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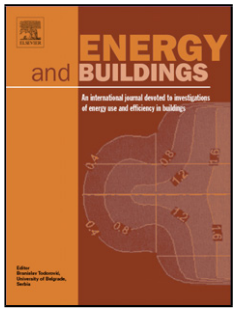

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Characterization of the Household Electricity Consumption in the EU, Potential Energy Savings and Specific Policy Recommendations

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Abstract

Although significant improvements in energy efficiency have been achieved in home appliances and lighting, the electricity consumption in the European Union household has increased by 2% per year during the past 10 years. Some reasons are associated with an increased degree of basic comfort and level of amenities and with the widespread utilization of new types of loads. Wishing to increase the understanding of the energy consumption in the EU households for the different types of equipment including the consumers' behaviour and comfort levels, and to identify demand trends, an energy monitoring campaign, was carried out in 12 geographically representative EU countries, accompanied by a lifestyle survey. From the measurements carried out it was concluded that Information Technologies and entertainment loads are key contributors to the power demand. In basically all types of loads there is wide range of performance levels in the models available in the market. Available technology, associated with responsible consumer behaviour, can reduce wasteful consumption. Based on a bottom up approach the European residential sector potential electricity savings that can be implemented by existing technologies and improved behaviour can reach 48%. The paper presents policy recommendations promoting market transformation and behavioural changes in the equipment selection and operation.

Keywords

Energy, electronic loads, standby consumption, savings, efficiency policies, climate change

Introduction

Although significant improvements in energy efficiency have been achieved in electrical home appliances and lighting, the electricity consumption for these end-uses in the average European Union-27 Countries (EU-27) household increased by about 2.5% per year in the period 2000-2006 (ODYSSEE, 2009 [1]), despite the numerous policies and programmes to promote energy efficiency at EU and national level. In 2006, total electricity consumption for home appliances and lighting in the residential sector amounted to 492 TWh in EU-27 (ODYSSEE, 2009 [1]). In the period between

1999 and 2007, the total electricity consumption in the residential sector has grown by 13% or 1.6 % per year - from 708 TWh to 801 TWh - (Bertoldi and Atanasiu, 2009 [2]). Some of the reasons for such increase in the electricity consumption in the residential sector in general, and especially in ICT and CE devices, are associated with a higher degree of basic comfort and level of amenities (particularly in the new EU member countries), with the widespread utilisation of relatively new types of loads whose penetration and use have experienced a very significant growth in recent years (Bertoldi and Atanasiu, 2009 [2]), (Schlomann 2005, [3]), (REMODECE 2008, [4]). A monitoring study of the electricity consumption in 72 dwellings carried out in the UK over a two years period showed that the mean annual electricity consumption of the households increased significantly by 4.5% between the first year and the second year of the monitoring. The overall increase was attributed to a 10% increase in the consumption of standby appliances and 4.7% increase in the consumption of active appliances (such as lighting, kettles and electric showers) (Firth and all, 2008 [5]). According to IEA (IEA, 2009, [6]), the energy consumption of information and communication technologies (ICT) and consumer electronics (CE) has risen considerably in recent years and now accounts for approximately 15% of global residential electricity consumption. Among these types of technologies, standby energy consumption plays an important role and offers a considerable saving potential. According to the EcoDesign EuP Lot 6 study (EuP Lot6, 2007, [7]), the business as usual standby consumption by 2020 will amount to around 100 TWh without implementing measures, whereas in the improvement scenarios based on least life cycle costs (LLCC), a reduction to around 20 TWh could be realised until 2020, which means an improvement potential of 80 %. The recommended implementing measure under the Eco-Design Directive (2005/32/EC), which is the most important policy tool directed at

reducing energy consumption of electrical appliances at the level of the EU, was already adopted by the European Commission in December 2008 (Regulation No. 1275/2008 for implementing the Eco-design Directive with regard to requirements for standby and off-mode electric power consumption of electrical and electronic household and office equipment) and became effective in January 2010.

Despite the large increase in the use of electricity in the residential sector and the consequent impact on CO_2 emissions, there is little reliable knowledge at European level on how electricity is used. According to Gallachóir (Gallachóir, 2007, [8]) data on energy supply and end-use are a prerequisite for developing policies and initiating a change towards increased sustainability. The REMODECE project, which results are herein presented, was targeted at bridging the existing lack of information, through a relatively large concerted effort, contributing to a better understanding of current and impending electricity use by European households resulting from different types of equipment, consumer lifestyles, and comfort levels (REMODECE, 2008, [4]). The project evaluated how much electricity could be saved by using the most energy efficient appliances, by adopting a suitable behaviour and by reducing standby consumption. The project also aimed at identifying policies and strategies that could transform the market and thus promote electricity end-use efficiency in the residential sector. This would contribute to enforce efficiency policies with regard to electrical appliances both at the level of the EU and individual countries. Current regulations and fuel subsidies, for example, often favour consumption over efficiency. Many simple measures to save electricity in a household are not put into practice because of barriers such as: lack of information at the consumer level (as buyers and users of electrical appliances) and retailers or the minor role of energy efficiency, when compared to other criteria (particularly the price), when buying an appliance.

Methodology

The detailed characterization of residential electricity use and credible estimates of the huge energy savings potential are important results of the REMODECE project, carried out in 12 European countries such as: Belgium, Bulgaria, Czech Republic, Denmark, France, Germany, Greece, Hungary, Italy, Norway, Portugal and Romania. The choice of these countries which cover around 60 % of the total electricity consumption for electrical appliances and lighting in the EU-27 (ODYSSEE, 2009, [1]), covers both a considerable amount of residential electricity consumption in the European Union as well as a variety of EU Member States (southern and northern countries, old and new members) which may possibly influence the electricity consumption patterns in households. A large-scale monitoring campaign in these 12 countries and a consumer survey has been carried out: 100 households have been audited per country and 500 detailed questionnaires have been collected in each country.

The decision about what data to collect is very important for a cost-effective and reliable characterization. However, due to budget limitations and the high cost of the monitoring campaign, leading to a limited number of monitored houses (even so 100 households per country, in a total of 1300 households – the largest effort by far in the EU) there were some unavoidable variations in the sample representativeness from country to country. This has obviously consequences on how the data can be used for later analysis. Therefore a common ground has been established to ensure a minimum consistency within the collected data, hereinafter.

The list of loads investigated was divided according to their main function: domestic computers and peripherals, new domestic entertainment, other standby loads and additional loads perceived to be changing fast, such as lighting and air conditioning.

In the new EU countries and Norway, the monitoring campaign focused on appliances with a high consumption of electricity, lighting and on electronic loads, while in the old EU countries, that had performed earlier measurement campaigns, the REMODECE focused on new electronic loads, standby consumption and lighting.

Besides the data collected in the field with the REMODECE monitoring campaigns and survey questionnaires, energy consumption data from previous campaigns has been collected and was considered for analysis whenever useful/applicable. All the collected data is stored in the European Residential Electricity Consumption Database. This database was developed within the project and is available at the project web-site: http://www.isr.uc.pt/~remodece/database/login.htm.
The idea was to take advantage of existing monitoring and surveys, by structuring all the available data into a data base of the residential electricity measurements and consumptions (per country and per appliance), which has been updated with the project results.

Table 1, shows the types of equipment that have been monitored per country. The criteria used to decide which appliances should be monitored was based on the following evidences:

- In most Western European countries the consumption of the main domestic appliances, namely the load curve, and the peak power, is roughly known. Conventional “main domestic appliances” include cold appliances, washing machines, dryers and lighting.
- In Central and Eastern European countries there are no significant measurements on residential electricity consumption. Therefore it is essential for the policy makers to have relevant data on electrical consumption for all domestic appliances in these new EU countries.

- In all countries, four types of consumption seem to be rising particularly fast, namely: domestic computer and peripherals, new domestic entertainment, standby power, and some lighting technologies such as halogen lamps. The increasing number of CFLs was also being investigated. Residential air conditioner loads are also increasing significantly in Southern Europe and their use was also assessed during the project.

(Table 1 goes here)

About 11500 appliances were analysed. The survey involved the collection of about 500 questionnaires per country, in a total of 6000 replies, addressing both quantitative and qualitative data. Questionnaires have been accompanied by expert interviews whenever possible, and user behaviour has also been addressed.
The audits have been carried out without taking into account the season, because the use pattern (load factor) of the individual countries has been considered when aggregating the values for loads such as lighting. Figure 1 shows the annual electricity consumption per appliance and household per country, and the estimated average for the countries of the study, considering the ownership rates.

(Figure 1 goes here)

On average 5-10 meters have been used to monitor major appliances or end-uses per household (cold appliances, washing machines, consumer electronics, …). For electricity load recording, the serial data loggers and watt meters have been used to record load profiles with 10 minutes integration period. The measurement period was

two weeks per household. For spot measurements and standby measures, standby energy monitors have been used. In the case of lighting, at least 10 light sources have been monitored per household including the lamps with the highest burning hours. Lamp meter loggers that require no connection to the supply network have been used.

At the time of installation of end-use recording equipment additional information has been collected, such as:

- Information about every end-use recorded - this was especially important when several appliances went in as a sum and only one end-use recording meter was used for recording the load for the cluster.
- Information from the appliance label.
- Size of the family, type of home and area.
- Spot metering on small appliances not included in the end-use recording including standby consumption measurement.
- Survey questionnaire

For the analysis of the huge amount of collected end-use data, a powerful analysis software tool, Useload[1], was adapted to the needs of the project and employed. Several features have been added, Useload has both been used for the data analysis and calculation of the potential electricity savings that can be implemented by existing means through replacing the old inefficient appliances (Present State) by the best

[1] Useload was originally developed by SINTEF in a join project with financial support from EDF (France), Defu (Denmark), Electricity Association (UK), VTT (Finland) and SINTEF (Norway). The main purpose of Useload is to analyse metered time series of energy consumption to find load curves that describes the behaviour of customer types, taking temperature dependency into account and considering the dependency of season- and day- types. Useload can be used to find coincident peak demand in a network. The load can be segmented into different customer dependent appliances and end-uses. This powerful software analysis tool has been improved and adapted for the REMODECE Project. Several features have been added, to comply with the specifications of the REMODECE methodology. Useload has been used for the analysis of the collected monitoring data, and for the evaluation of the potential electricity savings in the residential sector that can be implemented by existing means through very efficient appliances and reduced standby consumption.

available technology present in the market (BAT) and changing to best practice use of application (BP) including reduced standby consumption.

The measurements were cleaned for data errors, first manually by each partner and then automatically by the software. The consumption of two weeks of measurements was multiplied by a factor of 25 to account for the number of utilization days in the year, to obtain the yearly consumption. The total consumption is based on the number of weeks in the year minus two weeks for vacation, etc. Refrigerators and freezers are assumed to be in use the whole year, while air conditioning is defined to have a utilisation period of 3 months per year. The resultant value is called yearly consumption per appliance [kWh/appliance/year]. This value per appliance is multiplied by the appliance ownership to obtain the average yearly consumption per household [kWh/household/year]. Finally, the yearly consumption per household is multiplied by the number of households in the country in order to obtain the national and multinational consumption per appliance [GWh/appliance]. This is the Present State (PS) of residential electricity consumption. The Present State is country specific, is based on data from the monitoring campaigns, and is also based on previous campaigns, for some appliances.

For lighting, an annual distribution was used so that metered data from a summer day was corrected upwards, and similarly, a winter metering was corrected downwards. Moreover, the seasonal effects of Nordic countries were modelled properly. A national project of SINTEF in Norway monitored the total electricity demand of more than 10000 households, with hourly sampling, for periods of more than a year per household. This information was used to identify the average daily, weekly and seasonal distribution of the households. An overview of the electricity consumption of lighting and the installed power per household in each country is presented in Figure 2.

(Figure 2 goes here)

Besides the Present State (PS), also the Best Available Technology (BAT) and/or Best Practice (BP) need to be established for the calculation of the potential national energy efficiency savings. The power (Watt) used by the BAT of the appliance was found by scanning and analysing the collected measurements, manufacturer specifications, information from databases like Top Ten[2] and results from the Eco-design[3] studies. The BAT (Watt) per appliance is the same for all countries. The aggregate saving potential through BAT/BP depends on the country specific hours of utilisation and ownership level per appliance. The annual energy demand of BAT appliances are found by multiplying the BAT power (Watt) by the load factor (utilisation hours) of the country. This way each country's load pattern of is applied. In addition BAT calculations assume that the standby consumption is reduced to a minimum of 0.5 W.

Structural effects as change of load patterns due to possible change of behaviour were not integrated in the calculations. Also, market transformation is not taken into account. It may take several decades to replace inefficient equipment with more efficient one. Old equipment may also be replaced with larger sized equipment using more energy.

The ownership rate for electrical appliances in the 12 REMODECE countries was calculated based on the survey carried out in the REMODECE project. In the few cases, where the survey did not produce this information, national statistics have been used

[2] Top-Ten is a consumer-oriented online search tool, which presents the best appliances in various categories of products. The key criteria are energy efficiency, impact on the environment, health and quality (www.topten.info).
[3] Ecodesign aims the integration of environmental aspects to into product design with the aim of improving the environmental performance of the energy-using product throughout its life cycle (http://ec.europa.eu/enterprise/eco_design).

additionally. The ownerships were weighted by the number of households in the respective countries. Most of the appliances, in particular some electronic appliances like computers and TVs, have high ownership rates. The number of households with more than one refrigerator in Belgium, Norway, France and Germany is quite high, and there is also a very high internet penetration rate.

Monitoring every individual electronic load (like computers, peripherals, home cinema, DVD, satellite/cable set top box, etc.) was virtually impossible because the number of data recorders would be too large and they are not available. A pragmatic solution found was to record the load of the sum of every set of appliances which work as a cluster, and if possible to record separately on some appliances of special interest. This means for example using one data recorder for computers and peripherals, and another for the entertainment cluster of TV plus peripherals. When meters were being installed, spot measurements have been carried out on all appliances for off, standby and active standby mode.

To avoid losing data from one whole campaign (typically 2 weeks of data), all the meters were checked before and during its installation on site. Whenever possible, the collected data was downloaded every night from the houses, and consistency of the data was also checked.

Although there was a common methodology, the conditions in which the campaign took place, the timing, the measurement method, the type of data loggers used, the sampling method and sample representativeness have been slightly different from country to country.

RESULTS

The average yearly electricity consumption per REMODECE household, when the results from the measurement campaigns in the 12 countries were aggregated and corrected for ownership in each country, amounted to 2700 kWh (excluding electric space and water heating). Electronic loads (PCs & accessories and TVs & peripherals), which have been growing at a very fast rate during the last years, are a key contributor to the electricity consumption representing 22% of the total consumption for electric appliances and lighting. In basically all types of loads there is wide range of performance levels in the models available in the REMODECE households.

Figure 3 shows the distribution of yearly electricity consumption (without space and water heating) for a typical (average) REMODECE household. Refrigeration, including refrigerators and freezers, is the group of appliances requiring the largest part of the total household electricity consumption, with a share of 28%. Lighting is the third largest electricity end-user with a share of 18%. Other appliances such as vacuum cleaners and chargers represent about 3% of the total household electricity consumption. Standby consumption, which represents about 11% of the total consumption, is embedded in all end-uses, but is mostly concentrated in office equipment (i.e. information and communication technologies including internet connection) and in entertainment devices (i.e. consumer electronics). The standby consumption might have been slightly higher if all the appliances (such as white appliances, home security, etc.) with standby consumption within the household had been monitored.

(Figure 3 goes here)

If this structure of residential electricity consumption, which was derived from the measurements and surveys in the 12 European countries, is compared to a similar breakdown for EU-27 provided by JRC (Bertoldi and Atanasiu, 2009, [2]), the general picture looks similar, though there are some differences in the percentages of the end-uses (calculated without electric space and water heating). This difference can be both due to differences in the geographical scope (12 REMODECE countries vs. EU-27) and in the methodological approach (measurements and surveys in a limited number of households vs. statistical data and analysis of several studies). Whereas the share of cold appliances (21%), washing appliances (12%) and lighting (14%) is smaller for EU-27, the shares of air-conditioning (including ventilation), and especially of other end-uses, are bigger for the average REMODECE household. However, the shares of office equipment and entertainment devices (22 %) and of cooking (10-11%) are almost the same in both breakdowns. With regard to standby consumption, in the REMODECE project a share of 11% was obtained, whereas the share in the JRC breakdown (Bertoldi P. and Atanasiu, 2009, [2]) it only amounts to 7.4% (both values related to residential electricity consumption without space and water heating).

Figure 4 a), b) and c) show results for the yearly energy consumption for all the devices audited in the REMODECE project: average, minimum and maximum consumption values per appliance are presented as well as the total number of equipments monitored, at the top of each bar. The values presented are not corrected for ownership levels.

(Figure 4 a goes here)

(Figure 4 b goes here)

(Figure 4 c goes here)

Most of the differences between the minimum and maximum values can be explained by different usage pattern and by the different technologies. For appliances that are automatically operated, it is difficult to find a reasonable explanation for the large variations apart from some differences due to different sizes and technologies. In some cases it may be that the appliance has not been normally used during the measurement periods and/or that the estimated minimum values for the yearly consumption is only the standby consumption. Old inefficient appliances (e.g. refrigerators and freezers) can have a much poor performance than "up-to date" appliances.

The value of the energy consumption figures for electrical appliances from the REMODECE project are based on real measurements in individual households. In that way, they give a real picture of the energy consumption performance of the appliance stock, which is an important add-on compared to other studies on the same topic, which are often based on theoretical stock modeling approaches. For e.g. in Germany, the total energy consumption for information and communication technologies and consumer electronics in 2007 was calculated based on a stock model using statistical data on the appliance stock and assumptions on the average yearly energy consumption for ICT and CE devices (Fraunhofer IZM/Fraunhofer ISI 2009, [9]). In this study, the assumptions were mainly taken from the Eco-Design preparatory studies for these appliances. When comparing both studies, it can be stated that the assumptions in the German study are lower than the REMODECE results for most of the appliances, which could mean that, in a more theoretical approach, the real age of the appliance stock may be

underestimated. Only for TVs, higher consumption values are assumed as those measured in REMODECE, because relatively big screen sizes were estimated for the stock, which may be an overestimation of the observed trend towards larger screens with regard to the TV stock. Real measurements as they were carried out in the REMODECE project can therefore deliver an important data input for this kind of stock modeling approaches.

Energy demand per appliance type

Based on the time series data for each major appliance group and using the Useload software tool, it was possible to analyse the metered time series of energy consumption to find load curves that describes the behaviour of customer types, taking temperature dependency into account and considering the dependency of season - and of day types. The load curves for a typical REMODECE household, for a typical working day of the year, are presented in Figure 5.

(Figure 5 goes here)

Washing and drying are mainly used during the day, with peaks at 11:00 and 22:00. Night time consumption is low, although it is recommended to load shifting these loads if cheap night tariffs are available. The refrigeration consumption is relatively flat although it is possible to see a greater variation of the consumption demand during the day, due to more use of these appliances and more door openings. Concerning electronic equipment, (PC & accessories and television and peripherals), these loads are mainly used during late afternoons and evenings when people are back home from work, but in the case of PC & accessories, it is noticeable that many of these loads are

being used 24 hours per day (an increasing amount of people work at home and others do not turn the equipment off), and in the case of TVs and peripherals, some activity due to standby mode is visible during the night. Lighting is clearly more used during late afternoon and evening hours, after 17:00 with a peak at around 22:00. Some lights are on during the whole night, mostly outdoor lights since, according to the survey, people tend to shut off lights in unoccupied rooms. The total average number of lamps per household is 27. On average there are 4 compact fluorescent lamps per household. Incandescent and halogen are the most widely used lamps, and there is a large potential for the application of CFLs and LEDs in the households, for the replacement of incandescent lamps, which represent 50% of the total lamps installed.

The Standby definition in the REMODECE was based on the standard IEC62301 (IEC62301, 2005, [10]), and its European on going transcription EN62301. According to this international standard, the definitions for standby mode and standby power are as follows:

The standby mode is the lowest power consumption mode which cannot be switched off (influenced) by the user and that may persist for an indefinite time when an appliance is connected to the main electricity supply and used in accordance with the manufacturer's instructions. The standby power is the average power in standby mode.

The standby mode is usually a non operational mode when compared to the intended use of the appliance's primary function. The measurement of energy consumption and performance of appliances during other operating modes or intended use are generally specified in the relevant product standards and are not intended to be covered by this standard. Based on the experience from some partners in the project, it was found to be useful to measure two major standby modes for some appliances, like for example, TVs, DVDs, Power Supplies/Chargers, some domestic equipment, etc.

These modes are: the Off-Mode and the Standby Active Mode. The first, the Off-Mode is when the device is totally switched off (i.e. the power button is off, but the mains plug is connected). The later, the Standby Active Mode, is the mode when the device is able to respond to outside commands, such as when it is possible to use the remote control to switch on the equipment (i.e. typically is when the LED or display is still on).

The standby electricity consumption for the appliances measured under the REMODECE project is presented in Table 2.

Measurements were taken both of load curves of equipment clusters (entertainment and office equipment), as well as spot measurements of the low power modes for different types of electronic equipment in the households. These are values for the typical EU REMODECE household.

Many appliances which may have significant standby energy demand were not part of the metering campaign of REMODECE. These appliances are for example: electrical toothbrush, shavers and other toilet requisites, electrical tools with chargers, musical instruments, video games, home cinema, garden equipment with chargers, home security systems, garage door openers, etc.

Some of the new electronic appliances have a relatively high share of standby consumption, but in some of these appliances standby may be required[4] to keep information in the appliance memory (e.g. storing TV stations in set top boxes, etc.). On average the standby electricity consumption per household and per year is about 305 kWh, which is about 11% of the total annual electricity consumption per household (excluding heating loads). Standby power is roughly estimated to be about 40 W per household. Assuming that electronic appliances are in the standby mode during 7665 hours per year (corresponding to 3 hours of active use per day), the standby power

[4] Can be avoided by using "non-volatile" electronic components storing information even if the power supply is disconnected.

consumption of these appliances represents about half of the electronic loads consumption, which is 585 kWh per year per household.

In terms of behaviour, households present a positive behaviour in what concerns turning off computers and monitors. However, they leave fax machines, modems and routers/hubs, on standby mode because they fear to loose the pre-definitions and to have to reprogramme them if they turn them off. Roughly 40% of the households do not turn off the television with the on-off button, keeping it on standby mode.

(Table 2 goes here)

Potential Electricity Savings

As it was already mentioned, the technical electricity savings potential was estimated based on the replacement of the existing installed inefficient technologies with the Best Available Technology (BAT). The lifetime of the equipment or penetration time of BAT was not taken into account. Equipment with short lifetimes, e.g. desktops and laptops, will be replaced soon but other appliances like electric cooker/oven may have a long lifetime and it may take several decades to replace today's equipment with the Best Available Technology.

The annual electricity savings in a typical REMODECE household by switching to the BAT per type of appliance is presented in Figure 6.

(Figure 6 goes here)

The aggregate savings from switching from present state to Best Available Technology were estimated to be about 1,300 kWh per year for an average REMODECE household, representing a savings potential per household of almost 50%

of its total consumption, excluding electric space and water heating. The aggregated annual electricity savings by using best available technology for the 12 countries covered by the REMODECE project amounts to 165 TWh per year. These electricity savings are equivalent to 72 million ton CO_2 emission savings[5] per year by switching from present technology, also called Present State (PS), to best available technology (BAT). Projected to the European level (EU-27), the electricity savings would amount to 268 TWh (or 116 million tons of CO_2), which is around one third of total electricity consumption in the residential sector in EU-27 (based on the total electricity consumption in EU-27, including electric space and water heating, which was 801 TWh in 2007; [2]).

For assessing the quality of the estimated values for the different appliances, the number of measurements per appliance and confidence intervals was calculated with standard statistical methods. A higher number of measurements give a more accurate and representative estimate than just a few measurements. A small confidence interval indicates a significant estimate, which is due to a low standard deviation in the energy consumption. In general, within each appliance, there are a lot of models with different yearly consumption (e.g. energy efficiency classes). Also, the use of some appliances can vary a lot between different consumers. A high confidence interval indicates a large uncertainty, probably associated with the fact that there are too few measurements for this appliance type. The result of this analysis is that the estimates of refrigeration and washing appliances, PCs, CRT and LCD TVs are trustworthy, whereas they are uncertain for PC peripherals and plasma TVs.

For a better assessment of the total savings potential of 268 TWh for the electrical appliances in EU-27, excluding electric space and water heating, which has been

[5] For calculation of the saved CO_2 emissions, a factor of 435 ton CO_2/GWh is used as a common value for Europe except Norway. The factor is calculated as the European average CO_2 emissions of electricity production under

estimated based on the linking of REMODECE results with BAT/BP values, a comparison with other saving potentials which have been calculated based on bottom-up modelling approaches, can be useful, too. In a study for the European Commission, Fraunhofer ISI has calculated energy savings potentials in all final energy consumption sectors for EU-27, using the MURE model (Fraunhofer ISI et al. 2009, [11]). For electrical appliances in the residential sector, a total savings potential in the technical scenario, which is comparable to the BAT approach in REMODECE, of 95 TWh was estimated for 2020. This potential will increase to 234 TWh in 2030, which is not far from the potential calculated in REMODECE. This shows that in the long run (since the MURE stock model takes into account the lifetime of the appliances), the REMODECE calculation fits very well with other savings calculations based on a stock modelling approach.

POTENTIAL STRATEGIES FOR MARKET TRANSFORMATION

In the European Union, the most important policy tool directed at reducing energy consumption of electrical appliances is the Eco-design Directive (2005/32/EC). It establishes a framework under which manufacturers of energy-using products will, at the design stage, be obliged to reduce the energy consumption and other negative environmental impacts occurring throughout the product life time. The Directive was revised and enlarged to all energy-related products in 2009 (2009/125/EC). Since the end of 2008, the Commission already adopted Regulations implementing the Eco-Design Directive for several products: simple set-top-boxes, TVs, standby and off-mode losses, battery chargers and external power supplies, office and street lighting, electric

average generator efficiency using the average mix of fuel.

motors, refrigerators and freezers and domestic lighting.[6] In addition, the Energy Labelling Directive of 1992 (92/75/EEC) was revised both with regard to the scope of the Directive (more products are included in the mandatory labelling scheme) and to the classification scheme. In December 2010, the EU Parliament agreed on new energy labelling regulation.

Minimum energy performance standards (MEPS), as they are set under the EU Eco-design Directive, are a suitable policy tool in order to remove the worst performing products from the market. They are, even if completed with mandatory energy labels for some appliances, not sufficient to promote the best performing products and to overcome other important barriers, e.g. information deficits of consumers and retailers. One target of the REMODECE project, which was finished in autumn 2008, i.e. some time before the first implementing regulations under the Eco-Design Directive have been adopted and the revision process of the Energy Labelling Directive started, was to identify actual problems with regard to a successful market transformation of energy-efficient electrical appliances and to make recommendations for an improvement. Therefore, some results of the REMODECE projects can also serve as justification for the recent European policy strategy with regard to electrical appliances. In addition, a lot of country-specific conclusions could be drawn from the surveys and the collection of policies and measures by country, which has been provided by each partner.

Recommendations

Boardman (Boardman B. 2007, [12]) mentions that the most effective way for market transformation is the combination of policies such as: tough minimum energy standards for homes, lighting and appliances, regulation of utilities, generous financial

[6] http://ec.europa.eu/energy/efficiency/ecodesign/eco_design_en.htm

support through grants, funding and the reform of energy tariffs, and much greater information for the consumers. To take advantage of REMODECE identified energy-saving opportunities, the setting of demanding minimum efficiency standards for a couple of products (e.g. air conditioners), as it has already been done or is intended for under the EU Eco-Design Directive, seems to be a promising strategy. This can, however, be coupled with suitable further policy incentives, as it is e.g. done in Denmark, which has the most recent stock of appliances due to the intensive Danish energy saving policies available. Several energy-efficiency incentive programmes are available in Denmark to help households to replace their old inefficient appliances with new ones. Labelling of electricity consumption, including low power modes, appears to be essential to raise consumer awareness. Current regulations and fuel subsidies, for example, often favour consumption over efficiency. But many possible actions are not taken, because energy users lack information and they do not give enough importance to energy efficiency, to change their buying habits. Regulation changes, information campaigns, with clear and simple messages targeting households, together with suitable financial incentives, revision, enforcement and expansion of the energy label ratings, and behavioural changes in the equipment selection and operation, are among the most effective strategies to stimulate energy efficiency in the residential sector. Based on the findings of the project, a set of policy recommendations to promote energy efficiency are identified below.

Revision of the energy label ratings A-G and its enforcement

Since the introduction and implementation of the energy labelling Directive, European consumers have become familiar with the A-G energy label. However, REMODECE survey concluded that a large number of households do not know about the efficiency level of their appliances, usually because of the age of the equipment or

because of the lack of interest in energy efficiency issues, leading to bad choices when buying new appliances. In general, the share of A++ and A+ appliances was still very low in the REMODECE survey which was carried out between 2006 and 2007. However, in order to get a real picture of the appliance sales by label class, household surveys are probably less suitable than data based on large retail panels as they are provided e.g. by GfK According to (Farunhofer ISI, GfK, 2009, [13]), the share of A+ and A++ for most appliances is very low. However, for refrigerators, freezers and washing machines, there was a considerable share of A+ appliance even in 2006.

Feeling the need to have a more flexible and dynamic labelling scheme, and in general the need for renewal, the European Commission set up new energy labels for refrigerators, dishwashers and washing machines, extending the scale upwards with an A+++ class, and setting up energy labels for TVs for the first time.

Energy labelling of refrigerators-freezers, dishwashers and washing machines has been hugely successful since its introduction in 1992. Today 90% of these appliances sold in the EU are in class "A". However, new technologies would allow reducing by half the energy consumption of an A-class product. The EU has therefore decided in June 2010 to extend the colour scale upwards with three new classes: "A+", "A++", and "A+++" for products with a better than A-performance, shifting the colour in a way that green applies to the most efficient class.

The label was allowed on a voluntary basis immediately after the entry into force of the Regulation, in December 2010, and will be mandatory on all appliances placed on the market one year after the entry into force of the Regulations.

Raising awareness about labelling schemes

Even though energy labelling is a well known and accepted scheme that is active for quite some years now, work still needs to be done in the area of consumer's

awareness and enforcement. This is even more important with regard to the revised EU Energy Labelling Directive which includes more appliances in the labelling scheme and adds new label classes. In the REMODECE survey in 12 European countries, two trends could be observed: a lack of awareness concerning energy labelling in general and especially concerning the voluntary Energy Star label for office equipment (REMODECE, 2008, [4]). Therefore, it is important to inform consumers with awareness campaigns in any form (TV spots, brochures, etc.) about the importance and the benefits of buying energy efficient appliances and about the importance of labels like the EU Energy label and the Energy Star, when it comes to office equipment. Another strategy is to organize training programs for retailers giving them also sales arguments, though this is rather difficult because front desk staff in shops is frequently changing.

Expansion of the energy label in order to include more products and setting more ambitious Minimum Energy Performance Standards

Up until now, the energy labelling scheme referred to white appliances, light bulbs and air-conditioners. Recent market surveys (Schlomann, 2005, [3]), have shown that the household electronics market has increased significantly in the EU countries in the last years. Most of the electronic appliances have high ownership rates in REMODECE households and this is valid for all the EU 27 countries (REMODECE, 2008, [4]).Therefore, the expansion of the energy labelling scheme, which now includes TVs, should be extended to other entertainment and office equipment as well. Moreover the survey carried out by the REMODECE project showed that the knowledge of the households on the (voluntary) Energy Star Label for office equipment is poor which means that a mandatory label as the EU energy label will probably be more effective.

Another aspect of the electronic equipments is the standby consumption which was estimated to represent about half of the electronic loads consumption. The potential

of energy savings that lies in this standby consumption can be achieved, with consumer behavioural changes, and especially with setting strict requirements for standby power, as they have already been introduced under the Eco-Design Directive. In December 2008, the Commission adopted the Regulation No. 1275/2008 for implementing the Eco-design Directive with regard to requirements for standby and off-mode electric power consumption of electrical and electronic household and office equipment. The regulation, which comprises a wide range of products (household equipment, information and communication technologies, consumer electronics, other products as toys etc.), stipulates that from 2010 power consumption of this equipment in any off-mode condition and in any condition providing only a reactivation function shall not exceed 1 W and equipment also providing information or status display shall not exceed 2 W. From 2013, these limits are further strengthened to 0.5 W and 1 W respectively.

According to the REMODECE results, demanding Minimum Energy Performance Standards (MEPS) are urgently needed for air conditioning equipments being sold in Europe, too: residential air conditioning loads are increasing fast in Southern Europe and are already a major contributor to summer peak demand in Mediterranean countries. The European air conditioning market is flooded with very low cost and very inefficient units. Therefore action is urgently needed banning low efficient units as low efficient air conditioning units that are even not allowed in China and Japan are invading the European market.

Promotion of behavioural changes

One of the most effective ways to save energy and achieve the reduction potential in the residential sector is probably through behavioural changes. From the analysis of the data collected in the REMODECE surveying campaigns, consumers' behavioural trends were established through a series of questions that were included in the

questionnaires. The identified "false" behaviours (pretending rational behaviour) were related with most of the domestic appliances and many of these behaviours could change through awareness raising campaigns which would focus on behavioural matters. Change of washing temperature and less use of tumble dryer are examples of campaigns concerning change of behaviour. The installation of an intelligent metering system, as it is foreseen in the gas and electricity directives of the third energy package, adopted in 2009, can help households to control and reduce their electricity consumption. (Fisher C. 2008 [14]) suggests the most successful feedback on household electricity consumption should be given frequently and over a long time for promoting electricity conservation in households.

Combination of technological progress (introduction of new products) with financial incentives

The biggest electricity savings potentials identified in REMODECE [4] concern cooling appliances (for refrigerators with freezer compartment the savings are estimated to be 182 kWh/year/household and for freezers 162 kWh/year/household), desktop PCs including monitors (the savings are 139 kWh/year/household), oven/cookers (with 60 kWh/year/household) and in lighting (303 kWh/year/household). For these categories of appliances, additional incentives for switching to best available technology could be given, as they will deliver important reduction to electricity consumption. An additional solution is to forbid the sales of electrical appliances in classes below "A", as well to ban the sales of incandescent light bulbs and appliances without on/off power switch. Based on the EcoDesign EuP lot 19 works, EU decided to phase the use of incandescent light bulbs (GLS) (frosted GLS by October 2009 and clear GLS and the worst halogen lamps by 2016).

For lighting, one other possible solution in order to speed up market transformation could be the establishment of add-on carbon taxes related to inefficiency

into the price of the lamp. According to that solution an incandescent light bulb will have the higher price, due to tax impose while efficient CFL or LEDs lamps will be tax free, leading to a lower price.

The most efficient LED technology has already reached over 160 lumen/Watt, which is three times more efficient than CFL, therefore presenting a huge savings potential, as prices are progressively coming down. The replacement of halogen incandescent spot lights, which are increasingly used in modern homes, deserves particular attention. Taxation might also be imposed for TV screens over a certain size (e.g. 45 inches) in order to stop the actually trend of buying larger and larger screens resulting in a electricity consumption much higher than necessary.

Financial incentives for the replacement of old appliances

REMODECE [4] found that in most of the countries, white appliances such as fridge, freezers, washing machines, tumble dryers etc. are older than ten years, in percentages that in some cases reached 50%. The only country that has very low percentages (1-3%) of appliances older than ten years is Denmark. So, in the rest of the countries the issue of giving incentives to consumers to replace their old appliances deserves to be carefully addressed to promote the scrapping of old inefficient appliances. Possible incentives are:

- Reducing VAT on highly energy efficient products may not be the best solution, as this measure lowers the price of the product to the eyes of the consumer and creates a false perception that energy efficient products do not have an extra cost (people usually retain the gross price of a product and do not look whether the reduced price is the result of a reduced VAT or not). The signal that should be sent out is exactly the opposite, meaning that energy efficiency has a value. So, it is better if

the financial incentive is given in an indirect way in the form of personal tax credits or rebates.

- If the incentives given to consumers are in the form of rebates and subsidies, then it must be assured that they will be given only for appliances with small market penetration and only for best available technologies. It is also important when giving a subsidy to have a fixed amount of money (xxx euro/appliance) in order to avoid over sizing, as people tend to buy larger appliances if the amount of the subsidy depends on the size.
- Demand side management programs from utility companies, also considered in the ESD directive, can lead to giving incentives to consumers. These incentives could be rebates and subsidies for replacement of old appliances or for buying state of the art energy efficient appliances and lighting, aimed at lowering the cost of more efficient energy-using equipment at the point of purchase (P. Waide & B. Buchner, 2008, [15]).
- Tax credits given to manufacturers as suggested by CECED (CECED, 2008, [16]), could be an effective incentive for market transformation that would also benefit the consumer. The tax credits philosophy is to grant to the manufacturer a fiscal benefit for each new eco-efficient product, for example Class A+ or A++ refrigerators, manufactured and sold that is above what was manufactured and sold in a reference year. The consumer would benefit from buying a technologically advanced product in a highly competitive market. By reducing the amount of taxes paid, producers of household appliances will have the resources to offer new products at competitive prices, which, combined with appropriate marketing and information campaigns, will lead to consumers replacing their appliances at a quicker rate.

- White certificates scheme can be a powerful mechanism which can create dynamic energy services market in the residential sector. There is an increasing political interest in market-oriented schemes to promote energy savings in the sectors not covered by the EU Emissions Trading Scheme and one suggested route is a tradable white certificates (TWC) scheme. Each certificate represents a certain amount of energy savings achieved through, for example, better insulation of a building (Energy Efficiency, 2008, [18]). A (tradable) white certificate scheme does not replace but complements existing policies and measures, and aims to contribute to achieving current or newly formulated Energy Efficiency targets in a cost-effective way (EuroWhiteCert, 2007, [18]). With respect to energy efficiency in the household sector White Certificates scheme can be implemented in projects promoting the use of energy efficient lighting and energy efficient household appliances, including air conditioning. An example of such a scheme is the promotion of the use of CFLs in the household sector that has been applied in France by ADEME, EDF and others relevant parties.

Conclusions

The REMODECE project increased the level of knowledge about electricity use in the 12 geographically representative EU member states involved in the project. A comprehensive database of measurements has been established, and the potential savings by changing to the best available technology and best practice behaviour have been estimated to be 1,300 kWh per household per year, being cold appliances (refrigerators/freezers), lighting and desktop PCs (including monitors), the main appliances responsible for the electricity savings of about 26.8%, 23.6% and 10.8%, respectively. The information provided by this study can serve as a base for future analysis of residential electricity consumption, energy modeling and decision making.

In some cases, more measurements are necessary where they have not yet been performed or where there are too few (e.g. air conditioners). It is necessary to perform new measurements to observe changes over time and to include new energy efficient appliances and new lamps (e.g. LEDs). It is also important to keep track on the influence of new trends like changing to larger sized appliances or to many more lighting points than before (rebound effect). Such measurements will permit to obtain better estimates of the potential savings by replacing old inefficient equipment as well as to design suitable strategies to tap those savings.

Regulation changes, as they have been started in the EU during the last years, information campaigns with clear and simple messages targeting households, combined with suitable financial incentives seem the most effective way to stimulate market transformation towards more energy efficient appliances in the residential sector. Setting up ambitious European Minimum Energy Performance Standards under the Eco-Design Directive on as many energy-relevant products as possible, and its rapid implementation, connected with a strict compliance market control are needed. The same strict control applies to the additional energy labelling of these products under the revised Energy Labelling Directive, which will further increase the share of highly efficient A+, A++ and A+++ appliances in the sales of the years to come. Additional information campaigns, however, will be necessary to overcome the lack of information and awareness of consumers and retailers and to reach behavioural changes with regard to energy-efficient appliances.

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Table 1 List of type of loads monitored per country

Belgium Denmark France Germany Greece Italy Portugal	- domestic computers and peripherals - new electronic loads (new domestic entertainment such as home movie systems, game/play station consoles, DVD players and recorders, large plasma/LCDs) - other standby power (setop-box, chargers for cordless phones and mobile phones, cordless tools, etc.) - lighting - residential air conditioning loads (southern Europe)
Norway Bulgaria Czech Republic Hungary Romania	- cold appliances - washing machines - dryers - lighting - new electronic loads - domestic computers and peripherals

Table 2 Standby energy consumption – results from REMODECE measurement campaign [5]

Appliance	Spot Measurements	Average Standby Power Considering Ownership	Considering Ownership At participating countries
Unit	W	W	kWh/year/household
Microwave oven	2,2	1,5	11,2
Desktop PC including monitor	6,4	5,0	38,7
Laptop PC	2,1	0,9	6,7
Router for internet, Modem, Wireless access point	8,0	3,8	29,4
Scanner	6,3	2,3	17,8
All in one printer	4,4	1,9	14,9
Printer	4,8	3,2	24,6
Fax machine	4,0	0,7	5,3
Phone	2,8	2,5	19,4
TV CRT	3,1	2,9	22,0
TV LCD	1,8	0,4	3,2
TV Plasma	1,6	0,1	1,1
TV Projector	37,5	0,4	3,2
Home cinema	2,7	0,5	3,7
VHS recorder/player	4,9	3,2	24,3
DVD recorder/player	3,8	2,5	19,4
Hi-Fi	4,7	3,4	25,8
Satellite/cable/air set top box	6,4	2,6	20,2
Hard disk (TV recorder)	2,1	0,5	3,5
Video game	1,5	0,4	2,9
Compact Hi-Fi	2,8	1,0	7,7
Total	113,9	39,8	305 kWh/Year

Figure 1: Annual Electric Energy in European Households (excluding space and water heating), kWh/year per household

Figure 2: Electricity demand and installed capacity (watt) per household

Figure 3: Electricity consumption breakdown in the residential sector in the countries participating in the REMODECE, excluding electric space and water heating [4]

Figure 4a) Annual electricity consumption range for several appliances [4]

Figure 4b) Annual electricity consumption range for office equipment [4]

Figure 4c) Annual electricity consumption range for entertainment equipment [4]

Figure 5 Electricity consumption for the average day for a typical Remodece household in Europe [4]

Figure 6: Electricity savings potential per household and appliance, by switching to the BAT [4]