Evaluating participation of residential customers in demand response programs in the UK

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Abstract
Demand Response programs for residential customers refer to direct control of appliances at certain times or dynamic prices or other incentives that invoke end users to reduce demand at peak times. In order to evaluate demand response possibilities a more detailed simulation of domestic electricity consumption is needed to provide information about when specific electric devices are in use and how they contribute to a household's demand. Household composition, socio-economic characteristics and most important lifestyle and energy use behaviour are key factors that influence electricity consumption.

This study describes a bottom-up model of household electricity demand to be used in the assessment of Demand Response and generally DSM strategies, using the UK 2000 Time Use Survey. Information on people's lifestyle, ownership of appliances, household composition and socio-economic characteristics are combined with results of appliance-use surveys and used to generate load profiles for each selected household type. The study discusses the possible outcomes of Demand Response from the end-user's and the utility's points of view. In bringing together detailed data on energy-using activities and appliance characteristics this research represents a valuable resource to investigate factors that influence people's energy use behaviour and therefore forms a basis for future work on DSM strategies.

Introduction
Demand Response in the electricity market is defined as load response called for by others and price response managed by the end-users, at times when the demand and the prices reach a peak (Goldberg et al. 2003). More traditional Demand Side Management (DSM) refers to ways to increase the energy efficiency and shift peak load but not through market-based pricing strategies (IEA 2003). Most Demand Response programs in place concern large industrial and commercial customers however there are some targeting residential customers and they mainly concern load control of water and space heating and air-conditioning. However, the connection of generation at the distribution level and the trends for more local management of the electricity network are expected to increase the role of the residential sector in the balance of supply and demand. Moreover in accordance with the new market for energy services and the trend for more efficient use of electricity, some suppliers have already started to look at more options offered to their customers and consider new tariff structures including Time-of-Use (ToU) tariffs. Currently the International Energy Agency's DSM group (IEA, 2005) looks at the appropriate methods to motivate small consumers to participate in Time-of –Use tariffs or enter voluntary agreements for load control with network operators.

In order to convince network operators, network owners and suppliers to pursue demand response options it is useful to evaluate the potential load reduction. To do this it is important to examine the impact of each sector on system peaks and implement surveys to quantify the impact of different DSM and pricing options on the load profiles. Efflocom project (Efflocom Project 2003) part of EU SAVE addresses the issues above, analysing past data and conducting pilots in different EU countries to test the impact of Smart house technology, dynamic tariffs and web based energy efficiency information on load profiles and makes a cost-benefit analysis from the network owner's point of view. When quantifying the participation of the residential sector in this type of programs it is important to take into account the factors that influence the household's electricity consumption such as household type, socio-economic characteristics and lifestyle. The best scenario would be to conduct detailed end-use metering surveys such as CIEL, 1996 that give very useful information on people's energy use behaviour and the load profiles of domestic appliances, however these surveys are usually difficult and expensive to implement in a satisfying sample size to produce representative results. When evaluating the results of DSM programs the most cost-effective solution would be the use of load simulation models that do not only describe the engineering aspects of the end-uses but also contain behavioural elements (Capasso et al. 1994).

This paper presents a simulation model of domestic electricity consumption using a bottom-up approach that constructs from the UK 2000 Time Use survey the aggregated load profile from the various electricity- using activities of the household members. It is related to the model from Capasso et al., 1994 which also uses data from Time of Use surveys, Surveys of Energy Consumption and demographic statistics to design behavioural functions such as availability at home, proclivity of home activities and appliance usage. Models to incorporate lifestyle and end-use demand of electrical appliances are very useful when trying to represent the load on a specific grid point as it is important to represent the variability of household electricity consumption when the number of houses is not big enough to smooth this variability. The model uses very fine time steps (1-min), which give the necessary accuracy for balancing demand and supply (especially intermittent renewables sources) at the distribution level and determining the participation of specific electrical appliances in the household's peaks (Stokes et al. 2003, Newborough et al. 1999 and BRANZ 1999). This is just the first step in a mutli-partner research programme which is exploring demand response for residential customers in the UK. The model described here represents the energy-using activities in a household by individual members, the appliances used and the electricity demands resulting. The model has a fine time resolution, and has activities described according to a detailed socio-demographic classification. With this functionality, it is possible to identify key activities and appliances which contribute to system peaks, and which might technically be most amenable to demand response measures. Parallel and ongoing research within the programme is looking at behavioural aspects, to afford a greater understanding of the likely response of individuals to such measures. The ultimate intention is to bring these two strands together to evaluate the response of people to different policies and services offered by utilities in the deregulated environment.

Background

The residential sector is responsible for the 33% of annual energy consumption in the UK (Efflocom Project 2003). The day of peak demand occurs in winter for example in 2001 it was on the 17th of December between 5-6 pm when a peak of 52 079 MW occurred. The contribution of the residential sector was as high as 46.8% (Efflocom Project 2003). It is obvious that targeting this sector with DSM programs could result in better load factors and avoidance for investment on peak generation. Electrical appliance use quite important in the UK's load profile as water and space heating are fuelled mainly by natural gas. However few studies have investigated the impact of appliances on the household's profiles (e.g. Newborough et al. 1999), making it difficult to evaluate the impact that DSM measures on specific appliances would have on the system peaks. This study tries to capture the participation of end-uses in the peaks aiming to provide a basis of evaluation for schemes such as Time-of-Use tariffs.

Sources of information

HOUSEHOLD CHARACTERISTICS AND LIFESTYLE

The UK 2000 Time Use Survey (National Statistics 2000), conducted on behalf of a funding consortium consisting of the Economic and Social Research Council, the Department of Culture, Media and Sport, the Department for Education and Skills, the Department of Health, the Department of Transport, Local Government and the Regions and the Office for National Statistics, aimed to measure the amount of time spent by the UK population on various activities and was the first major survey of this type ever conducted in the UK. It took place from June 2000 to September 2001 in England, Wales, Scotland and N. Ireland and consisted of household questionnaires, individual questionnaires, diaries (for weekdays, weekends) and worksheets (work and education time sheets for one week). Household questionnaires (6 414 records) contain information on household composition (age, sex, relationships), tenure, type of accommodation, household income, car availability, ownership of appliances and internet (also use of internet). Individual questionnaires (11 664 records) give information on economic activity, job, income, education, voluntary work, leisure activities, health problems and childcare arrangements. In the worksheets (9 823 records), there are data on start and stop times of work or education for each day of the week, also there are data on the start and stop times of travel while at work and means of travel for the whole week. Finally all individuals from 8yrs-old completed a diary both for a weekday and a weekend (20 981 records). Here for each 10-minute period of the day information was required on main activity, secondary activity, location and who the activity was carried out with. The information used in the first stage of the study described here is based on the Diaries and the Household questionnaires which give a good starting point when drawing the household's lifestyle and the socio-economic characteristics likely to influence energy consumption.

APPLIANCE INFORMATION

Specific information on energy-related characteristics of appliances such as load profiles, energy consumption and the factors that influence it, usage patterns and also information related to ownership can be acquired from surveys and end-use measurement campaigns.

The trends towards energy conservation and efficiency make many European utilities and energy agencies conduct these campaigns in the residential sector with valuable results for the development of effective EU efficiency policies and DSM programmes (Lebot et al. 1997). Unfortunately, in the UK there is not much available information of this kind to be used in research, though there is systematic metering of residential demand by research companies, mainly to be used when designing mechanisms for the electricity market (e.g. the Electricity Association Load Research Group in the UK keeps a dataset of half-hourly demands for 1 200 households in addition to household type and socio-economic characteristics and ownership of appliances). For the purpose of this research a series of surveys were reviewed in order to gather sufficient information to make the assumptions while building the household's load profile.

Metering surveys and energy use studies

A relatively small but detailed survey in the UK was conducted by Mansouri et al., 1996 in South-East England between May and November 1994 which focused on ownership levels of appliances and their utilisation patterns, energy-use behaviour, energy and environmental attitudes and beliefs and the kind of information people would like to receive on their energy consumption. The sample size was 1 000 adults of different ages and different socio-economic and income groups. The results of Mansouri et al, 1996 on usage patterns of each domestic appliance are a key information source for the development of the bottom up model presented in this paper as they are the most UK specific.

Another important source of information on the use of electrical appliances in the UK is the DECADE (Domestic Equipment and Carbon Dioxide Emissions) work by the University of Oxford (DECADE 1995). An end-use model of residential electricity use from lights and appliances (space and water heating is excluded) was developed to make long-term predictions for the UK, using information on ownership, sales, usage and electricity consumption, taken from surveys in UK and Europe, and test different policy scenarios for the reduction of CO_2 emissions in the UK. The behavioural aspects of energy consumption were also analysed to produce a good tool when assessing the impact of DSM policies (Strang et al., 1995 and Hinnells et al. 1995).

At the European level there was a series of end-use measurement campaigns to help designing effectively EU energy conservation policies (Lebot et al. 1997). The results of CIEL end-use monitoring campaign (CIEL 1996) initiated by the French National Energy and Environment Agency and EDF and supported from the EU SAVE program provide a very useful basis of understanding for appliances electricity consumption. The survey monitored the appliances electricity consumption in 115 monitored households every 10 minutes. The results provide appliance information such as sample characteristics, monitored load profiles, distribution of average daily energy consumption, average hourly load curve, seasonal variation of consumption, other factors that influence consumption like age and volume and standby losses. Additional sources of information were the initial results of the Household Energy End-Use Project in New Zealand (BRANZ 1997/1998/1999/2000) and also Siderius et al. 1995, Lebot et al, 1997 and EURECO, 2002.

Methodology and results

The general idea behind the model's structure at the household level is to represent when and how appliances are used and to aggregate their loads following a bottom-up approach.

The households participating in the Time Use survey can be grouped by household size or type or a combination of these and other characteristics such as income, educational level, age of adult members etc according to the objectives of the research. For each household case an aggregated activity vector is produced by the 10-min activity questionnaires. The activities responsible for the use of electrical appliances are grouped in ten categories: hygiene, cooking, house cleaning, dishwashing, laundry, ironing, TV and video watching, use of computer / internet and listening to music. If for example there are three people participating in cooking at the specific 10-min period of the day the value of the vector for cooking will be three. The way these people interact with each other during the activity is not taken into account and the probability of appliance usage is not influenced by the number of people but depends only on the available statistics. Also secondary activities like watching TV while cooking have not been included in this stage of the model's development.

The activities are combined with the use of certain appliances subject to ownership information taken from the Household questionnaire information of the Time Use survey and from other sources like DTI , 2002, ECI , 20001, DECADE, 1995/1996 and Mansouri et al., 1996 when additional and more detailed (e.g. combination of cold appliances) information is needed. Table1 shows in detail the ownership sources of information and the appliances considered while building the household demand profile. Electric space heating is not taken into consideration here. The drawback is that with this approach the ownership information for the most important residential appliances is more or less dependent on the information provided by the Time Use Survey and thus the model does not incorporate future ownership and substitution trends.

The sequential 10-minute intervals are added to find the total duration of the activity and the relevant electrical appliances owned by the household are switched on according to the information taken from energy use surveys like this shown in Table 2. For example if the duration of the cooking activity is 20 min, the electric hobs, the electric oven, the microwave, the toaster and the kettle could be switched on at any-time during this period. It must be noted that the actual activation times of the appliance and the duration of their usage are not indicated in the Time Use survey diary and thus they are decided by a random number generator subject to the total duration of cooking activity. In cases like washing machines, tumble driers and dish washers the time of activation is taken to be the last minute of the 'laundry' or the 'dishwashing' activity as the period before is used for the

Table 1. Ownership of appliances model inputs.

Source of information	Appliances and ownership data
Time Use Household Dataset	Microwave, dishwasher, washing machine, tumble drier, fridge-freezer and freezer only, computer, colour/ black&white TV, video recorder, cd player
DTI, 2002 ECI, 2001 DECADE, 1995/1996 Mansouri et al., 1996	Electric hob (46.2%), electric oven (58.2%), iron (99%), kettle (96.6%), clock (68%), toaster (80.2%), vacuum cleaner (99.5%), electric water heating (16.2%), electric shower (1%), chest freezer (17.3%), fridge-freezer (64.1%), refrigerator (43%), up-right freezer (26.8%)

Table 2. Usage pattern of hobs (Source: Mansouri et al. 1996).

Electric Hobs	Period of usage					
	<15 min	15-30 min	30-45 min	45-60 min	Other	Non-Use
	% Households using:					
Ring 1	19.6	42.5	20.4	9.1	5.9 for >60 min	2.4
Ring 2	29.7	33.4	14		6.4 for > 45 min	16.5
Ring 3	29.1	16.5	4.7		3.7 for > 45 min	46.1
Ring 4	29.9	7.9	3.5		3.4 for > 45 min	55.4

Table 3. Usage patterns of washing machines (Source: CIEL 1996).

Cycle	Cold	Hot (>=30 °C)	30- 40 °C	60 °C	90 °C	Source
Distribution of all cycles (%)	23.4	76.6	53.2	18.6	4.8	CIEL
Distribution of hot cycles (%)	–	100	69.5	24.2	6.3	CIEL
	–	100	57	38	5	NUTEK

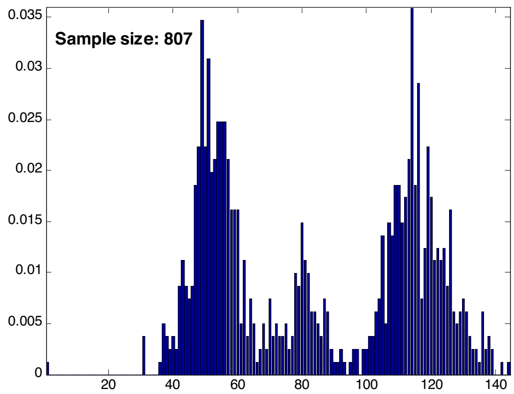

Figure1. *Probability of dishwasher activation at each 10-min interval of the day.*

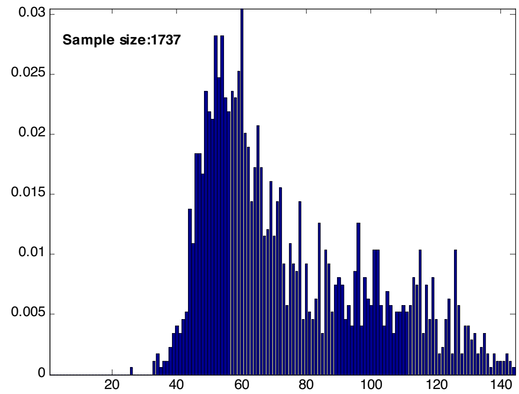

Figure 2. *Probability of washing machine activation at each 10-min interval of the day.*

washing preparation. Also statistics of operation mode like those in Table 3 are used when applicable; this will influence the duration of operation and the load profile. Ironing, TV and video watching, use of computer and listening to music concern the use of a particular appliance that will be 'on' during the stated duration of the activity. Hygiene usually takes place early in the morning or late in the evening. It assumes the use of hot water for a shower, the duration of which is decided randomly between seven minutes and the whole duration of hygiene activity. Also it is assumed that the electric storage heater is switched on prior to the time of hot water demand for a time period that depends on the amount of hot water needed, the inlet and outlet water temperatures and its rated capacity. Lighting (represented by the number of lighting bulbs switched on) is dependent on the number of people at home and sunrise-sunset times. Some appliances are assumed to run continuously, notably cold appliances and stand-by loads.

After it is decided when and for how long each appliance will be 'on' their one-minute load profiles are added to build up the household's profile. For appliances like washing machines, tumble driers, dish-washers, fridges, fridge-freezers and upright-freezers, the load profiles come from monitoring campaigns such as CIEL, 1996 or laboratory experimental results (Deering et. al 1993, Newborough et al. 1999) which provide typical load profiles depending on the operation settings. For the rest of the appliances average ratings were used. More detailed load profiles of appliances de-

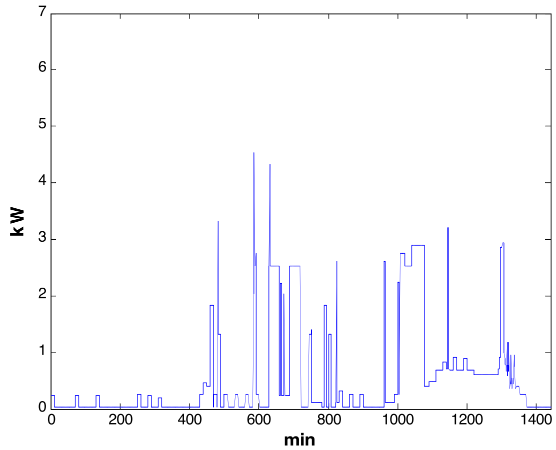

Figure 3. *Load profiles of a winter weekday for a 4-persons household using gas for water heating.*

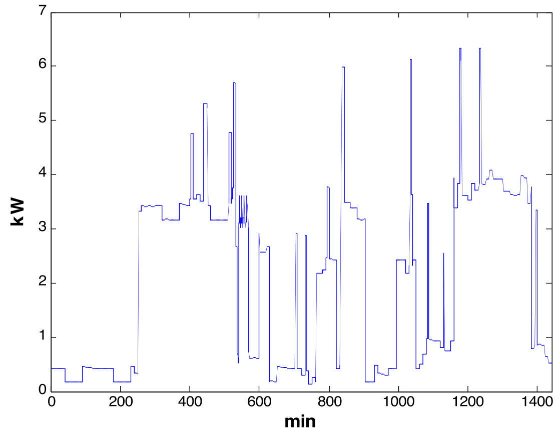

Figure 4. *Load profiles of a winter weekday for a 4-persons household using immersion water heater.*

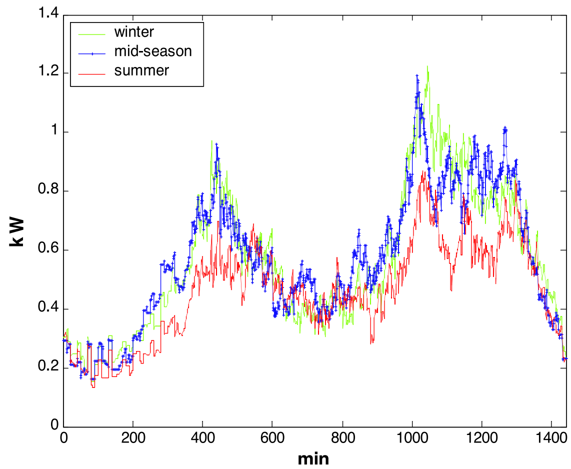

Figure 5. *Average seasonal weekday profiles for a 3-persons household.*

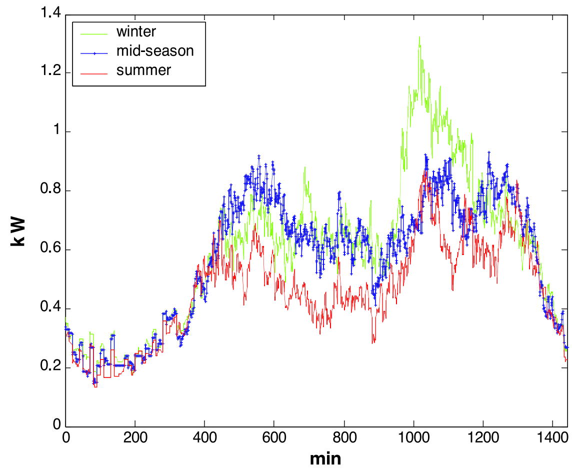

Figure 6. *Average seasonal weekend profiles for a 3-persons household.*

pending on their efficiency would be helpful in order to investigate the impact of different penetration levels of residential appliances energy efficiency on system's peaks, however this is the objective of further research.

The method of using the Time Use information to generate load is valuable for the analysis of household load shape, as it reveals more specific facts for the likelihood of utilization of appliances such as dish-washers, washing-machines and tumble driers at each time during the day (the usage information taken from previous studies indicated only how many times per day the appliances were likely to be used but did not indicate when). The figures below give the probabilities of activation time for the dishwasher and the washing machine.

The results of the method presented above are one-minute profiles for each household, one for a weekend day and one for a weekday. The load profiles are accompanied by the contribution of each electrical appliance and specific household characteristics (e.g. household type and size, number of children, income and unemployment rate) and are saved in a database. The load profiles for two examples of 4-person households (with and without electric water heating) are shown below. These profiles are very similar to the metered household profiles presented in Newborough et al., 1999 and as they have the advantage of capturing people's lifestyle they result in completely different load patterns for households of the same size and type.

In order to produce seasonal profiles the households of the selected size or type are grouped according to the period the Time Use questionnaire was completed. As the survey ran for more than one year there is a satisfying number of weekday and weekend profiles for winter, summer and shoulder seasons. For example for a 3-person household 445 winter, 366 summer and 249 mid-season weekday and weekend profiles were calculated. The average seasonal weekday and weekend profiles are given below. These profiles give a better idea about the time the peaks tend to occur, for example for a weekday the first peak occurs around 7-8 am when people wake up, have shower and prepare breakfast and the second around 5-6 pm at the time of dinner's preparation. The seasonal variations are mainly due to differences in the duration of sunlight and the ambient temperatures. Also the fact that people prefer to stay outdoors when the weather gets better is quite clear looking at the weekend profiles.

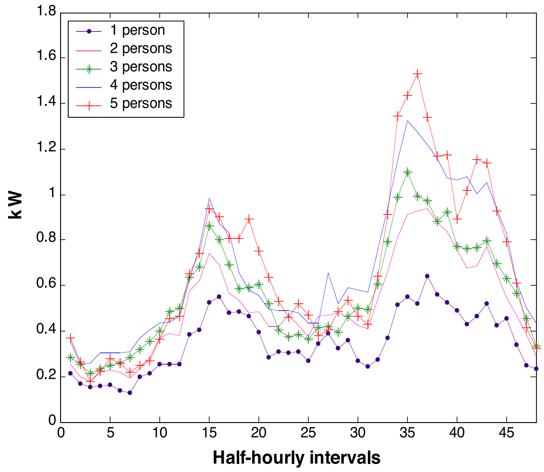

Figure 7. *Average winter weekday profiles by household size.*

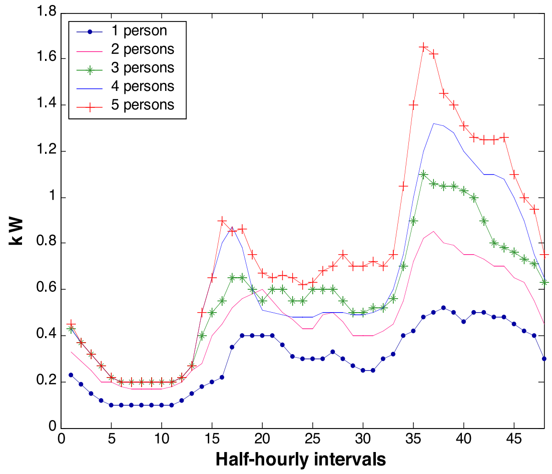

Figure 8. *Average winter weekday profiles by household size from the Electricity Association.*

Table 4. Average yearly electricity consumption by household size.

Household size	Average yearly electricity consumption (kWh/yr)
5-persons	5 619 (total sample size 304)
4-persons	5 061 (total sample size 751)
3-persons	4 684 (total sample size 859)
2-persons	4 163 (total sample size 1 707)
1-person	3 065 (total sample size 1 189)

GROUPING HOUSEHOLDS BY SIZE (AND INITIAL MODEL VALIDATION)

Figure 7 illustrates the average load profiles for a winter weekday for households with different sizes. These results can be compared against the typical domestic profiles of the Electricity Association (EA 2005), an industry trade body in the UK. The load profiles appear to be quite consistent in terms of the times the peaks occur and the size of the peaks, which provides one form of overall validation for the modelling approach. However, the profiles taken from the EA are 'smoother' as the sample size used to generate the average values is bigger.

For each household type the average yearly electricity consumption is calculated.

The average seasonal load profiles can be broken down in loads of specific appliances. The segmented load profiles can provide information on which appliances comprise the load profile. This is very important in DSM research when trying to quantify the impact of measures targeting specific groups of appliances. In the following example for a 4-persons household the contribution of cooking to the evening peak is obvious implying that energy conservation strategies targeting cooking appliances could reduce these peaks to the benefit of the system. Also considerable is the demand for water heating suggesting the importance of further fuel switching or the use of production and storage of hot water at off-peak times.

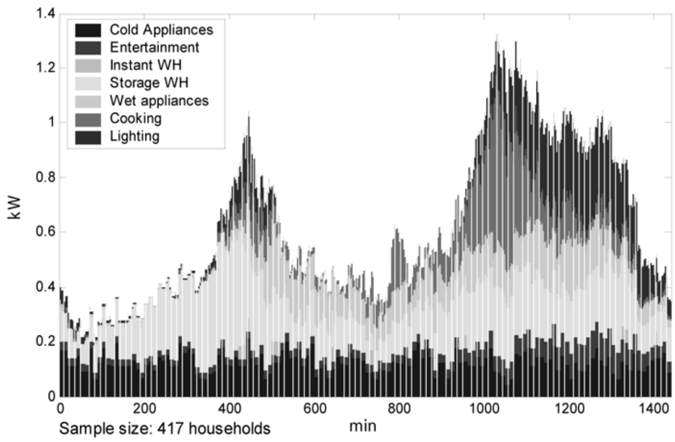

Figure 9. *Participation of electrical appliances in a 4-person-household peaks for a winter weekday.*

HOUSEHOLD BY TYPE ANALYSIS

Grouping the households by household type gives interesting results on how the different lifestyle influences the load profiles. Here two cases of households are compared: one couple without children and one couple with children. The averaged profiles are used because they make daily demand variations more obvious. The profiles follow similar patterns and the two daily peaks occur the same times. Between 8 am and 5 pm as children are usually at school they do not con-

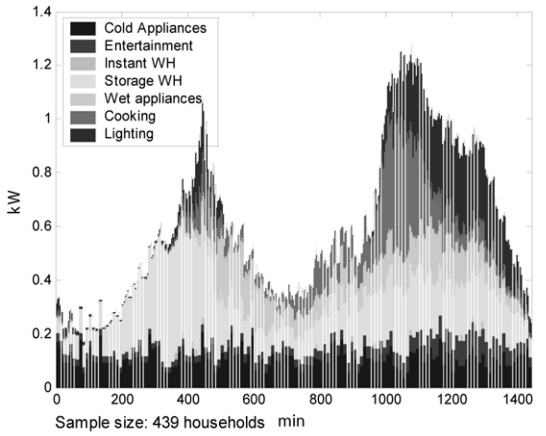

Figure 10. Average segmented load profile of a winter weekday for households of one couple with children.

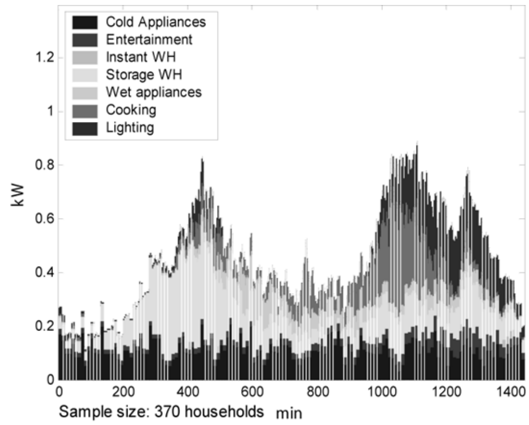

Figure 11. Average segmented load profile of a winter weekday for households of one couple without children.

tribute directly to the household's energy consuming activities and though there seems to be higher cooking activity and usage of wet appliances for the households with children the two profiles are quite alike. This, changes after 5 pm when parents and children return at home and the dinner preparation begins. The demand for more hot water and greater needs for laundry and dishwashing, combined with the greater involvement of members to the food preparation makes the difference between the two profiles distinctive. More detailed information on how different kinds of families use their electrical appliances and more detailed ownership statistics would result in more accurate characterisation of the electricity consumption.

SCALING UP TO REGION

Scaling up the load simulation in a wider area could be achieved by using socio-demographic statistics for that area, when these are available. As the Time Use survey is very extensive it could provide satisfying load profiles for many combinations of characteristics like household type and size, income band, and employment status. For the purpose of this paper, in order to have a load profile in the scale of a region and to have a first evaluation of the likely impact (mainly in terms of load reduction) that different demand response options would have, we assume a hypothetical group of 300 000 households to represent a large town. As it is not a real example the grouping takes into consideration only the households sizes for reasons of simplicity. According to information from Social Trends 2004 (National Statistics 2005), 29% of households in Great Britain are one-person households, 35% two-persons, 15% three-persons, 14% four-persons, 5% five-persons and 2% six and more. Taking this into consideration we create the demand profile of the group by multiplying the average profiles of each size with the number of households. Figure 12 gives a typical winter weekday for this group of households. The added segment on top represents the standby loads that become considerable at bigger scales like this.

As mentioned earlier, the household peak between 5-6 pm is responsible for about 45% of the system peak. In the load profile above the average participation of appliances in this one hour peak is 37.6% from cooking (105 MW), 16.5%

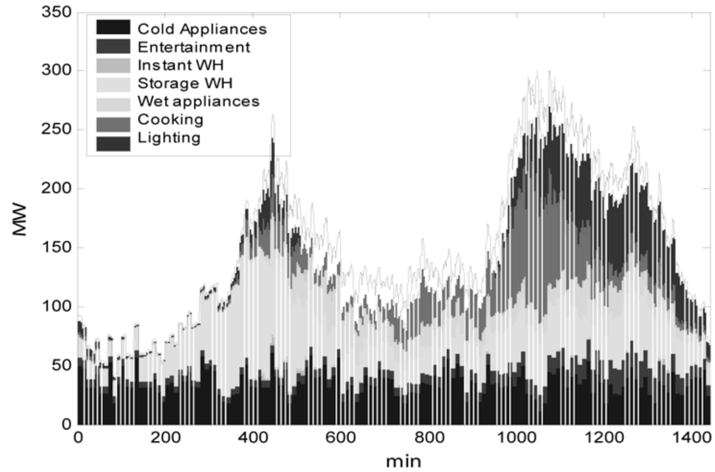

Figure 12. Segmented profiles for a group of 300 000 households in a winter weekday.

from electric water heaters (46 MW), 15.7%, lighting (44 MW), 9% from cold appliances (25 MW), 6% from wet appliances (17 MW) and 5% from stand-by and on-mode TVs, videos and stereos (13 MW). In a real case study this segmented profile of an area could be quite useful for demand side management studies as it may not be the most accurate projection of the actual electricity consumption but it gives a fairly good idea about the involvement of residential loads in the total demand produced by the residential sector.

Demand response for residential customers

Designing mechanisms to convince people to change the way they use their electrical appliances is rather complicated. According to Van Raaij et al., 1983 energy use behaviour is influenced by energy attitudes of people such as price concern, environmental concern, energy concern, health concern and attitudes towards personal comfort. The authors suggest that attitudes do not necessarily cause behaviour and set four factors between them: acceptance of responsibility for energy conservation, knowledge of energy costs, energy conservation behaviours and their consequences, perceived effectiveness of one's contribution and cost-benefit trade-offs. In this context socio-economic factors and lifestyle are quite important elements.

In order to influence people's energy use behaviour and increase their participation firstly the advantages of DSM-demand response need to be communicated effectively to the customers, secondly, the right incentives should be given to boost the change of behaviour and thirdly the means of altering demand should be made clear and easy with education campaigns and accessible technology.

TOU PRICING

Prices are the main incentive offered to residential customers to persuade them participate in demand response. ToU tariffs (voluntary or mandatory) are static time varying prices that reflect better the match between the actual cost of electricity supply at the specific time and the price offered to the residential customers, providing appropriate signals to customers which may encourage them to shift some of their loads to off-peak times when prices are lower or reduce their peaks employing more efficient appliances. ToU pricing could cause a long-term change in the use of particular appliances and result in better load factors and lower costs for all the parties involved in the electricity market (suppliers, system operators, customers). A number of pricing experiments have been the source for studies of consumer's response to ToU pricing (Filippini,1995, Ham et al.,1996, Baladi et al., 1998, Pyrko et al., 2003, Wolsink, 1997). The most effective design of the tariffs was investigated comparing voluntary to mandatory programs, looking at different combinations of validity periods and price differentiation and exploring the influence of feedback information. The outputs were mainly benefits to the customers in terms of money saved and benefits to the utility in terms of power factor improvement and peak reductions. Most studies concluded that the right pricing policy is a very effective mechanism for achieving a more efficient matching of demand and supply.

There are not many equivalent tariff experiments for the UK. Deering et al., 1993 presents three tariff experiments conducted in the seventies from which two were time related and one demand-related. The most effective one was offering peak pricing periods for December to February from 8 am to 1 pm and 4.30 pm to 7.30 pm, off-peak from 11 pm to 7am and a standard pricing period for the rest of the time. The ratio between peak and off-peak price was 7.5 and the ratio between peak and standard price was 3.75. Currently there are mainly two tariffs offered in the UK: the *unrestricted rate* which consists of a standing charge for each quarter or a different charge for the first 'day units' of the quarter (usually 225 kWh) and a unit charge for each kWh supplied and the *Economy7 rate* which has a higher quarterly standing charge or a kWh charge for the first units and two unit charges one cheap during seven hours (between 11 pm/12 am-6 am/7 am) and one expensive for the rest hours of the day (the ratio peak and off-peak tariff is 8.30 p / 3.33 p = 2.5 times higher for London area). Economy7 tariff concerns mainly domestic customers with electric storage heating and electric water storage as 20% of the total household energy consumption should be used at night to have an economic benefit (Energywatch 2005).Wolsink, 1997 points out that this kind of pricing system is not very efficient for the reduction of peak loads. New tariff structures should be tested to assist UK's policies for energy conservation and the targets for emissions reductions (as the peaks of the system are mainly responsible for the expansion of generation capacity).

When designing TOU tariffs for the residential sector, it is important to investigate which loads are better candidates for 'shifting' in terms of inconvenience caused to people. Most existing demand response load shifting is implemented by using heat storage for electrical space heating and additional storage for water heating. As discussed above, the further potential for such storage heating is limited for the UK as the ownership of electric space heating is 9.7% from which 8% is storage heating (BRE 2003) and the ownership of electric water heating is around 17% and is being reduced with the trend of fuel substitution. As a result specific attention should be given to electrical appliances such as dishwashers, washing machines and tumble driers which would not cause a great deal of inconvenience to the people if switched at off-peak period, using for example timers.

Here we give a simple illustration of the impact a successful tariff scheme could have to the profile of a group of houses (Figure 12). Taking into account that the system peak in the UK occurs on winter weekdays between 4.30 and 9 pm (3 peak days for 2001, Efflocom1) and comparing it with the generated winter residential profiles, we assume an off-peak pricing period between 12 pm and 7 am (like in the case of "Economy 7 tariff"). The washing machine and the dishwasher, thus, can be switched on randomly during the off-peak period, the generation of hot water which is assumed to take place prior to the actual activity is also shifted at night to meet mainly the morning hot water demand and tumble driers could be switched on when people wake up (as clothes washing is assumed to take place during the night). For the hypothetical group of households studied here, the impact of these usage patterns would be a considerable decrease in the winter weekday morning peak (47% between 7-8 am) due mainly to the shift of water heating and a smaller decrease of 6% (17 MW) in the evening peak (4.30-6.30 pm) mainly due to the shifting of wet appliances (the reduction of the evening hot water load is not big as most of the off-peak generated hot water is consumed in the morning). This implies that even if the consumers receive the right incentives to shift their loads a considerable reduction in the evening peak could only be achieved with additional energy conservation strategies targeting loads like lighting and cooking which are responsible for more than half of the peak.

In this case the benefit for the suppliers is that they would avoid buying power to meet the shiftable demand at times when wholesale prices are very high. In our example a shift of washing machines and dish-washers at off-peak times (0-7 am) that corresponds to 315 MWh could result in 38% (£7 329 = 10 261 Euro) reduction in the cost of buying electricity to meet their customers' needs, using average spot prices of a random winter day from the UKPX (UKPX 2005). The actual economic benefit for the consumers depends on the tariffs offered to them by the suppliers. For example a shift of the dishwasher and the washing machine at night corresponds to a 4.3 kWh shift at off peak time. Using the Unrestricted and the Economy7 tariff from London Energy (London Energy 2005) the economic benefit for a customer in London area would be £52/year (73 Euro), assuming the washing machine is used three times per week and the dishwasher every day. Different tariff structures could result in higher economic benefits and thus better incentives for participation.

The example above is used just to illustrate the load shifting potential assuming a situation where all households behave like 'good citizens' to give an idea of the technical potential for load reduction achieved by certain kinds of domestic appliances. The example doesn't take into account the actual energy attitudes of the people and resulting behaviour. The evaluation of people's response is quite complicated as it involves well-designed surveys and analysis. Few studies examine in depth the role of energy use perception in the participation in these pricing schemes. In Baladi et. al,1998 an extensive set of socio-demographic and attitudinal questionnaires is used to distinguish whether or not customer participation is based on their actual patterns of usage or on household perceptions. Train, 1987 uses a qualitative choice model between ToU and flat electricity rates that uses 'factor analysis' to determine the impact of attitudes about energy conservation. The difference between the two prevailing factors lies to whether the household feels that it can do something to help ('personal effectiveness' versus 'something should be done'). The choice models included an attitude variable (the factors mentioned above), a cost variable (cost differential between ToU and standard rates), socio-economic variables (income, sq ft of residence, electric space heating, age of household head, education in years, household size and number of children under 6) and variables to indicate the different ToU rates offered.

The results of tariff experiments and accompanied by energy conservation surveys like these conducted for the UK that link people's attitudes towards energy conservation, their perceived effectiveness of participation in DSM programs, their price concern and their socio-demographic characteristics could be used in conjunction with the generated 'Time-Use profiles' to give a quantitative estimation of demand response due to different tariff structures offered to a group of households with specific socio-demographic characteristics. This is the subject for further research.

PEAK SHAVING

Another Demand Response mechanism targeting the residential sector is the direct control of certain appliances to achieve peak shaving. The direct control of specific loads like electric heaters, water heaters and air-conditioners can be achieved in a number of ways. Perhaps most simply, devices can be fitted to household appliances, which monitor the frequency of the electricity supply, and respond with load shifting when a certain frequency drop is detected – indicative of capacity shortage on the system. To achieve greater levels of control, some form of remote control is necessary with the System Operator or other agent sending signals to local devices which can effect certain delays in appliance operation, for example when generation reserve margins are approaching lower limits, or as a form of low-cost system balancing. Where such programmes have been established, participants usually do not have to pay for the control equipment. DLC programs are mandatory from the moment the customer joins the program. The utility has the right to cycle or switch-off the appliance for a limited number of occasions per year and for a limited period of time per event. The incentives are typically monthly credits on electricity bills and depend on the type of unit under control, the degree of control and the value of load reduction to the utility (AESP 2001). Though the control may be triggered only a few times per year, it may come in conflict with people's freedom of decision with negative effects on the acceptance of this kind of demand response. A more customer-friendly option of this program would be to give people the option to disrupt the interruption when they feel discomfort by using an internet-based interface.

As the highest peaks in the UK occur in winter between 5-6 pm, here we investigate the impact of direct load control on the peak caused by the residential sector. The appliances to be controlled are water heaters, washing machines, tumble driers, dishwashers and cold appliances, however the kind of control and its duration depends on the specific characteristics of each appliance. For example switching off completely the wet appliances during the period of system constraint may not cause great inconvenience to the people, with this not being the case for the supply of hot water. As a result in this case we may choose to better cycle the water heater. Other load control strategies could target lighting and cooking without causing 'discomfort' to the people, for example Newborough et al, 1999 suggests a 'cascade' control for electric hobs that can result in 15% to 60% peak power reduction during meal preparation without affecting the performance of the hobs. During load control it is very important to take into account the payback effect, referring to the additional energy needed to restore the interrupted energy-related service (heat water or cool down fridge-freezer). As a result detailed research is essential to investigate the behaviour of each appliance after an interruption that unfortunately is not in the scope of this study.

As an example here we assume that the load reduction is needed between 5-6 pm and we employ the following load control strategies: switch-off washing, machines, tumble-driers, dishwashers and cold appliances (as temperature increase for after one hour is not significant according to Efflocom Project, 2003) and cycle the water heater. The result of switching off the wet and cold appliances for one hour would be a peak reduction of 15% (42 MW). The additional cycling of water heating (on and off) for example every 10 min would decrease the water heating load 50% and thus the total peak 23% (65 MW). It should be noted that again the actual participation of people in these kinds of programs depends on the economic incentives offered through the 'switch-off contracts', the design of these contracts in terms of duration and frequency of interruption and energy attitudes and is the subject for further research.

END USE METERING AND FEEDBACK INFORMATION

Heberlein et al. (1986), Hartway et al. (1999) and Wolsink, 1997 indicate that the response to price mechanisms and contractual agreements, aiming to reduce the peaks in demand is influenced considerably by the kind of additional information provided to the costumers. This confirms the fact that prices interact also with psychological factors such as awareness, moral obligation to reduce consumption, perceived impact of reducing consumption and trust in complex ways to cause energy use behaviours (Stern, 2000).

There are many studies that investigate the effects on energy consumption of different feedback mechanisms on energy savings (Wood et al.,2003, Wilhite et al., 1995, Vanhouwelingen et al.,1989, Centre for Sustainable Energy, 2004, Arvola, 1993). Most of the experiments were conducted by energy utilities and different kinds of feedback were tested like historical feedback, feedback combined with energy conservation tips, feedback compared to households of different type and size and feedback (consumption and generated energy costs) giving dissagregation of end use into categories. In this case research has been done on how factors like age, income and education are likely to affect people's energy use behaviour (Wilhite 1995).

As demand response techniques and traditional DSM are expected to be included in the new markets for Energy Services the promotion of technologies such as smart meters, two-way communication (of prices and energy consumption feedback) between the consumer and the supplier and technologies to control certain domestic appliances at the minimum inconvenience could increase demand side participation. Examples include GoodWatts energy management system by Invensys (Invensys 2005), Comfort Choice System by Carrier and Silicon Energy (Carrier 2005), Express gate system by Honeywell-Cannon (Honeywell-Cannon 2005) and GoodCents Select system by Honeywell-Comverge (GoodCents 2005).

THE FUTURE OF RESIDENTIAL DEMAND RESPONSE IN THE UK

As indicated above behavioural studies to investigate the psychological factors that make people participate in demand response programs are needed to be able to simulate the people's response and their attitudes towards demand response technology. The link between more detailed socio-economic characteristics of households and the actual demand response would create a good basis for designing relevant energy policies and programs. Having more information on how factors like household type, income, education level etc influence the willingness of participation in demand response programs we could incorporate a behavioural component in the model presented in this paper, to assess the likely demand response potential of a group of houses with certain characteristics (using load profiles incorporating these characteristics) and to compare different demand response strategies.

There are currently two studies that are expected to produce the necessary information in order to build the energy behavioural component. IEA-DSM (task XI) investigates which mechanisms could increase the participation of demand side, quantifying the impact of time-of-use pricing and end use metering and feedback on the residential profiles. In the UK, a publicly funded consortium of major universities and industry is researching the Future Network Technologies (EPSRC 2004) within the Supergen research programme which looks more broadly at sustainable power generation and supply. That consortium's Demand Side Participation Working Group (of which the authors are members) aims to assess the public acceptability of different load control technologies taking into account the socio-economic status, values, beliefs and attitudes that influence it and decide on the right signals that should be given to the residential consumers by conducting surveys and interviews.

Conclusions

Demand Response techniques offer many benefits such as system reliability, reduction and avoidance of costs for the system operators, the suppliers and the customers, more efficient operation of the electricity market, risk management and energy conservation. In the UK more attention should be given to the residential sector, which is responsible for the 45% of the system peaks. When trying to quantify the participation of the residential sector in this type of programs it is important to take into account the factors that influence the household's electricity consumption such as household type, socio-economic characteristics and lifestyle.

This paper presented a method of producing load profiles using an extensive survey conducted in the UK that produced information about people's energy-use activities combined with detailed characteristics of the households. The resulted load profiles proved to be quite close to average profiles used in the currently in the electricity market. The participation of electrical appliances in the peaks for each season was made clear through the segmented profiles, giving useful information concerning the load control-shifting potential of particular appliances and therefore allowing scenario assessments of possible future load shapes. An exercise of load shifting resulted in a considerable decrease in the morning peak mainly due to the use of off-peak hot water and a small decrease in the evening peak from the wet appliances. Assessing the load control potential we found that it could cause a 23% peak reduction.

More research is needed to investigate the mechanisms (economic incentives, feedback information and combination of the two) that would increase the consumer's participation in these programs. The results of such behavioural studies combined with the generated demand profiles using people's lifestyle information could provide a useful tool for the assessment of residential demand response potential in the UK.

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