Measuring Electricity Consumption by End-Use : Lessons learned from a Monitoring Project in the Residential Sector

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1. SYNOPSIS

A monitoring project in the residential sector measures electrical consumption by end-use.

2. ABSTRACT

Recent developments in electronics allow the design of an innovative tool that monitors energy consumption and power demand by end-use in an electrical installation. The new system is being used for the monitoring of 100 households in France.

First, the paper describes the monitoring technology that relies on two advanced techniques : electronic metering and power lines carrier. It then presents preliminary results of in-field data collection using this technology, which provides a wide range of information on energy consumption and usage patterns for all the common electrical domestic appliances : refrigerators, freezers, washing machines, cooking appliances, television sets and other electronic equipment. Many findings highlight the relevance of developing this type of advanced monitoring in order to understand better domestic load curve and electricity consumption. The whole project is designed to provide a solid background for on-going Demand-Side Management actions in the residential sector where the monitoring project takes place.

3. INTRODUCTION

Estimating the potential of electricity savings and load shifting is a prerequisite to any DSM program. This implies a knowledge of where the Watts and kilowatts-hours are consumed, i.e. in which end-use, at what time...etc. Field monitoring greatly helps in providing the needed data. However monitoring projects are often very limited because of cost constraints, lack of flexibility in the manipulation of the hard-ware, unpredictable change in the behaviour of the customer during the campaign...etc. This explains why most of the data available and used for understanding electrical load shape and energy consumption are based on statistical surveys, global analysis of load shapes and engineering judgement. Many electrical end-uses can not be disaggregated and are lumped together in utility records.

In France, analysis of the electricity used in the building sector is limited to four end-uses : space heating, domestic water heating, cooking and miscellaneous. The last category comprises lighting, household appliances, office and leisure equipment...etc., i.e. a large variety of usages presenting very specific load patterns and characteristics.

In order to fill that gap and thanks to the recent advanced in electronics, a new concept for end-use monitoring has been developed. The new system is called DIACE, standing for Individual & Automatic Diagnostic of Electricity Consumption. The DIACE system is described in more detail in the following pages.

The present project is the first monitoring campaign using DIACE. It has been launched in France in a sample of 100 households. The monitoring effort concentrates on the main residential specific end-uses, namely refrigerator, freezer, clothes washer, dishwasher, cooker, lighting, television set, and electronic equipment... The data collected presents the quality and the reliability expected. The new system has proved to be both convenient and accurate.

4. A CONTEXT FAVORABLE TO END-USE MONITORING

4.1 The French Experimental DSM programs

Demand Side Management programs are built around two main concepts : decreasing the energy consumption for a specific usage, or shifting the load from peak hours to valley hours.

The energy management policy of the French national utility company, Electricité de France, is gradually being oriented toward Demand Side Management. For many years, the wide-spread availability of an advanced tariff has been very efficient at leveling the load curve, particularly among High Voltage and Medium Voltage customers. The same approach based on tariff incentives is currently being developed for domestic customers. In the near future the domestic customer will be able to choose tariffs which reflect the variations of the cost of electricity throughout both the day and the year.

In February 1993, the French government asked EDF and the French Agency for the Environment & Energy Management (ADEME) to join forces in order to experiment with DSM actions promoting a greater rational use of electricity. All economic sectors are included but domestic customers merit a special attention as many initiatives are directly oriented towards them.

4. 2 A Growing Need for End-Use Monitoring

Estimating the potential for electricity savings and load shifting is a prerequisite to any type of DSM program. This implies knowledge of where the Watts and kilowatts-hours are consumed, i.e. in which end-use, and at what time. In the building sector records are available mainly for four end-uses : space heating, water heating, cooking and miscellaneous. A large variety of very different end-use, from refrigerators and clothes washers to lighting and televisions, are lumped together in this last category, making it difficult to identify the potential for energy savings.

Let's suppose that each time one went to the grocery store, there were no prices on the items or on the shelves. No advertised prices. At the check-out, only a single bill for "grocery and miscellaneous : 241.50 ECU ". How well Would one expect economic theory to explain purchasing behaviour? How easy would it be to market a better or cheaper product, or to promote a sale? would one expect consumers to buy only what they really need, choosing prudently among what they want, and shopping for the best deals?
Yet this is essentially what happens with electricity bills for most utility customers.

Of course, some databases do exist. Saturation levels of relevant appliances are fairly well known through regular surveys. Energy requirements of a variety of equipments are measured in laboratory under well accepted test procedures. Forecasting models are designed with the help of engineering judgement. Models are indeed used to forecast trends and evaluate possible savings. However, DSM actions require explicit calculations and data collection. For example, very little is known today about the field consumption of a domestic refrigerator, a television set or a clothes washer. Many questions remain unanswered : Is there a difference between field consumption versus lab measurement, according to the test procedure? How does the behaviour of the user affect the overall efficiency of an appliance? What is the effect of ageing on the energy efficiency of an appliance? etc.

End-use monitoring can help formulate answers to these and other questions and validate forecasting models and end-use databases.

5. INTRODUCING A NEW MONITORING TECHNIQUE

End-use energy monitoring is usually very expensive and difficult to organise. However, recent improvements in electronics and controls allow the development of a promising tool for monitoring electricity consumption and load shape by end-uses in buildings. The system, called DIACE (Individual and Automatic Diagnostic of Electricity Consumption), relies on two technologies : electronic counting and communication through the mains or power lines. The basic element is an electronic box, called the DIACE adapter plug, which is installed between the monitored appliance and the power line.

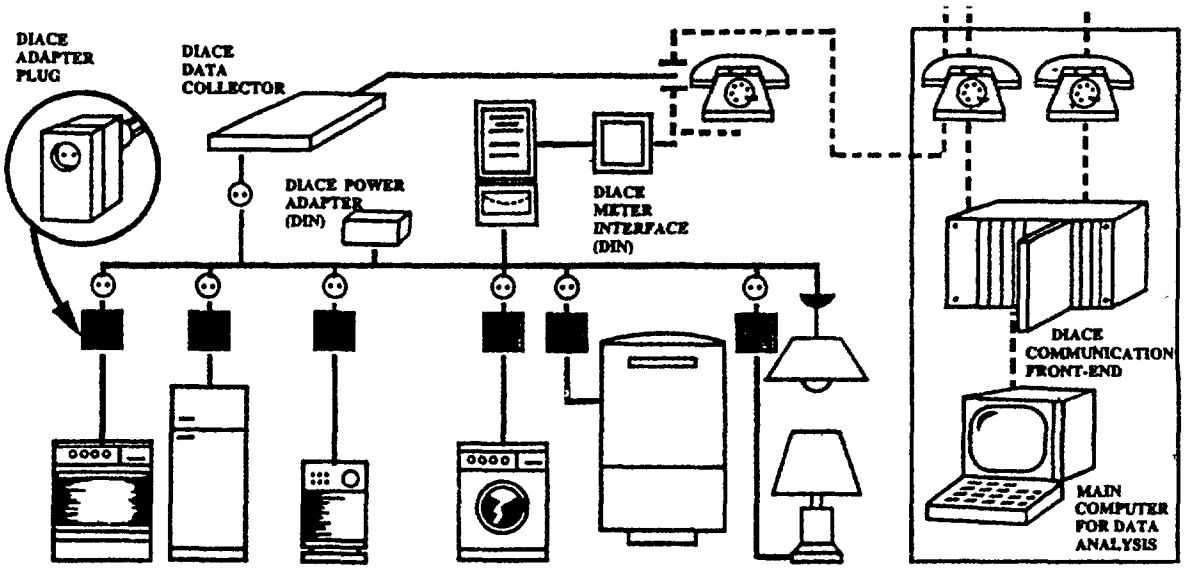

Figure 1 : Schematic of the Complete DIACE system.

The DIACE adapter plug contains an electronic counter that permanently records the electricity demand and the energy consumed by the connected appliance. The electronic counter uses the Hall effect to measure the components -voltage, ampere, phase angle- of the electrical energy. This new generation of electronic counter has a higher resolution than older technologies. It can with more flexibility handle advanced tariff schemes and will slowly replace existing meters in electrical installations in France and possibly elsewhere.

There is one DIACE adapter plug for each monitored appliance and there is no limit to the number of plugs which ca be used on one site during the campaign.
Elsewhere in the installation, a data collector is connected to the power line by means of a simple electric plug. The data collector is the size of a PC modem. At regular intervals the collector sends a "reading pulse" through the mains. When receiving the reading pulse, each DIACE adapter plug stores the current energy (Wh), the power (W) and the voltage measurement (V). It then sends this information back, along with its own identification number, to the DIACE data collector.

The DIACE data collector records all the incoming data. The data collector is connected to the phone line and is downloaded every 24 hours by telemonitoring. A DIACE communication front-end located at the utility headquarters polls all DIACE data collectors corresponding to monitored customers.

The DIACE system is able to record the consumption (in Wh), the instantaneous power demand (in Watt) and the voltage (in Volts) of any given appliance every 10 minutes. The system allows the treatment of the data almost in real time : the total disaggregation of electricity consumption and the load shape can be performed every day or averaged for a longer period of time. In addition, the system will provide information on the behaviour of the customer regarding the use of an appliance, such as the number of washes per weekby a given clothes washers, how long and when the television has been stayed on, etc.
One of the advantages of the system is the use of the mains to communicate the measures. This is not only convenient for the operator during the setting of the system, but the customer is not disturbed by wires lying on the floor or meters displaying running digits next to each appliance. The system does not require any participation by the customer, such as writing down when he used an appliance or which washing cycle he used to do his laundry. All components of the system, the DIACE plugs and the DIACE data collector, are small so they can be totally ignored by the customer when in use.

Despite all its advantages, the DIACE system presents one minor inconvenience : it is intrusive in its installation, i.e. the operator has to enter private household to install it. It is also possible to ask the customer to connect the different components. However, the operator benefits by entering the customer's privacy, he or she can see the appliances, their characteristics, their location and can fill in questionnaire which is useful to the analysis of the monitoring.

6. PRESENTATION OF PRELIMINARY RESULTS

Through the SAVE programme, the Directorate General for Energy (DG XVII) of the Commission of the European Community has decided to co-finance an initial monitoring campaign using a panel of 100 French households. This program is jointly organised by ADEME and EDF (Electricité de France). A complete set of 10 DIACE systems has been ordered. Each household in the panel will be monitored for a month. Each DIACE set consists of a data collector and 10 DIACE plugs, allowing the monitoring of 10 different end-uses. A specific questionnaire has been designed in order to obtain information of explanation regarding consumption patterns. General questions are asked, such as type of housing, number of people in the house, etc. Specific questions focus on the type of appliance used : brand name, capacity, age, location in the home, etc. One of the goals of the campaign is to have a better understanding of the influence of the customer's behaviour regarding the use of the appliances. It is important to collect a maximum number of explanatory factors for the electrical consumption and power demand pattern for a given end-use.

At this stage, not enough households have been monitored to offer statistically significant results. The monitoring campaign will last until the end of 1995, and a large amount of data is yet to be treated.

6.1 Refrigerators and Freezers

The following figure (figure 2) represents a typical daily load curve of a domestic refrigerator. We can see when the compressor turned on and off and calculate the run time. In order to obtain a better view of the load curve of such an appliance, the next figure (figure 3) is an histogram of the hourly consumption averaged over the entire month of energy monitoring. The energy consumption is not flat and there are peaks of consumption after meal times. The variation between the maximum and minimum are on the order of 10%.

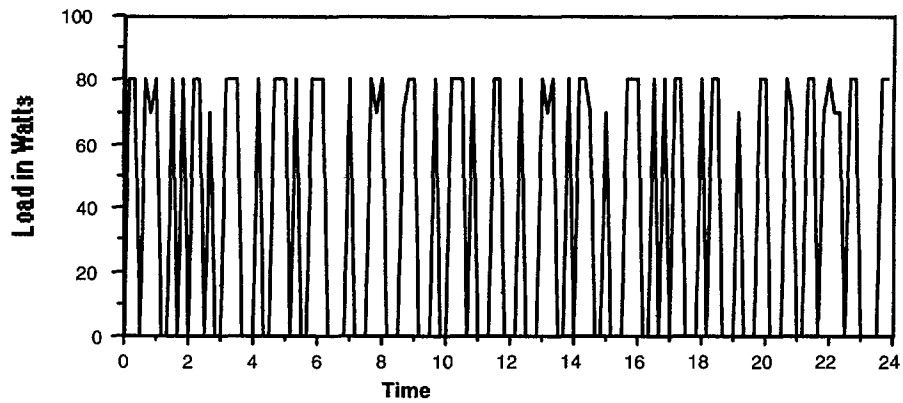

***Figure 2** : Typical daily load curve of a refrigerator*

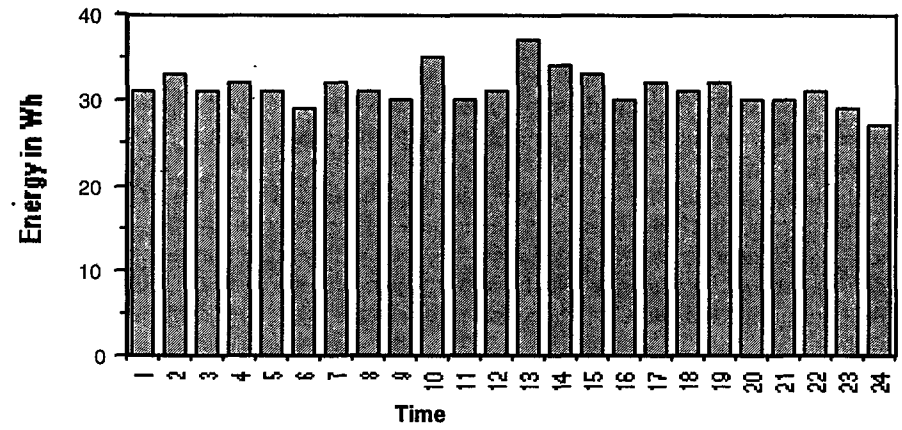

***Figure 3** : Energy consumption of a refrigerator over the entire monitoring period*

6.2 Clothes-washer

The energy consumed by a clothes washer depends of the temperature selected for the wash cycle. There are 4 main selections : cold, 40°C, 60°C & 90°C. Figure 4 shows a typical daily load curve of a clothes washer. It is easy to see the different phases of the washing cycle : the peak demand (typical aroung 2000W) corresponds to the heating of the water during the washing phase. Figure 5 presents the energy consumed by the different clothes washers during the same period of time. The distribution of the energy consumed depends on the washing temperature chosen. Site N°3 used only the 60°C washing cycle. Site N°2 used the 4 different washing temperatures. This type of data collection will greatly enhance the knowledge on usage patterns, frequency of use, etc. It is also noted that the data collected up to now points toward a significant discrepancy between the answers found in the questionnaire on usage of the clothes washers and what is actually monitored. With more and more households monitored, analysis wil help assess the influence of the number of persons in the house, the age of the appliance and the type of clothes washer on the energy performance and usage pattern.

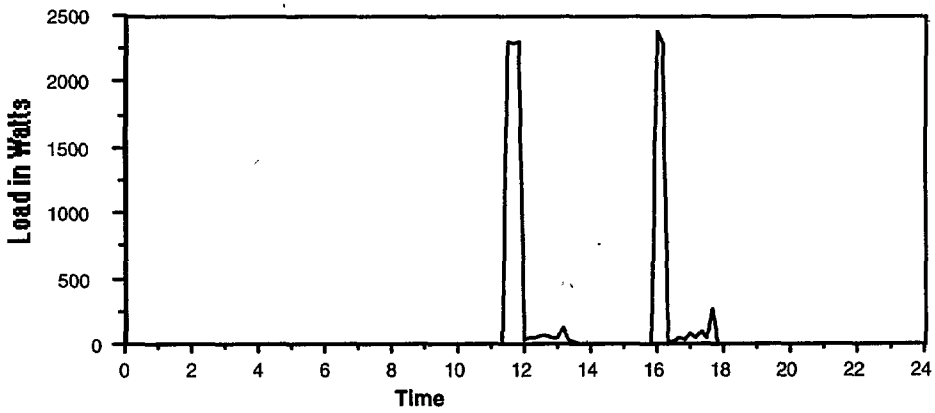

Figure 4 : Typical load curve of a clothes washer (two washing cycles observed in the same day)

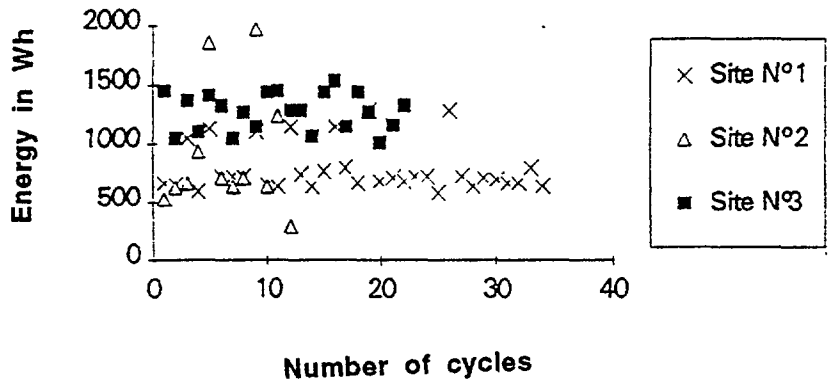

Figure 5 : Energy consumption of clothes washers on three different sites

6.3 Microwave Oven

Figure 6 presents a histogram of the energy consumption of a microwave oven in a given household.

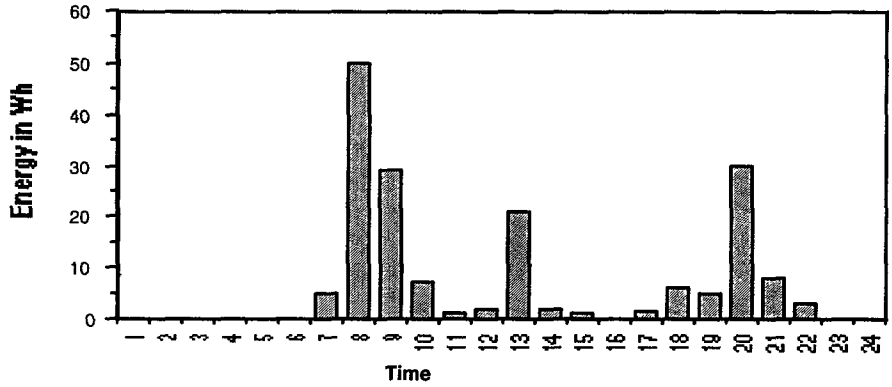

***Figure 6** : Energy consumption of a typical microwave oven*

6.4 Television Set

Figure 7 presents a typical load curve of a television set, while figure 8 presents a histogram during an entire month. In Figure 7 we can clearly see the three phases of use of a television set : when the TV is off (no power required), when it is on and when it is in the standby mode. The latter mode represents a significant share of the total energy consumption.

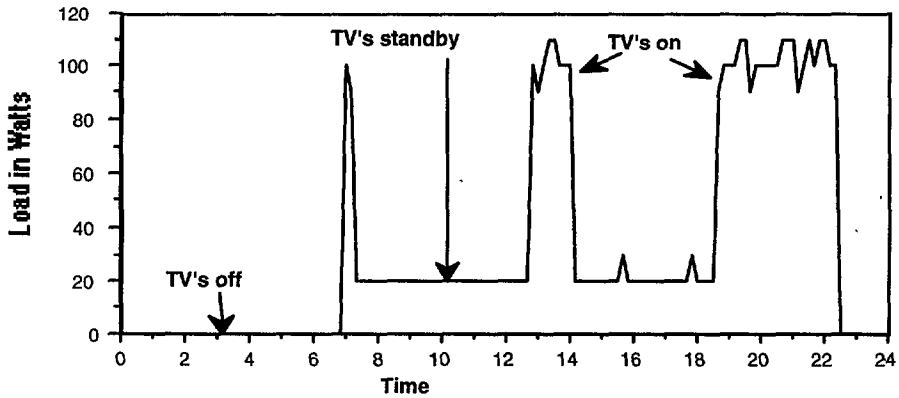

***Figure 7** : Typical daily load curve of a television set*

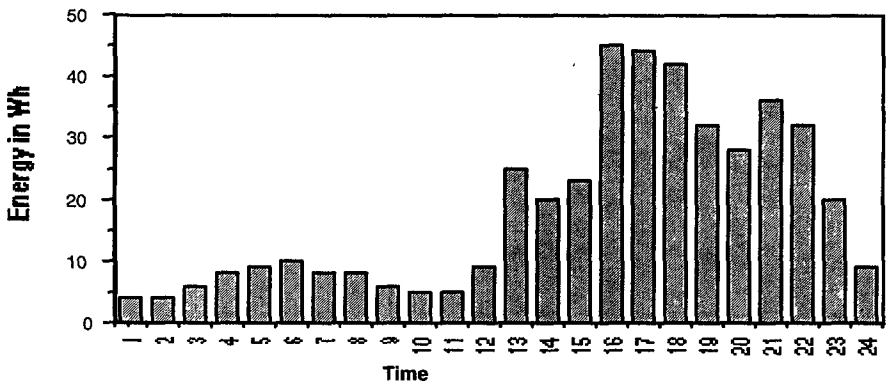

***Figure 8** : Distribution of average hourly energy consumption of a television set over the whole monitoring period*

As with clothes washers, It is noted that there is, for the time being, a significant discrepancy between the answers found in the questionnaire on usage of the television and what is actually monitored.
Special attention will be given in the analysis of television use. Very little is currently known about this end-use but because of the fast development of electronic equipment, it is anticipated that television sets along with their accompaning devices (decoders, satelite dishes, VCRs, etc.) could become major energy users in the residential sector.

7. CONCLUSION

The present paper shows that because of advanced electronics, it is now possible to monitor electricity consumption and load shapes by end-use with a system that is precise, convenient, unobtrusive, reliable and efficient. Preliminary results of a first monitoring campaign are very encouraging and will support a wide range of opportunities for DSM actions focusing on domestic customers.
Even though the data collected to date are not yet statisticaly significant, a qualitative analysis shows a wide range of very valuable conclusions on both consumers' behaviour and domestic appliance technologies.
In the coming months, with more and more households monitored, the present project will provide an improved understanding of appliance energy consumption and load patterns.

8 . ACKNOWLEDGEMENTS

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