Lessons Learnt from European Metering Campaigns of Electrical End Uses in the Residential Sector

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Synopsys

End-use metering campaigns are providing invaluable information on how, where and when electricity is used in the home.This paper reports the latest results.

Abstract

In recent years, several institutions in Europe have carried-out metering campaigns in the residential sector in order to monitor electricity consumption by individual end-use. The specific goals of these campaigns have been: to explain the aggregate residential load curves observed; to understand how electricity is being used and in particular how much and for what activities; to provide data for use in bottom-up forecasting models; and to guide energy conservation and DSM programme development. The overall aim is to enable better conduct of demand side management efforts in the residential sector.

This paper presents the results of major European metering projects carried out in France[1,3], Portugal[2], Sweden[4] and the United-Kingdom[5]. It establishes the extent of commonality and differences in electricity use between the different regions. It focuses on the most significant and comparable end-uses, namely: cold and wet appliances, lighting and domestic electronic equipment. The main findings are analysed from both the behavioural and technical points of view and linkages between the two are discussed.

The paper illustrates the relevance of metering campaigns for the provision of sound background data required for energy efficiency policy development in Europe.

Introduction

Throughout Europe, more and more local or national authorities are encouraging efforts to promote Demand-Side Management (DSM) programmes in order to manage the ever-growing demand for electricity. As the building sector represents the largest share of the electrical consumption, many projects focus on the promotion of energy efficient lighting, appliances, and electronic equipment. In order to design proper DSM programmes in the residential sector and because of the absence of knowledge or the lack of reliability on existing information, several utility companies and government energy agencies have organised metering campaigns. The common objective of these campaigns is to collect the most detailed data of the electricity consumption by end-use in a representative panel of households.

During the last decade, technological developments in the field of microelectronics, computers and communications have had a large impact on metering and monitoring equipment. Several systems have been designed to meet the requirements of a successful end-use metering campaign, namely: good accuracy, high reliability, moderate cost, a large number of monitored end uses, high storage capacity, flexible communications, non-intrusiveness, powerful pre-processing of data[6,7]. This paper focuses on the most important findings regarding the main electricity-specific end-uses in European households, namely: cold appliances, wet appliances, lighting and some of the electronic and miscellaneous equipment. Electric space heating and water heating are excluded from the paper. Addiitonally, the paper discusses how the choice of metering equipment may affect the quality of the results and the data analysis.

1. Presentation of the various metering projects

1.1 Context of the metering projects

The following table summarises the general context of the different metering projects we have analysed :

Table 1: Characteristics of each metering campaign

Name of Project	CIEL1	ECODROME3	CCE2	NUTEK4	EA5
Location	Bourgogne France	Drôme, France	Portugal	Sweden	Great-Britain
Sample size (number of households)	115	20	25	66	100
Year of project	1995	95-96	1995	91-93	1992-96
Duration of the metering	1 month	2 years	2 x 15 days	2 years	1 year
Main data & frequency of metering	W,Wh, / 10 minutes	W,Wh / 10 minutes	Wh / 5 minutes	Wh/day	W/ 30 minutes

1.2 Description of the metering equipment

The metering equipment used in the various projects was specific to each country thus the results may be partially dependant on the nature of the equipment used; however, any differance caused in this way is likely to only be a second order effect. The following table summarises the description of the different metering systems used.

Table 2: Metering equipment in each campaign

Name of Project	CIEL1	ECODROME3	CCE2	NUTEK4
Main Characteristics	Multi-channel data collector	Multi-channel data collector	Dedicated data collector for each appliance with storage capacity	Multi-channel data collector
Local communication	Power Line Carrier	Power Line Carrier	Local Bus	Local Bus
Down loading	through Modem to a Central Computer	through Modem to a Central Computer	Manual to PC	Manual to a PC
Other Characteristics		Mon. of Kitchen Temperature		
Accuracy	High (<2%)	High (<2%)		
Questionnaire	Yes	Yes		
End-used	Main individual appliances only	Main individual appliances only	Main individual appliances + total power demand	Main individual appliances only

Table 3: Average measured energy consumption of each appliance type (kWh/year)

	France		Portugal	Sweden	UK
	CIEL1	ECODROME3	CCE2	NUTEK4	EA5
Fridge	373	363	274	485	320
Fridge/Freezer	581	720	622	763	655
Freezer	617	629	729	1048	615
Washing Machine	235	263	145	315	240
Dishwasher	262	293	284	568	360
Clothe Drier	480	379	347	372	260
TV	140	203	152		
Lighting		500	425		
Halogen		242			

2. Main Findings for Cold Appliances

2.1 Comparison of cold appliance energy consumption

Cold appliances are studied in 3 separate categories: refrigerator, combined refrigerator/freezer and freezer. Figure 1 illustrates the differences found between the different metering campaigns. In each of the metering campaigns, cold appliances represented the end-use with the highest energy consumption. These results are extremely useful for validating estimates of average annual energy consumption per household by cold appliance type.

The average consumption of the main types of cold appliance in Sweden is higher than in any of the other countries considered. The greatest difference is noted for freezers. The results are fairly consistent between the French, Portuguese and British measurements. The difference can be explained by the location of the cold appliance with respect to typical room temperatures. In Sweden, freezers are generally located in the kitchen or in an heated room next to the kitchen, while in France, the UK or Portugal they are commonly located outside the kitchen in non-heated rooms such as a garage or cellar. As the most significant parameter influencing the consumption of a fridge or a freezer, is the difference between the storage temperature and the temperature of the room of its location, this has a large impact. Information on the cold appliance storage volume is lacking in most of the campaigns so it has not been possible to normalise the comparisons. However, it is also likely that some of the observed difference between the panels is caused by differing storage volumes.

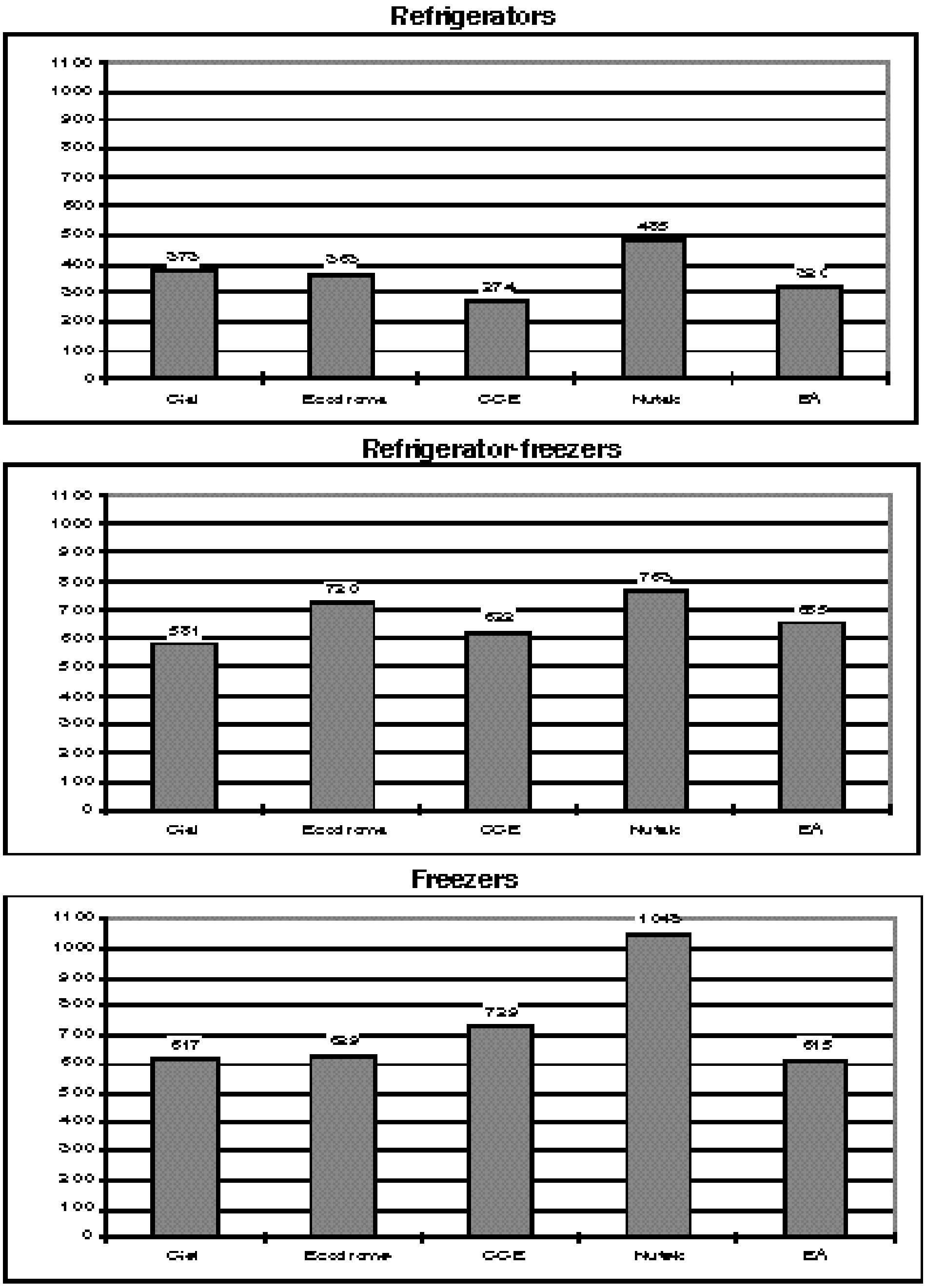


Figure 1 : comparison of the in-situ consumption of the cold appliances in the 5 panels

2.2 Comparisons using the new European Union energy label

The use of a detailed questionnaire in the French CIEL project allows some interesting observations regarding the energy consumed, the storage capacity and the age of the appliances. For each metered appliance, an energy index has been calculated. The energy index is defined in the European directive 94/2/CE “Energy labelling of household refrigerators, freezers and their combinations”. It indicates the energy efficiency of a given appliance, according to its main physical characteristics. Once the energy index is known, the appliance is then classified in an energy category ranging from A (more efficient) to G (less efficient). This provides a very convenient way to analyse the energy efficiency of the appliances. Figure 2 compares the distribution of the appliances according to their energy category in the panel with those sold on the French market in 1993. Apparently, the consumption measured in-situ seems to be lower than the energy displayed on the energy label, which is the energy consumption measured in a laboratory according to a measurement norm. More analysis is needed to directly compare the energy consumption measured on site and the energy consumption measured according to the norm. However, there is a real difficulty to get the required information from the field.

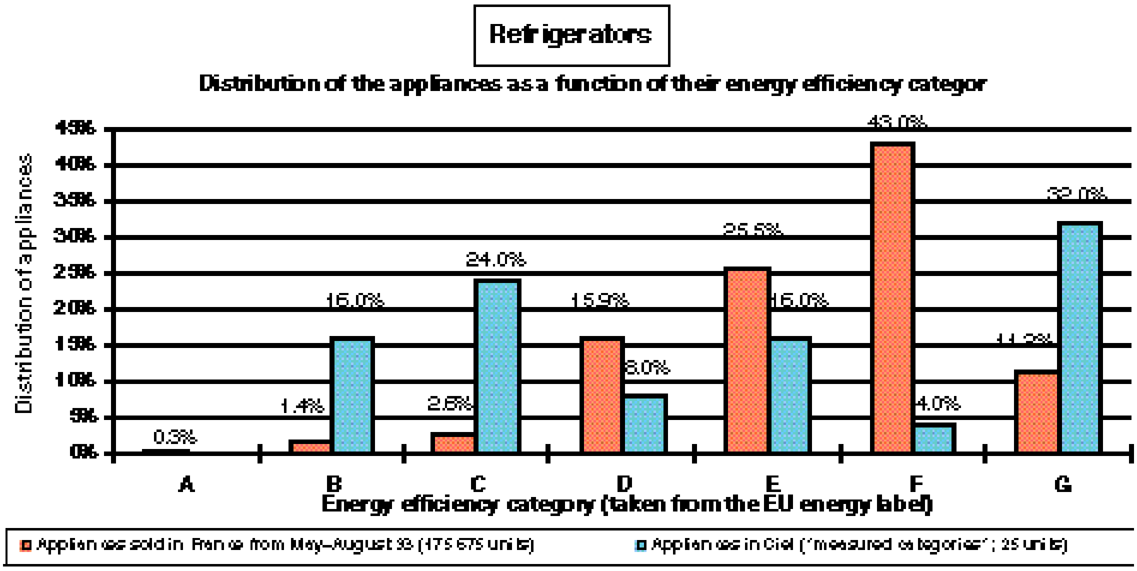


Figure 2 : comparison of the energy efficiency class of the refrigerators in the CIEL panel and those on the French market in 1993

Figure 3 shows the average energy index of the freezers in the CIEL panel as a function of the age of the appliance. It appears that the older the appliance is, the higher its energy consumption; however, this tendency is not so evident with the combined refrigerator-freezers and the refrigerators.

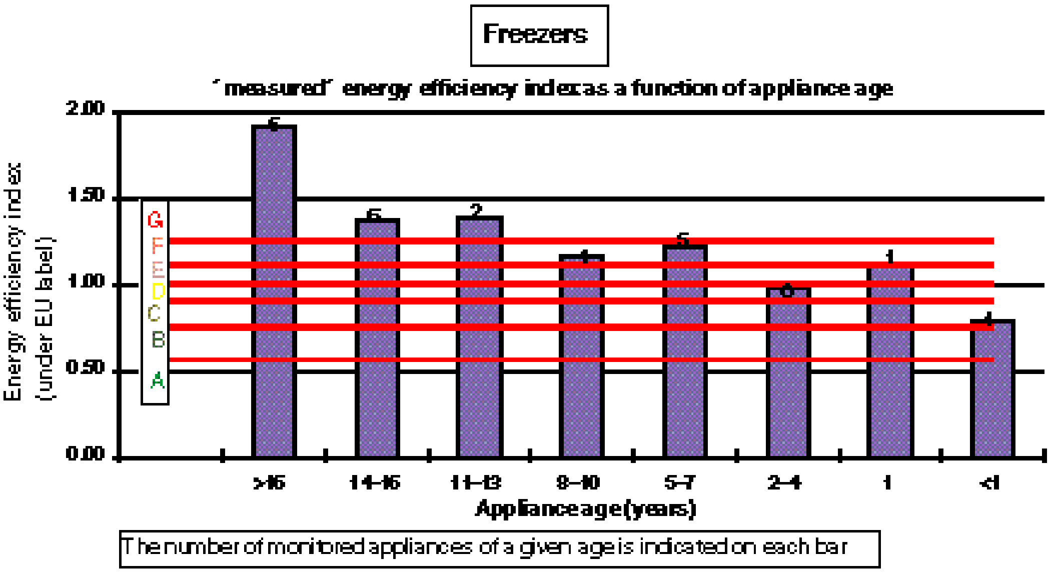


Figure 3 : Average energy index versus the age of the freezers in the CIEL panel

2.3 Time and season dependency of the energy consumption

Cold appliances are known to exhibit comparatively time of day invariant load curves; however, it has been observed that there are some "peaks" of energy demand during and after meals which are about 10% greater than the average. These are associated with door opening, food loading and a tendency for the kitchen to be warmer at these periods.

The energy consumed by a cold appliance is highly dependant on the temperature of the room where it is located. Figure 4 presents the correlation between the daily energy demand of a refrigerator in the CIEL panel and the outside temperature during the same period. The strong correlation between the two indicates the existence of a coupling between the kitchen temperature and the exterior temperature as well as a close link between the energy consumption of the fridge and the ambient temperature. Similarly, metering data of the variation in the monthly energy consumption of all the refrigerators from the ECODROME panel shows that the cold appliance consumption stays relatively constant during the heating season but increases by up to 40% during the summer period.

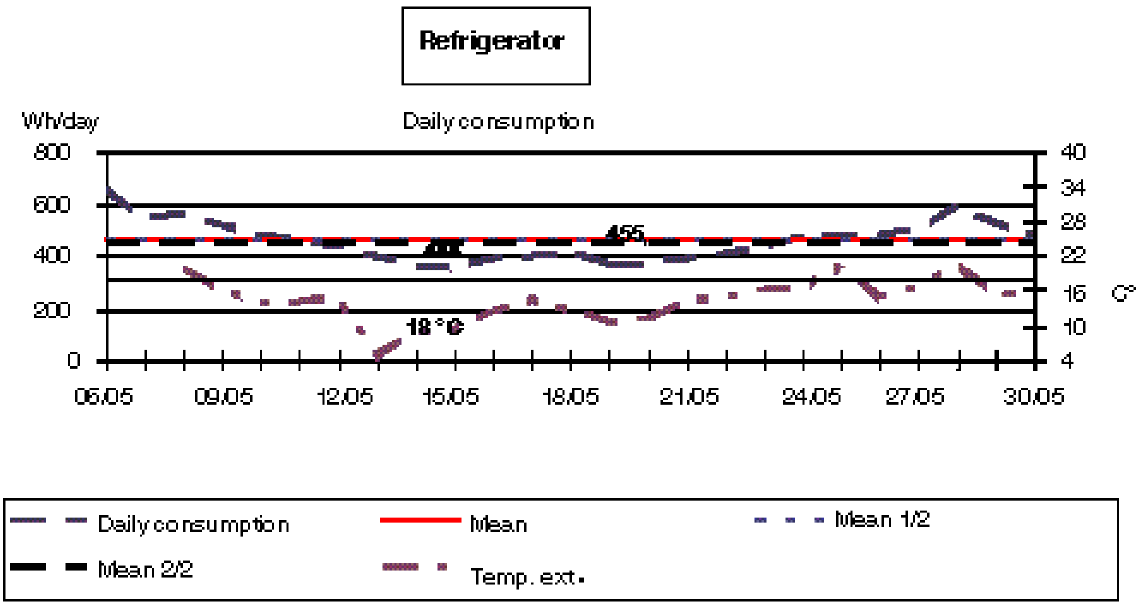


Figure 4 : Variation of the daily energy consumption of a refrigerator with the outside temperature

Despite the findings presented here, there is a strong need to improve the design of cold appliance metering campaigns. Most of the metering campaigns studied here lack important information and data to allow a true and convenient comparison within a panel and between various panels. They further lack enough information to be able to accurately assess how representative are the current European test measurement norms. The use of the energy efficiency index from the new energy label can be a powerful tool providing the necessary information is known about the storage capacity, the star rating (defining the maximum temperature of the frozen food compartment), etc. The internal and external temperatures of the compartments also need to be measured in future campaigns. Nonetheless, despite their short-comings, all the metering campaigns have confirmed the importance of cold appliance energy consumption in European households.

3. Main Findings for Wet Appliances

3.1 Comparison of clothes-washer energy consumption

A main finding of all the campaigns is that the energy consumption of clothes-washers is much lower than was hitherto thought. In fact, in Portugal it represents only from 3% to 6% of total household consumption and is less important than the TV sets. However, there is an appreciable variation in average clothes-washer consumption between the panels (greater than two fold) which suggests that consumer behaviour may vary significantly for this appliance, see Figure 5.

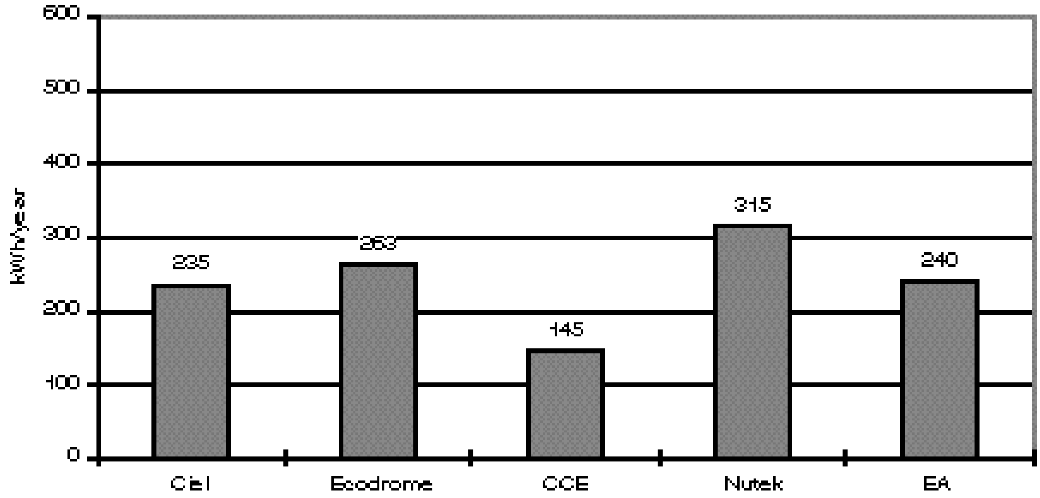


Figure 5 : comparison of the in-situ consumption of the clothes-washers in the 5 panels

An important feature of the analysis performed in both the CIEL and ECODROME campaigns is the development of an algorithm to identify the different wash temperature cycles at: 30/40, 60 and 90°C. This has allowed a thorough investigation of both the technical and behavioural aspects influencing clothes-washer consumption. Of the former, the energy consumption per cycle was calculated for every cycle performed, broken down into the three main phases of: heating, washing and spinning. Figures 6 and 7 show the power Vs time and the integrated consumption of different clothes-washer cycle types.

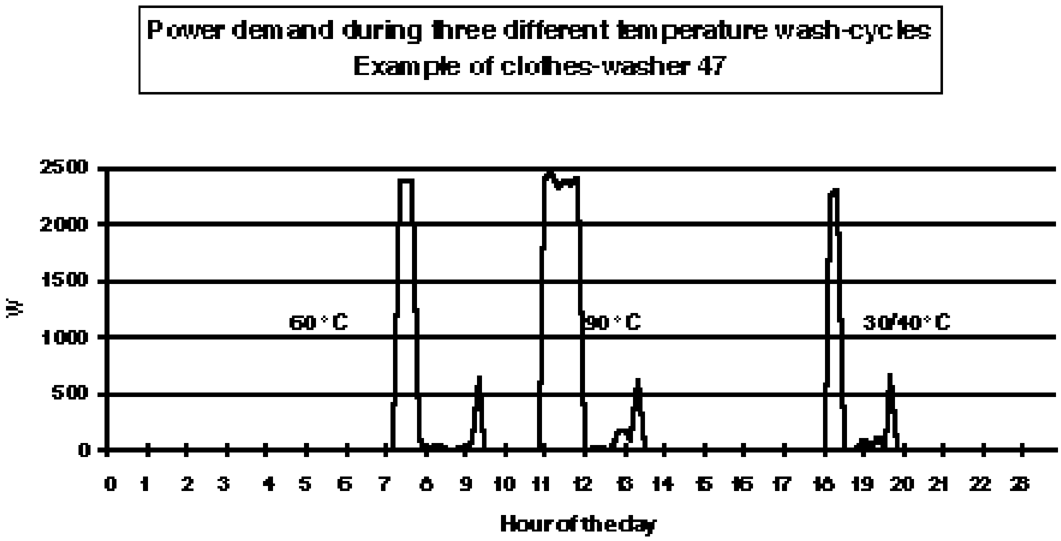


Figure 6 : Clothes-washer power demand under three wash-cycle temperatures

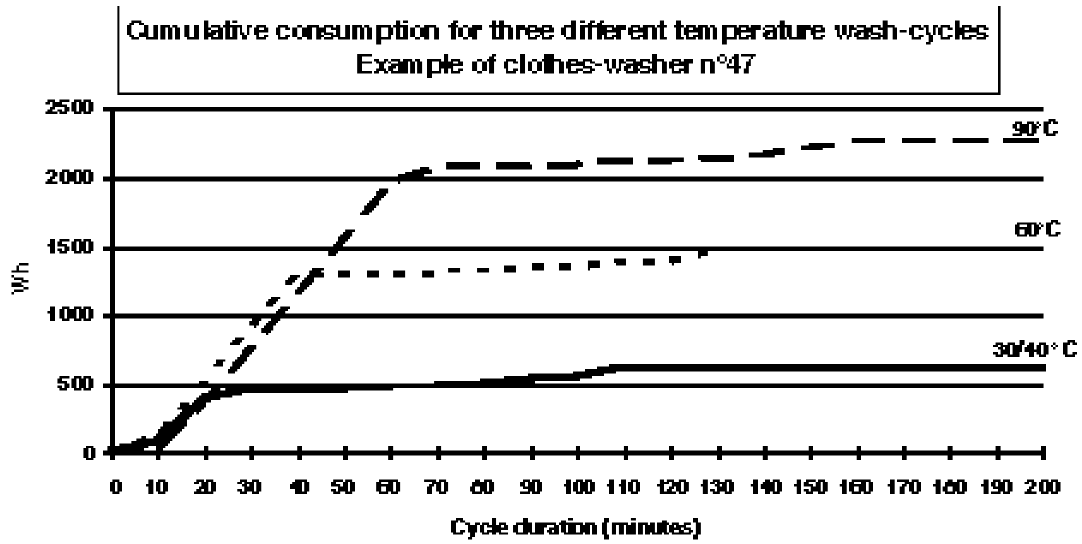


Figure 7 : Cumulative clothes-washer energy consumption under three wash-cycle temperatures

The results show the exact number of cycles conducted per type and temperature. This allows the difference between the consumers' estimates in the questionnaire of the number of wash cycles they perfume at a given wash temperature and the actual number to be assessed. The difference is only significant for the number of high temperature wash cycles which tends to be over-estimated by consumers. However, due to the higher consumption under this type of cycle, if estimates of the average annual energy consumption were to be based on the consumer questionnaire they would produce an overestimate as high as 44%1. It is possible that the mere existance of a high clothes wash temperature (90°C cycle) in a questionnaire causes consumers to overestimate the frequency with which they conduct these washes as if they are unsure of their real behaviour they might tend to spread their reported use between the options offerred. This result emphasises the importance of metering campaigns and their value in correcting false assumptions which are otherwise repeated over the years.

Interestingly, there is no correlation between the age of the clothes washer and it's energy consumption, which suggests that the efficiency of these appliances has not significantly improved over the last fifteen years which is contrary to manufacturer claims. However, efficient new technology stimulated by the new European energy labelling directive should transform the average efficiency of the market such that in the future an age/efficiency relationship will be observable. The power demand of clothes washers should also decrease.

The choice of spin speed has an influence on both the washer and drier energy consumption such that, higher clothes-washer energy consumption associated with high spin speeds is more than compensated for by lower dryer consumption when the use of a drier is an option.

3.2 Comparison of clothes-drier energy consumption

Figure 8 shows the average annual clothes-drier consumption in each panel and confirms that clothes-driers can be a major end-use. Consumption is highest in the two French surveys although the reason is not clear. Interestingly, the UK is the country with the lowest measured consumption per appliance but has the highest ownership levels with 39% of households possessing a clothes dryer in 1995. In the same year 22% of EU households owned a clothes-dryer. This is a suprising finding as the price and quality of clothes-dryers in the UK tends to be lower than the EU average which would suggest that the UK sample were using their clothes-dryers less (on a drying-mass times frequency basis) than in the other surveys.

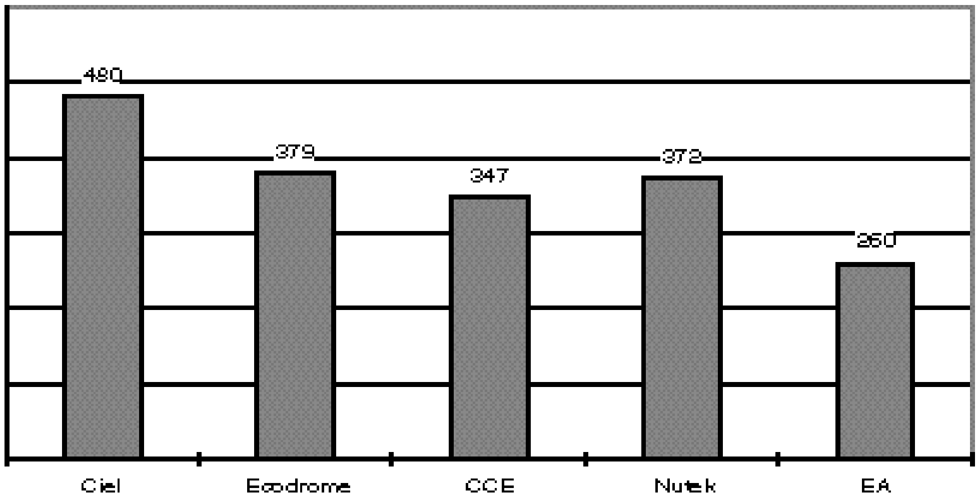


Figure 8 : Comparison of the in-situ consumption of the clothes-driers in the 5 panels

3.3 Comparison of dishwasher energy consumption

Figure 9 shows how the measured average annual dishwasher consumption varies among the panels. The results across the panels are quite consistent excepting the Swedish panel which reports an average dishwasher consumption almost twice as high as the mean of the other four panels. About 47% of households own dishwashers in Sweden while only 19% do in the UK and 38% in France. The EU average is approximately 30%. These results confirm that dishwashers are a major consumer of electricity but that they use less than has been previosuly thought; e.g. new dishwashers in the UK were estimated to use ~500 kWh/year in 1990[8], while it was previously estimated that the EU average consumption for new models would be 380 kWh/year[9]. The EU average annual consumption estimated for new dishwashers in a recent study[10] was 344kWh/year which is consistent with the measured data.

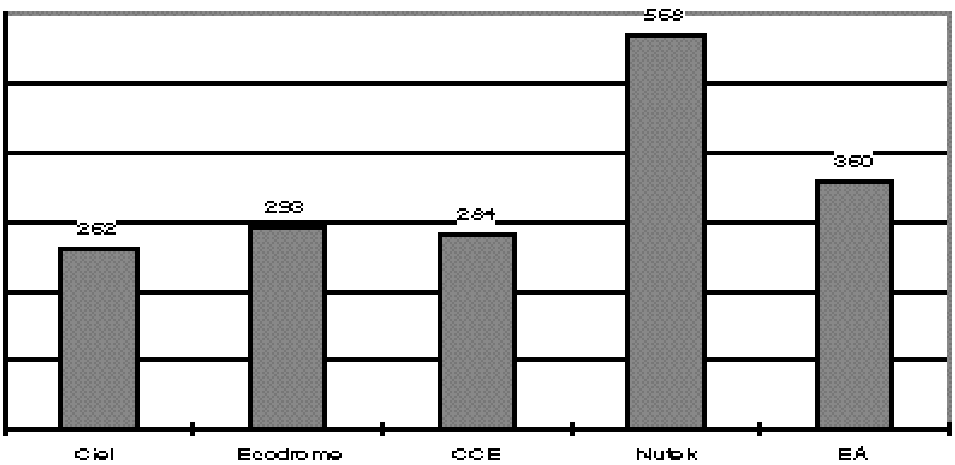


Figure 9 : Comparison of the in-situ consumption of the dishwashers in the 5 panels

4. Main Findings on Lighting, Electronic Equipment & Miscellaneous end-uses

4.1 Lighting

Due to the difficulty of metering the lighting circuit and all the individual lighting plug loads only two of the campaigns have attempted to measure all domestic lighting loads. The results illustrate that lighting is an important end use although it is not yet possible to estimate the average European lighting consumption per household from this data.

4.2 TVs and VCRs

Television Sets

Table 3 shows that the average annual TV energy consumption is fairly consistent between the different panels at around 165kWh/year; however, this masks considerable variability among households as the annual TV energy consumption per household varies by more than a factor of 10 in each panel.

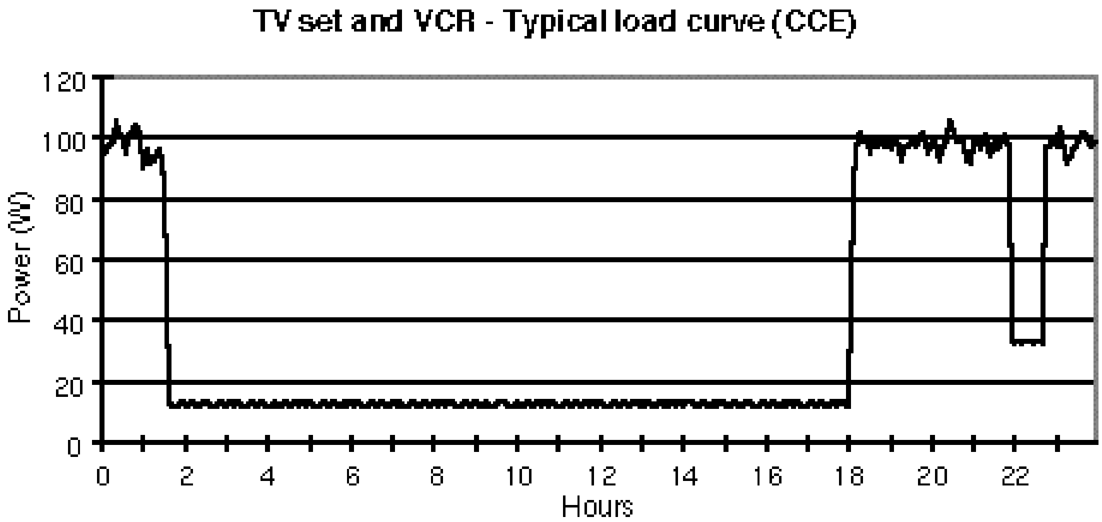
The variation in TV stand-by consumption is even larger, since it is always used in some cases (at all times when the TV is not in the on-mode) while it is never used in others. In some cases it represents half of the total annual TV consumption although in global terms the stand-by consumption accounts for from 6% (CIEL) to 11% (CCE) of the average annual TV energy consumption.

The time of year has an important influence on TV energy consumption such that during the winter periods with shorter days people are more likely to watch television.

Peak power demand for TVs usually occurs after the utilities evening peak demand, although TVs still contribute strongly to it. Figure 10 illustrates a typical one piece load curve for a TV and a VCR and highlights the importance of the stand-by power demand for both appliances. The figure is an aggregated load curve of the TV's consumption (reflecting the utility's perspective).

The stand-by consumption is becoming more and more important, not only due to the increased number of televisions in each household, but also because of VCR's, satellite tuners, decoders, hi-fi systems, etc. Therefore, forthcoming monitoring projects should give this subject special attention. However, the proper study of stand-by consumption will require improvements in the metering systems to be used due to the low power demand involved and the possibility of signal decoding failures for power line carrier systems.

The European Commission has recently published a study which characterises TV and VCR stand-by energy consumption and identifies the most appropriate instruments to reduce stand-by power demand. This study illustrates the great potential for savings since appliances can be found with stand-by power ranging from 0,1 to 20 W; which is a 200-fold difference. The study proposes the establishment of voluntary agreements with industry as the preferred efficiency policy instrument.



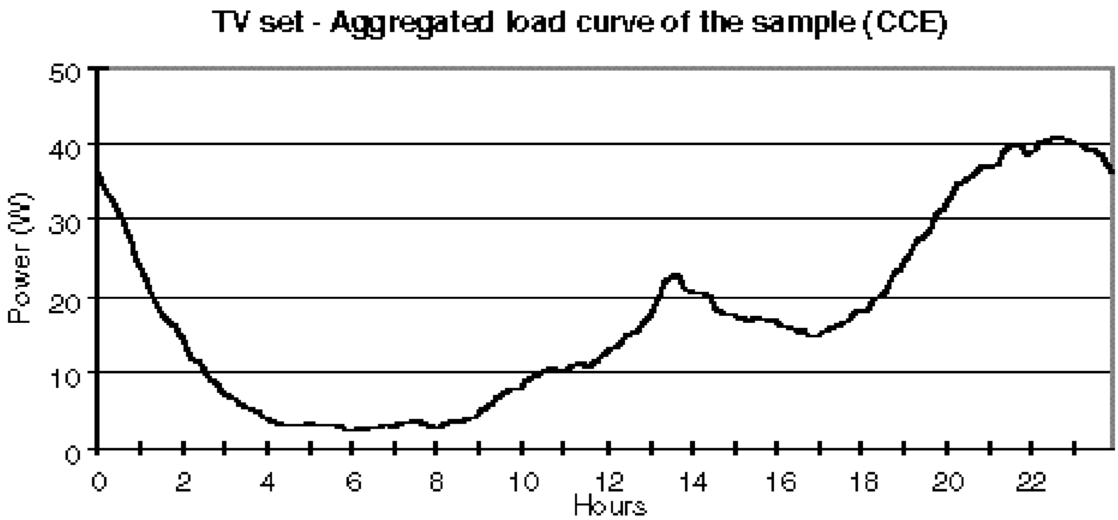


Figure 10 : TV and VCR load curves

5. Conclusions

This paper is a first attempt to assemble outputs from several independent European monitoring campaigns; however the reader is invited to return to the source reports where the results and analysis are presented in much greater depth.

Cold appliances (refrigerators and freezers) are confirmed to be the highest energy consuming appliances in typical European households: a result which is consistently recorded in all the metering campaigns. Cold appliances are the best known end-use and as expected, their energy demand is relatively independent of user behaviour. However, the temperature of the room where the appliance is located is shown to have a large influence on the energy consumption. More information is needed on the distribution of European kitchen temperatures for European cold appliance electricity consumption to be properly estimated.

For clothes-washers, the influence of the user is shown to be a key parameter. Cultural and behavioural differences between countries are the most important factors explaining variations in the observed end-use data. Clothes-driers and dishwashers are found to be important energy consumers in households which have them and as EU average ownership levels in 1995 were only 22% and 30% of households respectively, these appliances represent potentially large sources of growth in domestic electricty consumption.

Overall, lighting is a major end-use in the residential sector but practical limits exist which hinder metering it specifically. As a consequence, analysis of lighting is scarce. Finally, electronic equipment, such as television sets, VCRs, etc., are confirmed to be important sources of domestic electricity consumption.

More work needs to be done to assemble data from European monitoring campaigns and to organise future campaigns in a consistent and complimentary fashion. Some of the major areas which need to be considered in the conduct of future campaigns are:

how can the metering results be used to make energy measurement norms more representative of in situ conditions?
characterisation of lighting loads,
characterisation of 'leaking electricity' loads (stand-by power consumption),
monitoring how expected benefits from efficiency policies (labelling, standards, etc.) are translating into actual energy savings.

To be of general use the results from future campaigns will need to be pooled and the findings disseminated.

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