

Simulating the Impact of Household Energy Consumption on the Electricity Grid

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Abstract. This paper presents a bottom-up modelling approach for stochastic production of electricity consumption profiles in households. It represents a preliminary work on individual appliance use modelling in households, as part of a bottom-up simulation to assess the impact of household consumption, and changes to consumption patterns and behavior, on the overall energy grid. By collecting household electricity consumption data, a model is developed based on daily activity profiles for individual appliances. The domestic load model obtained from simulating electricity consumption for household appliances will enable the large-scale simulation of multiple households to gain insight into individual household implications of demand-side load management strategies, as well as the combined effects on the electricity grid.

Keywords: Domestic appliance modelling, bottom-up model, stochastic, simulation

1 Introduction

Characterizing electricity demand profiles for households is an important prerequisite for analysing demand side management, (Richardson & Thomson, 2008). These researchers suggest that electricity demand is influenced by active occupancy, (see Figure 1). This graph shows very low levels of active occupancy during the night, delayed arising at weekends, and peaks corresponding to mealtimes - breakfast, lunch and dinner.

Because the use of household electric appliances varies with time, since understanding time-of-use profiles for producing household appliance use models based on various parameters such as location, socio-economic class, age groups and household size is necessary as an input to any domestic energy model that is to be used for assessing the effectiveness of demand-side load management on efficient energy, and its impact on comfort and quality of life at individual household, community, regional and national levels.

In this vein, the development of a model for generating residential electricity and hot-water load profiles from time-use data was developed by

Widén et al. (2009). Daily time-use data sets and energy measurements for different appliances were used to develop a model that can be used for the determination of households' energy consumption. The study collected data for each occupant over ten years old in participating households, recording at 5-min intervals, including a description of the activities, geographic location of the person, their means of transport (if relevant), and by whom they were accompanied while performing the activity. One application of the developed model is visualization of energy use associated with everyday activities. The study demonstrated that energy use profiles can be generated from time-use data measurements with reasonable accuracy when compared with actual electricity consumption measurements.

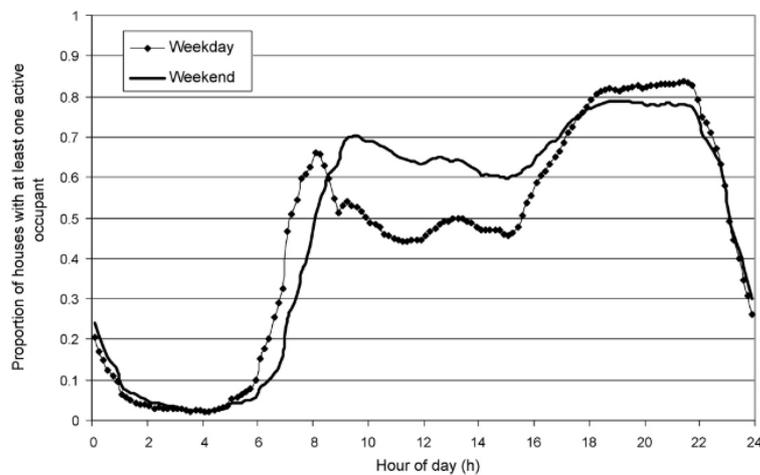


Figure 1: Aggregated active occupancy for households by weekday and weekends, (reproduced from Richardson & Thomas, 2008)

Grandjean et al. (2011) described the simulation of power consumption and the development of a domestic load curve model for individual electric appliances, in order to investigate their individual power demand. The study was motivated by the need for behavioural and lifestyle modifications of household's electricity usage as their energy consumption are likely to increase in the near future through new electrical domestic end-uses, including the plug-in hybrid and electric vehicles, increased heat pumps utilization, and improvement and technological advances in small electrical appliances. The research considered real power consumption measurements for individual appliances, and simulated the behaviour of households to develop their load profiles. This approach is referred to as a bottom-up modelling process.

A more recent description of household power consumption simulation (Ortiz, Guarino, Salom, Corchero, & Cellura, 2014) developed an energy consumption model for generating random profiles, useful for simulating

energy consumption for a cluster of buildings or individual appliances, as well as to model their peak loads. The stochastic model developed for this study reproduced random synthetic profiles for household consumption, applied in high time resolution aimed at modelling peak loads as well as producing average data for households. The research quantified the benefits of improving the energy efficiency of appliances by showing a reduction in energy consumption by half when high performance appliances were introduced (Figure 2). However, the study is highly reliant on the input data of energy consumption for the households under consideration. Dependency on data at this level places demands on data storage system and on continuous internet connectivity of households.

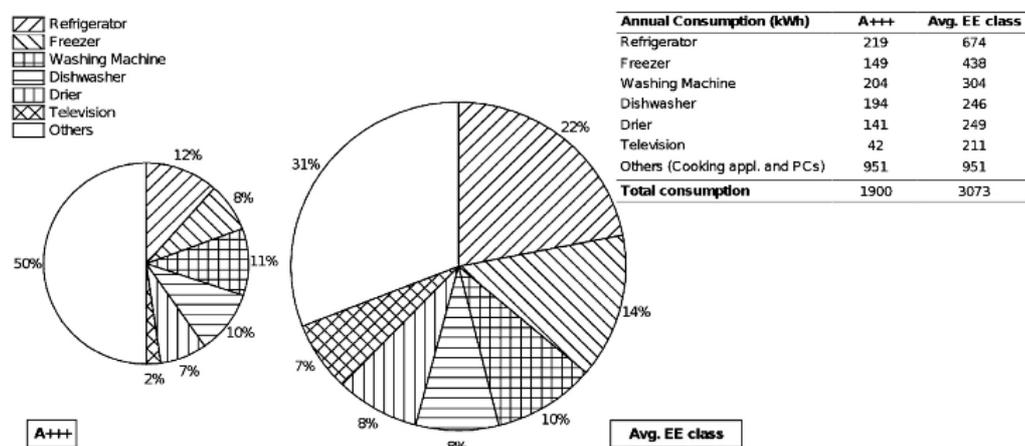


Figure 2: Comparison of household's appliance use and energy efficiency ratings of appliances (reproduced from Ortiz et al., 2014)

Another study of the consumption of electric appliances in domestic buildings was carried out to identify the trends in their energy use pattern, (Firth, Lomas, Wright, & Wall, 2008). In this research work, the consumption of different energy user groups (low, medium and high) was investigated. The study identified low and high power users as major contributors to total electricity consumed by appliances. Yao & Steemers (2005) discussed a simple method of formulating load profile (SMLP) for domestic buildings in the United Kingdom, in which electric appliance load profile and domestic hot water profiles were calculated by gathering input data for the daily average end-use energy consumption and daily average hot water consumption of households respectively. The study confirmed that load trend for households are close to the national statistics data. It is suggested that the SMLP method can help electricity suppliers predict the likely future development for household electricity demand.

A number of other reported studies discuss industrial and household energy consumption. An exploratory analysis of domestic electricity profiles recorded at a high time resolution, taken at one minute time intervals suggested usage pattern of households varies widely, with some larger loads requiring much greater energy supply, suggesting the need for the development of effective storage technologies (Wright & Firth, 2007). The potential for information feedback to reduce rates in the home through energy consumption indicators (ECI) or smart meters is explained in Figure 3 (Wood & Newborough, 2003). The study focused on collecting data from individual appliances and then compared the effectiveness of providing paper-based energy use/saving information with electronic feedback of energy-consumption via specifically designed energy-consumption indicators.

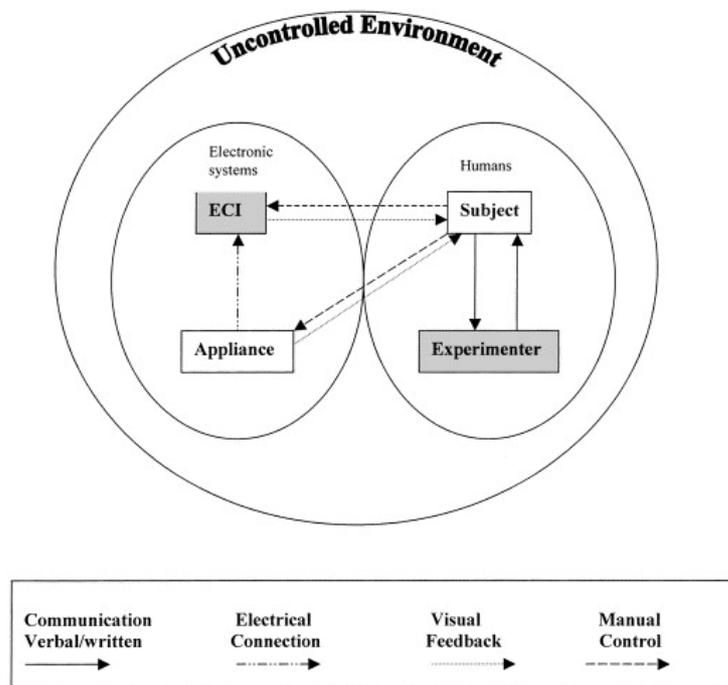


Figure 3: The feedback process for domestic appliance use (reproduced from Wood & Newborough, 2003)

Mansouri, Newborough, & Probert (1996) described the need to provide end-users with accurate energy-consumption and environmental impact information to stimulate energy saving and environmentally sustainable behaviour. The paper focused on identifying energy-use behaviour, environmental activities and benefits, ownership levels for certain appliances and their utilization patterns among households.

Various studies have discussed the development of load profiles for electric appliance use in households. However, most come with challenges and shortcomings, such as complexity of the modelling and a lack of explicit

description of consumption at appliance level, and detailed time-of-use information which is essential for effective modelling of the grid impact of demand-side management strategies. In this paper, a stochastic model based on appliance-specific measurements in households is developed. The aim of this research is to keep the required input data at minimum and the model structure as simple as possible, to enable the measurement of appliance use impact on the electricity grid. In Section 2, data-sets of domestic load for appliances used in this study are described. Conclusions are drawn in Section 3.

2 Model Framework

Data-sets of daily load in kilowatts were collected from households in Hamilton, New Zealand between August 2011 and March 2012. Data was collected using monitors connected directly to individual appliances. Data quality for the measurements was generally high, although there were some gaps in the data, but only complete data-sets were used in the analysis. The time series analytical technique was used to model data collected. This method was selected because it models consumption data for individual appliances over time and investigates the behaviour of appliance-use data.

The pattern of appliance use for domestic loads in buildings depends on the appliance use. Some appliances are ‘always on’, while others appliances are not constantly on and their state depends on occupancy, occupant behaviour and weather conditions, which vary between households. Typically, electricity consumption by appliances is higher than usual in winter because of heating, and occupancy issues such as time spent indoors.

Figures 4(a) to (d) show load profiles for refrigerator, LCD-TV, microwave and play-station and follows an undulating pattern. The figures show the load-profile of electricity consumed by different appliances at different times of the day. The figure shows sharp increases in consumption for refrigerators at certain periods of the day. This could be due to defrosting of fridges in households, as this process consumes much power. There are times when power for appliance-use was low, because they were in ‘standby’ mode, i.e. appliances are not in use, but ready to go into operation.

The load profiles developed for individual appliance give information about habits of household inhabitants in their appliance use. Load shifting by consumers enables reduction of peak demand on the energy grid and increases the reliability of the electricity network, since consumers will have a more active role concerning electricity management.

An outline of electricity consumed by individual appliances is shown in Figure 5(a). The figure indicates a high consumption by the refrigerator (10%) compared to other appliances; LCD-TV was 2.7%, play station 2.1%, and microwave 1.2%. The remaining power consumption was for several other appliances in use consisting of 84% of total consumption. There were some fluctuations due to appliance use resulting in peak and off-peak periods, depending on whether appliances are in use. There is more near-constant load for LCD-TV and the play station except when the appliances were in standby mode.

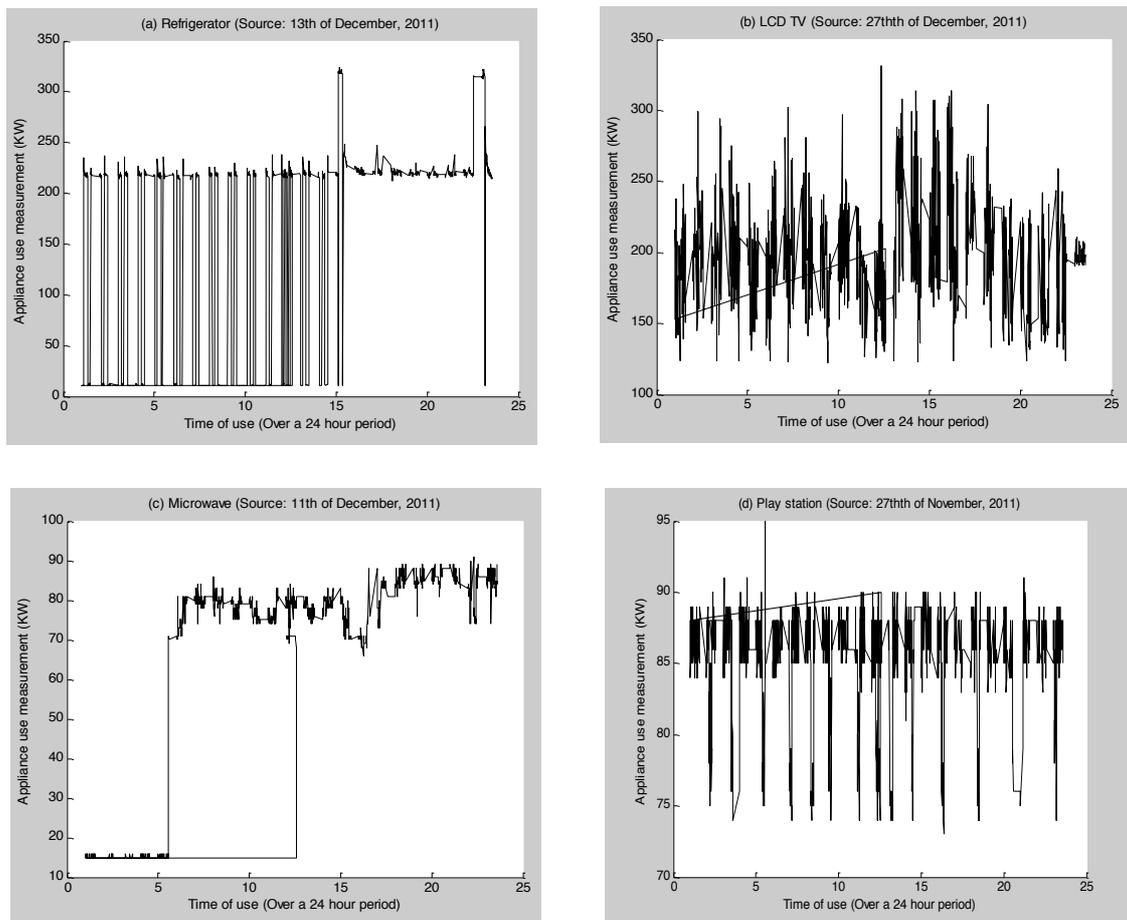


Figure 4: Daily one-minute interval load profiles for appliances (in kW)

There are several other electric appliances contributing to total consumption in individual households. Some of them include electric kettles, television sets, washing machines, dryers, iron, toasters, iPhone chargers, laptops, freezers, etc. These appliances constitute ‘others’ in Figure 5(a). A collection of appliances comprising of refrigerators, microwaves, LCD, and play stations were identified and used in this study because these appliances were in use in most households used for data collection.

The load profiles of the refrigerator, microwave, play- station and the LCD-TV were developed in order to investigate the impact on the energy grid of consumer use of electric appliance during peak and off-peak hours. Electricity consumption in households is about 33% of the national grid load in New Zealand (Ministry of Economic Development, 2012); see the relationship between Figures 5(a) and 5(b).

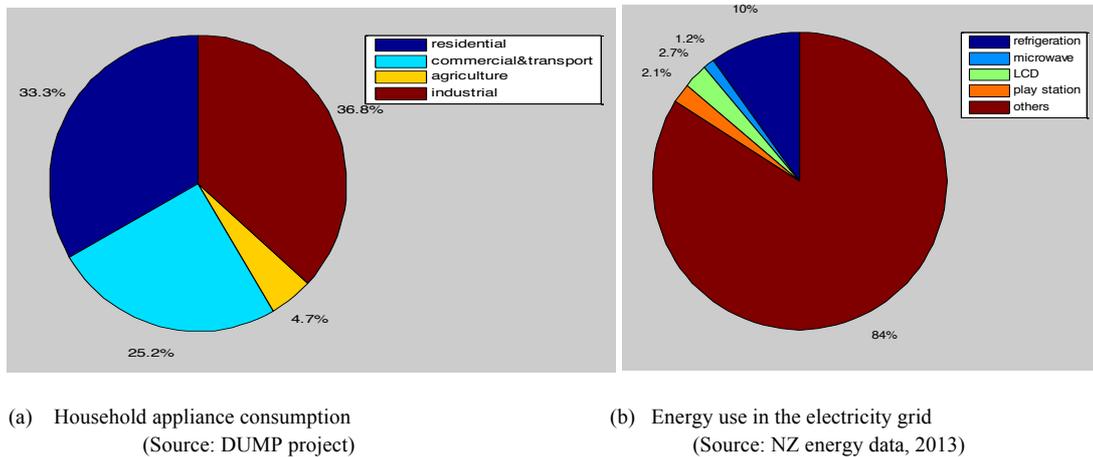


Figure 5: Relationship between residential appliance use and sectors in the electricity grid

3 Conclusion and Future Work

This paper describes work in progress to model household individual appliance use in order to assess the impact of different demand-side strategies on individual household consumption, and the energy grid. The development of load profiles for individual household appliances enables investigating the impact of load shifting strategies aimed at reducing energy costs and the optimal management and control of the electricity grid. Furthermore, the introduction of time-of-use energy plans by energy companies to better manage electricity consumption will enable households reduce their electricity bill, become responsive to using their appliances in a more efficient manner, and economically conscious users, thereby making optimal use of the energy grid. This will bring about load balancing and optimal use of the electricity network by redistributing energy demand in the electricity network.

Investigative research carried out in this study suggests that data on socio-economic factors is relatively sparse and conducting more research on the effect of socio-economic factors on household electricity consumption would help in providing insight to household appliance use. The next stage of research involves collecting data from households from different location/regions and will focus on developing load profiles for different group

of users based on location, income level and household size. The research will also investigate the effects of load shifting strategies on individual appliances based on these factors.

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