Energy Consumption by End-Use: Introducing a New Technique for Advanced Monitoring

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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 system called DIACE (in French, *Diagnostic Individuel et Automatique des Consummations Eleclriques,* Individual and Automatic Diagnostic of Electricity Consumption) relies on two technologies: electronic metering and communication through the mains or power lines. The basic element is a small electronic box, called the DIACE adapter plug, which is installed between the monitored appliance and the power line. The DIACE adapter plug contains an electronic meter that permanently records the energy (Wh) and the power (W) consumed by the appliance. Elsewhere in the installation, a data collector is plugged into the power line. At regular intervals the collector sends a "reading pulse" in the mains. When receiving the reading pulse, each DIACE adapter plug sends the stored Wh and W, along with its identification number, back to the DIACE data collector via the power lines. The DIACE data collector records all the incoming data. It is also connected to the phone line and is polled every 24 hours by telemonitoring. A DIACE communication front-end located at the utility headquarters polls as many DIACE data collectors as there are monitored customers.

The DIACE system answers all the functions needed for accurate monitoring of electricity consumption by end-uses: it is precise, convenient, flexible, unobtrusive, and efficient.

This paper presents the context in which the system has been developed as well as the preliminary results of a initial monitoring project performed on a sample of French households.

Introduction

Estimating the potential of electricity savings and load shifting is a prerequisite to any type of DSM program. This implies the knowledge of where the watts and kilowatt-hours are consumed, e.g., 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 hardware, unpredictable changes in the behavior of the customer during the campaign,... and so on. 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 shape, and engineering judgement. Many electrical end-uses cannot be disaggregated and are lumped together in utility' records.

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

In order to fill that gap and thanks to the recent development of electronics, a new concept for end-use monitoring has been developed. The new system is called DIACE (in french, *Diagnostic Individual et Automatique des Consummations Electriques,* standing for Individual & Automatic Diagnostic of Electricity Consumption). The DIACE system is described in more detail in the following pages.

A first monitoring campaign using DIACE was launched in France in a sample of 100 households. The monitoring effort concentrates on the main residential end-uses, namely refrigerator, freezer, clothes washer, dishwasher, stove, lighting, television set, and other electronic equipments. The preliminary data collected attained the quality and the reliability expected. The new system has proved to be both convenient and accurate.

Context: The Need for End-Use Monitoring

When France Decides to Experiment DSM Programs

Demand Side Management (DSM) programs are built around two main concepts: decrease the energy consumption for a specific usage, or shift the load from peak hours to valley hours.

The energy management policy of the French National Utility Company, Electricity de France, has gradually become oriented towards Demand Side Management. For many years, the implementation of an advanced tariff has been very effective in flattening the load curve, especially among high voltage and the medium voltage customers. The same approach based on tariff incentives is currently being developed in the household sector. In the near future, the domestic customer will be able to choose tariffs that reflect the variations of the cost of electricity throughout both the day and the year. Until recently, most DSM efforts focused on the envelope of the building, generating large savings on space heating.

In February 1993, the French government asked EDF and the French Agency for the Environment & Energy Management (ADEME) to join forces to research DSM actions which promote a more rational use of electricity, specifically in the non-thermal use of electricity. All economic sectors are concerned but especially domestic customers, so as many initiatives are directly oriented towards them.

End-Use Monitoring a Key Element in DSM Programs

Estimating the potential of electricity savings and load shifting is a prerequisite to any type of DSM program. This implies the knowledge of where the watts and kilowatts-hours are consumed, e.g. in which end-use, and at what time. In the building sector, records are available for mainly three end-uses: space heating, water heating and miscellaneous. A large variety of very different end-uses, from refrigerators and clothes washers to lighting and television sets, are lumped in one category. This does not facilitate the identification of the potential of 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, and at the check-out, only a single bill for "grocery and miscellaneous: $ 115.00". How well would one expect economic theory to explain purchasing behavior? 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 of utility customers.

Of course, some databases do exist. The level of saturation of some appliances is fairly well known through regular surveys. The energy efficiency of many appliances is measured in laboratory under well accepted test procedures. Forecasting models are designed with the help of engineering judgement. Further models are used to forecast trends and to evaluate possible savings. However, DSM actions require explicit calculations and data collection. For example, very little is known today on field consumption of domestic refrigerators, television sets or clothes washers. Many questions like the following stay unanswered: Is there a difference between field consumption versus lab measurement according to the test procedure? How should the behavior of the user be taken into account in estimating the overall efficiency of an appliance? What is the effect of aging on the energy efficiency of an appliance?.. etc.

End-use energy monitoring can positively respond to these types of questions and validate forecasting model and end-uses database collection.

DIACE: Individual & Automatic Diagnostic of Electricity Consumption

End-use energy monitoring is usually very expensive and difficult to organize. However, recent improvements in miniaturisation of electronics and communications controls allowed the development of a promising tool for monitoring electricity consumption and load shape by end-uses in buildings. The DIACE system relies on two technologies: electronic metering and communication through the mains or power lines carrier. The basic element is an electronic box, called the DIACE adapter plug, which is installed between the monitored appliance and the power line.

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

There is one DIACE adapter plug for each monitored appliance and up to a hundred plugs can be used on one site.

Elsewhere in the installation, a data collector is connected to the power line again, by means of simple electric plug. This data collector is about the size of a telephone answering machine. At regular intervals, the collector sends a "reading pulse" over the mains. When receiving the reading pulse, each DIACE adapter plug stores the energy (Wh), the instantaneous power (W, average on the last 10ms) and the voltage measurement (V). It then sends back this information along with its own identification number to the DIACE data collector through the power lines.

The DIACE data collector records all the incoming data. The data collector is connected to the phone line and is polled every 24 hours by telemonitoring. A DIACE communication frontend located at the utility headquarters polls the DIACE data collectors at each customer site (see Figure 1).

The DIACE system is able to record every 10 minutes the consumption in Wh, the instantaneous power demand in Watts and the voltage in Volts of any given appliance. The system allows the treatment of the data almost in real time. In consequences, the total disaggregation of electricity consumption and the load shape can be accomplished every day or averaged for a longer period of time. In addition, the system can provide information on the behavior of the customer regarding the use of an appliance, e.g., how ; any loads of laundry are done each week, how long and when the television set is used, and so on.

One of the advantages of the system is the use of the mains to communicate the measurement. This not only makes it convenience for the technician to set up the system, but also minimizes the risk that the customer will be disturbed by wires lying on the floor or meters displaying information next to each appliance. The system does not require any intervention from the customer, like writing down when he or she ran such appliance or which washing cycle was used to do the laundry. All components of the system—the DIACE plugs and the DIACE data collector—have a small size so they can be totally forgotten by the customer when in use.

The DIACE system answers all the functions needed for an accurate monitoring of electricity consumption by end-uses. It is:

1. Precise: the Hall effect sensor as an accuracy of 2%

2. Convenient: there is no need to use any wire for connecting the system

3. Unobtrusive: the customer's behavior is not affected during data collection

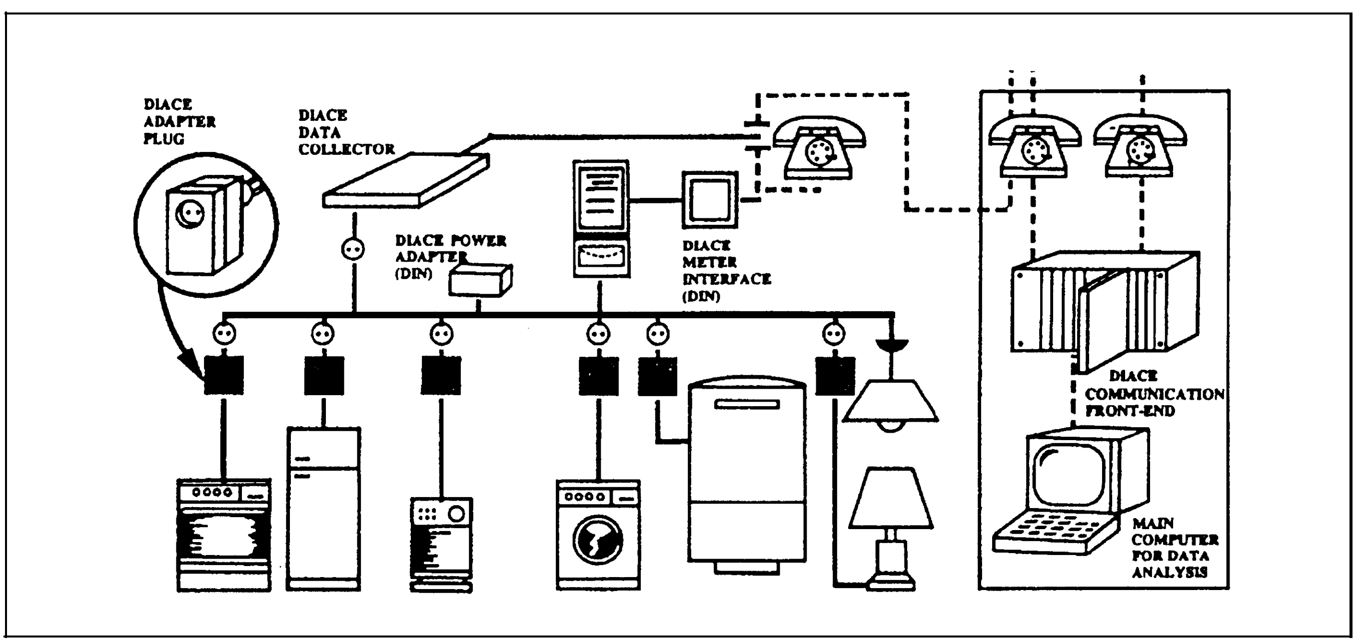

Figure 1. Schematic of the Complete DIACE system

4. Flexible: the system can record consumption every 10 (minimum), 15 or X minutes depending on the choice of the operator and the precision needed to draw the load curve

5. Efficient: the system can monitor as many appliances as needed within one installation (with a maximum around one hundred plugs).

Despite all its advantages, the DIACE system presents one inconvenience: it is an intrusive tool. That is the technician must enter a private household to install it. Of course, it is also possible to ask the customer to install the different components. However, entering a customer's household presents an interesting advantage: the operator can see the appliances, their characteristics, their location, and fill in a questionnaire useful in the analysis of the monitoring.

Organizing a Monitoring Project

The Directorate General for Energy (DG XVII) of the Commission of the European Community has decided to sponsor a pilot monitoring project on a sample of 100 French households. This program is jointly organised by ADEME and EDF (Electricity de France). A complete set of 10 DIACE systems has been ordered. Each household in the sample will be monitored for a month.

Each DIACE set consists of a data collector and 10 DIACE plugs. This allows the monitoring of 10 different end-uses. These are:

1. refrigerator
2. clothes-washer
3. lighting (halogen luminaire,...)
4. television set
5. freezer*
6. dishwasher*
7. stove*
8. microwave oven*
9. miscellaneous (vacuum cleaner, dryer, iron, aquarium...) 1 *
10. miscellaneous (vacuum cleaner, dryer, iron, aquarium...) 2*

* when existing

As one can see, this pilot monitoring project focuses on non-thermal electrical end-uses. There is some flexibility to choose from among the miscellaneous end-uses the ones that are more interesting to monitor. In some households, the monitoring will be limited to less than 10 end-uses.

Professional electricians are used to install the system. They go to the residence twice. At the initial installation, at the beginning of the month, an employee of the utility company helps the customer to fill in questionnaire. Plugs and data collector are easy to install, but some large appliances need to be moved a little bit in order to access the electric plug they are connected to. The system is removed at the end of the month.

The questionnaire is designed to seek customer's point of view on consumption patterns. General questions are asked, such as type of housing and number of people in the house. Specific questions detail the type of appliance used: brand name; capacity; age; location in the kitchen,... and so on. One of the goals of the campaign is to gain a better understanding of the influence of the customer's behavior regarding the use of the appliances. It is important to collect a maximum of explanatory factors for the electrical consumption and power demand pattern for a given end-use.

Preliminary Results

At this stage only preliminary results are available. The monitoring project will last until mid 1995 and there is a large amount of data to be analyzed. Not enough data has been yet collected to allow significant conclusions on the sample of households. However, the preliminary results that are available illustrate the overall efficiency and flexibility of the new monitoring technique. As an illustration, results of one-day monitoring of a given household are presented in Figures 2, 3 and 4. A total of seven DIACE plugs were installed on seven different appliances: a combined fridge/freezer, a clothes-washer, a dishwasher, a television set plus VCR, a stereo equipment, a microwave oven and a 200 liter aquarium. Table 1 presents the daily consumption of each appliance.

Table 1. Summary of a One-Day Monitoring on One Site

Appliances	Consumption in Wh
Aquarium	1,378
Dishwasher	2,161
Refri/Freezer	1,378
Clothes-Washer	924
TV set + VCR	938
Stereo	305
Microwave Oven	172
Miscellaneous	~1,400
Total	~10,000

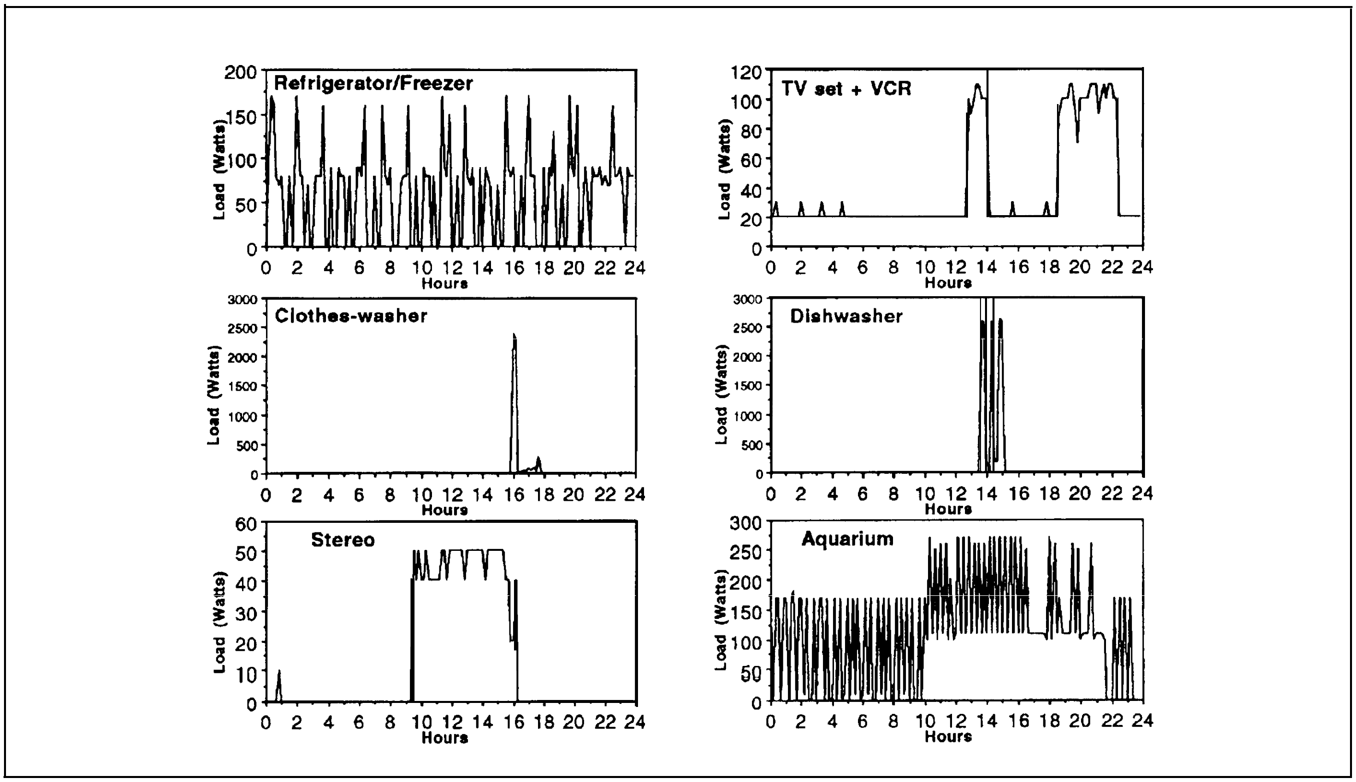

Figure 2. Daily Load Shape of Individual Appliances Monitored

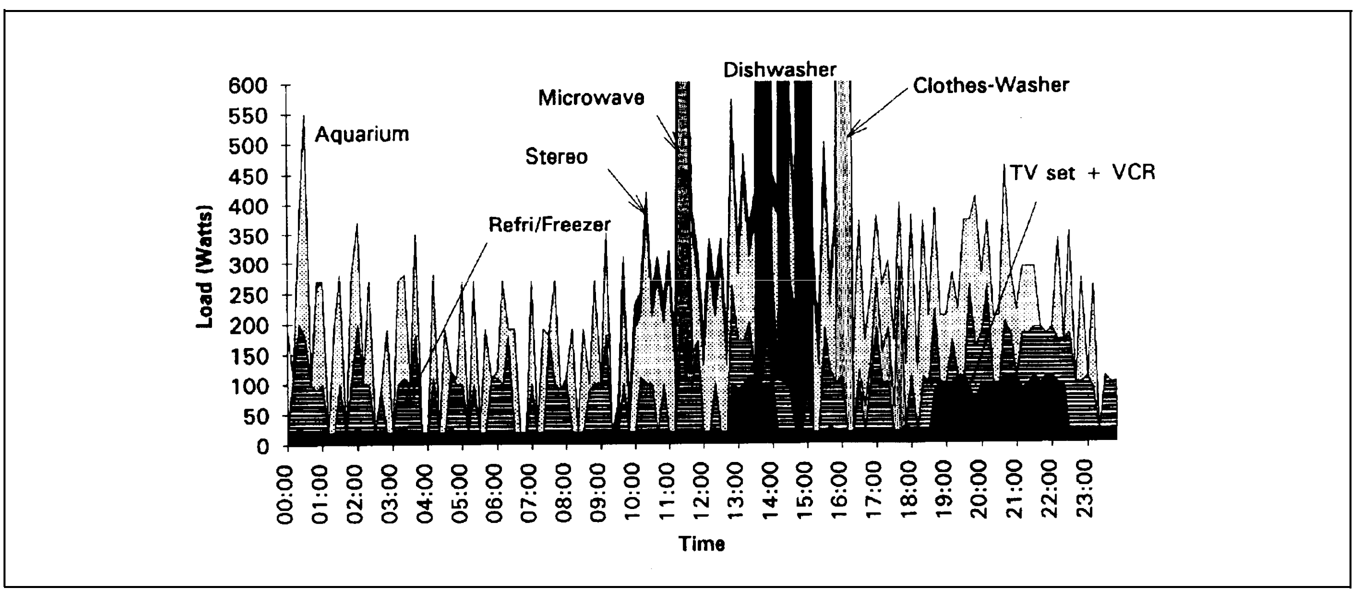

Figure 3. Daily Load Shape of the Monitored Household

Figure 2 presents the load shape of each individual appliance during that typical weekday. Figure 3 is the total load shape of the site.

In Europe both dishwashers and clothes-washers heat the water they use with a 2000 to 3000 W electric resistance. This load largely dominates when the appliance is used as seen in Figure 3. The combined refrigerator/freezer has two compressors. This explains the patterns of the load for this appliance. The aquarium is the most consuming appliance in the house. On Figure 2, the electric heater cycles on and off to maintain the 200 liters of water at 27°C. Two fluorescent tubes light the aquarium 12 hours per day, from 10:00 am to 10:00 pm. The standby mode

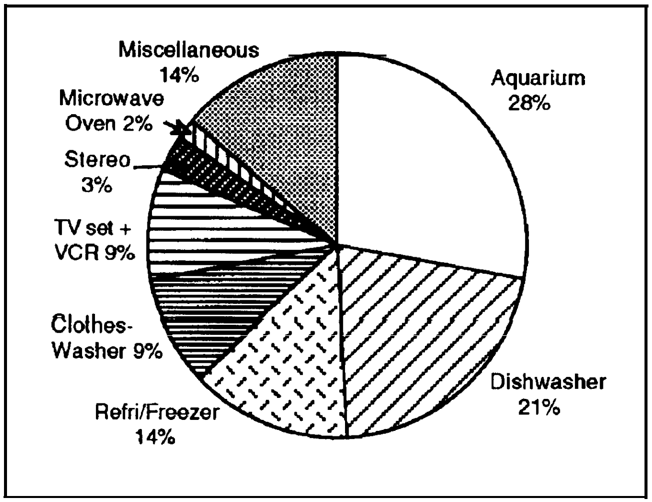

Figure 4. Total Disaggregation of the Total Daily Electricity Consumption

on the television set and the VCR is clearly seen on Figure 2. Figure 4 is a disaggregation of the total electricity consumption of the monitored household during that day.

With the compilation of the questionnaire, one expect an interesting picture of appliance usage and consumption in the sample of households.

Future Directions

The new monitoring technique has already proved its reliability during this pilot monitoring project. More will be learned as the project progresses. A wide range of opportunities are now opened for future projects. The main one is part of a large program from Electricity de France to improve the knowledge of the pattern of electrical consumption and load shape in the residential sector. For that purpose, EDF is developing a three-phase approach. The first phase consists in monitoring a limited sample of households, possibly a hundred like in the current project, with the DIACE system. In a second phase, EDF projects monitoring a sample of 1000 or so households analyzing the power load using non-intrusive techniques. In the third stage, EDF anticipates conducting a residential mail-back audit program over a sample of 4000 customers.

The monitoring campaign, because of its accuracy and its detailed results, will feed the survey of non-intrusive monitoring of 1000 households (phase 2), that will itself provide a strong background for analysing the mail-back audit survey. This 3-step approach is expected to greatly enhance the knowledge of the usage of electricity in France in the residential sector. This will facilitate the definition of adequate DSM programs and strengthen efforts of validation and evaluation.

A new program in the commercial sector will start soon. It will focus on office equipment for which very little information is known on usage patterns, energy consumption and effect on the load shape. Another program is also being planned to validate field energy savings due to the introduction of efficient electrical equipment in the residential sector.

Because the DIACE system is quite flexible-like the possibility to monitor as many appliances as needed inside an installation- new developments are being considered. Temperature sensors can be coupled to the monitoring of energy use to gather data on the thermal condition of the room where the appliance is located. There is no technical barrier to designing special thermometers that could be connected to a regular plug and send the temperature data the mains to the DIACE data collector. Indeed, the monitoring project could not only record the consumption of individual electric appliances, but also temperature, humidity, light level, noise, and occupancy of each room of the building.

Conclusion

Because of advanced electronics, it is now possible to monitor electricity consumption and load shape by end-use with a system that is flexible, precise, convenient, and unobtrusive. Preliminary results from a pilot monitoring project are very encouraging and open a wide range of opportunities for new programs. Future DSM programs will benefit from the emerging technique.

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