http://dx.doi.org/10.1016/j.enpol.2011.03.012

Gyamfi, S. and Krumdieck, S. (2011) Price, environment and security: Exploring multi-modal motivation in voluntary residential peak demand response. Energy Policy, 39 (5). pp. 2993-3004.

Price, Environment and Security: Exploring Multi-Modal Motivation in Voluntary Residential Peak Demand Response

Samuel Gyamfi, Susan Krumdieck*

Department of Mechanical Engineering, University of Canterbury, Private Bag 4800, Christchurch, New Zealand. Telephone: +64 3364 2987 Ext: 7249, Fax: +64 3364 2078.

*Email:susan.krumdieck@canterbury.ac.nz

Abstract

Peak demand on electricity grids is a growing problem that increases costs and risks to supply security. Residential sector loads often contribute significantly to seasonal and daily peak demand. Demand response projects aim to manage peak demand by applying price signals and automated load shedding technologies. This research investigates voluntary load shedding in response to information about the security of supply, the emission profile and the cost of meeting critical peak demand in the customers' network. Customer willingness to change behaviour in response to this information was explored through mail-back survey. The diversified demand modelling method was used along with energy audit data to estimate the potential peak load reduction resulting from the voluntary demand response. A case study was conducted in a suburb of Christchurch, New Zealand, where electricity is the main source for water and space heating. On this network all water heating cylinders have ripple-control technology and about 50% of the households subscribe to differential day/night pricing plan. The survey results show that the sensitivity to supply security is on par with price, with the emission sensitivity being slightly weaker. The modelling results show potential 10% reduction in critical peak load for aggregate voluntary demand response.

Keywords: Voluntary Demand Response, Residential Peak Demand, Demand Side Management

1. Introduction

Reliable and affordable electricity has historically been a primary policy objective. Initially, government owned utilities focused on the “supply side”. Public agencies and utilities planned, built and operated the electricity generation, transmission and distribution system ahead of customer demand growth. Generation and network capacity have been dimensioned to operate with a capacity margin above the highest peak loads that could occur on the system. During the initial development phase of centralized power generation, utility costs declined as plants became larger and more efficient. Starting in the late 1960s, costs began to rise due to many factors including slowing down of technological advances, increasingly high cost of fuel, acceleration of environmental controls, and overruns in nuclear power projects (Eto 1996; AESP 2001). In the 1970s, increasing demand for electricity coupled with increasing electricity price as a result of the world energy crisis gave rise to conservation initiatives. In many cases it was found to be cheaper to reduce demand than to increase supply (Lovins 1971; Ford-Foundation 1974). The 1980’s saw the introduction of demand-side-management (DSM) as an energy engineering tool (de Almeida, Moura et al. 2007). DSM programs consist of the planning, implementing, and monitoring of programs to modify utility load shape. A range of successful DSM projects were cost-effective and were carried out by utilities (Gellings and Chamberlin 1993; Goldman, Eto et al. 2002).

Critical peak demand typically occurs when there is co-incident high usage among all the end use sectors; residential, industrial and commercial. Peak demand is typically characterized as annual, daily or seasonal and has units of power (MW). Critical peak demand poses high risk of power system failure and maintaining critical reserve margin through continued generation and distribution investments results in high marginal cost (Sweeney 2002). As peak load is usually supplied with fossil fuels, peak generation has high emission factors. Demand charges and peak time pricing have been effective in managing peak load in the industrial and commercial sectors, but the residential sector peak demand continues to grow at historically high rates in most networks (Barbose, Goldman et al. 2004).

Energy efficiency programmes, smart meters and demand response efforts have been deployed together and can have synergistic benefits (Goldman, Reid et al. 2010). Significant demand response potential has been estimated to exist in the residential sector, based on direct load control for air conditioning and water heating plus dynamic pricing programmes (Rohmund, Wilker et al. 2008). The realistic achievable level for demand response, estimated to be 2.2% in 2010 in the USA, is estimated to be half the maximum economically achievable peak demand reduction, which in turn likely ten times less than the maximum technical potential (EPRI 2009). EPRI also reported that in the long term, combined energy efficiency and demand response programmes across all sectors have the potential to reduce the historic 2.1% growth rate in summer peak demand in the USA to around 0.53% under ideal conditions.

Despite the economic and technical potential for peak demand savings, management programmes are still not in widespread use, and smart meter technologies are not mature. Information barriers and lack of understanding of residential customer behaviour in responding to demand response requests and pricing signals has impeded development of programs that might realise the benefits of effective peak demand response in the residential sector (DRRC 2007). It is difficult to develop policy that effectively encourages the engineering and management investments needed to realise energy efficiency and demand response savings, when the costs and benefits of a particular programme in a given market cannot be modelled and quantified.

This paper aims to contribute knowledge necessary for prospecting and developing voluntary demand response (VDR). The work explores voluntary participation and behaviour change in demand response as the critical issue for developers of peak demand management programmes. A mail-back survey was designed to provide basic information about the local power supply network, gather key information about activities and appliance use during critical peak demand times, gage sensitivity to three main issues in power provision, and assess the willingness to adjust energy consuming behaviour to mitigate these issues. The three main power supply issues are: (1) risk of black-out due to grid congestion, (2) increased emissions profile due to local peak diesel generation, and (3) price rise at peak times. A case study was conducted in Christchurch, New Zealand to explore the effectiveness of using the three kinds of information as signals to persuade residential customers to change their electricity usage behaviour during peak times. The results of the survey involved expressed level of concern and willingness to adjust the usage of certain appliances. Using the maximum diversified demand method, the maximum voluntary demand response potential for peak load reduction was estimated. A future monitoring experiment in which the behaviour of households is observed under realistic conditions would be needed to calibrate the results. However, the potential level of peak load shedding suggested by the model should justify further investigation and engineering research to develop a multi-mode demand response programme.

The next section gives a literature review of peak demand management in the residential sector. Section 3 explains the novel idea explored in this research – that information other than price could be developed to signal voluntary demand response, and describes the survey, and the analysis method. Section 4 describes the method of diversified demand and the modelling of the potential voluntary peak load reduction. Section 5 gives the results of the case study survey and modelling for maximum potential peak demand savings and costs and benefits for this case. Section 6 is the conclusion.

2. Literature Review

2.1 Direct Load Control

Direct load control programs are typically mass-market programs directed at all residential customers. A customer signs up for the program and allows the utility to temporarily control a specific electrical appliance and in return receive monthly bill reduction. The most frequently "ripple" controlled residential end-use appliances are central air conditioners, water heating cylinders, electric space heaters with storage features, and lighting. In the southern regions of Australia and the USA, direct load control is used to control summer air conditioners (USDOE 2006; ETSA 2007). The price signal for this form of load shedding is weak as the bill credit given is the same regardless of load size, and homes without a controllable appliance are not eligible for the credits, although they are not contributing to the peak problem (Herter, McAuliffe et al. 2007).

2.2 Time varying pricing

Time varying pricing is another strategy to control residential peak load. Real-time pricing is often an order of magnitude higher at peak times in order to influence customers to shift their electricity usage from peak to off-peak hours. An example is the Commonwealth Edison (ComEd) of Chicago's real time pricing program for residential customers, where the price of electricity can vary hourly over the day (ComEd 2007). It is intended to provide some fairness and market reality by allowing consumers to pay an amount that reflects the relative cost of electricity at the time it was provided. Customer demand reduction in this case is driven by an internal economic decision-making process and the load modifications are entirely voluntary (Sanstad and Howarth 1994; Wilson and Dowlatabadi 2007). However, psychological experiments show that individuals do not make consistently rational decisions, as suggested by economics (Stern and Aronson 1984; Stern 1986). Time inconsistency, framing, reference dependence and bounded rationality are some of the issues affecting energy use behaviour (Wilson and Dowlatabadi 2007). The economic theory of rational behaviour does not adequately capture energy related behaviour in the residential sector. Behavioural economists therefore seek to integrate a more robust psychological understanding of decision making (Stern 1992).

International research shows that low-income households have reduced ability to conserve electricity (Brandon and Lewis 1999). When confronted with an increase in energy costs, lower-income families tend to make "lifestyle cutbacks" (Dillman, Rosa et al. 1983). Using pricing mechanisms to achieve demand response is not consistent with all the policy principles of rate design such as the promotion of social equity (Bonbright, Karmerschen et al. 1988).

The California State-Wide Pricing Pilot (CRA 2006) was conducted to test the impact of several pricing structures on peak demand. A total of 2,500 customers were involved in the experiments that ran from July 2003 to December 2004. The experiment found average demand reduction of 13% for customers (mainly residential) with demand less than 20 kW. The estimated price elasticity of substitution varied from 0.04 to 0.13 for peak to off-peak price ratio of 3 to 6. Ontario Hydro found overall saving of 13% across 25 homes (Dobson and Griffin 1992). A review of past studies drawn from North America found price elasticities of between -0.12 to -0.35 (King 2005). A review of G7 countries concluded that electricity demand is income inelastic and price elastic in the long-run (Narayan, Smyth et al. 2007).

2.3 Environmental response factors

There is a direct relationship between peak demand and environmental emissions in nearly all power supply networks. This relationship depends on the generation mix and dispatch to the market (Keith, Biewald et al. 2003). Though literature on pro-environmental energy behaviour is quite rich (Picherta and Katsikopoulosa 2007; Wall and Crosbie 2009; Ek and Soederholm 2010), at the time of writing, there have been no demand response studies that use the disproportionate peak generation emissions as a signal to persuade consumers to reduce peak demand.

One example of environmental response is the *Earth Hour* environmental campaign.[1] On March 29, 2008, the residents of Christchurch responded to a well

---

[1] http://www.earthhour.org

advertised and council supported call to reduce electricity demand for one hour as a symbolic action. The campaign focused on turning off lights for one hour to "make a difference" and to "show concern for climate change". The official measure of demand response between 7:00 and 8:00 pm was a 13% reduction.

2.4 Supply security response factor

On August 14, 2003, 50 million customers in the North-eastern United States lost power in the country's largest black-out in history. Even though most people had not had power for several days, customers responded to calls for emergency demand reduction measures to aid in efforts to restore the grid to all residents. The remarks of William Flynn, Chairman of the New York State Public Service Commission make the role of voluntary demand response to ensure supply security clear:

> *"In the end, the call for emergency demand reduction played a critical role in restoring power throughout the state in a timely and effective manner."*[2]

The kind of massive blackout experienced in the Northeast USA in 2003, and other major blackouts were exacerbated by high demand. Publicity of the risks posed by high peak demand is expected to lead to policy initiatives aimed at peak demand management mechanisms.

The risk of black-outs was used to achieve demand reduction in France during the 2003 heat waves (IEA-a 2005) and in California during the 2001 energy crisis (Lutzenhiser, Bender et al. 2002). Table 1 shows the most important motivating factors for conserving energy given by respondents in a survey that was conducted after the energy conservation campaign in California in 2001.

---

[2] http://www.pulp.tc/business_council9-23-03.pdf

Table 1. The Most important motivation factors given by participants during the “Flex Your Power” Energy Conservation Campaign in California after 2001 energy crisis (Lutzenhiser, Gossard et al. 2002).

Motivation for reducing demand	Respondents (%)
Very important to stop energy suppliers from overcharging	79%
Using energy resources wisely	78%
Keeping bills down	77%
Trying to avoid blackouts	77%
Doing our part	69%
Qualify for utility rebate	33%

This study explores the customer response to three external factors: cost (increased price), environment (increased CO2 footprint) and security (risk of blackout). It has been established that the effectiveness of an intervention depends on the fit between the intervention and the set of barriers to behaviour change in the target population (Stern 2008). Because there are typically multiple factors that maintain an existing behaviour pattern, multiple-factor intervention could significantly affect the behaviour (Abrahamse, Steg et al. 2005).

3. Methods

The idea in this research is that, in order to get effective, time critical demand response, a new type of smart meter technology will be needed to signal the residence. As long as a new device is to be developed, why not consider advanced signal design and multi-mode signalling? Information about energy shortages, supply security and environmental concerns may also influence conservation behaviour and technology choice. These signals could be designed into a new signalling technology if the potential for additional response is promising.

3.1 Multi-mode VDR

Voluntary demand response (VDR) is defined as external signals or information changing normal electricity usage patterns for a certain period of time. These load changes may be due to improved efficiency or from modification of normal activities and behaviours of members of a household during the peak demand hours. The response may involve turning off un-necessary loads, shifting activities to later time, curtailing an activity, or shifting load to other fuels. Customers will respond in different ways to each of the signals, but the overall level of power consumption is the key factor in assessing potential load shedding. For example, a strong response from a low-income retiree in a small apartment with peak demand of 1,500W would have lower potential load shedding than a large affluent household with peak demand of 13,000W. The framework of household classifications and response characteristics is shown in Fig. 1 along with the different ranges of activity response and demand modification. The price signal is defined as the increase over non-peak unit price. The environmental signal is defined as the increased percentage CO_2 emission. The security signal is defined as the increase in loss of load probability over the non-peak level, but would be expressed to customers as “low”, “medium” or “high” risk of black-out.

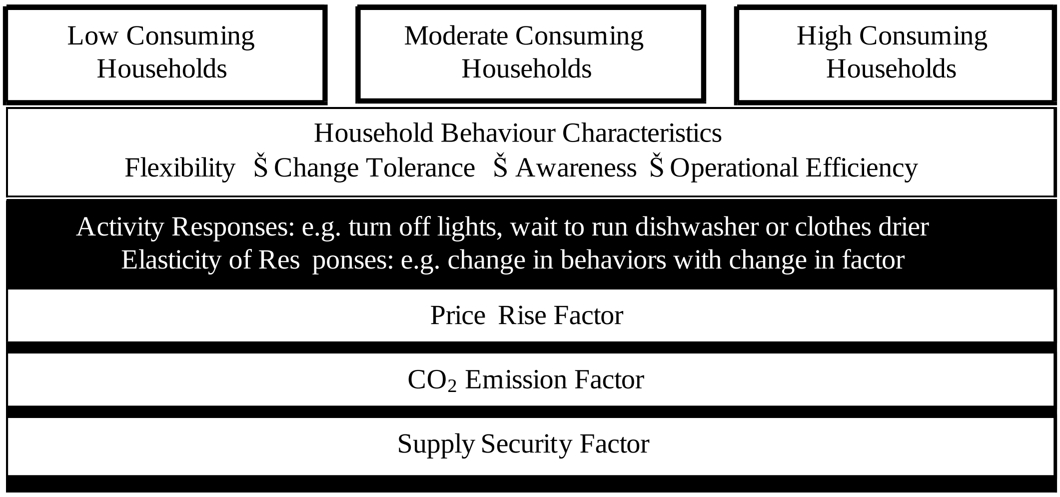


Fig. 1. Framework of residential household characteristics of response to the three supply factors.

As demand starts to rise toward a peak, the signals could be deployed to an increasing number of customers. The strength of the signals could be increase until the required load reduction is met. Customer response to the combination of three signals (or factors) is expected to follow an S-shaped logistical curve, as shown in Fig. 2, starting from lower demand response at low signal penetration and low signal strength, and increasing to a high response until a saturation limit is reached.

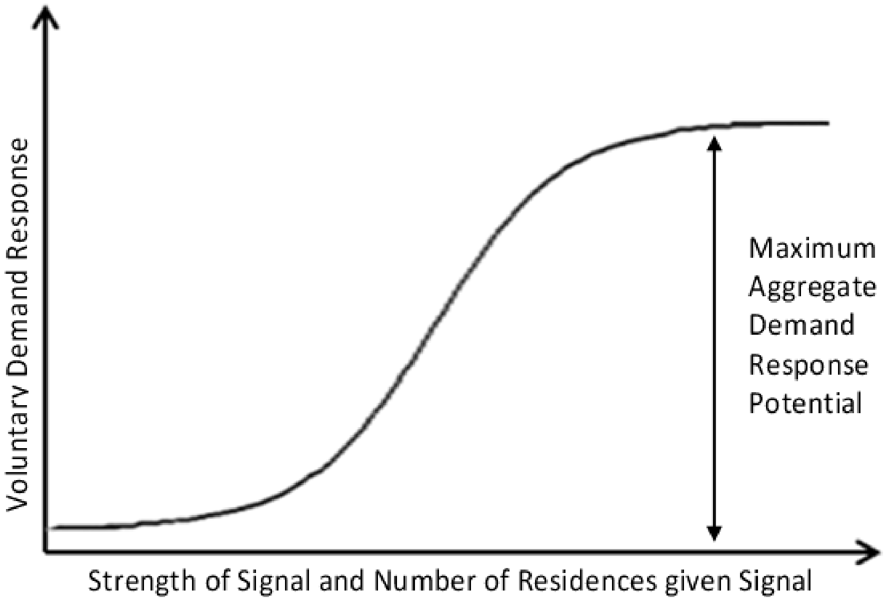


Fig. 2. Illustration of customer aggregate demand response to signal factor strength, number of residences given a signal, and effects of multiple signals.

3.2 Survey design

The multi-mode VDR survey is designed as a mail-back paper survey to be distributed widely across a target area. A cover page with essential information about the local power supply system is written in the style of a newspaper article, with a plot showing the residential power demand pattern. The privacy, consent, and instruction page is similarly kept concise, and any reward for participation is clearly stated.

The survey questions were divided into the following parts:

Energy Audit Information

1. Household information
2. Personal information
3. Household winter power bills
4. Household energy features and electricity price schedules
5. Electricity usage in ordinary winter peak times

Signal Factor Sensitivity

6. Future change issues
7. Electricity allocation scenario and behaviour change
8. Energy saving motivation

The Energy Audit section obtains household background information such as family size, power bills, home insulation levels, the size of houses, income levels, and gender of respondents. Section 5 was structured to gather data about how electricity is currently used in the households. Participants were asked about how they use electricity to carry out their normal daily activities during winter morning and evening peak hours. This was done by supplying a list of the usual appliances, organized by activity that participants could tick and then circle a number representing the frequency of this activity (1 = seldom, 2 = sometimes, 3 = always).

Survey Section 6 asked three questions in order to assess the sensitivity of customer response to the three factors (price, environment and security). In Section 7 a scenario was set out whereby an emergency situation such as an earthquake required allocation of a restricted amount of power for each household during the peak hours, and the amount was less than what is normally used. Participants were asked about the appliances they would switch off, turn down, or avoid using. They were also asked if they would shift their shower times.

To determine which of the three factors could have a significant influence on behaviour; the Section 8 asked participants to rate on a scale of 1 “not important” to 5 “very important”, price, environment and security as reasons to reduce their electricity demand. Figure 3 shows the questions asked in sections 6 and 8 of the survey. Most questions in the survey refer to the household as the unit to which the survey information refers, and the respondent who completed the questionnaire is assumed to be a representative of the household. However, responses to price, environment and security factors are considered characteristic of the respondents themselves rather than the household they represent.

Section 6. Questions to Explore Factor Sensitivity

If your electricity price were to go up, what percentage increase above your last bill would you consider to be large?

[ ]10% [ ]20% [ ]30% [ ]40% [ ]50% [ ]above 50%

What percentage of non-renewable power generation (e.g. coal, gas and diesel) would you consider to be too high?

[ ]10% [ ]20% [ ]30% [ ]40% [ ]50% [ ]above 50%

How many power cuts on winter mornings or evenings would you consider to be too many over the season?[ ]1 [ ]2 [ ]3 [ ]don’t know

Section 8. Question to Explore Factor Importance

Please indicate how important you consider each of the following factors as a reason to reduce your electricity use for a designated period.

	Not important			**Very important**	
Price	1	2	3	4	5
Environmental: (e.g. carbon reduction)	1	2	3	4	5
Supply Security (e.g. black out)	1	2	3	4	5

Fig. 3. Survey Questions from Section 6: Signal Sensitivity, and Section 8: Importance from the Christchurch household survey.

The relative sensitivity or weight of each factor as a motivation factor is determined from equation 1 for all participants.

$$\mathrm{W_i} = \sum_{j=1}^{n} w_{ij} \qquad (1)$$

Where W_i represents the importance of the factor i and w_{ij} is the score given by the j^{th} customer to that factor.

A further analysis is carried out using the Statistical Package for the Social Sciences (SPSS software), to test if there is any statistical difference between the “means” of participants’ responses to the motivation factors. The responses of participants were subjected to a statistical technique called one-way analysis of variance (ANOVA) (Norusis 1998), with the factors as independent variables and the importance attached to the factor as the dependent variables.

4. Modelling

If we consider residential voluntary demand response (VDR) as a potential power resource at peak demand times, then we must assess the magnitude of the resource, the cost of securing it, and the value of the resource to the market. The magnitude of demand response is usually estimated at an aggregate level. While this method may be suitable for the industrial and the commercial sectors, in the residential sector a better understanding of the customer behaviour may be required (DRRC 2007). There is concern that VDR in the residential sector may simply move the peak problem with scale from one point in time to another. Load disaggregation, or the behaviour of the different components of the residential load, is required to study this problem.

The appliance-based load curve model is a “bottom–up” approach of generating the aggregate load profile of residential customers in which the patterns of usage of individual appliances are represented (Capasso, Grattieri et al. 1994). The load curves of the major household appliances, whose aggregate defines the load profile of residential customers, are generated using the method of diversified demand (MDD). Arvidson developed MDD in 1940 to estimate the load on distribution transformers but has been of interest in recent times due to the growing interest in VDR and the need for component-by-component analysis of residential loads (Gönen 2008). The method employs standard usage behaviour of the various types of household appliances for a group of residential customers through statistical correlations.

According to MDD, if a location can, in aggregate, be considered statistically representative of the residential customers as a whole, a load curve for the entire residential class of customers can be prepared (Gönen 2008). Load saturation and demand diversity data are needed for the class of customers whose load curve is to be generated.

Fig. 4 illustrates the modelling approach used to estimate the demand curves of the individual appliances. A_1, $A_2 \ldots A_N$ represent the different household appliances in a house. H_1, $H_2 \ldots H_m$ are houses on a distribution transformer on feeder, F_4.

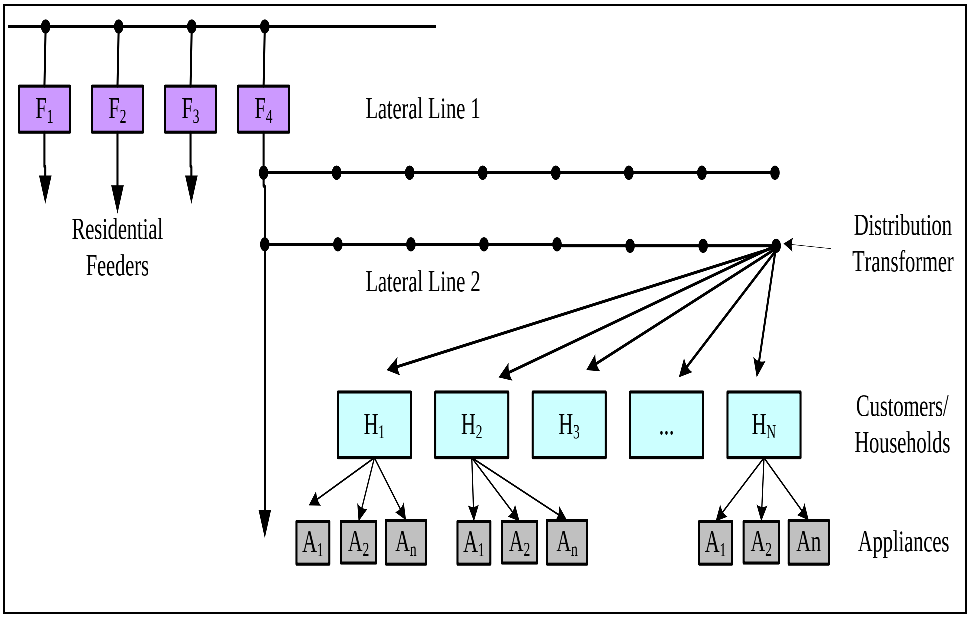


Fig. 4. Illustration of the modelling approach for a group of customers.

The average maximum diversified demand of the appliance categories for a group of customers is calculated from Equation 2.

$$MDD(_{av,\max})_i = MDD_i * n_i \qquad (2)$$
$$n_i = m \cdot s_i$$

MDD($_{av,\ max}$)$_i$ is the average maximum diversified demand of an appliance category for a group of customers. MDD_i is the maximum diversified demand of an appliance per customer, n_i is the number of appliance of that category, *m* represents the total number of households under consideration, and s_i represents the saturation rate of the appliance category and is defined as the number of households that own at least of one of the appliance category. *MDD* depends on the total number n_i of appliance *i*. The *MDD* corresponding to different *n* for several household appliances is presented in Table 2 (Gönen 2008). As the number of appliances (*n*) increases the maximum diversified demand per customer (MDD_i) decreases until it becomes a constant at large *n* values.

Table 2 Average maximum diversified demand per customers (in kW) for given number (*n*) of different household appliances.

Appliances	**n=1**	**n=5**	**n=10**	**n=20**	**n=40**	**n=80**	**n=100**
Direct Water Heater	1.1	0.37	0.22	0.18	0.14	0.1	0.1
Heat Pump	4.50	3.00	3.00	2.80	2.80	2.80	2.80
Electric Heater	7.00	4.00	3.50	3.20	3.20	3.20	3.20
Cloth Dryer	4.30	1.80	1.50	1.20	1.00	1.00	1.00
Home Freezer	0.30	0.13	0.10	0.08	0.08	0.08	0.08
Refrigerator	0.18	0.07	0.06	0.05	0.05	0.05	0.05
Range	2.30	0.90	0.70	0.60	0.50	0.50	0.50
Lighting & Misc.	1.10	0.65	0.60	0.55	0.52	0.52	0.52

The hourly maximum diversified demand for a group of customers, $MDD(_{t,max})_i$ is calculated from Equation 3.

$$MDD_{(t,\max)i} = MDD(_{av,\max})_i * f_i(t) = MDD_i * n_i * f_i(t) \tag{3}$$

Where $f_i(t)$ is the hourly variation factors of the appliance categories. $f_i(t)$ reveals the behaviour characteristics of appliance usage and depends on the living habits of the individuals in a particular area and may differ from location to location. These factors define the pattern of the load curves. These living habits in turn depend on the socio-economic factors such as the number of occupants in the individual household, their age and income. The maximum load on the distribution transformer at any time is the sum of the maximum diversified demand of the individual appliances and is determined from Equation 4.

$$MLT(_{t,\max}) = \sum_{i=1}^{N} MDD(t,\max)_i = \sum_{i=1}^{N} MDD_i * n_i * f_i(t) \tag{4}$$

Where $MLT(_{t,\,max})$ is the maximum load on the distribution transformer at any hour of the day, and N number of appliance categories (i.e. washing machine, heat pump, clothes dryer, etc.).

Activity demand response of a customer group is defined here as the magnitude of demand response obtained as a result of customers adjusting the usage of a given household appliance. The magnitude of the customers' Activity Demand Response (ADR) was calculated from equation 5.

$$ADR_{i(t)} = MDD_i(t) * dx_i \tag{5}$$

Where $ADR_i(t)$ represents customer demand response, and dx_i is the likelihood that an appliance would be offered to participate in demand response by customers in winter. dx_i was obtained by multiplying the probability that an appliance would be used during the peak hours by the likelihood that the usage of that same appliance would be adjusted in response to critical supply constraints at peak demand hours as determined from survey responses.

5. Case study in Christchurch, New Zealand

The residential sector uses about 33% of annual electric consumer energy in New Zealand, but accounts for more than 50% of the peak power demand (Electricity-Commission 2007). National peak power demand has grown from the range of 5400-5600 MW prior to the year 2000, to 6400-6600 MW in 2006 (MED-d 2008). Space heating, water heating, cooking, lighting, refrigeration and entertainment are the major residential electricity end uses in New Zealand (Isaacs, Camilleri et al. 2007). Residential peak demand occurs in the mornings and evenings during the winter months, coinciding with breakfast and dinner times and coincident with commercial and industrial loads. Hydropower supplies most of the peak load, but gas peaking power plants are needed to ensure security of supply in the winter months if precipitation is not adequate (IEA-c 2006; IEA 2007). In Christchurch, the transmission network is constrained and diesel generators owned by the city council and other institutions are used to meet demand during peak hours (CCC 2007).

Policy imperatives for reliability, resilience, environmental responsibility and fair and efficient prices are to be achieved by increasing energy efficiency and supporting innovation according to the New Zealand Programme of Action (MED 2004). The 2006 National Energy Strategy set a national renewable electricity generation target of 90% by 2050, up from the current range of 70% (MED-a 2006). Demand response can therefore play a very important role in maintaining the supply-demand balance in New Zealand.

Direct control is widely used in the residential sector to control water heating cylinders in the winter (EnergyWise 2003). The water heaters are thermostatically controlled but on a circuit that can be interrupted by the power supplier for 15-30 minutes to reduce the load on the system. The distribution company in Christchurch with a distribution capacity limit of about 600 MW has achieved 90% ripple control penetration for water heating cylinders, and is able to shed 125 – 150 MW of residential peak load (EECA 2004; IEADSM 2008). A discount of about 11% on the monthly electricity bill is received for participation in the ripple control programme (EnergyWise 2003).

Time-varying pricing is employed in New Zealand for big industrial and commercial users with special half-hour interval metering that records customer demand during peak times. This type of pricing is currently not deployed in the residential sector. Most retailers provide an option of split meters for night and day-time rates so that certain appliances can be hard-wired on the night rate.

A case study was conducted in Halswell, a relatively new suburb of Christchurch city in New Zealand. The study area has its own residential power feeder supplying electricity to roughly 400 homes. No commercial, municipal or industrial customers are on the feeder. This suburb was selected in consultation with power distribution company, Orion Networks, who supplied power consumption, ripple control, economic and power system data used in modelling. Fig. 5 shows the load profile on the Halswell feeder for three typical days in the winter of 2006. The morning peak is between 7:00 and 9:00, and the evening peak period is from 18:00 to 20:00.

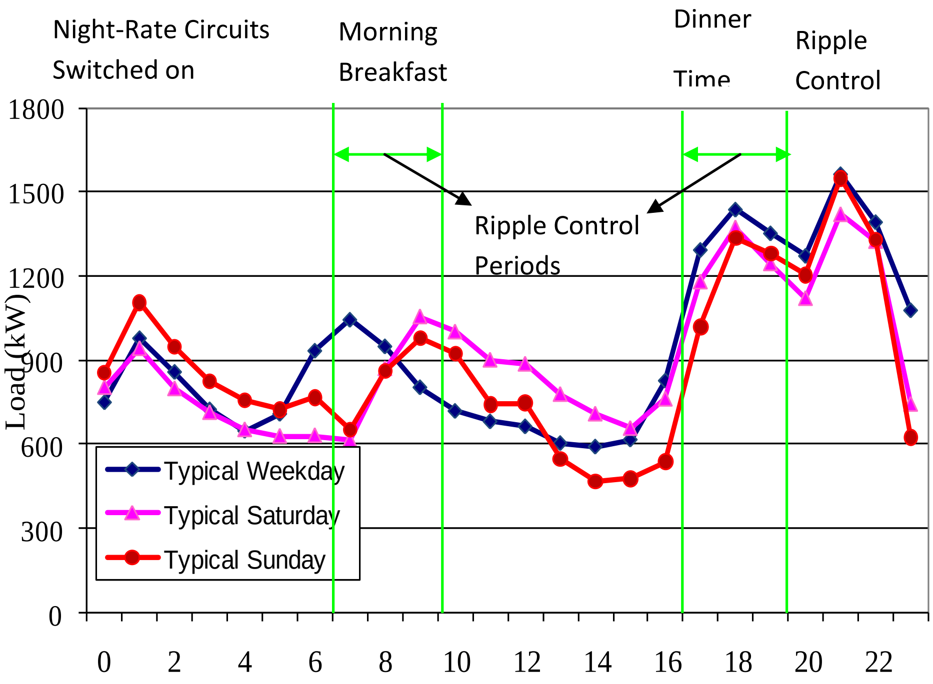


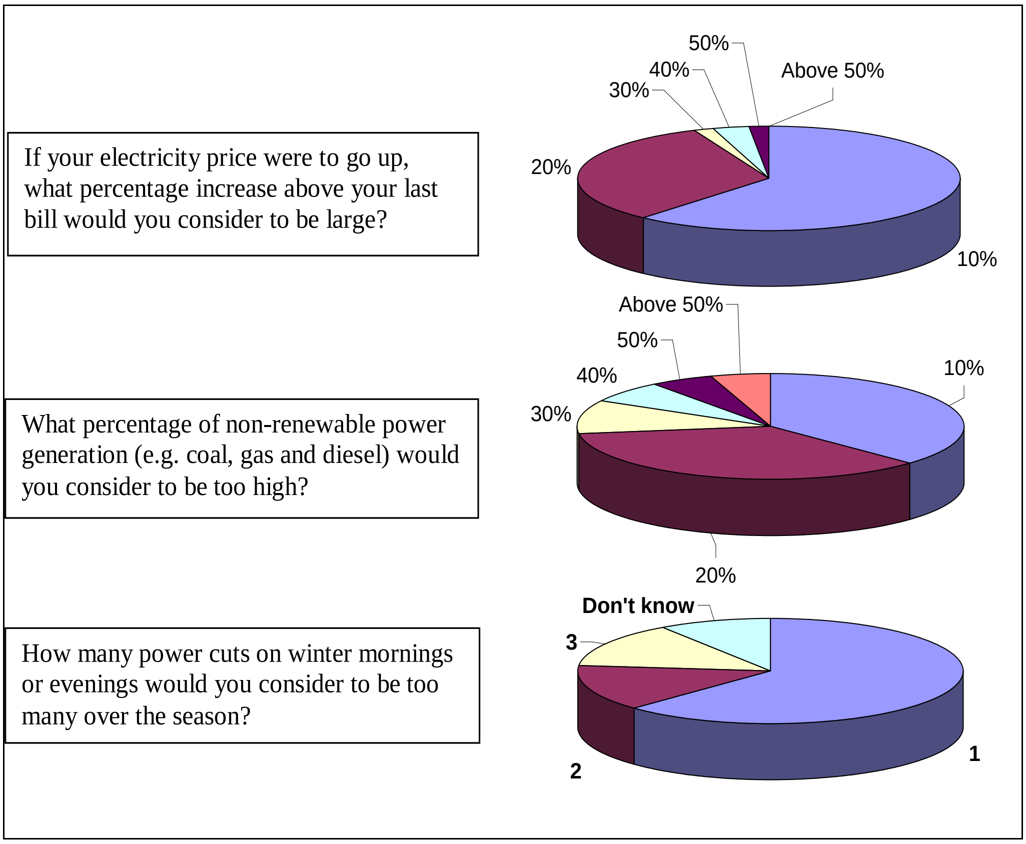
Fig. 5. Typical electricity demand profile for the 400 residents in the Halswell suburb during the winter month of July 2006.

The morning peak is coincident with the industrial and commercial start-up period. The evening peak is much higher as it includes substantial cooking as well as space heating. The evening peak occurs when children return from school and coincides with high industrial and commercial loads. It is dark during the morning and evening peak times, so lighting loads are high. New Zealanders tend not to have thermostatically controlled central heating and they do not heat the house overnight or during the day when not at home. Thus, electric heating loads are large as heaters run at full capacity to take the chill off cold homes, 40% of which are not insulated. The peaks in the late night and early morning are the water heaters and storage space heaters that are activated by the utility when the other sector (industrial and commercial) loads have decreased. Ripple control is used to some degree nearly every morning and evening to manage the ultimate peak.

5.1 Survey Results

The survey was placed in an envelope addressed to “resident” along with a stamped return envelope, and hand delivered to every mailbox in the Halswell subdivision identified as being on this residential feeder. The survey included a cover letter that explained the research purpose. There was also a plot of the Christchurch power demand on the day that the Earth Hour was conducted, showing the demand response. A short explanation was given in the cover letter about the high cost of producing peak power, the higher CO_2 emissions due to diesel generators used in the city during peak, and the increased risks of power outage if demand is too close to the supply capacity of the grid. The number of respondents was 63, giving a response rate of 16% with no follow-up reminders given.

All of the homes were fully insulated. The respondent household size distribution was 42% two persons, 21% three persons and 19% four persons. The winter monthly power bills ranged from less than $99 to $350 with the average around $200. 37% of the households had a night store heater. The direct responses to the factor sensitivity questions are shown in Fig. 6. It is clear that people are sensitive to price increase. Generally, the results show that nearly all customers would be strongly concerned about a 20% price increase.



If your electricity price were to go up, what percentage increase above your last bill would you consider to be large?

What percentage of non-renewable power generation (e.g. coal, gas and diesel) would you consider to be too high?

How many power cuts on winter mornings or evenings would you consider to be too many over the season?

Fig.6. Responses to the signal sensitivity questions from Halswell Survey.

An interesting result was the answer to the renewable energy question. Currently, more than 34% of the total annual electricity is generated by burning coal, natural gas or diesel. Yet nearly 80% of respondents indicated that they would consider this level to be too high. The South Island of New Zealand, where Christchurch is located, is famous for the large hydro-power generation facilities. The largest electricity retailer, Meridian Energy, advertises that the company is a 100% renewable generator. Meridian's literature does not indicate that fossil fuel generation is purchased and transmitted from the North Island to supply the peak demand. Finally, the respondents indicated a general intolerance for blackouts with 64% indicating that even one power outage over the course of the year is too many.

Participants were the most sensitive to price (W_{price} = 82%) followed by security ($W_{security}$ = 79%) and then environment (W_{CO2} = 64%) as calculated by equation 1. The factor comparison results are shown in Table 3 using the Tukey HSD test. Significant differences (according to the 0.05 criterion) are indicated by (*). There is no significant difference between price and security as motivation factors. People may respond to a security signal at peak demand hours in much the same way as price. There were significant differences between the importance attached to the environment and the other two factors.

Table 3. Statistical comparisons of the importance of motivation factors.

(I) Factor	(J) Factor	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Price	Environment	0.89	0.25	0.00*	0.29	1.49
Price	Security	0.16	0.25	0.80	-0.44	0.76
Security	Environment	0.73	0.25	0.01*	0.13	1.32

* the mean difference is significant at 0.05 level according to Tukey HSD test

5.2 Maximum Diversified Demand

The appliance saturation rates for New Zealand were used for the m = 400 homes in Halswell (Electricity-Commission 2007). The saturation rate of heat pumps was taken from a recent BRANZ study (French 2008). The saturation rate of electric heaters was adjusted to reflect the survey results. The generic household appliance load curve methodology described above was applied. Table 4 shows the maximum diversified demand for each appliance.

Table 4 Maximum diversified demand for 400 households in the Halswell suburb of Christchurch.

Appliances	**Appliance saturation rate (%)**	**Total number of appliances n_i**	**Average Maximum Diversified demand per customer (kW)**	**Maximum diversified demand for the 400 households (kW)**
Domestic Water Heater (DWH)	87	348	0.72	250.56
Heat Pump*	35	140	2.60	364.00
Electric Heater*	93	372	3.00	1116.00
Clothes Dryer	34	136	1.20	163.20
Washing Machine	95	380	1.20	456.00
Freezer	64	256	0.08	20.48
Refrigerator	31	124	0.06	7.44
Fridge/Freezer	80	320	0.08	25.60
Microwave/Oven	78	312	0.50	156.00
Range	93	372	0.55	204.60
Lighting & Misc.	100	400	0.54	216.00

*Saturation levels for New Zealand were adjusted to reflect the situation at Halswell.

5.3 Estimation of the hourly variation factors

Hourly variation factors for the Halswell area were estimated from the results of the first two years of Household Energy End-Use Project (HEEP) study (Stoecklein, Pollard et al. 1998), and with data from Orion Networks (OrionNetwork 2006) and the survey results for the Halswell suburb. The HEEP study measured interval electricity demand data of household appliances in winter in a large sample of houses in New Zealand. Figure 7 gives the hourly variation factors for the Halswell area.

Figure 8 shows the estimated aggregate load for the group of 400 households compared with the actual load measured by the utility. The shape of the estimated load curve compares very well with the utility load profile, while the magnitude was a bit higher during the morning and the afternoon hours. The shape of the load curve measured by the utility on different days remains largely the same. The magnitude of the curves may vary greatly from day to day, mainly due to the weather affecting the heating loads.

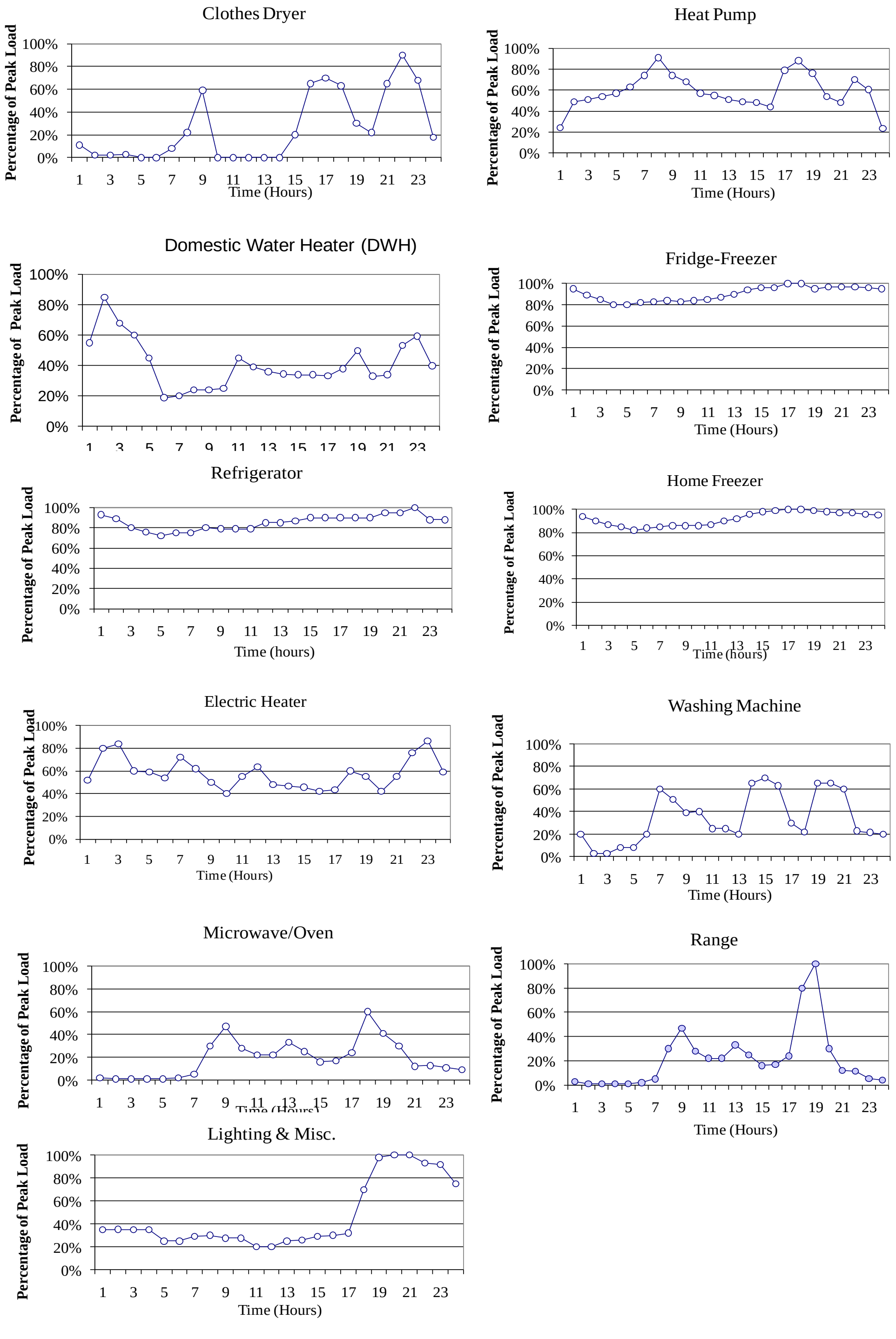


Fig. 7. Appliance hourly variation factors for the Halswell area.

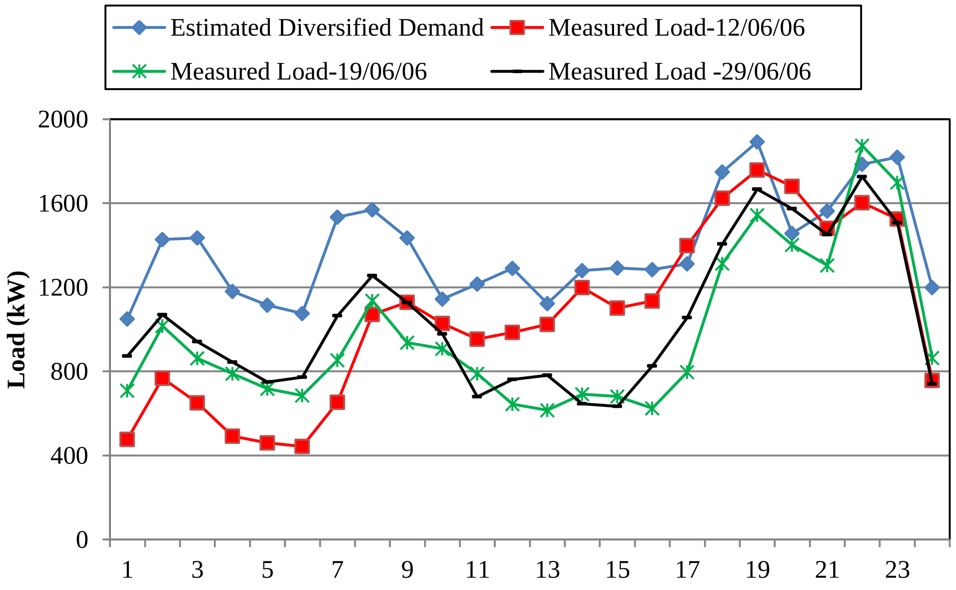


Fig. 8. Estimated load curve for the 400 households in Halswell compared with the measured load by the utility in winter, 2006.

5.4 Magnitude of Demand Response in Halswell Neighbourhood

The likelihood of a particular appliance being used in the Halswell area during the peak period is determined from the responses to the energy audit section of the survey. The households' willingness to adjust their demand for each appliance in the scenario of a hypothetical supply constraint situation in winter is reported as a percentage of participants who selected the appliance. The survey results are presented in Table 5, with the resulting achievable level of demand response participation, dx_i. It is interesting to note the high willingness to turn off computers, heated towel rails and even to some extent electric heaters and heat pumps. There is high level of willingness to forgo use of the oven and the range in the mornings, but the electric kettle and the microwave are not considered available for demand response at either peak time. New Zealanders can go without heat for a time, but not so the cup of tea. Importantly, there is good willingness for delaying use of washing machines, clothes dryers and dishwashers during peak demand times.

Table 5. The likelihood of appliances demand response participation

Appliances	Likelihood of Use During Peak Tmes (%)		Likelihood of Demand Response Participation (%)		Achievable Demand Response Participation, dx_i (%)	
	Morning	Evening	Morning	Evening	Morning	Evening
Cloth Dryer	8	12	33	33	3	4
Computer	15	36	42	46	6	17
Dishwasher	12	31	37	36	5	11
Electric Kettle	65	61	13	19	9	12
Hair Dryer	46	4	31	35	14	2
Heat Pump	46	59	26	19	12	11
Heated Towel Rail	32	26	41	42	13	11
Microwave	44	49	22	17	10	8
Electric Heaters	21	18	33	28	7	5
Oven	9	47	49	40	5	19
Range	12	47	42	24	5	11
Spa Pool	2	4	15	15	0	1
Stereo	10	6	33	33	3	2
TV	16	70	32	19	5	13
Vacuum Cleaner	17	12	35	35	6	4
Washing Machine	33	21	42	42	14	9

The magnitude of the customers' activity demand response (ADR) associated with a voluntary reduction of appliance use, or curtailing of an activity, was calculated from equation 5 for the Halswell households and presented in Table 6. The ADR during the morning (7.00 – 9.00) peak hours ranged from 2 kW for clothes dryer, representing just over 0.1% of the average morning peak load to as high as 50 kW for electric heater, representing 3.4% of the morning peak load. The second highest ADR at the morning peak hours was from heat pump, representing a reduction of 45 kW or 3% of the morning peak load. The highest ADR during the evening peak hours (18:00 - 20:00) was 33 kW obtained from switching off heat pumps. Washing machine and electric heater each produce a reduction of 32%. The total ADR was higher during the morning peak hours at

143.8 kW, representing 9.9% of the morning peak, than 124.5 kW during the evening, representing 7.4% of the evening peak load.

Table 6. Detailed activity demand response (ADR) (in kW) for 400 households in Halswell, Christchurch.

Peak Time	Washing Machine	Clothes Dryer	Range	Micro-wave	Electric Heater	Heat Pump	All
7.00-8.00	39.5	1.1	3.7	5.6	55.4	49.7	155.0
8.00-9.00	30.2	2.9	5.8	8.8	44.6	40.4	132.7
Morning Average	34.9	2.0	4.7	7.2	50.0	45.0	143.8
% Morning Peak	**2.4%**	**0.1%**	**0.3%**	**0.5%**	**3.4%**	**3.1%**	**9.9%**
18.00-19.00	32.6	2.4	28.6	6.4	36.8	38.7	145.6
19.00-20.00	32.6	1.8	8.6	4.7	28.1	27.5	103.3
Evening Average	32.6	2.1	18.6	5.5	32.5	33.1	124.5
% Evening Peak	**1.9%**	**0.1%**	**1.1%**	**0.3%**	**1.9%**	**2.0%**	**7.4%**

The total activity demand response during the evening peak hours was compared with the instantaneous domestic water heating loads that are ripple-controlled by the distribution company in the Halswell to maintain system reliability during critical evening peak hours. The result of this comparison is shown in Fig. 9. The customer activity demand response was quite similar to the domestic hot water heating load that is ripple-controlled during the evening peak hours indicating that if household customers would change their energy usage behaviour in accordance with their stated behavioural intensions (from the survey) then such change would be enough to maintain system reliability.

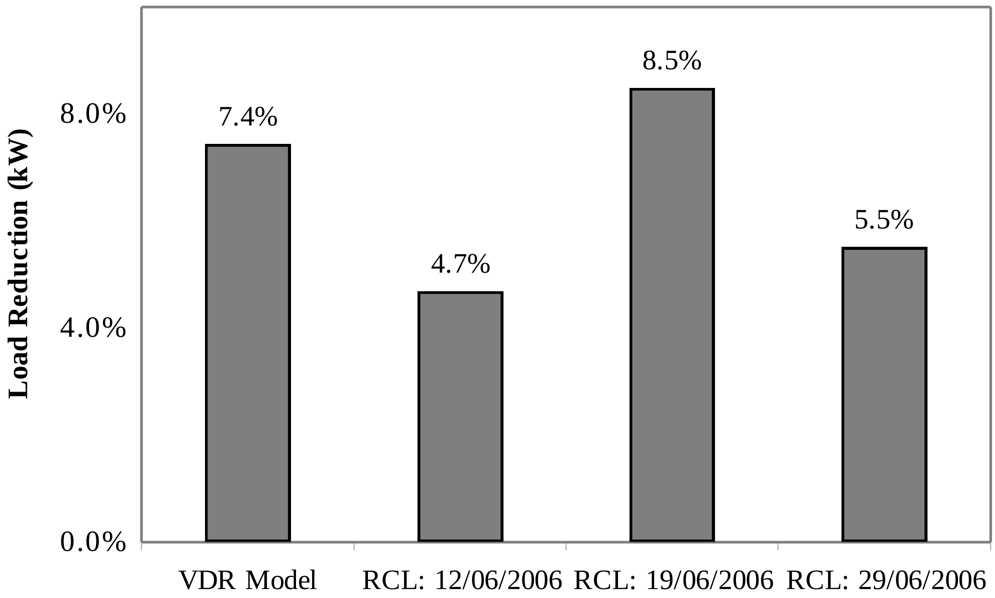


Fig. 9. Comparison of the modelling results to ripple-controlled load (RCL) by utility company during the evening peak hours in some selected days in winter 2006.

5.5 Potential maximum VDR peak load reduction in Christchurch

In order to calculate the potential of the VDR in Christchurch, the peak demand reduction obtained for the 400 households in Halswell for June 19th 2006 was scaled onto the number of all households in the Christchurch city (approximately 131,833 households). Fig. 10 shows the actual load curve on the entire Orion's distribution network on the 19th of June 2006 compared to the load with maximum VDR for all appliances. This actual load was already a controlled load, as the Orion network had a capacity limit of about 600 MW in 2006. Note that the load on the entire network has all customers (industrial, commercial and residential).

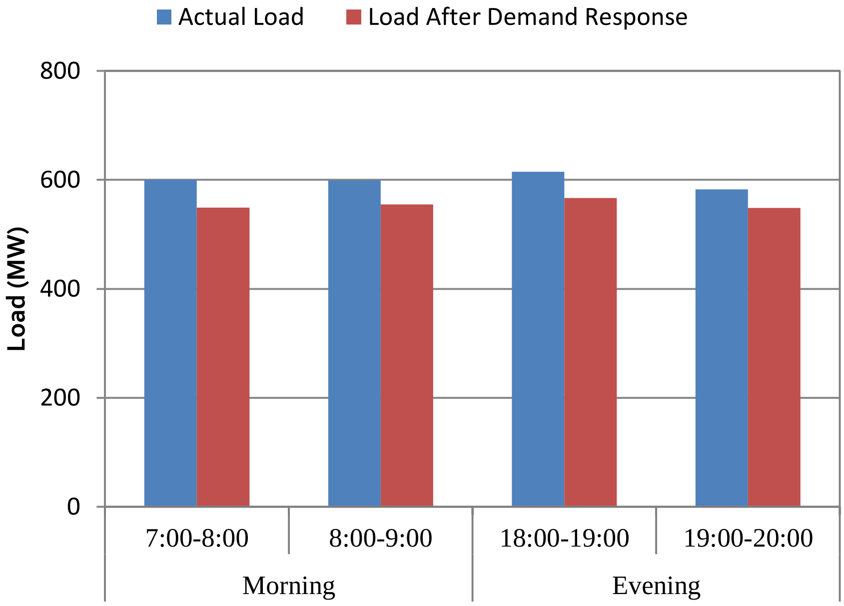


Fig. 10. Voluntary demand response potential in Christchurch modelled for actual network load (including all sectors) on 19 June 2006.

It was shown that the average morning (07:00 – 09:00) peak load could be reduced with the DVR by 47 MW, representing 7.9% of the morning peak load on the entire Orion’s network, while the evening peak load could be reduced by 41 MW, representing 6.7%. This result is based on the assumption that all the households in Christchurch will behave the same way as the customers in the Halswell neighbourhood.

5.6 Economic value of VDR in Christchurch

The value of VDR in Christchurch was estimated based on avoided cost methodology or Standard Practice Methodology that is used to assess the cost effectiveness of energy efficiency projects. This method estimates the economic value of demand response load reduction by comparing the costs per kW to the levelized costs of a new fossil fuel power plant and avoided costs of upgraded transmission, and distribution costs. The spot market price of electricity could also be used to estimate the value of the VDR, but the spot price varies widely so would introduce a large uncertainty. The avoided investment cost is a more conservative estimate and excludes benefit that are not easy to quantify such as environmental benefit, societal cost, risks and market effect of reduced peak load.

Avoided Generation cost

The generation cost of the reduced peak load was estimated using the threshold conditions for the dispatch of the Whirinaki power plant. The Whirinaki power plant is a 155-MW oil-fired power plant, commissioned by the New Zealand government to provide reserve generation in specific situations, primarily dry year hydro shortages or unexpected plant outages. This plant is offered at NZD $200/MWh into the wholesale market when the price at the Whirinaki node reaches NZD $200/MWh for a four hour period. According to the information obtained from the New Zealand Electricity Commission, the Whirinaki plant was “fired” for a total of 60 hours in 2006 for purposes other than testing. The price of NZD $200/MWh and the number of hours that the plant was offered into the market in 2006 were assigned to the peak load reduction obtained for Christchurch through the voluntary demand response. The generation cost of the reduced load at the morning peak hours translates into approximately NZD $0.57 million per annum and that of the evening translate into approximately NZD $0.49 million per annum.

Avoided Transmission and Distribution Cost

The distribution company in Christchurch estimates demand response value based on avoided new network addition. The value of demand response is calculated based on the so called Long Run Average Incremental Cost (LRAIC) of new transmission capacity to be around NZD $50/kW and distribution LRAIC is reported to be NZD $100/kVA per annum (IEADSM 2008). Adopting these values, the 47 MW load reduction during the morning peak hours translates into approximately[3] NZD $2.37 Million per annum of transmission capacity and NZD $4.76 million per annum of distribution capacity.

5.7 Cost Effectiveness of the Reduced Load

The demand response program cost was estimated based on a small portable device, with effectively the same functionality as a pager that could be mailed out to households with an accompanying explanation pamphlet and DVD. The device would not require installation other than plugging in to a wall outlet. The estimate includes the device cost, direct mail solicitation, media campaign etc. These costs are average over a 15 year time horizon of the program. The cost per kW of the reduced peak load was calculated by making the following assumptions:

- Demand response program cost of NZD $200 per year per household.
- Average peak hour demand reduction of 44 MW (average of the morning and evening peak demand reduction on a hypothetical supply constraint situation)
- The demand reduction is persistent over 15 year horizon
- Total number of 131, 833 households in Christchurch
- Assumed annual interest rate of 5%

The future cost per kW (FC) of the reduced load at any particular *n* was calculated from Equation 6.

$$FC_n = \frac{TC(1+i)^n}{\sum_{n=1}^{n} DR} \qquad (6)$$

---

[3] Assuming a power factor (PF) of approximately 1. PF = kW/kWA

FC is the cost per kW ($/kW) of the reduced peak load, *TC* is the total project cost (in $), *n* is the year under consideration, *i* is the interest rate and *DR* is the reduced demand (kW). This value was compared to the avoided transmission and distribution cost of NZD $50/kW and NZD $100/kVA per annum, respectively, assuming an interest rate of 5% over the 15 year time horizon. Table 7 shows the cost per kW of the demand reduction over a 15 year time horizon compared to the benefit of such a demand response project. The results show that the benefit of demand response project will exceed the cost after the 5th year, assuming a persistent demand reduction. It should be noted that the figures presented are for the maximum VDR, and not all customers would modify their demand in accordance with their behaviour intention stated in the survey. The reduction that can be achieved in a real-time case study is expected to be lower.

Table 7. Cost-Benefit Analysis of VDR in Christchurch, New Zealand

Cost Components	Year 1	Year 2	Year 5	Year 10	Year 15
Cost of 44 MW VDR (NZD/kW)	629	330	153	98	83
Avoided Generation Cost (NZD/kWh)	0.21	0.22	0.26	0.33	0.42
Avoided Transmission Cost (NZD/kW)	53	55	64	81	104
Avoided Distribution Cost (NZD/kW)	105	110	128	163	208

Value of the demand response compared with the avoided cost over a 15 year time horizon, assuming a persistent saving and interest rate of 5%.

6 Conclusions

Voluntary demand response is expected to play an important role in the supply of power in the future. In a resource constraint power system where the option of increasing supply to balance demand is limited and/or available at high cost, VDR can make an important long range contribution to maintaining the supply-demand balance, ensuring that voltage and particularly frequency remain within their normal operating values. The potential of prospecting for and developing residential sector VDR can be significant, but it is still a largely unexplored resource. Information barriers and lack of proper understanding of customers' behaviour are among the factors that limit the extension of VDR programs to the residential customers. This research has demonstrated that information about the power system security and emission are factors that can be used in addition to price signals to influence people's energy use behaviour.

The objective of demand response is to reduce electricity demand during peak hours. It does not necessarily require peak time pricing. However, the benefits of demand response to all consumers include lower price, market discipline, better electrical service and lower environmental emissions. Better explanation of all these benefits to the consumer may be necessary to achieve effective residential sector demand response. A survey was developed in this study to determine through customers' willingness to adjust their demand for power when they receive enhanced information about supply constraints and environmental impact.

A case study in a suburb of Christchurch, New Zealand shows that customers' maximum VDR can represent as high as 10% and 7% of the morning and evening peak load respectively. Economic analysis of avoided costs was used to evaluate the competitiveness of VDR with conventional supply-side capacity growth. The maximum VDR, delivered consistently over a 15 year programme would be a more affordable option than supply growth in New Zealand. The country's energy policy should include innovation and development of VDR programmes and technologies.

Acknowledgments

The authors would like to acknowledge the valuable modelling input of Dr. Larry Brackney, former senior lecturer at the Electrical and Computer Engineering Department of the University of Canterbury. The acknowledgement is also given to Prof. Hans Peter Peters of Juelich Research Centre in Germany for his advice in the development of the survey tool. The Energy Efficiency and Conservation Authority (EECA) of New Zealand provided financial support.

References

Abrahamse, W., L. Steg, et al. (2005). "A Review of Intervention Studies Aimed at Household Energy Conservation." Journal of Environmental Psychology **25** (2005): 273–291.

AESP (2001). "Peak Load Management or Demand Response Programs: a Policy Review " Association of Energy Services Professionals International, Inc. 6746 Finamore Circle Lake Worth, FL 33467 (561) 432-8000.

Barbose, G., C. Goldman, et al. (2004). "Real Time Pricing Tarrifs: A survey of Utility Program Experience." LBNL-54238. Barkeley, California: Lawrence Barkeley National Laboratory.

Bonbright, J., D. R. Karmerschen, et al. (1988). "Principles of Public Utility Rates." 2nd Ed. Arlington, VA: Public Utility Reports.

Brandon, G. and A. Lewis (1999). "Reducing Household Energy Consumption: a Qualitative and Quantitative Field Study." Journal of Environmental Psychology **1999**(19): 75-85.

Capasso, A., W. Grattieri, et al. (1994). "A Bottom-up Approch to Residential Load Modelling " IEEE Transactions on Power Systems Vol. 9, (No. 2): May 1994

CCC (2007). "Christchurch City Council (CCC).Sustainable Energy Strategy for Christchurch: 2008-2018." Web. Last Accessed 11 Nov. 2008. <www.ccc.govt.nz/environment/sustainableEnergy>.

ComEd (2007). "ComEd Real Time Pricing Demand Response Program " Web. http://www.thewattspot.com. Last accessed 20.09.08.

CRA (2006). "Residential Hourly Load Response to Critical Peak Pricing in the State-wide Pricing Pilot." Presented by CRA International, 5335 College Avenue, Oakland, Ca. 94618-2700.

de Almeida, A. T., P. S. Moura, et al. (2007). "Distributed Generation and Demand-side Management, in:Krieth, F., Goswami, D.Y. (eds), Handbook of energy efficiency and renewable energy." CRC Press, Taylor & Francis Group 5-1 - 5-53.

Dillman, D. A., E. A. Rosa, et al. (1983). "Lifestyle and Home Energy Conservation in the United States: The Poor Accept Lifestyle Cutbacks While the Wealthy Invest in Conservation." Journal of Economic Psychology **3**: 299-315.

Dobson, J. K. and J. D. A. Griffin (1992). "Conservation Effect of Immediate Electricity Cost Feedback on Residential Consumption Behaviour." ACEEE Summer study on Energy Efficiency in Building, American Council for Energy Efficiency Economy, Washington DC.

DRRC (2007). "Understanding Customer Behaviour to Improve Demand Response Delivery in California " PIER Demand Response Research Centre Research Opportunity Notice DRRC RON -3. .

EECA (2004). "Mass Market Load Control - Its Use and its Potential Use." Report Prepared for the Energy Efficiency and Conservation Authority. See the Appendix to the Report Prepared by Orion Networks.

Ek, K. and P. Soederholm (2010). "The devil is in the details:Household electricity saving behaviour and the role of information." Energy Policy 38(2010): 1578–1587.

Electricity-Commission (2007). "New Zealand Efficiency Potential Study Vol.1 " Electricity Commission Wellington, New Zealand

EnergyWise (2003). " Exploring our Untapped Electricity Resource: Demand-Side Participation in the New Zealand Electricity Market " EECA Report, NZ, Feb. 2003.

EPRI (2009). "Assessment of Achievable Potential from Energy Efficiency and Demand Response programs in the U.S. (2010 - 2030), Executive Summary." Electric Power Research Institute Palo Alto, CA.

Eto, J. (1996). "The Past, Present, and Future of U.S. Utility Demand-Side Management Programs." Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory LBNL-39931.

ETSA (2007). "The Electricity Trust of Southern Australia (ETSA) Utilities Demand Management Program." Progress Report.

Ford-Foundation (1974). "A Time to Choose America's Energy Future - Energy Policy Project of the Ford Foundation." Ballinger Publishing Co., Cambridge, Massachusetts.

French, L. (2008). "Active Cooling and Heat Pump Use in New Zealand." Study Report No. 186, BRANZ, Wellington

Gellings, C. W. and J. H. Chamberlin (1993). "Demand-Side Management; Concepts and Methods, 2nd Ed " The Fairmont Press, Lilburn, GA.

Goldman, C., M. Reid, et al. (2010). "Coordination fo Energy Efficiency and Demand Response." National Action Plan for Energy Efficiency, Lawrence Berkeley National Laboratory.

Goldman, C. A., J. H. Eto, et al. (2002). "California Customer Load Reductions during the Electricity Crisis: Did they help to keep the lights on? ." Lawrence Berkeley National Laboratory, Berkeley, CA.

Gönen, T. (2008). "Electric Power Distribution System Engineering. 2nd edition " Taylor & Francis Group.

Herter, K., P. McAuliffe, et al. (2007). "An exploratory analysis of California residential customer response to critical peak pricing of electricity " Energy 32(2007): 25-34.

IEA-a (2005). "Saving Electricity in Hurry: Dealing with Temporary Shortfall in Electricity Supplies." International Energy Agency Online Book. Web.last accessed 20 Oct. 2008.

IEA-c (2006). "Energy Policies of IEA Countries: New Zealand 2006 Review." International Energy Agency (IEA) Energy Policy for New Zealand.

IEA (2007). "Electricity Information." International Energy Agency (IEA) Statistics.

IEADSM (2008). "Case Studies of Network-Driven DSM: Orion Network Demand DSM, New Zealand." Web. >http://www.ieadsm.org/CaseStudies.aspx< Last accessed: 10 Oct. 2009.

Isaacs, N., M. Camilleri, et al. (2007). "Energy Use in New Zealand Households: Report on year 10 Analysis for the Household Energy End-use Project (HEEP) " BRANZ Study Report No. SR 155

Keith, G., B. Biewald, et al. (2003). "Modelling Demand Response and Air Emissions in New England." Synapse Energy Economics Inc.

King, C. (2005). "Ontario-Power eMeter Communication."

Lovins, A. B. (1971). "World Energy Strategies: Facts, Issues, and Options." Friends of the earth, Inc.

Lutzenhiser, L., S. L. Bender, et al. (2002). "Using mass media to influence energy consumption behaviour: California's 2001 Flex Your Power campaign as a case study. ." <Web. 20 Oct. 2008>http://www.energy.ca.gov/papers/2002-08-18_aceee_presentations/PANEL-08_BENDER.PDF.

Lutzenhiser, L., M. H. Gossard, et al. (2002). "Crisis in Paradise: Understanding the Household Conservation Response to California’s 2001 Energy Crisis." In Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings.

MED-a (2006). "New Zealand Energy Strategy to 2050: Powering Our Future Towards a Sustainable Low Carbon Emissions Energy Systems " Ministry of Economic Development Draft Report.

MED-d (2008). "New Zealand Energy Data File, June 2008." Ministry of Economic Development.

MED (2004). "Sustainable energy, sustainable development, New Zealand Programme of Action." Ministry of Economic Development (MED),.

Narayan, P. K., R. Smyth, et al. (2007). " Electricity consumption in G7 countries: A panel cointegration of residential demand elasticities " Energy Policy 35: 4485-4494.

Norusis, M. J. (1998). "Guide to Data Analysis, SPSS 8.0." Prentice-Hall, Inc. Upper Saddle River, New Jersey 07458.

OrionNetwork (2006). "Orion Network databas." Received from the Orion's Network Planning Manager.

Picherta, D. and K. V. Katsikopoulosa (2007). "Green defaults: Information presentation and pro-environmental behaviour." Environmental Psychology 28 (2008): 63–73.

Rohmund, I., G. Wilker, et al. (2008). "Assessment of Achievable Potential for Energy Efficiency and Demand Response in the U.S. (2010 - 2030)." ACEEE Summer Study on Energy Efficiency in Buildings, 5, 261-272.

Sanstad, A. H. and R. B. Howarth (1994). "Consumer Rationality and Energy Efficiency " Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings.

Stern, p. (1992). "What Psychology knows about Energy Conservation." American Psychologist 47: 1224-1233.

Stern, P. C. (1986). "Blind Spots in Policy Analysis: What Economics doesn't say about Energy Use." Journal of Policy Analysis and Management; Contained in the Model of Decision Making and Residential Energy Use by Wilson C. and Dowlatabadi H. Annual Environmental Resources, 2007.

Stern, P. C. (2008). "Environmental Significant Behaviour in the Home. In Lewis A, ed." The Cambridge Handbook of Psychology and Economic Behaviour: P372.

Stern, P. C. and E. Aronson (1984). "Energy use : the Human Dimension " W.H. Freeman, New York.

Stoecklein, A., A. Pollard, et al. (1998). "Energy End-Use and Socio/Demograhic Occupant Characteristics of New Zealand Households." HEEP, Year Two Results.

Sweeney, J. L. (2002). "The California Electricity Crisis." Hoover Institution Press, Publication 513, Stanford, CA.

USDOE (2006). "Benefits of Demand Response in Electricity Markets and Recommendations for achieving them. Report to the United State Congress Pursuant to the Section 1252 of the Energy Policy Act of 2005, ." United State Department of Energy (USDOE).

Wall, R. and T. Crosbie (2009). "Potential for reducing electricity demand for lighting in households: An exploratorysocio-technical study." Energy Policy(2009): 1021–1031.

Wilson, C. and Dowlatabadi (2007). "Model of Decision Making and Residential Energy Use." Annual Review Resources and Environment 32: 169-203.