al.* (2006), a complete study on electricity consumption patterns requires besides statisticians, experts in social sciences to address behavioural aspects. The Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe -REMODECE project took a similar approach (monitoring of appliances and a survey were part of the process) (IEE 2008). Similarly, a specific in depth behavioural study was carried out in parallel to the monitoring process in Swedish household as part of the SEA project (Green and Ellegård 2007).

The results obtained by the different projects show a reference scenario (how electricity is used in households), and a prospective scenario (what would be the savings if efficient equipment is replaced with Best Available Technology –BAT-). For instance, the REMODECE project found that using BAT and improving consumer's behaviour, the total electricity savings from the participating countries could reach up to 268TWh/year (reducing emissions by 116Mton CO_2) (Fonseca *et al.* 2009). Grinden and Feilberg (2008) obtained an average savings of 48% respect to the reference situation for the participating countries. In the case of the Swedish project, the results indicated that up to 75% of the savings could be achieved by replacing cold appliances, lighting and computers. (Zimmermann 2009). With these results, some general and context based priorities can be identified to reduce electricity consumption from appliances.

Regarding general priorities currently the EU is taking actions aimed at improving the energy efficiency of household appliances. Among the traditional policy tools used to increase the energy efficiency are energy standards (MEPS) and energy label. Both have been in place as mandatory requirements for the major household appliances in Europe since the middle of the 1990s (Harrington and Damnics 2001). Cold appliances and washing machines have traditionally been the appliances targeted with these two instruments. The results have contributed to transform the market, increasing the stock of energy efficient appliances in European households. In the case of Central and Eastern European countries, the sales of efficient appliances are now similar to those of Western Europe (EU15) (Bertoldi and Atanasiu 2008). However, in the case of these major appliances, the market transformation has resulted in a situation in which most of the appliances are now in the most energy efficient categories (Boardman 2004). The energy label for cold appliances was updated to include new energy levels in 2003 (Directive 2003/66/EC).

However, there are appliances that are currently not covered by these instruments. Considering this, and the need to update the existing energy standards and label for appliances, the Council and the European Parliament issued the Directive 2005/32/EC (Ecodesign of energy using products). This framework Directive defines principles and criteria for setting environmental requirements for energy using products. In this sense, do not define specific requirements for particular appliances (Directive 2005/32/EC). The process for appliances involves preparatory studies and consultations with interested parties before the issue of any implementing regulation.

The process has resulted in the issue of regulations setting requirements (energy standards) for specific appliances. Among the most relevant are: energy standards for residential light sources, which will eventually lead to the phase out of incandescent technologies (Regulation EC 244/2009). The energy standards for TVsets include the definition of the maximum values for active and low power modes -off and standby- (Regulation EC 642 2009). Set top boxes have also mandatory standards for consumption in active and standby mode (Regulation EC 107/2009). The maximum consumption in low power modes for electrical and electronic household and office equipment is defined in the Regulation 1275/2008. Among these appliances are TV sets, DVD players and computers. It is expected that new regulations setting mandatory standards for TV sets will be in place soon. Additionally, the energy label will be updated for cold and washing appliances and introduced for the first time for TV sets (TopTen 2010). Similar steps for imposing mandatory standards for TV sets were taken in California and Australia during the late 2009 (CEC 2009, Horowitz 2009).

The above actions can be regarded as general policy actions focused on appliances that are needed to foster the market transformation. However, these policy measures (energy standards and energy label) are not enough *per se*. The awareness of consumers is also important in order to complement and catalyze the process (Wiel and MacMachon 2005). In this sense, the analysis of electricity consumption patterns in particular contexts can help to identify the priorities to achieve energy efficiency in households. For instance as presented previously, the increased use of air conditioning devices in southern European countries, or the consumption from light sources as the main end use in countries such as Sweden. These particularities constitute an indication that specific actions need to be taken to create awareness in the consumer. Awareness not only focused on the availability of energy efficient appliances in the market, but also about in the use of the appliances in households.

1.2 Problem definition

The above context describes briefly the relationship between different components of a particular situation. An increasing use of electricity in the residential sector leading to the potential increase in the GHG emissions (where generation is predominantly based on fossil fuels). Then, the identification of potential opportunities for electricity conservation through analysis of electricity consumption patterns in the residential sector (e.g. from monitoring appliances and analyzing behavioural aspects). This approach can provide supporting elements to improve existing policy instruments such as mandatory standards and labelling, in a general context (e.g. Directives and Regulations at EU level). Additionally, the analysis can show particularities of the context that can be useful to prioritize efforts. For instance, national policies to foster the acquisition of energy efficient fridges or lighting in the form of information, economic incentives, among others. The focus of this research is given to the analysis of electricity consumption patterns in the Hungarian residential sector, in order to elucidate particularities and to identify potentials for electricity conservation. Figure 1 shows the main factors associated with the electricity consumption in the residential sector.

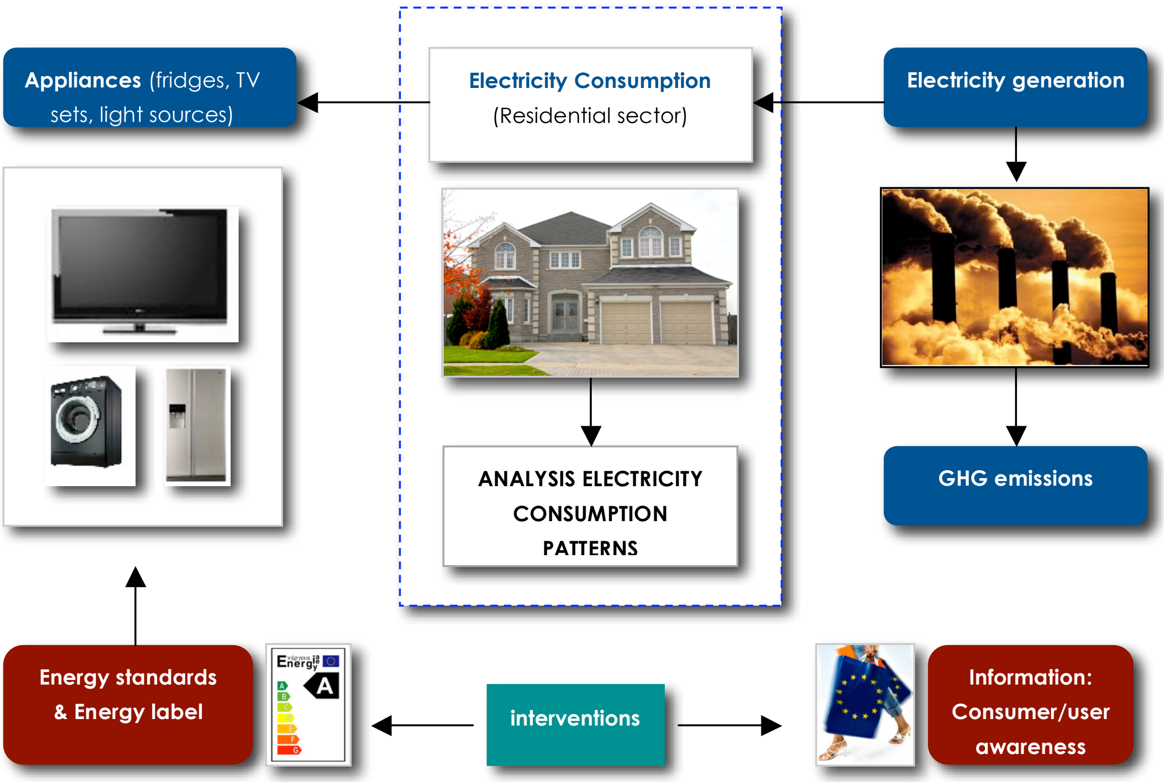

Figure 1. Electricity consumption in the residential sector and associated factors

The knowledge of electricity consumption patterns in the Hungarian residential sector based on high-resolution data from appliances is scarce in the country. Previous studies on electricity consumption in buildings have analyzed patterns in the tertiary sector (Koeppel *et al.* 2008), standby consumption from appliances in households (Valentova 2007) and standby from appliances available in the market (C3SEP 2008). Grinden and Feilberg (2008) analyzed electricity consumption using the data from the monitored appliances of the REMODECE project. In this analysis, the electricity consumption for the average European household was calculated. The analysis included all participating countries in the REMODECE project, including Hungary. In parallel with the monitoring campaign, the REMODECE project in Hungary applied a survey in statistically selected households (representative of the country). The analysis of the data by Boza-Kiss *et al.* (2009) revealed among others, an increased penetration of appliances such as dishwashers along and improvement in the energy efficiency of the stock of appliances present in Hungarian households.

Considering the above, this research contributes to narrow the existing knowledge gap in relation to electricity consumption patterns in Hungarian households. The analysis is based on high-resolution data gathered from individual appliances in real working conditions by the REMODECE project (Hungary). This condition makes the study pioneer in the sense that there has not been a previous analysis on this kind of data for the Hungarian residential sector. Therefore, the results provide an indication of the use pattern of the common appliances found in Hungarian households, helping to identifys potentials for electricity conservation.

1.3 Research question

The following major research question was formulated considering the research problem described above: Based on the analysis of the monitoring data from individual appliances,

How is electricity used in the average Hungarian household?

In order to answer the research question, the following main objectives are established for the study:

-To reconstruct the electricity consumption of the average Hungarian household using data from individual monitored appliances and the specific appliance penetration rates for the country.

-To analyze the daily load (24h-period) of the average individual appliances within each of the main end uses.

-To quantify the power use and the time spent in different power modes: off mode (LP1) , standby (LP2) and normal mode for ICT equipment -office and home entertainment-.

-To assess potential energy savings for the appliances with the highest electricity consumption in the average Hungarian household by using the best available technology (BAT).

1.4 Scope and limitations

The study analyzes electricity consumption patterns in Hungarian households using data recorded from individual appliances within the REMODECE project. Although the monitoring process took place in Budapest, representative data for the country (from the REMODECE survey and from the Hungarian Central Statistical Office –HCSO-) is used to determine the average Hungarian household electricity consumption.

The study uses appliance penetration rates to obtain representative values for the country. As the penetration rates for the regions of the country are not available for all the appliances, it is not possible to make comparisons of the electricity consumption within the country.

As the period of time in which the appliances were monitored at each household was in average two weeks, no analysis on seasonal patterns is possible. For this is necessary to monitor individual appliances in selected households for a period not inferior to 11months. However, considering that the monitoring campaign spanned for a period of almost two years, there is an intrinsic consideration of the seasonal variations during that period.

The study is not intended to analyze the effectiveness of policy instruments in the electricity consumption of Hungarian households. Instead, it analyzes a reference condition (use patterns) in order to identify potentials for electricity savings.

1.5 Outline

The document is organized as follows. First, the literature review provides a general overview of factors linked to the electricity consumption from the residential sector. It is divided in two parts, one focusing on electricity consumption in a global basis and the second focused in Hungary. The second part of the document presents a detailed description of the methodology used for the data analysis. The third part presents the results and the analysis of the electricity consumption patterns in Hungarian households. This sections includes three parts: *the reconstruction of the electricity consumption of the average Hungarian household using data from monitored appliances (present state)*, *the analysis of the daily profiles of appliances, and the analysis of power consumption of information and communication technologies –ICT- in different power levels.* Then, an assessment of the potential electricity savings is carried out. It compares the results of the present state with a scenario of energy efficiency considering the best available technology BAT. Finally, the document presents the conclusions derived from the main findings of the study.

2. Literature Review

2.1 Residential electricity consumption

Analysis of electricity related-issues usually implies the consideration of two interdependent aspects: *generation* and *consumption*. Although the present document is focused on residential electricity consumption, the reference to electricity production is necessary in order to understand how potential changes in consumption can affect the electricity generation. For this reason, the first part of this literature review will introduce relevant aspects regarding production and related emissions. Then, the focus will be placed on residential consumption, first describing its importance in the final electricity consumption in different contexts. Then, a reference of the main determinants is presented as well as the importance of carrying out monitoring process to analyze the present state and to identify potentials for energy conservation. This overview contributes to contextualize the research. Finally, the focus is placed on the Hungarian residential context.

2.1.1 Electricity generation

2.1.1.1 Energy sources

Electricity can be generated from different energy sources, including fossil fuels, nuclear, hydropower and renewables. Among fossil fuels, coal and peat constitute the main energy sources used to produce electricity (IEA 2008). In 2006, around 41% of world's electricity was produced using coal, while natural gas[2] was the second most used fuel (20%) (IEA 2009). In countries such as Australia (home to the world's largest coal deposits) and the emerging economies such as China, India and South Africa between 70% and 95% of the electricity is generated using coal (IEA 2009). In other developing countries coal remains with a low share in the energy mix, such as in Mexico and Thailand, with less than 20%. However, in these countries, other fossil fuels such as natural gas are important: Thailand (70%) and Mexico (40%) (Amayatakul and Berndes 2008). Unlike other regions, Latin America[3] generates most of their electricity using hydropower, accounting for up to two thirds of the production. In contrast, fossil fuels (coal, natural gas an oil) accounts less than one third (IEA 2009).

When it comes to generation among countries, the US is by far the largest electricity generator with one quarter of the world's generation. During 2006, 52% of that generation used coal in the process (USDOE 2009). However, in 2009 coal consumption from the electricity sector decline 10% compared to previous years. This was mainly due to increases in the use of other energy sources such

[2] Natural gas is important for electricity production since it is considered more efficient and less carbon intensive in comparison to other fossil fuels. Additionally, unlike other fossil fuel such as oil, natural gas prices are low and stable (EIA 2009)

[3] The figure excludes Mexico, as it is member of the OECD.

as natural gas and hydropower (EIA 2010). Japan (7%), France, Canada and Germany (4% each) are other large electricity producers (Narayan 2007). However, EIA (2009) projects that the biggest growth in electricity generation will take place in non-OECD countries (up to 3.5% per year). With living standards increasing, as well as demand for new appliances and expansion of services, electricity generation is expected to increase in these countries. It is important to mention however, that energy sources used for electricity generation can vary notably among the countries. For instance, in a country like Norway where water is an abundant resource and geographical features play an important role, 90% of the electricity is generated using hydropower. On the other hand, in the Netherlands, without these resources, 90% of the generation is based on fossil fuels (coal and natural gas) (UNDESA 2007).

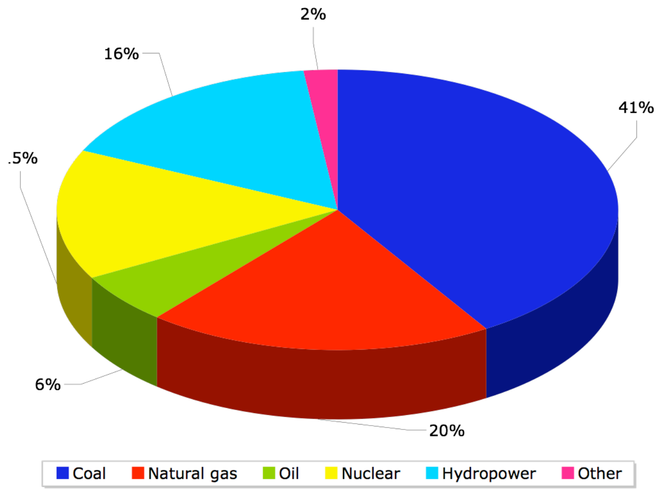

Figure 2. World electricity generation by fuel during 2006. Elaborated using data from IEA (2008)

2.1.1.2 Emissions

The predominant use of fossil fuels in electricity generation certainly has an impact. In 2004, the combustion of fossil fuels produced around 57% of the total (GHG)[4] emissions worldwide. Electricity generation plants were the largest individual sources of GHG, emitting around 10Gt CO_2. Industry (excluding cement) was second with 5Gt CO_2 in 2004 (IPCC 2007). When it comes to sectors, in 2007 electricity and heat generation was the largest emitter of CO_2 accounting for about 40% of the global CO_2 emissions, followed by transport and industry. Between 1970 and 2007, the emissions from electricity and heat generation increased from 25% to 40%. Similarly, emissions from the transport sector have also increased. In contrast, emissions from manufacturing and construction have been decreasing (EIA 2009). Figure 3 presents the behaviour of emissions from different sector between 1970 and 2007.

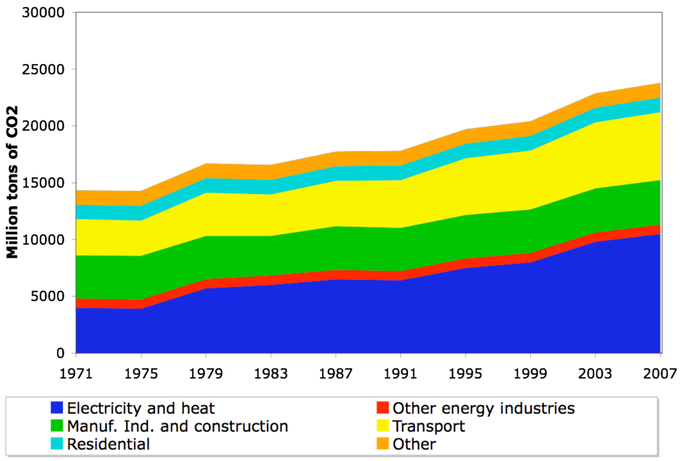

Figure 3. Global CO_2 emission per sector. Period 1970-2007. Elaborated using data from (EIA 2009)

Considering the importance of coal in electricity generation, it seems clear that a considerable share of the GHG emissions is produced by its combustion. Of the 10000Tg of CO_2 produced by the combustion of fossil fuels to generate heat and electricity, coal/peat was responsible for around 80% of world's CO_2 emissions (IEA 2008). Among countries, in 2006 China was the single largest emitter of CO_2, (around 2500Tg CO_2) while the US was the second (2100TgCO_2,) (IEA 2008). In the US alone, the electricity sector accounts for up to 40% of the country's CO_2 emissions (USEPA 2010). In the case of the EU27, the third largest emitter of CO_2 with around 1200Tg CO_2, electricity and heat production accounted for 27% of the total GHG emissions (EIA 2008, EEA 2008). Figure 4 presents the CO_2 emissions from fossil fuel combustion linked to the production of electricity and heat in different countries and geographic regions.

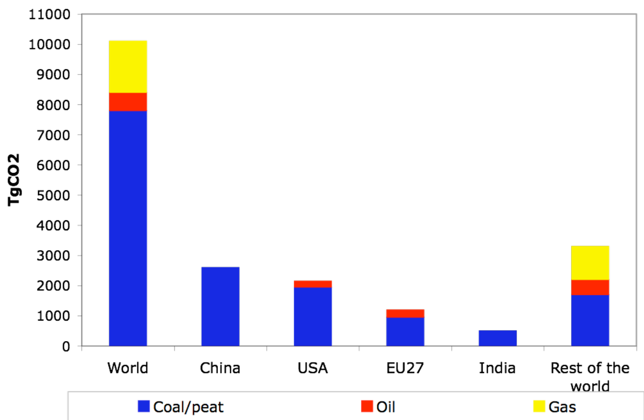

Figure 4. CO_2 emissions from fossil fuel combustion from electricity and heat production in 2006. Elaborated using data from IEA (2008).

[4] Up to 94% of the so-called GHG from energy emissions correspond to carbon dioxide -CO_2 (IEA 2009).

2.1.2 Electricity consumption

As with the generation, electricity consumption can vary notably worldwide. In Europe, households consume up to 28.6% of the electricity generated (4667kWh/household in average per year), while in the US the share is 37% (11209kWh/household in average per year) (Bertoldi and Atanasiu 2009, Hutts 2009). A similar pattern is found when per capita consumption of electricity is analyzed. World's annual average electricity consumption per capita increased from 2066kWh/year in 1990 to 2595kWh/year in 2005. North America and Europe are the regions with the highest consumptions (13993KWh/year and 8009kWh/year per capita capita in 2005 respectively) (Table 1) (IEA 2007). Despite the fact that Asia had only a fraction of that of North America, it doubled between 1990 and 2005 driven by their economic growth (IEA 2007, Maza and Villaverde 2008). On the other extreme are most of sub-Saharan countries: in 2000 the average electricity consumption per capita (excluding South Africa[5]) was only 112.8kWh/year in that African region. In some cases, consumption can be as low as 22kWh/year per capita, as it is the case of Ethiopia (Wolde-Rufael 2006).

Table 1. Electricity consumption per capita (kWh) in different geographical regions. Modified from IEA 2007.

REGION	1990	2005
Asia (excluding Middle East)	739	1404
Central America & Caribbean	1033	1526
Europe	5502	6008
Middle East & North Africa	1124	2107
North America	12123	13993
South America	1280	1834

Excluding the contrasting consumption figures between the geographic areas presented above, there can be considerable differences between countries or within countries belonging to a same geographic area. For instance, in some EU countries such as Sweden and Finland, electricity consumption can be as twice the per capita average of the EU27 (which is 3200kWh/year). In contrast, in a country such as Romania, the per capita average is just 600KWh/year (EUROSTAT 2007). In this case, such differences are mainly explained by the considerable use of electricity for space and water heating in Scandinavian countries. Norway (not a EU member state but usually included in this type of analysis) is an extreme case with an average of 12500kWh per capita. It is a value that can be explained mostly by low electricity prices and abundant hydropower (Bertoldi and Atanasiu 2007).

[5] South Africa constitutes an exception to the situation in Africa. Electricity consumption grew more than 200% between 1975 and 2005 at a rate faster than economic growth rates. The electricity consumption per capita during 2005 was 4847.6kWh/capita, well above the world's average of 2595.7kWh/capita. Economic and population growth, regional migration and urbanization are among the main determinants in this case (Ziramba 2008)

In the US, during 2006 the per capita electricity consumption was around 12300kWh. However, the state of California had the second lowest of the states (7000kWh) and Wyoming the highest (25600kWh) (USDOE 2009). In this case, as part of an analysis of several variables carried out by Sweeney and Sudarhshan (2008), it was found that up to 28% of such differences between states can be explained by policy related issues (e.g. particular policies at state level such as the recent approval of efficient standards for TV sets in California[6]), while the rest lies on policy independent factors such as income distributions, fuel mix, household size and type (apartment vs. single houses), locations (urban vs. rural), climate, among others determinants.

According to Maza and Villaverde (2008) electricity consumption per capita constitutes one of the most clear indicators of economic welfare and three main drivers help to understand differences between countries: *rapid economic transformations* in some developing countries such as India y China. In these countries the electricity consumption grows at a faster pace than GDP. Even so, consumption is below the world average, such as in India (Pachuari 2009). The second driver is *energy conservation policies* implemented by developed countries after the oil crisis of 1973. Even when consumption has increased in these countries due to other factors, it has been relatively offset by policies (Bertoldi and Atanasiu 2009). Finally, the third one is the *increasing social pressure to reduce CO_2 emissions,* linked to the production based on fossil fuels.

2.1.2.1 Electricity consumption by sectors

Residential and commercial sectors have driven the increase in electricity consumption since the first oil crisis in OECD countries. During the period 1973 – 2007, the combined share of these two sectors increased from 48% to 62% (Figure 5) (IEA 2009). In contrast, consumption from the industry has decreased in the same period as shown in Figure 5. In the EU27, the residential sector is the second largest consumer accounting for 29% of the final electricity consumption. (EUROSTAT 2007). In the US, the residential sector accounts for 37% of the electricity consumption followed by the commercial sector (36%) (EIA 2009).

[6] The adopted standards will enter into force in January 2011 requiring TV sets to consume 33% less electricity by 2011 and 49 by 2013. The expected benefits are twofold: on one hand, the energy savings after all equipment is replaced are around 6515GWh, and on the other hand, the energy cost savings for California residents will be around $8.1billion (CEC 2009a, CEC 2009b).

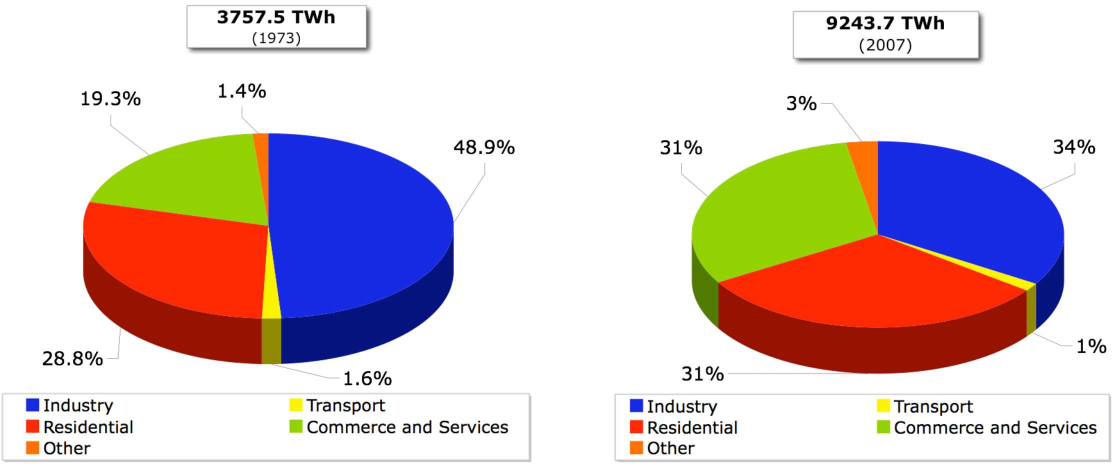

Figure 5. Final electricity consumption by sector in OECD countries in 1973 and 2007. Elaborated using data from IEA (2009)

While in developed countries the final consumption is in general dominated by the residential and commercial sector, in developing countries the proportions are different, reflecting the particularities of the context. For instance, a predominantly rural country like India, industry and agriculture account for up to two thirds of the final electricity consumption (37.8% and 33.7% respect.). The residential sector is the third largest consumer of electricity (20%) (Pachuari 2009). In Brazil, another emerging economy but more urbanized, the residential electricity consumption has a share similar to that of the OECD (around 28%) (Ghisi *et al.* 2007). In countries without heavy industry such as Lebanon, households consume 60% of the electricity generated in the country (Houri and Kourfali 2005).

2.1.2.2 Residential electricity consumption

2.1.2.2.1 End-uses

At household level, the breakdown of individual end uses presents variations, mostly in response to particularities of the context. Usually, space/water heating and cooling constitute an important share of the final household consumption in developed countries. Heating, ventilation and air conditioning –HVAC- accounts for 31% of the final electricity consumption in the US, while in Europe it accounts for 23% (Figure 6) (EIA 2005a, Bernoldi and Atanasiu 2009). In Europe, space heating accounts alone for up to 18.8% of the final household consumption (Bertoldi and Atanasiu 2009). When these end uses are excluded, cold appliances (refrigerators, freezers) and lighting are the main consumers of electricity in households. In the EU, cold appliances and lighting consume 15.3% and 10.8% of the final consumption respectively (EUROSTAT 2007). In Japan, refrigerators and lighting are responsible each for 16%. TV sets alone, account for up to 10% of the final consumption in households (JICA 2006). In New Zealand, electricity constitutes 69% of the energy used by households. Among the end-uses, space heating accounts for 34% of the final electricity consumption in the household (7240kWh/household/year). What is interesting in the breakdown is the fact that the second highest share (29%) is due to water heating (77% of the households use electricity for water heating) (Camilleri 2009).

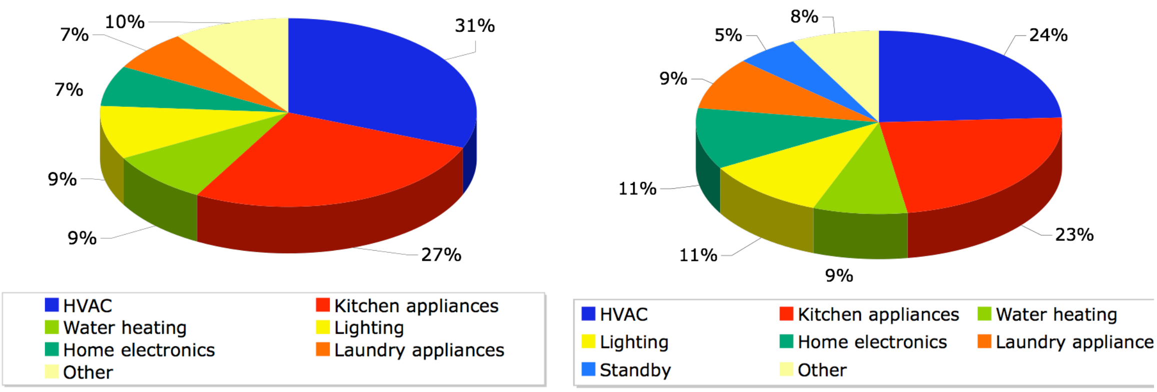

Figure 6. Residential electricity end use shares in the US in 2001 (left) and the EU27 in 2007 (right). Elaborated using data from EIA (2005) and Bernoldi and Atanasiu (2009), respectively.

A third important component in the breakdown is electronics (mainly the so-called information and communication technologies –ICT-). This is a broad category that includes home entertainment equipment (TV sets, DVDs, HIFI systems, among others) and office equipment (desktops, monitors, laptops, printers among others). In the EU these devices use around 13% of the total electricity consumption in households (Atanasiu and Bernoldi 2008). In the US computers and electronics (mainly entertainment equipment) account together for around 12% of the final electricity consumption (USDOE 2009).

2.1.2.2.2 Leaking power: Standby consumption

The several existing definitions of standby consumption show the complexity surrounding the subject (Gudbjerg 2008). For instance, according to Harrington *et al.* (2005) it corresponds to the power use when the appliance is not performing its main function. Benoit *et al.* (2000) states it corresponds to the minimum power consumption of appliances while connected to the mains. The International Energy Agency (IEA) provides a more general definition allowing to include a wide range of appliances: "standby power use depends on the appliance but it corresponds at minimum to the power used while the appliance is not performing its main function or it is the lowest power used while it is performing at least one function" (Cogan *et al.* 2006). For instance, VCRs and DVDs usually have active and passive standby and on mode. In passive standby, the appliance is off but responds to remote control. In active standby the appliance is on but it is no playing, while in on mode the appliance is performing its main function. PCs have also several power modes: standby when the appliance is off but it is drawing power from the mains, idle mode (sleep, screen saver modes) and active mode (Harrington *et al.* 2008).

As most of electronic devices are increasing its penetration in households, the importance of standby power use is expected to augment (Harrington *et al.* 2008, Rittenburg and Hashmi 2008). Even when the individual power use in this mode is not high, when taken collectively (several appliances with low power use), the share in the final electricity of the households become relevant (Siderius *et al.* 2006, Lebot *et al.* 2000). In Australian and American households it is responsible for 10% of the final electricity consumption, a share similar to refrigerators or lighting (Rosen and Meier 2000 a,b). It is estimated than in 2030, it could represent up to 30% of the final residential electricity consumption in the US (Harrington *et al.* 2006). According to EC JRC (2009) between 2004 and 2007 residential electricity consumption from ICTs grew by 2%, increasing the share in the final electricity consumption of households to 13% in the EU27. As this trend is expected to continue due to an increased ICT penetration, the standby consumption will also become more important. Currently, standby accounts for up to 5.9% of the final electricity consumption in European households (EC JRC 2009). The IEA projects that by 2030, 15% of the electricity consumption in households Europe could be attributed to standby consumption (IEA 2003). Considering the above, standby consumption represents an opportunity for electricity savings.

2.1.2.2.3 Emission and specific end-uses

In general, emissions from the residential sector are provided as an aggregated figure (e.g. emissions from residential electricity consumption). In this sense, references to particular emissions from specific residential end-uses are usually not known. However, in some countries the emissions linked to particular end-uses have been calculated. For instance, in the US, CO_2 emissions related to household energy consumption have been estimated in 1258 million metric tons of CO_2 for the year 2010 (IEA 2008). Of this, 904 million metric tons of CO_2 correspond to electricity consumption. When the breakdown per individual end-uses is made, lighting and space cooling contributes with almost one third of the emissions related to electricity consumption from the residential sector (USDOE-EIA 2008). Table 2 presents the contributions by end use in households.

In the EU27, despite the fact that electricity consumption in households increased between 1990 and 2005 by 19%, there was a decrease in electricity related emissions. According to EEA (2008), the main drivers for the decrease lies in improvements in the carbon intensity linked to power generation. However, as presented later, increases in the number of dwelling and penetration of a wide range of appliances have offset the reductions (Bertoldi and Atanasiu 2009).

Table 2. Household CO_2 emissions related to specific energy end-uses in the US. Adapted from USDOE-EIA (2008)

	Electricity related emissions (Million metric tons)	%
Space heating	67.1	7.4
Space cooling	144.5	16.0
Water heating	70.1	7.8
Lighting	131.4	14.5
Refrigeration	81.9	9.1
Wet clean	69.4	7.7
Electronics	71.7	7.9
Cooking	19.8	2.2
Computers	17.4	1.9
Others*	230.9	25.5
TOTAL	904.2	100

*Others includes: small electric devices, heating elements, motor, swimming pool heater, hot tub heaters, outdoor grill, among others (USDOE EIA 2009)

2.1.2.2.4 Electricity consumption in rural and urban households

Disparities between electricity consumption in rural and urban households are certainly more acute in developing countries. According to Dzioubinsky and Chipman (1999), electricity consumption in the urban side was up to four times that of the rural during the 1990s. The reason for the considerable gap between rural and urban sides lies in low electrification rates, low appliances penetration, and low incomes, among other factors. In India, despite the fact that 60% of the country is electrified, the gap between urban and rural is large: 87% and 42% respectively (Pachuari 2009). In the same sense, appliance penetration rates remain low. For instance, 12% of the households in the country had a refrigerator, but in the urban side the penetration rate is around 25% (five times higher than in the rural side) (Letschert and McNeill 2007, Pachuari 2009). This gap is therefore reflected in the final average electricity consumption: in urban households during 2000 it was 990kWh/year while in the rural side it was only 280kWh/year (Letschert and McNeill 2007).

In a country such as China, differences in residential electricity consumption between regions are also different. For instance, in regions such as Ganzu and Qinghai it is around 700kWh/year per household, while in Southeast and Northeast China is the double (1400kWh/year per household). Increased appliance penetration linked to economic prosperity is the driving factor, especially in urban areas (Zhang 2004). Similar relationships between electricity consumption and economic growth are presented in Latin American countries. Unlike China and India, more than two thirds of the population live in urban areas, where access to electricity is higher (Yoo and Kwak 2010). One exception to this pattern is sub Saharan Africa, where only 27% of the households are electrified. The figure is far below the world's average of 73%. Additionally, people without electricity in the urban and rural side has doubled and tripled in the last 30years respectively. Within countries, the disparities between the urban side and rural side are even higher. For instance, in Ghana 62% of the urban areas have electricity but only 4% in the countryside (Wolde-Rufael 2006).

2.1.2.2.5 Electricity consumption according to household type

There is a trend in recent studies not only to characterize electricity consumptions from appliances as a whole, but also to include variables such as the type of household and demographic aspects. For instance, a study found that the average household consumption in Taiwan is 5537kWh/year. However, the difference in electricity consumption between houses and apartments can be up to 1800kWh/year. The analysis found strong correlation between floor areas and particular living habits in the country (Tsai *et al.* 2008). A study in Florida assessed the electricity consumption of 10 households with identical appliances. The results showed a considerable difference in the electricity consumption of the households. For instance, the consumption of the house with the highest consumption was up to 2.6times that of the house with the lowest (Wiggings *et al.* 2009).

The SEA Sweden project analyzed electricity consumption not only by household type, but also linked to demographic aspects. The analysis found that electricity consumption in family houses, with occupants in the age range of 24-64years, is around 4100kWh/year (water and space heating excluded). In contrast, consumption in apartments with similar demography is around 3700kWh/year. In the lower side of consumption, it was found that apartments occupied by single persons in the age range of 64years old and above consume only 1682kWh/year. In the overall, the project found there is a gap of 2400kWh/year between the electricity consumption of houses versus that of apartments (Zimmermann 2009). More appliances, bigger areas in houses along with behaviour, are part of the drivers behind the differences (Green and Ellegård 2007). In both studies, it is clear that measuring consumption is not enough to characterize electricity consumption. Type of household, demographics and behavioural aspects are also important factors.

2.1.2.2.6 Drivers of residential electricity consumption

Electricity consumption in households is a dynamic and complex process affected by several factors. Depending on the particular context, some factors become more or less relevant. Additionally, there are some factors that contribute either to increase electricity consumption or to offset or even reduce consumption in the overall balance. Among these are:

-Economic prosperity: Along with population growth, it is one of the main factors correlated positively with electricity consumption (Brown and Koomey 2003, Mohamed and Bodger 2005). Two aspects can be distinguished in this point: the *willingness to pay WTP* for more comfort (without concern of electricity prices) and upgrades and acquisition of new electronic appliances (Narayan and Prasan 2008). According to the IEA (2009), unlike the industry sector, households are less prone to be affected by the economic downturn when it comes to electricity consumption. This because people still needs to consume electricity for the different end uses (space heating, cooling, refrigeration).

-Penetration of appliances: This factor is linked to the above in the sense that economic prosperity usually represents more disposable income that can be used to acquire new appliances. In many countries, the use of electric devices for space heating and cooling is increasing. In the US central AC increased from 23% to 65% in the period 1978 – 2005 (Hutts 2009). In southern Europe there was an increase in electricity consumption between 1990-2005. According to (Bertoldi and Atanasiu 2009) the increased can be attributed to the use of AC. In many cases, the appliances are relatively inexpensive but not very energy efficient. Technologies such as LCD and plasma TVs, along with PCs and gaming devices are some of the appliances whose penetration has increased during the last years (Hutts 2009). Additionally, the size and hours of use have increased for some of them, such as TV sets and computers (ECCJ-JICA 2004, Bertoldi and Atanasiu 2009). Most of these appliances consume electricity not only in active mode but also in standby mode. In the case of lighting, rooms that were previously illuminated by single bulbs in the ceiling are being replaced by multisource lighting arrangements (DTI 2002).

-Increase in household area and housing units: In general there is a positive correlation between dwelling area and energy use. The bigger the dwelling is, the more energy needed to power AC devices and other electrical equipment and lighting. In the US, the average size of households increased from 151m^2 to 170m^2 between 1993 and 2007. (Hutts 2009). Along with the increase in the areas, new housing units are being constructed, with the subsequent demand of electricity.

-Energy efficiency and conservation measures: There are several measures in place in different countries ranging from mandatory energy efficiency standards of appliances, energy labelling, to insulation of buildings (Attali *et al.* 2009). This has contributed to increase the energy efficiency of appliance in the market. For instance, the most energy efficient fridge available in the market can use up to 75% less energy than one device sold 10 years ago

(Rudenauer 2006). The energy efficiency of an AC device has increased around 50% during the last 25 years (NEED Project 2008).

-User behaviour and interaction with products: User behaviour is a strong driver of electricity consumption but it can vary widely among households and appliances. For this reason, it is important to know why people choose particular technologies and use them in a way or another (Wall and Crosbie 2009). Most of these differences in consumption in households of similar characteristics (building composition and arrangement of appliances) can be attributed to particular user behaviour patterns (Hutts 2009). For instance, the use of high temperatures in washing machines when it is not required (Atanasiu and Bertoldi 2008). In this sense, while monitoring of appliances can provide valuable data on electricity consumption, an integral approach addressing behavioural aspects is necessary to target users and buyers of electrical appliances (Green and Ellegård 2007). This is the approach used by some of the most recent projects analyzing electricity consumption in residential buildings, such as REMODECE in the EU, SEA in Sweden and HEEP in New Zealand.

-Declining in number of household occupants: In some countries, the number of occupants living in households has decreased over time. In the US, between 1969 and 2007 the average number of occupants in households went from an average of 3.2 to 2.6 (Hutts 2009). For some authors, the fewer occupants, the less is the consumption. However, fewer people living in bigger households (dwelling are per capita increase) represent the opposite: the larger the area the more demand for heating/cooling (Zacarias and Geyer 2003). Another argument to support the latter claim comes from the increase of one-household person. An increased life expectancy in developed countries have resulted in more older people living alone. For instance, in the UK the amount of electricity required by two people living in individual dwellings is higher than the two living in the same household in the 75 year old age class and above (DTI 2002).

-Climate: Considering that an important share of the electricity consumption is attributed to space heating and cooling, climate plays a relevant role in the kind of appliances used to create comfort. In southern Europe, the use of AC and other devices (e.g. electric fans) are also important end uses especially during the summer months (Sidler *et al.* 2002). In regions of rapid economic growth such as in India and China the use of electric fans and AC devices has increased (Zhang 2004, Pachuari 2009). In Hong Kong, located in a subtropical area, the most important end-use is air conditioning. It accounts up to 59% of the final electricity consumption during the summer months. During the wintertime, the value is reduced to just 23%. Because of the high summer temperatures even at night, most of the consumption takes place from 19:00 to 07:00, when people is at home and turn the air conditioning on (Figure 7) (Geoffrey et al. 2003).

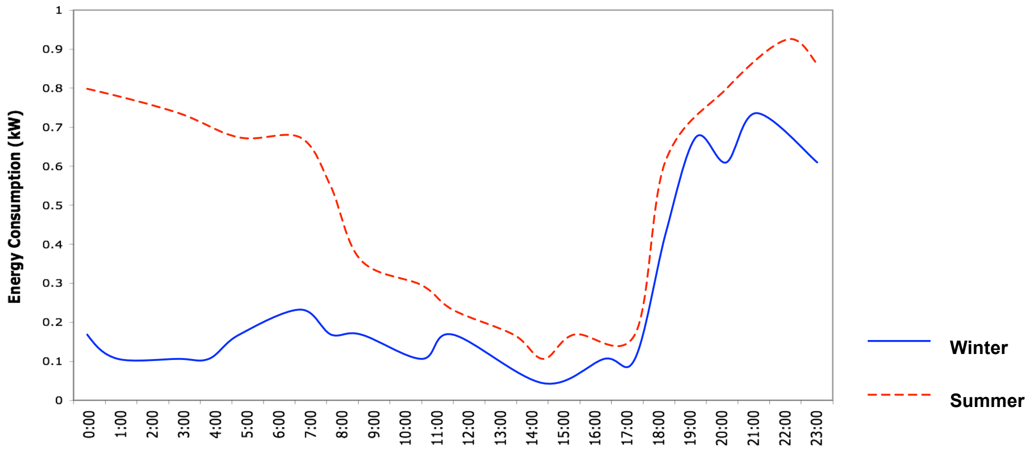

Figure 7. Electricity consumption in a typical household in Hong Kong during an average day in winter and summertime. Adapted from (Geoffrey et al. *2003).*

2.1.3 Energy conservation opportunities

In order to identify electricity conservation opportunities, it is important to know how people use electricity in households. The analysis of end-use metering data constitutes the starting point to identify end uses with the largest consumption, and those with the largest saving potential (Brown and Koomey 2003). In the EU, the appliances with the largest energy saving potential include: lighting (domestic, street and office), TV sets and appliances with standby consumption (EC JRC 2009). However, in the case of cold and washing appliances there are still some differences between the EU15 and new member states[7]. Although the sales of efficient equipment in these new member states have reached similar rates to those of EU15, many of the existing appliances in households are inefficient and outdated. Around 40% of the fridges and 50% of the washing machines are 10years old or above (Atanasiu and Bertoldi 2008). In general older appliances have lower energy efficiency. For this reason, they constitute an opportunity for electricity conservation. Energy efficient technologies and replacement of outdated equipment must therefore, be promoted (Atanasiu and Bernoldi 2008).

Similarly, lighting represents a relevant end use for electricity conservation. Inefficient incandescent bulbs are still dominant in households, despite the availability of energy efficient options in the market. It is true that there are some barriers such as information and price. However, even when the barriers are overcome, it seems that consumers still prefer the use of incandescent. The EU and

[7] New member states refer to countries that joined the EU in 2004. These include Hungary, Czech Republic, Slovenia, Slovakia, Poland, Malta, Cyprus and the Baltic States (Latvia, Lithuania and Estonia).

some other countries are phasing out of energy inefficient light sources. In the US, a bill was signed in 2007 to phase them by 2012. Other countries such as Australia and Canada have similar plans (Waide 2010). In the case of the EU, the phasing out began in September 2009. The process will progressively remove inefficient lights sources from the market, based on their energy performance (DEWHA 2008).

Standby consumption constitutes a third opportunity for electricity saving. Most ICT equipment consumes electricity when is not performing its main function. In the EU, the Regulation EC 1275/2008, that implements the Directive 2005/32/EC on ecodesign requirements, established the requirements for power consumption in standby and off modes of electrical and electronic equipment in household and office equipment. According to the regulation, annual electricity consumption derived from off and standby power during 2005 was 47TWh, representing 19Mt of CO_2 emissions. With the implementation of the Regulation, the EU is expected to reduce up to 75% the standby consumption of these products by the year 2020.

2.1.3.1 Residential monitoring of appliances

The approach to analyze electricity consumption in households at national level can be divided in two types: studies or projects in which electricity consumption in households is estimated (Type I) and projects that based the analysis on actual measurement in individual appliances (Type II). Below there is a brief description of the main projects:

2.1.3.1.1 Recent projects

One of the examples of Type I approach is the Residential Energy Consumption Survey (RECS)[8] in the US. It is a national survey that has been carried out in the US since 1978. In 2005, the last year the survey took place, 4382 households were surveyed on aspects regarding housing unit characteristics, appliances (type, power, patterns of use, among others) and socioeconomic aspects (USDOE-EIA 2005). Each of these households is assumed as representative of over 30000 similar households in the country. These surveys are designed in a way that socioeconomic aspects such as income, level of education, occupants, behavioural aspects, among relevant aspects are included (USDOE 2009). Usually the individual consumptions from appliances are estimated using statistical tools employing the data from the surveys (USDOE-EIA 1998). This reduces costs, as no equipment is required for the estimation (Larsen and Nesbakken 2002). In general, the data estimated in this way can be used to describe the patterns of electricity consumption as well as for other purposes. The methodology

[8] The Energy Information Administration (EIA) a governmental office, part of the US Department of Energy carries out the survey with a periodicity of between 3-4 years. The next RECS survey will be carried out this year, with an increased number of samples: 19500units (USDOE 2009).

used by RECS has been replicated and adapted in other contexts, such as in Hong Kong, where electricity consumption from 1500 households was analyzed by Geoffrey *et al.* (2003).

In the case of Type II approach, measurements from individual appliances are recorded automatically every 10minutes during intervals that go from 1month to 12months (depending on the objectives. For instance, to analyze seasonality a 12month monitoring would be needed (Isaacs *et al.* 2009). This high-resolution data is complemented with a survey, similar to that in Type I. This kind of studies are one step forward of those Type I in the sense that, besides the description of electricity consumption patterns, the analysis of potential electricity savings and standby can be made with more accuracy. It is a relevant aspect to promote new policies or enhance existing ones. The most recent examples of this kind of approach carried out at national level, are found in the EU: EURECO, REMODECE[9] and the SEA Sweden project. Outside Europe, New Zealand's (HEEP) is one the most comprehensive analyzing not only household electricity but also other energy consumptions. Table 3 provides a summary of the project's main features.

Table 3. Summary of the most recent projects monitoring electricity consumption from appliances in households

	EURECO[1]	REMODECE[b]	Sweden –SEA-[c]	HEEP[d]
Country	Denmark, Greece, Italy, Portugal	12 European countries (11 EU[10] + Norway)	Sweden	New Zealand
Responsible for the study	ENERTECH	University of Coimbra[11] (coordinator)	Swedish Energy Agency	FRST and BRANZ*
Year	Jan 2000 – Jun 2001	2006 - 2008	2005 - 2008	1999 -2005
Monitored households	100 per country	100 per country(1300 in total)	400	399
Period of monitoring	All monitored 1 month	Between 2-4weeks per household	360 hh monitored 1month 40monitored 1year	All monitored 1year
Complementary survey	yes	yes, 6000 in total	yes	yes

a. (ENERTECH 2006, Sidler *et al.* 2006) b. (ISR-UC 2008, De Almeida and Fonseca 2008, De Almeida *et al.* 2009, EACI 2008) c. (Benich and Persson 2006, Zimmermann 2009) d. (Camilleri, 2009, Isaac *et al.* 2004, Isaacs *et al.* 2009). *Foundation for Research Science and Technology and Building Research Association of New Zealand.

In general, the motivations to carry out these projects include:

[9] Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe. Considering that most of the data comes from this EU project, a further overview is provided in the Methodology as part of the data collection.

[10] Belgium, Bulgaria, Czech Republic, Denmark, France Greece, Germany, Hungary, Italy, Norway, Portugal, Romania was among them.

[11] Partners of different type: universities, energy agencies, research institutions. In the case of Hungary, the coordination was in charge of the Central European University.

-**To Increase the understanding of electricity consumption:** Statistics on the electricity consumption from appliances (measured or estimated) along with information collected in surveys, allows having a better understanding on how electricity is used. In projects such as EURECO and REMODECE, since protocols to collect information are standardized (De Almeida *et al.* 2009), the comparison between participating countries is possible.

-To identify potential energy savings: It is possible to determine the potential energy savings from appliances (Hutts 2009). This is particularly true for the European studies (EURECO, REMODECE and SEA Sweden). The energy savings constitute an argument for supporting policy interventions directed to specific appliances (refrigerators, TVs, among others) (EACI 2008, Zimmermann 2009). Energy savings are relevant in terms of environmental impact since a reduction in consumption (without compromising comfort levels), can help to reduce greenhouse gas emissions. This is especially relevant in places in which the production of electricity heavily relies on coal and other fossil fuels (UNDESA 2007).

-To improve statistics: In many cases, most of the information used for the management of aspects related to electricity in households (from the planning of the supply to the introduction of policies for energy efficiency) is outdated or absent (Issacs *et al.* 2006). The importance of having reliable statistics is also highlighted outside these projects. In 2008, the Department of the Environment, Water, Heritage and Arts of Australia, express the need of having updated information: *there is a desperate for ongoing collection of much more comprehensive end-use metering data to underpin policy analysis, program development and future research…"* (DEWHA 2009)

-Further research: Most of these projects generate reports presenting the main findings after an initial analysis. However, the benefit of the generated information continues after completion. The databases containing the records from the metering (Type II) and data from the surveys (Type I and II) are in general, available at no cost for different stakeholders. More in depth analysis can be made to deepen the knowledge in aspects found in the initial reports (this is the case of the present study). These projects are expensive and demand time (Hutts 2009, Larsen and Nesbakken 2002). As it is presented in Isaacs *et al.* (2006) the value of the project is not appreciated until the data is collected.

2.1.3.1.2 Main findings of recent monitoring initiatives

When space and water heating are excluded, cold appliances are the most consuming end use in households. The sole exception is Sweden, in which lighting is the most electricity consuming end use (Zimmerman 2009). According to the EURECO project, an average refrigerator in Greece consumes up to 40% more electricity than one in Denmark (Sidler *et al.* 2002). In New Zealand, around 70% of the households use electric cylinders to heat water, a level of penetration that is probably one of the highest in the world (Camilleri 2009). Of the four projects, SEA Sweden is the only that provides a stratified description of the electricity consumption in households. This is, the average consumption for household type, occupants, and age class among others. As it can be seen in Table 4, there is a considerable gap between the electricity consumption in apartments (2139kWh/year) and houses (4143kWh/year).

In the case of standby, in all cases it constitute between 10-11% of the final electricity consumption in households. Entertainment equipment (TVs, set top boxes, stereo systems) and computers are the main standby energy consuming appliances. Both the description of electricity consumption and standby are the baseline scenario for the calculation of energy savings. With the exception of the HEEP project, the others compared the obtained baseline scenario with the consumption that would be obtained using the best available technology (BAT). For instance, the use of cold appliances in A+ and A++ categories, the replacing of incandescent bulbs by CFLs, use of laptops instead desktops, reduction of standby setting maximum values (Zimmermann 2009). The REMODECE project was the only that calculated the impact of the savings in the reduction of emission as it is presented in Table 4.

Table 4. Summary of the main findings of recent monitoring projects in the residential sector.

	EURECO	REMODECE[b]	SWEDEN SEA[c]	HEEP NZ[d]
Breakdown of EC* (main end uses)	Fridge – freezer: 17% Freezer: 14% Refrigerator: 10.1% Clothes Dryer: 11% Lighting: 10%	Refrigeration: 28% Lighting: 18% Washing/Drying: 16% Office equipment: 12% Cooking app.: 11% Entertainment: 10%	Lighting: 26% Cold Appliances : 22% Cooking appliances: 12% Washing/Drying: 7% TVs: 4%	Refrigeration: 27% Lighting: 23% Entertainment: 18% Kitchen: 9%
Total Annual EC kWh/household (excluding water and space heating)	3492	2695 (average participating countries)	Apartments: 2139 Houses: 4143	3588
Standby: Share of the final EC in households (%)	12	11	11	10
Calculated annual energy savings (kWh/household) by using Best Available technology (BAT)	Between 1000 and 1200	1300	Between 600 and 1800	Not calculated but opportunities for savings were identified
Electricity saving potentials on specific appliances or end use*	**Standby: 33%** Cold appliances: 29% Lighting: 22% Clothes washers:16%	**Standby** Mitigation/elimination up to 48% of the savings	**Combined savings from:** cold appliances, lighting and computer sites: 75% of the total savings	
Environmental impact of the savings: GHG emissions	Not calculated	165TWh/year** 72million t of CO_2 avoided (165TWh/year) 268TWh/year*** 116million t of CO_2 avoided	Not Calculated	Not Calculated

a. (ENERTECH 2006, Sidler *et al.* 2006) b. (De Almeida and Fonseca 2008) De Almeida *et al.* 2008, De Almeida *et al.* 2009, EACI 2008) c. (Benich and

Persson 2006, Zimmermann 2009) d. (Camilleri, 2009, Isaac *et al.* 2004, Isaacs *et al.* 2009)*Comparing baseline conditions with best available technology –BAT- **Aggregated value for the 12 participating countries (EU12) ***Extrapolated value for the EU27

In relation to the energy savings, EURECO and Sweden SEA found that for *cold appliances* the values are not as high as expected. This is probably due to the fact that in Europe, most of the devices in the market are now in the most energy efficient categories (e.g. A, A+, A++) (De Almeida *et al.* 2009). *Air conditioning* use has been increasing its penetration, especially in Mediterranean EU countries. Most of the devices are inefficient according to the studies (Sidler *et al.* 2002). In the case of *lighting*, even when there has been a penetration of energy saving devices such as CFLs, and informative policy tools are in place (energy label and appliance standards) inefficient incandescent bulbs still dominate the households. In the case of the EU, a more drastic approach is being taking: as indicated previously a progressive ban of inefficient light sources began in September 1 2009[12]. This can be an indicator that existing policies in place were not the good enough to promote a market transformation towards more efficient devices.

2.2 Hungary: Energy facts

This section presents a description of the main aspects related to energy for the Hungarian context. It includes a brief reference on the production (sources, emission, among others) and then the focus is put on the electricity consumption, with emphasis in household electricity consumption.

2.2.1 Energy Sources

Hungary depends heavily on imported primary energy sources to meet its needs. Only 32% is covered using domestic sources, while the remaining share is imported (EC 2007, IEA 2010). Between 2000 and 2007, the level of dependence grew from 57% to 63%, a figure above the EU27 average (52.3% in 2007) (HCSO 2008). Natural gas and oil constitutes the main energy sources imported to the country, mainly from Russia (EC 2007). Between 1990 and 2004 natural gas use increased by 31%. This increase has supposed a reduction in the share of solid fuels such as coal. When it comes to renewables, despite a rapid increase following the country's accession to the EU, their share in the primary energy use of the country (5.3% is still below that of the EU27 (7.8%) (HCSO 2009e). Among renewables, 74% of the energy is produced using biomass and biogas (HCSO 2008). The rest is distributed more or less evenly between wind and hydropower. It is important to highlight the changes in the shares: in 2000, 63% of the renewable energy was produced using hydropower while only 4% using biomass and biogas (HCSO 2010).

[12] Regulation EC 244/2009 (March 18th, 2009)

2.2.2 Electricity generation

In 2008, domestic power stations generated 40026GWh of electricity. Natural gas and nuclear energy were used to produce three quarters of the total (HCSO 2010). Coal is the third largest energy source used for electricity generation (Figure 8) (IEA 2008). When the period 1973 – 2008 is analyzed the most significant aspects are the reduction in the use of coal and oil to produce electricity in the country. These two fuels have been gradually displaced by the use of natural gas (EC 2007). Nuclear energy constitutes the most important domestic energy source, with an important share in the production (37%) (EC 2007). Unlike the previous, hydropower is probably the most stable energy source during this period. Its share has been fluctuating between 0.1 and 0.2TWh per year (HCSO 2008, IEA 2009). Finally, the increase in the use of renewables is notorious after 2004, driven specially by the use of biomass and biogas. The volume of electricity produced from these fuels grew from 7.6GWh in 2001 to 47GWh in 2007, with a share of 4.6% in the electricity production in 2005 (HCSO 2008).

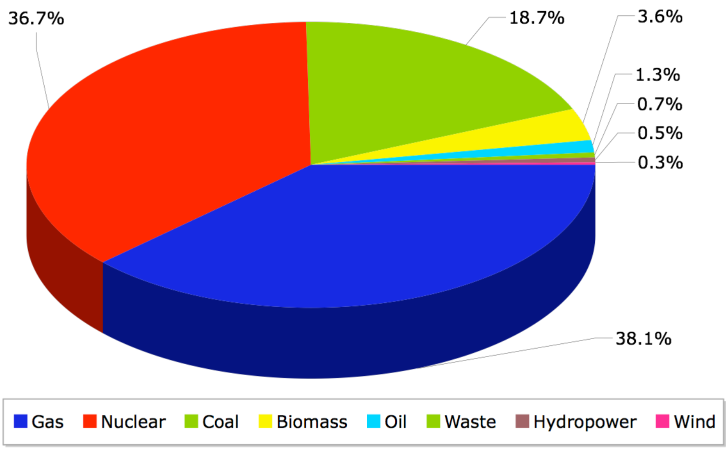

Figure 8. Electricity generation by fuel type in Hungary. Left. Generation in 2007. Elaborated using data from IEA (2008) and IEA (2009).

2.2.2.1 Energy related emissions

Under the Kyoto Protocol, Hungary is committed to cut by 6% its GHG emissions in the period 2008-2012 compared to 1990 levels (HCSO 2008). Between 1990 and 2007, CO_2 emissions decreased by 20% (from 72.5 to 57.8million tonnes). This means, the country is in compliance with its commitments to the protocol in relation to CO_2 emissions (HCSO 2010). When compared with the EU27 figures, Hungary's emissions represent 1.35% (54Mt of CO_2 eq) of the total EU27 emissions (4004Mt CO_2 eq). The emission per capita (5365Kg CO_2) is well below the average of the EU27 (8180Kg CO_2/capita) (EC 2007). In 2005, the total GHG emissions produced by the different economic activities in the country accounted by 80.20Mt of CO_2 equivalent. Among them, energy production sector was responsible for 17.9Mt of CO_2 (22%) (HCSO 2008). In 2007, the residential sector emitted 14.4% of Hungary's CO_2 emissions (Figure 9). However, the largest emission sources are power stations with 36% of the final share (20.4Mt of CO_2). Among these, combined Heat and Power plants (CPH) produced 22.4% of the electricity used in the country during 2006. An important fraction considering that GHG emission from CHP plants is approximately less than half per unit of electricity in comparison with traditional power plants (HCSO 2009d).

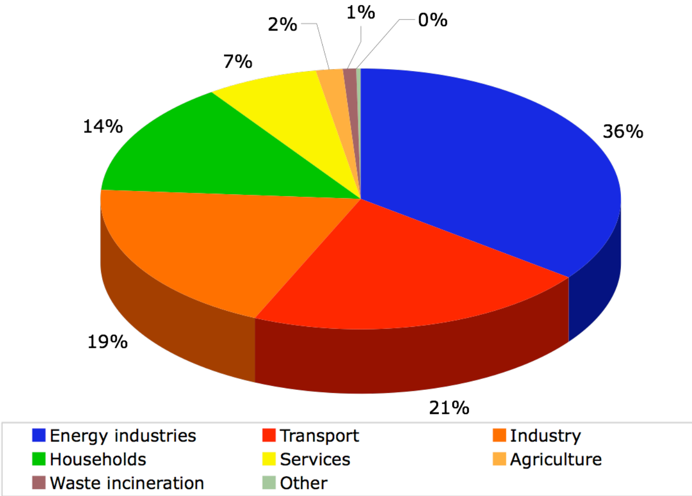

Figure 9. CO_2 emissions per sector during 2007. Adapted from HCSO (2008)

2.2.3 Electricity consumption

In 2008, the Hungarian residential sector consumed 36% (400PJ) of the total primary energy use, second only to industry (37.8%) (HCSO 2009e). However, when only the final electricity consumption is analyzed, the panorama changes. The Hungarian residential sector (Figure 10 right) accounts for one third of the electricity consumption in the country (33.3%), followed closely by the commercial and service sector (32.2%) (IEA 2009). This share is relatively higher than that of the EU, which is 26% (EC 2007). Taking together, households, commercial/service sector and industry sectors, the electricity consumption represents up to 94% of the total. The above description provides a recent overview of the final electricity consumption in the country. However, it is interesting also to see the evolution over time. For instance, the final electricity consumption almost doubled between 1973 and 2007 (from 16.7GWh to 33.7GWh, respectively) (IEA 2009). Along with the overall increase, the share in the final electricity consumption has drastically changed in some sectors as result of the economic transformation of the country. For instance, in the early 1970s the industry sector was the largest electricity consumer (Figure 10 left). However, with a economy moving towards the service sector, the increase in the number of households and new appliances in Hungarian homes, the weight of these sectors in the final consumption rose notably.

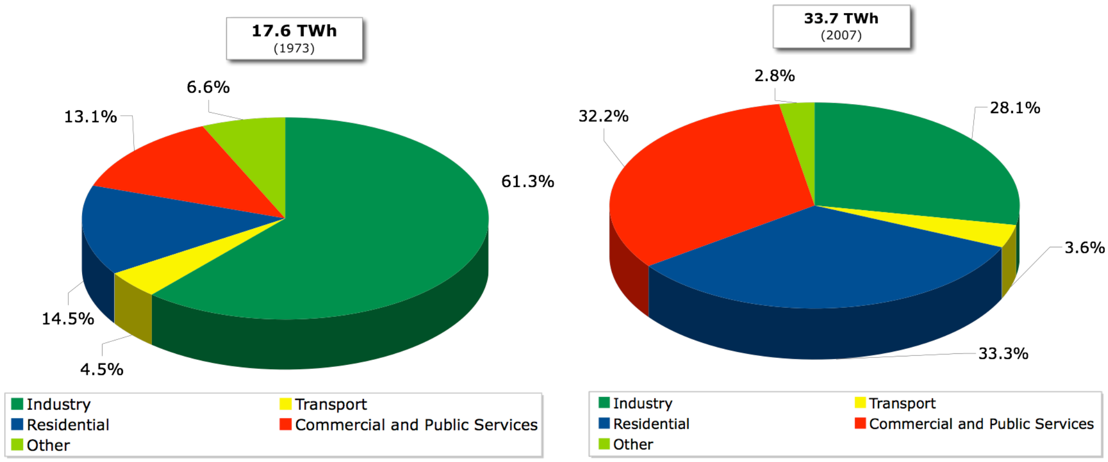

Figure 10. Final electricity consumption in Hungary in 1973 (right) and 2007 (left). Elaborated using data from IEA (2009)

2.2.3.1 Household and energy expenditure

In the EU15, housing and household energy constitutes the most important component of the household expenditure (28.4%), followed by food and non-alcoholic beverages (13.5%). Conversely, in Hungarian households, the expenditure on food and non-alcoholic beverages occupies the first place (22.6%), while housing and household expenditure is the second (19.4%). This difference is attributed to the fact that in western Europe the number of tenants paying rents is higher than in Central and Eastern Europe where most people live in privately owned households (HSCO 2009c). For instance, in Hungary 87% of the dwellings are occupied by their owners, while tenants occupy only 7.2% of the dweelings. (HCSO 2007). Among the category of housing and energy expenditure, the largest proportion corresponds to heating. Considering the type of household, detached houses pay almost twice the value paid by a unit in a building (apartment) (HCSO 2009a). As with the other states that joined the EU in 2004, the electricity consumption per capita of Hungary is still below the average of that of the EU. The low level of appliance penetration compared to that of the EU15 is one of the main factors. However, the sales of new appliances are becoming more similar to Western Europe (Atanasiu and Bertoldi 2008). For instance, in 2004 the sales of washing machines in energy efficient class "A" was 71.2% in the EU15, while in Hungary it was 70%. In the case of fridges, the sales of equipment rates "A" was 56%, while in Hungary, the share for the appliances in the same "A" class was 52%. The exception of this patterns is freezers: in the EU15 the sales of appliances in A classes (A and A+) was 47% while in Hungary the sales of these appliances in A classes (A and A+) was only 16% (Soregali 2004).

2.2.3.2 Residential electricity consumption

In 2007, Hungarian households consumed 10945 million of kWh (around one third of the total consumption). Household electricity consumption grew by 19% during the period 1990 - 2007 (IEA 2009, HCSO 2008). Along with the commercial/service sector, the residential sector was the only to maintain an increasing trend over time: average of 7.8% per year during 1973-1990 and 1.2% between 1990 and 2007 (Figure 11) (IEA 2009). Some of the factors to explain the growth after 1990 include: increase in the household stock plus the expansion of the electricity network to holiday homes or weekend houses (HCSO 2008).

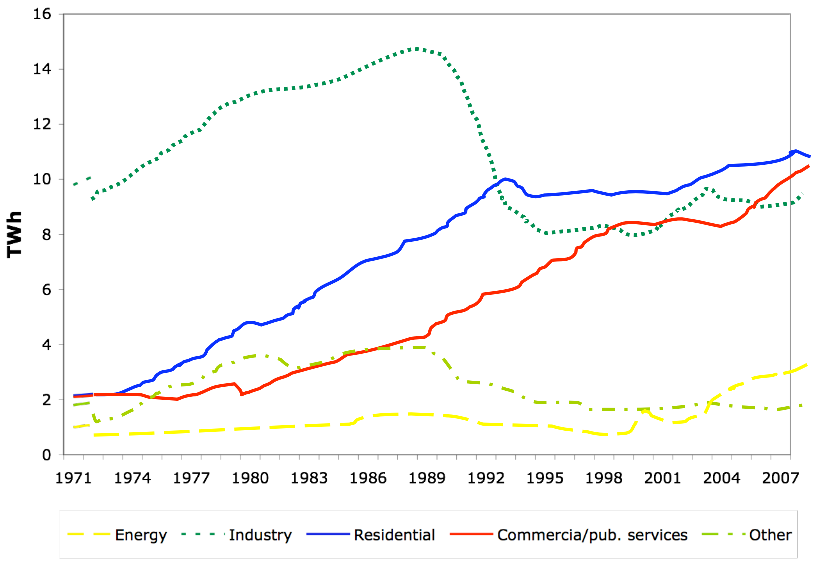

Figure 11. Electricity consumption by sector in Hungary. Period 1971-2007. Elaborated using data from IEA (2009)

Additionally, increase in the number of electric appliances and change in their use patterns constitutes one of the main factors for the augment in electricity consumption. For instance, washing machines that use electricity for warming water, TV sets with larger sizes and people watching for more hours (Atanasiu and Bernoldi 2008, HCSO 2008). The rapid penetration of ICT is important for two reasons: more appliances in households represents more electricity consumption. Secondly, most of these equipment consume electricity even when not performing its main function (for instance in standby mode). Entertainment equipment (TVs, DVDs, HI-FI systems, among others) and office equipment (PCs, laptops, printers, among others) are among the appliances that are rapidly increasing its penetration in Hungarian households (HCSO 2008, EC JRC 2009). As the saturation level of these appliances in many cases is still low (e.g. dishwashers and laptops), it is expected that electricity consumption will increase in the country from the residential sector.

Considering that penetration of appliances is a function of the disposable income, among other factors, the presence of certain appliances is far from being uniform. For instance, appliances such as

TV sets and DVDs are relatively common in Hungarian households with similar penetration rates (Table 5). However, the penetration of other appliances is considerable higher in households with higher incomes (HSCO 2009a). For instance, the PC penetration rate in the highest income decile is almost twice the one in the lowest income decile. Dishwashers have in general a low penetration in the country (7%), but penetration in high-income households is up to five times higher than in low-income households. Laptop penetration is six times higher in the highest income decile. Table 5 present the penetration rates for selected appliances in the higher and lower income categories along with the average for Hungarian households (HCSO 2009a).

Table 5.. Appliance penetration rates in Hungarian households for the highest and lowest income categories (in appliances per 100households). Adapted from HSCO (2009d).

Appliance	Lowest income decile	Highest income decile	Average Hungary
TV set	133	149	148
DVD player	48	50	43
PC	38	65	46
Dishwasher	3	14	7
Laptop	3	16	6

3. Methodology

The goal of this work is to analyze how is electricity used in Hungarian households. This study determines the electricity consumption of the typical Hungarian household. To reconstruct the typical household, it is necessary to have the consumption of the typical appliances. The consumption of the typical appliance is obtained from the data gathered on individual metered appliances by the REMODECE project in the country. As not all households in the country have the appliances, it is important to consider the penetration rates. It is defined as the number of one specific appliance per 100 households. For instance, a penetration rate of 0.95 for TV sets means there are 95 unites per 100 households –virtually all households own the appliance.

By combining penetration rates with the consumptions from the individual appliances it is possible to define the electricity consumption in the typical Hungarian household. From this approach the individual contribution of each appliance to the consumption of the typical Hungarian household can be identified. This is the so-called present state (Grinden and Feilberg 2008). With the reference state it is possible to identify the opportunities for electricity conservation that can be obtained by using, for instance the best available technology (the most energy efficient appliances) in households. Additionally, the analysis based on monitored appliances allows the determination of the power consumption in different power levels. This is, how much electricity is consumed when the appliance is switched on or off. For appliances in the ICT category (e.g. TVsets, computers), the consumption in modes other than the normal (on mode) are important (e.g. standby). As presented in the literature review, standby consumption is increasing in European households, due to the higher penetration of appliances (especially electronics).

In summary, the methodological concept is used in the analysis of electricity consumption in Hungarian households include: the reconstruction of the electricity consumption of typical Hungarian household (obtained from the monitored appliances and the appliance penetration rates). This present state is the reference to identify potential for electricity conservation by using energy efficient equipment. The analysis of the power use in ICT equipment, as the main source of stanby consumption, is made to identify what is its contribution to the typical Hungarian household.

The base of this methodological context is the analysis of the of the monitoring campaign that was part of the REMODECE project. In this sense, this results of this work complement the previous works that have analyzed the results of the REMODECE project in Hungary, and ultimately the entire project. Considering the importance of the data gathered by REMODECE (Hungary) to carry out this study, a description of the project is provided below.

3.1 Data collection

The data used in this study comes from two main sources: the REMODECE project and the Hungarian Statistical Central Office (HCSO). Considering that the base of the study is the data analysis from this EU project, an overview is presented below:

3.1.1 REMODECE Project

The Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe (REMODECE) was a project funded by the Intelligent Energy Europe programme. It involved the participation of 12 European countries between 2006 and 2008 (Hungary was one of them). The aim of the project was *to increase the understanding of how electric/electronic equipment is used in European households* and *to assess the potential electricity savings by the use of more efficient appliances and by reducing standby*. The results are also important as a base for the development of more energy efficient appliances. Additionally, the project helped to update the European database on household consumption. Prior REMODECE, the information on household electricity consumption in some European countries, such as those of CEE (including Hungary) was scarce or absent (IEE 2008). The project has an integral approach: it combines the metering of individual appliances in real working conditions (monitoring campaign) and a consumer survey (hereafter, REMODECE survey) (Fonseca *et al.* 2009). The features of these two components are presented below.

3.1.1.1 Monitoring campaign: metering appliance electricity consumption

The REMODECE project defined a standard methodology for participating countries in order to harmonize data collection and make results comparable. Considering there is a myriad of electrical appliances that can be found in a household, one of the first steps was the definition of the main end-uses and appliances to monitor. In the case of CEE countries, the monitoring campaign was focused on cold appliances, washing machines, lighting, new electronic loads and other equipment with standby power. The reason lies in the fact that the information available on residential consumption from these end uses is scarce for these countries (Fonseca *et al.* 2008). The monitoring data allows the identification of the energy demand as result of both user behaviour and characteristics of the appliances. Additionally, it constitutes the base for identifying opportunities for electricity conservation, as it shows a reference condition (Present state)

(REMODECE n.d.). Table 6 shows the end-uses and the main appliances selected for monitoring.

Table 6. End uses and appliances selected for monitoring.

END USE	APPLIANCES
HOME ENTERTAINMENT	TV sets (LCD, CRT)
	Home cinema, HI-FI
	VCR, DVD Player
	Set Top Boxes
	Video games
OFFICE EQUIPMENT	Printer, Fax
	Router, Modem
	Speakers
	Laptop
	PC (Desktop & Monitor)
COOKING APPLIANCES	Microwave over
	Oven
	Electric kettle
	Coffee maker
WASHING APPLIANCES	Dishwasher
	Washing Machine
COLD APPLIANCES	Fridge with freezer
	Fridge without freezer
	Freezer
MISCELLANEOUS	Iron, Hair dryer, vacuum cleaner, phones among others
LIGHTING	Incandescent
	Low wattage halogen
	High wattage halogen (>70W)
	Fluorescent
	Compact Fluorescent Lamp CFL

A team of the Central European University between 2006-2008 coordinated and carried out the monitoring (The timeline is presented in Appendix III). Between 5 and 10 major electrical appliances and an average of 10 light sources were monitored in each household at 10min intervals. Wattmeters and lampmeters[13] were used to record power consumption from electrical appliances and light sources respectively. Once installed, the monitoring devices were left for a period of at least two weeks. However, in some cases, the appliances were monitored between 3-4 weeks. In this type of monitoring process, the more observations the better to capture diversity of power use in households. After the period is completed, the data is downloaded from the metering devices for treatment and analysis. The organization of these data is a time demanding

[13] Unlike lampmeters, which record consumption in Watts, these devices monitor the time in seconds in which the light source is on. The power use is calculated by relating time and power of the light source.

process considering the high volumes. For instance, there are 10min records for every single appliance, which means 144 records per appliance per day. Assuming a minimum of 5 appliances and 7 light sources monitored per household during 14 days (2weeks), the quantity of available records for one single household is around 24000. The monitoring campaign involved the participation of 75households located in Budapest and agglomeration area.

3.1.1.2 REMODECE survey

Along with the monitoring campaign, the project applied a survey in around 400 households across Hungary in a process carried out by a market survey company. This survey was also applied to the monitored households. The purpose of the survey was to gather data on end-use behavioural patterns, information on appliance penetration and technical related features (e.g. type, age, energy efficiency level). The analysis of the data performed by Boza-Kiss *et al.* (2009) for Hungary revealed trends in relation to the penetration of new appliances (e.g. dishwashers) and improvement in the energy efficiency level of appliances in the country. The database created to analyze the information of the REMODECE survey constitutes the base for the determination of appliance penetration rates for major appliances and light sources in this study. This information is relevant for the characterization of the average Hungarian household electricity consumption, as presented later.

3.1.2 Data from HCSO

The Hungarian central statistical office (HCSO) has a complete database on the level and structure of household consumption in Hungary. The Living Standard and Labour Statistics (LSLS) provides detailed information on housing conditions, consumer durables[14], household composition and income. This information is important since it provides among others, the appliance penetration of the major electrical appliances in Hungarian households. This data is representative of Hungary and it was collected during 2007 (coincidentally, the year in between the REMODECE project). In this sense, this data is coherent with that of the REMODECE project in temporal terms.

[14] According to HCSO (2010), the category *consumer durables* makes reference to electric and electronic appliances present in Hungarian households.

3.1.3 Representativeness of the data

As the present study aims to provide an analysis of electricity consumption patterns in the average Hungarian household, the representativenes of the data is of prime importance. As presented above, there are three main data sets used for this research.

3.1.3.1 Household selection

The REMODECE project select two sets of households for particular purposes: monitoring individual appliances and application of the survey. Table 7 shows the main features of each data set.

Table 7. Features of the samples taken under the REMODECE project.

	DATA SET 1 Monitored households	DATA SET 2 Surveyed households
Number of households	80	400
Sampling method	Non random sampling	Random sampling
Representativeness	Restricted to the sample	National
% Houses/apartments	30/70	50/50
Household size (individuals per household)	2.8	2.48
Household size (m^2)	72.4	77

In dataset 1, the method to select households was non-random sampling. As presented in Loftus *et al.* (2009) the sample for the monitoring campaign was based on personal contacts and contact of contacts. In this sense it cannot be considered as representative of the entire population (Hungarian households). The reasons for this selection process in the project include: willingness to participate (there should be an explicit allowance from the occupants to install the metering devices in their households), cost effectiveness, time constraints for a random selection, among others. However, the project aimed at selecting households with high ownership of appliances (in this sense, the selection of the households is not entirely non-random). This is important since a high level of appliances in households allow increasing the number of monitored appliances. In a process like this, by increasing the number of monitored appliance it is possible to include a higher variability of use patterns. Previous studies have shown that the electricity consumption from monitored appliances is highly variable among appliances of the same type due to use patterns, energy efficiency of the appliance, among other factors (Isaacs *et al.* 2006, Zimmerman 2009).

All selected households are located in Budapest and agglomeration area. One of the main differences with dataset 2 is the proportion apartments and households in the sample. As presented in Table 7, single houses constitute 30% of the sample. In dataset 2, the proportions are even (50-50). In terms of dwellings average area, dataset 1 has a lower value (72.4m). This is probably due to the fact that 70% of the households in the sample correspond to apartments. An additional factor to consider is that in general, income and education levels are higher in the capital compared to other regions (Boza-Kiss *et al.* 2009). Considering the above, a direct extrapolation of the results to the national would result in skewed results.

A specialized market survey company used quota-based sampling method to recruit households for the application of the REMODECE survey (dataset 2). The variables used to match the entire population (Hungarian households) were size of town, sex and age of the respondents. Doherty (1994) states, that the method requires good data on the entire population, such as the distributions of the variables to set the quotas. The sample was selected from a representative list of Hungarian households for face-to-face interviews (Boza-Kiss *et al.* 2009). Considering these two aspects, households and variables to set the quotas, the selection is regarded as representative of the Hungarian context.

3.1.3.2 Appliance penetration data

The appliance penetration rates for Hungary were determined using two sources: the REMODECE survey and data from HCSO. The representativenes of the survey was discussed above. The data of the HCSO is considered representative of the Hungarian households. The HCSO uses a stratified, multi-staged sample selection procedure in which the unit of analysis is the private household. As it is the case with this type of sampling, a paper-based questionnaire is applied via face-to-face interview. The survey covers aspects such as living standards of the household, income and ownership of goods. The last category includes the major electrical appliances present in Hungarian households. A total of 2154 households were sampled as part of the so-called Household Budget Survey –HBS-. Similar approaches for household sampling are used in the US (RECS survey), SEA Sweden and HEEPS New Zealand (Zimmermann 2009, Isaccs *et al.* 2006, USDOE 2009, EIA 2005b).

3.2 Data Analysis

This section presents the procedures followed to determine the *average Hungarian household power use* and the *analysis of different power levels for ICT equipment*. From the analysis of these two parts, it is expected to identify opportunities for electricity conservation. Figure 12 shows a basic scheme of the main components of the data analysis.

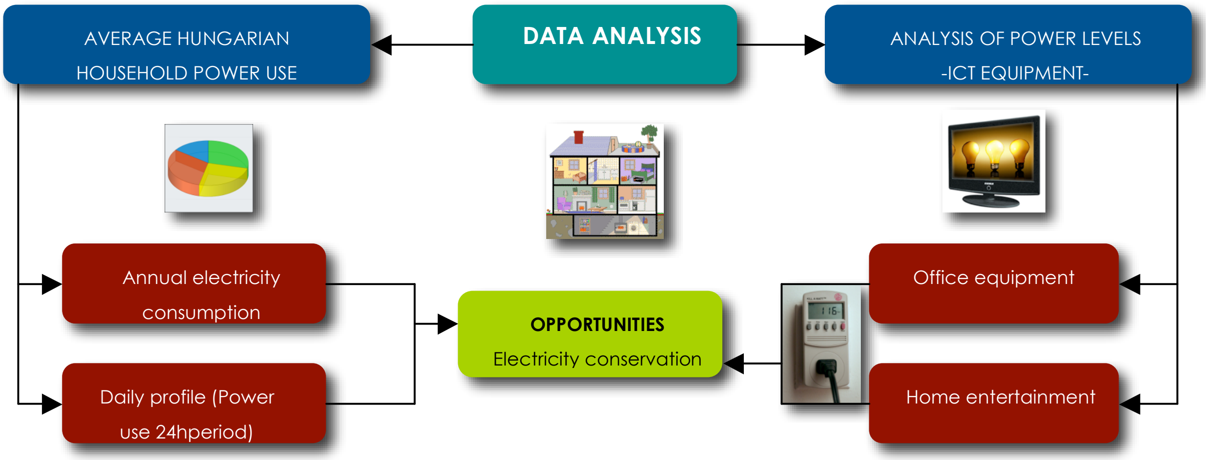

Figure 12. Main components of the data analysis.

3.2.1 Average Hungarian household power use

There are two basic inputs required to determine the average Hungarian household electricity consumption: –*averaged appliance electricity consumption*- calculated from the data gathered during the monitoring campaign and the country's specific *appliance penetration rates,* determined from the REMODECE and HBS surveys. Below, a description of the procedures is provided.

3.2.1.1 Averaged appliance power use (annualized consumption)

The equation 1 summarizes the procedure used to calculate the annual power consumption of each appliance (AC). The measurements *a* are recorded every 10min and *m*, is the number of monitoring days. Since most of the appliances were monitored around 2 weeks, the annual electricity consumption is extrapolated, using a conversion factor (CF). If the appliance is consuming electricity all year long (such as cold appliances), the CF is 0.365 (365 days a year). For the rest of appliances[15], a CF of 0.348 was taken into account (a period of 14 days, corresponding to holidays is discounted). The procedure is iterative and applied to all appliances in the sample. Once the individual consumptions of the same appliance type are obtained, an average is obtained. This value is the so-called *yearly consumption per appliance* and represents the present state or baseline consumption (in kWh/appliance/year) (Fonseca *et al.* 2009).

$$AC = CF \frac{\sum_{i=1}^{n} a_i}{m} \qquad \textbf{Equation 1}$$

Where,

[15] In the case of washing appliances, the annual consumption is based on the power consumption per cycle (kWh) and the number of cycles during the monitoring period.

CF = *Conversion factor*

a = *10 min power use record*

m = *number of monitoring days*[16]

n = *number of records during the monitoring period*

When it comes to *lighting*, there are basically five major technologies or types of light source: CFLs, incandescent, fluorescent and halogen (low and high wattage). The project monitored these light sources in seven room types (living room, bedrooms, kitchen, bathrooms, hallways, outdoors and other rooms). By having this, it is possible to calculate the yearly electricity consumption per room type and light. These values are aggregated per lamp type and an overall value is obtained. The procedure to obtain the yearly consumption values is rather similar to the described above. However, as the lampmeters record the time the lights are on, a procedure linking time and power of the devices is necessary as a preliminary step to obtain power use. The individual values are cross – checked with the database of the REMODECE project.

3.2.1.2 Appliance penetration rates in Hungary

The power use values obtained using the procedure illustrated above are not representative of the Hungarian context. Therefore, a direct extrapolation would produce skewed results. A direct extrapolation to national values is only feasible if the selection of households for monitoring is statistically based (e.g. by using a probabilistic random selection), such as in recent studies in New Zealand (HEEP) and SEA Sweden (Zimmerman 2009). For this reason, it is necessary to adjust the appliance power use in a way that reflects best, the consumption of the typical Hungarian household. Although the sample is not representative of the country, it contains a diversity of power use values, reflecting different use patterns and characteristics of the equipment. This is especially true for high consumption appliances such as fridges, washing machines, which are one of the priorities of the project in CEE countries.

In order to obtain an adjusted value, the averaged appliance power use is related to representative values for the country. Fonseca *et al.* (2009) and Grinden and Feilberg (2009) use appliance penetration rates as representative values to obtain the average European household power use. For this study, a similar approach is used, considering both the appliance penetration from the HCSO databases and from the REMODECE survey (Hungary). Both REMODECE survey and

[16] In Fonseca *et al.* (2009), the consumption during the monitoring period is extrapolated to yearly values considering a period of no consumption of two weeks (vacation).

HCSO survey (HBS) are comparable in temporal terms since the former was carried out between 2006-2008 while the latter in 2007. In other words, the idea is to link the averaged consumption per appliance type with the ownership rate of the appliances to obtain a representative value of the average Hungarian household power use. As presented in the concept of typical household using penetration rates is rather virtual. For instance, an appliance penetration rate of 0.9 means the appliance is almost present in all households. As presented later, a high penetration rate and high consumption increase the weight of the appliance in the final electricity consumption of the average Hungarian household. This approach helps to focus on the appliances that are important for potential electricity savings.

3.2.1.3 Calculation of the average Hungarian household power use

Once the averaged appliance power use is obtained and the country's specific /ownership rates are available, it is possible to calculate the average or typical Hungarian household power use (HH_{PU}). The averaged appliance power use (AvAPP) is multiplied by their respective appliance penetration rate (PR_{app}) in order to determine the specific typical appliance power use. The process is iterative for each appliance. Then, the adjusted values are added in order to obtain the average Hungarian household power use. Equation 2 summarizes the process:

$$\mathbf{HH_{PU}} = \sum_{i=1}^{n} \mathbf{AC_i * PR_i} \qquad \textbf{Equation 2}$$

Where,

HH_{PU} = Average Hungarian household power use

AC = Averaged power use of the appliance *i*

PR_{app} = Specific penetration rate of the appliance *i*

n = Number of appliances

3.2.2 Average appliance power use (24h daily load)

3.2.2.1 Patterns of power use

The level of resolution (10min) allows further analysis of electricity use in Hungarian households. An average hourly power use (Hv_b) for every appliance and light source allows the determination of use patterns throughout the day (e.g. intervals of higher/lower power use of TVs, lights, PCs, among others). As with the annual averages, it is necessary to adjust the hourly values in order to make them representative of the Hungarian households, using the specific appliance penetration rate (PR). Equation 3, summarizes the procedure followed for the calculation of the average hourly power consumption (Wh) of a particular appliance:

$$\mathbf{Hv_b} = \mathbf{PR_i} \left[\sum_{i=1}^{n} \mathbf{a_i} \right] \qquad \textbf{Equation 3}$$

Where,

a = 10 minute power use record in the hour *b*

n = Number of records in the hour *b* for the appliance

PR = Penetration rate of the appliance

b =The hour of the day for which the average is calculated

The process is iteratively applied to every hour of the day (00:00– 24:00).

3.2.3 Analysis of ICT equipment power levels

According to EC JRC (2009) ICT equipment is growing in importance in the final electricity consumption of European households. New appliances in households and technological changes in existing ones are among the factors driving the increase in electricity consumption. Laptops, modems, home theaters, bigger TV sets, satellite receivers are among the equipment increasing their presence in households. Considering this, it is relevant to analyze how power is used by this type of equipment in Hungarian households. According to the literature, there are different approaches to analyze levels of power use. Rosen and Meier (2000) use a *bottom-up* approach combining measurements on appliances and survey data. The process includes the definition of the principal operating modes, the record of the power use and the time spent in each mode. Additionally, the appliance penetration rates in the country are taken into account.

Zimmermann (2009)[17] and Firth *et al* (2008), determine high and low power mode uses from monitored appliances using daily profiles. This is, the power use during a typical day (constructed from the averages of the data available for each hour). For instance, the value of the 02:20 is obtained from all values recorded for that exact time. In consequence, each typical day has 144 values representing the daily load (from 00:00 to 23:50). The reference standby power use

[17] This is the author of the final report of the most recent monitoring project in Europe (Sweden SEA) in 400 households. This report was issued by Enertech, the French company involved in similar monitoring campaigns in the EU such as EURECO. The project used a similar methodology as REMODECE but the main difference lies in the selection of the households (in Sweden SEA it was statistically based).

corresponds to the lowest consumption of the day. This interval depending on the study, is between 01:00 to 04:00 or 03:00 to 04:00. The reason to use this value as reference lies on the fact that most people are asleep during that time. While useful to determine the lowest power use level during the day, the identification of low and high power use levels at later hours is more diffuse and therefore, less accurate.

There is a third method that uses a different approach by analyzing the time series of the recorded data. Cogan *et al* (2007) analyze low power and active electricity consumption by using the frequency distribution of the data. This method allows the calculation of the different levels of power use by finding the power peaks in the distribution of the time series. For appliances that are most of the time inactive (e.g. DVDs, VCRs) the low power modes usually corresponds to what in statistics is the so-called *mode* of the distribution. This is, the value that occurs most often. If the most common value is larger than the low power mode –idling modes- (e.g. when the appliances is most of the time in use), the modal value of the data values less than the average power is taken. This methodology is used in the HEEP project (New Zealand), which is probably the most comprehensive to date (along with that of Sweden SEA), based on monitored appliances.

Considering that methodologies are not mutually exclusive, an approach combining elements of the briefly described ones is used in this research. The overall procedure includes: *definition of the power levels to be analyzed* (active and inactive modes), *time series analysis* (frequency distribution) for each type of appliance to determine the reference values of power use. The daily profile provides indications on the likely power use for some power levels (e.g. off modes during the early morning), etc. By having this integral and comprehensive approach, it is possible to determine the power use in each level and the proportion of the time spent on it. Finally, a quantification of the proportion of low power modes (lopomos) in the final electricity consumption of the Hungarian average household is provided.

3.2.3.1 Definition of the power levels

The definition of the power levels used in this research is adapted from the one proposed in Schlomann *et al.* (2005). These authors propose three main levels of power use: *Off level, idling mode* and *normal mode.* In off level the appliance is not carrying any function and it is no drawing electricity from the mains. In *idling modes* the appliance is carrying at least one function but not the main one (usually waiting for an activity). This mode includes *off mode* (appliance is switched off, but consuming electricity) and *standby* (appliance is on but the electricity consumption is reduced, such as the sleep function in PCs). In the *normal mode,* the appliance is performing its main function. Figure 13 shows the main power levels and their relation with the power consumption.

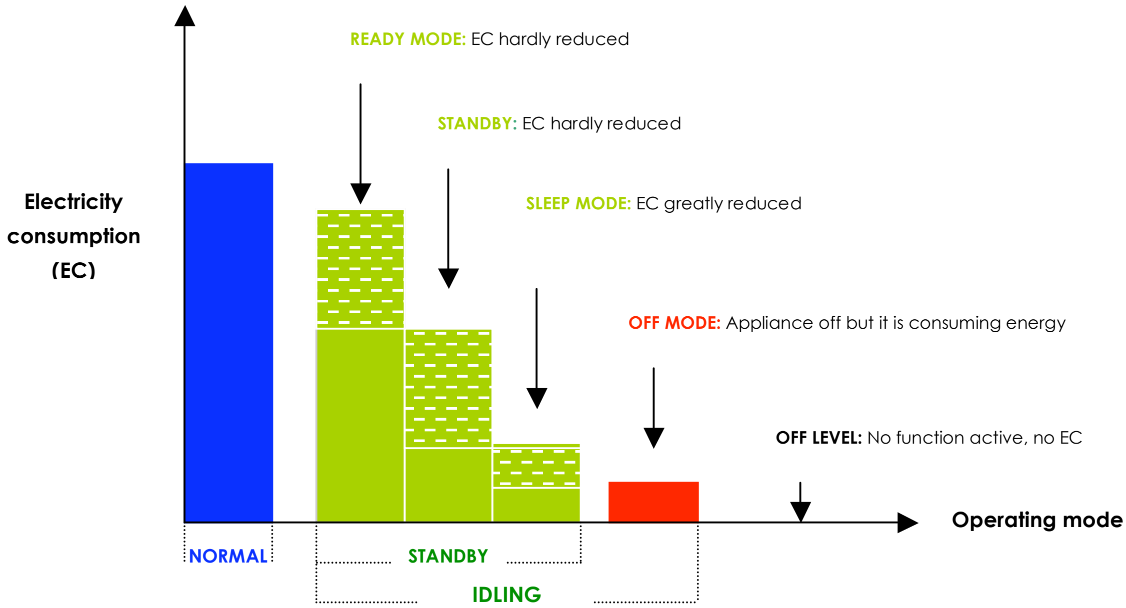

Figure 13. Different levels of power use. Adapted from Schlomann et al. *(2005)*

The above scheme constitutes a reference situation since not all ICT equipment has the described power modes. For instance, a PC is likely to have most of the power modes. However, for appliances such as TV sets, the power use may fluctuate only between off mode and normal power levels. For this reason, the analysis is performed on an individual basis (appliance by appliance) in order to identify the main trends. The procedure for the individual analysis is presented below. The power levels analyzed are based on Schlomann *et al.* (2005). However, a particular nomenclature is use in this study include (Table 8):

*Table 8. Equivalence between the nomenclature used in this study and the classification by Schlomann*et al. *(2005)*

NOMENCLATURE	Equivalence to the classification Schlomann *et al* (2005)
LP1 (Low power mode 1)	**Off mode** (passive standby)
LP2 (Low power mode 2)	**Standby**
NM	**Normal mode**

As the power levels are defined by specific power values, there is some intermediary consumption that is also recorded in this study. These values basically correspond to the process of switching between modes (e.g. from LP1 to LP2). A particular reference and analysis on this power levels is provided in the corresponding section.

3.2.3.2 Analysis of frequency distributions

The analysis of the frequency distributions of the power used by appliances during the monitoring period is used to determine the reference values of the different power levels. The data collected by the REMODECE project on a 24/7 basis, with a 10minutes resolution constitutes the starting point for the analysis. Below, it is the description of the procedures follow to analyze the frequency distributions: *Calculation of the frequencies, determination of the reference values* and *calculation of the time and power spent in each power level.*

-**Frequency distributions:** A frequency distribution is a statistical procedure that allows the organization of the consumption records by different values of power use. As the wattmeters used to record electricity consumption have a resolution of 0.1W, the frequency distribution is built using this interval. In other words, the frequency analysis allows the organization of the number of observations (frequency) recorded per unit of power. The statistical tool used to organize the data is the histogram of frequencies. A range from 0W to 25W (250 intervals) was defined to organize the distribution of the data. It is assumed that this interval captures all relevant values of power use by ICT equipment. In general power values above 15W or 20W are an indication of appliances in normal use mode. Conversely, lower values usually correspond to power use in low power modes. Values above 25W are also included in the histogram as a class called higher than 25W. The use of 0.1W interval allows an accurate determination of the different power levels for each individual appliance. This is important considering that spot measurements[18] are not available for all appliances. The process is iteratively applied to all individual appliances considering that even similar appliances (make and model) may have different distributions. The reason for this is that users may use their appliances in different ways. For instance, they may leave the devices in on modes while others may turned them off. The individual frequency distributions can help to include these variations.

-**Reference values**: Once the frequency distributions are calculated for all appliances, the power values with the highest frequencies are determined and classified within the defined power use levels. In the case there is uncertainty in the classification of the value, the time series of the particular appliance is examined By default, the time period of day between 03:00 and 04:00 hours is used as reference to determine the consumption in the lowest power use level -off mode- (passive standby). Higher values can either represent other low power modes or active modes. However, this varies with

[18] Spot measurement: It is the record of power use in the different levels of appliance use. This is, the power the appliance uses when it is in one of the different states: off mode, idling modes, active. Theses values are often recorded when the wattmeters are installed in households.

the type of appliance. Some appliances can be switched from the off mode to normal mode, without having another low power mode. In some other cases, such as for PCs, it may be possible to find different low power modes before the active or normal mode. That is why the analysis is focused on individual appliances.

-**Time and power in each power level**: By having the reference values for the different levels of power use, it is possible to determine the time spent and the power consumed in each of them. Basically, the frequency distribution is an indication of the time the appliance spent in one particular mode. The higher the frequency is, the higher the time the appliance is in a particular power level. With the proportion of the time defined and the reference value, the power consumption can be deducted. As the time series is based on cycles of 24hours, the power use and time spent on each mode is calculated using this reference time. The time spent and power used in intermediary frequencies (this is, between the reference values), is also taken into account. Then, the power consumption in the average day is annualized in order to obtain a value of the electricity consumption in the average household. Figure 14 shows graphically, the procedure to determine reference values of power levels using the frequency distribution of a hypothetical appliance. For this hypothetical appliance, the highest frequency is located in low power values (right side of Figure). It is an indication that most of the time the appliance is a low power mode, most likely in off mode (LP1). This analysis is more comprehensive that most of the methodologies analyzing low power modes, since it considers not only the reference values (corresponding to spot measurements in other studies) but also intermediary power use.

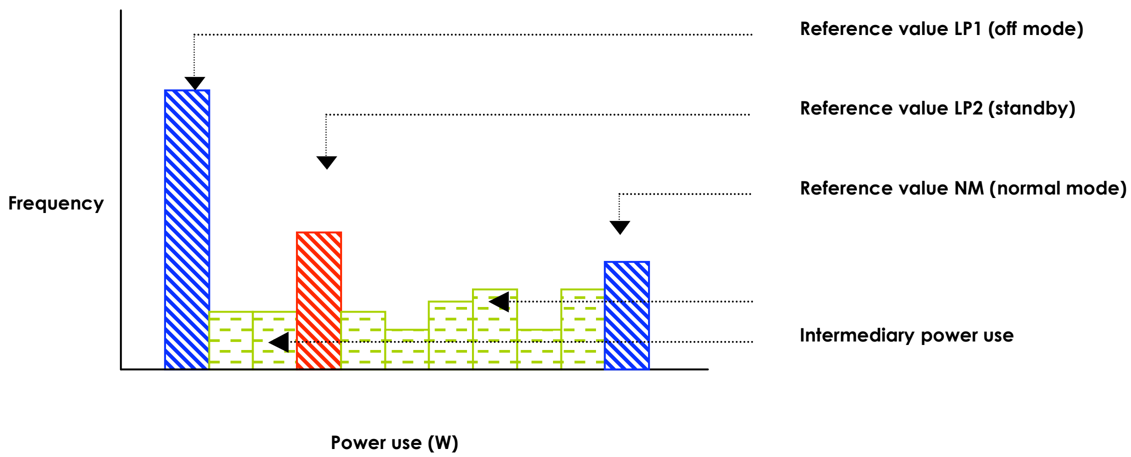

Figure 14. Determination of reference values using frequency distributions for a hypothetical appliance.

4. Results and analysis

This section presents the results of the analysis carried out for the monitoring data collected by the REMODECE project (Hungary). It is divided in two main parts: *electricity consumption of the average Hungarian household* and *analysis of power use for ICT equipment in different power levels.* In the first part, the annual electricity consumption is obtained for each appliance type within defined end use categories. These values are adjusted using the appliance penetration rates for the country in order to obtain representative results for the country. This analysis shows what are the main end uses and their share in the final electricity consumption of Hungarian households.

In the second part, the focus is placed on ICT equipment, which basically covers two main end uses: home entertainment and office equipment. This part analyzes the power use of appliances in different power levels (inactive –low power modes- and active mode). In other words, it analyses the time and the electricity consumed by appliances when they are either in use or not. The analysis shows the impact of low power modes of ICT equipment in the final electricity consumption of Hungarian households. The results and analysis of both sections will provide the base to identify the potential for electricity conservation.

4.1 Appliance penetration rates

As discussed in the methodology section, the appliance penetration rates are used to make the results of the analysis of the monitoring campaign, representative of the national context. For this reason, the definition of the rates constitutes the first step in the process of data analysis. As some of these rates were calculated using data from the REMODECE project, those are considered part of the results of this research. In any case, the source of the penetration rates is provided in Appendix I. Figure 15 shows the appliance penetration rates used in this research.

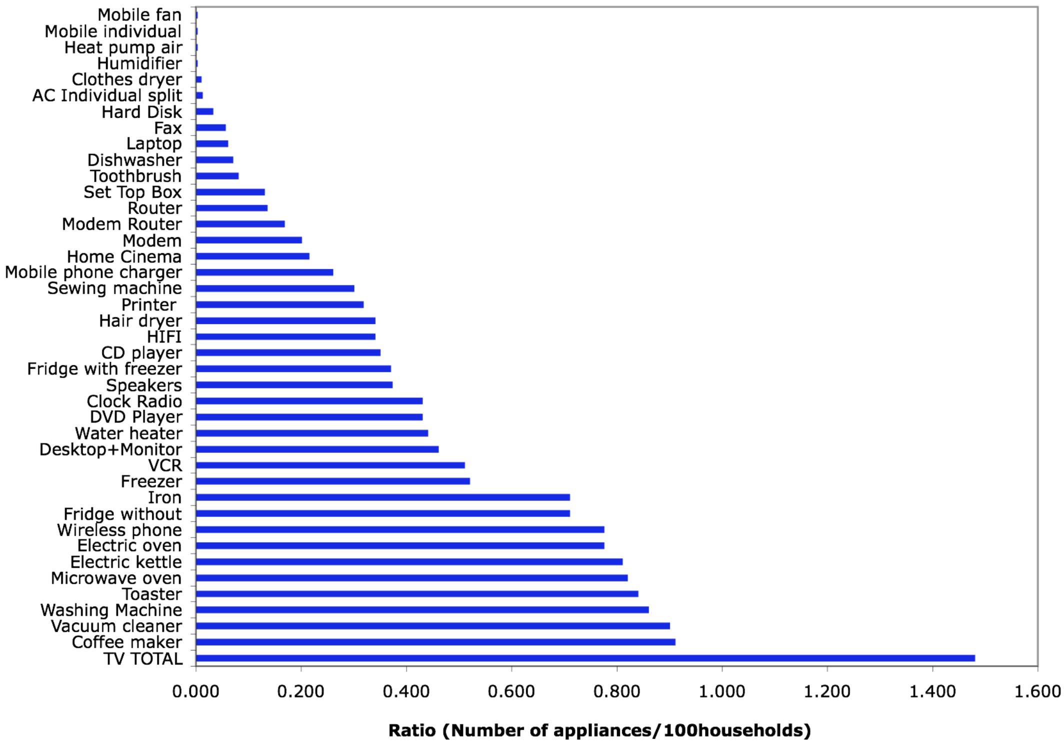

Figure 15. Appliance penetration rates in Hungarian households during 2007. Elaborated using data from HCSO (2010) and data from REMODECE project, chapter Hungary.

4.1.1 Penetration rates of major appliances (regions and income)

This research aims to analyze the electricity consumption of the average Hungarian household. The available data (power use from a sample of monitored appliances) do not allow making detailed analysis by regions or income levels. However, it can be argued that the use of national figures may conceal differences between regions and/or income levels in the country. In order to see how different the appliance penetration rates are between households of different regions and household of different income level, a similarity index[19] was calculated. This index uses a common attribute (the appliance penetration rates of the major appliances[20]) to compare the households of the different regions and income levels. In this case, the higher the index, (usually above 0.8) the higher the similarity is between households.

Conversely, a low value indicates there are big differences between households of the regions or households with different income levels due to a big difference in the penetration rates of appliances. For instance, if in the households of a specific region the penetration rate of fridges is above 0.9, and

[19] The Morisita index compares entities (e.g. regions or incomes), based on common attributes (penetration rates) to provide an index of similarity.

[20] "Major appliances" makes reference to: cold appliances, washing machines, dishwashers, tumble dryers, TVs, PCs, laptops, DVD players, VCR, HIFI, and microwave ovens). Their presence is recorded by periodic surveys carried out nationwide by the Hungarian Statistical Central Office – HCSO-.

in the households of other region the penetration rate is only 0.3, the index will determine there is a considerable difference between the households of these regions. This index compares all penetration rates at once in order to define how similar or different are the households. As presented below, the households in the different regions have similar penetration of appliances. The same is true for households of different income levels.

Figure 16 (left) shows the similarity among the households of the seven administrative regions in the country. Central Hungary -region that includes Budapest- is the less similar to the other regions considering differences in the penetration rates for some particular appliances in households. For instance, in households of Central Hungary the penetration rate of personal computers is higher than in the Southern Great Plain (54 vs. 35 PCs per 100 households). Even though, there are not extreme differences in the overall picture (considering all the penetration rates of all appliances). When penetration rates are compared for households of different income levels, there is homogeneity between income deciles D2-D9 (above 0.9) Figure 16 (right). The largest differences are between households with extreme income levels (D1, the lowest and D10, the highest). It is caused by considerable differences in the penetration rates of selected appliances. For instance, in the households with the higher income level (D10), the penetration rate of dishwashers is three times that of the lowest income level (D1). A similar situation occurs with laptops and at a lesser extent, with personal computers. However, as with the regions, the overall differences between households (considering all appliances) are not extreme considering that the overall index is above 0.8.

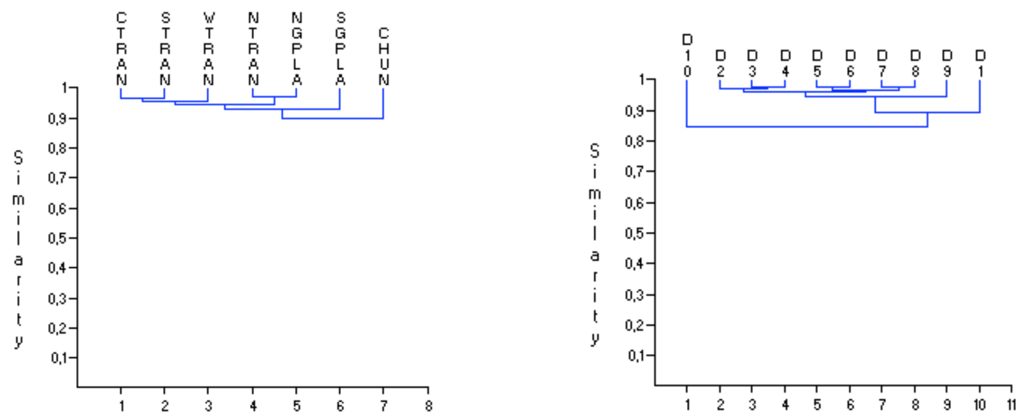

Figure 16. Similarity index between Hungarian regions[21] (left) and income levels –deciles- (right) based on the penetration rates of major appliances in 2007. Elaborated using data from HCSO (2010).

[21] CTRAN=Central Transdanubia, STRAN =Southern Transdanubia, W=Western Transdanubia, NTRAN=Northern Transdanubia, NGPLAN=Northern Great Plains, SGPLAN=Southern Great Plains, CHUN (Central Hungary). Divisions according to the KSO (Hungarian Central Statistical Office)

The similarity index is based upon the presence of appliances in households (HCSO does not include specific features, brands or energy efficiency rating of the appliances in its survey). Under this premise, it can be said that penetration rates for most of the major appliances in households across regions and income levels in the country is similar. Only for selected appliances such as laptops and dishwashers there are important differences in penetration, especially when income levels are compared.

4.1.2 Penetration rates of light sources

The official statistics do not provide figures on the penetration level of light sources for the country. However, the REMODECE survey recorded the number of light sources by technology and room type. With this information it is possible to determine the level of penetration of each technology in a typical room (and therefore, for the average household). Figure 17 shows the number of light sources found in different rooms disaggregated by technology type. According to the analysis of the data, a typical Hungarian household has an average of 13.7light sources. This figure is remarkably similar to that reported by the ENERLIN project in Hungary during 2007 (13.8light sources per household) (Farsan and Boza-Kiss 2008). As it can be seen, incandescent light sources are by far, the most dominant technology in the average household (8.3light sources per household), mainly used in living rooms, bedrooms and bathrooms. CFLs (3.2light sources per household) are the second most used technology, mainly in living rooms, bedrooms and kitchens.

The remaining technologies (halogen lamps and fluorescent) have a lower penetration (less than 1.5light sources in the average household). Even when the different light sources can be found in the different room types, there are some exceptions. For instance, fluorescent technologies are basically confined to kitchen and bathrooms (penetration rate –PR- is below 0.2 per room type). It is a technology rarely found in living rooms and bedrooms. Some authors argue that the consumer misconception on CFLs is due to the comparison with fluorescent technologies. People still assume that CFLs are similar to fluorescent in terms of light quality ("cold light"), aesthetics (unattractive designs), flickering (non reliable and constant lighting), not compatibility with dimmers among other factors (Krantz *et al.* 2007, Rasmussen *et al.* 2007). In Figure 17, there is a low penetration of all technologies in combined use, pantry and storerooms. The most likely explanation for this is that most of these rooms may be not common in most of the Hungarian households, or other rooms are used to fulfil the function (e.g. storing elements in cabinets in kitchens or other rooms). In the case of WC, the reason could be attributed to the fact that toilet and shower can be part of the same room and not separated entities in the sampled households.

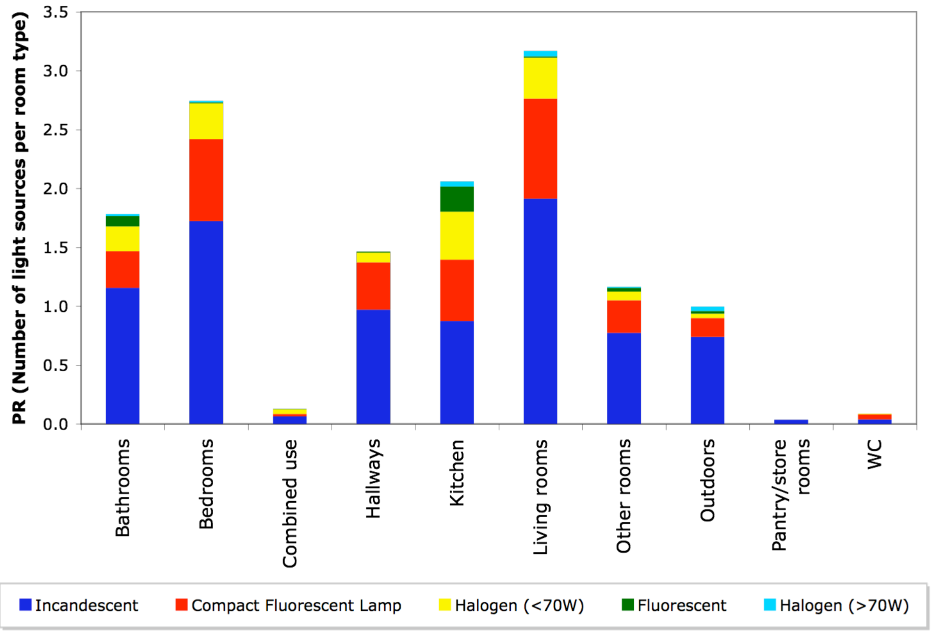

Figure 17. Penetration of light sources in different room types of the average Hungarian household. Elaborated using data from REMODECE survey , Hungary.

4.2 Average Hungarian household power use

This section addresses two main parts. The first one includes the calculation of the average electricity consumption of the monitored appliances (one value per appliance type). This consumptions are adjusted using the respective appliance penetration rates (defined in the previous section). After the process is completed, the adjusted values are added to obtain the average Hungarian household electricity consumption. In the second part, the adjusted consumption values per appliance type are grouped by end uses in order to provide a breakdown of the electricity consumption.

4.2.1 Power use by individual appliances

4.2.1.1 Electrical and electronic equipment

The range of appliances present in households is far from being uniform both in number and types. This is especially true for appliances in the miscellaneous category. Additionally, the number of devices to monitor consumption (mainly wattmetters and lampmeters) is usually limited in most of projects. The priority for the monitoring in CEE countries was given to the so-called white appliances[22], lighting and electronic loads with standby power (e.g. PCs) (ISR-UC 2008). As use patterns are varied, the monitoring of several appliances of the same type under normal working conditions (in a 24/7 basis) helps to capture the variability in consumption. For this reason, as it can

[22] White appliances include fridges, freezer and washing machines.

be seen in *Table 9*[23], the number of monitored appliances (n) is higher for these types of appliances. For instance, washing machines were monitored in 70 out of 75 households. In any case, it is necessary to mention that along with the variability in appliance use patterns by users, there is also a significant diversity in the type of models and efficiencies.

There are two factors making an appliance relevant in terms of electricity consumption using this methodology: high electricity consumption in normal working conditions and elevated penetration rates in the country (usually above 0.8[24]). Considering these two aspects, the appliances with the highest (adjusted) consumption in Hungarian households include: fridges with and without freezer (179.4kWh/year and 174.5kWh/year respectively), washing machines (81.5kWh/year), TV sets (143.7kWh/year) and lighting (378kWh/year). There are some other appliances with intermediate levels of penetration (around 0.5) and important power use in the home entertainment (e.g. DVD players, set top boxes) and office equipment categories (e.g. laptops, PCs). This group is important since, as it can be inferred from their penetration rates, the saturation level has not been reached. Additionally, for most of this equipment not only the consumption in normal (on mode) is important, but also the one in low power modes as it is presented later. On the other extreme, there are appliances with low penetration rates such as air conditioning devices (A/C). In this particular case, the project measured power use for one A/C unit equivalent to 1500kWh/year (not adjusted). Their impact in the final share in the power use of a typical Hungarian household is low (due to its low penetration rate), but it is an indication of the potential effect on the final electricity consumption if the penetration of these devices increases in Hungarian households.

The miscellaneous category is a complex one since it can include a variety of appliances whose penetration rates are in most cases not known[25]. Most of the earlier studies and projects on residential electricity analysis from monitored appliances have focused their attention in the most consuming end uses such as cold appliances (e.g. ECODROME and EURECO in France and some EU countries in the early 2000s) (Sidler *et al.* N.D.). In the case, of REMODECE, even when there were measurements on appliances in this category, most of the reports give predominance to major appliances. This is basically due to the significance that policy actions (e.g. energy efficiency labels, energy standards, informative instruments for awareness raising) may have on the power use of

[23] *Table 9* shows the appliances that were taken into account in the final electricity consumption of the average Hungarian household. The extended list with all the monitored appliances in provided in Appendix II

[24] Usually the penetration rates are displayed as number of unites per 100 households. For convenience in relation to calculation, the penetration rates in this paper are written as proportional values. If the penetration rates is 80 per 100 households, the factot used is 0.8.

[25] Of the consulted projects, only two have appliance penetration rates for miscellaneous appliances that can be considered as representative of the country: HEEP in New Zealand and SEA Sweden. Unlike REMODECE, these projects selected households using statistical sampling (Isaacs *et al.* 2006, Zimmerman 2009).

appliances. In other words, the major electricity savings can come from the major appliances, in general. Even when in most cases the power use of appliances in this category is relatively small compared to major appliances, there are some exceptions. For instance, vacuum cleaners, which are relatively common in households, have an important power consumption of 43kWh/year) in the average Hungarian household. In this particular case, the preparatory studies for the upcoming energy requirements (implementing the Ecodesign Directive) in the EU are finished. Discussion with relevant stakeholders is taking place before the implementation of the energy standards via regulation (AEA 2009).

Other appliances not as common as vacuum cleaners in households may have elevated electricity consumption values. For instance, the team in charge of the monitoring process found that aquariums in households are complex devices using electricity to generate bubbles and for lighting. According to the data, the consumption of the monitored aquariums was up to 152.1kWh/year, a figure similar to the average obtained for TV sets. Even when the penetration rates may not be as high as that of other appliances, it was considered pertinent to include the consumption of appliances in this category in the final counting. For this reason, appliance penetration rates from other contexts were used. As with the rest of penetration rates, an indication of their source is provided in Appendix I

Table 9. Average power use of different appliances in Hungarian households.

END USE	APPLIANCE	n	Power use (kWh/year)	PR	Adjusted power use (kWh/year)
HOME ENTERTAINMENT	Amplifier	8	26.5		0.0
	DVD Player	9	47.5	0.430	20.4
	HIFI	14	57.2	0.340	19.4
	Set Top Box	3	29.2	0.130	3.8
	Stereo	5	13.5	1.350	18.2
	TV TOTAL	51	97.1	1.480	143.7
	TV CRT	40	92.2		0.0
	TV LCD	11	115.0		0.0
	TV Plasma	0	0.0		0.0
	VCR	8	42.9	0.510	21.9
COLD	Fridge without freezer	33	252.7	0.710	179.4
	Fridge with freezer	48	471.7	0.370	174.5
	Freezer	9	1125.1	0.520	585.0
OFFICE EQUIPMENT	Computer site -cluster appliances-	50	316.6	0.460	145.6
	Desktop+Monitor	12	177.5	0.460	81.6
	Monitor -CRT-	8	74.9		0.0
	Monitor -LCD-	2	33.2		0.0
	Laptop	20	61.5	0.060	3.7
	Printer	9	13.4	0.317	4.3
	Modem Router	3	66.3	0.168	11.1

END USE	APPLIANCE	n	Power use (kWh/year)	PR	Adjusted power use (kWh/year)
	Modem	9	52.4	0.200	10.5
	Router	2	53.6	0.135	7.2
	Speakers	5	61.0	0.373	22.7
	Fax	5	83.5	0.056	4.6
COOKING	Coffee maker	22	20.6	0.910	18.7
	Electric kettle	14	44.1	0.810	35.8
	Electric oven	4	100.0	0.775	77.5
	Microwave oven	57	25.5	0.820	20.9
	Toaster	16	9.9	0.840	8.4
DRYING	Clothes dryer	2	63.0	0.010	0.6
WASHING	Dishwasher	10	149.8	0.070	10.5
	Washing Machine	70	94.7	0.860	81.5
MISCELLANEOUS	Aquarium	4	152.1		0.0
	Clock Radio	6	27.5	0.430	11.8
	Hair dryer	6	13.2	0.340	4.5
	Iron	3	1.4	0.710	1.0
	Mobile phone charger	1	4.3	0.260	1.1
	Sewing machine	1	3.1	0.300	0.9
	Toothbrush	3	18.5	0.080	1.5
	Vacuum cleaner	9	47.7	0.900	42.9
	Wireless phone	6	9.6	0.775	7.4
SPACE COOLING	AC Individual split	1	1542.1	0.012	18.4
	Heat pump air	1	268.7	0.002	0.5
	Mobile fan	2	17.0	0.002	0.0
WATER HEATING	Water heater	10	190.3	0.440	83.7
LIGHTING					378
TOTAL					**2116.9**

n=number of sampled appliances. PR=Penetration rates

4.2.1.2 Electricity use by lighting

Lighting constitutes one of the main electricity end uses in Hungarian households with an average consumption of 378kWh/year. Figure 17 shows the power use by room and light source type. The first pattern that emerges is that electricity consumption can be attributed to the combined use of more than one technology (except outdoors, for which incandescent is basically the most preferred light source). Among the lights sources, incandescent is found in all room types and it is responsible for at least two thirds of the final consumption in each case. CFLs are the second most frequent technology in room types and also the second largest consumer light source in households. However, its consumption represents a minor fraction of that of incandescent light sources. This makes sense considering that CFLs use up to 75% less energy of that used by incandescent bulbs to produce the same light effect (Madsen 2008). Another interesting finding is that unlike CFLs and incandescent, fluorescent technologies are only found in kitchen and bathrooms. As mentioned previously, part of the explanation for the low penetration of CFLs (excluding financial considerations) is attributed to the fact that consumers think that CFLs are basically the same technology compared with fluorescent.

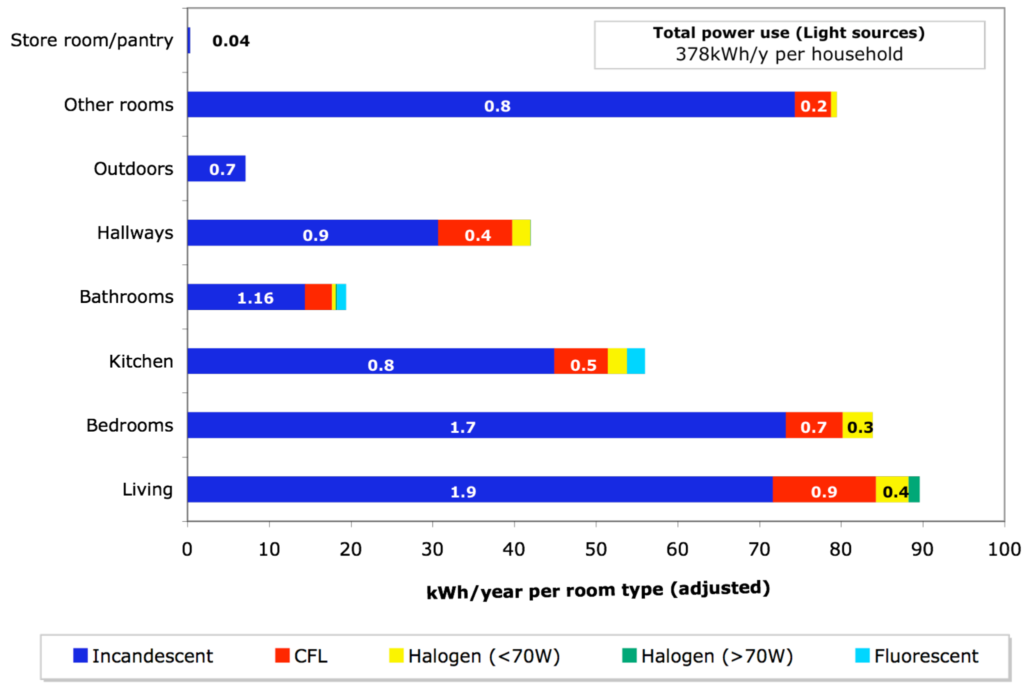

Figure 18. Power use per light source and room type (adjusted). The number within the bars indicate the count of light sources per room type

When it comes to room types, most of the electricity consumption from lighting takes place in living rooms and bedrooms. Taken together, electricity consumption in these two rooms accounts for up to 46% (175kWh/year) of the total consumption by light sources in an average Hungarian household. Kitchen and hallways are the next room types with the largest consumptions (56kWh/year and 42kWh/year respectively). The category "other rooms" has a considerable consumption since it includes several room types: cellar, dining room, entrance and washing rooms, among others. As with the previous rooms, incandescent are the most dominant technology with the highest consumption, followed by CFLs. In the case of store room/pantry, the low consumption can be attributed to the fact that these rooms may not be present as such in Hungarian households. For instance, their functions may be fulfilled in other rooms, such as compartments in kitchens to store food or cleaning products.

In the overall, the distribution of electricity consumption patterns by room types and technology can provide some ideas on the dweller's activity patterns and lighting preferences in households. In general, a higher consumption is the result of more time spent in one particular room plus the technology used. In this sense, living rooms and bedrooms concentrate the activity of dwellers while in households and incandescent light sources are the prime technological option in these rooms. In contrast, fluorescent technologies are restricted to bathrooms and kitchens, which can be an indication they are not an attractive option for other rooms. In the case of hallways they are basically corridors communicating different rooms in households, something that can explain their high share in the final consumption of the households. Dwellers might prefer to leave the lights on rather than switch them off while going from one room to the other. Lighting outdoor consumption presents relatively low values. This can be due to the fact that the sample for the monitoring campaign includes more apartments (70%) than houses (30%). It is likely that outdoor lighting is more important in houses than in apartments where outdoor lighting is basically set for the whole building and it is part of the common share utilities (not included in the consumption of the household).

4.2.1.3 Electricity consumption breakdown by end-use

When the individual adjusted electricity consumptions from appliances are added, a typical Hungarian household consumes 2117kWh/year. Cold appliances (fridges with/without freezers and freezers) represent the end use with the highest share of the final electricity consumption (44%). Lighting is the second end-use (18%), dominated mostly by electricity consumption from incandescent light sources as shown previously. This pattern is similar to that found in the analysis of the data for all participating countries carried out by Fonseca *et al.* (2009). Home entertainment is the third largest with 11% of the share. Cooking and Office equipment have similar shares (8% and 7% respectively) while washing and drying along with water heating have each 4% of the final electricity consumption.

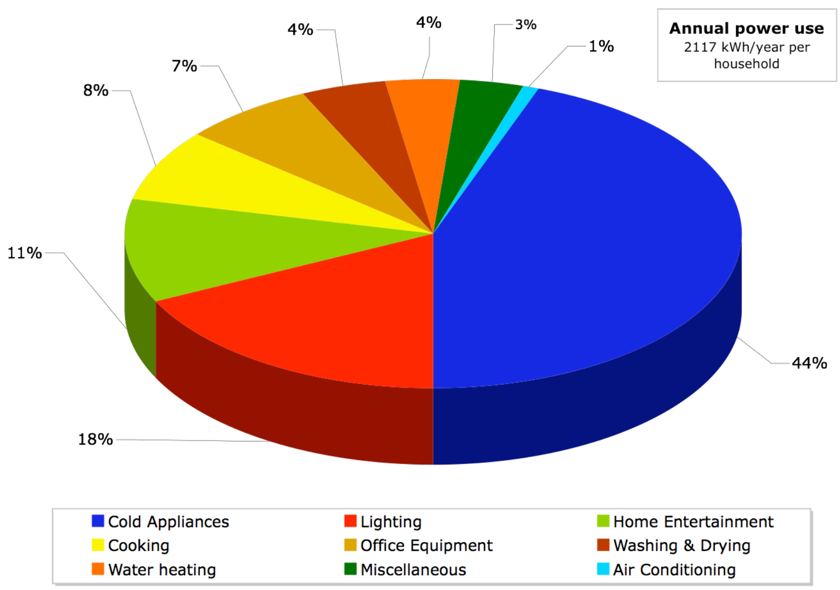

Figure 19. Breakdown electricity consumption in an average Hungarian household

Cold appliances: When comparing the shares obtained in the analysis of Fonseca *et al.* (2009) with the ones of this research it is found that cold appliances have a higher share in the latter case (44% vs. 28%). Considering that in the overall, the penetration rates are in both cases similar, the most plausible explanation for the high share in Hungary could be attributed to the presence of very low efficient appliances in the sample. This can be supported by the findings of the REMODECE survey (Hungary) in relation to energy class and age of the stock of cold appliances. In general, fridges with freezers are considerably older than fridges without freezers. For instance, in the first case, up to two-thirds of the fridges with freezers were 6years and older (half of them older than 10years). In contrast, the stock of refrigerators without freezers is relatively newer: 54% is less than 5 years old while the remaining was above 6years (Boza –Kiss *et al.* 2009). These factors could help to explain the similar consumptions between the two appliances even when their penetration rates are markedly different in the country.

In the case of freezers, the adjusted average electricity consumption for freezers is 585kWh/year. This high value could be the result of very low energy efficient appliances in the sample in a reduced number of monitored appliances. In this sense, the results for this particular appliance are more uncertain. However, in a modelling scenario of replacement of outdated appliances performed by Atanasiu and Bernoldi (2008), the values of electricity consumption used for outdated freezers in the New Member States of the EU –NMS- were 700kWh/year while for outdated fridges the values were less (360kWh/year). Yet these assumed values are higher than the ones obtained from the analysis of the monitored appliances, the trend is similar: freezers consuming more electricity than fridges.

The results from the REMODECE survey in terms of age and energy class presented in Bosa-Kiss *et al.* (2009) along with the obtained consumption values from the adjusted consumption values are consistent with results from other studies. For instance, in 2004 (two years before the REMODECE project) a study by CECED (2004) found that 40% of the fridges and freezers found in the NMS (Hungary is part of them) were 12years or older. Considering this, it is likely that the sample contains appliances that are old enough for not being covered by the mandatory energy-labelling scheme implemented by the EU (Commission Directive 94/2EC[26] January 1994). These appliances are certainly very energy inefficient. As presented by Atanasiu and Bernoldi (2008), a new fridge requires up to 70% less energy that one model of 10 years ago.

Home entertainment: With 11% of the final electricity consumption in households, it is the third end use after cold appliances and lighting. TV sets are the individual appliances with the highest share in the electricity consumption (143.7kWh/year). This adjusted average value includes the

[26] The energy class label was amended in 2003 by the Directive 2003/66/EC which among others, updated the energy label by incorporating the A++ and A+ energy classes. It entered into force on July 1 2004.

consumption of both traditional CRT and LCD technologies, as no plasma TV sets were monitored by the project in the country. Additionally, the HCSO only records in its survey the presence of TV sets in households but not the type of technology (Evenesi[27] pers.comm.). In any case, the consumption of TV sets appears to be dominated by CRT technologies. According to Fonseca *et al.* (2009) and Grinden and Feilberg (2008), the average penetration rates in the REMODECE project for traditional CRT TVs is 92 per 100 households and 23 per 100 households for LCDs. In the case of plasma TVs, the penetration rates is considerable low (5 per 100 household). For this reason, it is assumed that the absence of plasma TV sets in the sample has not an important impact in the adjusted value for the country.

DVD players and VCRs have similar adjusted values of electricity consumption (20.4kWh/year and 21.9kWh.year respectively). This is interesting considering that the penetration rates are relatively lower for DVD players than for VCRs and for the fact that in terms of technological development, DVD players are a more recent technology. However, it is probably that DVD players are used with relatively more frequency that VCRs. This makes sense considering that VCRs are basically an outdated technology that is being progressively replaced by options such as DVD players. Under this scenario, it is very likely that most of the electricity consumption of VCRs is due to consumption in one of the low power modes. An in depth analysis of the consumption in low power modes of ICT equipment is presented later in this document.

Cooking appliances: The appliance with the highest consumption in this category is electric oven/cooker (77kWh/year), which is product of a high consumption from the monitored appliances and a high penetration rate (in this case, the European average was used as no figures for the country are available). In contrast, microwave ovens are one of the few appliances that have a high penetration rate but a relatively low power use (20.9kWh/year). Along with TVs, fridges and washing machines, this was one of the appliances with a high number of monitored devices. Finally, other relevant appliances in terms of electricity consumption and penetration rates are electric kettles and coffee makers (35.8kWh/year and 18.7kWh/year, respectively).

Office equipment: The highest electricity consumption (and penetration rates) corresponds to PCs (monitor and desktop) with a value of 81.6kWh/year. Speakers are the second most consuming devices with 22.7kWh/year, followed by modems and routers (10.5kWh/year and 7.5kWh/year). Interestingly, laptops and printers are not big consumers of electricity in the average Hungarian household. In the case of laptops, the main reason lies in a low penetration rate in the country (6 per 100 households) (HCSO 2010). However, this value contrast with the penetration rate obtained using

[27] Eva Menesi, senior statistician of the Section of Living Standards Statistics Surveys of the HCSO, consulted via email on March 14th 2010.

the data of the REMODECE survey (18 per 100 households). This is one of the recurrent discrepancies in the penetration rates determined using the REMODECE survey and those from the HCSO. Boza *et al.* (2009) attributes this phenomenon to the weighting given to Budapest in the survey. As presented previously, the penetration rates for certain appliances (such as PCs) are higher in Central Hungary (region with the highest income, where Budapest is located). In fact, the PR of laptops in households with higher incomes is very similar: 16 per 100 households (HCSO 2010). In the case of printers, the situation is relatively different to laptops in the sense that most of the consumption is produced when the appliance is not in use (especially in low power modes as it is presented later) and also because of a lower penetration.

Washing and drying: Washing machines are the appliances with the largest consumption in this end use (81.5kWh/year). Although the high penetration rate of this appliance in the country, the obtained share of 4% is notably inferior to the one found in the analysis of Fonseca *et al.* (2009) for all participating countries in the project. However, according to the most recent report on electricity consumption for the EU27 issued by EC-JRC (2009), the share in the final electricity consumption in European households is 6.4%. This figure, obtained using data for a similar period, is certainly closer to the one obtained in this research. The REMODECE (Hungary) survey found that the most energy efficient washing machines in the country are in the range of 6-10years. In contrast, the energy class for around 60% of appliances under 5years old is not known. In any case, in the overall around 50% of the stock is in energy classes A and above (A+ and A++), while 17% is in classes B and C (Loftus *et al.* 2009). Considering this, the relatively low share can be explained by a stock of appliances that is no so outdated in comparison to that of cold appliances.

In the case of dishwasher, the low consumption appears to be explained by two factors: a low penetration rate in the country and a newer stock of appliances. As it was shown previously, this is one of the few major appliances that present one of the biggest gaps in terms of penetration rates considering income levels in the country. In relation to the second factor, Loftus *et al.* (2009) found that most of the appliances are not older than 5years and most of them are rated in A classes. This can be consistent with the claim by Atanasiu and Bernoldi (2008) in relation to the apparent fact that the process of market transformation in CEE countries of the EU appears to be taking place faster than the time it took for the EU15.

Water heating: Electric water heaters as a single appliance, is one the highest consumers in the country with an important penetration rate (44 per 100 households). The adjusted consumption is 84kWh/year, which represents a share of around 4% in the final electricity consumption (similar to that of washing appliances). This figure is below the average obtained for the EU27 (8.6%) (EC JRC 2009).

The **miscellaneous category** is composed by a myriad of electric appliances, a fact that makes the analysis of patterns certainly more complex than the previous ones. Although most of the devices have relatively low power consumption when added, they represent a relevant fraction in the final consumption. For this reason, it was considered relevant to include the consumption of these appliances in the final counting. However, one factor that makes the estimation uncertain is that the penetration rates for most of the appliances in this category are not known. This is partially due the lack of statistics, which are usually focused on the major appliances. For this reason, the penetration rates from European averages or somewhere else were used. In this sense, it was found that vacuum cleaners are by far the highest consumers of electricity in Hungarian households in this category (42.9kWh/year). Clock radios (11.8kWh/year) and cordless phone (7.4kWh/year) are the next appliances with relevant consumption and high penetration rates.

4.2.1.4 Summary of findings

The electricity consumption of the average Hungarian household is 2117kWh/year. The end use with the highest share is cold appliances (fridges and freezers). Among them, freezers are the main consumers of electricity the average Hungarian household (585kWh/year). Even when the energy efficiency of these appliances has improved, outdated inefficient appliances are still present in Hungarian households. Lighting is the second end use with the highest consumption with 18% of the final share. Incandescent light sources continue to be the favourite technology in all room types of the average Hungarian households. Of the total 13.8light sources that a typical household has, 8.3light sources are incandescent. CFLs are the second most used technology but their penetration is still low. Home entertainment is the third largest end use with 11% of the share. One of the most interesting findings is that washing appliances have a relatively low share compared with the EU27 average. Considering the high number of monitored appliances and their high penetration in the country, the likely explanation for this lies in a reduced used during the two-week monitoring period and/or the presence of energy efficient appliances in the sample of monitored appliances. The miscellaneous appliance contains a variety of appliances that in general have a relatively low electricity consumption. However, among them there are also appliances that can have a high electricity consumption and users are probably not aware of that. For instance, the electricity consumption of the aquariums measured by the project was in average 152kWh/year.

4.2.2 Benchmarking electricity consumption from appliances

The above analysis presents the electricity consumption of the average Hungarian household from the adjusted consumption of individual appliances. In this calculation, not all the appliances presents in households are included. The reason for this is that measurements and/or appliance penetration are not available for all the potential appliances found in households. In this part of the analysis, the obtained consumption is compared to the total consumption household draw from the mains. Basically, two approaches are analyzed: the used in this study (reconstruction of the consumption from individual appliances –Bottom up-) and consumption from the total electricity consumed by households in the Hungarian residential sector (Top-down). Below there is a brief explanation of the two consumption types.

-Average Hungarian household electricity consumption: It refers to the power consumption of the typical house that was obtained using the data from the monitoring campaign and the appliance penetration rates for the country. As it was presented, the process it is a *bottom up* approach in which the individual –adjusted- consumptions (from TV sets, fridges, etc.) are summed to obtain the average consumption of the Hungarian household (Figure 20left). As the obtained consumption takes into account penetration rates, the value can be considered representative of the average Hungarian household.

-Total electricity consumption drawn from the mains: It refers to the power consumption of the household as a whole. It is obtained by dividing the total electricity consumed by the Hungarian residential sector by the number of households in the country (*top-down approach*). By using this approach it is possible to obtain the total electricity that, in average, is draw by a household from the mains. However, unlike the previous approach it is not possible to determine contribution of individual appliances (Figure 20right). The obtained average of the Hungarian household is representative, considering that national figures (total consumption of the residential sector and number of households) are used.

In order to compare these values two main aspects must be taken into account: representativenes and temporal aspects. As presented above, the two values are considered representative for the country. In temporal terms, the data used is comparable since it was obtained during similar time periods. The monitoring campaign was carried out between 2006 and 2008, and data on national electricity consumption and number of households corresponds to 2007. Figure 20 shows in a schematic way, the process followed by these two approaches:

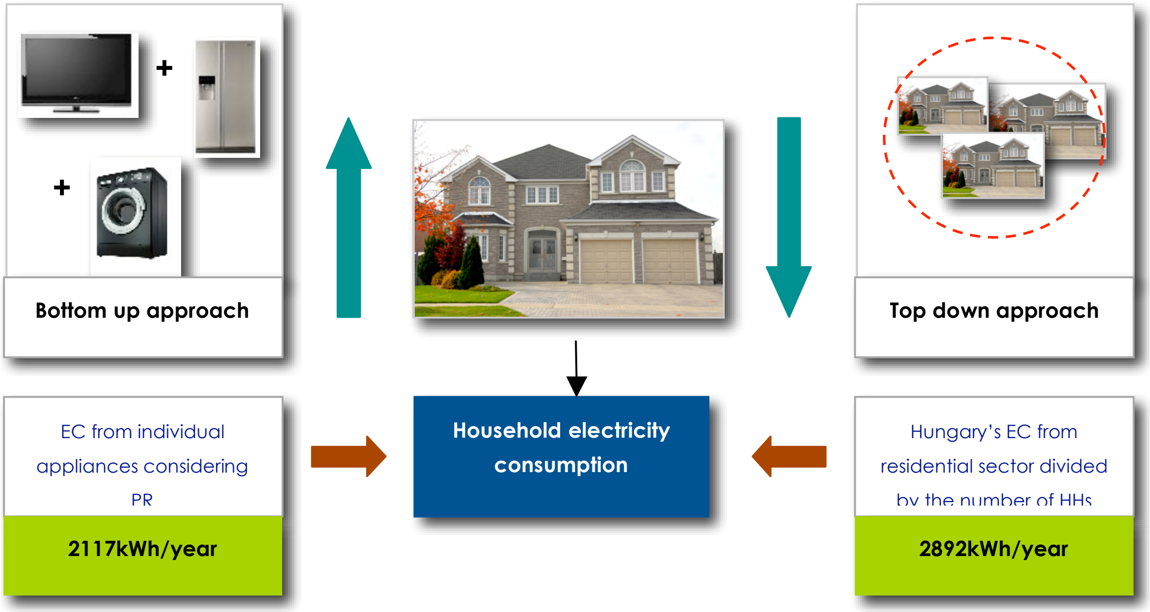

Figure 20. Bottom-up and top-down approaches to obtain the average electricity consumption of households

According to the HCSO (2010), in 2007 the Hungarian residential sector consumed 11TWh. Considering the number of households in the country (3.81million), an average electricity consumption of 2872kWh/year is obtained (Top down approach)[28]. As presented previously, the obtained electricity consumption in this study is 2117kWh/year (Bottom-up approach). Between the two values there is a net difference of 775kWh/year. The gap can be attributed to the following:

-The main appliances dominate the electricity consumption in the bottom up approach. As presented in Appendix II, the project monitored more appliances that were not included in the final counting. The penetration rates for some appliance (especially in the miscellaneous category) are not available. Additionally, the number of monitored appliances was low (e.g. one or two). As presented in the analysis, there variety of appliances that can be found in households is high. Among the particularities found by the project was the presence of aquariums (lights and bubble maker to oxygenate the water), an electric grass cutter and electric fans (in some households monitored during the summertime). These are just examples of the myriad of appliances present in households, some of which may have a considerable electricity consumption that was not accounted in the final value. These particularities have also been reported in others studies such as HEEP. For instance, the project found an incubator for emu eggs (a large Australian flightless bird), electronic devices to run a trout farm, among others (Isaacs *et al.* 2006).

[28] The REMODECE survey also recorded the annual consumption from information given by the respondents. It found an average value of 2240kWh/year. For family household with two kids, the average is 2400kWh/year. These vales are not so far form the one calculated using the consumption from appliances (Boza-Kiss *et al.* 2009).

-Some other plausible explanation for this hidden consumption can come from appliances that were not monitored by the project. As presented in Benoit *et al.* (2000), despite the fact that researchers are cautious to include all consumptions, there are appliances that for some reason are not taken into account. Among these are burglar and fire alarms (constantly drawing power) and doorbells just to mention a few. Only projects at national level such as HEEP have measured a wide variety of appliances, especially in the miscellaneous category. As the consumption of all major appliances has been included in the final electricity consumption of the typical households, it appears that the "invisible" consumption can come from appliances in the miscellaneous category, appliances in the kitchen and even from appliances in the bathroom (electric toothbrushes and shavers). The wide variety of appliances and power consumption that can be found in households can explain at some extent, the gap between the two consumptions.

-An additional factor can be the characteristics of the sample: As presented in the methodology section, there is an unbalance between the proportions of the household types monitored by the project. In the sample 70% of the households are apartments, while the remaining 30% are apartments. Several studies have found that consumption in apartments is in general lower than in detached houses (Zimmermann Isaacs *et al.* 2009)

4.2.3 Daily load: patterns of power use by end-uses

This section describes the electricity consumption patterns for the main appliances during a typical day (24h-period). Even when the monitoring process in each household took place between 2 and 4 weeks, the monitoring campaign spanned over a two-year period as a whole. In this sense, the daily averages implicitly capture the seasonal variations, especially for appliances that present changes in their use patterns, such as lighting (according to the length of the day). However, as there were no monitored households for a period of one year, it is not possible to compare and quantify the variability between seasons.

4.2.3.1 Cold and washing appliances

Electricity consumption (in Wh) of **cold appliances** is relatively constant during the day as can be seen in Figure 21. There is a small increase during the nighttime for the three types of cold appliances, probably as result of an increased activity in the kitchen area, where they are usually located. For both type of fridges, the electricity consumption is very similar (around 20Wh) while that one of freezers is well above 60Wh. However, it is important to mention that even when cold appliances are constantly switched on, they do not draw power constantly. As presented in Firth *et al.* (2008), the consumption usually follows a cyclic pattern between zero (or close to zero) and a predetermined level. For instance as it is shown in Figure 22 for two randomly selected households, the fridge in household HH28 cycles between 0W and 14.4W every two hours approximately while the fridge in household HH17 does it more frequently (around 50minutes between 0W and 10W). Some authors consider that the lower value of the cycle corresponds to standby consumption (Camilleri *et al.* 2007). Even when this may be true, the reported values of consumption of cold appliances in standby are not as high as for ICT equipment in proportional term. For instance, the share of standby consumption of a freezer in the total electricity consumption of the appliance in a year is generally less than 1%, while for appliances in the ICT category it can be between 10% and 100% of the total consumption of the appliance (Grinden and Feilberg 2008).

In the case of **washing appliances** there are some interesting patterns. For washing machines there are two clear use patterns. The first one can be considered as one of active consumption between 07:00 and 20:00. However, it is not constant and two peaks can be identified: the first one takes place between 10:00 and 12:00 with values around 20Wh, which are the highest of the typical day. The second peak occurs between 18:00 and 19:00 but it is relatively lower than the previous one. The fact that the consumption does not drop in between these periods is an indication that there is also an activity pattern of consumption in the afternoon hours. The second pattern corresponds basically to a phase of reduced use after 20:00 extending until 07:00, in which consumption basically falls close to zero around midnight and staying in that level until 07:00. In summary, process of washing clothes in Hungarian households take place predominantly during the central hours of the average day. However, the washing process can also take place during the early hours of the night, but certainly not after 21:00.

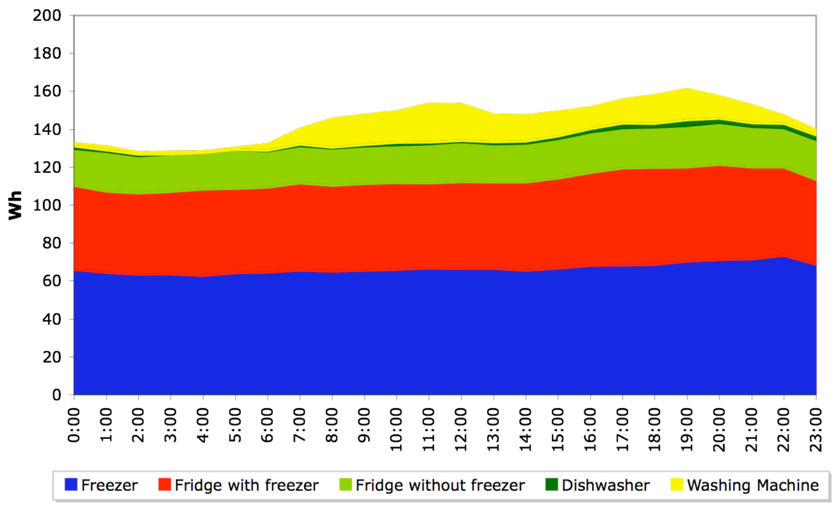

Figure 21. Daily load of cold and washing appliances

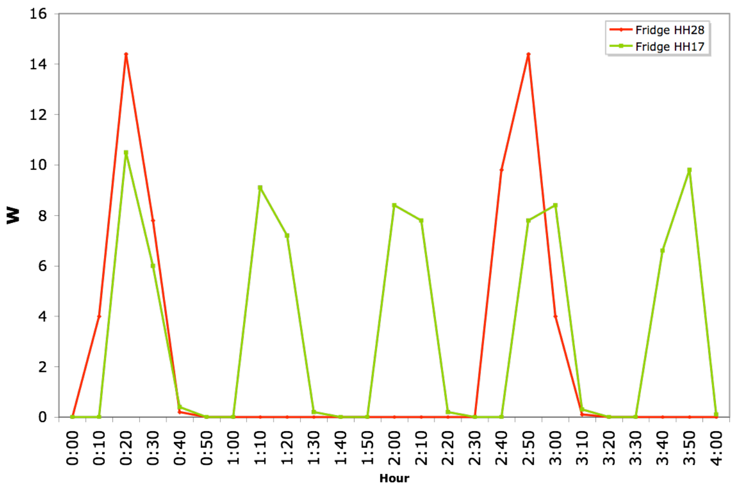

Figure 22. Ten-minutely power consumption for two sampled fridges in households HH28 and HH17 between 00:00 and 04:00

Dishwashers have an interesting pattern and somewhat opposite to that of washing machines. The highest consumption occurs around 19:00 (above 4Wh) after which, it decreases slightly to around 2.5Wh until midnight. This pattern of activity can be explained by the fact that the washing activity takes place before and after the dinner, which usually is between 20:00 and 21:00 hours. This can also help to understand the low peak around this time since basically washing and eating can be mutually exclusive activities. There is some minor consumption between midnight and 02:00 that can be attributed to late dinners or other type of celebrations that extends beyond the 00:00. As this activities are not predominant (not all days the dinner is extended or dwellers have social activity in the early morning), the average values are relatively less than during the peak time. Although there is some activity during the morning and afternoon, it is not as relevant as that of the nighttime. In other words, in the typical Hungarian household the dishes are washed during the night either prior and/or after dinner. Compared to both cold appliances and washing machines, the penetration rates for dishwashers are still low in Hungary. For this reason the power use with the adjusted consumption in Figure 21 look almost flat.

4.2.3.2 Lighting

Figure 23 shows the power consumption during a typical day in the average Hungarian household. It is important to mention that the average power consumption includes data for both winter and summer[29]. There is a clear use pattern with the highest consumption in the interval 17:00 -23:00 (up to 125Wh). In contrast, the lowest consumption takes place around 03:00 (10Wh). Along with its high penetration, the consumption of incandescent light sources dominates the hourly consumption

[29] The number of daylight hours range from 8:54 (during January) to 15:58 (during June).

in households (up to 105Wh at 20:00). CFLs, the second technology in terms of power consumption has just a fraction of that one of incandescent (15Wh at 20:00). The other technologies such as halogen have low participation in the consumption of the average household. Among them, fluorescent have the third largest power consumption, which is only noticeable during the nighttime, especially considering that this type of light source is usually located in kitchens. Considering that a standard CFL light source uses up to 75% less energy that an equivalent incandescent light sources, there is a large potential for electricity conservation from the replacement of this technology in the different rooms of the average Hungarian household.

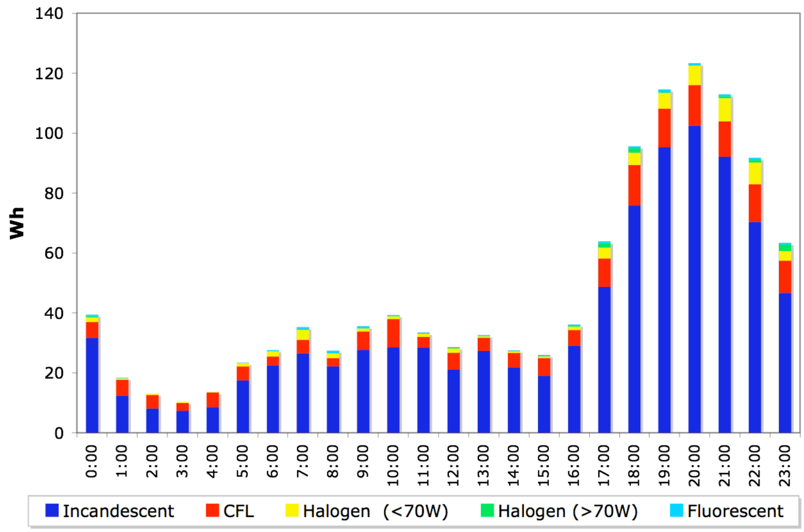

Figure 23. Hourly power consumption of light sources in the average Hungarian household

4.2.3.3 Home entertainment

Figure 24 shows two clear trends: appliances that have relatively constant electricity consumption and those with notable variation along the daily profile. The first one includes DVD players, VCRs and HIFI systems. Although the consumption is relatively constant along the day, it is possible to see an increase in the consumption during the nighttime. This is more evident for HIFIs after 20:00 and extending even beyond midnight. As HIFI systems are devices intended to enhance the quality of the sound, it is possible that they are is used altogether with TV sets. In the case of DVD players there is a minor increase between 18:00 and 20:00. This relative flat behaviour can be attributed to the fact that dwellers can eventually use their players to watch movies. However, it is clear that it is not a day-to-day activity since the changes along the day are minor. Unlike HIFI systems, there is no a direct relation with the use of TV sets. In other words, the use of DVD players (unless to watch a movie) does not provide anything additional to the experience of watching TV. In contrast, if dwellers have HIFI systems it is possible that they used it to improve the sound of their TV programs. In the case of VCRs, there are no major changes during the day in terms of consumption. The likely explanation for this is that VCR is a technology that is being progressively replaced by DVD players and now by the next generation of DVD players (Blue-Ray systems). In this sense, the use of VCRs in households is becoming less frequent, and most of the consumption, as it is presented later, can be attributed to low power modes. Along with VCRs, a common factor for DVD players, VCR and HIFI is the presence of consumption in low power modes during most of the day as is it presented in a later part of this document.

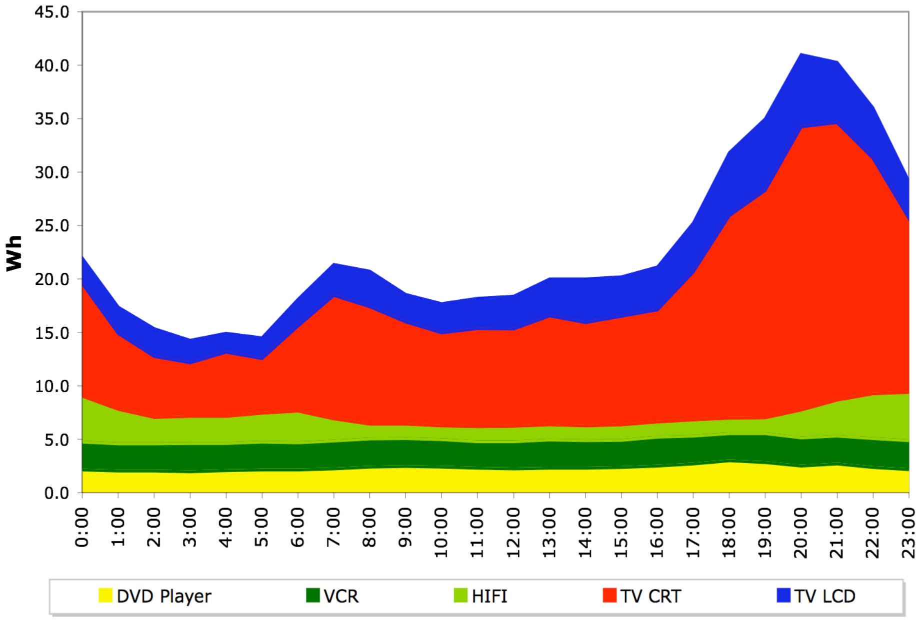

Figure 24. Daily load of appliances in the home entertainment end-use

The second pattern corresponds to TV sets independently of the technology used (CRT or LCD). There are two clear peaks along the day: the first one between 06:00 and 08:00 in which consumption is around 15Wh. This pattern can be attributed to the fact of people watching TV as they are preparing to leave their homes to their respective working or studying places. After this period, there is a decrease in the power use to around 8Wh, which remains relatively constant until 17:00 (time when dwellers start returning home). It can be considered as a period of mixed use between an eventual use in normal mode and consumption in a low power mode. Additionally, as Figure 24 presents a typical day, the values of both weekdays (Monday to Friday) and weekends (Saturday-Sunday) are included. It is possible that people watch more TV on weekends during the periods they usually do not during the weekdays (e.g. between 08:00 and 17:00).

The next segment of the typical day shows a higher consumption (around 25Wh), especially between 20:00 and 22:00. From this pattern, it is clear that dwellers in the average Hungarian household prefer to watch TV during this fraction of the day. As values are consistently high in comparison to those of the previous hours, it can be assumed this pattern is similar for both weekends and weekdays.

Although the patterns between the two technologies are basically the same, there is a difference in the power use according to the technology type. CRT sets are still the dominant technology in households. For this reason, their consumption in the typical household is considerably higher than that of LCD technologies. However, with the advent of digital broadcasting, larger high-resolution screens are becoming a requirement to benefit from features not available for traditional CRT technologies such as high definition (Lee *et al.* 2006). As prices of LCDs fall, the penetration of these devices in household is expected to continue increasing.

4.2.3.4 Office equipment

There are three predominant trends in the daily profile of office equipment: the first correspond to appliances with constant electricity consumption (e.g. modems, routers). The second to appliances with relatively constant consumption but with slight changes along the day (e.g. printers). The third one involves appliances with significant differences in power use during particular segments of the day. Within the first group, the power use of modems and routers is practically constant (around 1.5Wh) without any evident change during the 24hours period (bottom of Figure 25). These devices (modems and routers) must be turned on to allow users the connection to internet. In this sense, the fact that there are no variation along the day, suggests that users rarely turn the devices off even when PCs and laptops are not in use. In the case of faxes, the pattern of use is similar to that of modems and routers, meaning that most of the time the device is in an idle mode.

The second pattern is relatively similar to the previous one especially during the early morning (00:00 to 06:00). During this period when most of the dwellers are asleep, the consumption can be attributed to low power modes (e.g. off mode). However, during the rest of the day it is possible to observe an increase in the consumption, especially between 09:00 and 17:00 (an average 0.8Wh). This consumption can be the result of a combination of eventual printing periods with the periods in an idle mode (low power mode). After 18:00, the consumption reduces but still is slightly superior to that in the early morning. Unlike modems and routers, the pattern suggest that dwellers turn on their printers probably at the same time as PCs, and turn them off when they finish their activity during the late night.

The third pattern, typical of PCs, laptops and speakers (Figure 25 Top) presents a low consumption (between 3Wh to 5Wh) during the early hours of the morning (01:00-06:00). However, there is an increase in the power use from 08:00 until 14:00 (around 15Wh, mainly for the set desktop-monitor). After this period there is a new increase during the nighttime (especially from 20:00 to 23:00). Unlike TV sets, the differences between the consumption peaks between the day and night are not so acute. Even when the Figure 25 shows an average value that includes both weekdays and weekends, it seems clear that the use of PCs in households is higher than TV sets during the morning and afternoons. In both cases, during the nights, the consumption of the two appliances is the highest. Speakers, as peripheral devices, appear to have the same structural behavior as PCs: an increasing power use as the day progresses, especially during the night from 19:00 to 20:00. The fact that consumption during times of no use (such as during the early morning) does not drop to levels close to zero, suggest that speakers are probably left in an idle state. Finally, laptops show a similar activity pattern to that described for PCs. However, in this case the overall pattern is not as evident as it is for PCs. This low electricity consumption in the average Hungarian household (represented by a thin strip in Figure 25) can be attributed to the low penetration rate of laptops in comparison to that of PCs.

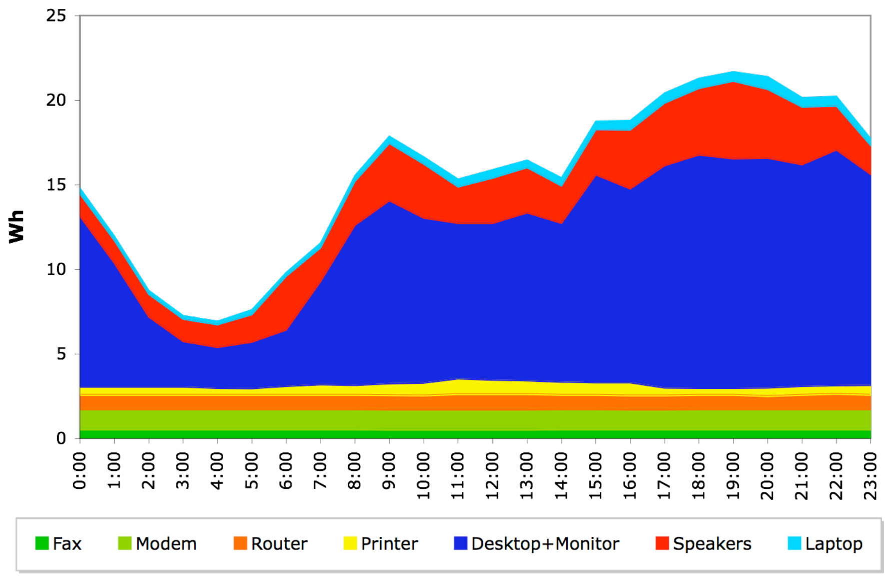

Figure 25. Daily load of office equipment

4.2.3.5 Cooking appliances

Unlike the previous end uses, for which there are some appliances with few variations in the power use, in this category it is possible to identify two peaks of activity during the day. Microwave ovens have a phase of inactivity during the early morning from 00:00 to 05:00 with a power use of around 9Wh, the highest of the displayed appliances (Figure 26). After this phase it is possible to recognize increases in power use taking place at 07:00, 12:00 and 19:00. Interestingly, these periods of the day basically corresponds to the times in which people usually have their main meals of the day (breakfast, lunch, dinner). Another interesting fact is the high consumption of this appliance during the periods it is not in use (around 2/3 of the highest consumption). This finding is important considering that it can be reflecting consumption in a low power mode. For the other three appliances displayed in Figure 26 (coffee maker, electric kettle and toaster) there are only two peaks in the consumption: one during the morning (between 07:00 and 08:00) and one during the night (19:00-21:00). For toaster appliances the height of the peaks are relatively similar for the two periods. It may indicate that sliced bread is an important complement of the meals not only for breakfast during the morning but also during the dinners. The pattern is also shown by electric ovens, which are basically used during the times around meals (especially lunch and dinners).

For the next two appliances the patterns are certainly more revealing in terms of user's preferences. For instance, coffee makers are actively used during the breakfast time (between 07:00 and 08:00). Although there are some power use onwards, the height of the peak is a clear indication that coffee is most preferred as part of the breakfast but not later in the day in the average Hungarian household. A different pattern is found for the use of electric kettles. This appliance is used in both breakfast and dinnertime periods. In general it is used for boiling water to prepare hot beverages such as tea and coffee. However, considering the use patterns of coffee makers, it is likely that kettles are mostly used in the night to prepare other hot beverages such as tea. For both type of appliances it appears to be a minimum consumption during times when its use is not expected (between 01:00 and 04:00 hours). In general, this type of appliances are not considered as big consumers on standby periods. For instance, Grinden and Feilberg (2008) found for the REMODECE project that standby from water kettles is around 0.1kWh/year, while in New Zealand, the HEEP project reported no consumption from coffee makers in standby mode (Isaacs *et al.* 2006)

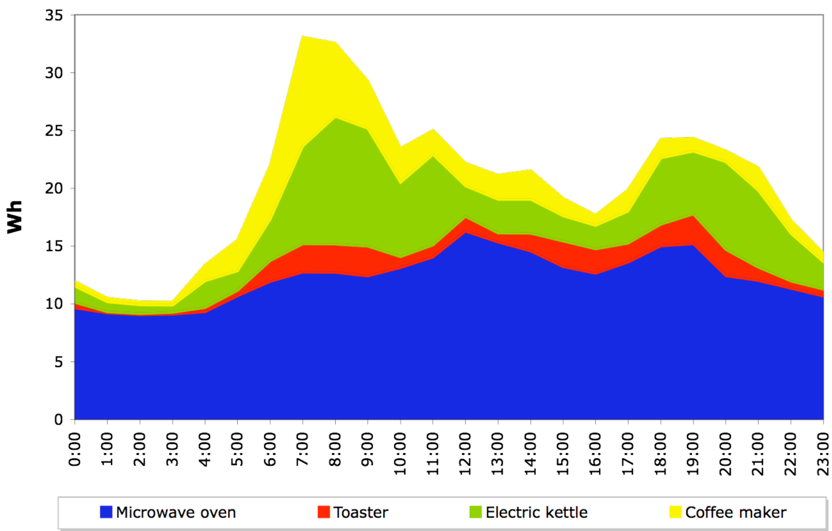

Figure 26. Daily load of cooking appliance

4.2.3.6 Water heating

According to the results of the breakdown of end uses, this is one of the single appliances with the largest electricity consumption in the average Hungarian household. As shown in Figure 27, the strongest peak takes place around 07:00 hours (35Wh), a time in which most people is preparing for their daily activities (work, school, among others). After this time, the pattern is not defined with consumption fluctuating between 15Wh and 25Wh. This can be the result of a random pattern of use involving not only water heated for showers but also for use in bathrooms (e.g. hand washing) and in kitchens. Even when the share in the consumption can be considered as high, the analysis of the sales show a downward trend. In 1990, electric water heaters had a market share of 75% in the country, while in 2005, the shared plummeted to 44% (for 2010 the estimated market share is 40%) (Kemma *et al.* 2007)

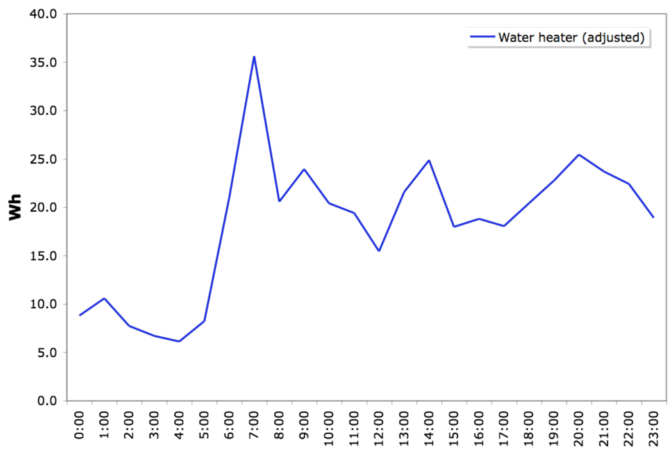

Figure 27. Daily load of water heating

4.2.3.7 Miscellaneous appliances

This is probably the end use for which it is most difficult to provide an analysis of use patterns considering the variability of appliances and also the few number that were monitored. Figure 28 provides a general overview of the daily load for selected appliances. A combination of peak times and periods of no use are the most distinguishable patterns. For instance, electricity consumption from radios presents two peaks: one during the morning and another during the night. Cordless phones and toothbrushes present a constant consumption throughout the day (flat strip in the bottom of the Figure 28, with consumptions below 1Wh). Vacuum cleaners are predominantly used between 10:00 and 14:00 hours (with a power use as high as 12Wh). For this particular appliance it interesting to see that there is a significant consumption during the earlier hours of the day. As it is not common to use vacuum cleaners during the early morning (01:00 to

05:00), this consumption is basically due to low power mode, indicating that the at least some of the appliances are not unplugged from the mains after use.

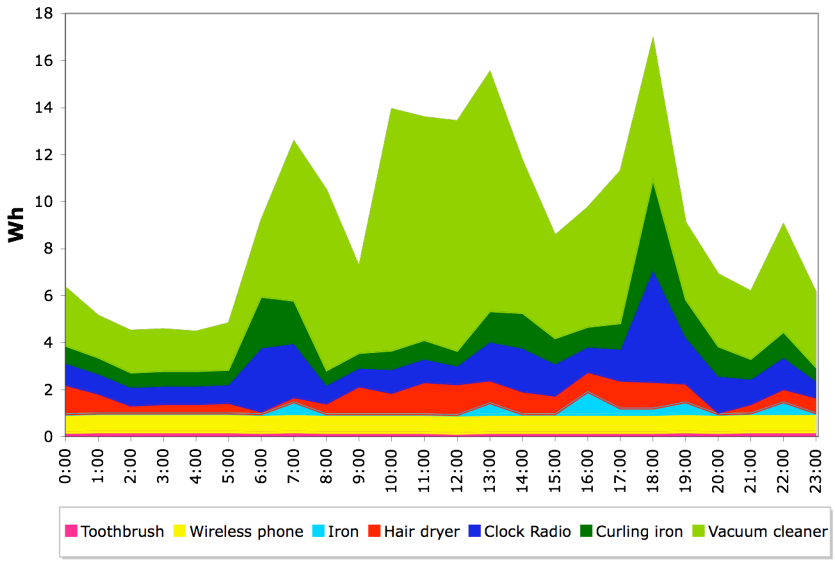

Figure 28. Daily load of miscellaneous appliances.

4.2.3.8 Summary of findings –daily profiles-

The analysis of the daily profile provides a reference on how selected appliances are used duringa typical day in Hungarian households. The identified patterns include: *appliances with an active use during specific periods of the day* and *appliances with a relatively constant power consumption*. Among the first, appliances such as light sources, TV sets, computers present their highest electricity consumption between 19:00 and 23:00 hours. Some other appliances, such as washing machines present two defined peaks: around noon and during the night (around 19:00). Coffee machines are used exclusively during the morning (07:00), while in contrast electric kettles are used both in the morning and during the night. Apparently, coffee consumption during the night is not a widespread practice in the average household.

In the second group, appliances such as modems, routers, DVD players, VCRs, cold appliances present a relatively constant consumption during the day. In this case, as appliances such s DVD players, modems are certainly not performing its main function during the day. In this sense, the daily profiles provide additional information on the electricity consumption patterns of the household. In this case, it constitutes an initial indication of the consumption in the so-called low power modes (e.g. standby when the appliance appears to be off, but it is drawing power from the mains). As presented in the next section of this work, for some appliances (especially ICT equipment) most of the electricity consumption takes place when they are in low power mode.

4.3 Analysis of power use levels ICT equipment

This section presents the results of the analysis of power use levels for ICT equipment (home entertainment and office equipment). It has three main components: the *determination of reference values* for the different power levels, the use of these reference values to determine the *time spent and the power consumed* in each power level during a 24hour period). Finally, the *consumption values in the low power modes are annualized* in order to determine its share in the final electricity consumption of Hungarian households. Data from different sources was used as criteria to classify a value as low power or normal modes in this study. The main one is the Lawrence Berkeley National Laboratory, which has a set of measurements in different power levels for selected appliances (LBNL 2010). Other sources include: The HEEP project (Isaacs *et al.* 2006) and low power mode measurements for different appliances in Hungarian households by Valentova (2007).

4.3.1 Power use levels: reference values

4.3.1.1 Home entertainment

Table 10 presents the average values (in bold) for the different power use levels obtained by using the analysis of frequency distributions. For all appliances it was possible to determine at least one low power mode (LP1 and/or LP2). One of the most interesting findings is the fact that there are usually two reference values for the low power mode. This means, for instance that when the appliance is in off mode, the consumption fluctuates (usually between contiguous values). In other words, the power use is not constant when the appliance is in low mode. When the time series is examined for the period in which the appliance is in off mode (e.g. between 02:00 and 04:00 hours) it is found that fluctuations can take place as often as every 10 minutes.

The analysis complements the spot measurements since usually one single value is recorded as reference value for a particular power level. This explains the presence of two average values for the LP1 (off mode) and LP2 (active standby). For the normal mode, the average represents the value at which usually the active mode starts. It is assumed that values above are also part of normal mode. As it can be seen, there are no zero values as part of the minimum values recorded for the LP1 (off mode). The analysis of this finding is presented later.

Table 10. Reference values for different power use levels (Home entertainment)

		LP 1 (Off- mode –passive standby-)			LP 2 (Active standby)			Normal mode		
Appliance	**Count**	**Mean (W)**	**Min (W)**	**Max (W)**	**Mean (W)**	**Min (W)**	**Max (W)**	**Mean (W)**	**Min (W)**	**Max (W)**
TV (Total)	43	**1.1**	0.1	4.0				**10.3**	6.0	18.0
		1.5	0.2	4.5						
TV (CRT)	39	**1.0**	0.1	3.6				**10.0**	6.0	18.0
		1.3	0.2	4.0						
TV (LCD)	4	**2.5**	0.1	4.0				**13.6**	12.8	14.4
		2.9	0.2	4.5						
DVD	9	**0.4**	0.1	0.8	**2.8**	1.0	6.0			
		0.8	0.6	0.9	**3.9**	1.8	5.0			
VCR	8	**0.9**	0.3	2.8	**1.5**	1.0	2.4			
		1.2	0.4	3.2	**1.8**	1.2	2.8			
HIFI	12	**0.6**	0.1	1.5	**2.3**	0.6	4.5			
		0.8	0.2	1.8						
Radio	10	**0.2**	0.1	0.4	**1.2**	1.0	1.5			
		0.3	0.2	0.8						
Stereo	5	**0.5**	0.2	1.0	**3.6**	2.8	4.5			
		0.6	0.3	1.2						
Set Top Box	3				**1.9**	0.1	2.4			
					2.2	0.2	2.8			
Amplifier	7	**0.6**	0.1	1.5	**3.5**	2.4	4.5			
		0.8	0.2	1.8						

Among the appliances there are two clear patterns: the presence of either one or two low power levels. The former pattern can be regarded as typical of TV sets for which the low power use basically corresponds to off mode. This claim can be supported with two arguments: first, the analysis of the time series for the periods in which the appliance is assumed not in active use (e.g. during the early morning). Second, the analysis of the responses in the REMODECE survey showed that 60% of the TV users claim to turn off the device using remote control (Loftus *et al.* 2009). As usually TV sets are either in on or off mode, the next reference values in the analysis of the frequencies correspond to normal or active mode. For this reason, there are no values in the LP2 in Table 10. The frequency distribution for all TV sets in the sample (Figure 29) shows the difference between the two modes: *low values of power use with high frequencies* (up to 85%) at the left of Figure 29 (between 0.1 and 1.3W) and a *reduced frequency in higher power use* values (usually no higher than 20%), from 6W to around 20W). In other words, the higher the frequency is, the higher the amount of time the appliance is in a determined power use. For instance, a high frequency (e.g. 85%) in a low power value (0.2W) constitutes an indication the appliance is predominantly in off mode.

Valentova (2007) report reference values for lopomo (low power modes) that are relatively higher than the ones presented in Table 10 for office equipment. For instance, for TV sets the average lopomo is 6.8W, while the one obtained in this study is 1.5W. The high value is basically due to the fact there are appliances with lopomos of up to 30W in the sample analyzed by Valentova (2007). In this study, as part of the assumptions, values above 10W-15W are considered as normal mode (appliance in on mode performing its main function). When the time series are examined, it is possible to determine two power modes as it is presented in (Figure 29). For some TVs the minimum power use can be as low as 0.2W and the active can be as low as 6W. Values like this were also inspected in the time series for the hours the appliances are in that power value (e.g. a 0.5W at 03:00 indicates the appliance is off, while if the same appliance at 21:00 has a power use of 8W, it is assumed to be on, based on the analysis of the daily profile).

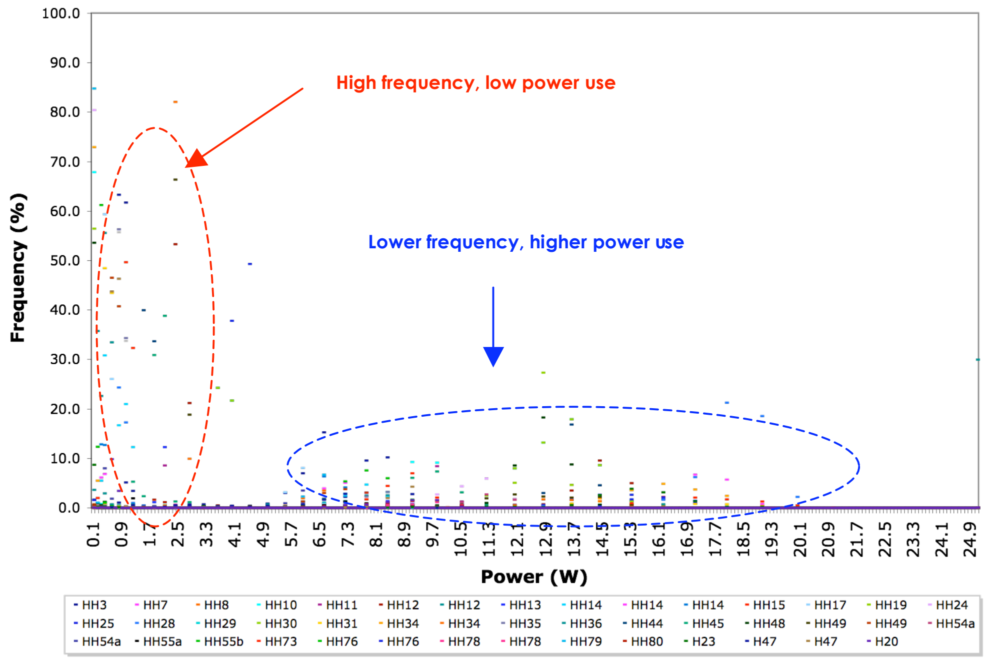

Figure 29. Frequency distribution of monitored TV sets. The dashed lines cover the areas where low power (red) and normal (blue) modes are distributed in the plot.

The second pattern shows equipment for which it was possible to determine two low power modes (LP1 and LP2). DVD players, VCRs, HIFI systems are among the appliances representative of this pattern. As with TVs, LP1 values are basically those find in the early hours of the day when it is assumed that the appliance is switched off. However, there is another set of reference values that are relatively close to the LP1. These values are considered as a low power mode for two reasons: first, the values are low to be considered as typical of consumption in normal mode. For instance, a DVD player in on mode playing a a disk uses between 5.28W-17W (LBNL 2010). Second, their frequency is relatively high, which in practical terms would mean that DVD players and VCRs are playing media actively for more than 30% of the time (e.g. between 7 and 8h a day). This is certainly not a common pattern considering that in general, DVD players and VCRs are sporadically used in households. Figure 30 shows the frequency distribution for the power use of monitored DVD players. The plot shows only the power use values whose frequencies are above zero (indication of power consumption). As it can be seen, most of the values in low power modes are below 6W, with the highest value of power use in 10.5W. This indicates that the monitored appliances were predominantly either in off modes or in on modes (but not playing).

The values obtained Valentova (2007) for VCRs (6.38W) and DVD players (1.44W) are also less basically for the same reason presented above for TVs. In this study in order to define a value as part of a low power mode (e.g. LP1 off mode) an analysis of the time the value is presented (e.g. power values at 04:00 hours and 22:00hours). Additionally, reference values from Lawrence Berkeley National Laboratory (LBNL 2010) were used as reference for the power use in off, standby and on modes. An additional factor tha can explain the difference with Valentova (2007) is the number of monitored devices. For instance, 49 DVD players were monitored in her study, while the time series analyzed in this study include 9 devices. In general, a higher number of devices, the higher the potential variability.

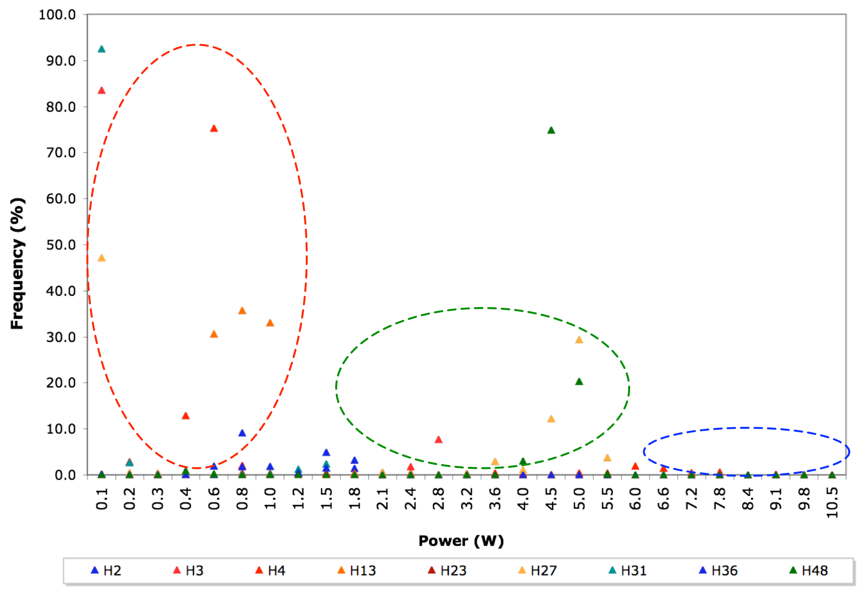

Figure 30. Frequency distributions for DVD players. The three main power levels are shown surrounded by dashed circles

For VCRs, a similar plot for power values with frequencies above zero show that most of them are in an interval of power values shorter than that of DVDs. For instance, in Figure 30 the maximum power value with frequencies above zero is 10.5W, while for VCRs (Figure 31) the maximum value is only 3.2W. This basically indicates that the appliance is basically not being used in households, but it is using power in one of the low power modes (off mode and standby). The likely explanation for this lies in the fact that VCRs are an outdated technology that is being progressively replaced by DVDs and other technologies. In other words, the appliance is not being used by it is still present in Hungarian households as part of the entertainment centre drawing power while plugged to the mains. This finding is consistent with the behaviour during the 24h period presented previously, in which the appliance shows a relatively constant draw of power.

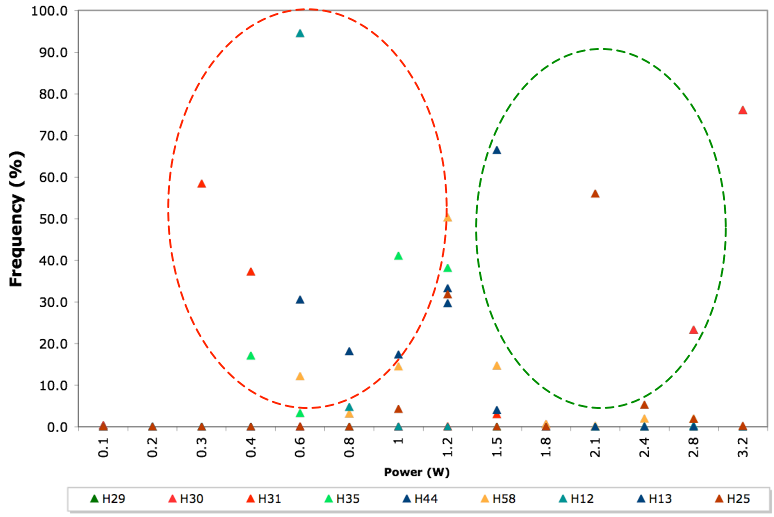

Figure 31. Frequency distributions for VCR equipment. The dashed lines surround the low power modes

4.3.1.2 Office equipment

Table 11 shows the average reference values obtained from the individual frequency distributions of the main appliances. As it can be seen, the project monitored both individual appliances and the whole consumption of the site. In this last case, the reference values are the result of the different power use of the major appliances such as –desktop and monitor- and peripheral equipment (mainly printers, modem, routers and speakers). However, in this case it is not possible to distinguish the individual contributions to the overall reference value. For the individual appliances, a similar pattern to that of the home entertainment end use was found: low power modes (LP1 and LP2) usually have two reference power values. In other words, a range of power values in which the low power fluctuates. For instance, the average LP1 (off mode) of monitor & desktop fluctuates between 0.8W and 1.2W, while the LP2 does it between 8.0W and 9.3W. Usually, when the spot measurements are used to determine the reference values of the different power use levels, they provide only one value, assuming the consumption in one particular power level is constant. The analysis of the time series demonstrates that usually this is not the case.

Table 11. Reference values for different power use levels –office equipment-

		LP 1 (Off mode)			LP 2 (Active standby)			Normal mode		
Appliance	**Count**	**Mean (W)**	**Min (W)**	**Max (W)**	**Mean (W)**	**Min (W)**	**Max (W)**	**Mean (W)**	**Min (W)**	**Max (W)**
Computer site	39	**2.3**	0.6	4.5	**13.9**	9.1	19.0	22.1	20.0	24.6
Monitor & Desktop	17	**0.8**	0.1	2.8	**8.0**	5.5	11.2	18.5	11.2	22.0
		1.2	0.3	3.2	**9.3**	7.8	12.0			
Desktop	5	**2.0**	0.3	5.0	**7.9**	6.6	9.1	14.0	12.0	17.1
Monitor	6	**0.3**	0.1	0.6	**3.6**	3.6	3.6	10.7	9.1	11.2
		0.3	0.3	0.3	**4.0**	4.0	4.0			
Laptop	18	**0.3**	0.1	1.0	**7.9**	6.6	9.1	14.0	12.0	17.1
		0.4	0.2	1.2	**7.8**	7.8	7.8			
Printer	9	**0.4**	0.1	1.5	**1.9**	0.4	3.2	6.1	5.0	7.2
		0.7	0.3	1.8						
Modem	9				**1.0**	0.8	1.8			
					1.3	1.0	2.1			
Router	4				**0.9**	0.8	1.0			
					1.1	1.0	1.2			
Speakers	5				**0.3**	0.1	0.8			
					0.5	0.2	1.5			
Phone	5				**0.3**	0.2	0.4			
					0.4	0.3	0.6			

Two main patterns can be observed in Table 11: The first includes a complex power use level involving three reference values (two for low power modes –LP1 and LP2, and one for normal mode). Desktop, monitor, laptops and printers are the type of appliances with these power use levels. This situation is consistent with the expected use pattern of this equipment. For instance, as it was shown in the daily profiles when not in use the PCs (monitor and desktop) are usually turned off during the early morning. During this period, the power use values are low and correspond to the ones presented in the left of Figure 33. As the day progresses, the devices are turned on again. In general, appliances such as PCs have low energy consumption modes (e.g. sleep) that activate when the user is not performing any activity in the equipment for a given of time. For instance, when users do break times for lunch, dinner or any other reason. In Figure 33, these values are located in the centre of the plot.

Unlike TV sets for which most of the frequencies are in low power use values, for desktop and monitors there are appliances with high frequencies present in high power use values (Figure 33a to the right). This may be an indication than PCs are being used more actively in households than TVs.

In the case of laptops the pattern is similar to PCs. This means that it is possible to differentiate the three power use levels. However, the main difference lies in the fact that for both LP2 and normal modes, the power use is considerably less than PCs. This can be appreciated in Figure 33b where LP2 and normal power use values for laptops are displaced to the left compared to the ones for PCs. This difference in power use is analyzed as one of the potential scenarios for electricity savings later in this study. Zimmermann (2009) proposed for one the most recent projects monitoring electricity in households (Sweden-SEA), the replacement of PCs by laptops as a strategy for energy conservation. In the case of printers it is possible to identify the three power levels. However, unlike PCs and laptops most of the frequencies are present in low power values, indicating the idle status in which these devices usually are.

Compared with the values obtained by Valentova (2007), this study present lower reference values for printers, modems and routers. Again, in this study the number of time series analyzed for those appliances is less than the measurements carried out in that study. However, for these appliances as presented later, most of the time is spent in one power mode. The analysis of the time series clearly show the power values in which the appliance spend most of the time as it is shown in Figure 33 and Figure 34. Only for PCs monitor and desktops, the values obtained in this study are higher than the ones in Valentova (2007): 11W vs. 6W.

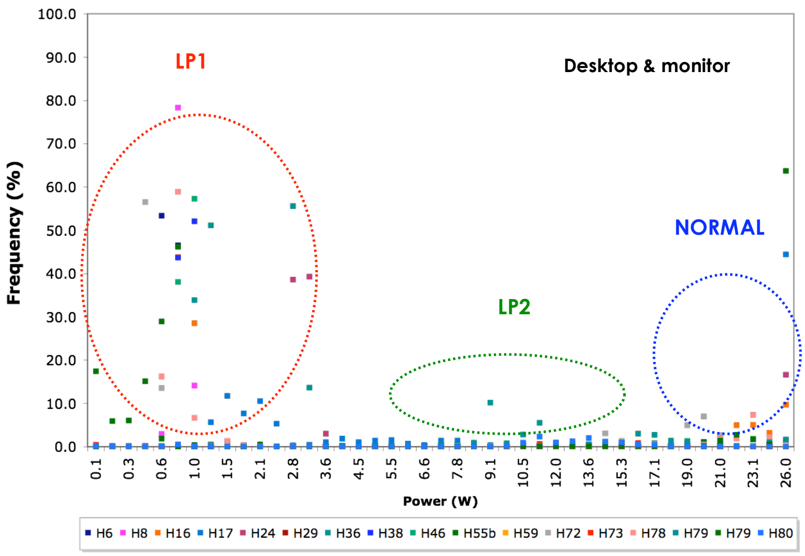

Figure 32a. Frequency distribution of power use values for desktop and monitors

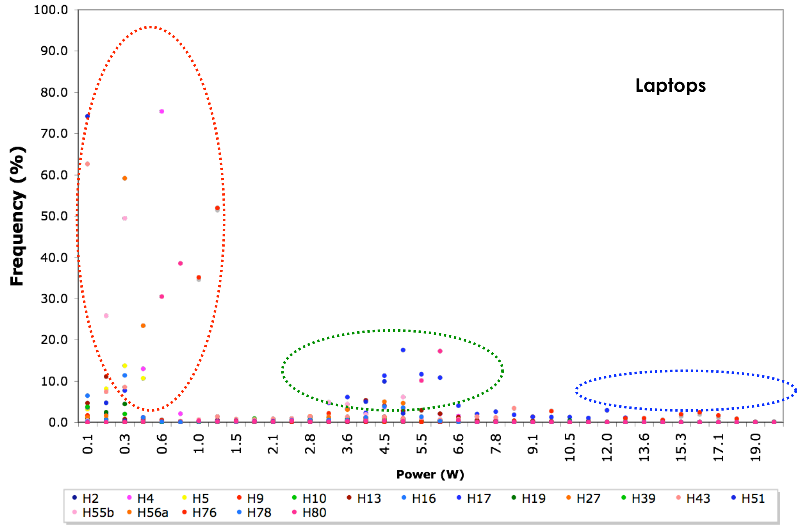

Figure 33b. Frequency distribution of power use values for desktop and monitors (top) and laptops (bottom)

The second pattern found for the office equipment corresponds to appliances that have one low power that basically contains most of the records (frequencies). Within this group, modems and routers are the typical appliances. However, for this equipment there is also an active or normal mode with low frequencies in values higher than 5W[30]. This is coherent with the daily profile analyzed previously for which the appliance appears to have a relatively constant power use with small fluctuations during the day. The pattern is an indication that the appliance is in an idle mode most of the time and rarely turned off. The fluctuations can be caused when the user is using the web. Generally, modems and routers have LED that flashes when they are in active mode (exchanging information with servers). When the PCs and/or laptops are turned off, generally, the LEDs stop flashing. These differences in activity may be the responsible for the fluctuations and the higher values of power use. Figure 34 displays only the power values for which there are records of consumption (frequency higher than zero). The obtained values are inferior to the ones obtained by Valentova (2007) (6.8W and 6W respect.). Again, for this appliance the reference value for the on mode is above 5W. In this case all values in the time series of each appliance are considered as normal mode.

[30] This value is highly consistent with measurements in on mode performed by the Lawrence Berkeley National Laboratory BNL (2010) on modems (average 5.37W). The value in off mode of 1.37W is also highly consistent with the values obtained in this research.

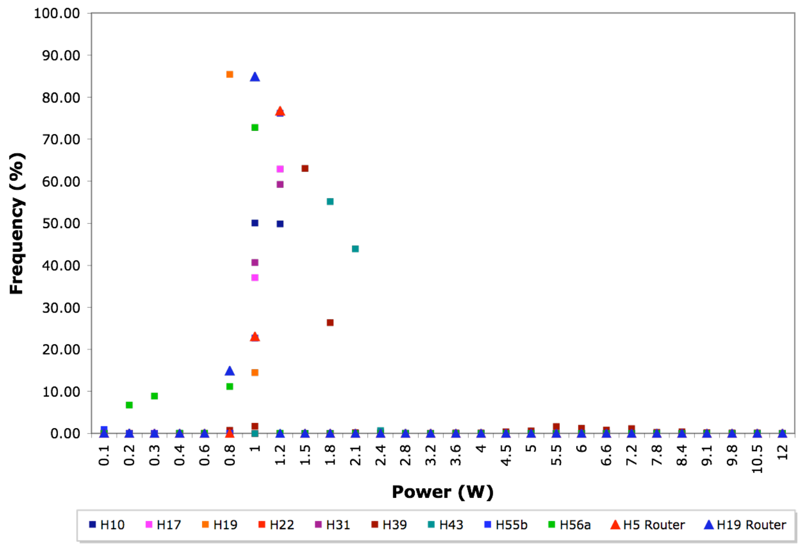

Figure 34. Frequency distribution for modems and routers

In summary, the reference values of the low power modes (LP1 and LP2) for the different appliances were obtained by analyzing the time series of each monited appliance. It was found that the reference values for low power modes are usually two. For TV sets, it was possible to determine two power modes: a low power mode LP1 off mode (1.1W - 1.5W) and an active mode (starting in average at 10.3W). For appliances such as PCs and laptops, the analysis of the time series revealed three power modes: LP1 (off mode), LP2 (active standby) and the normal mode. The comparison with other studies , mainly Valentova (2007), revealed that the valued obtained in this study are relatively less for most of the appliances. A higher number of monitored appliance along with different reference values for power levels such as normal mode can explain these differences.

4.3.1.3 Summary of findings: reference values for power modes

This first part of the analysis of ICT equipment (home entertainment and office equipment) identified the power values (reference values) that helped to define the different power levels. These power levels are: LP1 (off mode), LP2 (standby) and normal mode (appliance in on mode performing its main function). The analysis of the time series (the sequence of measurements on electricity consumption for appliances during the two week period) showed that there are usually two reference values that defined a low power mode. For instance, the average reference values for LP1 of a TV set are 1.1W and 1.5W. However, there are appliances with different reference values for that power mode (for instance, due to different models and efficiencies). That is the reason why the minimum and maximum values are shown in each case. For most of the appliances, the analysis revealed the presence of one low power mode (LP1) (e.g. TV sets). In contrast, for some other appliances such the analysis found two low power modes (LP1 and LP2), such as in the case of computers. Another main finding is that most of the records gathered during the monitoring campaign for ICT equipment are located in low values of power use (less than 7W). As the frequencies are an indirect measure of time, a high frequency in low power value is an indication that the appliance spent most of the time in a low power mode during the monitoring. The analysis of time spent and power used in the different power levels constitutes the analysis of the following section.

Compared to the values of previous studies in the country, the reference values for low power modes are relatively lower in this work. The analysis of the frequency distribution of the power values during the monitoring period found no values for low power modes in frequencies above 10W. For this reason, a value for a low power mode above 20W (found for one of the previous studies), even when it is possible, it is assumed as typical of normal power use. As the process used in this work analyzes the time series of each appliance one by one, the determination of the reference values for each appliance is relatively precise. When compared with international measurements, the values obtained in this work are relatively similar for the low power modes.

4.3.1.4 Treatment of the zero in the time series

As spot measurements are not available for all the monitored appliances, it is not possible to determine in what cases a zero consumption is attributable to: *low power use of the appliance* (connected to the mains but not consuming electricity), *behaviour of the household occupants* (e.g. appliance unplugged from the main) and/or *some other factor* (e.g. failure in the monitoring devices). Given the uncertainty to determine the nature of the zero value in the frequency distribution of some appliances, it has not been displayed as a minimum value of power use in Table 10 and Table 11. In other words, it is not possible to isolate objectively in which cases the zero corresponds to a low power mode from the cases in which zero consumption is due to some stochastic event. As this condition may introduce an error (overestimation of the zero value), these cases were excluded from the calculation of the time spent and the power used in each mode. In fact, in most cases where the zero is present, its frequency is above 90%, while the remaining values correspond to those typical of low power modes (chiefly off mode). This would mean that the appliance was predominantly disconnected and when it was not, it was in off mode.

Figure 35 shows the monitoring period for two TV sets in the same household (HH14). For both, there was a period of six days in which zero values are present. However, it seems that these zero values do not correspond to zero consumption but product of some stochastic event. The reason to assume that lies in the fact there are no other values than zero during that period. After that period, the values show a normal pattern between low and high values. For TV set 1, it is clear that zero is not the lowest power use value, while for TV set 2 it is. As the routine applied to extract the data do no recognize this differences events, all zeros are recorded as if they were part of the normal operation of the appliance. The outcome is a frequency distribution in which the zeros are overestimated and certainly, not part of the normal operation of the appliance. The situation illustrates the uncertainty with the zero value in the time series. However, these cases are basically exceptional and do not correspond to the majority of the distributions.

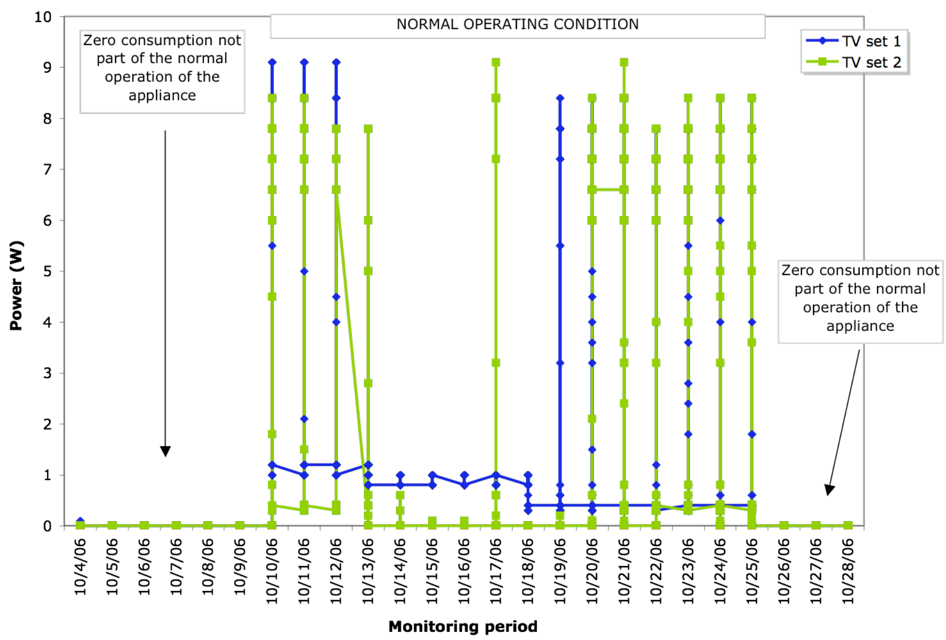

Figure 35. Time series for two TV sets in household 14 (H14)

4.3.2 Time and power use

As presented previously, the analysis of frequencies provides an idea of how the equipment is used. For instance, if most of the frequencies are located in low power values it is an indication that the appliance is predominantly in one of the low power modes (e.g. in off mode). In order to provide a more accurate description of the situation, this section analyzes the *time* the typical appliance is in each of the defined power levels and the consumed *power* during a typical day. In other words, the section analyzes how much time the appliance is in the different power levels (off mode, standby, normal mode) and the electricity it uses on a typical day (24h period). For this purpose, the reference values defined for each of the ICT appliances constitute the basis of the analysis.

As the reference values were determined based on the higher frequencies found for the power values in the time series, there are some intermediate values between them. For instance, in the case of TV sets the average reference value of LP1 (off mode) is between 1.1W and 1.5W while the average for the next power level (normal) starts at 10.3W. As presented in Cogan *et al.* (2007), the power uses in-between the highest frequencies correspond in this case, to switching between off and normal mode and vice versa. The analysis of frequency distribution is a more inclusive and integral approach since these intermediate values are considered. The intermediate (Int.) values are defined as:

Int. 1: Power uses below LP1. It takes place when the appliance changes its status from an off level to an off mode (e.g. when it is connected and disconnected from the mains). It is not very common considering the low frequencies it usually has.

Int. 2: Power uses between LP1 and LP2 for appliances with two low power modes such as PCs and laptops. Alternatively, it is the power use between LP1 and normal mode, such as in the case of TV sets. It corresponds to the power used in the process of changing between operation modes.

Int. 3. Power use in-between LP2 and normal modes. Equipment with function such as sleep modes and other energy saving options such as PCs and laptops, usually have this intermediate power use.

4.3.2.1 Home entertainment

4.3.2.1.1 Time in each power level

The main pattern that emerges from the analysis of Figure 36 is that most of the average appliances spend at least three quarters of an average day in low power modes (either in LP1-off mode and/or LP2 –standby-). For instance, TV sets are in off mode up to 18h a day, while for HIFI systems, radios and amplifiers it can be up to 20h. DVD players and VCRs spend around 15h a day switched off and up to 7h in standby mode (in on mode but not playing). In general, most of the appliances in this category have linked functions with TV sets. For instance, DVD players and VCR are used mainly to play movies. HIFI systems are devices used to enhance the quality of the sound, a feature that is attractive when movies or music is being played. Amplifiers are devices to improve the quality of the reception in households where reception is poor and the households are not subscribed to paid systems (cable or satellite TV). Considering these relationships between appliances it is possible that when TVs are turned on some of the appliances are turned on as well and vice versa.

It is interesting to note the importance of intermediate levels of power use in terms of time for some appliances. The frequency of these intermediary levels relies on how often the appliance switches between modes. In this sense, it is an indicator that the appliance is not continuously in one mode during the day. For instance, TV sets have a relatively high intermediate value between the off mode and normal mode. From the analysis of the daily profile it is possible to confirm that, even when most of the activity takes place during the nighttime, there is some consumption during the day.

In the case of the normal mode, the obtained proportions are consistent with the expected use that can take place in households. TV sets are the appliances that certainly spend more time in this mode (around 4h a day) compared to the other appliances in this category. Equipment such as DVDs and VCRs are in general, sporadically used. For this reason the fraction of the time in normal mode is considerably less. Moreover, considering that the period of monitoring was in average 2weeks, the probability of the appliance being used in that interval was not very high. In the case of HIFI systems, as devices used to improve the quality of the sound, it is probable that its use is increased when movies or music are being broadcast on TV or played by DVD players.

Set top boxes present a different pattern in comparison to the other appliances in this category as they spend most of the time in a single power mode. This is probably due to the fact that when TV sets are used, the set top boxes must be in on mode as well. But when users stop watching they turn off their TV set but not the set top boxes. When the user turn their TV set on again, the set top box is still on. With a pattern like this, it would be understandable the user do not feel the necessity to turn the box off when finishing watching TV. In the analysis of the results of the REMODECE survey, 75% of the respondents said they turn off the appliance, either using the on/off button or with the remote control (Loftus *et al.* 2009). This declared pattern is certainly not reflected in the obtained results in which the appliances seem to be virtually, on all the time. It is a contradiction between declared behaviour and what the data analysis really shows.

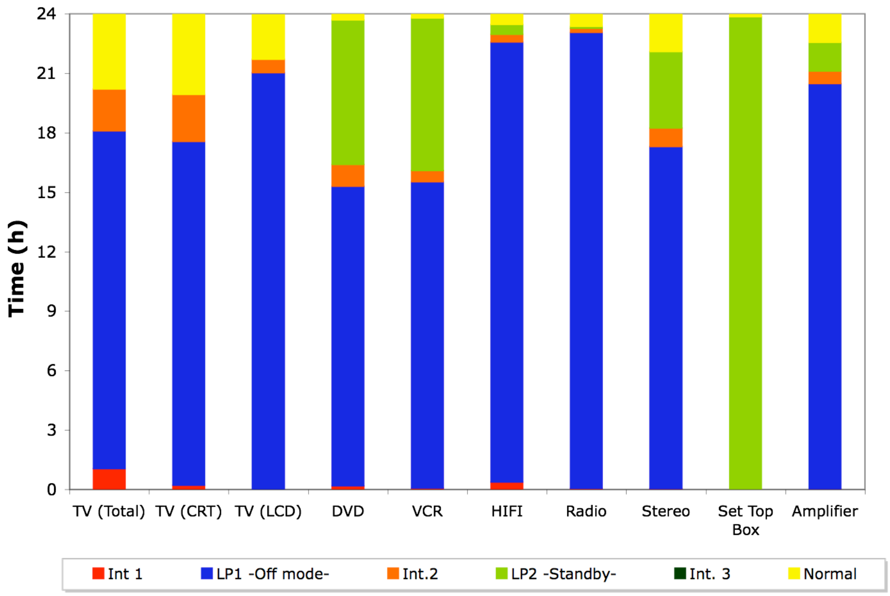

Figure 36. Time spent by the average appliances in different levels of power use. Home entertainment.

In comparison with the results of Valentova (2007), the time spent for the different appliances in the home entertainment category is very similar. TV sets are up to 18h in low power mode, VCRs and DVD players up to 21h (combining LP1 and LP2). Similar values are obtained for set top boxes, which are basically in the same power level all the time.

4.3.2.1.2 Power use in each level

Figure 37 shows the power used by appliances in the different power levels in a 24h period. Unlike the pattern described above in which appliances spend most of the time in low power modes, when it comes to power use there are some differences. For instance, for TV sets most of the power use can be traced to the normal mode and when the appliance switches between off and normal modes (63W). The remaining power use corresponds basically to LP1 (off mode). Even when it is expected that most of the power use comes from the appliance in normal mode, it is interesting to notice that the process of turning off and on appliance has also a relevant consumption. Again, this pattern puts in evidence that the process of watching TV is not continuous. It is carried out in different periods of time, especially between 07:00 and 18:00 when the pattern is not well defined. In contrast, during the nighttime the use pattern is clearly defined and most of the consumption takes place during this period. For TV sets, Valentova (2007) obtained a value of 124Wh/day of electricity use in lopomo. This value is almost 4 times higher than the one obtained in this study (37Wh/day). The most likely explanation for this gap is the fact that in that study the reference values for lopomo for this particular appliance are as high as

30W. In this study, these types of values are regarded as consumption in active (normal on mode).

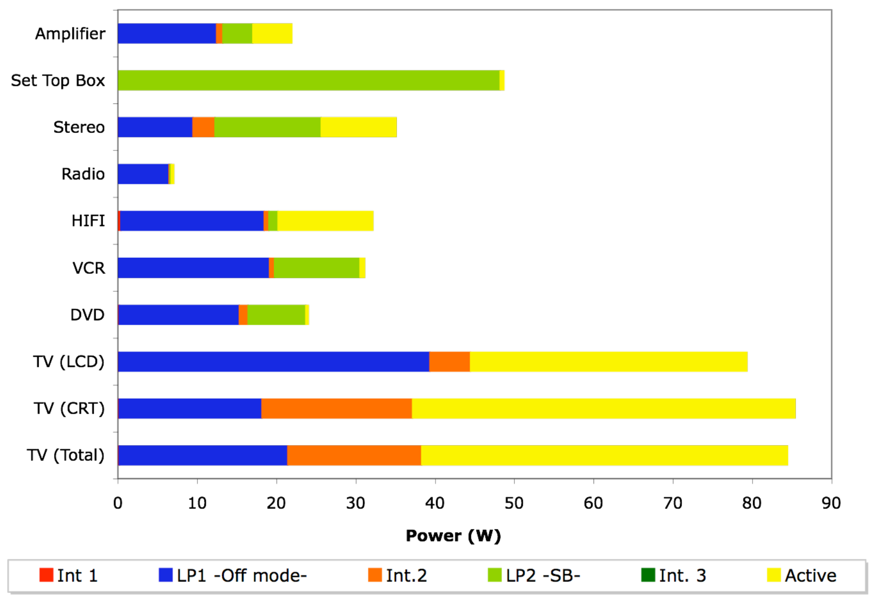

Figure 37. Power use of home entertainment appliances in different power levels during a typical day

In contrast, most of the power used by DVD players and VCRs can be attributed to the low power modes, especially the off mode. As it can be seen, the fraction of power use in normal mode is marginal compared to the one in low power modes. Stereos, amplifiers and HIFI systems present a pattern that it is relatively in the middle of that of TV sets and DVD players. For these appliances, the proportion of power use in normal modes exceeds that of VCRs and DVD players, but it represents a lower proportion of that of TV sets. In other words, this equipment is used more often than DVD players and VCR but even so, it has a considerable power use in low power levels. This can be explained considering the important fraction of the time spent on these modes. In comparison with the results of Valentova (2007), DVD players have a similar consumption in lopomos: 25Wh/day (LP1 and LP2) vs. 30Wh/day in her study. However, for VCRs and HIFI systems, the values are again considerably higher than the ones in this study: 133Wh/day and 76.8Wh/day respectively. In this study, for these appliances the obtained values were 34Wh/day (VCR) and 20Wh/day (HIFI). The most likely explanation for these gaps can be attributed to the values used in each study as reference for low power modes.

4.3.2.2 Office equipment

4.3.2.2.1 Time in each power level

There are two clear patterns that can be distinguished in relation to the time spent in each of the power levels (Figure 38). The first correspond to appliances that are in low power modes during important fractions of the average day (chiefly LP1 –off mode). PCs (monitor and desktops), laptops and printers are representative of this pattern. The average PC and laptop spend at least two thirds of the day in off mode. This pattern is confirmed when the whole set of appliances–PC and peripherals (computer site)- is analyzed together. For laptops, the intermediate values between LP1 and LP2 are more relevant in time than for PCs. As with TV sets, it can be an indicator that the use of laptops in households during a typical could be more intermittent than for PCs. However, as shown in Figure 38, the importance of intermediate values between LP2 and normal mode can indicate that even when the appliance is on, there is an important switch between phases of inactivity and activity. For instance, PCs going from sleep mode or other low energy option to normal mode and vice versa. In the case of printers, the main difference with PCs and laptops resides in the fact that the time spent in normal mode is considerable less. This is pattern is consistent with their daily profile, which shows that printing is not a regular and constant activity, in the average household. However it is important to highlight that even when not in active use, printers are usually switched on and remain in an idle state during a period of time relatively less than PCs and laptops (around 4h a day).

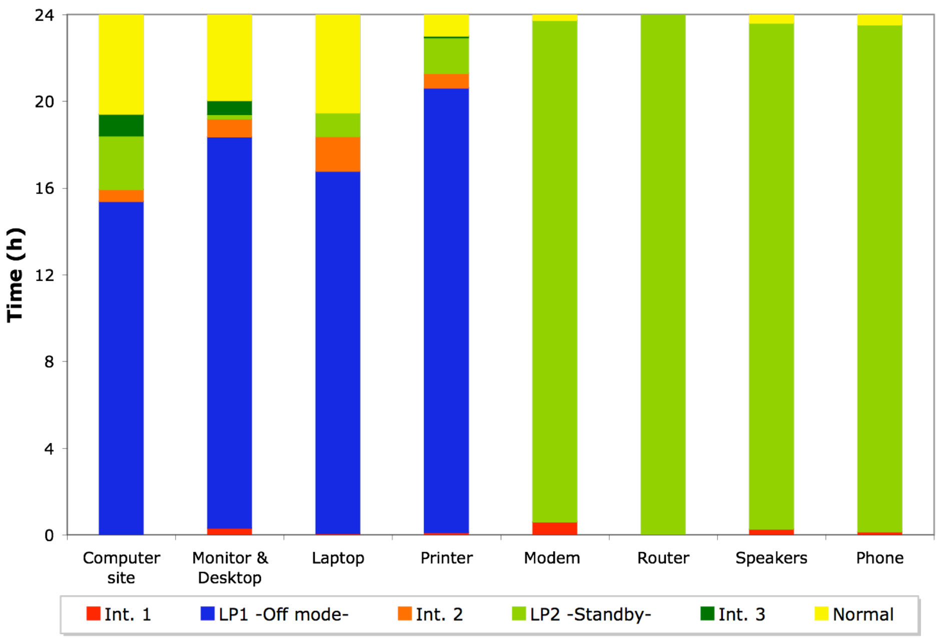

Figure 38. Time spent by office equipment appliances in different power levels during an average day

The second pattern is present in appliances for which one single power level dominates the average day. Modems, routers and speakers are among the appliances showing this pattern. During the analysis of the time series it was difficult to define whether this power level corresponded to standby (LP2) or to normal mode. According to the definitions adopted for the different power levels in this research, the normal mode corresponds to the situation in which the appliance is performing its main function. However, PCs and laptops (appliances for which modems, routers and speakers carry out their functions) clearly show periods of time in different modes. In other words, independently of the power mode in which PCs and laptops are during the day, the one of modems, routers and speakers remains the same. Considering this, the peripheral equipment (modems, routers and speakers) does not execute its main function all day long. For this reason, the convention used in Figure 38 to represent the power level of these devices corresponds to LP2 (active standby).

In general the time spent by office appliances in low power modes (LP1, LP2 and intermediates) is very similar to the reported by Valentova (2007). In her study, PCs are in low power mode 19h (18h in this study). For appliances such as modems and routers, basically all day (24h) is spent one power mode.

4.3.2.2.2 Power use in each level

The description of the power use in different power levels can be grouped in two patterns. One for which most of the power use occurs in normal mode and other for which it occurs in low power modes. For PCs (desktop and monitors) and laptops –representatives of the first group- the share of the power use in normal mode can be up two thirds of the total power use (around 40W). The remaining power use occurs when the appliances are in off mode (LP1)(Figure 39). It is interesting that intermediate levels of power use have an important share in comparison with the other appliances. As discussed previously, an increased share of these intermediate values usually correspond to an intermittent use of the appliance. For instance, when PCs are left unattended for some period of time, energy saving options such as sleep for either the computer (desktop) or the display (monitor) may be activated. This switching process between power levels is the responsible for the increase in the share of intermediate values.

The pattern is also confirmed by analyzing the share of the power use in the different power levels for the computer site. It is important to mention that the values displayed in Figure 39 for computer site correspond to actual measurements for the whole set of monitor, desktop, speakers, modems among others. Additionally, the appliances monitored as a whole are not the same that were individually monitored and whose power use is shown in the same Figure 39. Interestingly, if the total power use of the average individual appliances (speakers, router, modem, printer, desktop & monitor) is added, the obtained value is rather similar to that obtained for the computer site. The obtained values are inferior to the ones in Valentova (2007). She reported a daily consumption of 114Wh/day for desktops and monitors. This figure is ostensible higher than the 37Wh/day obtained in this study.

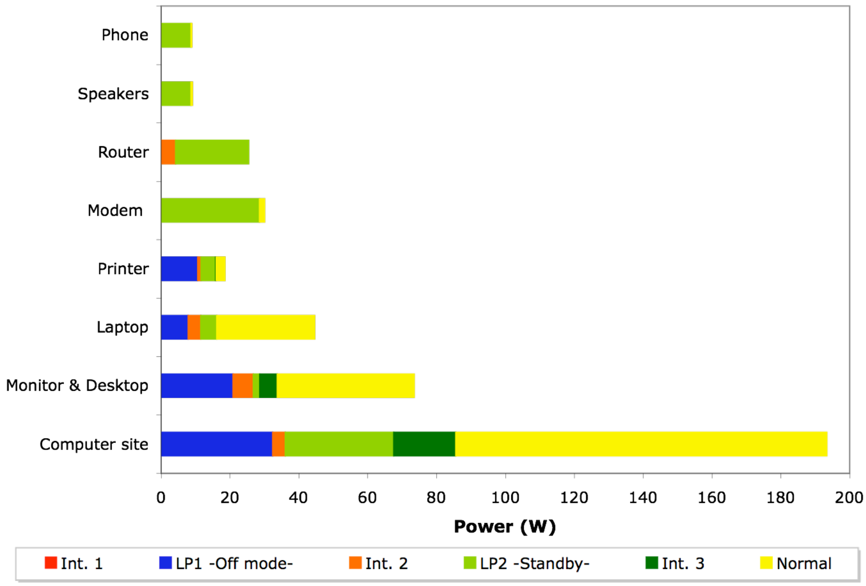

Figure 39. Power use in different power levels (office equipment) during a typical day

The second group of appliances includes those for which most of the time is spent in one power level: modem, router and speakers. As mentioned previously, this single power level can be considered either as active standby (LP2) or normal mode depending on the definition. In this case, as it is unlikely that most of the time the appliance is performing its main function, it was decided to regard it as active standby (LP2). However, it can also be argued that the absence of relevant changes in power use between the periods in which the appliance is used and the period when it is not can be considered also as normal mode. This pattern is similar to the described for set top boxes. In Valentova (2007), the consumption in lopomos of modems and routers is higher (141Wh/day and 163Wh/day respect.). In this study, the consumption values for both appliances are not higher than 35Wh/day.

Finally, printers are the only appliances for which low power modes (LP1 and LP2) represents the levels that are responsible for most of the power use. According to the data, it seems that printers followed the same pattern of power use in low power modes as PCs. This can be an indication that when PCs (and eventually laptops) are either turned on and off, the same may be true for printers. However, as discussed previously, the appliance executes its primary function on sporadic occasions (it is usually on an idle mode). This is the main difference with the pattern described for PCs and can explain the low values of power use in normal mode of printers.

4.3.2.3 Summary of main findings

The main finding in relation to *time* is that all appliances in the ICT category (home entertainment and office equipment) spend up to 75% of the time in low power modes. TV sets and computers are the appliance with the highest number of use hours during a typical day in the average Hungarian household (Between 4-5hours). In contrast, most of the remaining devices are predominantly in one of the low power modes (especially LP1 – off mode). Appliances such as modems, routers are all time in one power level even when they are not in use (e.g. when the computer is off). Appliances such as VCRs and DVD players, which are sporadically used, spend most of the time in off modes.

When it comes to *power consumption,* for appliances with the highest hours of use such as TV sets and computers, around 60% of the electricity consumption occurs when they are in normal mode performing its main functions. The rest of the consumption takes place when the appliance is in a low power mode. In this sense, these appliances are the exception compared to the remaining ICT equipment. For DVD players, VCRs, speakers, printers, more than 90% of the electricity consumption occurs when the appliances is in a low power mode. Modems and routers are in one power level all time (practically, all day). In this case, the appliance is on but not always performing its main function (e.g. during the early hours of the morning when the occupants are asleep). For this reason, it is difficult to define either if it is in a low power mode or in a normal mode. As computers are most of the time in low power mode (appliances for which modems and routers perform their function), the consumption from these appliances was regarded as that one of a low power mode (LP1).

4.3.3 Discussion with previous studies in the country

The main reference for this section is the study carried out by Valentova (2007) in Hungarian households. As presented above, the reference power values for lopomos are higher than the ones obtained in this study. When the results of that study are analyzed it can be found that for some appliances, there are values that in this study were not regarded as lopomos. For instance, a lopomo power of 30W in the study of Valentova (2007) is not considered as a low power mode in this study. From the analysis of the time series of each appliance in none of the cases the higher frequencies in the lowest power use were above 6W for TV sets. Any power above 15W was considered as normal mode. This different approach can explain the differences between the values found in the two studies. In addition to the analysis of the times series for each appliance, reference values from measurements carried out by the Lawrence National Berkeley Laboratory (LBNL) in different power levels (on, off, standby) were used. As the reference values for low power modes in this study (LP1, LP2 and intermediaries) were less than those in Valentova (2007), the obtained electricity consumption for individual appliances is different.

However, when it comes to the time spent by appliances in low power modes, the results between the two studies were strikingly similar. For instance, TV sets and computers spend around 18h in low power modes in the results of the two studies. Appliances such modems, routers and printers are virtually in the same power during all day (between 23 and 24h). DVD players, and VCRs are between 20-22h in low power mode. This similarity in the use patterns (in terms of time) confirms that the main difference with the study by Valentova (2007) was the definition of the power values for low power modes. In this study, those values were defined using the frequency distributions of the power use during the two week monitoring period. Virtually, for all appliances it was possible to determine the power values with the highest frequencies in the time series. These values were also compared with the measurements of the LBNL (2010).

4.3.4 Electricity consumption from low power modes: How big is it?

The previous section showed the proportion of the time and the power used in different power levels by ICT equipment. Among others, the analysis revealed that most of the time ICT equipment in Hungarian households is left in any of the low power modes: LP1 (off mode) of LP2 (active standby). Additionally, it showed that in terms of power use, low power modes are responsible for a considerable fraction of the appliance power use. This section completes the analysis of power use by providing an overall result of the electricity consumption attributed to low power modes and its share in the final electricity consumption of the average Hungarian household. Table 12 shows the power use in different low power modes (LP1, LP2 and the intermediate values *Int. 1,2,3*). These values correspond to the power used during an average 24h period as it was presented in the previous sections. The addition of these values represents the electricity consumption (in Wh/day) from ICT equipment in low power levels. These values are then annualized (kWh/year) and adjusted using their corresponding penetration rates. Additionally, Table 8 presents the fraction of the total power (in %) that corresponds to low power mode.

The appliances with the highest consumption during the average day include set top boxes (48.2Wh/day), TV sets (38.3Wh/day). PCs -monitor & desktop- (33.7Wh/day). DVD players, VCRs, modem and routers have also consumptions above 20Wh/day. With the exception of TV sets, laptops and PCs, for most of the appliances, the consumption in low power modes represents in some cases more than 90% of the daily power use (VCRs, DVD players, routers, modems, set top boxes). As mentioned previously, it seems that appliances (especially some PC peripherals) are left in on mode even when they are not carrying out their main function. This explains the high share in the consumption of the average day. The value of the computer site is put as a reference value of the electricity consumption of the system PC -peripherals in an average day. If the proportion of power use in low power levels is compared for both computer site and PC (only monitor & desktop), the values are relatively similar (44.2% and 45.8% respectively). In general, the larger appliances (TV sets, PCs and laptops) have considerable consumption in low power modes. However most of the electricity consumption takes place when the appliances are in normal operation mode. For the rest of the appliances, most of the consumption occurs when they are in low power modes, indicating that they are ideal targets for energy savings. As discussed previously, the obtained values are lower than the reported by the most recent study on standby in the country (Valentova (2007)

Table 12. Electricity consumption from ICT equipment in low power (LP1-LP2) and intermediate modes (Int. 1-3)

	Int. 1 (W)	LP1 - Off mode- (W)	Int. 2 (W)	LP2 - Standby- (W)	Int. 3 (W)	Total (Wh/day)	Daily power use*** (%)	kWh/year	kWh/year (adjusted)**
TV (Total)	0.2	21.3	16.9	0.0	0.0	**38.3**	**45.3**	**14.0**	**20.7**
DVD	0.2	15.1	1.1	7.3	0.0	**23.7**	**98.7**	**8.6**	**3.7**
VCR	0.0	19.1	0.6	10.8	0.0	**30.5**	**98.1**	**11.1**	**5.7**
HIFI	0.3	18.1	0.6	1.1	0.0	**20.2**	**62.7**	**7.4**	**2.5**
Radio	0.0	6.4	0.1	0.1	0.0	**6.7**	**95.2**	**2.5**	**1.1**
Stereo	0.0	9.4	2.8	13.4	0.0	**25.6**	**73.0**	**9.4**	**12.6**
Set Top Box	0.0	0.0	0.0	48.2	0.0	**48.2**	**99.0**	**17.6**	**2.3**
Amplifier	0.0	12.4	0.8	3.8	0.0	**17.0**	**77.6**	**6.2**	**3.1**
Computer site*	0.0	32.4	3.7	31.5	18.0	**85.6**	**44.2**	**31.2**	**39.4**
Monitor & Desktop	0.2	20.7	5.9	1.9	5.0	**33.7**	**45.8**	**12.3**	**5.7**
Laptop	0.0	7.9	3.6	4.7	0.0	**16.1**	**36.2**	**5.9**	**0.4**
Printer	0.0	10.6	1.0	4.2	0.1	**15.9**	**85.7**	**5.8**	**1.8**
Modem	0.2	0.0	0.0	28.4	0.0	**28.6**	**95.0**	**10.4**	**2.1**
Router	0.0	0.0	4.2	21.3	0.0	**25.5**	**100.0**	**9.3**	**1.3**
Speakers	0.0	0.0	0.0	8.6	0.0	**8.7**	**95.4**	**3.2**	**1.2**
Phone	0.0	0.0	0.0	8.6	0.0	**8.7**	**97.4**	**3.2**	**2.5**
Total ICT equipment						**347.4**		**126.8**	**66.5**

*Not included in the counting **Using the corresponding penetration rates. *** percentage of the consumption attributed to low power modes.

The above description is based on the results obtained from the analysis of the sample without the use of the penetration rates. It allows a more realistic understanding of the proportion of the power used by appliances in the different power levels during the average day. For instance, it is clear that for set top boxes most of the consumption takes place when they are not performing their main function. In the case of TV sets, most of the power use takes place when the appliance is in normal mode. However, the use of the penetration rates is necessary to obtain the share of low power modes in the final electricity consumption of the average Hungarian household. As it can be seen in Table 12, the adjusted values of electricity consumption (kWh/year) differ notably from the ones obtained for the sample. The final electricity consumption of ICT equipment obtained for the sample was 126kWh/year, while the obtained adjusted value was 66.5kWh/year. This is basically caused by the differences in the penetration rates of appliances. In general, the lower the penetration rates the less the impact in the final share in the electricity consumption of low power modes. In terms of end-uses, the home entertainment accounts for 78% of the total electricity consumption in low power modes (LP1, LP2 and int. 1 and 2). This is attributable to the effect of the appliance penetration rates. Most of the appliances with the highest consumption in the office equipment category (PCs and laptops) have a low penetration (0.46 and 0.06 respectively) in comparison with TV sets (1.46).

4.3.4.1 Comparison with previous studies

The adjusted value of the electricity consumption of low power modes (66.5kWh/year or 8W) constitutes 3.2% of the final electricity consumption of the average Hungarian household. This value is notably lower than the reported in earlier studies for the country: Elek (2004) using data from 1997 obtained a yearly consumption of 455kWh/year (52W). Strukanska (2001) obtained a power consumption of 324kWh/year (37W). EIA (2001) estimated in 181kWh/year (20W) the standby in an average household in Hungary. In these cases, outdated appliances and limited sample sizes can explain the high values. The most recent study by Valentova obtained a power consumption of 236kWh/year (27.3W), which corresponds to around 8% of the final electricity consumption of an average Hungarian household. In the case of Valentova (2007), the main reason for the differences with this study are correspond to reference values for the low power modes. In some cases, there were appliances with low power values of up to 30W. These type of values in the present work are regarded as consumption in active mode. In contrast, the time spent in low power modes by the different appliances was remarkably similar to the ones obtained in this study. The obtained value is also lower than the average of EU27 (5.9%) EC JRC (2009). In general, besides the reasons for the differences with the study by Valentova (2007), there are some other likely reasons to explain the low share in the final electricity consumption of the average Hungarian household:

In general, the penetration rates for some ICT equipment are still low for the country (values less than 50 per 100 households). This is especially true for office equipment. For instance, the overall PC penetration rate is 46 per 100 households while that of laptops is only 6 per 100 households. Modems and routers have also low rates (20 and 14 per 100 households respectively). TV sets constitute an exception to this pattern considering that its penetration rate in the country is certainly well above the rest of the other ICT equipment: 148 per 100households. As penetration rates are basically a weighting factor, lower values reduce the impact in the final electricity consumption of the average household. Similarly, the effect is enhanced when the non-adjusted average consumption of the appliance is low.

Another feasible explanation is the combined effect of low reference values for the power levels and the time the appliance spend on them. The analysis of the frequencies showed that for most of the appliances the reference values for the LP1 (off mode) were in general below 2.0W. For the second low power mode (LP2) it was possible to find values above 8W such as in the case of laptops and PCs (desktop and monitor). However, the time the appliance spends in the LP1 is considerable higher than the one spent on the other low power (LP2). The fact that the monitored households were located in Budapest, where the income levels are relatively higher than the rest of the regions, may have had an influence in this sense. In general as income raises, the probability of finding modern energy efficient equipment in household increases. This can explain the low values obtained for low power modes. In many cases, it is possible to find appliances with low power modes below the limit established by the Regulation EC 1275/2008 of 1W for off mode. Considering this, it is possible that the combination of low reference values found for the low power modes and the considerable time appliances spend in LP1 is the responsible, at least partially, for the low share in the final electricity consumption of the typical Hungarian households.

Another factor that can partially explain the low share is the fact that the figure only includes ICT equipment (home entertainment and office equipment). Other studies (Isaac *et al.* 2006, Feilberg and Grinden 2008, CEU 2008, Valentova 2007, Zimmermann 2009) include more appliances in the counting (e.g. cold, washing and cooking appliances). However, considering that these appliances have in general low consumption in low power modes, the obtained figure still appears to be low. In summary, it appears to be there is no a single factor causing the obtained low share but the combination of them: low appliance penetration rates for some of the appliances, combination of low reference values plus extended periods of time in low power modes and the no inclusion of other appliances in the counting.

5. Opportunities for electricity conservation

The potential energy savings can be calculated by comparing the consumption of the monitored appliances with the consumption of energy efficient equipment. Previous studies use the annual consumption of the appliance as the base for the comparison (Fonseca *et al.* 2009 Grinden and Feilberg 2008, Zimmermann *et al.* 2009). As the energy savings are calculated for the average Hungarian household, the values are adjusted using the corresponding appliance penetration rates. The results for the main appliances (cold appliances, lighting, TV sets, laptops, PCs and washing machines) are presented below.

5.1 Energy savings from major appliances

The method to determine the energy savings compares the present state (the one obtained in this study) with the consumption of the Best Available Technology under the same use patterns. The difference between the two scenarios provides the potential electricity savings. By using this approach, it is possible to calculate how much electricity can be saved for each one of the appliances in the sample. Other approaches compare directly the adjusted consumption with the consumption of the energy efficient appliance (Grinden and Feilberg 2008). However, this last approach assumes a similar consumption for all the appliances in the sample. As described previously, the consumption between appliances of the same type can be very different. For this reason, in this section an individual comparison (appliance by appliance) between the obtained consumptions and the energy efficient appliance (BAT) is carried out. This method has been used in the most recent projects that have monitored electricity consumption from appliances, including REMODECE (Fonseca *et al.* 20089) and Zimmermann (2009) use this method in the most recent project monitoring of appliance in the residential sector in Sweden.

5.1.1 Cold appliances

Cold appliances constitute the end use with the largest electricity consumption in the average Hungarian household. For this reason it constitutes one of the main opportunities for energy savings. The consumption of the most energy efficient appliances was obtained from the TopTen[31] (Table 13)

[31] TopTen is an online tool (www.topten.info)that shows a selection of the best appliances available in the European market in terms of energy efficiency, impact on the environment, health and quality.

Table 13. Electricity consumption of the Best Available technology in the market for cold appliances. Elaborated using data from TopTen (2010).

COLD APPLIANCE	Energy use (kWh/year)
Refrigerator without freezer	88
Refrigerator with freezer	161
Freezer (up to 250l)	113

Figure 40 shows the savings obtained when the monitored appliances are substituted with the BAT for both fridges with freezers, (left) and fridges without freezers (right). When the averages are adjusted by their respective penetration rates, the obtained savings are 64kWh/year (fridges with freezer) and 168kWh/year (fridges without freezer). In the case of freezers (not shown in the Figure 40), the calculated savings are the highest with an average of 495kWh/year. The distribution of the savings confirms at some extent, the results of the REMODECE survey. For instance, the highest savings in the left side of both figures show there is an important share of low energy efficient equipment. However, it also shows there are appliances for which the savings are relatively minor (indication of more energy efficient equipment).

When the two BATs are compared, it is clear that the one for fridges without freezers have a higher impact in the savings than the one for fridges with freezers. This is because in the first case, the BAT is considerably more energy efficient than the appliances in the sample. This result is interesting considering that according to the survey the stock of fridges with freezers is relatively older -and potentially, low energy efficient- than the other type of fridge. In the case of freezers, the differences between BAT and the obtained consumption are the highest among cold appliances. This is an indication that the stock of freezers is considerably less energy efficient than the one of fridges.

In any case, considering the differences between the obtained values and the BATs, the exercise shows the existing potential in this end use to reduce electricity consumption in the average Hungarian household.

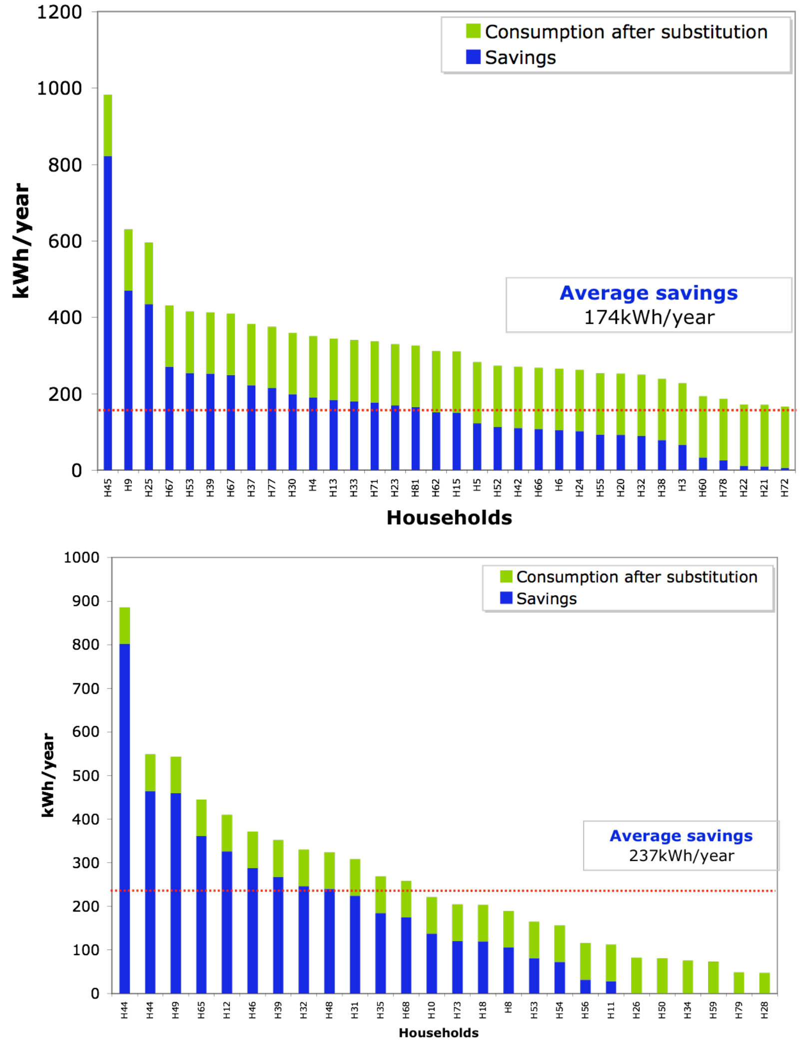

Figure 40. Energy savings obtained by replacing fridges with freezers (top) and fridges without freezers (bottom). The averages in the figures are not corrected by penetration rates.

5.1.2 Lighting

5.1.2.1 Electricity savings

The method to assess the energy savings in this end use consist in the substitution of incandescent light sources with CFLs in each of the room types of the average Hungarian household. As shown in Figure 41, most of the savings are obtained in the living room and bedrooms (the room types with the highest consumptions). Additionally, the category "other rooms" shows an important potential for electricity savings. The kitchen and bathrooms show lower savings considering that the consumption is lower than the previous rooms and the fact that there is an important presence of energy efficient light sources (CFLs and fluorescent). The consumption of the average household after replacement is around 93kWh/year, a value that is almost one quarter of the consumption before replacement. This finding confirms that light sources have one of the most readily available potentials for electricity savings. The ongoing ban on incandescent light sources will foster the achievement of these savings.

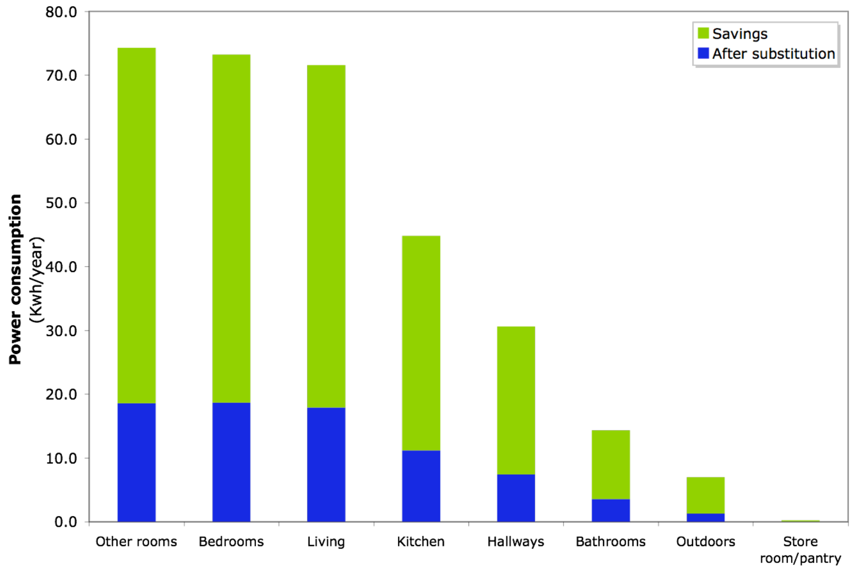

Figure 41. Energy savings after substitution of incandescent lights by room type

5.1.3 Home entertainment (TV sets)

Most of the appliances presents in the sample correspond to CRT technologies with a diagonal less than 110cm. As it was shown in the analysis of the different power levels, theconsumption in active mode is important but also that in low power mode (standby). In this sense, the obtained savings reflect the consumption in both low power and active modes. The most energy efficient TV set available in the market as of May 26 2010, has a power use of 27W in on mode (normal mode) and a standby power use of 0.3W[32]. The reference values were obtained from the TopTen database. Figure 42 shows the annual savings per appliance and the consumption after the substitution of equipment. As it can be seen, the savings are important for some of the appliances, while for others are lower. Additionally, it is also clear that within the sample there are TVsets with lower consumption than the BAT (no savings). High energy efficient equipment and/or low use pattern can explain this result. In any case, the obtained average savings (adjusted) are 68kWh/year per appliance. Prior substitution, the average consumption was of TV sets was 136kWh/year).

[32] These reference value is well below the maximum of 1W set by the Regulation EC 1275/2008.

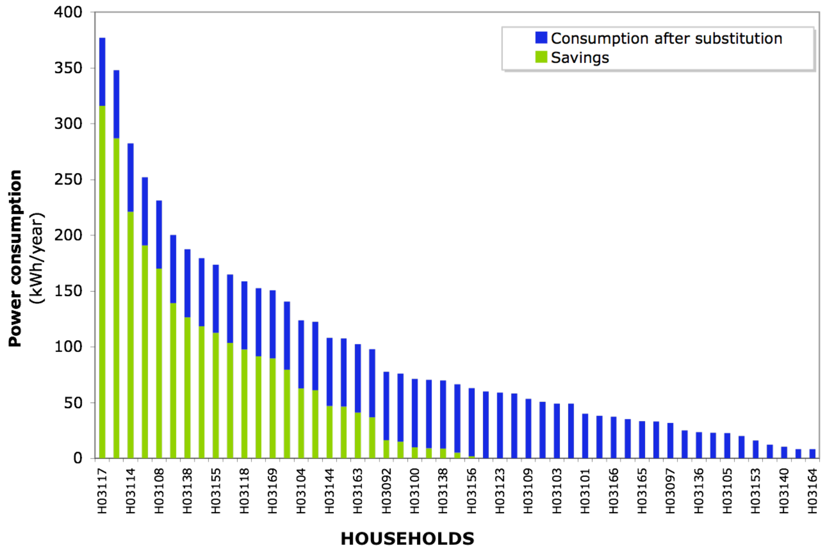

Figure 42. Energy saving from replacement of TV sets with the most energy efficient technology

5.1.4 Office equipment

5.1.4.1 Desktop & Monitor

As with TV sets, the consumption in both low power mode (standby) and active (normal mode) is taken in to account. In order to assess the savings of desktop and monitor, the scenario of energy savings considers replacement of equipment by a laptop with a power use of 20W in on (normal) mode and 0.5 in off mode (passive standby). As laptops are becoming more popular, it was considered as an option to replace traditional desktops. Moreover, the use of equipment like this is becoming more individualized, a factor that is fostering the penetration in households (Green and Ellegård 2006). Figure 43 shows that certainly laptops are more energy efficient than the traditional desktops. As presented in Zimmerman (2009), laptops constitutes and important option to achieve energy savings. The (adjusted) average power consumption before substitution was calculated in 82kWh/year. The use of efficient laptops results in an average (adjusted) savings of 58kWh/year.

Considering the number of computer sites monitored by the project, it was considered interesting to assess the potential energy savings. Taking into the penetration rates derived from the REMODECE survey, a typical computer site includes monitors and desktops and peripheral equipment (speakers, routers, modems and printers).

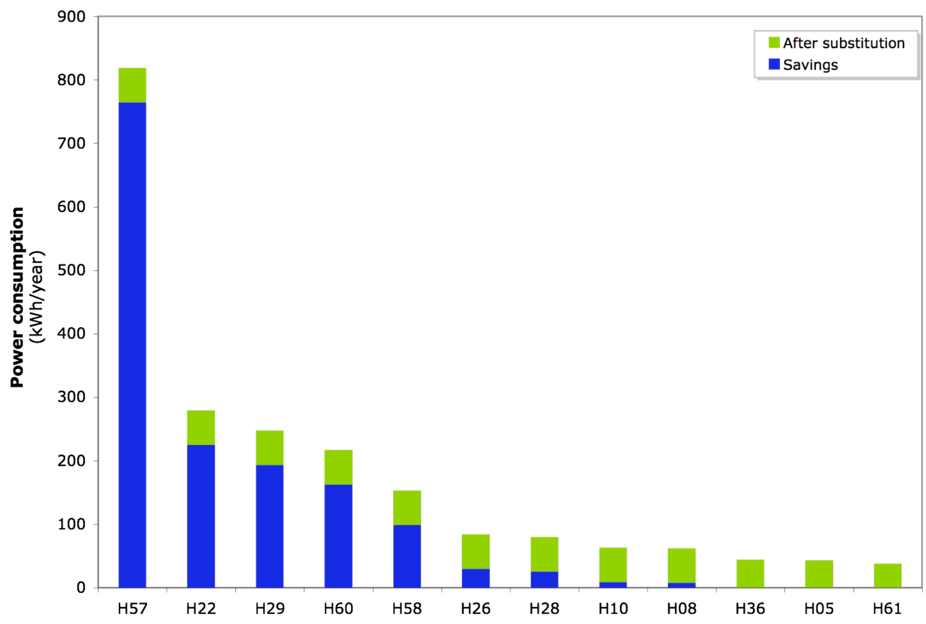

Figure 43.Electricity savings as result of desktop and monitor replacement

As presented in previous sections, the addition of the annual electricity consumption from these appliances produces a value close to the one found for the computer site as a whole. Zimmermann (2009), introduce a method to quantify the potential savings for the computer sites. It includes reference values for desktop and monitors and the others appliances in the typical computer site. As with TV sets and PCs, the values of consumption in low power and active modes are also taken into account. The following assumptions and values were considered when calculating the savings:

Table 14. Parameter fo the energy efficient equipment in the computer site

Energy efficient appliance	Power use in off mode (W)*	Power use in on mode (W)
Laptop	0.5	20
Modem	0.5	8
Router	0.5	8
Printer	0.5	8
Speaker	0.5	8

*Values below the threshold of 1W set by the Regulation EC 1275/2008

Figure 44 Figure 44. Energy savings for the computer siteshows the considerable diversity in consumption patterns with important savings for some appliances. The obtained average savings (adjusted) was 80kWh/year per appliance represents an important potential for energy saving considering that the consumption before substitution was 146kWh/year. This finding confirms the potential existing in Hungarian households to reduce electricity consumption from this end use.

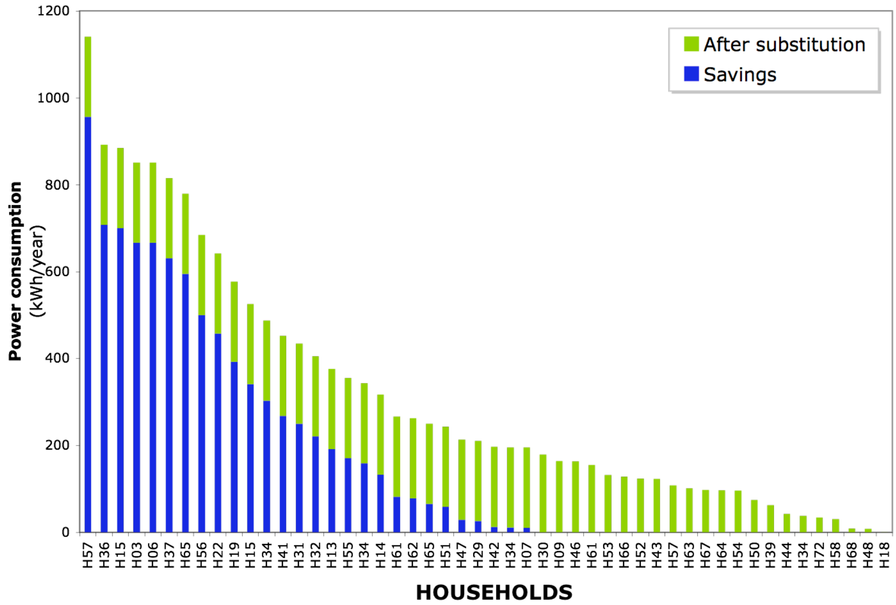

Figure 44. Energy savings for the computer site

5.1.4.2 Laptops

For the calculation of the potential energy savings the laptops in the sample were replaced with energy efficient equipment considering power use in off (standby) and on (normal) modes. The reference values of the energy efficient laptops is the following:

-Power use On (normal mode)	= 20W
-Power use standby (off mode)	=0.5W

Unlike the previous appliances the average savings obtained for laptops are more reduced. The average (adjusted) savings are only 1.5kWh/year per appliance. As shown in Figure 45, the yearly consumption of an important fraction of the sampled laptops is well below that of the efficient appliance. This can be attributed to two factors: the first is that laptops are in general more energy efficient than desktops. The second factor lies in the low penetration rate of the appliance in the country (6 per 100 households). The combined effect of these two factors is expressed in a low average savings.

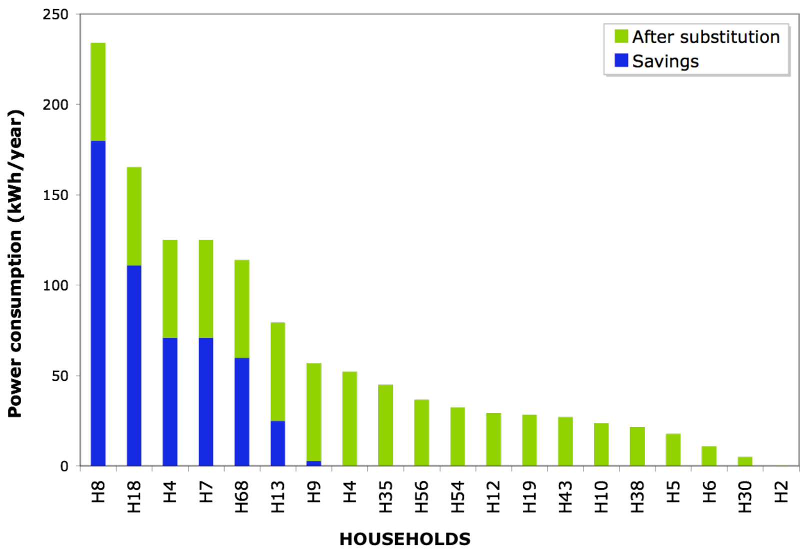

Figure 45. Energy savings for laptops

5.1.5 Washing machines

Washing machines were the appliance type with the highest number of monitored devices in the sample. For this reason, the obtained results have a relatively high degree of accuracy. In the final electricity breakdown, the obtained share (together with dishwashers) was around 4%. A relatively low share that can be attributed to a reduced use pattern during the monitoring period and/or the presence of energy efficient appliances in the sample. As this appliance is not in constant use, the parameters for the calculation of the electricity savings are relatively different from the previous ones. In this case, the number of cycles (indication of the number of times people use the appliance to wash their clothes) and the electricity consumption in each of them are relevant. The reference values for the energy efficient appliance are the following:

Electricity consumption (kWh/cycle)=	0.900
Number of cycles per year=	100

The obtained (adjusted) average savings are 6kWh/year, which is a relatively low value compared to the savings obtained for the other appliances. Prior substitution, the consumption of the washing machines in the average household was 81kWh/year. The obtained value can be explained by the fact that a relatively low number of appliances were above the reference values. As mentioned previously, this phenomenon can be attributed to a low use activity pattern during the monitoring and/or to the fact that a considerable fraction of the appliances are energy efficient. Otherwise, it is relatively difficult to explain this pattern.

5.2 Potential CO_2 savings by changing to energy efficient appliances

The procedure to calculate the CO_2 that can be reduced by saving electricity is the one presented in Grinden and Feilberg (2008). The factor used in order to relate electricity generation with CO_2 emissions is 435t CO_2/GWh. According to the authors, this factor corresponds to the European "average emission produced by an average generator efficiency, using the average fuel mix". Only the savings of the major appliances are considered in this calculation. As the savings are adjusted by penetration rates, the obtained value is actually, the saving per household. The savings per household are then translated to national figures in order to obtain the savings for the country. In order to do this, the savings per household are multiplied by the number of households in the country. The total (adjusted) savings per household (976kWh/year) represent around 46% of the final electricity consumption in the average Hungarian household (Table 15). If multiplied by the number of households in the country (3.8million), the obtained savings are in the order of 3718GWh/year. In terms of CO_2 emissions, the savings in a national context from the major appliances represent 1618Kt of CO_2/year that can potentially be reduced under the conditions of this analysis. If the 66.5kWh corresponding to the obtained power consumption in low power modes (LP1 and LP2) were totally removed (e.g. by using standby killers), the estimated CO_2 reductions would be around 110kt CO_2/year.

Table 15. Summary of the potential annual savings per household from major appliances and related CO_2 emission savings.

Appliance	Saving per household (kWh/year)	Total saving for the country (GWh/year)	CO_2 savings (kilo ton/year)
Fridge with freezer	64	244	106
Fridge without freezer	168	640	278
Freezer	495	1886	820
Lighting	93	354	154
TV sets	68	259	113
Desktop & Monitor*	58	221	96
Computer site	80	305	133
Laptop	2	8	3
Washing machine	6	23	10
TOTAL	**976**	**3718**	**1618**

*Not included in the total as it is considered part of the computer site

5.3 Discussion on the potential electricity savings

The method used to calculate the potential electricity savings in a substitution scenario has been used in the most recent on electricity consumption at national level in the world (SEA Sweden)[33]. The advantage of the method is that it compares the reference appliance (a real energy efficient appliance existing in the market) with the annual consumption of the individual monitored appliances. In general there are appliances for which the savings are notably high, but in some other cases the savings are low or even there are no savings. A situation that reflects not only a diversity of use patterns, but also the differences in energy efficiency of the appliances. However, it is difficult to isolate the difference in consumption due to use pattern and efficiency of the appliance. The method also considers the particularities of the appliance type. For instance, for washing machines it is important to know the number of cycles in order to determine the electricity consumption in each of them. Otherwise if only the annual value is taken, it is assumed the appliance consumes energy at all times.

In the case of ICT appliances the method takes into account consumption in low power mode (off mode) and normal mode (active on mode). For TV sets, this consideration is important as its general use pattern consist in switching from low power mode (off mode) to an active mode. For PCs the situation is more complex considering they usually have more than one low power mode (e.g. sleep function). The model does not consider these intermediary consumptions. Because of the low penetration rates of laptops, the savings are not as high in the average Hungarian household. However, when considered as an option for the replacement of desktops (which have a higher penetration rate and consumption), results show that important savings can be achieved. In the same sense, as the use of ICT equipment such as computers is becoming more individualized, it is probable that more appliances of this type will be present in households. According to the findings, in terms of electricity savings is certainly better to have efficient laptops than desktops.

In general the savings confirms the overall patterns found in this study: the highest savings are found for the appliances with the highest consumption: freezers, fridge without freezer, lighting, TV sets and PCs. Among them, up to 50% of the total savings can come from freezers. Considering both the high consumption and the savings, these appliances constitute an ideal target for electricity savings in the average Hungarian household. In the case of lighting, the consumption after substitution is just around one quarter of that prior substitution. This also puts

[33] The monitoring process was carried by ENERTECH, a French based company that has been involved in previous residential monitoring campaigns both in France and at European level.

in evidence the existing potential considering the predominance of energy inefficient light sources (incandescent). For freezers, TV sets and PCs, the consumption can be reduced up to 50%, which are also important share of the consumption prior substitution. In contrast, savings from washing machines and laptops are relatively modest when considering penetration rates.

The savings from other appliances such as DVD players, HIFI systems among other equipment were not assessed for two reasons: the few number of monitored appliances in the sample and scarce data regarding energy efficient equipment available in the market. The use of other data such as the lowest power consumption in the sample as presented in Grinden and Feilberg (2008) could be an option if there would be a high number of monitored appliances. In any case, it is assumed that most of the potential electricity savings can come from the largest appliances considered in the analysis. In this case, up to 46% of the electricity consumption of the average Hungarian household consumption can potentially be reduced only with savings from the major appliances. It is important to take into consideration that the model is static. It assumes an "overnight" change in the appliances, to achieve electricity savings. Therefore it does not evaluate variables such as increasing penetration of appliances, the improvement in the best available technology, among others. In the same sense, the emission factor used to relate the electricity savings with emissions that can potentially be avoided is static.

6. Conclusions

This study analyzed the electricity consumption patterns of Hungarian households based on the monitoring data collected as part of the REMODECE project (Hungary). Electricity consumption was measured for individual electric/electronic appliances and light sources with a 10-minute resolution. A total of 75 households were monitored by the project during a period of two weeks, between 2006 and 2008. The analysis of the high-resolution data carried out in this work show the particularities linked to the use patterns of appliances in Hungarian households and the existing potential for electricity conservation. In this sense, this work complements the results obtained by the REMODECE survey (Hungary), the second component of the project. This study covered three main parts: the power consumption of the average Hungarian household, the electricity consumption in different power levels and the potential for electricity savings. Key conclusions are:

Electricity consumption in the average Hungarian household

- The obtained annual electricity consumption of an average Hungarian household was 2117kWh/year. In general, the share of a particular end use in the electricity consumption of the average households is attributed to: the presence of appliances with high penetration in households and high consumption from the monitored appliances. In this sense, the end uses with the highest electricity consumption are cold appliances (44%), lighting (18%) and home entertainment (11%). According to the findings of the REMODECE survey, within the stock of cold appliances there is a significant share of outdated appliances. This is particularly true for freezers, which are the appliances with the highest consumption in the average household (585kWh/year). Considering this, cold appliances especially freezers constitute a potential target to achieve substantial energy savings.

- Electricity consumption from lighting continues to be dominated by inefficient incandescent light sources. Of the average 13 lights sources found in the average Hungarian household, 8 light sources correspond to incandescent technology. Of the total consumption from lighting (377kWh/year), three quarters can be attributed to incandescent light sources. By room type, lighting in living room and bedrooms dominate the consumption in the average Hungarian household. Although CFLs are the second most used technology, their penetration is considerable lower than incandescent (3.28ligth sources per household). Considering the high penetration rates and high power consumption of incandescent light sources, the potential for achieving considerable electricity savings by using energy efficient equipment is high.

-TV sets dominate the electricity consumption in the home entertainment end use. Along with the obtained consumption from the monitored appliances, the penetration rate –the highest of all major appliances in the country- contributes to this fact. Most of the monitored devices correspond to CRT equipment (traditional TV sets). For this reason, the obtained consumption is basically dominated by this technology. However, this situation is expected to change considering the increasing penetration of technologies such as LCDs.

- In the case of office equipment (mainly PCs, laptops, printers, modem and routers) a share of 7% was obtained. Even when there can be several potential explanations for these results (ranging from a low consumption during the monitoring period or caused by energy efficient devices), the low penetration rates are certainly one determining factor. None of the appliances have a penetration rate superior to 50 appliances per 100 households. For instance, there are 46PCs per 100 households for PCs, and only 6 laptops per 100 households. As the penetration rates are basically a weighting factor, low values determine a low share in the consumption of the average Hungarian household. However, as with technologies in the home entertainment, the penetration rates of office equipment (e.g. laptops) are expected to change, as they are becoming more popular in households. This will be traduced in an increased consumption in households in the average household.

-Miscellaneous is a complex category since it can include virtually any type of appliance outside the other end uses and for which the penetration rates are usually unknown. In general the consumption of the monitored appliances in this category is relatively low. However, some households own appliances with consumption similar to the main appliances. For instance, the team in charge of the monitoring measured the electricity consumption of four aquariums (lights and mechanisms to produce bubbles) in different households. The obtained results showed that the consumption of these devices (up to 152kW/year) is similar to that of TV sets. In some cases, the occupants of the households may not be aware of this consumption.

- Even when the monitoring process and the subsequent analysis basically correspond to a snapshot of the situation, it is true that it can also provide warnings for the future. The monitoring campaign measured the electricity consumption of an air conditioning device that was around 1500kWh/year. Given the low penetration in the average Hungarian household (less than 1%), the share in the final electricity consumption of the household is low. However, it constitutes an indication of the potential effect that an increased penetration of these devices can have in the final electricity consumption of the average household.

-The electricity consumption of the average Hungarian household is constructed from the contribution of the monitored appliances considering the penetration rates in the country. However, not all appliances in households were monitored, and for some of them, the penetration rates are not known. For this reason, the final electricity consumption does not include all the consumptions from appliances found in households. The obtained value of 2117kWh/year from the analysis of the data was compared with the annual electricity consumption of Hungarian households[34] (2892kWh/year). The gap is around 770kWh/year. The difference shows that even when the major appliances are included and are responsible for most of the consumption, there is an "invisible" electricity consumption that remains unaccounted. Most of these consumption can probably come from appliances in the category such as the miscellaneous, for which both consumption and penetration rates are not known. For instance, from appliances such as fire and burglar alarms, toothbrush, intercoms, cell phone chargers, electric blankets, spa pools among others. As noted previously some of them can have low power consumption but for some other the consumption can be high.

Daily profiles

The analysis of the daily profiles reveals how appliances are used during a typical day in the average Hungarian household. In general, there are two main patterns of use: the first include appliances that are used during specific periods of the day. The second pattern reveals appliances that are constantly consuming electricity during the day, even during the periods when their use is not expected.

-Among the first group there are appliances such as TV sets that are predominantly used during the nightime between 20:00 and 00:00. Computers also show an important consumption during the night. However, both show a low consumption when their use is not expected (during 03:00 to 05:00, as people are asleep). Washing machines present two clear patterns of use: one during noon and other during the early night (around 19:00). The profile of the cooking appliances reveals some interesting patterns since the point of view of behaviour. For instance, coffee makers are only used during the morning (around 07:00), but not in any other hour of the day. It seems that coffee is not preferred as a drink during the night. In contrast, electric kettles are used both during the morning (07:00) and during the night (between 21:00 and 22:00). Dishwashers

[34] Total electricity consumption of the Hungarian residential sector divided by the number of households

are used in periods before dinner (19:00) and after dinner (23:00). Microwaves have peak consumption during the times corresponding to the main meal. However, there is also consumption when not in use. The above patterns are in concordance with the regular routine of the residents considering that in general, dwellers are either working or studying during the daytime.

- The second pattern corresponds to appliances for which there is a relatively constant consumption of electricity during the day. Cold appliances (fridges and freezers) and appliances in the home entertainment and office equipment are typical of this pattern. However, in the case of cold appliances the pattern is expected as these appliances are basically providing their main function during the day (preservation of food). Some increases are present during the nighttime, probably as a result of more openings and closings of the fridges/freezers' door. In the case of the ICT equipment (home entertainment and office equipment), appliances such as modems, routers, DVD players and VCRs have a relatively constant power consumption during the day. As their function is linked to that of TV sets (playing movies) and computers (facilitating access to internet), it is clear that they are not performing their main function during the whole day.

ICT in low power modes

From the daily profiles the analysis revealed there are ICT equipment that consume electricity when not performing their main function (such as DVD players and modems). Additionally, for appliances with defined use patterns such as PCs and TV sets, there is also a minimum consumption when they are not in use (for instance during the early morning 03:00 to 05:00). The conclusions of an in depth analysis of the power consumption ICT equipment are:

- The constant consumption found in the analysis of the daily profiles for appliances such as DVD players, modems, and printers corresponds to power consumption in a low power mode. These appliances spend most of the time during a typical day in low power modes: off mode (LP1) and active standby (LP2). For instance, the period of time in low power modes can be between 23hours (DVD players, VCRs, printers) and 24 hours a day (set top boxes, modems, routers and speakers). In terms of power consumption, set top boxes consume up to 50Wh/day, DVD players (25Wh/day) and modems up to 30Wh/day. More than 90% of this power consumption takes place when they are not performing their main function.

- For ICT equipment with defined use patterns during the day such as TV sets and computers (desktop & monitor and laptops), the time in normal mode is between 4h and 5h a day. During this lapse, the appliances consume most of the electricity of the day (between 45-50Wh day). However, in the remaining 18h-19h these appliances are in a low power mode (off mode –LP1- and/or active standby LP2). The power consumption in these modes corresponds to around 45% of the consumption in a typical day. In the case of laptops, the figure is relatively less but still important (36%). In this sense, consumption in low power modes constitutes an important fraction of the total consumption of ICT equipment in the average Hungarian household.

- The power consumption of ICT equipment in low power modes in the average household is 66.5kWh/year (mainly in off mode). It corresponds to 3.2% of the final electricity consumption of the average household. 78% of this consumption comes from appliances in the home entertainment end use and 22% from office equipment. The disparity between the shares is basically, the result of lower penetration rates for some appliances in the office equipment category. For instance TV sets have a penetration rate of 146 appliances per 100 households while that of PCs is only 46 per 100 households. In general, the obtained value is lower than previous estimates for the country and the EU27 average (5.9%). The likely reasons for this include: the incidence of low penetration rates for some of the appliances, the no inclusion of other appliances outside the ICT equipment category and potentially energy efficient appliances in the sample. In this last case, considering that the monitoring took place in households of the capital where education levels and incomes are higher, may have had an influence. In any case, as consumption in low power mode represents the majority of the consumption for some of the appliances, it constitutes a potential for electricity savings. Currently, the EU (Regulation EC 1278/2008) has defined limits for consumption in low power modes for appliances in the market. However, it is important to address aspects related to behaviour of the consumers to reduce standby consumption of the existing equipment in households and not only to wait until replacement.

Potential electricity savings

The analysis of the electricity consumption patterns in the average Hungarian household helped to identify the present or reference state (e.g. appliances with the highest shares in the consumption). The assessment of the potentials for electricity conservation compared the present state with a reference scenario: the replacement of the existing technology with energy efficient equipment. All the main appliances in the average household were considered (fridges and freezer, lighting, TV sets, PCs and peripherals, laptops and washing machines). The main conclusions of this exercise are:

- By switching to energy efficient equipment is possible to achieve electricity savings of up to 976kWh/year in the average household. This represents 46% of the total electricity consumption obtained for the average household. In environmental terms, the savings represent a potential reduction of 1618Kt CO_2/year. In general, the higher electricity savings are obtained for appliances with the highest consumption in the average household. Cold appliances offer the largest saving potentials (freezers = 495kWh/year and fridges without freezer = 168kWh/year). In the case of lighting, by replacing inefficient incandescent lights it is possible to achieve savings of up to 93kWh/year in the average household. In this last case, the progressive ban that is undergoing in the EU (Resolution EC 244/2009) will certainly promote once and for all, the adoption of more energy efficient light sources.

-The potential energy savings for the remaining equipment (TV sets, computers) are between 60 and 80kWh/year. For these appliances, the reduction of the consumption in standby (to 0.5W) and the consumption in normal mode were taken in to account. This is a more realistic approach than just removing the standby overnight (e.g. by assuming dwellers use standby killers or unplugging all the appliances when not in use). The savings for laptops and washing machines are considerably lower (2kWh/year and 6kWh/year). In the case of laptops, a low penetration rate and a lower consumption of the monitored appliances are the most likely reason. For washing machines a relatively energy efficiency stock can explain the low energy savings.

This work has demonstrated the value of high-resolution data to determine electricity consumption patterns in order to identify context-based particularities. In this sense, it also complements the results of the REMODECE survey (Hungary). The REMODECE survey addressed aspects linked to the energy efficiency of the stock of appliances and the behaviour of the occupants in relation to the use of appliances. The combined results offer an integral overview of the electricity consumption in the Hungarian residential sector. With this increased knowledge it is possible for relevant actors (e.g. Hungarian Energy Office, other governmental offices) to explore options in order to influence and foster changes in the critical points identify in this work (e.g. cold appliances, lighting and consumption in low power modes). Information to users is of prime importance as well. Project such as REMODECE provide a unique opportunity to enhance the knowledge on electricity consumption in the residential sector. However, electricity consumption is a dynamic process fostered by among others, the increasing penetration of appliances. For this reason it is important to continue increasing and updating the knowledge of those particularities (and the new ones that can emerge) in the Hungarian context.

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8. APPENDICES

APPENDIX I. Appliance penetration rates and source

The table shows the penetration rates used in this study along with their source. When two PR are available, the one from KSH is taken as reference.

Group	Appliance	PR – REMODECE (Hungary)	PR-KSH	PR Other	PR USED	SOURCE
Cold Appliances	Fridge with freezer	0.25	0.37		0.37	KSH
	Fridge without freezer	0.81	0.71		0.71	KSH
	Freezer	0.46	0.52		0.52	KSH
Washing appliances	Washing machine	0.97	0.86		0.86	KSH
	Dishwasher	0.11	0.07		0.07	KSH
Cooking	Microwave		0.82		0.82	KSH
	Bread Maker			0.24	0.24	HEEP
	Coffee maker			0.91	0.91	RME1
	Cooker Hood				ND	
	Electric cooker -Hot plate oven-				ND	
	Electric kettle			0.50	0.50	RME2
	Electric oven*			0.78	0.78	RME1
	Food processor			0.40	0.40	HEEP
	Juice Blender				ND	
	Toaster**			0.84	0.84	HEEP
	Wok				ND	
Office appliances	Desktop	0.51	0.46		0.46	KSH
	Monitor	0.50	0.46		0.46	KSH
	Laptop	0.18	0.06		0.06	KSH
	Printer	0.28			0.28	RSM
	Multifunction Printer	0.10			0.10	RSM
	Scanner	0.07			0.07	RSM
	Copier	0.04			0.04	RSM
	Fax	0.03			0.03	RSM
	Modem	0.14			0.14	RSM
	Speakers	0.32			0.32	RSM
	Router	0.09			0.09	RSM
Home entertainment	TV	0.98	1.48		1.48	KSH
	Home cinema	0.22			0.22	RSM
	VHS recorder/player	0.45	0.51		0.51	KSH
	DVD recorder/player	0.57	0.43		0.43	KSH
	CD Player		0.35		0.35	KSH
	HI-FI	0.38	0.34		0.34	KSH
	Set top box	0.13	0.13		0.13	KSH
	Hard disk	0.02			0.02	RSM
	Video game	0.05	0.04		0.04	KSH
Miscellaneous	Answering machine				0.10	HEEP
	Aquarium				ND	
	Clock Radio			0.43	0.43	HEEP
	Cluster small appliances				ND	
	Curling iron				ND	
	Electric clock				ND	
	Electric clock with radio				ND	HEEP

Group	Appliance	PR – REMODECE (Hungary)	PR-KSH	PR Other	PR USED	SOURCE
	Hair dryer			0.34	0.34	HEEP
	Humidifier			0.00	0.00	
	Iron			0.71	0.71	HEEP
	Mobile phone charger			0.26	0.26	HEEP
	Sewing machine			0.30	0.30	HEEP
	Toothbrush			0.08	0.08	HEEP
	Vacuum cleaner			1.00	1.00	RME2
	Wireless phone			0.78	0.78	RME1
Air conditioning	Centralized AC	0.00	0.03	0.002	0.03	KSH
	Heat pump	0.00		0.002	0.00	RMS
	Monosplit	0.01		0.012	0.01	RMS
	Multisplit	0.02		0.018	0.02	RMS
	Mobile AC	0.00		0.002	0.00	RMS
	Humidifier	0.00		0.004	0.00	RMS
	Fan	0.00		0.002	0.00	RMS
Water heating	Water heater				0.44	VHK

CONVENTIONS
HEEP = Household Energy End Use Project New Zealand (Isaacs *et al.* 2006).
KSH = [Kosponti Statistikai Hivatal] Hungarian Central Statistical Office (KSH 2010)
RSM= REMODECE Survey (Hungary)
RM1= REMODECE Survey (Fonseca *et al.* 2009)
RM2= REMODECE Survey (Grinden and Feilberg 2008)
VHK= Van Holsteijn en Kemna (Kemna *et al.* 2007)

APPENDIX II. Statistical analysis of the monitoring sample

The table shows the average power use of individual appliances adjusted using the respective PR for the country (or from other context as shown in the above appendix). The confidence interval (%) has been calculated using the corrected standard deviation for each appliance. In general, the lower the % the more reliable the estimate is. This is the case for the major appliances (such as washing machines, fridges, laptops among others). As it can be seen, the interval is relatively high for many appliances suggesting. This can be due to a low number of samples, different use patterns and models with different energy efficiency.

APPLIANCE	n	Average* (kWh/y)	Min** (kWh/y)	Max ** (kWh/y)	PR	Average Corrected (kWh/y)*	St. Deviation	Confidence interval (CI)	(CI) %
Amplifier	8	26.5	0	99		0	31.4	21.7	82
CD player	4	40.3	4	123	0.35	14.1	19.3	19	47
Discman	1	5.7	6	6		0	ND		0
DVD Player	9	47.5	1	182	0.43	20.42	25.5	16.7	35
Hard Disk	1	29.5	30	30	0.032	0.9	ND		0
HIFI	14	57.2	0	323	0.34	19.4	28.7	15	26
Home Cinema	1	10.3	10	10	0.214	2.2	ND		0
Set Top Box	1	29.2	29	29	0.13	3.8	ND		0
Tape Player	2	33.9	11	57		0	33.1		0
TV TOTAL	51	97.1	8	377	1.48	143.7	128.4	35.3	36
TV CRT	40	92.2	8	377		0	85.6	26.5	29
TV LCD	11	115	8	348		0	92.9	54.9	48
TV Plasma	0		0	0					
VCR	8	42.9	22	94	0.51	21.9	12.1	8.4	20
Fridge without freezer	33	252.7	48	886	0.71	179.4	127.4	43.5	17
Fridge with freezer	48	471.7	0	10374	0.37	174.5	544.4	154	33
Freezer	9	1125.1	160	6095	0.52	585	978	638.9	57
Computer site - cluster appliances-	62	289.7	1	1141	0.46	133.2	128.9	32.1	11
Desktop+Monitor	12	177.5	38	819	0.46	81.6	100.9	57.1	32
Monitor -CRT-	8	74.9	0	235		0	98.6	68.3	91
Laptop Monitor	1	311.4				0	ND		0
Monitor -LCD-	2	33.2	16	51		0	24.5	34	103
Laptop	20	61.5	0	234	0.06	3.7	3.7	1.6	3
Printer	9	13.4	0	41	0.317	4.3	16	10.5	78
Modem Router	3	66.3	8	98	0.373	24.7	18.9	21.4	32
Modem	9	52.4	0	139	0.2	10.5	7.4	4.8	9
Router	2	53.6	47	60	0.135	7.2	1.3	1.8	3
Speakers	5	61	3	262	0.373	22.7	41.9	36.8	60
Fax	5	83.5	25	183	0.056	4.6	3.3	2.9	4
Bread Maker	1	0.2	0	0		0	ND		0
Coffee maker	22	20.6	0	94	0.91	18.7	22	9.5	46
Cooker Hood	2	38.1	16	61		0	31.9		0
Electric cooker - Hot plate oven-	5	96	2	289		0	119.3	104.6	109
Electric kettle	14	44.1	0	124	0.81	35.8	28.5	14.9	34
Electric oven	4	100	35	224	0.775	77.5	66.5	65.1	65
Food processor	2	8.9	0	18		0	12.6		0
Juice Blender	1	0.7	1	1		0	ND		0
Microwave oven	59	130.4	1	86	0.82	106.9	470.4	120	92
Toaster	16	9.9	0	70	0.84	8.4	14.2	7	70
Wok	1	11.4	11	11		0	ND		0
Clothes dryer	2	63	0	126	0.01	0.6	0.9	1.2	2
Dishwasher	10	149.8	28	376	0.07	10.5	7.6	4.7	3
Washing Machine	70	94.7	0	344	0.86	81.5	67.6	15.8	17

Answering machine	2	12.6	5	20		0	10.5	14.5	115
Aquarium	4	152.1	18	317		0	123.6	121.2	80
Clock Radio	6	27.5	7	59	0.43	11.8	9.5	7.6	28
Cluster small appliances	6	29.4	3	151		0	59.5	47.6	162
Curling iron	4	12.7	4	23		0	8.1	8	63
Electric clock	1	16.9	17	17		0	ND	4.8	28
Electric clock with radio	2	4.3	2	7		0	3.5		0
Hair dryer	6	13.2	2	47	0.34	4.5	5.9	4.7	36
Humidifier	1	6.4	6	6	0.002	0	ND		0
Iron	3	1.4	1	2	0.71	1	0.5	0.6	39
Mobile phone charger	1	4.3	4	4	0.26	1.1	ND		0
Sewing machine	1	3.1	3	3	0.3	0.9	ND		0
Toothbrush	3	18.5	1	33	0.08	1.5	1.3	1.4	8
Vacuum cleaner	9	47.7	3	210	1	47.7	66.9	43.7	92
Wireless phone	6	9.6	3	18	0.775	7.4	4.7	3.8	39
AC Individual split	1	1542.1	1542	1542	0.012	18.4	ND		0
Circulation pump annual	2	187.5	132	244		0	79.2	109.8	59
Electric heating	1	1679.5	1680	1680		0	ND		0
Heat pump air	1	268.7	269	269	0.002	0.5	ND		0
Power supply for wall boiler	3	14.2	0	43		0	24.7	27.9	196
Mobile individual	1	7.4	7	7	0.002	0	ND		0
Mobile fan	2	17	6	28	0.002	0	0	0	0
Water heater	10	190.3	18	606		0	212.3	131.6	69

*per appliance **Not adjusted (without considering ownership)

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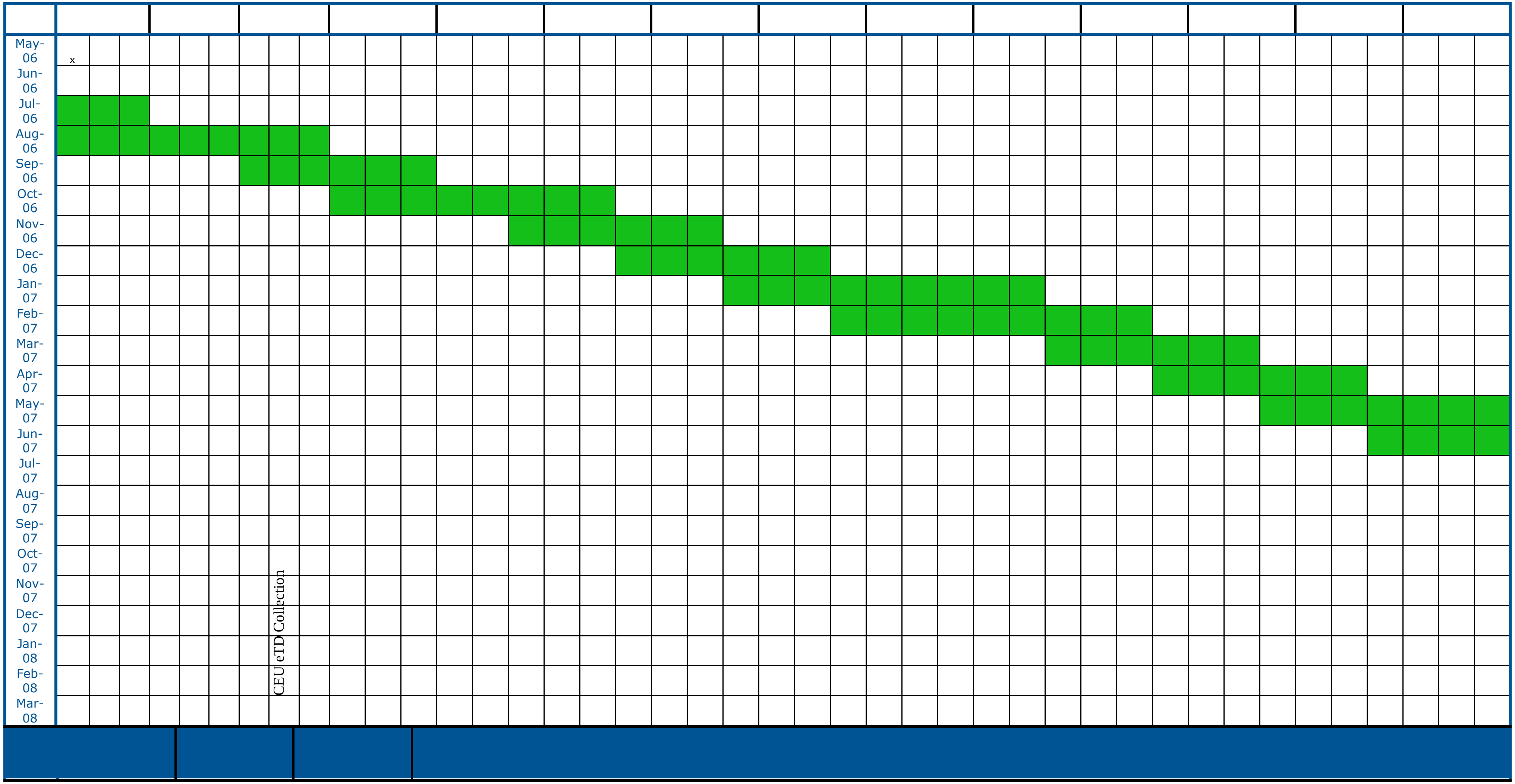
APPENDIX III. Monitored Households –Timeline 2006-2008-

The table presents the timeline of the REMODECE monitoring campaign in Hungary (2006-2008). Green (data available). Red. (missing data).



	43	44	45	46	47	48	49	50	51	52	53	54-1	54-2	55-1	55-2	56-1	56-2	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
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	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
May-06																										
Jun-06																										
Jul-06																										
Aug-06																										
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