People as the Main Influence on Real Energy Consumption

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1. SYNOPSIS

How does it change over the year ? How do load curves differ between the families ? And how can one really save energy ?

2. ABSTRACT

The more reduction of energy consumption in the domestic sector becomes a theme of common interest, the more attention is focussed on efficient appliances. Various studies point out saving potentials of about thirty percent by replacing inefficient appliances by the best available.
While those technical potentials are well-known, little attention is directed to the user of the appliances.
To show the major influence of users on energy consumption and to identify the resulting saving potentials, we performed the CUMBER-Project. In this project measurement of loadcurves of sixty households for more than one year is combined with two inquiries about the people living in these homes and their appliances. The first measurement results show how the need of electricity differs between homes, varies between summer and winter, between weekday and weekend and how it depends on other factors. Continuous measurement over the year also shows differences in electricity consumption for different applications and between families with different structure. Figures for "real technical saving potentials" based on real everyday conditions and the actual measured users behaviour are given. Furthermore the effect of a realization of these potentials on energy consumption and load curves can be estimated. As one of the most important results, possible points of impact for an effective realization of "real saving potentials" can be elaborated.

3. INTRODUCTION

3.1. Background

Currently, some 26% of electric energy in Austria is consumed by the domestic sector. Official data from the power utilities indicate, that in the average Austrian household, 22% of electric energy is for space heating, 20% for water heaters, 38% for large appliances and 20% for small appliances, computers and pumps. Although technical development in the domestic appliance sector aims to increase not only user comfort but also efficiency, electricity consumption in Austrian households increases by about 3% annually (Sakulin,Dell 1992).
It may be supposed that this is due not only to an ever-greater number of appliances but also to increases in the number of households and the trend toward smaller households. In urban areas especially, one- and two-person households form a majority of households (somewhat more than 60%). Further reasons for the increase in domestic electricity consumption are very probably to be found in actual user behavior, which to date has received little attention in studies on domestic energy consumption and energy savings potential.
Studies involving technical measurements on domestic appliances show, that possible changes in energy consumption due to appliance utilization habits are of an order of magnitude that is close to that given in previous studies as "technical energy savings potential".

3.2. Scope

This work is an interim report that aims to present and analyze the energy consumption of various categories of households, and to estimate actual energy saving potentials.
For a qualitative and quantitative assessment of magnitude, achievability and long-term effectiveness of these real user savings potentials and their effects in combination with real technical savings potentials, 2 large survey were conducted, along with a comprehensive field study involving long-term measurement of energy consumption and load curves in actual households.

4. METHODOLOGY

4.1. Household survey

The primary data collection is based on two household surveys that were conducted by professional institutions using a questionnaire developed by our department.The first representative survey was conducted throughout Austria in 1990; it covered 1500 households, 500 of them in Styria. It permits conclusions to be drawn on a number of objective factors including domestic appliances in use and their age distribution, as well as the manner of their use. A second survey in 1992 covered 1000 households and paid particular attention to operation time and manner of use, in order to determine household load curves. On the basis of these data load curves for the individual appliances and then for various household cathegories were determined (Iskra et al. 1993). Besides these large surveys, the test households, whose load curves were metered, have been queried in detail as to appliances available, and the way they were used.

4.2. Measurements

In addition to a large number of laboratory measurements on individual domestic appliances (Furtner 1993) and individual studies in actual households (Sakulin, Schmautzer 1992) a detailed measurement project was undertaken in cooperation with a small local electrical power utility (EPU). In February 1993, two apartments blocks with the same exposure to climatic influences were selected. In July 1993 the necessary wiring for the electrical measurements to determine load curves was done, and the first measurements were made.The experimental period comprised the calendar year of 1994, during which the electrical load curves from 60 households were measured with the multichannel power recording system MPX developed for this study by our department.As to the physical setup, the load multiplexer was situated in the mains connection of the respective building. With voltages measured directly and currents measured with current transfortmers, active power of all households was formed.Four load multiplexers with 21 channels each were connected to a PC via the serial interface; the measurement-data collection program MPL was used and the measured loads from the households were stored as average values for 1- or 15-minute periods.

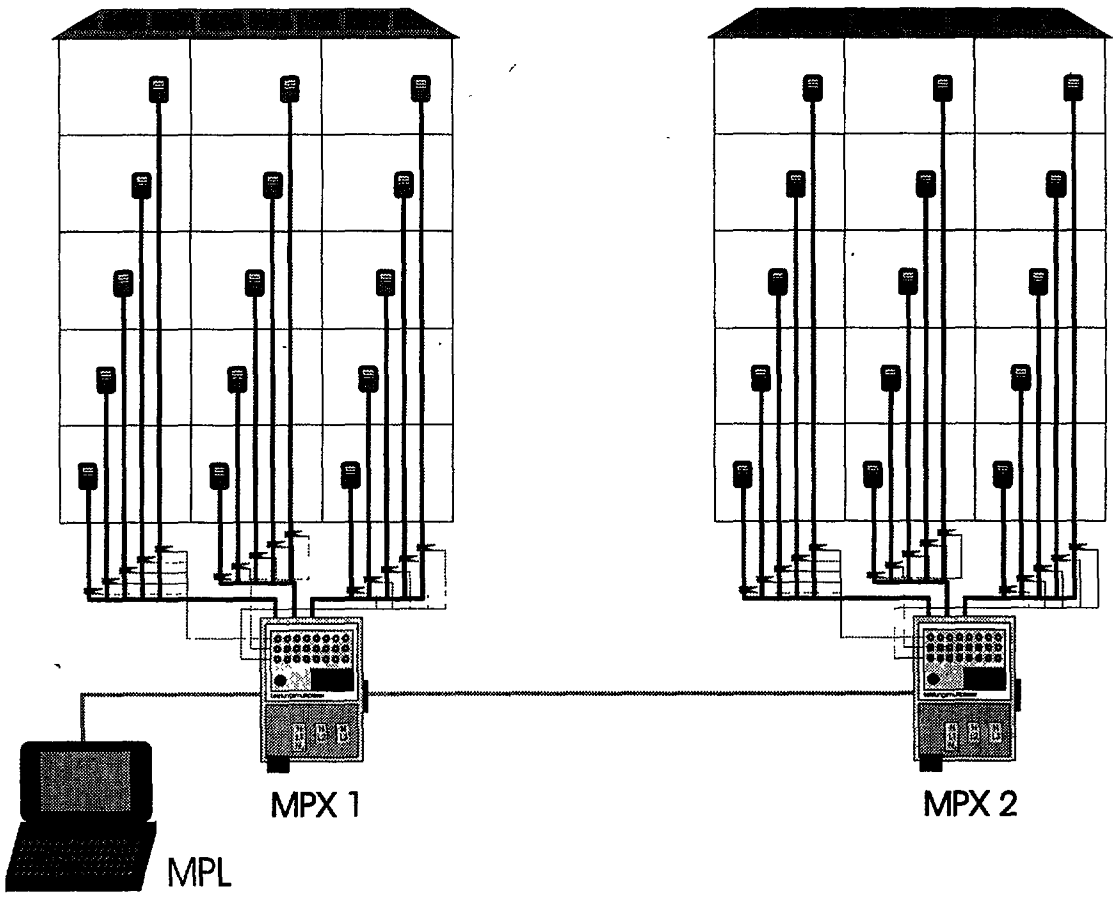

Figure 1: Load curve measurement

Whenever possible, EPU employees read the kWh-meters weekly, to monitor electricity consumption and to verify and supervise the measurements. Each household is equipped with separate meters for water heaters (low-tariff consumption, LT) and other electrical equipment (high-tariff consumption, HT).
The households studied have district heating and residents say that their apartments become very warm during the heating period as the only way to regulate heating is by opening windows.

5. RESULTS

5.1. Calculating average consumption

Electricity consumption for the entire household can be calculated from data obtained on the electrical appliances present (household-, space heating-, water heating-), their age distribution, technical characteristics and the way they are used. There is a preliminary classification of households on the basis of extent of use of electrical equipment, and urban or rural location.

Table 1: Electricity consumption for different electrification

household category	average consumption per year[kWh]		
	total	city	country
without electric cooking without electric water heating without electric room heating	1844	1670	1897
with electric cooking without electric water heating without electric room heating	2350	2113	2417
with electric cooking with electric water heating without electric room heating	3200	3226	3186
with electric cooking with electric water heating with electric room heating	4046	4394	3942

In the following we will take a closer look to that homes, that are equipped with electrical cooking and electrical water heating, but without electrical space heating.

5.2. Annual electricity consumption and household size

Calculating the annual electricity consumption (without hot water) based on the data from the big household-surveys, shows the variation of electricity consumption considerably according to the number of persons in the homes (Lins 1992).

Of the total of 60 metered households, 39 responded to a questionnaire; they thus formed the basis for further observations.
Measurement data show the additional amount for water heating and so allow to quantify the total electricity consumption for the different household sizes.
After averaging and interpolation, however there is a very good agreement of the total electricity consumption values with data from official studies (Bundeslastverteiler BLV 1986).

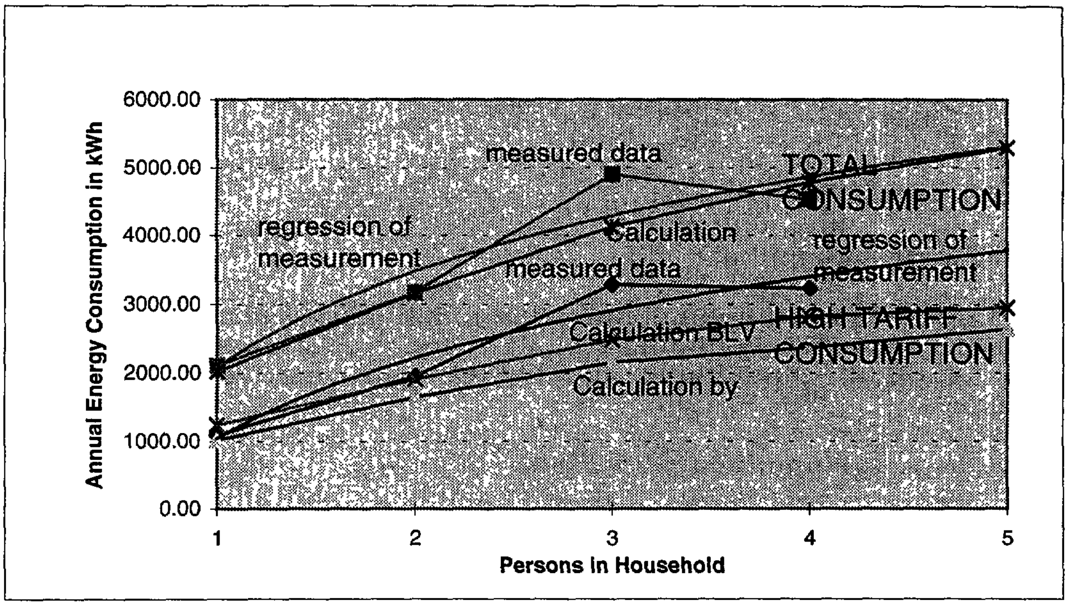

Figure 2 : Number of persons and electricity consumption (various studies)

Agreement of these data is best for the categories of one- and two-person households, also with regard to the ratio of HT to LT (= water heating).There is a major difference with respect to the division of energy consumption into water heating (LT) and all other applications for large households. A simple explanation for this can be found through careful analysis of the measured load curves: the large households tend also to heat water during the day, using additional high tariff electricity.
This is evident in the fact that these households have a ratio of HT/LT of about 3, meaning that they use about three times as much day rate (HT) as night rate (LT).
Because of the small number of the measured households (39, see above) it was not possible to relate domestic energy consumption to such other parameters as degree of employment, income, age or education.
We tried, for example, to relate energy consumption for hot water (LT) to other total energy consumption (HT)as a function of the age of the "household-head", but the result was an inconclusive cloud of dots. The values of this ratio (HT/LT) are between 0.5 and 2, meaning that power consumption for hot water ranges from half to twice that used for all other electrical applications.

5.3. Annual curve for weekly household energy consumption

Evaluation of the weekly meter readings leads to the annual curve for weekly energy consumption. It shows distinct variations over the year, disregarding errors due to incorrect entry of the date and other irregularities in the meter readings. These meter readings can be approximated by a cosinus-shaped line, describing the annual line of the weekly consumption E(w) of the average household.
The formula for this line can be given as

E(w) = Ey/52 + A.cos(w.2.PI/52 +/- Phi)

with Ey .... Energy consumption per year (Ey =3148 kWh)
A ..... Amplitude of the cosinus (A = 5,45 kWh)
w ..... weeks (1.... 52)

In our case the amplitude is about 9 % of the average total consumption, with nearly no phase shift.

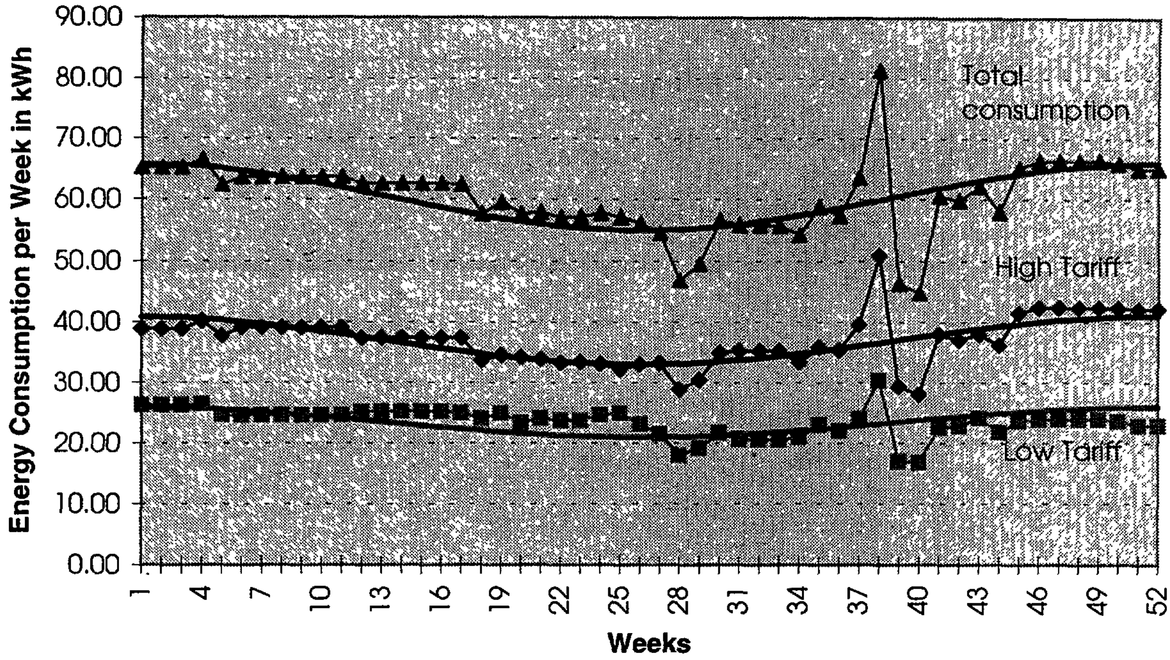

Figure 3 : Annual change in electricity consumption

The evaluation of short-term variations due to weather and other influences like holidays will be possible after the measurement data has been processed completely. The high resolution of measurement of the daily diagrams will then show the changes in users behaviour, which lead to different values in energy consumption.

5.4. Results of load-curve measurements

Evaluation of load curves involves a distinction among households on the basis of time spend at home; the main criterion used is whether household members are employed.
Time spent at home of course has a major effect on the times when power is drawn.

5.4.1. Typical load curves for different households

- Household category 0:
  Members of these households are generally away from home from Monday to Friday, either because they work farther away from home all week and only return on weekends, or because they for some other reason only use the apartment on weekends. During the week, their consumption only consists of losses, as they keep the water heater and refrigerator on and have their electronic equipment in standby mode (Fig. 4a)
- Household category 1:
  These are households where no one is at home during the day. The residents either work, or are active retirees who spend their days out. Main consumption is in the morning and evening hours; during the day, electricity is needed only for cooling and standby.(Fig.4b)
- Household category 2:
  In these households usually someone is at home during the day. Consumption is higher during the course of the day, with peaks during the morning, noon and evening hours (Fig. 4c).
- Household category 3:

Two or more people are at home during the day. Otherwise as in category two, but with higher consumption(Fig. 4d).

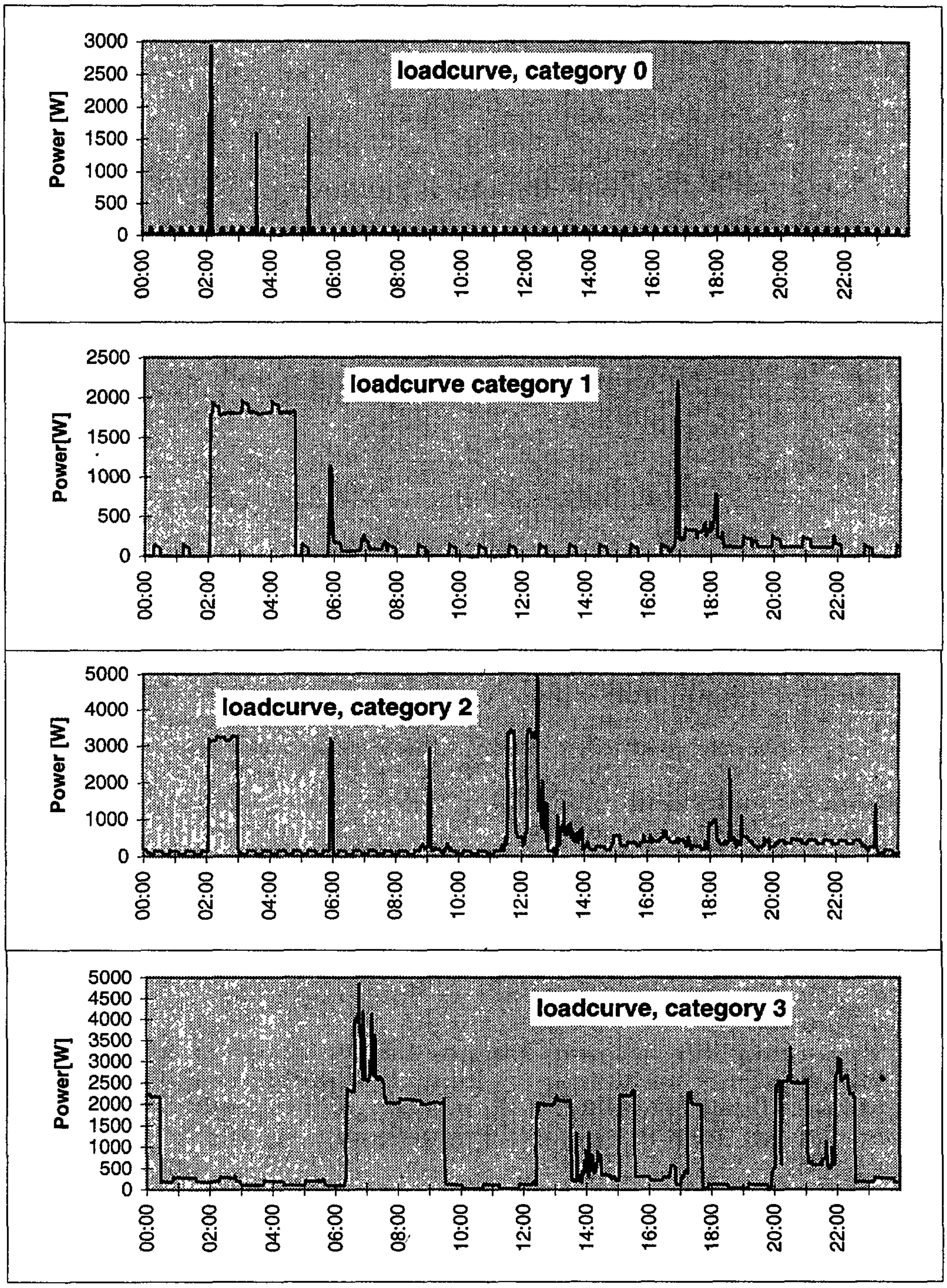

Figure 4 : Typical load curves for different household categories

5.4.2. Analysis of load curves with respect to standby and refrigeration

A preliminary analysis of the load curves permits an estimation of real consumption in these areas. There are enormous differences in energy consumption of the appliances , as can be expected from the analysis of the market situation in Austria (Gross et al. 1995). As Fig. 5 shows, that there are large differences in how long and often the compressors in the various refrigerating and freezing appliances run as well. The periods range from a few minutes to several hours and two refrigerators appear to run constantly. Laboratory tests show, that at least two factors are needed to explain this phenomenon: for one thing, newer models tend to have shorter periods. Secondly, time constants depend on the amount of food in the appliance, as well as ventilation to the heat exchanger. These factors appear to differ considerably in real use and conditions. Energy consumption by refrigerators and freezers also shows a relationship to the number of people in the household.

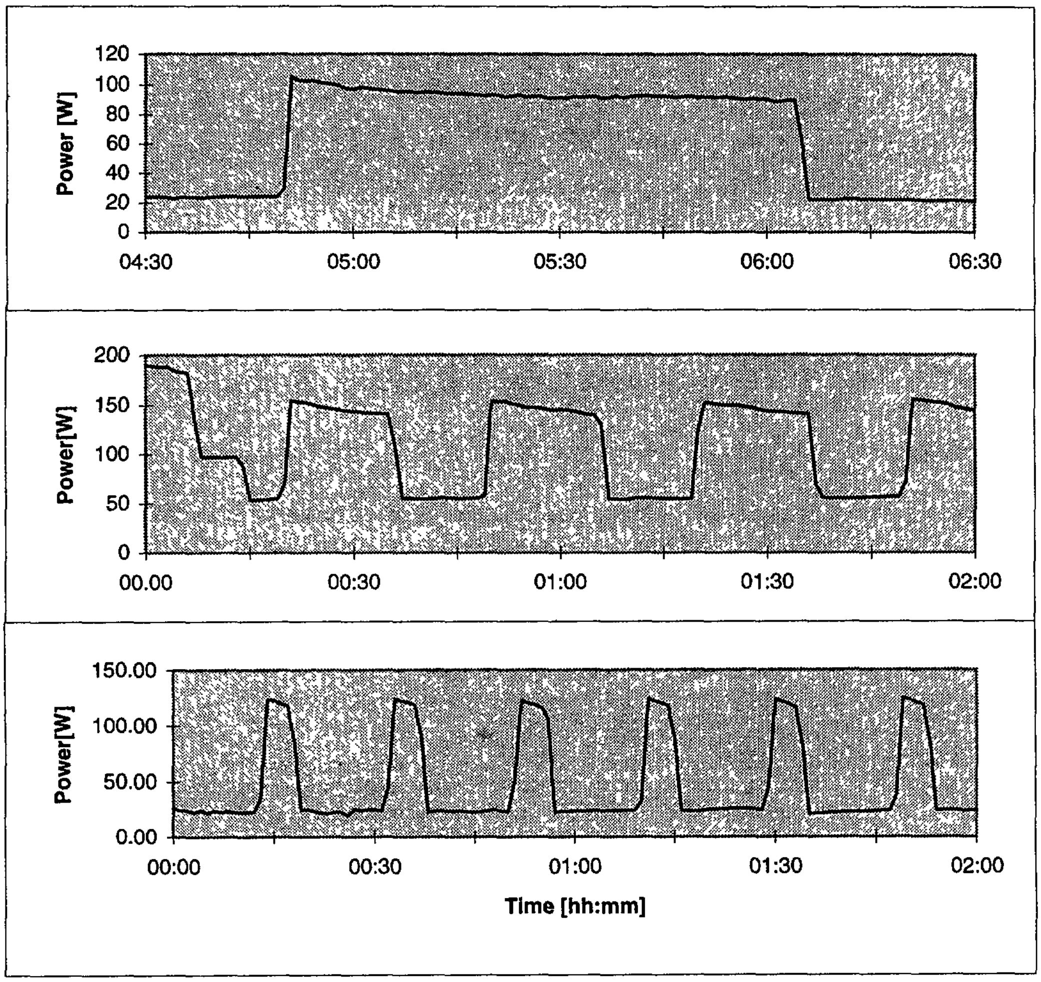

Fig. 5 : Some typical refrigerators load curves

Load curves show that standby losses in household electronic equipment vary between 0 and about 80 Watts. Standby consumption shows a similar relationship to the number of people in the household too.

5.5. Estimation of standby losses for water heating

Calculation of real standby losses - not including distribution losses of hot water - is done in two steps. First, losses are calculated for each household with the data from the questionnaire as

Ev = Nominal Volume/100 * (Twater-Troom)/40 [kWh/day]

An analysis of the market situation shows, that standby losses under standard conditions can be estimated by : Nominal Volume/100 in kWh/day.
The second term in the formula adapts the nominal losses (at standard conditions) to real temperatures.
This product is entered as a function of the number of people in the household. Then the curve is weighted by comparison with measured water-heating consumption on days when no one is at home, i.e. when all energy consumed just covers standby losses.

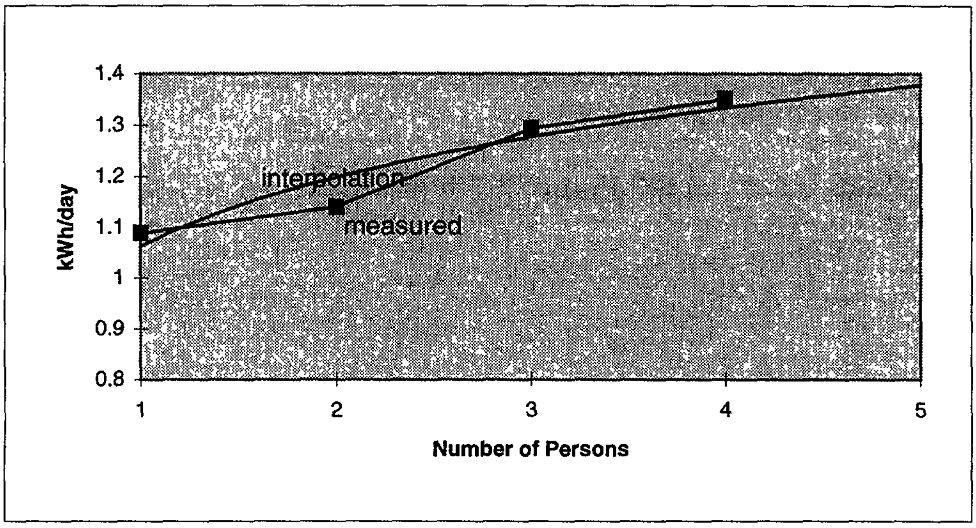

Fig. 6 : Hot water storage losses and number of persons

5.6. Savings potentials

There is no longer any doubt that significant savings can be achieved when old appliances are replaced with newer, more efficient ones. In addition to these well-known technical savings potentials, more attention should be paid to technologies that are better suited to the respective application, i.e. that use less energy. There is also the matter of changes in user behavior. Energy savings should not place limitations on users or their needs, but should aim to avoid waste and unnecessary loss. This can be achieved through proper use and optimal operation of the appliances available.

5.6.1. Annual energy requirement for different appliances

Information from the questionnaire on the number of appliances, their ages, net volumes and their manner of use was used to relate electrical energy consumption for different applications (excluding space and water heating) to the size of the household.What is especially noticeable here is the large proportion of energy consumed for refrigerators and freezers, as well as lighting.

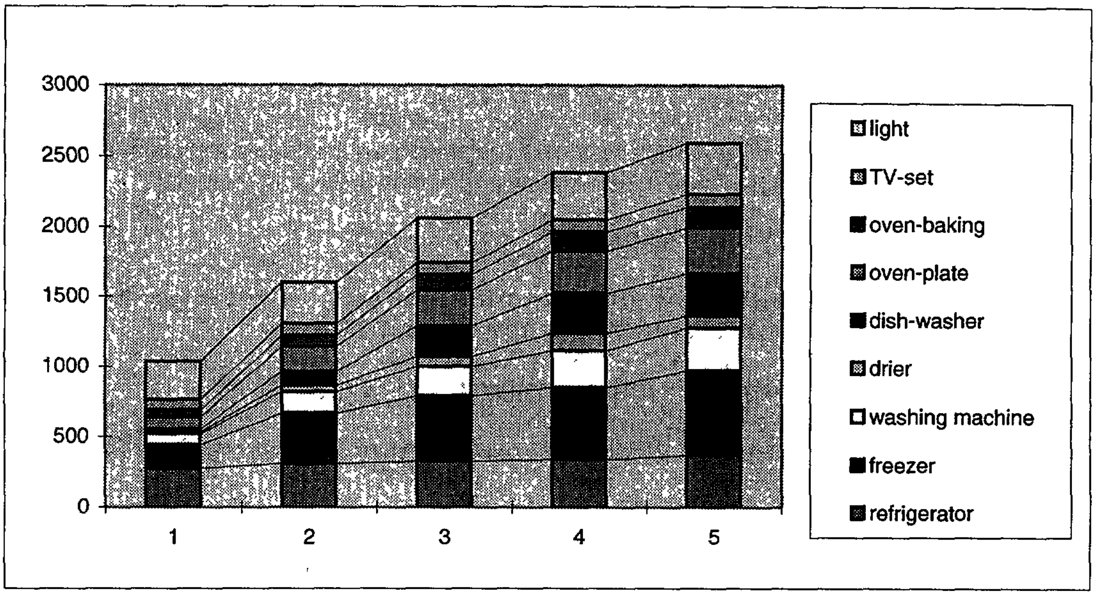

Figure 7 : Energy consumption in household and number of persons

5.6.2. Specific consumption per person

Adding our data about electricity consumption for water heating leads us to the total consumption. If the total energy consumed in a household is related to the number of persons, the result is a specific electricity consumption per person as a function of household size.

We can see, that the amounts for warm water, as well as for refrigeration and freezing are the main part of the energy consumption, especially for people living in the one- and two-person homes. The reason is, besides the fact that due to physical circumstances heating water consumes a lot of energy, that in this application in particular, a large amount of the energy consumed goes to covering losses (see Fig. 6).

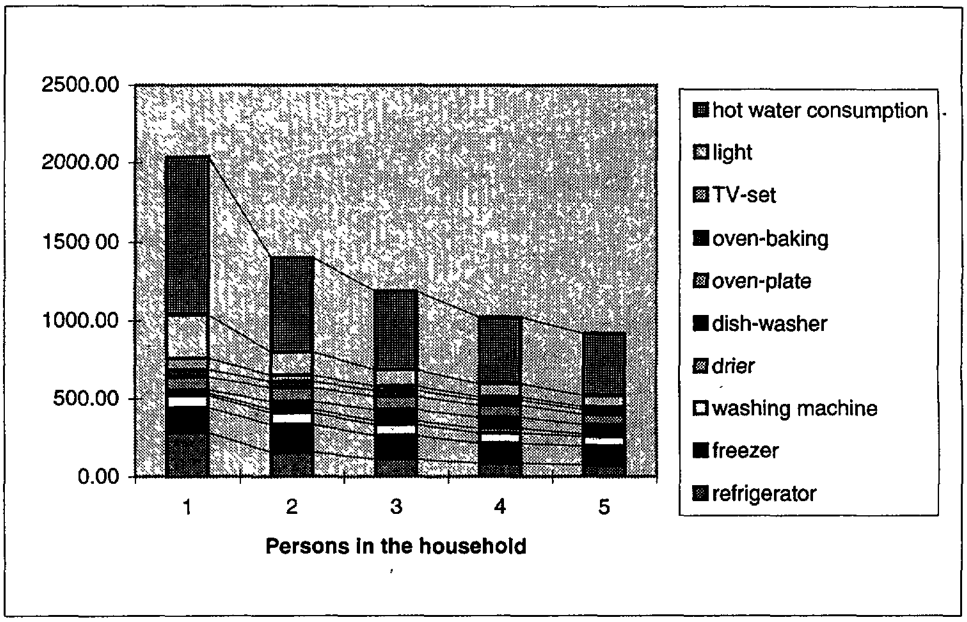

Figure 8 : Specific consumption per person and number of persons

5.6.3. Savings in the water heating sector

Eliminating or reducing these losses without doubt would be the most efficient way to achieve major reductions in household electricity consumption. The losses we are talking about in the warm water sector are about 20 % of the total electricity consumption for an average single home and 15% for a two person home.

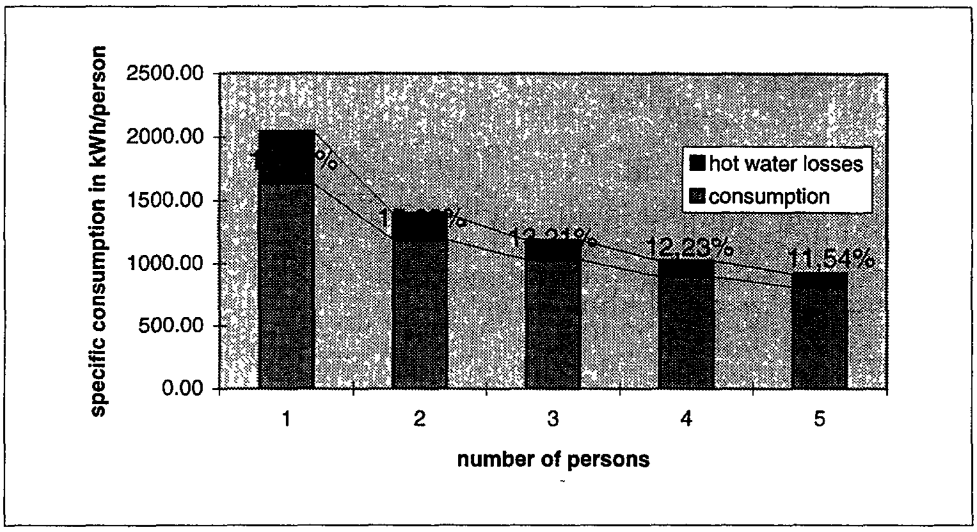

Figure 9 : Saving potentials due to water heating

5.6.4. Solutions

Theoretically, standby losses in the hot-water area can be prevented by heating water only when it is needed. This would be technically possible with the use of flow-through heaters, using either gas or electricity. The savings in electrical energy would of course be greatest with substitution, but even the portion of electrical energy that can be saved by using electrical flow-through heaters is considerable - the whole standby losses (cf. Fig. 9). However there is to consider that these require a high-power supply that usually requires a special permit from the EPU. They also cannot be controlled to operate at low load periods.
Another way of reducing losses would be to let the user determine at which time a larger amount of hot water should be available. But this would need a change in peoples minds. They must have the willingness to accept that the service of hot water is not possible at once, as it is usually today. This idea could be realized with a programmable timer, if the user had very regular habits, or with a rather small heater that could be switched on manually by the user at short notice and would heat up to a chosen temperature.
A future possibility would be to cover the energy requirement for basic everyday hot water needs by waste-heat from cooling appliances. A combination of this sort, which is ready for series production in Holland (Kemna 1994), also considerably reduced power consumption for refrigerating and freezing.
It is basically up to manufacturers to reduce standby consumption, but realization of consumption-reducing measures in this area will only occur when pressure from consumers and legislature is strong enough.

6. CONCLUSIONS

The main factors influencing domestic electricity consumption are technical equipment, people's needs and habits. The only way to obtain precise information on how people actually use electricity is by combining surveys with detailed measurements on a large number of households. Longterm, high-resolution monitoring of a large number of households with the equipment we used is only a cost question. What is more expensive and time consuming and makes more head ache is the processing and interpretation of the data, which for this project are far from complete. The results presented here and the experience obtained should serve as a basis for further projects of this sort.
Nevertheless it can be shown, that only the combination of efficient technology and human behaviour can lead to significant savings. The problem is, that users potentials are uncertain, while technical potentials are - once realized - steady.
More attention should be payed to the 1- and 2- person homes, because it is very difficult to find efficient technical equipment that meets their needs and is efficient.

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