DSM: major findings of an end-use metering campaign in 400 households of four European countries

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Abstract

EURECO project allowed to measure during one month, the electricity consumption of the main end-uses in 400 households of four European countries.

This study gathers the most relevant information available today in Europe, concerning electricity consumption in the residential sector. The consumption and load curves of each domestic appliance types are depicted. This study brings two major contributions to the knowledge of electricity consumption in the residential sector, thanks to:

- the use of a new type of measuring device that monitors the consumption of any light source,
- a new approach which determine the total household standby characteristics by a global measurement.

This study enabled to quantify the potential electricity saving that could be reached by substituting efficient appliances for existing ones.

We shall remember that:

- 1 000 to 1 200 kWh/year could be saved depending on the country, that is 150 to 180 TWh/year at the EC scale, standby-powers represent the first source of potential electricity saving, neck to neck with cold production,
- the replacement of 7 to 10% of the most consuming cold appliances would allow to reach 30% of the potential energy saving of this end-use,
- the replacement of the five most electricity consuming light bulbs in each household would allow to reach 80% of the total potential saving for lighting.

This study is first and foremost a significant information source for all the parties involved in DSM in the residential sector, but it also includes many elements that could inspire the national and European DSM policies.

Objective of the EURECO project

The main objective is to assess the potential electricity savings in the residential sector in four European countries: Denmark, Italy, Portugal and Greece. Savings are obtained by simulating currently installed appliances with the most energy efficient ones available on the European market. In a first stage, the electricity consumption of each individual end-use is monitored during a full month. In a second stage, the savings are assessed appliance by appliance and estimated from the initial measured consumption as well as the potential savings from replacing the appliance with the most efficient one of similar size, feature and service. Consumption patterns are adjusted to consumer's habit and physical condition such as room temperature to match those observed during the end-use campaign.

EURECO follows a similar methodology and approach to the ECODROME campaign (Sidler 1997), performed in a panel of French households in 1997 and widely documented (http://perso.club-internet.fr/sidler/ecod_sum.pdf). An average saving of 1 200 kWh/year per household was then measured, representing 40% of the total initial consumption.

The present paper summarises a small portion of the EURECO results. The final report (in French or English) and summary are available on *Enerte*ch web site : http://perso.club-internet.fr/sidler.

Data Collection with an Advanced End-Use Metering System

The ECODROME project involved measuring appliance electricity consumption in 20 households over a 2 year period. The measurements used an ingenious system known as DIACE (Individual and Automatic Diagnostic of Electricity Consumption). This system allows the energy consumption of each appliance to be measured via a discreet meter plugged in series with the appliance. Measured data is transmitted via the power line every ten minutes to a data receiver using power line carrier technology that requires no action by the occupants. Every night each household's central data receiver automatically downloads its data by modem to a remote storage computer. All the plug-loads and the electric light circuit were monitored for the first year. At the beginning of the second year all the appliances and light bulbs were replaced by the most efficient equipment fulfilling the same level of service available on the European market. Replacing each individual equipment was expensive and require a heavy organisation.

In EURECO it was decided not to replace individual appliances, but to compare measured consumptions to the most energy efficient models of similar capacity and function, in order to get the potential savings. A panel of 100 households in each of the 4 countries was selected (Denmark: 100; Greece: 96; Italy: 102; Portugal: 99). In each household, individual electrical end-use is monitored every ten minutes over a full month of operation. On top of that, the overall electricity consumption and the temperature in the kitchen is monitored at the same frequency. All metering equipment belongs to the DIACE system, hence using power line carrier technology to circulate the information. A detailed questionnaire was used to survey the participants' habit and collect social and economical data.

Monitored appliances were selected from two lists. Only the first list was compulsory. The operator could choose either to monitor the appliances indicated in the second list or not, depending on the number of remaining metering plugs:

First list: appliances that must be monitored:

- household general consumption,
- every cold appliances,
- every light sources (individual monitoring),
- the audiovisual site (TV+VCR+TV-decoder + satellite + HiFi),
- the clothes-washer.

A temperature sensor was placed in the room where the cold appliance was installed, in order to be able to calculate the consumption of a substitute class A appliance that would work in the same conditions.

Second list: secondary appliances:

- circulation pump of individual boilers,
- computer site (PC + screen + printer, etc.),
- dishwasher,
- air-conditioning.

Although this study only deals with specific electric uses, some partners wished to monitor also some electric water-heaters.

Lighting is particularly scrutinised and each lighting feature is individually monitored in each room of each house during the whole month. Enertech developed an accurate and small metering devise, called Lamp-Metre, for that purpose. The data collected by the Enertech Lamp-Meter are fully compatible with the one gathered by the DIACE systems. The Lamp-Meters helped collect a unique series of data on lighting as described latter on.

The monitoring took place between January 2000 and June 2001. Each appliance was monitored just for one month in this period. Only a few of the 400 monitored households were dropped out of the database. The major reason for dropping out an household was the lack of well collected data.

The household selection did not comply with specific selection criteria because it was difficult to find 100 voluntary households in each country.

How do existing appliances behave?

The EURECO project helps understand how appliances consume electricity. The monitored data have been formatted into a large and very detailed electronic database including all parameters for each appliance surveyed. It's one of the most interest of EURECO: to assemble a large database available to everyone.

MAIN CHARACTERISTICS OF EXISTING APPLIANCES

The annual energy consumption and the profile of the power demand is analysed for each appliance. The load curve can be analysed on hourly, daily, weekly or monthly basis depending on what is most appropriate for each family of equipment. The following graph (Figure 1) show how data can be conveniently displayed for analysis. The average daily load curve of the total electricity consumption is desegregated by end-use in the panel of monitored homes in Denmark.

It is also possible to perform more detailed analysis, like the washing cycle of clothes-washers. Figure 2 presents the average consumption observed in Italian clothes-washers for the 60°C washing cycle sorted by vintage. In the panel of this study, older machines do not necessary consume more energy than more recent model. This graph shows that recent clothes-washers, among which some models are supposedly more efficient, do not have a significant impact on the specific consumption of the whole set of installed clothes-washers.

The analysis of the electricity consumption of artificial lighting brings a great deal of new information because of the technique used to monitor each individual lamps at

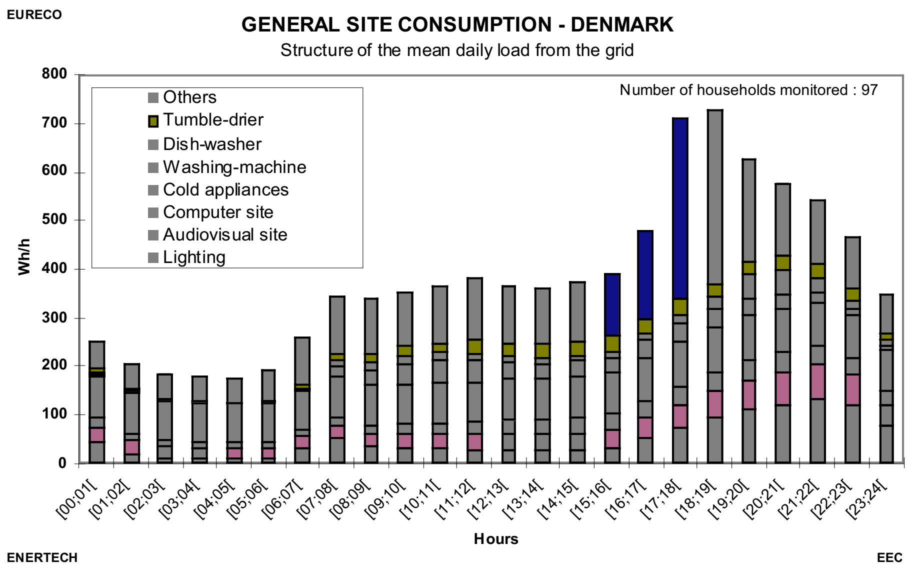

Figure 1: *Average Daily Load Curve of Total Electricity Demand in Households in Denmark, desegregated by end-use.*

home. Figure 3 shows the distribution of the average yearly electricity consumption in the panel of home in Greece.

It is possible to desegregate the lighting consumption room per room as showed in Figure 4 (Denmark: 100 households; Greece: 88; Italy: 101; Portugal: 74). This figure shows that in the four monitored countries, the most electricity consuming room is the Lounge-Living room-Dining room (1/3 of the total consumption), followed by the kitchen or the bedrooms, depending on the country. In every case, the living-room and kitchen lighting consumption together range between 50% and 55% of the total lighting consumption. Finally, it can be noted that in some countries, bathroom lighting consumption is higher than the lighting consumption of all the bedrooms taken together.

Usually the information regarding the time of use of lighting features is scare and uncertain. In the EURECO project, for the first time, it is possible to access such data. Figure 5 presents an illustration of this: the graph shows the cumulated frequency of use of the main luminaire and the 2nd main luminaire in Greek kitchen. For instance, from this graph, one can read that in 20% of the kitchen in Greece, the main luminaire runs at least 1 700 hour per year. On average (at the 50% threshold), the main luminaire is used more than 1000 hours per year. Or 30% of the 2nd main luminaire is used more than 600 hours, but less than 1 000 hours per year.

Such refined data can greatly facilitate where the largest savings can be expected on lighting.

ANALYSIS THE UNKNOWN: THE CASE OF STANDBY POWER WASTE

The method to study the level of standby power waste comprises three steps:

- Firstly, the consumption of the audio-video system and home PC system were individually monitored with the DIACE like any other end-use in the homes which provides both the standby power level and the electricity consumption,

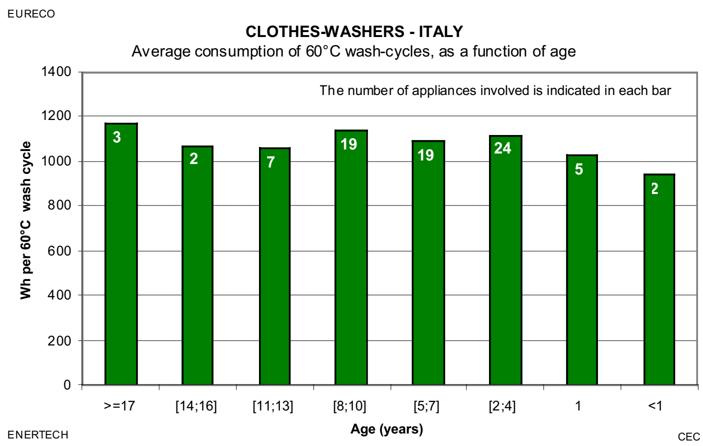

***Figure 2**: Clothes Washers Energy Consumption for the 60˚C Washing cycle sorted by vintage in Italy.*

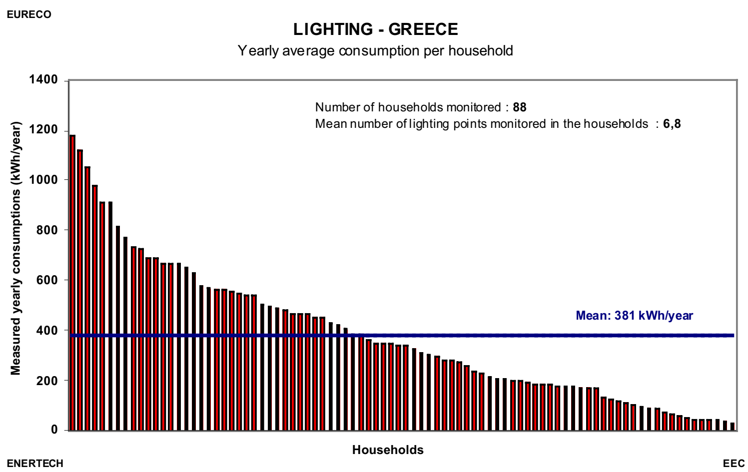

Figure 3: *Distribution of Electricity Consumption of Lighting in Greece.*

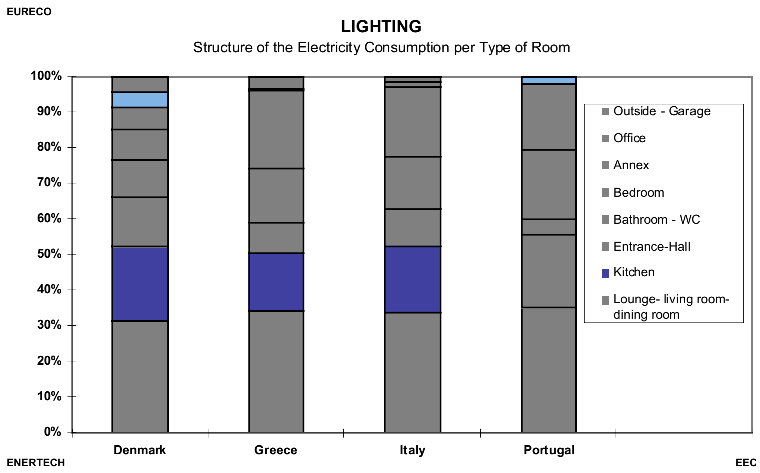

Figure 4: *Structure of the Lighting Electricity Consumption per Type of Room.*

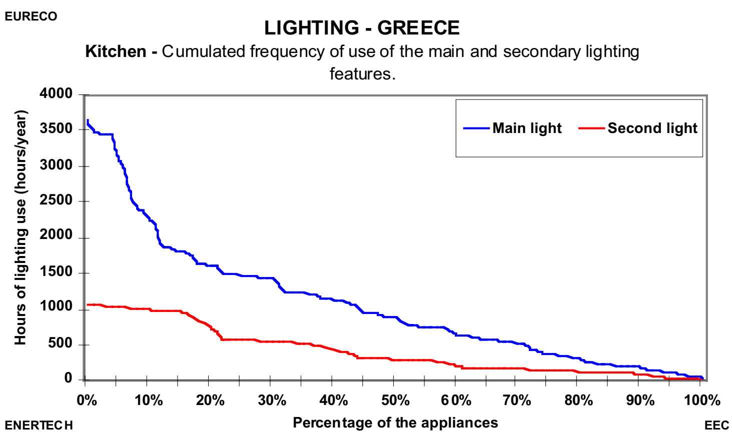

Figure 5: *Cumulated frequency of use of the main and secondary lighting features in the kitchen in Greek homes.*

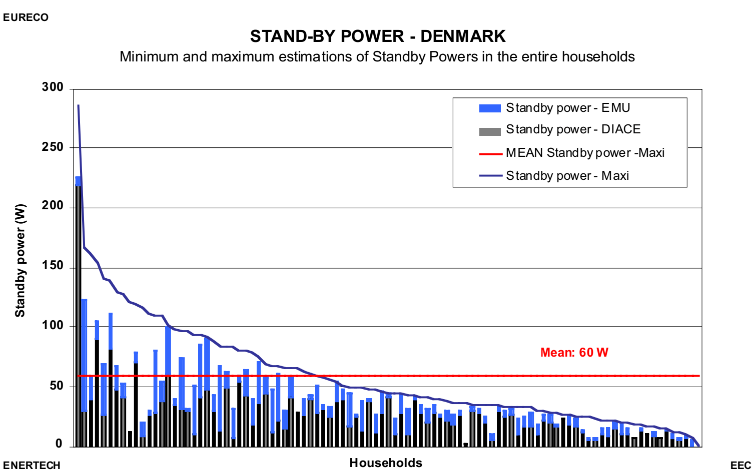

Figure 6: *Standby Powers measured in Danish Households.*

- Secondly, the standby power of some other appliances were measured with an accurate Wattmeter (called EMU). The consumption of these appliances in standby mode were estimated from the monitoring of other appliances of the same type in the same country, providing an average number of hours per year in standby mode.
- Finally, the permanent monitoring of the total electricity consumption of each home provides an indication of the total level of standby power. To determine the corresponding maximum standby consumption, DIACE and EMU standby consumption were added, as well as the consumption of the remaining part which was estimated by putting forward that these unidentified appliances were always working in standby mode (high hypothesis).

The standby power of a total of 370 European households has been analysed with a great deal of attention. The level observed is higher than what was originally estimated before (Sidler 2000; Meier 2001), especially by the International Energy Agency (IEA 2001). Figure 6 presents the total power consumed in the standby power mode in Danish households. The picture shows for each household the total standby power consumption recorded at the main meter, the level of standby measured on the audio-video and home PC system with the DIACE as well as the sum of the standby power measured with the Wattmeter (EMU).

On average, the standby power is 60 W per household in Denmark, 50 W in Greece, 57 W in Italy and 46 W in Portugal. This translates into 482 kWh/year in Denmark, 424 kWh/year in Greece, 472 kWh/year in Italy and 377 kWh/year in Portugal. The European average for these four country is 439 kWh/year.

Standby power accounts for 14% of the total specific electricity (excluding electricity space heating, water heating, and cooking) in Danish households and 16% in Italy.

The standby power consumption of a total of 1 080 individual equipment has been measured and formatted in a dedicated database. Figure 7 presents the histogram of the average standby power observed for each family of equipment. Figure 8 shows the average power factor.

Figure 9 shows that two thirds of the appliances with a standby power more have a power factor lower to 0.50. An appliance with a low power factor does not systematically leads to a high consumption or a poor efficiency. But it will for sure draw more apparent power from the electricity network than the same appliance with a high power factor. Therefore, the current losses in the power lines will be higher, and the electricity producers will have to supply more current, and to oversize the grid and transformers. Moreover, the low level of the Power Factor in standby power mode, is likely to imply a significant amount of harmonic distortion in the electric circuit.

Figure 10 shows the annual consumption due to the standby power mode for each family of equipment. Satellite dishes, set-top boxes and HiFi Stereo system present the highest level of annual standby power consumption.

Technical Potential Energy Savings

The technical potential electricity saving is estimated through the following assumption:

- replacement of all cold appliances with the most energy efficient models available of the European market. In Europe the most energy efficient appliances are rated with an « A »on the European Energy Label;
- replacement of all incandescent and halogen lamps with compact fluorescent lamps;
- reduction or elimination of the standby power waste whenever possible with simple means like a multiple plug with a hard on-off switch;
- replacement of clothes washers by class A model, or connecting the clothes washer to the hot water outlet, or stimulating cold temperature wash.

For each country, the potential savings are based on the observed characteristics of appliance usage. The average annual savings varies from 1 000 to 1 200 kWh per household representing between 35 to 40% of the total specific electricity (excluding electricity for space heating, water heating, and cooking).

Reducing standby power waste accounts for the largest share of the accessible savings, certainly at the same level as the savings from more energy efficient cold appliances. Compared to previous end-use metering campaign, standby power presents the fastest growth of all the end-use. This is a surprising finding of EURECO and indicates the urgent necessity to deploy and implement policy to reduce the standby power waste from new equipment but also on existing ones. Interestingly, the savings on cold appliance is less than initially thought. This is due to the impact of the transformation of the European refrigerators and freezers market which is happening since the introduction of the European energy label in 1995 and the minimum energy efficiency standard in 1999.

Compared to the situation observed on the consumption of cold appliances in the previous European metering campaign (Nutek 1995, Sidler 1996, Lopez 1996), refrigerators and freezers monitored in Denmark, Italy, Portugal and Greece seem to be one average more energy efficient. There are more cold appliances with a good average consumption today in European households. Figure 11 shows that for instance in Denmark the replacement of the top 7% least efficient freezers with the most energy efficient products on the market can generate up to 30% of the total potential savings estimated for this end-use. Early replacement of cold appliances may generate significant savings only if the least efficient models are indeed identified and addressed. This is clearly a new finding for European demand-side management programmes. It may be appropriate to develop in the next years a tool or a process to conveniently identify those poorly performing refrigerators and freezers still in use. Specific programmes could then be implemented to organise their replacement.

The analysis of the potential saving for lighting proves very interesting. As each lighting fixture has been monitored individually, it has been possible to access in great detail the precise amount of savings to be obtained by replacing the

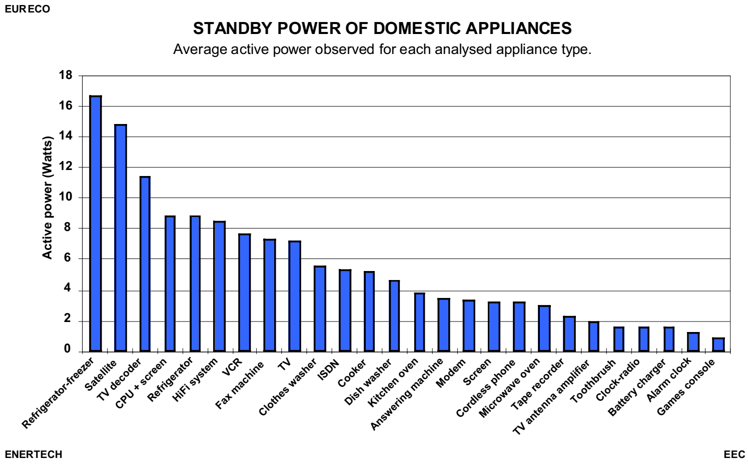

Figure 7: *Standby Power Level for Each Family of Equipment.*

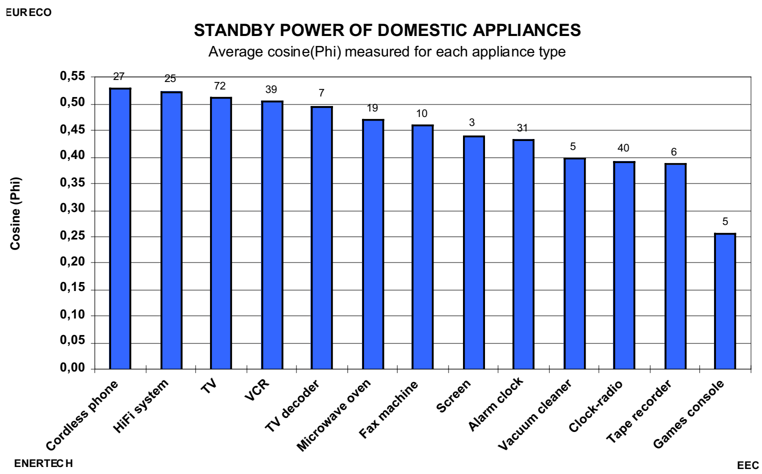

Figure 8: *Average cos φ (Power factor) for 13 types of appliances in standby mode.*

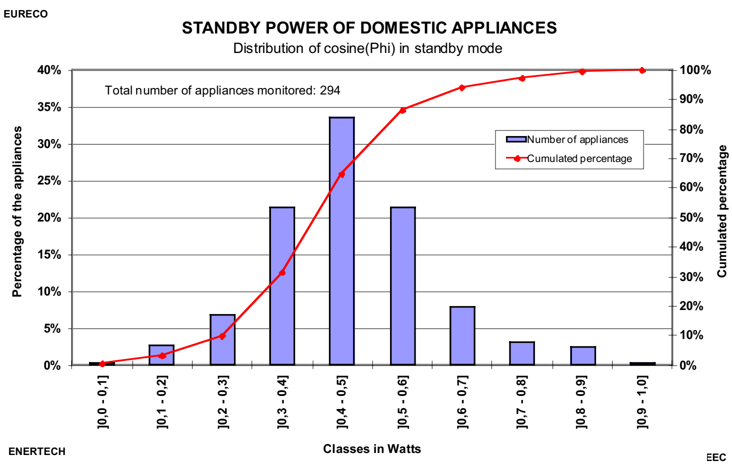

Figure 9: *Distribution of cos φ (approximation of the Power Factor) in the panel.*

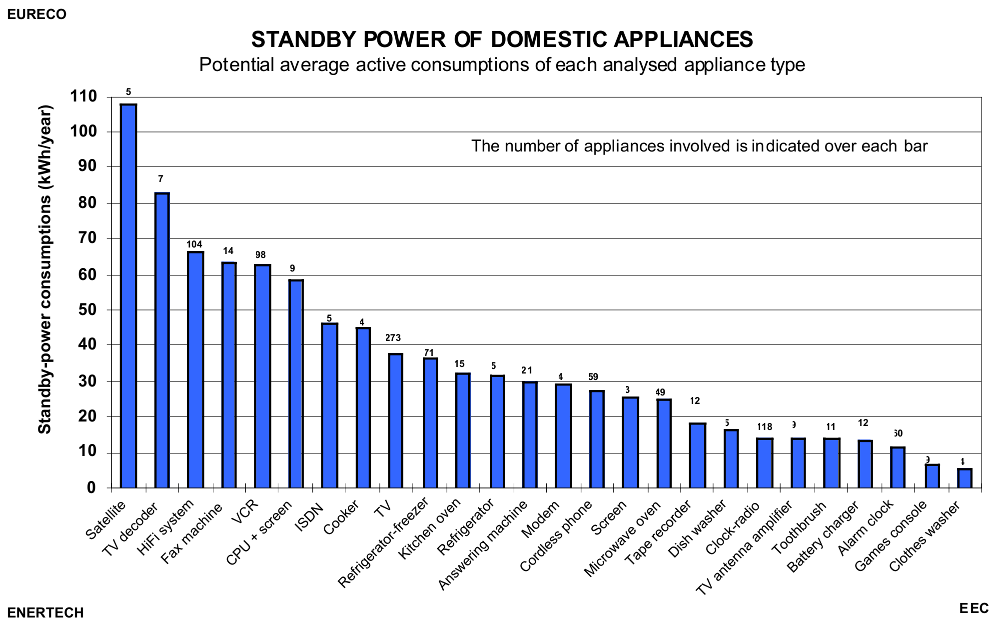

Figure 10. *Average Energy Consumption of appliances in standby mode.*

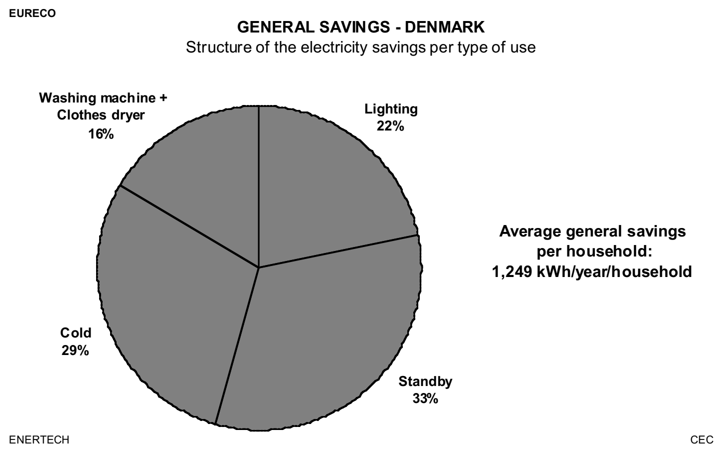

Figure 11: *Distribution of potential electricity savings by end-use (100 households).*

lamps having the largest use in the home. Questions such as "how many compact fluorescent light bulbs replacing incandescent light source does it take to reduce lighting consumption by 20%, 40% or 60%" or "what is the expected payback time if household installed one, two, or three compact fluorescent lamps? What is the influence on the price of electricity on such payback time?", etc.

For instance Figure 13 indicates the achievable savings with installing compact fluorescent lamps depending on the desirable payback time and on the cost of the lamp. With such graph, it becomes easier to design demand-side programme and target maximum impact of programme such as replacing inefficient lighting.

For a price of 6 Euro per compact fluorescent lamp and a maximum payback time of 2 years, the potential savings will not exceed 190 kWh/year/household. This represents 72% of the total potential savings assessed to be 264 kWh/year.

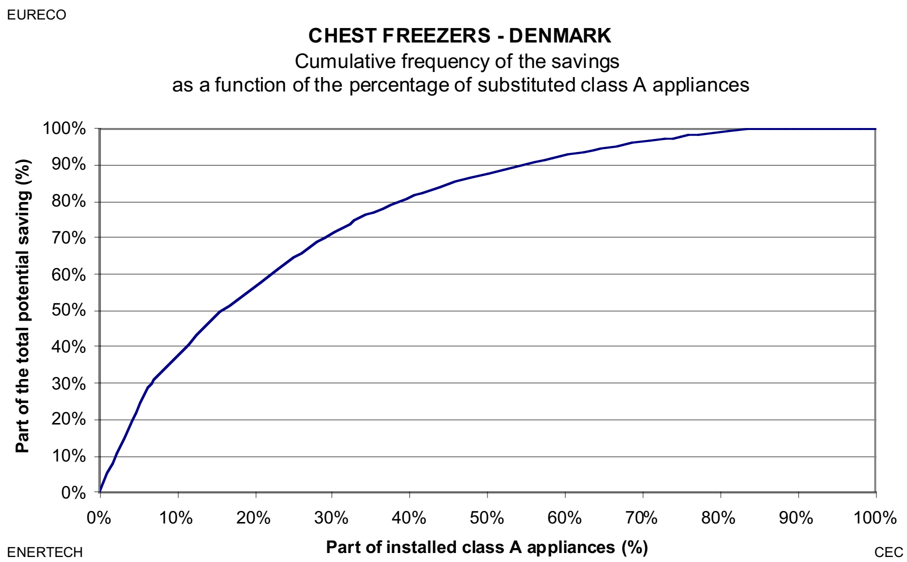

Figure 12: *Potential savings achievable by early replacement of Freezers in Denmark (expressed in cumulated figure).*

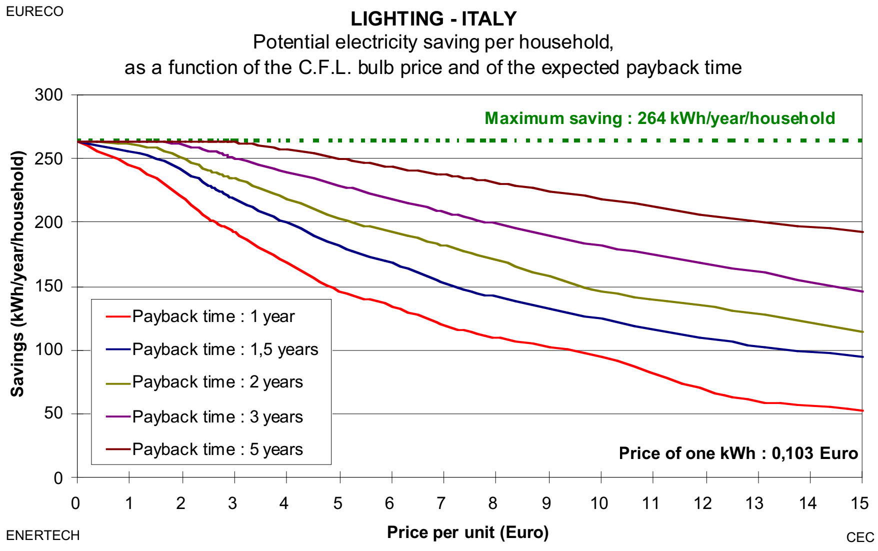

Figure 13: *Italy – Energy Savings per Household depending of the cost of the compact fluorescent lamps and desirable payback time.*

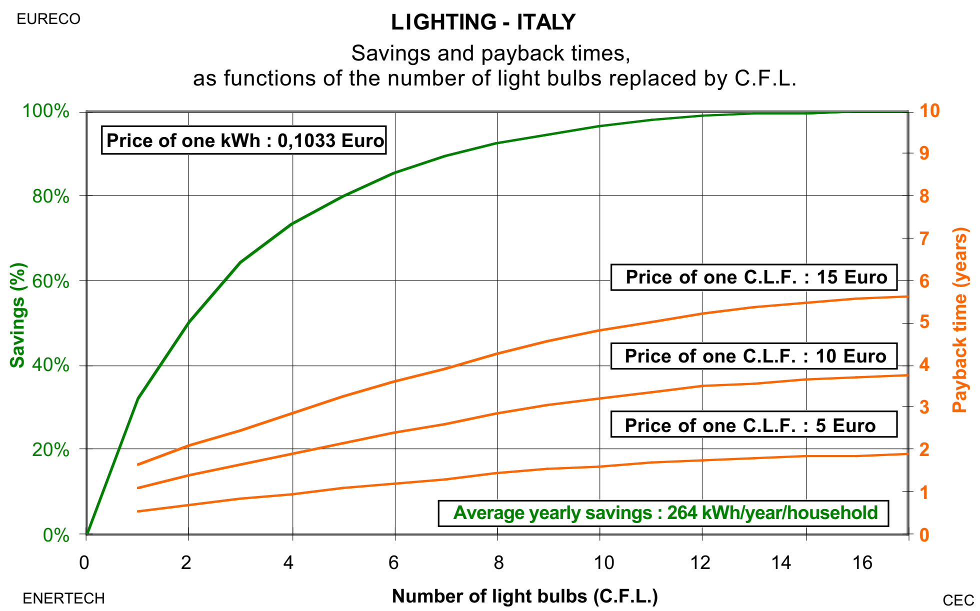

Figure 14: *Italy – Potential Energy Saving by replacing first the most used incandescent lamps with Compact Fluorescent Lamps.*

However this method does not indicate which lamp should be changed in which fixture first. It provides an indication of the level of savings for the whole panel.

Another approach is to change a given number of lamps per household. This method is more straightforward, but will generate less savings for a given cost of a programme. In other words, this method is less cost-effective for catching the savings. Figure 14 shows, in the same country, Italy, that the replacement of one lamp – the one having the longest use – will generate 33% of the potential savings. For a price of 10 Euro per CFLs, the payback will be 1.1 year.

Conclusion

The project EURECO provides an unique new understanding of the electricity demand in the European residential sector. Based on the thorough measurements of each end-uses in 100 households in each of the 4 participating countries (Denmark, Italy, Portugal, Greece), a robust database has been completed. The present paper summarises just a portion of some interesting findings, like the growing waste from the standby mode, like the possible savings from installing compact fluorescent lamps in the most appropriate fixtures. The final report is now available (French, English and summary) on web site http://perso.club-internet.fr/sidler.

Once again, this new metering campaign by end-use not only confirm the feasibility of such approach in very different national situation, it also provides a solid base for designing demand-side management programmes and energy efficiency policies the most likely to deliver.

The analysis of the data indicates the priorities for promoting energy efficiency in European households, the scale of the savings and the most appropriate path to achieve them.

The EURECO results will certainly be instrumental in shaping future efforts to reduce electricity demand in European households and contribute to greenhouse gas mitigation programmes.

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