Electricity Demand in European Households: Major Findings from an Extensive End-Use Metering Project in Four Individual Countries

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ABSTRACT

The EURECO project monitored electricity consumption of major end uses in 100 households in each of four European countries: Denmark, Italy, Portugal and Greece. This exceptionally detailed data set allows for comparative analysis of energy use among countries and illustrates the value of end-use metering for understanding load curves and assessing the potential for electricity conservation in the residential sector. Findings from this study's data analysis include: a combined refrigerator-freezer in a Greek kitchen consumes on average 40 percent more electricity than one in a Danish kitchen; standby power losses from domestic electronic equipment in all four countries are much more significant than expected; and dishwasher energy consumption is the figure that varies most among the four countries.

Lighting was monitored in particular detail; individual lighting fixtures were monitored in each room of each house. The lighting data reveal a wide range of information, especially about the contribution of the most heavily used lighting fixtures to lighting energy consumption.

This study demonstrates, among other conclusions, that installation of the most energy-efficient appliances can help reduce total peak power use by a factor of up to two in most cases and that the greatest potential for energy savings would come from reducing standby power losses; the potential savings are equal to those from installation of more energy-efficient refrigerators and freezers. This paper presents a small sample of the major findings of this unique, comprehensive disaggregation of electricity consumption in European households.

Objective of the Project

The main objective of the EURECO project is to assess potential residential-sector electricity savings in four European countries: Denmark, Italy, Portugal and Greece. Electricity consumed by each end use studied was monitored in 400 households during a full month. Potential savings were then assessed, appliance by appliance, by comparing measured consumption to consumption by the most energy-efficient models of comparable size and type available on the European market, simulated for the same household conditions. Consumption patterns were adjusted for consumer behavior and the physical conditions of each household, such as room temperature, observed during metering.

EURECO uses a methodology similar to that employed in the widely documented 1997 ECODROME study (http://perso.club-internet.fr/sidler/ecod_sum.pdf) of energy use in a group of French households. An average savings of 40 percent (1,200 kWh/year) of energy

consumption per household was measured after existing appliances were replaced with the most energy-efficient models.

This paper summarizes a small portion of the EURECO results. Complete data and the final report are available at http://perso.club-internet.fr/sidler/page22.html.

Data Collection with an Advanced End-Use Metering System

The 1997 ECODROME project measured appliance electricity consumption in 20 households over a two-year period. The measurements were performed using an innovative system known as DIACE (Individual and Automatic Diagnostics for Electricity Consumption). DIACE measures energy consumption of each appliance using a discrete meter plugged in series with the appliance. Measured data are transmitted every 10 minutes via the power line to a data receiver using carrier technology; no action is required by the household occupants. Every night, each household's central data receiver automatically downloads by modem to a remote storage computer. The electric lighting circuit and all plug loads were monitored for one year. At the beginning of the second year, all appliances and light bulbs were replaced with the most efficient comparable equipment available on the European market.

Because replacement of all equipment in the ECODROME project was expensive, the EURECO project did not attempt to replace individual appliances; instead, EURECO calculates potential savings by comparing measured consumption to consumption figures for the most energy-efficient appliance models of similar capacity and function. In each of the 400 households studied, individual electrical end uses were monitored every 10 minutes for a full month. Overall electricity consumption and kitchen temperature were also monitored at the same intervals. DIACE metering equipment was used, as described above for the ECODROME project. A detailed questionnaire documented household occupants' habits and socio-economic data.

Lighting was studied in particular detail; each lighting fixture was individually monitored in each house. Enertech developed a small metering device, the Lamp-Meter, for this purpose. Data collected by the Enertech Lamp-Meter are compatible with those gathered by DIACE. The unique data collected by the Lamp-Meters are described in detail later in this paper.

The monitoring took place during the period January 2000 - June 2001.

How Do Existing Appliances Behave?

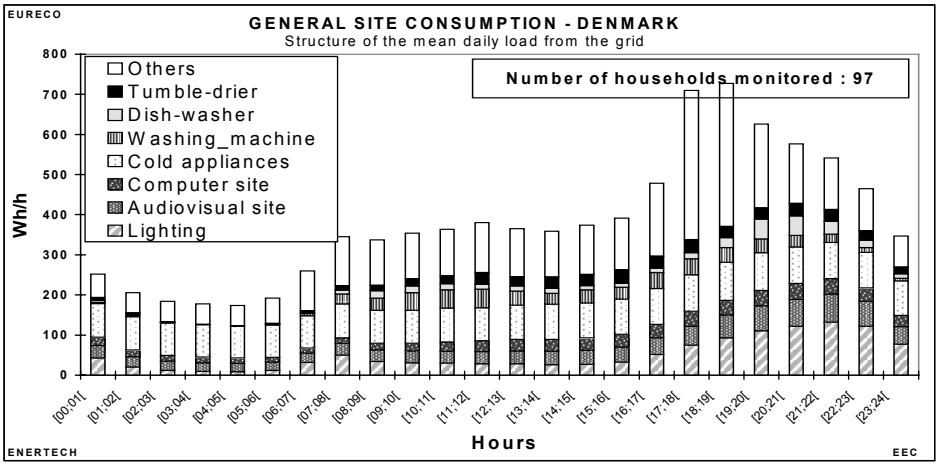
The EURECO project data add to our understanding of the power demand profiles for appliances. For ease of analysis, the data were formatted into a large, detailed electronic database that includes all parameters for each appliance surveyed.

Key Characteristics of Existing Appliances

The annual energy consumption and power demand profile were analyzed for each appliance. Load curves were analyzed on an hourly, daily, weekly or monthly basis depending on what was most appropriate for each family of equipment. Figure 1 shows an

example data display from the project – the average daily load curve of total electricity consumption disaggregated by end use for the homes monitored in Denmark.

Figure 1. Average Daily Load Curve of Total Electricity Demand in Households in Denmark, Disaggregated by End-Use



The average annual consumption of different appliance types and of the lighting equipment in the four countries are summarized in Table 1. For instance, on average, a combined refrigerator-freezer in a Greek kitchen consumes 40 percent more electricity than one in a Danish kitchen

Table 1. Average Annual Energy Consumption by End Use in EURECO Study

Uses	Denmark *in kWh/year*	Greece *in kWh/year*	Italy *in kWh/year*	Portugal *In kWh/year*
Refrigerator	288	687	354	228
Fridge-freezer	589	844	629	563
Freezer	409	636	517	598
Clothes-washer	243	163	211	154
Dishwasher	289	157	369	256
Clothes-dryer	368	-	-	546
Lighting	426	381	375	-
Audio-visual	330	258	355	306
Computer	226	110	132	219
Standby power	482	424	472	377

Detailed analysis, such as energy used by the wash cycle of clothes washers, is also possible with the EURECO data. Figure 2 shows the average consumption in Italian clothes washers for the 60°C washing cycle sorted by appliance vintage. These data do not support industry claims that more recent models of clothes washers are more efficient than older ones.

Figure 2. Clothes Washer Energy Consumption for 60°C Washing Cycle in Italy, Sorted by the Appliance Vintage

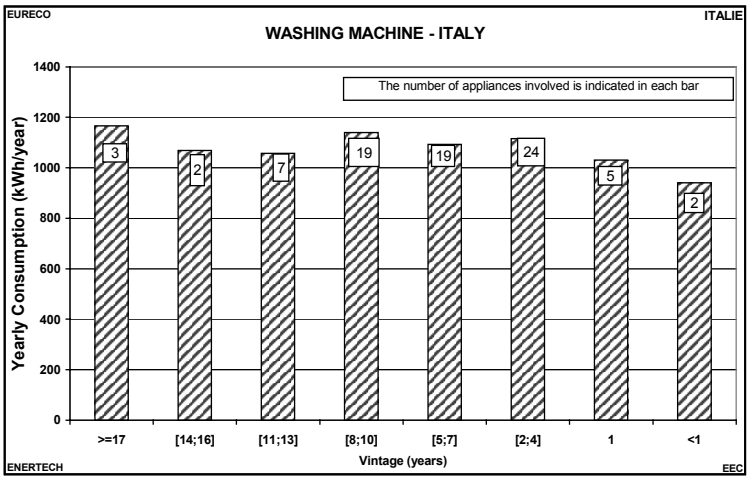


Figure 3. Distribution of Electricity Consumption of Lighting in Greece

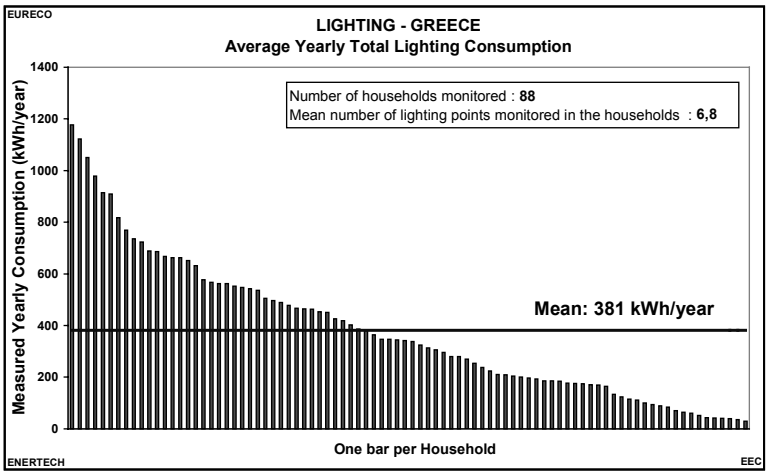


Figure 4. Lighting Electricity Consumption by Type of Room

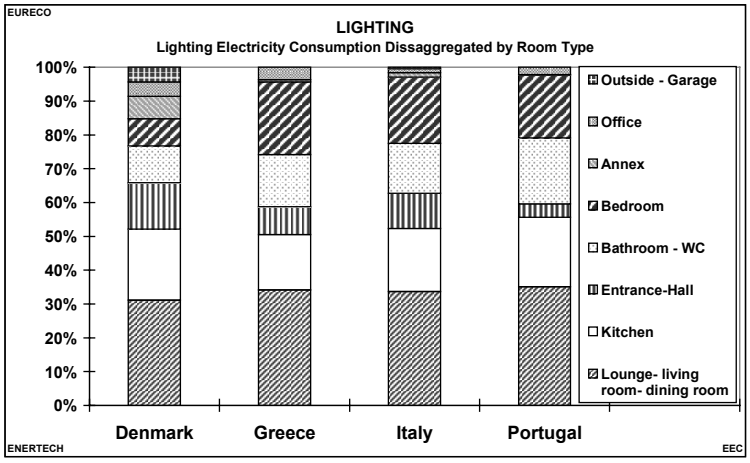


Figure 5. Cumulative Frequency of Use of Main and Secondary Lighting Fixtures in Greek Kitchens

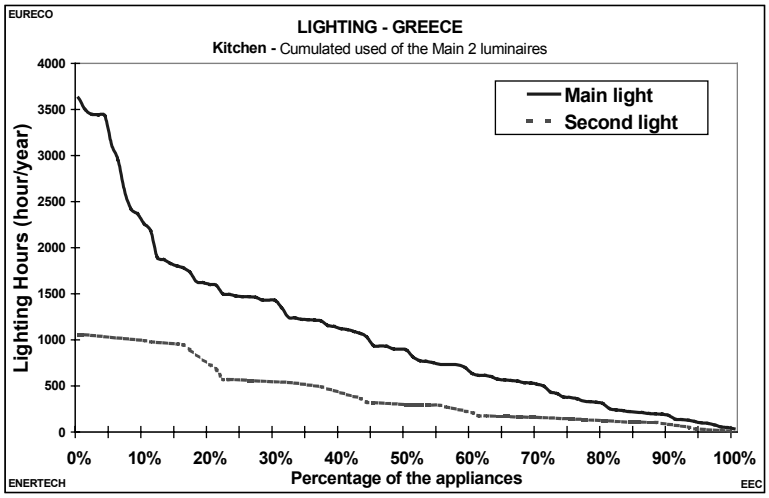


Figure 6. Standby Power Consumption measured in Danish Households

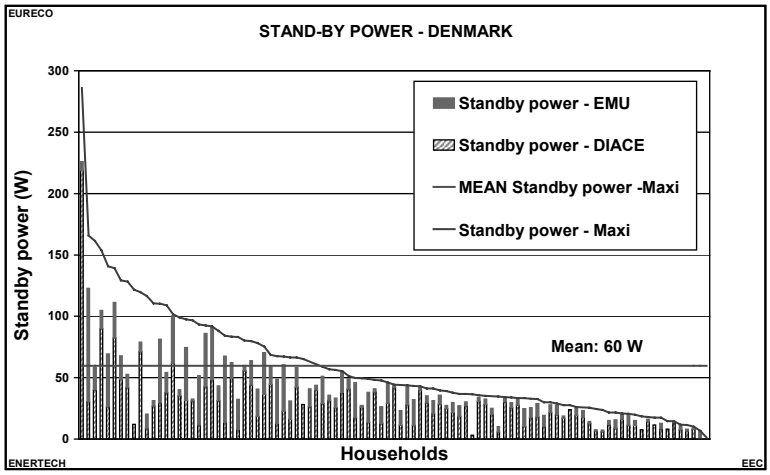
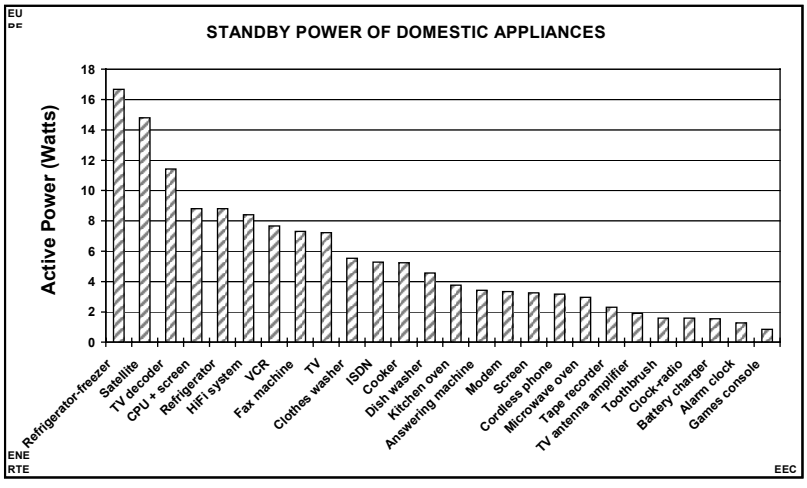


Figure 7. Standby Power Level for Each Family of Equipment



Analysis of EURECO data on electricity consumed by lighting reveals a great deal of new information because of the detail with which lighting energy use was metered. Because every lighting fixture in every room of each house was monitored, a huge number of lighting data were collected. This paper highlights only a sample of results. Figure 3 shows one example of the type of lighting data available in the EURECO data set: distribution of average yearly electricity consumption by lighting in the homes studied in Greece. The lighting data collected in this study allow analysis of lighting energy use on a room-by-room basis, as shown in Figure 4. In general, data on lighting time of use are scanty. EURECO makes available the first detailed set of such data. Figure 5 illustrates an example of these data, showing the cumulative frequency of use of the main and secondary main luminaires in Greek kitchens. These data show that, in 20 percent of Greek kitchens, the main luminaire is used at least 1,700 hours per year. In at least 50 percent of homes studied the main luminaire is used more than 1,000 hours per year. In 30 percent of the homes studied, the secondary main lighting source is used more than 600 but less than 1,000 hours per year.

These refined data allow us to determine which particular lighting fixtures offer the greatest potential for energy savings.

Analysis of Standby Power Loss

Standby power loss was studied in three ways. First, the energy consumed by individually monitored end uses was subtracted from the total electricity consumption of each home; the portion of total consumption not accounted for by individual end-use consumption is an indicator of standby power loss. Second, the consumption of audio-video and home personal computer (PC) systems was individually monitored with DIACE, providing an accurate picture of the energy consumed to operate these appliances and the standby power consumed when they are not in use. Third, standby power consumption of all other equipment was measured with an accurate Wattmeter (an EMU). Standby power use was analyzed in total for 370 of the households. The level of standby power loss found is greater, sometimes by a factor 2, than had been previously estimated by the International Energy Agency (IEA 2001). Figure 6 shows total energy consumed in standby power mode in Danish households. For each household, the figure shows the total standby power consumption recorded at the main meter (i.e., total electricity consumption minus energy consumed by individual end uses), the level of standby consumption measured for the audio-video and PC systems by DIACE, and the sum of the standby power measured with the EMU.

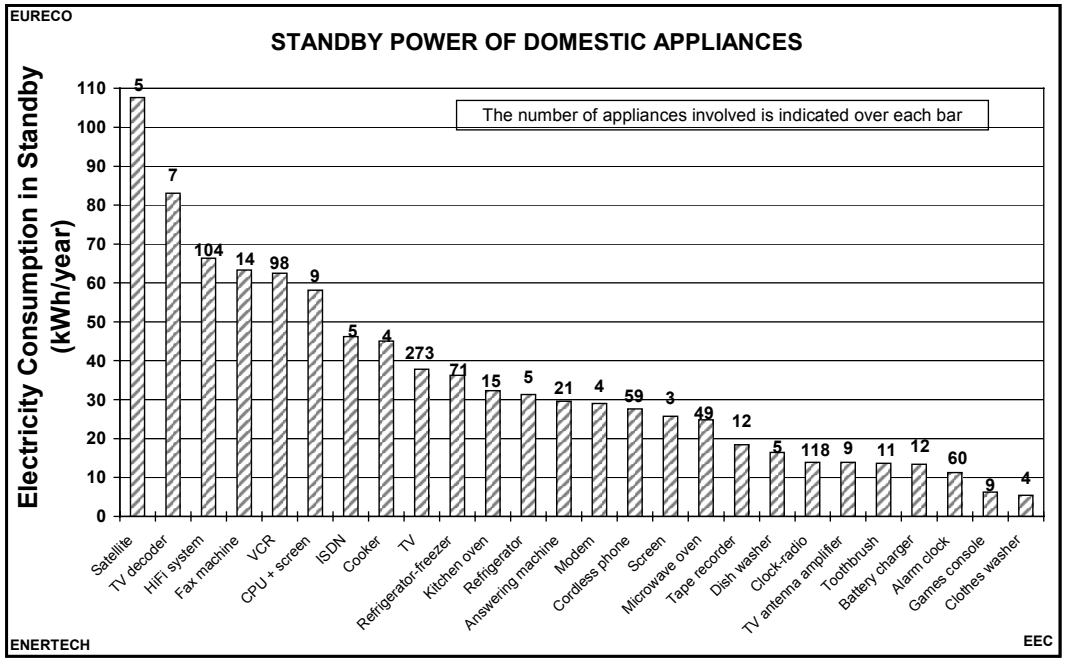
On average, total standby power consumption is 60 W (482 kWh/year) per household in Denmark, 50 W (424 kWh/year) in Greece, 57 W (472 kWh/year) in Italy, and 46 W (377 kWh/year) in Portugal. The average for these four countries is 439 kWh/year.

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

The standby power consumed by a total of 1,080 pieces of individual equipment was measured and formatted in a separate database. Figure 7 is a histogram of the average standby power consumption observed during the study for each family of equipment. Figure 8 shows the standby power consumption for each family of equipment on an annual basis.

Satellite dishes, digital TV set-top boxes, and stereo systems have the highest levels of annual standby power consumption.

Figure 8. Average Energy Consumption of Appliances in Standby Mode



Potential Energy Savings

Potential electricity savings were estimated based on:

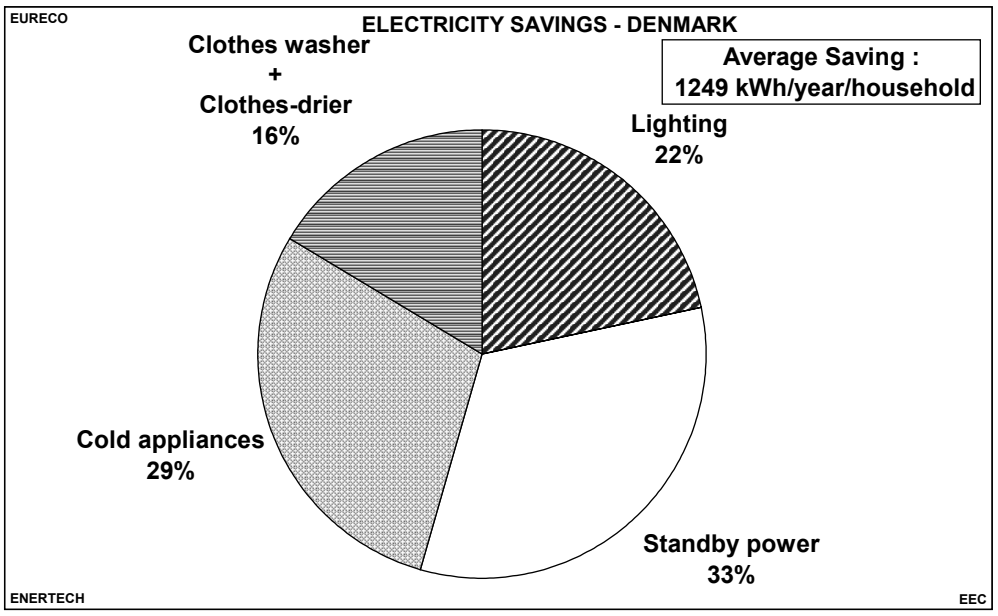
- replacement of all "cold" appliances with the most energy-efficient models of comparable type available on the European market (the most energy-efficient models have an "A" rating on the European Energy Label);
- replacement of all incandescent and halogen lamps with compact fluorescent lamps (CFLs);
- reduction or elimination of standby power loss whenever possible using simple means like a plug strip with a hard on-off switch;
- replacement of clothes washers with class A models or connecting clothes washers to the hot water outlet or encouraging the use of the cold-temperature wash setting.

For each country, potential savings are based on the characteristics of appliance usage as monitored during the end-use metering effort. Average annual savings vary from 1,000 to 1,200 kWh per household or between 35 and 40 percent of total specific electricity use (excluding energy for space heating, water heating, and cooking).

Reducing standby power loss represents the largest share of the possible savings, equal to the savings possible from installation of more energy-efficient cold appliances. Compared to data from the ECODROME metering study, the EURECO data show that standby power loss has grown more rapidly than energy consumption by any other end use. This surprising finding indicates the urgency of implementing policies to reduce standby

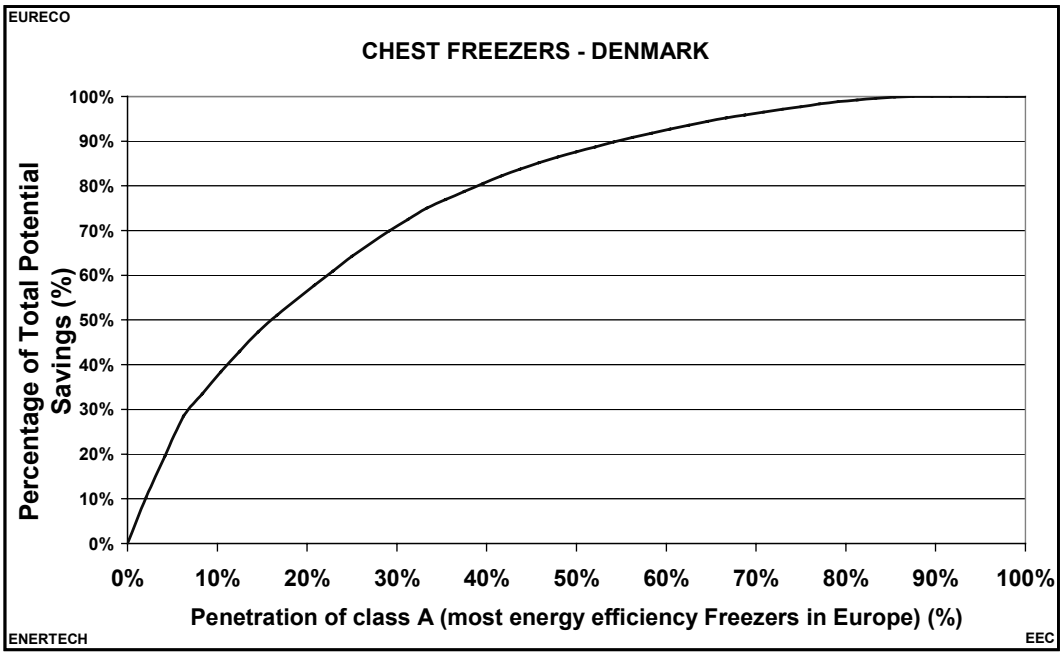
power loss in new as well as existing equipment. Interestingly, the savings from replacing cold appliances are smaller than anticipated, mostly likely because of the effects of the introduction of the European energy label in 1995 and minimum energy-efficiency standards in 1999.

Figure 9. Distribution of Potential Electricity Savings by End Use



Compared to the cold appliances observed in the French ECODROME project in 1997, refrigerators and freezers monitored in Denmark, Italy, Portugal, and Greece seem to be, on average, more energy efficient. Figure 9 shows an example of EURECO results for refrigerators and freezers; replacement of the top seven percent least-efficient freezers in Denmark with the most energy-efficient comparable products on the market could generate up to 30 percent of the total potential savings estimated for this end use. Early replacement of cold appliances is likely to generate significant savings only if the least-efficient models are targeted. This is a new finding with great significance for European demand-side management programs, which suggests that it might be appropriate to develop a method to easily identify the poorest-performing refrigerators and freezers still in use. Specific programs could then target these appliances for replacement.

Figure 10. Potential Cumulative Savings Achievable by Early Replacement of Freezers in Denmark



EURECO's analysis of the potential savings from lighting is very detailed because each lighting fixture was monitored individually, so it is possible to assess precisely the savings possible from replacing the most heavily used fixtures. The detailed EURECO data permit us to answer questions such as: how many incandescent light sources in a home must be replaced with CFLs to reduce lighting energy consumption by a specified percentage? what is the expected payback period from installing a specified number of CFLs? how does the price of electricity influence payback periods? As an example of using the EURECO data to analyze these kinds of questions, Figure 11 shows the savings achievable from installing CFLs, depending on the desired payback period and the cost of the lamp. Graphs such as this one make it relatively easy to design demand-side programs to target energy-efficiency improvements that will have maximum impact, such as replacing inefficient lighting.

Figure 11 shows, for instance, that, at a price of 6 Euros per CFL (on the horizontal axis) and a maximum payback time of two years (third curve from the bottom), potential savings in Italy will not exceed 190 kWh/year/household. This represents 72 percent of the total potential lighting savings (assessed at 264 kWh/year). However this method does not indicate which lighting fixture should be targeted first; it only indicates the level of savings possible for households in Italy.

Another approach to saving lighting energy is to change a given number of lamps per household. This method is more straightforward than targeting the most heavily used fixtures but will generate fewer savings for a given expenditure of demand-side management funds. In other words, this approach is less cost-effective. Figure 12 shows that the replacement of the most heavily used lamp in Italian homes will generate 33 percent of the potential lighting savings. At a price of 10 Euros per CFL, the payback will be 1.1 years.

Figure 11. Italy – Energy Savings per Household Depending of the Cost of the Compact Fluorescent Lamps and Desirable Payback Time

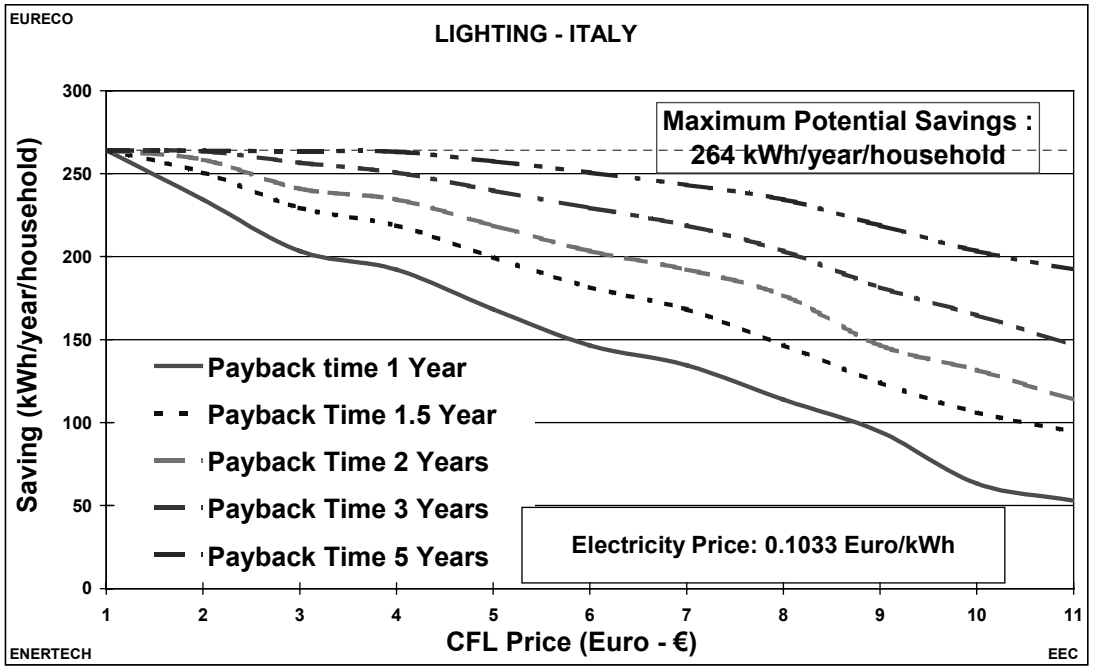
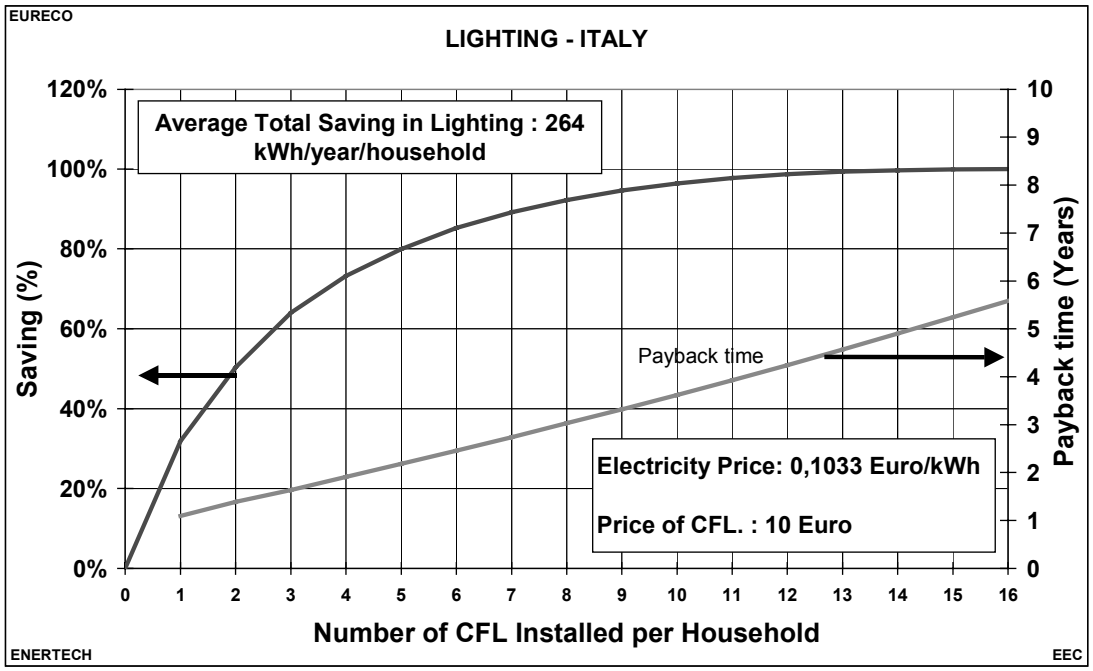


Figure 12. Potential Energy Savings from Replacing Most Heavily Used Incandescent Lamps with CFLs



Conclusion

The EURECO project offers a unique new understanding of electricity demand in the European residential sector. A robust database has been compiled of measured energy consumption by each major end use in 100 households in each of the four participating countries (Denmark, Italy, Portugal, Greece). This paper highlights some of the most interesting findings from the study, including the rapidly growing energy loss from appliances in standby mode and the possible savings from targeting CFL installation at the most heavily used incandescent fixtures. The EURECO database offers the international energy-efficiency community a unique source of information about electricity demand in a sample of European households. These data should be extremely useful to manufacturers, sociologists, energy modelers and researchers, and utility staff among others.

The EURECO study confirms the feasibility of metering individual end uses in households in very different national contexts, and it provides a solid basis for designing demand-side management programs and energy-efficiency policies that are most likely to deliver maximum savings.

Analysis of the EURECO data indicates the priorities on which to focus in promoting energy efficiency in European households, the scale of the possible savings, and the most appropriate approaches to achieving these savings. These results will be instrumental in shaping future efforts to reduce electricity demand in European households and to mitigate greenhouse gas emissions.

The final report from the EURECO study can be downloaded from http://perso.club-internet.fr/sidler.

Acknowledgments

The authors wish to thank Nan Wishner for her technical editing of this paper.

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