DEMAND RESPONSE ASSESSMENT AND MODELLING OF PEAK ELECTRICITY DEMAND IN THE RESIDENTIAL SECTOR: INFORMATION AND COMMUNICATION REQUIREMENTS

A THESIS SUBMITTED
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
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Abstract

Peak demand is an issue in power supply system when demand exceeds the available capacity. Continuous growth in peak demand increases the risk of power failures, and increases the marginal cost of supply. The contribution of the residential sector to the system peak is quite substantial and has been a subject of discussion internationally. For example, a study done in New Zealand in 2007 attributed about half of system peak load to the residential sector. International research has attributed a significant influence of human behaviour on households energy use. "Demand Response" is a demand side management tool aimed at achieving peak energy demand reduction by eliciting behaviour change. It encompasses energy needs analysis, information provision to customers, behaviour induction, smart metering, and new signalling and feedback concepts. Demand response is far advanced in the industrial and commercial demand sectors. In the residential sector, information barriers and a lack of proper understanding of consumers' behaviour have impeded the development of effective response strategies and new enabling technologies in the sector. To date, efforts to understanding residential sector behaviour for the purpose of peak demand analysis has been based on pricing mechanism. However, not much is known about the significance of other factors in influencing household customers' peak electricity demand behaviour. There is a tremendous amount of data that can be analyzed and fed back to the user to influence behaviour. These may include information about energy shortages, supply security and environmental concerns during the peak hours.

This research is intended to begin the process of understanding the importance of some of these factors in the arena of peak energy consumption behaviour.

Using stated preference survey and focus group discussions, information about household customers' energy use activities during winter morning and evening peak hours was collected. Data about how customers would modify their usage behaviour when they receive enhanced supply constraint information was also collected. The thesis further explores households' customer demand response motivation with respect to three factors: cost (price), environment (CO_2-intensity) and security (risk of black-outs). Householders were first informed about the relationship between these factors and peak demand. Their responses were analyzed as multi-mode motivation to energy use behaviour change.

Overall, the findings suggest that, household customers would be willing to reduce their peak electricity demand when they are given clear and enhanced information. In terms of motivation to reduce demand the results show customers response to the security factor to be on par with the price factor.

The Environmental factor also produced a strong response; nearly two-thirds of that of price or security.

A generic modelling methodology was developed to estimate the impact of households' activity demand response on the load curve of the utility using a combination of published literature reviews and resources, and own research work**.** This modelling methodology was applied in a case study in Halswell, a small neighbourhood in Christchurch, New Zealand, with approximately 400 households. The results show that a program to develop the necessary technology and provide credible information and understandable signals about risks and consequences of peak demand could provide up to about 13% voluntary demand reduction during the morning peak hours and 8% during the evening peak hours.

Glossary

Achievable demand response participation – the product of peak usage likelihood and demand response participation likelihood.

Activity demand response - the magnitude of demand response obtained as a result of customers adjusting the usage of a given household appliance.

Activity response – households change normal activity pattern by curtailing or shifting activities.

Anytime maximum demand – the average of 12 highest peaks over a year at the grid exit points.

Appliance saturation rate – the percentage of households that own at least one of a given appliance category.

Connected load – the sum of the continuous ratings of load-consuming apparatus connected to the system.

Demand – the amount of power that would be consumed if the system frequency and voltage were equal to their normal operating values for all consumers.

Demand factor – the ratio of the maximum demand of a system to the total connected load of the system.

Distribution transformer – the device use to converts electrical energy of higher voltage to a lower voltage, with frequency identical before and after the transformation.

Diversified demand –the demand of the composite group, as a whole, of somewhat unrelated loads over a specified period of time. It describes the variation in the time of use (or the maximum use) of two or more loads.

Feeder – the circuit which carries a large block of power from the service equipment to some points at which it is broken into smaller circuits.

Grid exit points – the points where high voltage transmission lines connect with the local distribution company's network.

Hourly variation factor –the ratio of demand of a particular type of load co-incident with the group maximum demand to the maximum demand of that particular type of load. It is simply the percentage of appliance load that coincides with the group maximum load.

Household – One person who usually resides alone or two or more people who usually reside together and share facilities (such as eating facilities, cooking facilities, bathroom and toilet facilities, a living area).

Likelihood of demand response participation – probability that appliance usage would be altered during the peak hours.

Likelihood of peak usage - probability that a particular appliance will be used, out of the pool of possible appliances during the peak hour.

Maximum diversified demand – the maximum sum of the contribution of the individual demand to the diversified demand over a specific time interval.

Mode response – households maintain normal activity pattern but reduce energy demand by turning off un-needed appliances or changing energy intensity.

Non-coincident demand –the demand of a group of load with no restriction on the interval to which each demands is applicable.

Residential feeder- the feeder that serves only residential customers, basically households.

Value of lost load – the average cost to customers per megawatt-hours of unnerved load when they are disconnected during involuntary load shedding.

Chapter 1: Introduction

1.1 Introduction

The electric power systems of developed countries provide electricity on-demand for all economic sectors: commercial, industrial, residential, agricultural, and in some countries transportation. The supply side consists of generation, bulk transmission, distribution and retail. The demand side results from consumption to support the economic and residential activities. The supply side and the demand side must balance at all times. For this reason, peak demand, which is the maximum demand for electricity over a specified period of time has been the focus of the electric utility industry for many years. Generation and distribution infrastructure has been planned, built and operated in response to both actual and anticipated customer demand.

Peak demand has a negative impact on the reliability of the power supply system. Two aspects of reliability are always contrasted: security and adequacy. Security is the system's ability to withstand sudden disturbances, while adequacy is the property of having enough capacity to remain secure almost all of the time (Stoft 2002). The electric utility industry has traditionally focused on peak demand because the likelihood of system outages, often measured by "loss of load probability" (LOLP) is by far the greatest at peak times. LOLP is typically concentrated in a relatively small number of hours per year, and those hours are often near the time of system or seasonal peaks (Koomey and Brown 2002).

Peak demand problems have traditionally been addressed on the supply-side through the construction of new power plants and reinforcements of the electricity grid. This is done to ensure that standard reserve margins are met. Reserve margin is defined as the percentage of installed capacity in excess of peak demand over a given period (IEA 2002). The recommended standard reserve margin for the electricity industry is in the range of 15 – 17 % of the historic maximum system demand (IEA 2002).

As demand increases over the day, the utility companies must dispatch some of the reserve generation capacity to meet the additional demand. These generators, commonly referred to as “peaking plants” are very expensive as they usually run on natural gas or diesel. They emit comparatively more CO_2 than hydro and nuclear power plants, but less CO_2 than coal-fired power plants that are usually used for base load supply. If there is not enough capacity available to meet the increased demand, the utilities are posed with the need to curtail demand. By this, customers are paid by the utilities to shed load when demand reaches specific peak levels or for local utility emergencies. The customer must commit to curtail a certain minimum amount of peak demand. Or customers agree for the utility to shed the load in exchange for bill credit. Rolling blackout is the last resort measure to meet supply and demand balance, when demand is exceedingly high.

The electricity market deregulation has fundamentally changed the framework in which investment decisions are made in the electricity sector, and has raised some concerns about a possible major decrease of investments in the electricity infrastructure. The investment planning process is no longer “directed” by security of supply, but rather is reactive to market signals. An assessment of security of supply by the International Energy Agency (IEA) shows that the average reserve margins have decreased in many countries since the introduction of deregulation in the electricity market (IEA 2002; IEA 2007). Most deregulated markets are as a result characterized by price volatility. Price volatility is often a reflection of a low reserve margin. For example, at the time of the energy crises in California, the state’s reserve margin was reported to be as low as 3.5 % compared to the utility standard practice of carrying a 15 % reserve capacity. During this time, the wholesale price of electricity went up to $US750/MWh compared to the state’s average of about $US81/MWh (McKinsey 2002).

The other fundamental causes of price volatility include the difficulty in storing electricity in a large quantity, network and generation capacity constraints, the long lead time for new capacity additions, and the disconnection between the wholesale and retail electricity markets. These factors make it easier and more profitable for a firm to exercise market power, which exacerbates price volatility. Market power is typically defined as the ability to profitably alter prices away from competitive levels (Stoft 2002). Price volatility increases uncertainties regarding the long-run average rate of return on peak capacity investment. This may reduce the security of supply and increase the risk of power rationing during peak demand periods.

An alternative to continually expanding infrastructure to balance demand at peak times is to focus on managing that demand. Demand-side management (DSM) is the planning, implementation, and monitoring of utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape (Gellings and Parmenter 2007). Gellings – who coined the term demand-side management and continued to work on the development of its method – set out the field of utility DSM programs to include: load management, strategic conservation, load shifting, customer generation, and adjustment in market share (Gellings and Parmenter 2007). DSM can take place in all of the demand sectors: industrial, commercial and residential. A very important part of the DSM process involves integrated resource planning. Integrated resource planning (IRP) is a planning process for electric utilities that evaluates the demand-side to supply-side alternatives and selects the optimal mix of resources that minimizes the cost of electricity supply while meeting the reliability need and other objectives.

Today DSM programs that decrease the load on the utility network during peak demand periods have become what is known as demand response. Demand response is defined broadly as "changes in electricity usage by the end-use customers from their normal consumption pattern in response to changes in price of electricity over time, or to incentive payment designed to induce lower electricity use at times of high wholesale market price or when system reliability is jeopardized" (USDOE 2006). Demand response may be elicited from consumers through a retail electricity rate that reflects the time dependent nature of the costs of supply and delivery of electricity or a program that induces customers to change their usage behaviour, which in turn reduces the need for increasing the system capacity. It encompasses traditional load management (or direct load control) and time differentiated tariffs. Load management programs seek to lower peak demand during specific time periods by temporarily curtailing demand or shifting the demand to other time periods. Time differentiated tariff programs charge high prices per unit of electricity consumed during peak hours in order to influence customers to shift their electricity usage from peak to off-peak hours.

The benefits of demand response include cost reduction, improved environmental sustainability (if it results in reduced fossil fuel use), increased supply reliability and market efficiency, customer service improvement and market power mitigation (PLMA 2002). A conservative estimate in the U.S. market, for example, put the economic benefit of shifting 5 to 8 percent of customers' load from peak demand hours to as high as 15 billion a year (McKinsey 2002). The other most obvious societal costs that could be avoided with active demand response participation include rolling blackouts, the environmental emissions from inefficient peaking generators, and the use of scarce land resources to build infrastructure for the provision of power.

Demand response programs in the form of time differentiated hourly pricing already exist in the industrial and commercial end-use sectors. Big users in these sectors are often exposed to the wholesale price of electricity that reflects the time-varying nature of the cost of supply. Most of these big users therefore have an energy management team (or program) in place that ensures cost effective use of electric energy. Notwithstanding, a recent review of 43 real time price response programs in these sectors showed a mixed result. Only a few have achieved a significant, absolute or relative impact in terms of load reduction achieved (Barbose, Goldman et al. 2004).

The residential sector is a sector for which large demand response potential has been stated. But experience shows that there is often a gap between predicted and actual delivered peak reduction. This is often attributed to the lack of connection between the wholesale and retail market. According to an expert in demand response (McKinsey 2002)**:**

"the demand side of the market is not functioning well because customers are not seeing real-time price signals . . . With real-time pricing options and their supporting technologies in play, we would get the full benefits of deregulation."

Although there has been a pioneering effort with residential price response in few places, it is too early to assess their impact in reducing peak demand. Some fundamental questions still remain to be addressed.

- How is residential customer participation in a demand response program related to price?
- Are there other signals that could be effective, such as the environmental impacts or supply security?
- What energy use behaviours are prevalent in households during the peak demand hours?
- How would residential customers perceive a demand response request, and what behaviour modification would they adopt?
- Do high peak prices disproportionately effect essential energy services or wellbeing of different socio-economic groups?

These questions need to be addressed before effective demand response programs can be implemented in the residential sector.

This thesis investigates the energy activity system of residential customers during peak periods, and the factors that could influence residential customers to change their electricity usage behaviour to achieve demand response. Two demand response signals, in addition to price, were explored, supply security and environmental impact. This thesis is based on the premise that an individual's behavioural response to a peak demand reduction request may have external as well as internal motivations. The objective of this thesis is to broaden the customers' information scope to include external factors: environmental emissions at peak times (CO_2 intensity of generation), and social factors (risk of black-outs) that have links to individuals' intrinsic motivation to change behaviour. The focus is on the residential sector, as it is the sector with huge demand response potential but many behavioural challenges.

The next section of this chapter gives the historical context of electricity supply and demand, and how this has developed over the last 30 years. The section that follows defines the peak demand problem and describes how it has been approached in the past, followed by the contribution of this work. The last part of this chapter provides an outline about how the rest of the thesis is organized.

1.2 History of Demand-Side Management

Reliable and affordable supply of electricity have historically been primary policy objectives. Large-scale government investment was made in generation and transmission infrastructure throughout the USA, Canada, European countries, Australia and New Zealand. Public utilities planned, built and operated the electricity generation, transmission and distribution systems in anticipation of customer demand growth. During the initial development phase of centralized power generation, utility costs declined as plants became larger and more efficient. Starting in the late 1960's, costs began to rise due to many factors including: a slowdown in technological advances, increased cost of fuel, increased environmental controls, and overruns in nuclear power projects (Eto 1996; AESP 2001). In the 1970's, increasing demand for electricity coupled with an increasing electricity price as a result of the world energy crisis, gave rise to conservation initiatives. Proponents of conservation at the time argued that it would be cheaper to reduce demand than to increase supply. The Ford Foundation's Energy Policy Project, carried out in the United States, was perhaps the first study that put forward the idea that "conservation is as important as supply" (Ford-Foundation 1974). The Ford Foundation presented three scenarios for the America's energy future:

1. **Historical growth scenario –** would lead to continued supply difficulties.
2. **Technical fix scenario** – that employs energy efficiency, could cut energy consumption without affecting standard of living, and can have positive outcomes for the environment.
3. **A zero energy growth scenario -** included more conservation to the extent of some sacrifice of standard of living (from projected levels) and changes in lifestyle.

Amory Lovins, a physicist and an energy commentator wrote non-technical popular books, including "World Energy Strategies: Facts, Issues and Options" (Lovins 1971) and "Soft Energy Paths: towards a Durable Peace" (Lovins 1979), all of which argued that a demand-side option could contribute immensely in meeting future energy needs.

The 1980's saw the introduction of demand-side management. During this time, integrated resource planning through demand-side management projects resulted in considerable cost savings and improved grid security in the USA (Gellings and

Parmenter 2007). Today, demand-side management that addresses the problem of electricity peak demand is commonly referred to as demand response.

1.3 Peak Load: the Problem and Management

1.3.1 The Problem

The peak demand of an installation or a system is simply the highest demand that has occurred over a specified time period (Gönen 2008). Peak demand is typically characterized as annual, daily or seasonal and has the unit of power (http://www.thewattspot.com). End-use peak load refers to the activities that are using power at the peak time and the resulting peak demand is measured at the customer's meter. System peak load is measured at the power plant busbar and is the load served by generating plants. The simultaneous peak load for all end-users (e.g., for an entire utility service territory) is referred to as the coincident peak load.

Peak load problems occur in the electricity networks due to either insufficient generation or transmission capacity. This often results in an imbalance between demand and supply. Utilities have traditionally dealt with this issue through the supply-side by building more power plants and increasing the capacity of the grid infrastructure, thus ensuring there is a safe margin between maximum supply and demand. Demand-side solutions seek to lower the peak by influencing customers to reduce demand during such “critical” hours, and thus avoiding the need to make expensive investments to supply peak load.

New Zealand is one of the Organization of Economic Co-operation and Development (OECD) countries where reserve capacity has decreased since the deregulation and partial privatization of electricity supply (IEA 2007). This combined with an imperfect market forced the government to acquire a 155 MW oil-fire strategic reserve plant to help meet demand during critical periods – when high demand causes the wholesale price to rise, or when there is an emergency. A previous study categorized the residential sector as the largest contributor to the peak demand, accounting for more than half of the system peak load (Electricity-Commission 2007). One aspiration of this thesis is to contribute to the understanding of households’ energy use behaviour responsible for the peak demand, and how it could be managed more effectively than the already existing strategies.

1.3.2 The Peak Demand Management in the Residential Sector

Two basic strategies have been used in the past by utilities around the world to control residential peak load: *direct load control* and *time varying pricing* programs. Direct load control programs (DLC) offer households recurring monthly bill credit in exchange for the utility controlling some large energy consuming household appliances. The most frequently controlled residential end-use appliances are central air conditioners, water heating cylinders, electric space heaters with storage features, and lighting. The use of direct load control differs between geographical areas and depends on the load pattern of the location. Ripple control of water heating cylinders is a typical example of a direct load control program in New Zealand (Stevenson 2004.). In Australia and some part of the United States, direct load control is used to control the air conditioning load in summer (USDOE 2006; ETSA 2007).

Direct load control programs have been very successful in reducing residential peak demand in many places (IEADSM 2008). DLC programs are feasible with the existing metering infrastructure – it does not require advanced metering and investment in direct communication equipment. However, critics argue that it deprives the residential customers of total control of their end use appliances. There are also equity questions, as customers who do not own big energy consuming equipment like central air conditioners, and as a consequence do not contribute to system peak demand, are not eligible for program benefits (Herter 2007).

Time-varying pricing, unlike direct load control, relies on a clear pricing signal – an order of magnitude higher at peak times – to influence customers to shift their electricity usage from peak to off-peak hours. Customer response in this case is driven by an internal economic decision-making process and the load modifications are entirely voluntary.

Examples of time varying demand response programs are:

- ***Time-of-use-pricing (TOU)*** rates charges different prices for electricity used within defined time periods. With this program, price per kWh of electricity used at peak demand hours is higher than electricity used during off-peak as illustrated in figure 1.2a. One particular feature of this program is that the prices are fixed for the blocks of time within which they apply.

- ***Critical-peak-pricing (CPP)*** rates have higher charges for electricity used during the periods that are designated as critical by the utility. This program is similar to the TOU rates except that the times and the rates are not fixed (see figure 1.1b). Based on the projected demand and the supply condition, a utility could designate a particular time as critical. CPP events amount to a few hours per year and are dispatched on a relatively short notice. CPP is illustrated in figure 1.1b. The dotted line means the peak rate is not fixed and could differ from event to event.

- ***Real-time-pricing (RTP)*** rates vary continuously based on wholesale price or regional demand. Unlike the critical-peak-pricing and time-of-use pricing, real-time-pricing rates provide different prices for the electricity consumer at each hour of the day. Figure 1.2 below shows the schematic drawing of the different types of time-varying pricing programs
- ***Peak time rebate*** is a customer friendly rebate approach to CPP. It is dispatched the same way as CPP. Customers remain on their current rates but receive rebate

payments if they reduce their consumption during peak load events. The rebate payment is usually based on the reduced consumption from a calculated baseline (based on an event day).

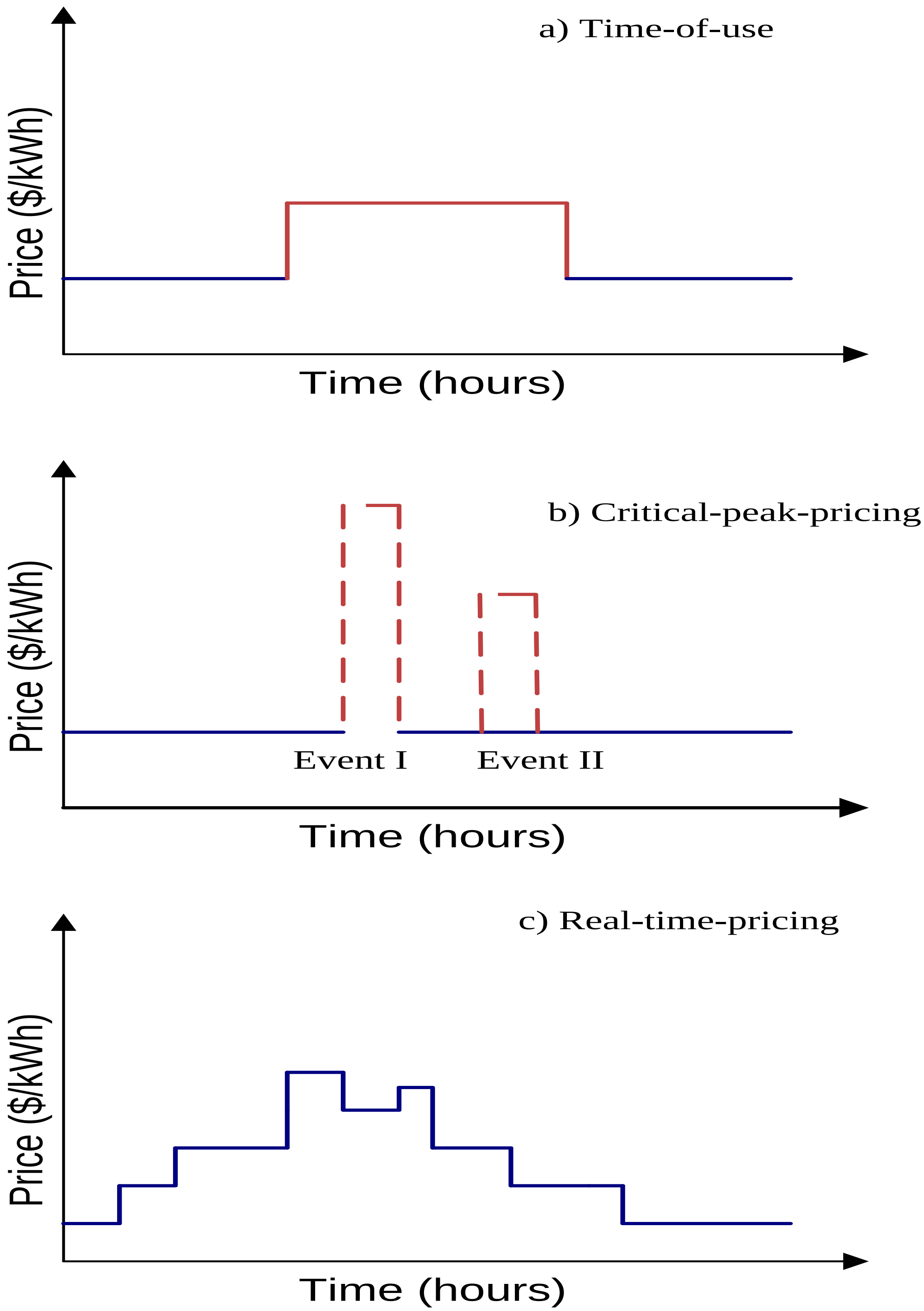

Figure 1.1: Schematic sketches of the types of time varying price response.

Time varying pricing tariffs have been criticized as they may have serious economic consequences on low-income households. It is well understood that when a necessity of life such as energy becomes scarce and expensive, the market mechanism deals harshly with the poor. Critics of the time varying pricing concept argue that the levels of price that may be required to achieve the needed peak demand response could be higher than what is affordable to lower socio-economic households and could lead to “lifestyle cutbacks” (Dillman, Rosa et al. 1983).

1.4 The Contribution of this Work

While direct load control and time varying demand response programs have been the two main strategies used to achieve residential peak load reduction, their limitations in addressing major customer concerns suggest that a broader perspective is needed in order to achieve effective demand response. In most cases, the programs rely on technology and economic principles with more emphasis placed on either the incentive paid to customers, or the price. The underlying reasons such as system security and environmental sustainability are often not emphasized.

This thesis investigates the potential of other factors that could influence customers and how these factors can be used in addition to price to achieve cost effective peak demand reduction. Given the potential economic, environmental and security (blackouts) implications of peak demand, it is important to understand how residential customers would respond, if they were informed of these factors. This thesis will help to advance the understanding of how customers value the environmental and security implications of peak demand and how they could be used as demand response signals. It is well known 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 is necessarily to significantly affect the behaviour (Abrahamse, Steg et al. 2005) .

The thesis has two main parts. The first explores the impact of broadening the scope of information that is conveyed to households during peak hours to include environmental emission caused by peak demand, and security information using stated preference surveys. This entails the study of energy use activities at peak times and customers' willingness to adopt any changes, such as switching off lights (curtailment), and running dishwashers late in the evening (demand shifting). The behaviour aspects related to the shifting are largely unknown in the residential demand response. There is an acknowledgement that demand response may just move the peak problem with scale to other time periods. The second part investigates this problem by analyzing the effect of customers' response on the load curve of the utility.

1.5 Thesis Outline

Chapter 2, **background I – The power system in New Zealand**, gives a thorough review of the electricity supply system in New Zealand. Chapter 3, **the peak demand problem and management in the residential sector,** defines the problem of the peak load and how it is managed using the concept of demand side management. Chapter 4, **background – energy use behaviour and its change in the residential sector,** gives a review of how energy use in the residential sector has been influenced in the past. Chapter 5, **Method**, discusses the method that is used to gather the data for this study**.** Chapter 6**, results and analysis of case study,** provides the results and analysis of a case study in Christchurch. Chapter 7, **demand response impact modelling,** discusses the modelling methodology used to estimate the potential of household customers demand response. In Chapter 8, the modelling methodology discussed in chapter 7 is applied in a case study in Christchurch to estimate the impact of residential demand response on the load curve of the utility. Chapter 9, **Conclusions and recommendations**, outlines recommendations regarding broadening the demand response information scope to the utility. Chapter 9 also includes subjects for future study.

Chapter 2: Background I – The Power System in New Zealand

2.1 Introduction

This chapter gives a thorough review of the electricity supply system in New Zealand. It gives a brief review of demand trends and the implication of these trends on the supply infrastructure. It focuses more precisely on peak demand and its implication on the security of supply. Finally, the strategies that are currently used to address the problem of peak demand are presented and discussed.

2.2 The Electricity Industry

New Zealand's net electricity generation in 2007 was 42,374 GWh from the total installed capacity of 9.133 GW (MED-d 2008). The electricity industry has undergone a series of drastic changes since 1978: the start of deregulation (1980s), market-based competition (1990s), the legislative reform of the industry (1990s), improvement for market functions (2000), and the single governance framework (2003) (Lee 2004). The government expects these changes to provide effective electricity market operation. Four priority areas of government policy are: security of supply, priority investment in transmission, hedge market arrangement and demand-side participation, and the promotion of efficient use of electricity (MED-b 2009). The New Zealand electricity industry, like that of the most deregulated electricity markets around the world, is separated into five main sectors: generation, transmission, distribution, retailing, and the market. The function of these five sectors is discussed in the following subsections.

2.2.1 Electricity Generation

New Zealand electricity generation is dominated by five main generation companies: Meridian Energy, Genesis Power, Mighty River Power, Contact Energy, and Trust Power. The first three are state owned companies that resulted from the corporatization of government electricity business, while the last two (Contact Energy and Trust Power) are currently owned by the public. These five companies provided about 92% of New Zealand electricity generation in 2007. The remaining 8% was supplied by independent power producers (IPP) and on-site generation. Figure 2.1 shows the percentage share by generation of the different generation companies.

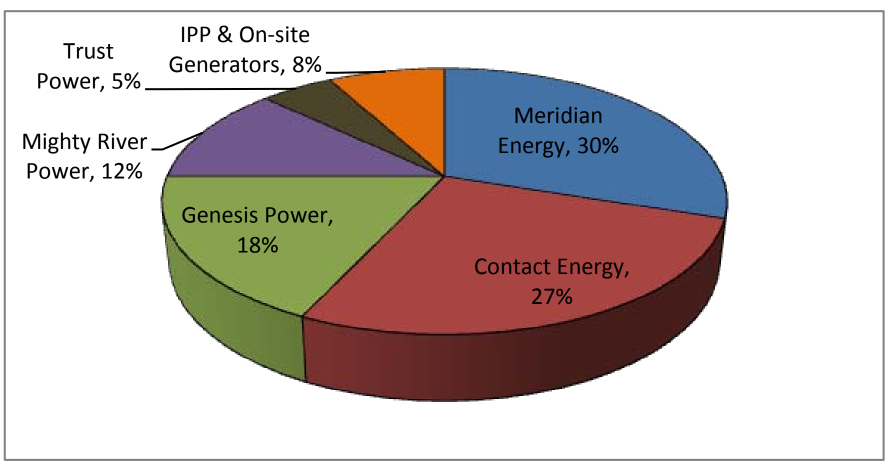

Figure 2.1: New Zealand Electricity Generation by Company in 2007
(MED-d 2008).

Table 2.1 gives the breakdown of the estimated installed capacity and their corresponding generation for 2007. It shows that New Zealand generation is dominated by hydro at 55%, followed by fossil fuels at 33% with the remaining 12% coming from other renewable sources such as wind, geothermal and biomass. The latest government *Energy Outlook* projects electricity generation from renewable sources to reach about 90% by the year 2040. Wind energy is expected to contribute about 40% of the total capacity that would be installed within the outlook period of 2009 to 2040 (MED 2009).

Studies show that as the penetration of intermittent renewable generation (such as wind, PV, etc.) reaches 15% or more, an additional control exercise is required to balance the generation variability that is introduced from the bottom-up, and the existing demand variability from the top-down. In some areas of mainland Europe (e.g. Demark and Germany), where a large renewable penetration exists on a network, the system is managed by a recourse to large flow of power across national boundaries. This flow ensures demand is met during periods of low renewable generation and also to allow excess power to be used elsewhere during periods of high renewable generation. In an isolated country like New Zealand, where there is no such option of power import and export, this problem could be solved by either adapting supply to demand or through demand response. However, when the fluctuating supply must be adapted to the electricity demand an increased storage need is created, which is very expensive compared to adopting demand to supply (Klobasa, Obersteiner et al. 2006; Stadler 2007). Demand response is therefore a critical feature to be developed for an efficiently functioning electricity grid in an isolated country like New Zealand, which is aspiring for a high intermittent renewable penetration.

In New Zealand, the dispatch of generation to meet demand varies over the day. Hydro and geothermal power plants have the lowest operation cost and are used to supply the base load. The output from coal, gas and hydro power plants varies over the year and the days, with the peaking hydro having the greatest daily variation. The market system described in section 2.1.5 is responsible for deciding the generation make up at any particular time. Figures 2.2 and 2.3 show how the different generation resources are dispatched to meet demand.

Table 2.1 New Zealand total installed capacity and generation, year ending 2007 (MED-d 2008).

Generation Source	**Installed Capacity**		**Generation**	
	(MW)	**Share (%)**	**GWh**	**Share %**
Hydro	5,366.2	58.8	23,283	54.9
Gas	2,029.1	22.2	11,199	26.4
Coal	670.6	7.3	2,921	6.9
Geothermal	449.8	4.9	3,272	7.7
Wind	321.7	3.5	928	2.2
Oil	155.7	1.7	0.523	0
Combustible Renewable, Waste and others	139.7	1.5	771	1.8
Total	9,132.8	100	42,374	100

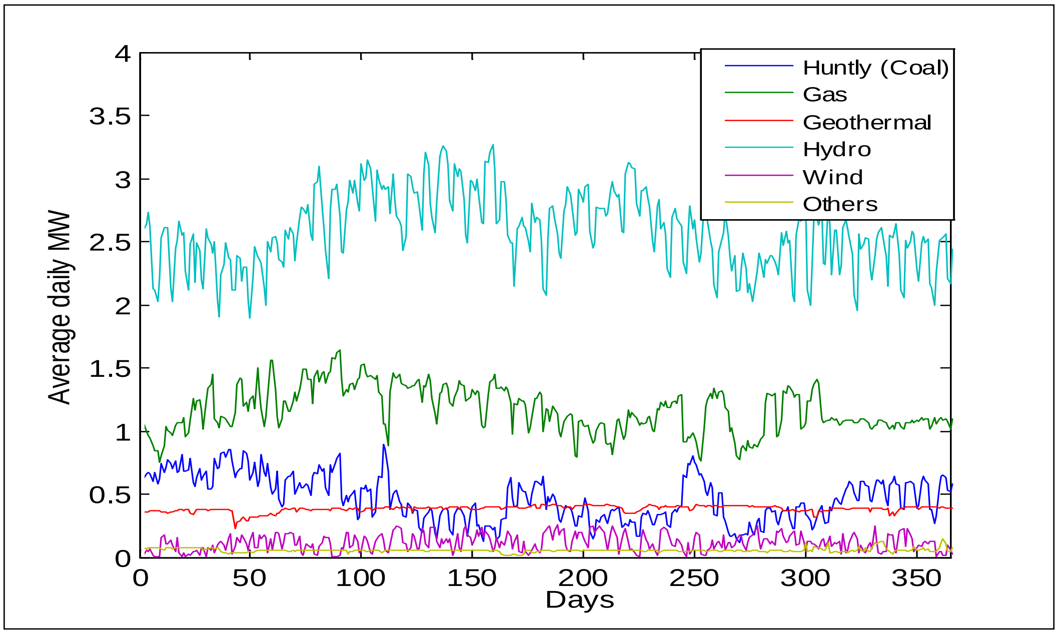

Figure 2.2: Typical dispatch of generation resources for a year (Electricity-Commission 2008).

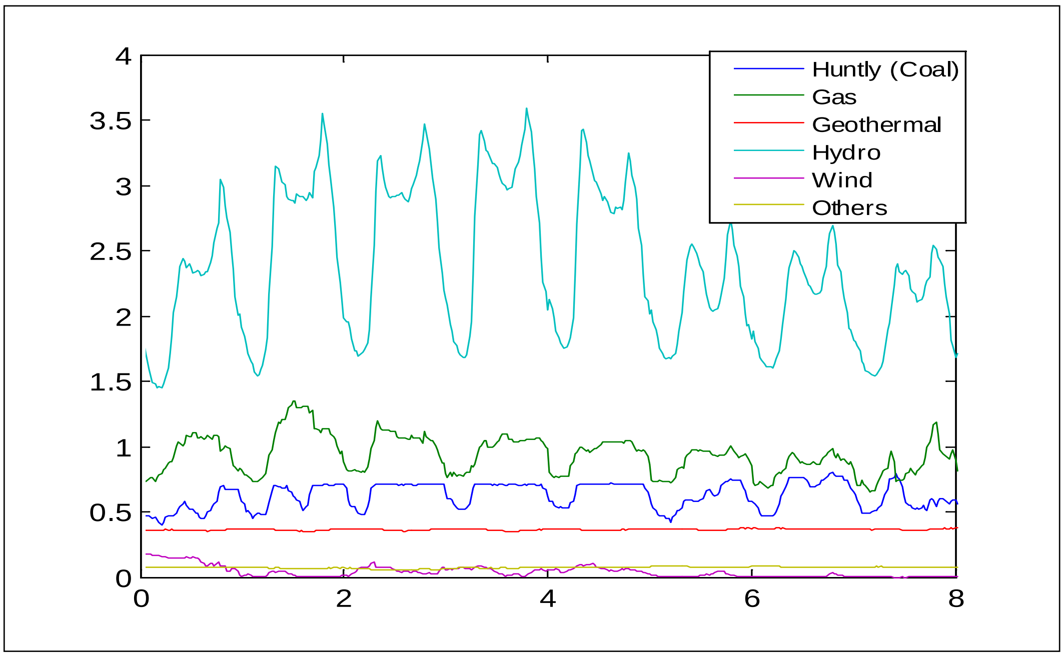

Figure 2.3: Typical half hourly dispatch of generation over a week (Electricity-Commission 2008).

2.2.2 Transmission

Electric transmission lines are the high voltage power lines that transport power from the generation stations to the key distribution points (grid exit points) around the country. New Zealand's electricity transmission network is radial (IEA-c 2006). A radial system is comprised of separate circuits "radiating" out of the source, each serving a given area (Pansini 2006). New Zeeland's transmission network is made up of 17,249 km of overhead lines and 85 km of underground cables. The two islands are connected by a high voltage direct current (HVDC) cable with a capacity of 1040 MW from the south to the north direction and 600 MW from the north to the south (IEA-c 2006). Transpower owns and operates New Zealand's high-voltage electricity transmission grid.

Much of New Zealand's electricity is generated from lakes and rivers in the South Island while most of the electricity demand is in the North Island, particularly the Auckland region. Transpower ensures that its network is capable of transmitting power between the two islands. It works in collaboration with electricity generation companies as well as distribution companies. Overall, Transpower acts as a system operator and "keeps the right amount of the energy flowing 24 hours a day" (http://www.transpower.co.nz/whatwedo 2009). It is responsible for the real-time coordination of electricity transmission and provides scheduling and dispatching of the services.

2.2.3 Distribution

There are currently 27 distribution companies that own the distribution lines in New Zealand. The distribution companies own the equipment between the transmission grid exit points and the point of connection to the consumer. The ownership of distribution companies is a mix of public listings, shareholder co-operatives, community trusts and local body ownership, with most companies being owned by trusts. The distributors are responsible for electricity delivery to the end users within their network area. Distributors have a contractual agreement with the retailing companies rather than the consumers directly.

To cover the costs involved in meeting peak demand, Transpower charges to the distribution companies are based on Anytime Maximum Demand (AMD). AMD is measured as an average of the 12 highest peaks over a year at the grid exit points. This creates an incentive for distributors to minimize peak demand. Most distributors have programmes to manage industrial and residential consumer load in order to minimize their peak load charges and also preserve their network security. For example, the distributor in Christchurch, Orion Energy, implements ripple control under a contractual agreement with the retailers.

2.2.4 Retail

The retail companies sell electricity direct to households and businesses. In total, there are 10 retail companies in New Zealand. The retail market is dominated by the five main electricity producing companies: Contact Energy, Genesis Power, Meridian Energy, Mighty River Power and Trust Power. These five companies have a total customer share of about 97% (see Figure 2.4 for details of the retail market share). The retailers are charged by the distributors for delivering the electricity. The charges for generation, transmission, distribution and retailing of electricity are bundled and the end user is invoiced.

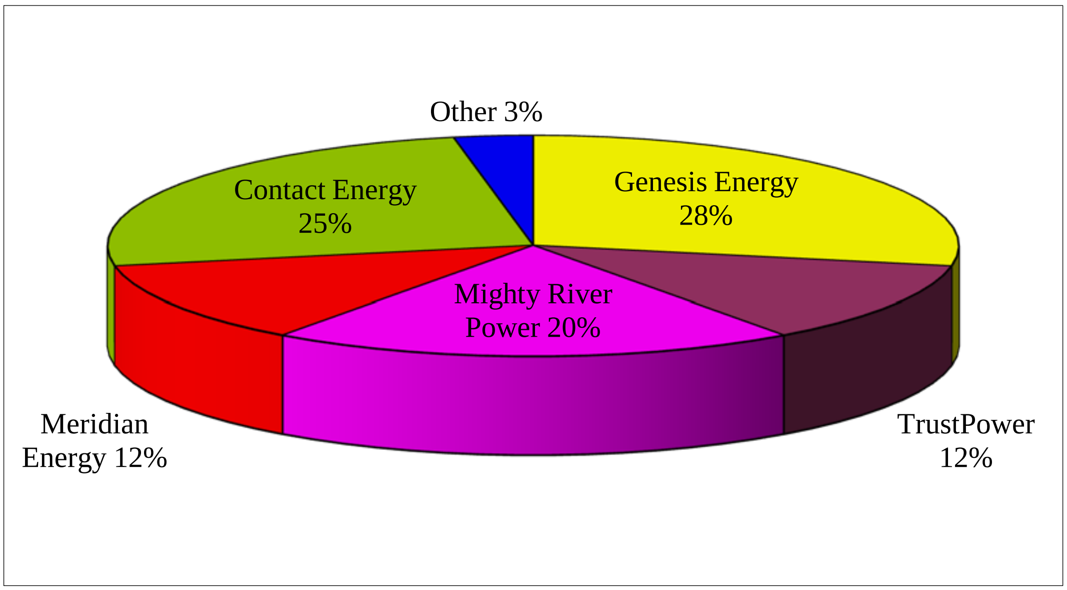

Figure 2.4: Electricity Retailers Market Share as Determined by Consumer Connection at March 2009 (MED 2009).

2.2.5 The Electricity Market

New Zealand's wholesale electricity market has been in operation since 1996. The market was first allowed to operate under the general market and competition laws. However, dissatisfaction with the competitiveness of the market led to the creation of the Electricity Commission in 2003 with the purpose to ensure an efficient operation of the electricity market. The Market is operated under the electricity governance rules and regulations 2003.

The market is divided into 48 half-hour trading periods and for each half-hour, wholesale electricity prices are determined by collecting offers from generators which are aggregated for all generators to determine a supply curve (See figure 2.5). Transpower then dispatches supply to meet demand at every half hour trading period. The wholesale price is determined on the basis of the Locational Marginal Price (LMP). The LMP includes the impact of marginal transmission constraints and transmission losses. There are approximately 266 nodes throughout New Zealand, and trading occurs at each. A node is the point where Transpower's high voltage grid connects with the local distributing company's network. The price at each location reflects the marginal energy price, transmission losses and transmission constraints. When there is not sufficient transmission capacity to meet demand in a particular region, generators within the region have the ability to set wholesale prices. "Price separation" occurs if the price set by the generators in the region is higher than the marginal price of an imported generation. Figure 2.6 shows the regional wholesale price in \$/MWh at 10:00 am on the 19th May,

2009. At this time, there was a lot of rain and the lakes (mostly located in the south) were spilling over, hence the very low prices in the south. High prices in the north are due to HVDC constraints for the transport of power from south to north and the expensive generation sources used in the north.

Although electricity is sold in the wholesale market, a system that allows market participants to hedge the risk associated with price volatility has recently been established by the four main New Zealand generators. However, this fixed price contract covers a small part of the New Zealand market. More information of the hedge market in New Zealand can be found in (IEA-c 2006).

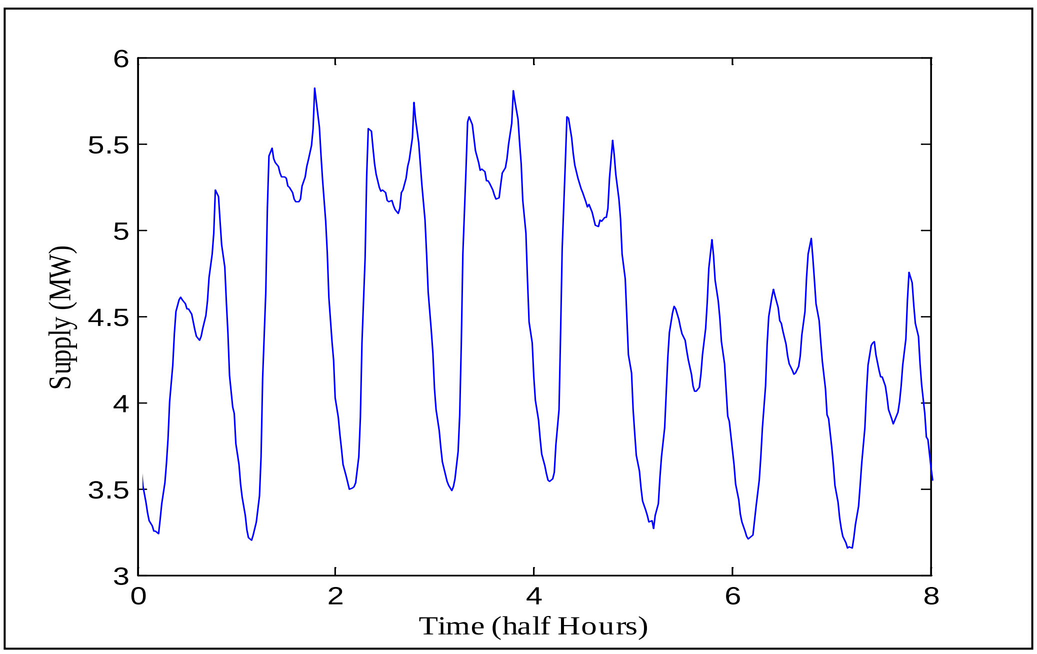

Figure 2.5: Aggregate Supply Curves for a Typical Week (Electricity-Commission 2008).

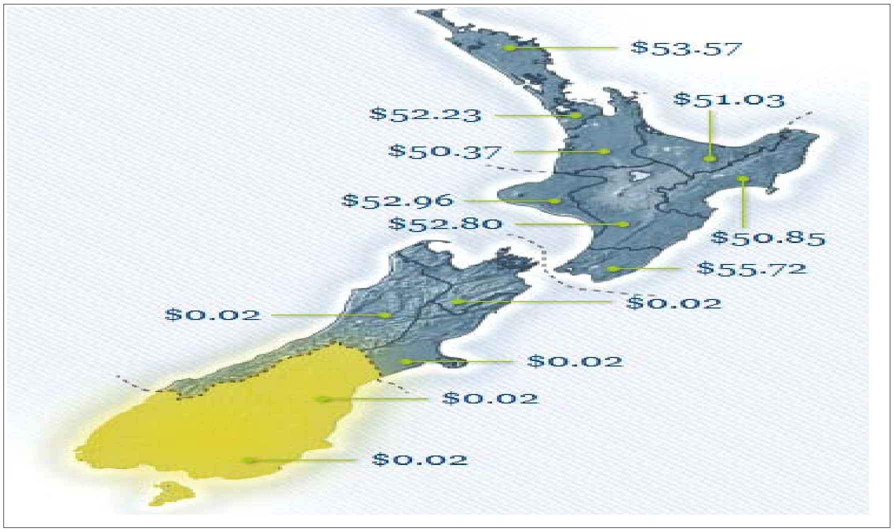

Figure 2.6: Regional Electricity Price ($/MWh) at 10:00 a.m on 19 May, 2009 (EMS 2009).

2.3 Security of Electricity Supply in New Zealand

The security of the electricity supply in New Zealand is strongly dependent on the legacy features of the power system (the stock of generation and network assets built to date) and other characteristics: its isolation, which rules out the possibility of electricity import, its geography; and the quantity, cost and location of its local energy resources (MED-b 2009). A particular important feature of the power system in New Zealand is the dominance of hydro electric power in the generation mix. A unique aspect of New Zealand hydro is the very small storage ability compared with other hydro systems around the world. Variability in rainfall therefore results in a variability of the amount of electricity that can be generated from the hydro power plants (see figure 2.7).

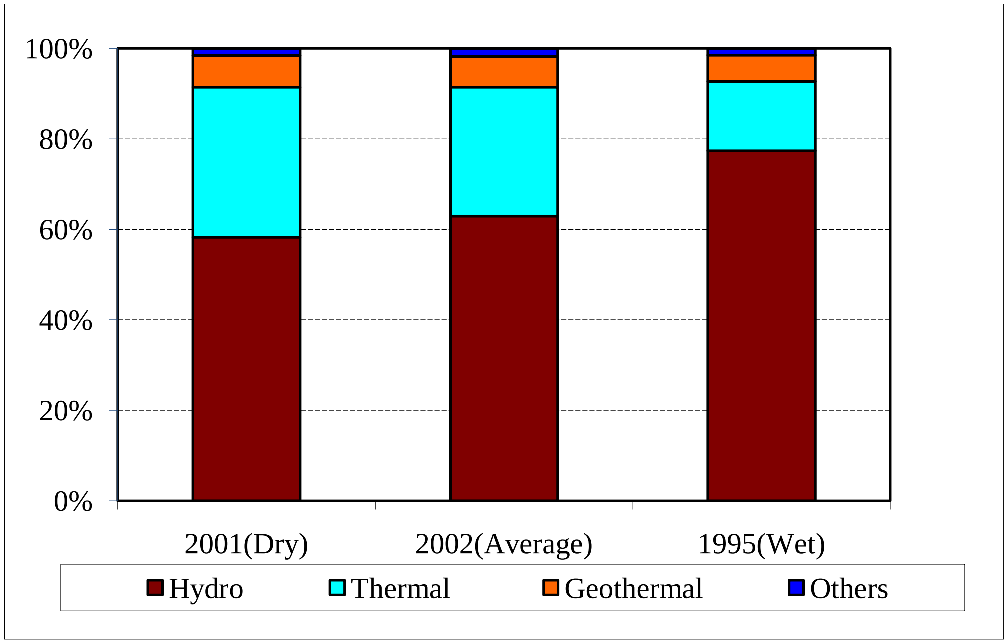

Figure 2.7: Average Annual Electricity Generation in Representative Years (MED-d 2008) .

Until 2007, supply security had been based on a “1 in 60 dry years” standard. This has been replaced with a “winter energy margin” standard. This margin is measured as the difference between the forecasted capacity of transmission and generation, and forecasted demand. This margin is set at 17% for the whole of New Zealand and 30% for the South Island (Electricity-Commission 2008).

Variability in supply from hydro power plants has been managed by building more thermal power stations that operate on fossil fuels like coal and natural gas. This has more than doubled the emissions from thermal electricity generation between 1990 and 2004 (see figure 2.8). The strong annual variations in emissions within the general variation trend reflect the availability of hydro generation in a particular year. Note that thermal power plants run as necessary to make up the required supply when there is a shortfall in hydro resources.

Figure 2.8: Changing Electricity Generation Mix and the Related Emission(MED-c 2007; MED-d 2008).

Despite the substantial increase in thermal capacity, the Ministry of Economic Development (MED) reports that there has never been enough thermal generation capacity to completely remove the risk of power interruptions caused by a potential hydro shortage. Instead, the power system has been managed so that the risk of power interruptions caused by a hydro shortage is kept to a low level. In 2005, a 155 MW oil fired reserve generation was acquired by the government to provide some certainty of supply security. This makes demand response an important component of the electricity supply.

2.4 Electricity Demand

In 2007, New Zealand consumed 38,545 GWh of electricity, with residential consumption at 33%, commercial at 22%, and industrial at 45% (MED-d 2008). On a per-capita basis, New Zealand consumes more electricity than Germany, France, and the United Kingdom. A recent study projected the total electricity demand to grow by an average of 1.4% with a high average expectation of 1.6% over the short-term, starting from 2005 (NZ-Treasury 2005). Figure 2.9 shows the projected electricity demand growth by sector from 2005 to 2030.

Actual current demand growth is somewhere between 2.0 and 2.5% (MED-d 2008). Peak demand has been growing on the average at about the same rate as the annual consumption growth. There are sometimes strong annual variations in the general variation trend. For example, the system operator, Transpower, recorded a New Zealand peak demand of 6748 MW (megawatts) on 29th June, 2006 (Transpower 2009). This surpassed the two previous records of 17th August and 9th June, 2004 and 2006 respectively. Until June 2006, the highest nationwide demand for electricity had been 6513 MW on 17th August 2004. The peak on 29th June represents an increase of 235 MW or 3.6%.

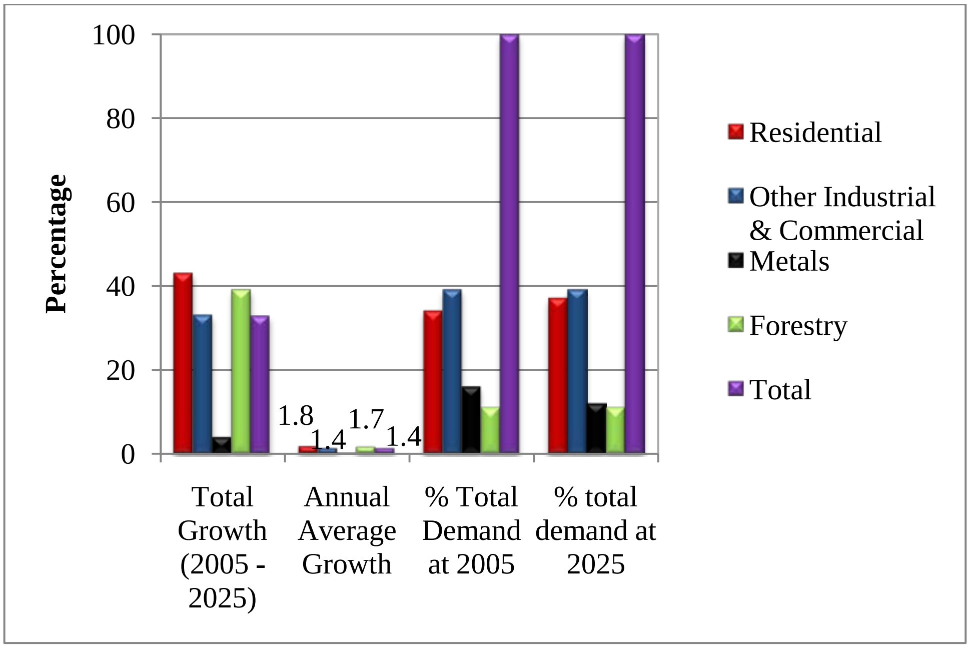

Figure 2.9: Projected electricity demand growth by sector (NZ-Treasury 2005).

Transmission infrastructure currently requires upgrading to manage increasing demand and to allow all renewable and existing thermal generation to get to the market. For example, since 2005, Transpower has obtained approvals for around $2.7 billion of investment, and a further $2.3 billion of upgrades are planned (NIU 2009). Figure 2.10 shows the national electricity consumption and peak demand recorded from 1998 to 2006.

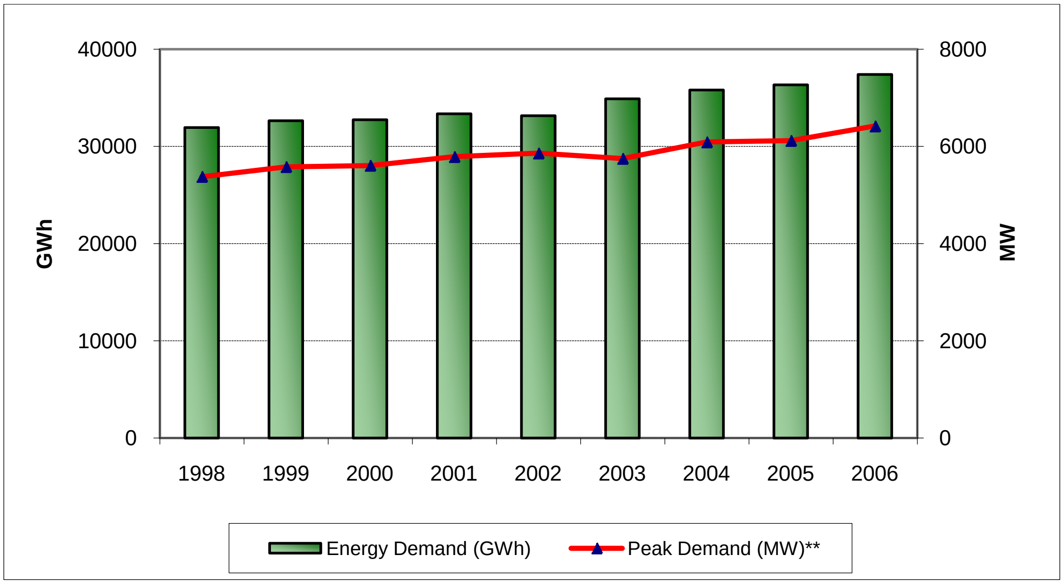

Figure 2.10: New Zealand's consumption and peak demand growth (MED-d 2008).

2.5 Summary

This chapter has shown that New Zealand's electricity consumption has been growing by an average of about 1.5 % annually. The growth is highest in the residential sector. Consumption per household has remained almost constant over the past years. Peak demand has been growing at a higher rate than the consumption growth rate. Residential sector contributes more than half of the system peak demand. On the supply-side, New Zealand generates a bulk of its electricity from hydro power. A unique feature of New Zealand hydro is the very low storage ability. Variability in rainfall results in variability of the amount of power that can be generated from the hydro power. In New Zealand, high electricity demand during the winter months coincides sometime with the dry years where generation capacity is limited. The ability of the supply system to meet peak demand in such situation becomes critical. The consequences of this are high wholesale price, and increased environmental emission as fossil fuel power plants are dispatched in such circumstances to meet demand. Consumption in itself is not a problem if it takes place at the time when there is enough capacity (generation and transmission) to support it. If consumption per household could be maintained while reducing per capita (household) peak demand, the supply system could function better. The challenge though is how to address the increasing peak demand.

Chapter 3: The Peak Demand Problem and Management in the Residential Sector

3.1 Introduction

This chapter defines the peak load problems that sometimes occur on the network of utilities and describes the particular nature of the problem in New Zealand. The contribution of the residential sector to the problem is discussed. This is followed by how the problem is solved using the concept of demand-side management.

3.2 The Peak Load Problem

Demand for power is the amount of power that would be consumed if the system frequency and voltage were equal to their target value for all consumers (Stoft 2002). The Peak demand of an installation or a system is simply the highest demand that has occurred over a specified time period (Gönen 2008). Peak demand is typically characterized as annual, daily or seasonal and has units of power. End-use peak load refers to the activities that are using power at the peak time and the resulting peak demand is measured at the customer's meter. System peak load is measured at the power plant busbar and is the load served by generating plants. The simultaneous peak load for all end-users (e.g. for an entire utility service territory) is referred to as the coincident peak load. In the residential sector, appliances that introduce spikes in demand are the range, oven, toaster, kettle, and washing machine (Wood and

Newborough 2002). Figure 3.1 shows the electricity demand profile of a single house recorded in a one-minute interval.

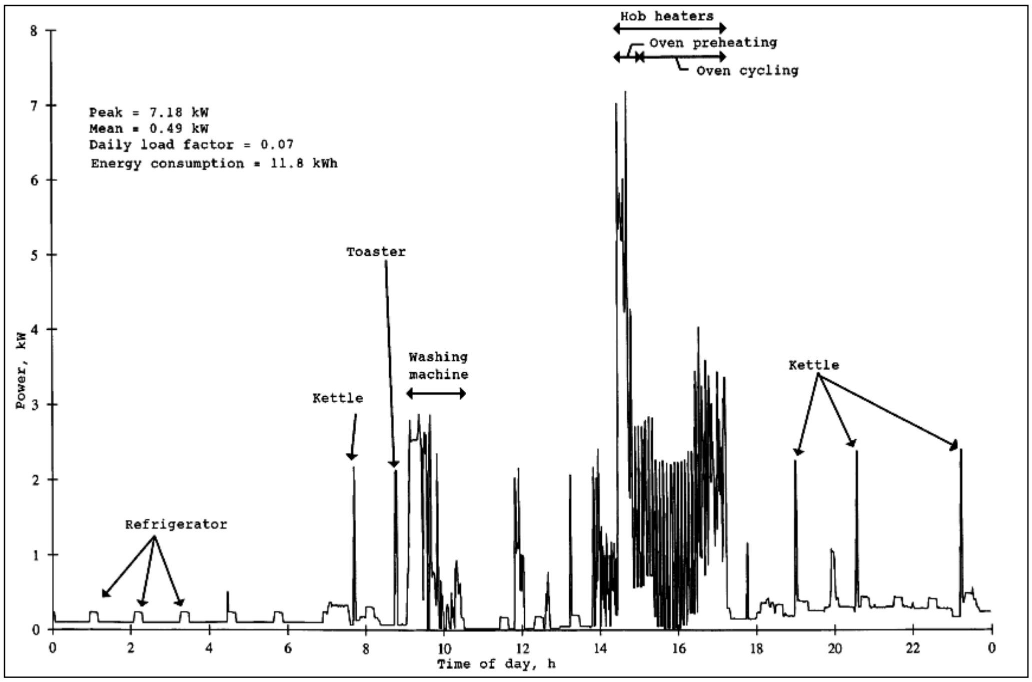

Figure 3.1: An example of the electricity demand profile of an individual household recorded on minute interval (Wood and Newborough 2002).

Peak load problems occur in electricity supply systems due to either insufficient electricity generation and/or transmission capacity. This results in an imbalance between demand and supply. This short–run supply-demand imbalance is indicated by voltage, and most especially by frequency. A drop in frequency and/or voltage below their target values is an indication that demand has exceeded supply. Similarly when the voltage and frequency exceed their target, it indicates that supply has exceeded demand.

At the time of low demand, only the utility's lowest marginal cost plants operate, while at peak times, almost all of the utility's available power plants must run to meet the demand and prevent system outages. The lowest marginal cost plants are often the most fuel efficient. For example, in New Zealand, the base load is supplied by geothermal and hydro power plants while the peak demand is met by dispatching peaking hydro and some local fossil fuel power plants that run on natural gas and diesel (Electricity-Commission 2008). These plants are expensive to run and they are also associated with high emissions and impact on the environment. Hydro is used to meet peak demand in New Zealand but in most countries hydropower supplies the base load.

The other part of the peak demand problem is related to network constraints. Power transmission and distribution networks become more congested during peak demand periods. The network constraints in power supply systems have both timing and spatial dimensions (IEADSM 2008). Peak time may be classified as either narrow or broad. Narrow Peak network constraint occur strongly at the time of the system peak and last for a short time. Broad peak constraints last several hours or days. In relation to the spatial dimension, network constraints can occur across the network in a particular geographical area, or be associated with one or more specific network elements such as lines or substations.

In a critical situation, if there is a lack of capacity to balance demand, load may be disconnected or “shed”. The disconnection is made without considering individual consumer welfare. The cost of such an outage across the range of customers – usually referred to as the value of lost load (VOLL) – can be very high. The electric utility industry has traditionally focused on peak demand because the likelihood of system outages, often measured by “loss of load probability” (LOLP) is greatest at peak times (Koomey and Brown 2002). LOLP is typically concentrated in a relatively small number of hours per year, and those hours are often near the time of system or seasonal peaks. Table 3.1 presents the different peak demand issues and their supply-side solutions.

Table 3.1: Different types of the peak load problem and their supply side solutions.

Peak Load Problem	Time Dimension	Spatial Dimension	Supply Side Solution
Problem with insufficient generation capacity	System peak, lasting few seconds, minutes, or hours	Occurring at a particular geographical location	Start reserve generator
	Seasonal peaks, lasting several days or months	Occurring throughout the entire system	Build additional power plants
Problem with insufficient transmission capacity	System peak, lasting few seconds, minutes, or hours	Associated with specific network element e.g. substation	Pay penalty for exceeding the peak limit
	Across the electrical load curve lasting several hours	Occurring across the network of a particular region	Network argumentation

Peak demand problems have traditionally been addressed by the supply-side through building of more generation capacity and network argumentation. There are a number of issues associated with the supply-side approach including high cost related to new capacity additions, environmental concerns, and difficulty in acquiring sites for power projects.

3.3 Demand-Side Management

An alternative to the supply-side solution is demand-side management. In the electricity industry, the term “demand-side management” is used to refer to the planning, implementation, and monitoring of utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility’s load shape (Gellings and Parmenter 2007). Instead of providing infrastructure to supply peak load that is needed for only a few hours in the year, demand-side management seeks to manage customers’ demand so that the option of having to supple the peak load does not arise. Peak demand reduction may be obtained by emergency demand response programmes that activate demand response resources in merit order, affecting consumers with the lowest benefit first. An example is contracts between consumers and their retail company that allows the power distribution company to control certain end use appliances when there is an emergency.

3.4 Demand-Side Management Concept

The term “demand-side management” (DSM) was introduced to the electricity industry in 1981 by Clark Gellings, a senior executive at the Electric Power Research Institute (EPRI) in the United States (Gellings and Parmenter 2007). DSM measures are designed to influence, and if necessary, change customer behaviour to achieve benefits for both the customer and the electricity industry. It has provided residential consumers with options to have energy services like water heating and air-conditioning curtailed during peak hours in return for lower rates. The different actions that fall under the DSM umbrella include:

- Actions taken on the customer side of the electricity meter such as energy efficiency measures.
- Arrangements for reducing loads on request, such as interruptible contracts, direct load control and demand response
- Fuel switching, such as changing from electricity to gas for water heating
- Distributed generation, such as stand-by generators in homes or photovoltaic modules on rooftops
- The different pricing initiatives, such as time of use, real time pricing, etc.

These actions can be used to achieve a particular load shape objective of the utility. Figure 3.2 shows the different load shape objectives for employing DSM. Time of day is on the horizontal axis and electricity demand is on the vertical axis. These load shape objectives can be described in the following ways:

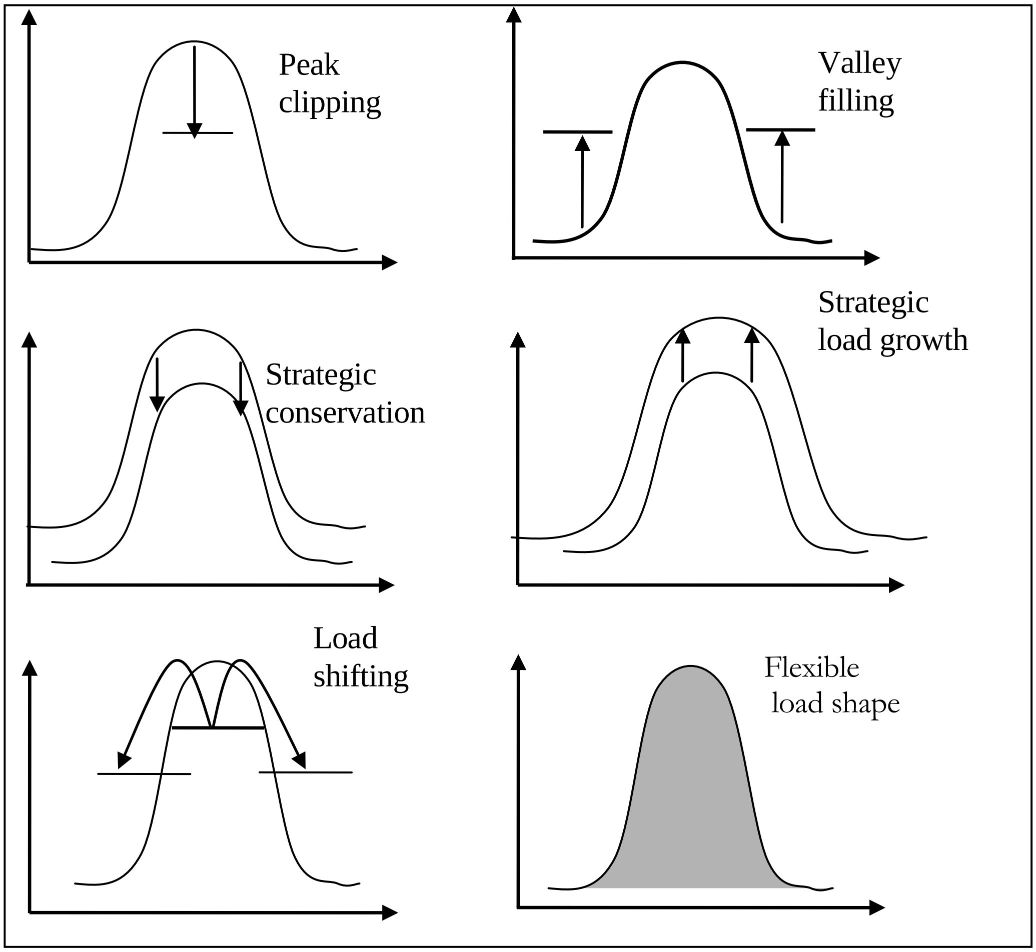

Figure 3.2: Basic load shape objectives of Demand Side Management (Gellings and Parmenter 2007).

- **Peak clipping**– reduction of peak load by using direct load control.
- **Valley filling –** building loads during the off-peak period.
- **Strategic conservation –** decreasing the overall load through reduction in consumption as well as a change in usage pattern. Appliance efficiency improvement is a typical example.

- **Strategic load growth -** increasing the market share of loads that are or can be served by competing fuel, as well as economic development in the service area.
- **Load shifting –** combines the benefits of peak clipping and valley filling by moving existing loads from on-peak to off-peak hours.
- **Flexible load shape –** specific contracts and tariffs with possibilities to flexibly control consumers' equipment.

3.5 Demand Response

Demand response is a type of DSM aimed at short-term behaviour changes to reduce peak demand to maintain the safe margin between generation and/or distribution capacity and demand. The term has arisen in recent times to describe a set of pricing structures, programs, and related technologies and services that provide options for customers to change their electricity demand in response to signals from the electric utility industry. Perhaps the most widely accepted definition of demand response is the one given by the United States Department of Energy (USDOE 2006): "…changes in electricity usage by the end-use customers from their normal consumption pattern in response to changes in price of electricity over time, or to incentive payment designed to induce lower electricity use at times of high wholesale market price or when system reliability is jeopardized". In a more general way, demand response can be defined as electricity consumers responding to external indicators by changing their normal grid-electricity usage patterns (Johnston 2001).

Demand response produces benefits primarily as resource savings that improves the efficiency of electricity provision. These benefits can be categorized under two main groups: benefits that accrue directly to customers and benefits that are not easily quantifiable but can have significant impact on electricity market operation (USDOE 2006). Table 3.2 shows the direct and indirect benefits of demand response.

Table 3.2: Direct and indirect benefits of demand response.

Direct Benefits	Indirect Benefits
participant bill saving- bill savings and incentive payments earned by customers that adjust their demand in response to changes in supply cost or other incentives	**Market performance** – reduces the ability of generators to excise market power
Bill saving for other customers - lower wholesale price that results from demand response that translate into lower electricity rate for all customers	**Improved choice-** customers have more options for managing their electricity cost
Reliability benefits- reduction in the likelihood and the consequence of forced outages that translate into reduced financial costs and inconvenience to customers	**Reduce Emission** -Depending on supply mix and the way it is deployed, demand response may result in reduced environmental emissions (Keith, Biewald et al. 2003)

3.6 Microeconomic analysis of demand response

The economic theory asserts that the most efficient use of resources occur when consumption decisions are based on a price that reflects the marginal cost of supply. In a competitive market, this is defined by the intersection of supply and demand curves. This point of intersection is usually referred to as the equilibrium point. The equilibrium point gives the price and consumption levels at which the market clears. Figure 3.3 above illustrates the demand and supply curve as applied to the electricity market, showing an equilibrium point (Q*, P*).

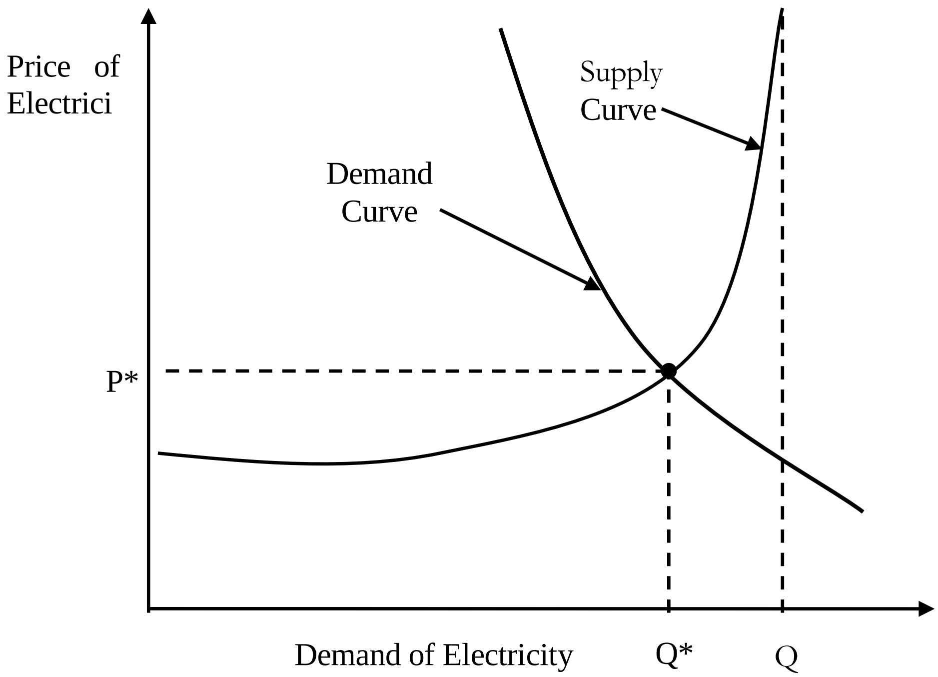

Figure 3.3: Illustrates of demand and supply curve as applied to perfectly competitive electricity market, showing an equilibrium point (Q*, P*).

In electricity markets, the marginal supply curve is constructed by ordering generators from the lowest to the highest operating costs. Due to technical characteristics (e.g capacity limits), the supply curve tends to increase very steeply at its upper limits, ending at maximum production capacity Q. This means that as demand approaches the maximum installed capacity, each additional increment in demand imposes increasingly more cost than the previous one. The demand curve slopes downward from left to right exhibiting declining marginal value.

If the price that consumer pays never varies, demand appears to be perfectly inelastic, and is characterized by a vertical line. But the demand for electricity unlike other goods changes with time, according to the activities of businesses, and residential consumers' lifestyles and consumption patterns. Since this change in demand is caused by other factors either than price, it can be represented on a standard microeconomic scheme by a shift in the position of the demand curve. Figure 3.4 illustrates a shift in demand curve from low demand period (off-peak demand) to high demand period (peak demand). At low demand, the wholesale market clears at the point ($Q_{off\text{-}peak}$, $P_{off\text{-}peak}$,) and during the high demand periods the wholesale market clears at the point (Q_{peak}, P_{peak}).

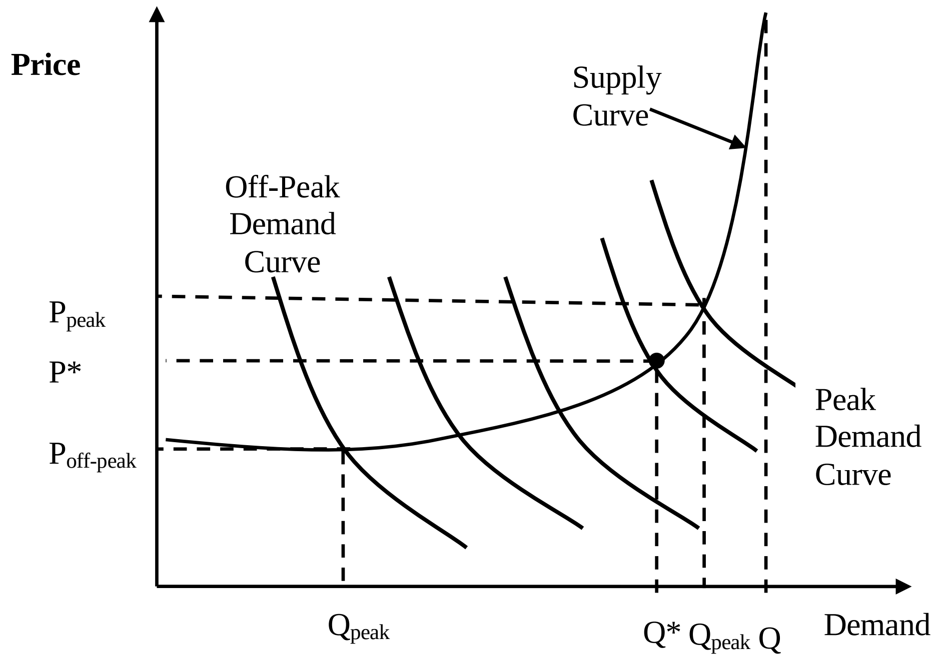

Figure 3.4: An illustration of change in electricity demand along the supply curve with no price change.

3.7 The Benefits of Demand Response

The benefits of demand response include improved economic efficiency, improved security of supply, reduced price volatility and the incentive for the exercise of market power, reduced investment in peak generation. The following sections explain some of the benefits using microeconomic analysis.

3.7.1 Improved Economic Efficiency in the Electricity Market

In most electricity markets, the residential customers are charged flat rates per unit of electricity they consume. As a result, they have no incentive to reduce their demand when tight supply conditions result in wholesale price spikes. Their demand is said to be perfectly inelastic. If residential consumers have some flexibility in their demand and are exposed to hourly variation in wholesale price, efficiency improves resulting in a welfare gain. Figure 3.5 illustrates the short-term effect of demand responsiveness in the electricity market. It shows that when information about customer demand responsiveness is brought into the wholesale electricity market, the demand curve will no longer appear vertical but would slope from left to right as shown in the figure 3.5. The market therefore clears at different consumption and price levels than before (i.e. when the demand curve is vertical). During high demand period, this occurs at a lower consumption and price levels (Q'_{peak}, P'_{peak}), than the situation with no demand response (Q_{peak}, P_{peak}). During a low demand period, the market clears at Q'_{off},P'_{off}, i.e. at a higher price level than the situation with no demand response (Q_{off}, P_{off}). The efficiency gains that arise due to customer demand responsiveness is represented by the shaded portion. The magnitude of the efficiency gain depends on how widely the average and marginal electricity costs vary, and consumer flexibility. In a tightly constrained market, as is the case in New Zealand, the potential of the short-term efficiency gain from demand response implementation can be substantial.

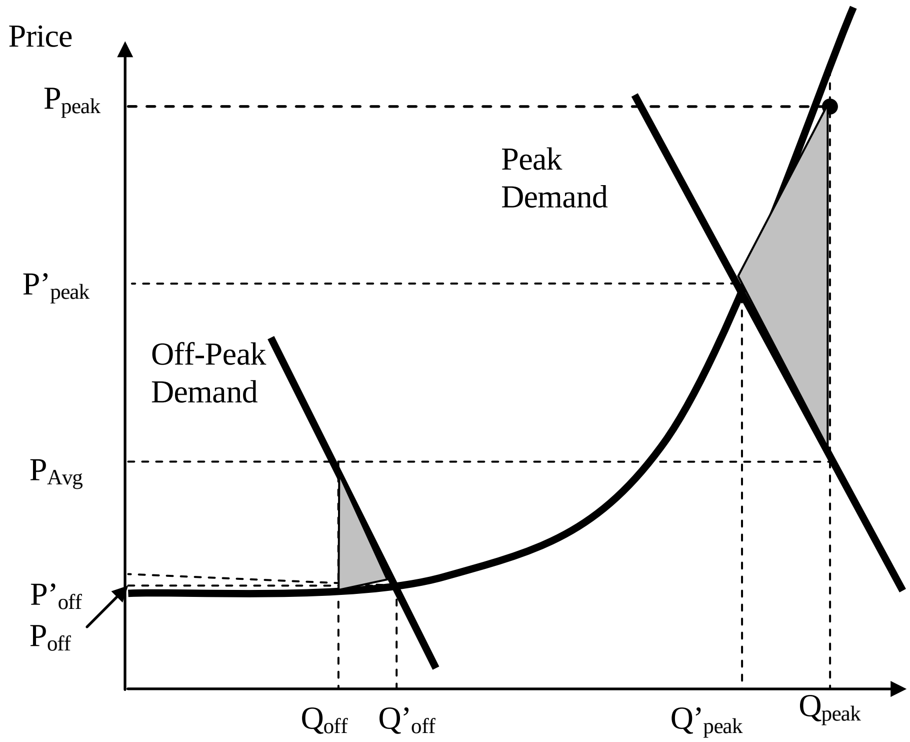

Figure 3.5: Effect of demand response to improve market efficiency.

3.7.2 Improved System Reliability

The electricity supply system requires a certain level of reserve margin to respond to contingencies. In the electric power industry, the reserve margin is often used as the measure of security. In New Zealand, the system security arrangements require a reserve margin of 17% of the historic maximum system demand. Demand response based load reductions can be used to replace some of the stand-by generation that provide the required reserve margin.

In case of generation outage or extreme weather event, if demand is not flexible, it may exceed supply and no market clearing price would be obtained. This is illustrated by the vertical line D1 in figure 3.6 below. In such situation, system operator may resort to power rationing.

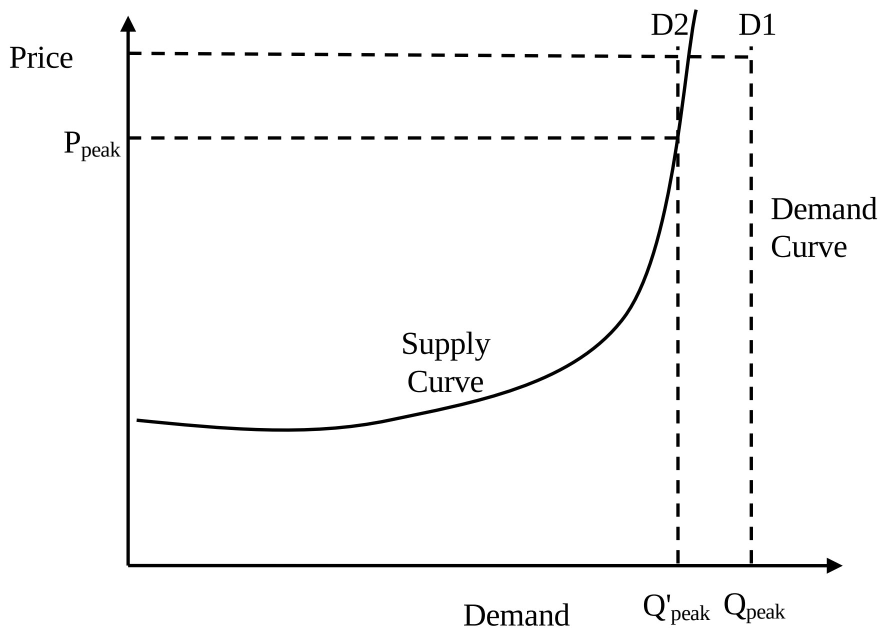

Figure 3. 6: An illustration of the reliability benefit of improved demand response.

Flexibility of demand may solve the problem by changing the position of the demand curve to D2 and obtain a market clearing price at $P_{peak.}$ The area under the curve that result, $D1D2Q'_{peak}Q_{peak}$ represents the value of the load that would have been disconnected, if there were no demand response.

The "Value of Lost Load" (VOLL) is used as a measure of how customers value electric reliability, or what they would be willing to pay to avoid a loss of service. "Given the wide range of customer circumstances and difficulties in predicting which customers will be affected by a particular outage, the accepted industry practice is to adopt a VOLL of $2-5/kWh, which represents an average value across the entire market" (USDOE 2006). The expected value of the curtailable load in avoiding outages can then be expressed as the product of the Expected Outages (hours/year) * the Expected Disconnected Load* VOLL ($/kWh).

3.7.3 Reduced Price Volatility and Incentive for the Exercise of Market Power

The wholesale price of electricity can be volatile. This price volatility occurs due to many factors including the inelasticity of demand in the wholesale market, the non-storage property of electricity, the uncertainty regarding customer demand that varies with time of year, week and day, and limited transmission capacity. A combination of these characteristics may cause the wholesale price to spike. Figure 3.7 show a ten year monthly average of New Zealand wholesale price of electricity for some selected nodes (Dupuy 2006). This example shows that wholesale prices could vary significantly between seasons.

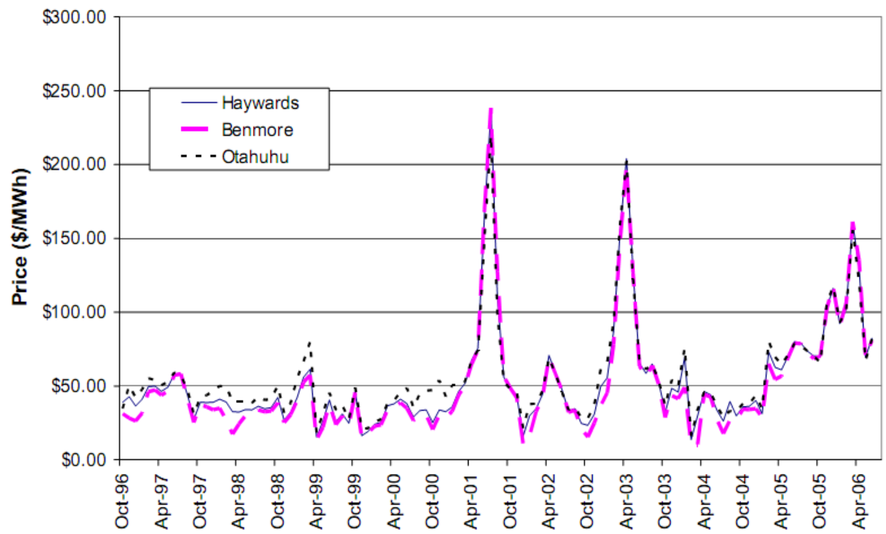

Figure 3.7: Wholesale price of electricity in New Zealand (Dupuy 2006).

Demand inelasticity may make it easier and more profitable to exercise market power which exacerbates the price volatility. Market power is typically defined as the ability to profitably alter prices away from competitive levels (Stoft 2002). It means that producers with a significant market share could withhold a fairly small amount of capacity and be rewarded with a substantial temporary increase in the market price. In this case, the high prices earned on the generators remaining online more than compensate for the lost revenue on the relatively small amount of the withheld capacity. Figure 3.8 illustrates the effect of withholding a small amount of generation from the market. If demand is inelastic this could result in increasing the price from P to P_{peak} and selling Q'_{peak} in the market generating an additional surplus of P_{peak} times (Q_{peak} - Q'_{peak}).

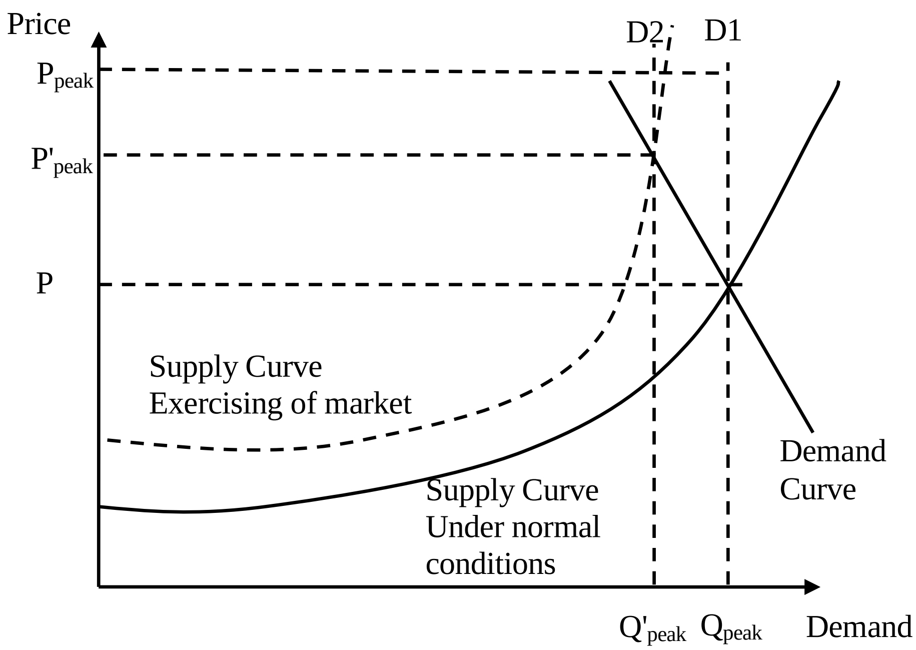

Figure 3. 8: An illustration of the effect of withholding supply from the market.

However, if consumer demand is flexible, it reduces to Q'_{peak} and the price only increases P'_{peak}, generating a lower additional surplus for the producer and therefore reducing the incentive to exercise market power. When firms exercise market power, prices deviate from the cost of production. Reducing market power therefore contributes not only to reducing price volatility and price spikes, but also reduces the wealth transfer from consumer to supplier.

3.8 The Problem of Peak Demand in New Zealand

The residential sector uses about 33% of annual electrical consumer energy (12,417 GWh) in New Zealand, but accounts for 54% 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 since 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. The growing peak demand coupled with a decreased margin of the installed capacity over peak load has required the building of new peaking power plants to ensure security of supply during the winter months (IEA-c 2006).

The peak demand problem in New Zealand is also related to limited transmission capacity and ageing transmission infrastructure. Most of the New Zealand hydro generation resources are located in the South Island while demand is concentrated largely in the North Island. The transmission between the two islands is via a High Voltage Direct Current (HVDC) submarine cable. The capacity of the HVDC determines how much power can be transmitted during the winter months from less expensive hydro generation stations located in the South Island to the main demand centres in the North Island. This can result in the high wholesale price of electricity in the North Island (as explained in chapter 2.2.5). In some parts of New Zealand, the peak problem is more related to the local distribution system. For example, in Christchurch, the most critical constraint on the electric system is the capacity of the regional distribution network.

In New Zealand the policy imperative for reliability and resilience, environmental responsibility and fair and efficient prices has been promoted by increasing energy efficiency and supporting innovation (MED, 2004). The previous Government's Energy Strategy set a target of 90% renewable energy generation (MED, 2007). The proportion of total electricity generation from renewable sources is currently at about 60%, as shown in figure 3.9. However, during winter, fossil fuel generation can make up as much as 40% of the supply in some regions.

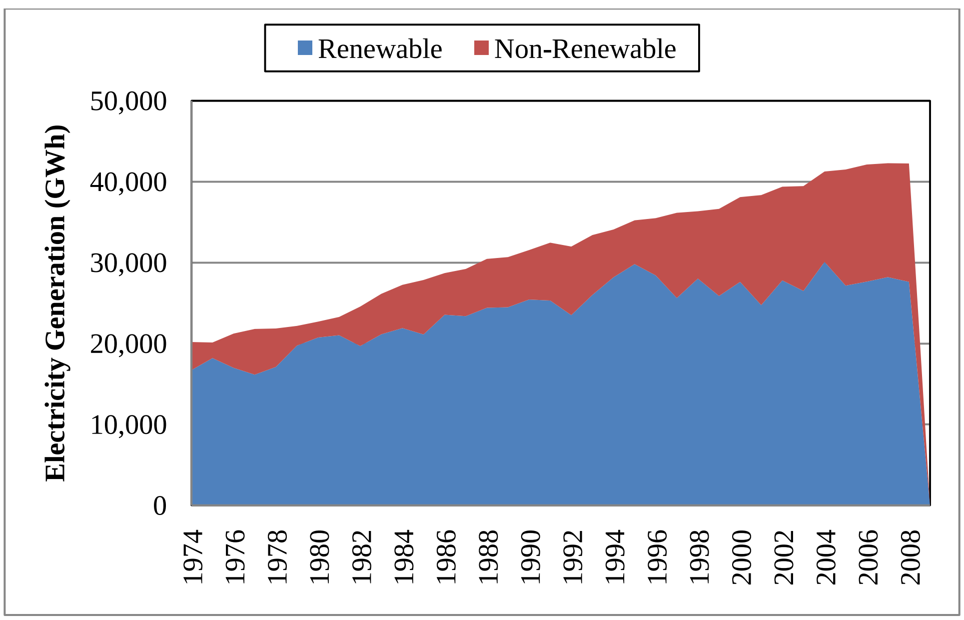

Figure 3. 9: Electricity generation sources in New Zealand classified as renewable and non-renewable. The renewable source consists mainly of hydro, geothermal, biogas, wood and wind. The non-renewable part is largely made up of coal and gas (MED 2008).

At more than half of generation capacity, the hydro supply can vary dramatically due to precipitation into the storage lake catchments (as discussed further in section 2.6.2). This results in variations from week to week and year to year with the risk of demand exceeding supply.

3.9 Global Experience with Residential Demand Response

Historically, utilities have used two strategies to reduce residential peak load: direct load control programs and time-varying pricing.

Direct load control programs are typically mass-market programs directed at residential customers. Customers agree to allow the utility to control the mode of operation of specific electrical appliances and in return receive discount on their monthly power bill. The end-uses act as a resource to ensure supply-demand balance. The most frequently controlled residential end-uses are central air conditioners, water heating cylinders, electric space heaters with storage features, and non-essential lighting. The use of direct load control differs between geographical areas and depends on the load pattern of the location. In Southern Australia and some part of the United States (e.g. California), direct load control is used to control summer air conditioners (USDOE 2006; ETSA 2007). Approximately 180 utilities in the USA offer their residential customers direct load control programs. Typical load reductions are in the range of 0.3 to 0.6 kW/house for water heating programs, and 0.4 to 1.6 kW/customer for programs that target only residential air conditions (USDOE 2006).

In Australia, direct control of residential air conditioners has been experimented and the result was quite impressive (ETSA 2007). Compressors of air conditioners were cycled in 15 minutes interval during two late afternoon hours. An average peak demand reduction of 0.25 kW per customer was achieved in the initial experiment that involved 20 houses. Figure 3.10 shows the result achieved in a hot afternoon day.

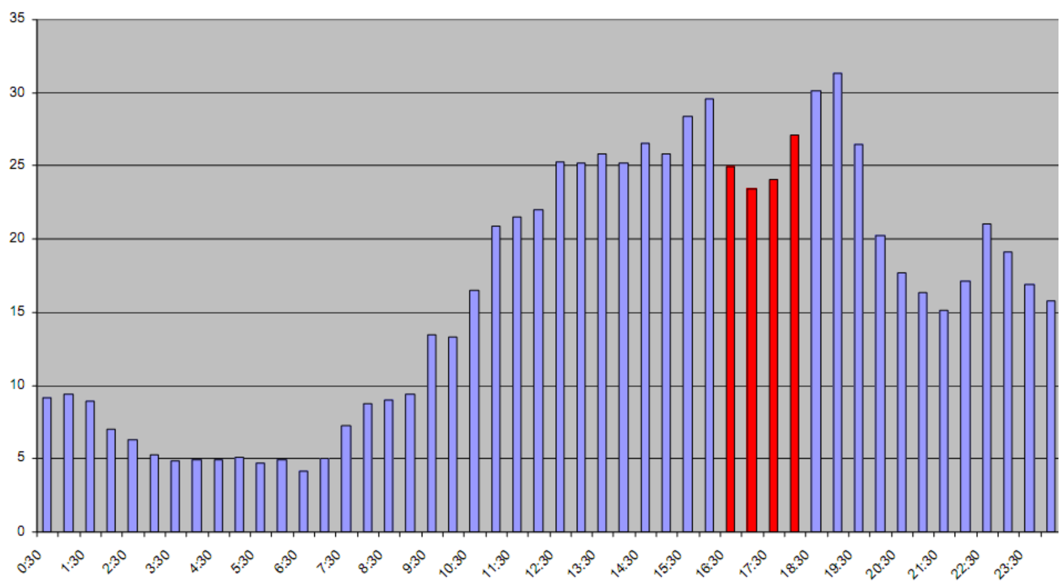

Figure 3. 10: The results of direct load control of residential air-conditioners for 20 houses in Australia; cycled at 15 minutes interval. The red bars indicate the controlled period (ETSA 2007).

In New Zealand, direct control is used to control hot water heating cylinders and night-store heaters in the winter. A signal is sent by the distribution company using ripple control technology. The time lag between the activation of a ripple control signal and the cycling of the water heating cylinder is about 6 seconds. The distribution company act as an intermediary on behalf of the individual houses and the transmission system operator. A typical effect of ripple control is 1kW/household. Customers who allow their water heating cylinders to be controlled receive a discount of about 11% on their monthly electricity bill. Figure 3.11 is an example of direct load control load management instituted by the Orion's network in the South Island of New Zeeland during a typical cold day.

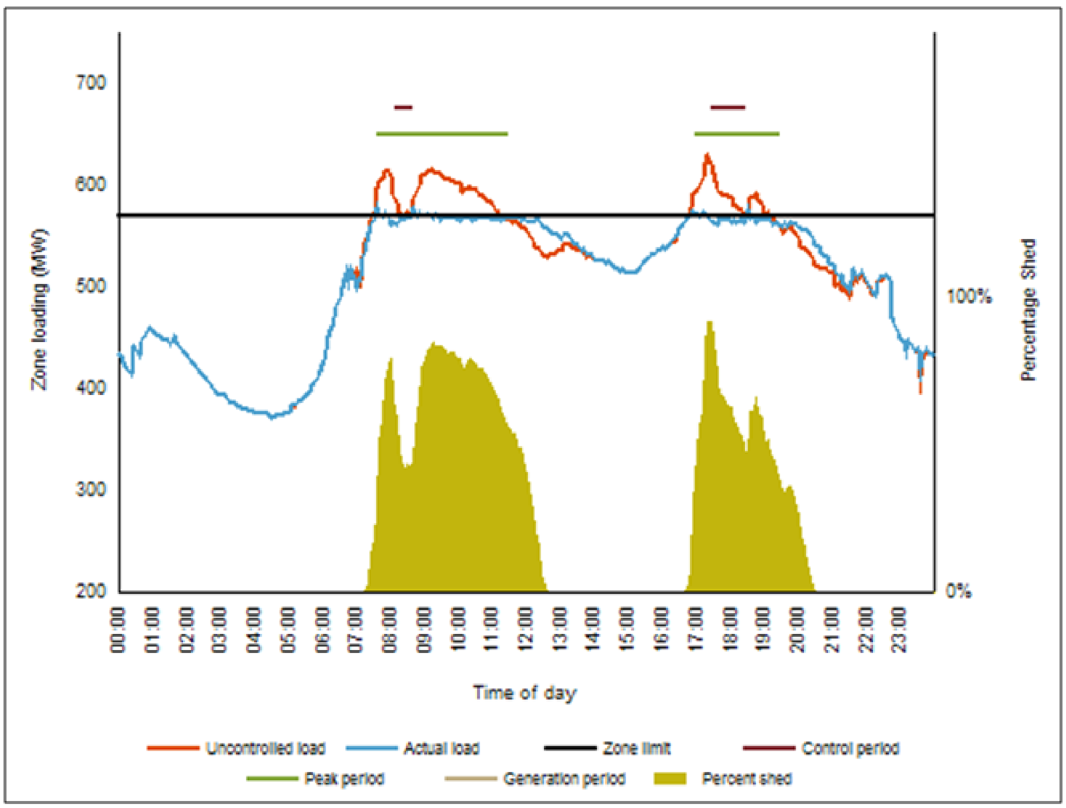

Figure 3.11: Load management instituted by the Orion's Network in the South Island of New Zealand(IEADSM 2008).

The light-blue curve indicates the actual demand and the red curve indicates an estimated baseline, i.e. demand that would have occurred if the direct load control programs had not taken place. The solid green line above the load curve shows the two peak periods, and the dark red line above it indicates the control period. The horizontal black line that cut across the load curve indicates the network's capacity limit (i.e. the maximum power that can be transported on the network). The two "mountains" below the load curves indicate the percentage of water heating cylinders that are switched off during the peak periods. Orion Networks has achieved a 90% penetration of water heating cylinder control in its service territory (IEADSM 2008). It is able to manage residential load ranging from 125–150 MW by the use of ripple control (EECA 2004).

Figure 3.12 shows a typical winter day electricity demand profile of residential customers in New Zealand. This chart represents the demand of approximately 400 homes in Halswell, a relatively new suburb in Christchurch, for some selected days in the winter month of July 2006. The infrastructure in the Christchurch area is owned by the Orion Networks. The profile shows that the hourly demand on a week day can vary from about 600 kW at low demand hours to 1600 kW during peak hours – an increase of 2.5 kW per house. The figure shows four peaks: a morning peak, an evening peak and two night rate peaks. Water heating cylinders and "night-store heaters" are on three different time-circuits and are switched on successively by the distribution company at 11:00 pm, 12 mid-night and 1:00 am, until 7:00 am.

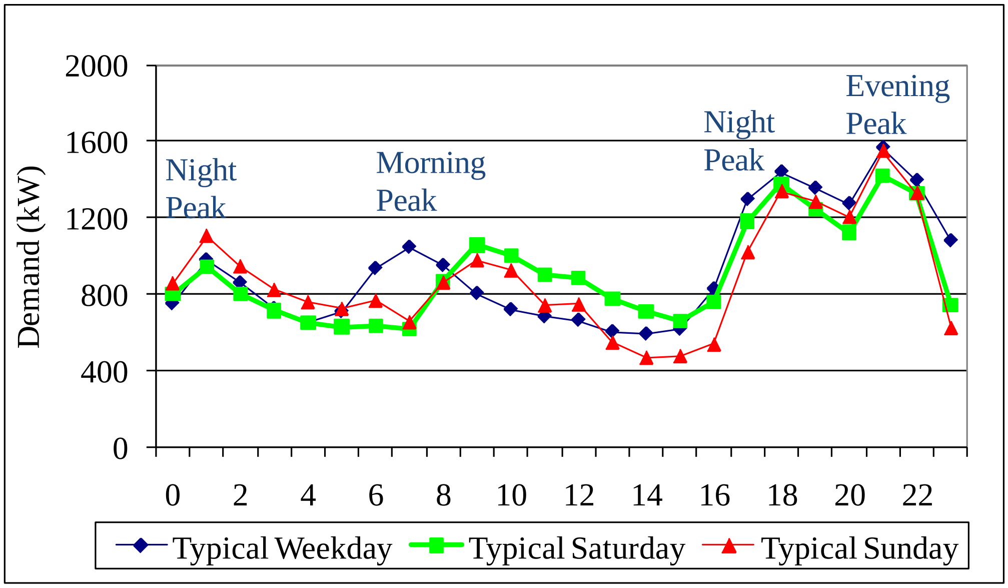

Figure 3.12: Daily load profile of approximately 400 households in Halswell, a relatively new suburb in Christchurch (OrionNetwork 2006).

At 1:00 am, all the water heating cylinders and the night-store heaters are "on", giving rise to demand spike at 1:00 in the morning. The peak between 6:00 - 8:00 am is due to routine household activities (getting ready for work, preparing breakfast, etc.). The peak between 6:00 - 8:00 pm is also due to household routine activities (e.g. preparing dinner). The evening and morning peaks are periods where the distribution company directly control demand with ripple control.

Despite the effectiveness of direct load control programs, they have been criticized for the following reason: they offer fixed financial incentives for unmeasured loads (Herter 2007). For example, the bill credit given by the utility is the same regardless of the amount of load reduction provided by the customer. In Orion's case, the benefit is linked to the ‘economy rate’. All customers on the ‘economy rate’ receive the same credit on their monthly electricity bill (Oriongroup 2008).

Time-varying pricing is the other residential peak demand reduction program. This category employs different pricing mechanisms including: time-of-use pricing, critical-peak pricing and real-time pricing. Instead of directly controlling the customer load at peak times, the pricing mechanism aims at influencing customers to shift the usage of electricity from peak to off-peak hours by charging high price per unit of electricity consumed during peak hours. Time varying pricing is employed in New Zealand for large industrial and commercial users with special half-hour interval metering that records customer demand during peak times. This type of pricing is currently not available to the residential customers. The residential sector pays flat rates for electricity consumption. Some residential customers receive split rate: day and night rates.

One of the main issues with the pricing mechanisms is its impact on lower socio-economic households. These households use less electricity than the average consumer, and as a result, their ability to conserve is lower (Brandon and Lewis 1999). Also, when confronted with an increase in energy costs, lower-income families tend to make “lifestyle cutbacks”(Dillman, Rosa et al. 1983). Therefore using a pricing mechanism to achieve demand response will not be consistent with all the principles of rate design such as the promotion of social equity and affordability to low income households (Bonbright, Karmerschen et al. 1988).

Chapter 4: Background II – Energy Use Behaviour and its Change in the Residential Sector

4.1 Introduction

In the residential sector, there are three basic routes to achieve reduction in the rate of energy consumption:

(i) Replacing the existing housing stock with low-energy buildings designed primarily to minimize heating and cooling loads.

(ii) Developing energy efficient domestic equipment.

(iii) Promoting and achieving 'energy-conscious' behaviour among end users.

Energy demand analyses usually tend to focus on the first two routes. In his review of the socio-behaviour energy literature, Lutzenhiser pointed to particular research/policy paradigms that constrain the energy consumption analysis: "a physical-technical-economic-model (PTEM) of consumption" that dominate energy analysis particularly in energy demand forecasting and policy planning" (Lutzenhiser 1993). The PTEM assumes that energy consumption in buildings depends almost entirely on the physical characteristics of buildings and the efficiencies of household appliances. Lutzenhiser's review pointed out that these models largely under-estimate and sometimes even overlook the importance of human behaviour in shaping the residential energy consumption.

This chapter gives a review of household energy use behaviour literature. It establishes from the literature the importance of household occupants' behaviour in achieving energy use reduction in the residential sector. It touches on the strategies that have been used to influence households' energy use behaviour and their effectiveness.

4.2 Energy Consumption in Households - the Significance of Behaviour

Households vary significantly in the amount of energy they use. These variations could be attributed to differences in engineering and economic factors, energy type and household characteristics (family size, age of household members, race/ethnicity, etc.). However, when these factors are controlled, large variations in the amount of energy use in individual houses still remain. This was first revealed by a study at the Princeton's Centre for Energy and Environmental Research (Twin River project, New Jersey) (Socolow 1978). In that study, Socolow and his team showed that houses of similar sizes occupied by demographically similar families with similar set of appliances and under the same geographical condition varied in energy consumption by as much as 200%. Again, when some houses were monitored for energy consumption after they have been retrofitted to the same standard, large variations in consumption still remained (Socolow 1978). Finally, in the houses where the occupants have moved, the energy consumption of the new occupants could not be predicted from the previous families' levels of energy use (Sonderegger 1978).

Similarly, a recent study that measured the energy use in ten identical Habitats for Humanity all-electric homes with the same appliances and equipment found the energy use of the lowest to the highest consumer to vary by as much as 260% (Parker and Mazzara 1996). A review of this type of research from the 1970s to the early 1990s conducted by Lutzenhiser, concluded that "...the residential-sector consumption seems to be characterized by variability and change, with human behaviour playing a central role in both the short-term and long-term initiation, maintenance and alteration of energy flow" (Lutzenhiser 1993). These results suggest that intervention strategies designed to promote sustainable behaviors could result in significant energy saving.

4.3 Energy use Behaviour Research

The study of energy use behaviour is concerned with how energy is commonly used and what those uses mean to the consumer, giving information about the likely success of the efforts to influence behaviour and choice. Energy use behaviour studies recognize human behaviour as a key driver of energy demand; turned in one direction, the consumption of energy and its related problems is increased, and when turned in another direction, it is reduced (Stern 1992). These studies also postulate individual behaviour to be responsive, and therefore the need to search for social, economic and psychological stimuli with which to trigger the desired outcome (Shove 2003). Literature on human energy use behaviour can broadly be divided between economics, where demand is calculated using income and price elasticities, and psychological studies that collect information about attitudinal and behavioural attributes that affect personal decisions to manage energy consumption more effectively and to forgo some of the benefits that result from energy consumption (Parker, Rowlands et al. 2002). There is also literature that explicitly classifies residential energy use as a social problem (Stern and Aronson 1984). The following subchapters review some of the disciplinary models of residential energy consumption and provide some results of their applications.

4.4 The Economic Model of Demand

As a social science discipline, a major part of economics is concerned with the study of human behaviour. In economics, price and income are important determinates of energy consumption. From the theory of demand, several useful predictions can be made about consumer behaviour. Engel curve shows how the quantity demanded of a good or service changes as the consumer's income level changes. The ratio of percentage change in demand to the percentage in consumer’s income is referred to as income elasticity of demand. If income elasticity is between 0 and 1, the good is called a primary good and when income elasticity is greater than 1, the good is called a luxury good.

Consumer demand behaviour has also been studied under price changes. A change in consumer demand that results from a unit change in price is commonly referred to as price elasticity of demand. It is determined as a ratio of percentage change in demand to the percentage change in price. If a price change has a very small effect on demand (ratio less than 1), demand is said to be inelastic. If a price change has a very sizable impact on demand (ratio greater than 1), the demand is said to be elastic. Generally, goods that are essential have inelastic demand.

The economic model of influencing consumer demand with price is based on the microeconomic theory of utility maximization and consumer rationality. This theory states that an individual seeks to maximize utility given a budget constraint and that a decision outcome with higher utility will be consistently preferred to an alternative outcome with lower utility. The utility theory is derived from axioms of preference that provide criteria for the rationality of choice. It assumes consumers to behave as rational actors in the normative sense of having preferences that are ordered, known, invariant and consistent (Wilson and Dowlatabadi 2007). According to the utility theory, a change in the price of goods constitutes a change in constraint and induces a change in behaviour. Behavioural change is thus taken as being caused from outside the person involved and basic preferences are taken to be constant.

4.4.1 The Price Elasticity of Electricity Demand

The elasticity of electricity demand with respect to price change has been determined in many residential sector electricity demand studies. One measurement of elasticity is the customer change in demand in the same time period that the price change occurs, known as own price elasticity (commonly referred to as just price elasticity). It is mathematically written as:

$$EP = \frac{\%\Delta Q}{\%\Delta P}$$ Equation 4.1

Where EP is the own price elasticity, $\%\Delta Q$ represents demand change resulting from $\%\Delta P$ price change.

The other measurement of load shifting behaviour is known as the elasticity of substitution. It is defined as the negative of the percentage change in the ratio of peak to off-peak demand, divided by the percentage change in the ratio of peak to off-peak price. Mathematically, it is written as:

$$EP_{subs} = \frac{-\%\Delta\left(Q_P / Q_O\right)}{\%\Delta\left(P_P / P_O\right)}$$ Equation 4. 2

Where, EP_{subs}, is price elasticity of substitution, calculated from the percent change in peak to off-peak price ratio, $\%\Delta\ (P_P/P_O)$, and the peak to off-peak demand ratio, $\%\Delta\ (Q_P/Q_O)$. When the necessary data is available, elasticity of substitution can be compared with own price elasticity (King 2005). According to King (2005) the elasticity of substitution of 0.17 is consistent with the own price elasticity of -0.30.

The price elasticity of electricity demand is calculated as either short-run or long-run. For short-run elasticity, customers make use of their existing infrastructure, technologies and resources to react to changes in prices. Customers make no changes in their appliance stock and response is purely through behavioural change. Long-run elasticity takes into account both changes in household appliance stock and human behaviour. With demand response, we talk about short-run elasticity (i.e. short-term change in demand due to price changes).

4.4.2 Historical Evidence of Residential Price Responsiveness

Programs that investigate the impact of price on electricity demand usually feature time-of-use (TOU) rates. However, due to the static nature of these rates (i.e. fixed price at specific time range), some experiments have investigated the impact of dynamic rate, such as critical peak pricing (CPP) rates and real-time-pricing (RTP) rates. The results of these programs are reported in various ways, usually as the effect of the program in reducing peak demand, which is the goal of most programs. This effect is usually expressed as a percentage of peak demand or as kilowatt reduction per customer. Dynamic pricing program results are usually in the form of percentage peak demand reductions, but often include customer price elasticity. The following sections presents review of some studies conducted in different countries.

Time of Use (TOU) Rates

The U.S. Federal Energy Administration initiated fourteen experiments in the 1970 and 80s to gain knowledge about how customers would change their electricity usage in response to TOU rates. Some years after the experiments, Caves and Christensen initiated a study to investigate whether consistency could be found across the experiments if differences in the experimental characteristics were controlled (Caves, Christensen et al. 1984). They reviewed several experiments and selected five with sufficient high quality that could be used to pool the data. Their pooled model yielded estimates of elasticity of substitution for any combination of appliance ownership, and house type, household size and climate. For the summer, they found the elasticity of substitution to be 0.14 for a typical customer and 0.07 for customer without major appliances (such as air-conditioners), while the elasticity for a customer with all the major appliances was found to be 0.21. For winter, the results were 0.10 for a typical customer, 0.06 for a customer without major appliance and 0.17 for customers with all major appliances.

One of the more recent large scale pricing experiments in the U.S. was the California State-Wide Pricing Pilot, conducted to test the impact of several pricing structures, including TOU price, on peak demand (CRA 2006). A total of 2,500 customers were involved in the experiments that ran from July 2003 to December 2004. This experiment found an average demand reduction of 13% for low-demand customers (mainly residential customers with demand less than 20 kW). The estimated price elasticity (kW change per unit price change) of substitution varied from -0.04 to -0.13 for a peak to off-peak price ratio of 3 to 6 (CRA 2006). This result is consistent with the Cave and Christensen results described above.

In Germany, tariff experiments with TOU rates for residential customers took place in 1970 and ‘80s. Examples of places where the experiments were conducted are Freiburg and the German state of Saarland (Schlomann 1993). In Freiburg, the TOU tariff was tested for 450 households over duration of about a year. The tariff had three different prices on workdays and only two prices at the weekend. The peak time price was about two and half times higher than the off-peak price. In between, there was a shoulder peak price of 1.5 times the off-peak price. The study found a reduction in peak demand of 3% and reduction in electricity consumption of 8%. The state of Saarland experiment which involved a much larger population (1500 households) found a peak demand reduction of 10%.

In Switzerland, Filippini examined the residential demand for electricity by TOU. For this purpose, a model of two log-linear stochastic equations for peak and off-peak electricity consumption were estimated from aggregate of four years data covering 40 cities (Filippini 1995). The study highlighted some of the characteristics of the Swiss residential electricity market. The study estimated short-run own-price elasticities of -0.60 during the peak period and -0.79 during the off-peak period. Filippini carried out a similar study in Indian households, but this time using disaggregated households level survey data (Filippini and Pachuari 2002). The study estimated household electricity demand elasticity with respect to price (and also income) for each of the three seasons in India (winter, monsoon and summer). The study estimates an own price elasticity of –0.42 for winter, -0.51 for summer and -0.29 for the monsoon season.

These results indicate that residential customers do respond to a time dependent electricity tariff, but the extent of their response varies between experiments. This may be expected due to the differences in the study methodology and also the share of energy costs of the total household budget in the study area. If the costs of energy are marginal to households, they may be insensitive to price signal. King and Chatterjee plotted results of some of the time dependent electricity price (TOU, CPP, RTP) of the United States and other countries, including Canada, the UK, France and Denmark and found an average price elasticity of -0.3 (King and Chatterjee 2003). Figure 4.1 shows the demand responsiveness of electricity demand with respect to time-of-use pricing.

Dynamic Pricing

Residential dynamic rate programs include real-time pricing (RTP) and critical-peak pricing (CPP). These programs normally incorporate demand response enabling technology that informs the householders of the period when the rates would be activated and the price of electricity during the period. One residential hourly pricing program has been described in the literature, that of Commonwealth Edison of Chicago in US. The program uses low cost technology (internet, text message) to inform its participants about the prices of electricity over the day. Customers are told a day in advance of hourly prices via the internet (http://www.thewattspot.com). They receive a special notice or "pricing alert" via text messaging and emails when prices exceed a certain threshold (0.13 U.S. cent/kWh in 2006). A price elasticity of -0.049 was estimated from the program's experiment conducted in 2005 (Faruqui and Sergici 2009).

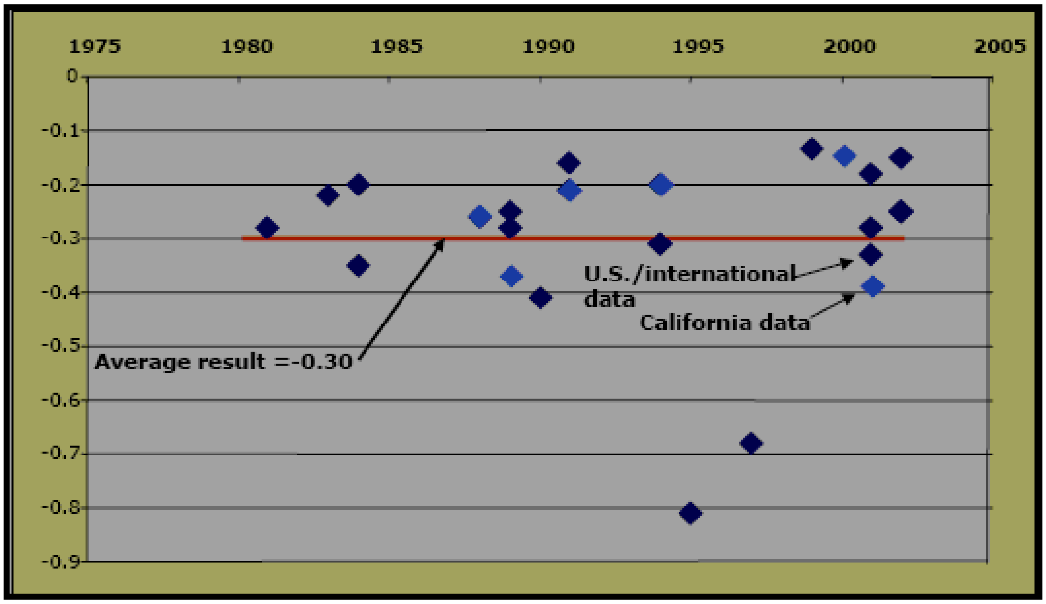

Figure 4.1: Compiled results of own price elasticity of electricity demand showing an average demand reduction of 30% for every 100% increase in price (King and Chatterjee 2003).

The critical peak pricing rate is an example of a commonly used tariff to reduce peak demand in the residential sector. In France, the Electricity de France (EDF) introduced critical-peak price tariffs for its residential consumers in 1996. Prior to this introduction, they conducted an experiment with the so-called *tempo tariff*. With this scheme, the year was divided into 22 red, 43 white and 300 blue days, and each day has a peak and an off-peak period. The red day charges the highest prices and has the largest peak/off-peak price ratio, while the blue day charges the lowest prices with the smallest ratio. Customers were informed of the next day's colour at the end of each previous day (usually at 8 p.m.) through a "smart meter" ("*Le compteur électronique*") as shown in figure 4.2. The prices corresponding to the colours are fixed and known to the customers, but the colour itself is unknown until the evening of the previous day.

Figure 4. 2: Electricity de France Tempo program meter showing the colour of the day.

The program participants in the residential sector totaled about 350,000. The tempo tariff led to a reduction in electricity consumption of 15% on white days and 45% on red days, representing an average reduction of 1 kW per customer (IEADSM 2008). An unusually high own price elasticity of -0.79 was estimated for the peak demand and -0.18 for off-peak demand (Aubin, Fougere et al. 1995). While the Tempo tariff has been successful, less than 20% of electricity customers in France have chosen this tariff option. It is important to note that the Tempo tariff was designed specifically for the situation where EDF is a monopolistic generator and retail supplier of electricity.

Dynamic pricing experiment in the form of peak time rebate is not very common in the residential sector. The peak time rebate program is quite similar to critical peak pricing program except that customers remain on their default tariff but receive a rebate for the amount of demand reduction they can offer to the utility during critical peak event. A customer can only gain by reducing his demand during critical peak event. The customer is not punished with higher monthly bill for failing to reduce demand, as would be the case if the customer was actually charged the sum of the fixed price and the rebate for the electricity demand beyond his reference level demand during the periods of critical peak pricing event.

Peak Time Rebate

A good example of peak time rebate program is the Ahaheim Critical Peak Pricing Experiment (Wolak 2006). In this program, customers receive a rebate of 0.35 U.S$/kWh for the amount of consumption reduction they achieve relative to their reference level peak consumption on non critical peak event days. Wolak estimated approximately 12 % reduction in consumption during the critical peak event days in an experiment that involved 123 residential customers from the period of June 1, 2005 to October 14, 2005 using a non-parametric conditional mean estimation framework. According to Walok, the financial viability of peak time rebate program depends crucially on the method that is used to compute the customer baseline (Wolak 2006). If the rebate mechanism is based on the history of customer's peak period consumption during peak periods of non-event event days, as was the case in his study, it provides incentive for customers to increase their consumption during the peak periods of non-event days. He further found that a large proportion of load reduction on which rebate was paid would have anyway happed without the incentive provided by the program.

Several experiments have been conducted to test the impact of price on electricity demand. They have taken place in many locations across the globe. A broader review of these kinds of studies can be found in (King and Chatterjee 2003; King 2005 ; Ericson 2006; Faruqui and Sergici 2009).

Price Unresponsiveness

While the results of most studies show that residential customers do respond to a time-varying electricity price, a detailed analysis by Reise and White indicates that a significant proportion of households do not respond to price (Reiss and White 2002). Using extensive data for a representative sample of 1,300 Californian households, the results of their model showed a strikingly skewed distribution of household electricity price elasticities in the population, with a small fraction of households accounting for most of the aggregated -0.39 price elasticity found by the study. A Significant fraction of households (44%) did not show any price responsiveness. Households with major appliances like space heating and air conditioners responded the most. Based on their findings, Reise and White concluded that there are two main group of household: those that use electricity for space heating or air conditioning and exhibit some electricity price responsiveness and those that do not use electricity for either of the purposes stated above and exhibit near zero elasticity. Figure 4.3 show the electricity price elasticity distribution estimated for California households.

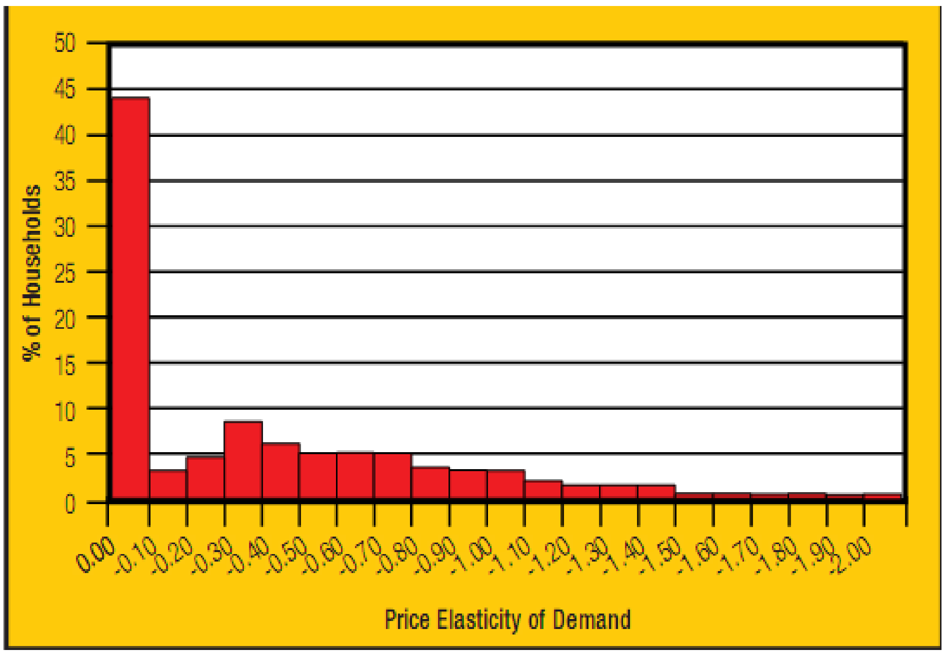

Figure 4.3 : Price elasticity distribution of Californian Households showing about 44% of households that are not price responsive (Reiss and White 2002).

4.4.3 Limitations of the economic model

Experimental work conducted by psychologists and real world evidence show that individuals do not make consistently rational decisions, as suggested by economists (Stern, Aronson et al. 1986). Time inconsistency, reference dependence and bounded rationality are some of the examples cited in the literature as far as energy use is concerned (Wilson and Dowlatabadi 2007). In each of these cases, individual choices violate one or more of the axioms of preference on which utility theory is based. The economic models of "rational behavior" should include the "cost" of the time, attention and effort required for adaptation to changing prices. In business decision-making these indirect costs are probably small as compared to the direct costs that depend on the decisions, but in household decisions the indirect costs might be higher than the possible savings in the direct costs.

The economic theory of rational actors does not fully describe human behaviour; specifically, it does not adequately capture energy related behaviour in the residential sector. Psychologists have therefore suggested alternative models grounded in psychological studies of human behaviour. The concept of bounded rationality by Simon (1986), for instance, suggests that individuals employ heuristics to make decisions rather than a strict rigid rule of optimization (Simon 1986). They do so because of the complexity of the situations, and their inability to process and compute the expected utility of every alternative action. Empirical studies of consumer decisions regarding energy use generally seem to support the bounded rationality hypothesis (Sanstad and Howarth 1994).

4.5 Psychological Models

There are a variety of psychological models that attempt to explain why people behave in certain ways. An example is the theory of reasoned action (Ajzen 1988). This theory proposes that behaviour (*B)* is explained by individual's intension to perform it *(BI).* This behavioural intention in turn depends on the individual's attitude towards the behaviour

(A) and subjective norm *(SN).* Attitude towards the behaviour is the individual's positive or negative evaluation of performing the behaviour of interest. The subjective norm refers to the perceived social pressure to perform or not to perform a behaviour i.e. an individual's perception of the extent to which others might think of the behaviour. The model can be presented mathematically as follows (Antonide 2008).

$$B \approx BI = w_1 \times A + w_2 \times SN = w_1 \sum_i b_i \times e_i + w_2 \sum_j nb_j \times mc_j \qquad \text{Equation 4. 3}$$

where w_1 and w_2 can be considered as regression weights correction factors for the different scale of attitude and social norms and for the differential influence on behaviour. Attitudes are further specified as the summated beliefs (*b*) about (*I*) relevant attributes of an object, weighted by the evaluations (*e*) of those attributes. Social norms are considered as differentiated with respect to a number (*J*) of relevant social parties in the environment of the consumer (e.g. family members, colleagues, etc.). Consumers hold normative beliefs (Bonbright, Karmerschen et al.) concerning these parties' convictions that the consumer should behave in a particular way, which are weighted by the motivation to comply (*mc*) with the respective social parties.

The theory of reasoned action also assumes individuals to be rational (i.e. people take account of available information and weigh the cost and benefits of their actions). This theory deals with behaviour in which the people have a high degree of volitional control. The performance of the theory of reasoned action in predicting behaviour has been assessed by a meta-analysis of Sheppard et al. (1988). They found an overall correlation of 0.53 between behaviour and behaviour intentions; and an overall correlation of 0.66 between behaviour intentions on one hand and attitude and subjective norm on the other hand (Sheppard 1988).

An extended version of the theory of reasoned action is the theory of planned behaviour (Ajzen 1991). This theory recognizes the possibility that many behaviours may not be under complete volitional control. As shown in figure 4.4, the theory of planned behaviour accounts for realistic constraints that may exist in performing behaviour by adding perceived behaviour control as a third determinant of behavioral intention. Perceived behaviour control is a subjective assessment of how contextual factors influence behaviour. These factors can be thought of as external conditions such as physical, financial, legal and social influences that support or hinder individual behaviour. The theory of planned behaviour has turned out to be a good predictor of behaviour. An average correlation of 0.71 between behaviour intentions on one hand and attitude, social norm and perceived behaviour control on the other hand has been reported (Ajzen 1991).

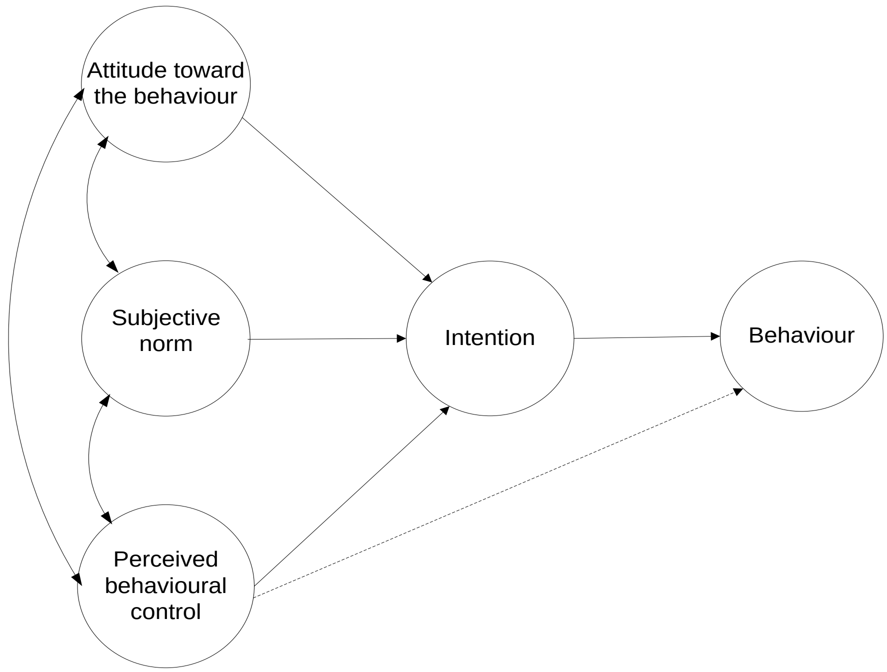

Figure 4.4: An illustrative diagram of the theory of planned behaviour (Ajzen 1988)

Failure of the theory of planned behaviour to explain all the variance of behaviour and intension led to the extension of the theory by the social and environmental psychologists. The social psychology theory of Value-Belief-Norm (VBN) proposed a causal chain from the stable essentials of personality (value) to specific beliefs about the consequences and responsibilities of particular actions, and on to attitudes and norms (Wilson and Dowlatabadi 2007). Stern and his colleagues propose that norm-based actions flow from three factors: acceptance of particular personal values, beliefs that things important to those values are under threat, and beliefs that actions initiated by the individual can help alleviate the threat and restore the values (Stern 1999). Stern distinguishes between three types of values as altruistic, egoistic and biospheric.

Biospheric people place an important value to the environment; altruistic people care for others regardless of the cost to themselves and egoistic people are self interested and do not care about the environment. The Value Believe and Norm theory is said to offer the best available account of environmental orientation when compared with other theories (Stern 1999).

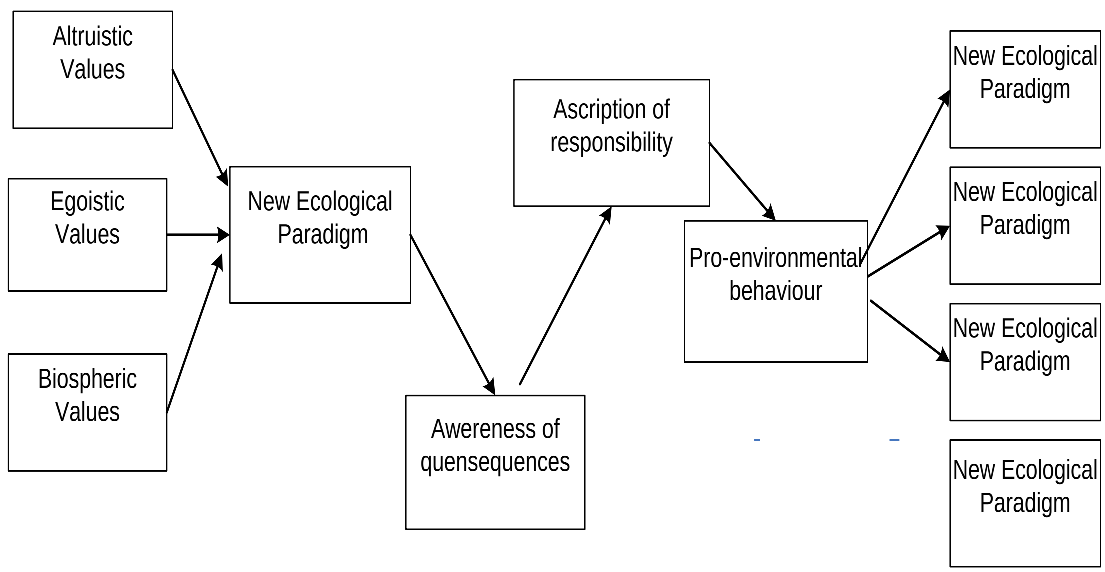

Figure 4.5: Schematic model of variables in Value-Belief-Norm theory as applied to environmentalism (Stern 1999).

4.6 Approaches to Determine Energy Use Behaviour

Several approaches have been used to study residential energy use behaviour. Among the approaches are the following:

4.6.1 Actual Behaviour

This involves determining how an individual actually uses energy. Such studies are time consuming and expensive and are thus conducted experimentally on a small scale. In the case of electricity consumption, this would involve installing measuring devices that would record the electricity usage in specific time intervals. An example is the measurement of household behaviour response to price in which "smart meters" are installed to provide price and feedback information to customers. In such a case, the behaviour change is recorded by the meters in terms of the actual changes in energy use.

4.6.2 Self-Reported Behaviour

This approach uses survey methodology, with both direct and indirect questions to find out how much energy an individual says he/she uses or saves. Such studies have an advantage in that they can be applied to a large and more diversified sample size than the actual behaviour studies, as they are cheaper and easier to conduct. The problem with this method is that people normally tend to tell the interviewer what he or she wants to hear (that is, people may be reluctant to say that they do not care about the energy problem). Also household occupants may have a limited idea about what they are asked to report on. It is a common held belief that respondents tend to underestimate their indoor air temperature. These drawbacks could be minimised by extensively pre-testing the questionnaire and conducting focus groups.

4.6.3 Behaviour Intentions

This approach asks how much energy an individual will be willing to save energy under certain conditions. This approach is sometimes referred to as the stated preference approach. This type of study is usually based on large quantitative survey methodologies. In comparison to the other approaches mentioned above, behaviour intentions research is comparatively cheap to conduct. Additionally, the results of the research could help policy makers assess the likely impact of energy legislation/policy. However, as people are reporting on what they would do under a certain future situation, it adds a certain level of uncertainty to the results. A large field experiment on a population implementing future scenarios would give more accurate results, but such experiments are expensive to conduct. Another problem cited in the literature about this kind of study is that behaviour intentions are not always good predictors of the actual behaviour.

4.7 Needs and Opportunities: Multi-Modal Demand Response

Most of the theoretical models and empirical studies reviewed in this chapter show that individually, decision makers respond to external conditions through psychological mechanism that can be unearthed through careful research. As a result, the lessons used for intervention design draw on the understanding of these mechanisms to persuade individuals to make decisions commensurate with public policy objectives.

In demand response, the fundamental assumption has been that there is no better signal than price and that socially optimum behaviour can be brought about with “high” prices.

Despite the growing interest in price-response, experience with such programs show mixed results. Dynamic pricing is the category of price response programs that has garnered the greatest attention in recent times. While customers have been found to respond to price on an aggregate level, a more detailed study shows a surprisingly high fraction of household that do not respond to price. This may be due to different reasons. Some (rich) households may not care about the price for energy as it is only a tiny fraction of their available budget. Some households may lack the competence of responding to the price signal (e.g. may not understand the pricing system or do not learn due to missing immediate feedback). Other household may simply have no decision options.

Researchers in demand response need to recognize that prices alone will not necessarily create the conditions needed to achieve effective peak demand management that could be reliably deployed to reduce the need to build more generation and transmission infrastructure. A range of factors could be used to influence people's energy use behaviour. Social and psychological research reviewed above show that people's behaviour can be explained by a combination of different factors (e.g. norm, beliefs, values etc.). For example, people who place much value on the environment will be more likely to respond to environmental information than they would do with price information. The benefits of demand response to consumers in all sectors include lower peak price, market discipline, and reliable electrical service and possibly lower environmental emissions. Better explanation of all these benefits to the consumer is perhaps necessary to achieve effective demand response in the residential sector.

The theory for this study is that there are different classifications of residences that will respond in different ways to the range of signals. This thesis therefore tries to answer the question of what information would motivate residential customers to reduce their electricity demand during peak demand periods. One factor is price, but the information about price is usually not co-incident with real-time decision making, e.g. a high bill at the end of the month is a consequence of usage. Energy shortages, supply security and environmental concerns may also influence conservation behaviour and technology choice. In this thesis, customers' voluntary demand response to three external factors: cost (increased price), environment (increased CO_2 footprint) and security (risk of blackout) is explored. The potential of each of these factors as a real-time customer peak demand reduction motivator was explored through a survey in Christchurch. The modification of demand with respect to price, environment and security is determined by asking about levels of concern and about levels of action in terms of customers' willingness to adjust their household activities during peak demand hours.

Chapter 5: Method

5.1 Introduction

Behaviour of household inhabitants in responding to demand response requests is largely not well understood in the residential sector. This research sought to answer some of the key *questions* that remain to be addressed.

- What would motivate customers to participate in demand response?
- Should the information presented to customers include only utility prices, or should non-price information be included as well?
- How is customer response related to price, the environment, or security?
- How do residential customers act to reduce demand –which appliance(s) do they adjust the usage when responding to demand response request usage?

These are critical questions when considering whether to extend demand response programs to residential customers and in designing, implementing and monitoring the programs.

Past studies of residential energy use behaviour change have used cost as feedback on consumption. Case studies in different countries have demonstrated that residential customers reduce their demand, especially peak demand, when faced with visible time differentiated prices (Darby 2006). A review of some of these studies discussed in chapter 4 shows that some householders are price responsive while a significant proportion is not (Reiss and White 2002). Some researchers have also examined the issue of the negative impact of price on low socio-economic households (Dillman, Rosa et al. 1983; Alexander 2007).

This study explores the effectiveness of other factors than price to influence customers to reduce their demand at peak hours and provides some answers to the questions raised above. Two factors: environment (CO_2 footprint), and security (blackouts) have been explored together with the price. Voluntary customer response to this kind of information is explored through the use of survey. This chapter discusses the survey and data analysis method.

5.2 The Survey Method

In this research, a mixed mode survey method was used to gather data on the energy use behaviour of household consumers during winter peak hours in Christchurch. **"**Mode**"** refers to the approach used to contact or to obtain data from survey respondents. Dillman (2000) states that self-administered surveys can be mixed with other types of surveys (e.g. interviews) in different ways (Dillman 2000). According to Dillman (2000), mixed mode surveys provide an opportunity to compensate for the weaknesses of each method. In this study, the data collection was done by the use of two survey methods: 1) self-administered questionnaire, and 2) focus group discussions.

5.2.1 The Questionnaire Survey

The first aim of the survey was to develop a picture of representative household electricity usage behaviour during peak times in Christchurch. This energy usage behaviour has two components; the activities being carried out and the appliances being used. The second aim of the survey was to determine the multimodal demand modification to three factors; price, environmental impacts, and security of supply. The third aim of the survey was to relate those modifications to particular behaviour changes;

- **Activity response –** households change normal activity pattern by curtailing or shifting activities.
- **Mode response –** households maintain normal activity pattern but reduce energy demand by turning off un-needed appliances or changing energy intensity.

This study does not look at consumer choices about purchasing more efficient appliances, which is a longer-term conservation response more indicative of DSM programs.

The survey questions were developed in consultation with Professor Hans Peter Peters of Humans-Environment-Technology Project Group at the Juelich Research Centre in Germany. The survey methods were reviewed and input given by Professor Lucy Johnston of the Department of Psychology at the University of Canterbury. Personnel at Orion also made input to the survey. The survey was submitted to the Human Ethics Committee of the University of Canterbury and was approved.

The survey questions were divided into the following eight sections:

1. Household information
2. Personal information
3. Winter power cost
4. Household energy features and electricity price schedules
5. Electricity usage in ordinary winter peak times
6. Future change issues
7. Electricity allocation scenario and behaviour change
8. Energy saving motivation

The Sections 1 to 4 were Energy Audit section designed to obtain household background information such as family size, power bills, home insulation levels, the size of houses, income levels of households, and gender of respondents.

The fifth section was structured to gather data about how electricity is currently used in the households. Participants were asked to tell us 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). The sixth section asked three questions in order to assess the sensitivity of customer response to the three factors (price, environment and security) as shown in figure 5.1. In the seventh section, a scenario was set out whereby supply constraints or emergency required allocation of a certain amount of power for each household during the peak hours, and the amount was less than what is required for normal use. 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. A monitoring experiment in which the behaviour of households is observed under realistic future conditions would give more accurate results, but such experiments are expensive to conduct and are not practical. And they would have to be long-term because of the "newness" factor mentioned before. The eighth section had an energy saving motivation question as shown in Figure 5.1. A copy of the actual survey can be found in Appendix A.

Section 6. Questions about the Strength of the Factors

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

Figure 5.1: Survey questions from Section 6: Sensitivity, and Section 8: Importance of each factor in motivating consumer to reduce electricity demand.

Sampling

Two different sample groups were chosen. The first group was households in Halswell, a relatively new neighbourhood of Christchurch. Figure 5.2 show the location of Halswell (marked with a red circle) in relation to other suburbs of the city. All the houses in this neighbourhood are insulated and relatively large. All the houses were built between 1980 and 2000 by the same developer in typical green field suburban development. Figure 5.3

shows the homogeneity of construction type, condition and house size in the Halswell neighbourhood. The Halswell neighbourhood was selected in order to be able to analyze the effect of customers' behaviour change on a particular residential feeder. According to the Orion's Network Development Manager, Halswell is the only neighbourhood in Christchurch that has its own residential feeder and the area was selected so that actual power demand data from the network company could be used for the subsequent demand response analysis. In 2006, there were approximately 400 houses on this feeder. These 400 houses were identified on a map in consultation with the Orion's personnel and the survey was conducted by mail box drop of a paper questionnaire with stamped, return addressed envelope in every home that was identified as being on the feeder in 2006. Sixty three questionnaires, representing 15.75% response rate, were completed and returned by the participants. Follow-up requests were not made.

The second group was randomly selected households in representative neighbourhoods across the Christchurch city area. These houses were selected to fairly represent the general characteristics of households in Christchurch. Figure 5.2 shows the relative locations of the suburbs where the survey was conducted. In all, 400 households were selected. This number was made up of mix of old houses constructed in the 1960s with no insulation, relatively new houses, large and small houses, town houses, etc. Out of the 400 questionnaires distributed a total of 78, representing 19.50% response rate, were completed and returned by the participants. Follow-up requests were not made. Table 5.1 shows the purpose, sample size and the response rate of the survey.

Figure 5.2: Aerial View of Christchurch Showing the survey Locations

(a) Survey 1: 400 homes on Halswell Feeder

(b) Survey 2: 400 homes in a variety of neighbourhoods across Christchurch

Figure 5.3: Representative home construction in the different Survey Areas.

Table 5.1: The survey objective, sample size and response rates.

Surveys	**Survey Purpose**	**Survey Sent**	**Usable Survey Returned**	**Response Rate**
Halswell	Typical residential feeder assessed	400	63	16 %
General Random Survey	Representative of households in Christchurch	400	78	20%
Total	_	800	141	18 %

Implementation

The survey was conducted in the winter month of June, 2008. The questionnaires were placed in envelopes addressed to the individual houses along with a reply envelop with a stamp affixed. The envelopes were hand-delivered to mailboxes of all the selected houses. In the Halswell area, the envelopes were delivered to every house that was identified as being on the residential feeder. The survey included a detailed cover letter that explained the reason for the research and a consent form. The cover letter stated the aim of the project as "to develop innovations for electricity supply security". The cover letter also explained that the survey was being carried out as part of a PhD project. Participants were assured of the anonymity of their responses, and were offered the chance to win one of ten CENT-A-METERS™ prizes, if they completed and returned the survey. CENT-A-METER ™ (http://www.centameter.com.au/) is an innovative product designed to help customers monitor their electricity demand. It displays the usage rate and cost of electricity being used on a portable, easy-to-read LCD monitor, which can be placed anywhere inside the house. The front page of the survey contained an explanation of peak demand and the relationship between peak load and the cost of electricity, environmental impacts and supply security. The questionnaire front page information contained load curves of the utility on the day of a global warming public campaign in New Zealand called *Earth Hour*, showing the effect of the voluntary customer energy use reduction on the load curve. *Earth Hour* is a global sustainability movement that started in 2007, where people switch off electrical appliances as a pledge for support for planet during a designated hour (http://www.earthhour.org). This event took place several months before the survey and was well publicized in Christchurch.

A trial of the survey was conducted on a group of 10 members, including some members of the Advanced Energy and Material Systems Lab (http://www.aemslab.org.nz/) research group, student volunteers and some members of the general public. This trial was used to improve clarity and readability. A second trial was conducted with a group of about 25 members of the Christchurch Graduate Women's Association after an invited evening lecture presented by Dr. Susan Krumdieck. This was very important as it gave an indication of how household consumers in general would understand the questions in the survey. It helped to identify parts that needed further improvement.

Analysis

The analysis of the survey was done with the research questions in mind. It was to:

- Establish household energy use behaviour during the peak demand period in Christchurch.
- Determine the behaviour response of the consumer to winter peak load information.
- Determine the relative motivation of household consumers to price, environment and security factors.
- Use the data collected to model the impact of the survey findings on the peak load of a typical residential feeder.

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. This may be a limitation of the survey as the person who completed the survey may not be the one that take energy use decision in the house.

5.2.2 The Focus Groups

The aim of the focus groups was to obtain qualitative information about household customer awareness, attitude, and willingness to participate in demand response. Three focus groups were conducted. The first focus group included a lecture about power grid operation and sustainability, followed by an open discussion. At the first focus group, Dr. Krumdieck presented a concept of sustainability. This idea is that sustainability doesn't depend so much on the type of energy used as it does on the way the people use energy. In a sustainable system, people adjust their consumption to match what is available in a way that provides equitable distribution of benefits of energy services to wellbeing. The amount of energy available is constrained more by resources and environmental impact than by technology. During this presentation the illustration of a household that lives off-grid using a micro-hydro, wind and solar energy system was given. The off-grid residence carries out the same core activities as the on-grid residence. However, they use information about the availability of their energy resources to adjust their behaviour (e.g. choice of appliances and timing of activities). They also practice conservation when the resource available is low. The off-grid household could put in a big enough system to collect and store enough energy so that they could have power on demand, without any demand response, but the price would be prohibitive. Thus there is a trade-off between costs and benefits. The focus group discussion was then directed toward the expectation of on-grid households for unlimited, low cost power, and whether on-grid people could learn to respond to signals about grid supply. This trial version was very important as it gave some ideas about how the subsequent ones should be conducted.

The second and third focus groups were conducted with a short presentation by the author followed by anonymous question and answer period. A note was included with the mail-box drop surveys that participants could provide their contact details if they were interested to participate in the focus group. Nineteen people responded positively. They were divided into two groups. The second focus group meeting took place on the 15th of October, 2008 and was attended by 9 people and the third one was held the following day and was attended by 5 people.

Each of the meetings was preceded with a presentation of what peak demand means and pointed out some of the main issues associated with peak demand. A set of questions about electricity use and peak demand were posed during the presentation. A set of interactive audience response “CLICKERS”, a data receiver and software were rented from the University of Canterbury Audio Visual Service Centre. These allowed participants to key in their responses and view the summary of their response in the form of bar graphs. The question time was followed by discussions, where participants were given the opportunity to share their experience of load control with the group and offer suggestions about how they think the problem of winter peak loads in New Zealand could best be solved. Some of the PowerPoint slides used are shown in Figure 5.4. Appendix B shows the presentation given during the focus group meetings.

Notes on the points raised, questions asked and general themes of the focus group discussions were kept by fellow PhD candidates who observed, took notes, but did not participate in the discussions.

Figure 5.4: Several of the PowerPoint slides from the focus group presentation.

Chapter 6: Results and Analysis of the Case Study in Christchurch

6.1 Introduction

In this chapter, the results of the households' energy audit and customers' behaviour response to scenarios of future supply constraints are presented. The Energy Audit obtained household information such as family size, gender, household income, home insulation level, and winter power cost. The peak demand behaviour looked at the activities that householders carry out during the winter morning and evening peak hours, and the appliances they use. The peak demand response behaviour indicates how participants would adjust their behaviour if they receive notice of supply constraint. The motivation levels of the customers to make changes based on price, environment and security information is also presented.

6.2 Halswell – Residential Feeder Area

6.2.1 Sample Representativeness

Gender and family size of respondents were compared with the 2006 census data for Christchurch obtained by Statistics New Zealand using chi-square test. The demand response survey results showed an under-representation of one-person households. Male respondents were more in the demand response survey than the Statistics New Zealand survey. This skewed result was expected as the survey targeted only single family detached homes, not multiple units or apartments.

Table 6.1: Comparison of family size obtained from demand response survey with that of Statistics New Zealand for Christchurch.

Occupant(s) Per Household	**Demand Response Survey**		**Statistics New Zealand Survey (2006)**	
	Households (Number)	**Households (Percent)**	**Households (Number)**	**Households (Percent)**
One Person	5	7.94	33,519	25.80
Two Persons	27	42.86	46,206	35.56
Three Persons	13	20.63	22,418	17.25
Four Persons	12	19.05	19,802	15.24
Above Four persons	6	9.52	7,993	6.15

Table 6.2: Comparison of gender of respondents in the demand response survey with that of Statistics New Zealand Results obtained for Christchurch.

Gender	**Demand Response Survey**	**Statistics New Zealand (2006)**
Males	56%	48%
Females	44%	52%

6.2.2 Demographic Information

Out of the 400 questionnaires distributed, a total of 63, representing 16% were completed and returned. The gender split was 56% male and 44% female. The majority of the houses (43%) are occupied by two people, and have two bed rooms (43%) and two living rooms (79%). Almost all the houses in Halswell are insulated. Most households

(24%) reported an annual income of $130,000 NZD or above, followed by $70,001–90,000 NZD (19%).

6.2.3 Winter Power Cost

The monthly power cost in the winter followed a normal distribution with average power cost of $206 NZD and standard deviation of 78. At the extreme ends of the distribution were low power users, who reported paying less than $99 NZD per month, and large users, who pay more than $300 NZD per month. To check the reliability of the cost information, participants were asked to tell us how much their electricity costs were in June, 2008; the month before the survey. June is a winter month in New Zealand and it is the period when electricity demand is high due to high use of electricity for space heating. This is also the period when constraint in the supply of electricity occurs due to low water levels in the hydro dams. Figure 6.1 shows the household average monthly power cost in the winter given by the participants and the cost of power in June, 2008. At the time of the survey, the average price of electricity for the domestic customers was about $0.21 NZD/kWh.

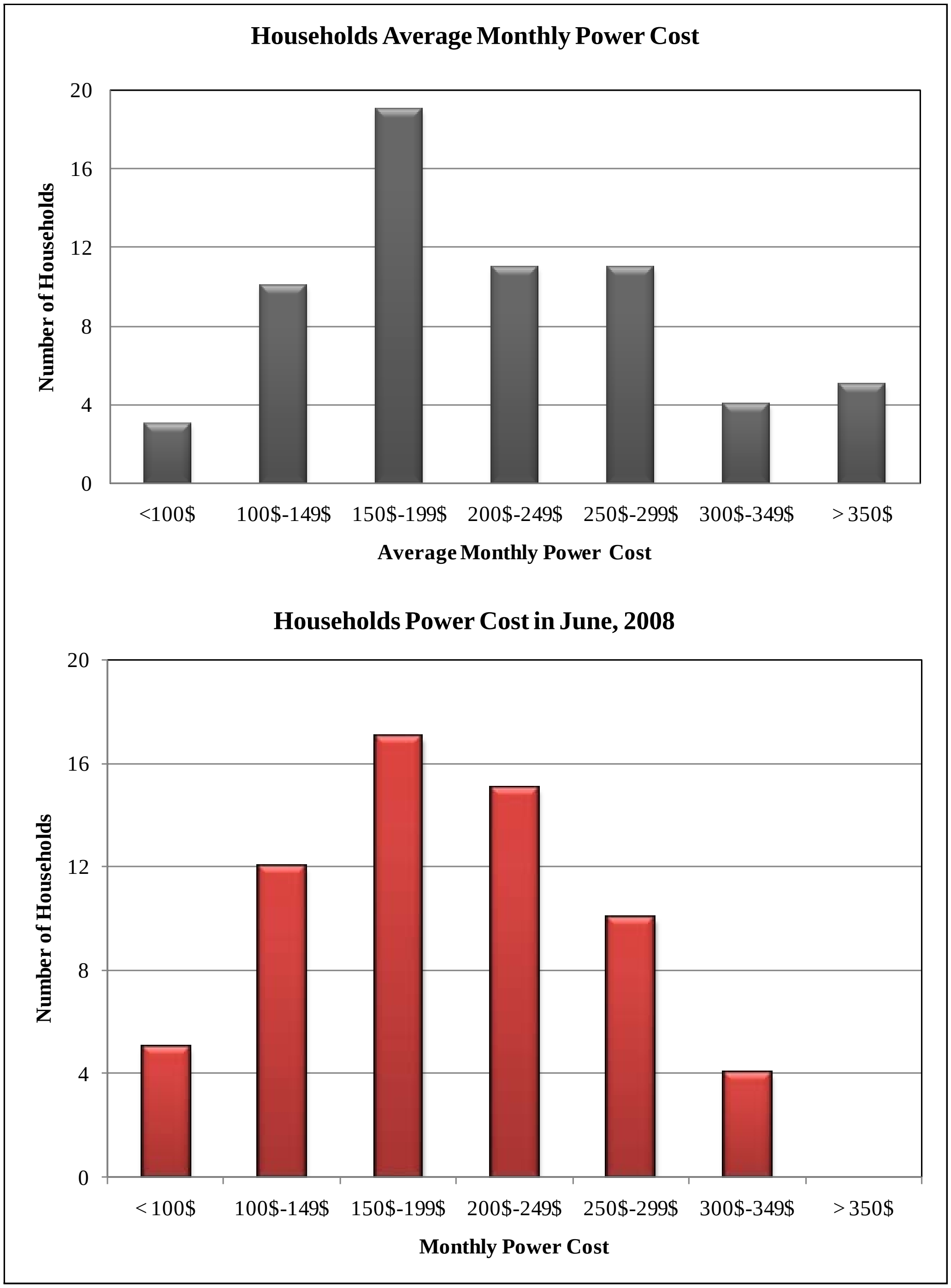

Figure 6.1: Average monthly power cost in winter.

6.2.4 Household Energy Features

In this section, specific questions about energy use characteristics were asked. In New Zealand, some retailers offer their household customers different rates for electricity consumed at night (night rate) and that consumed during the day (day rate). Night rates are lower than the day rates. Time of use rate is seen as giving households the opportunity to store the low cost power at night in the form of heat for use during the day. The ratio of day rate to night rate in the year 2008 was 2.40 for Contact Energy, one of the retailers in the Christchurch area.

The reference question was: “Do you have night-rate power? If yes, which appliance(s) are on the night rate? About half of the respondents (48%) said they are on the night rate plan. A third of the households (33%) reported having their water heaters on night rate while 14% have night-store heaters on that rate. A night-store heater is made of a core of high density bricks and metal plates which are heated over night. The night-store heaters release heat into the home both during the night and throughout the day as the bricks cool down. Table 6.3 shows the proportion of households that have split meters and the appliances on the night rate meter.

A question was also asked about the insulation status of the houses. Almost all the respondents indicated that their houses are fully insulated. The specifics of the findings are shown in table 6.4. Most houses (97%) have insulated ceiling while 86% have insulated walls. About half of the respondent indicated having the floor of their house insulated. This number is lower than that of the parts because most respondents indicated that they have concrete floor.

Table 6.3: Proportion of households with split meters, showing appliances on the night rate.

Source Question: Do you have night-rate power?		
	Houses (Number)	**Houses (Percent)**
Yes	30	48%
No	30	48%
Don't know	3	5%
If yes, which appliance(s) are on the night rate?		
Hot water heater	21	33%
Night-store heater	9	14%
Other	7	11%
Don't know	4	6%

Table 6.4: Insulation status of households indicated by the respondents.

Insulation	**Household (Number)**	**Household (Percentage)**
Insulated house-ceiling)	61	97%
Insulated house-walls)	54	86%
Insulated house-floor)	35	56%

6.2.5 Energy Use Behaviour during Peak Hours

The objective of the time of day energy use section of the survey was to obtain information on electricity use behaviour of households during winter peak hours. In a typical winter day scenario, participants were asked to indicate how they use electricity to carry out their daily activities during the morning and the evening peak hours. Participants were asked to indicate which appliances they always use, which appliances they normally use, and which appliances they seldom use during the peak hours. The level of usage of appliances by the households was calculated from equation 6.1.

$$R_k = \sum_{i=1}^{n_k} X_{ik} / n_K \qquad \text{Equation 6. 1}$$

Where R_k is the percentage of customers indicating a level of usage of a given appliance as always, sometimes or seldom, x_i is customer response to the question and takes values of 1 or 0 depending on the answer given by customer i , and n_k is the number of appliance in the response sample. Electric kettle emerged as the appliance which had, by far, the highest number of respondents (85%) indicating that they always use it during morning peak hours, followed by heat pump (59%), microwave (39%) and electric heater (21%). During the evening peak hours, it was the heat pump that was indicated by most people (80%) as the appliance they always use, followed by the electric kettle (61%), range (58%) and electric heater (30%). Figure 6.2 show the levels of usage of household appliances during the morning and the evening peak hours respectively.

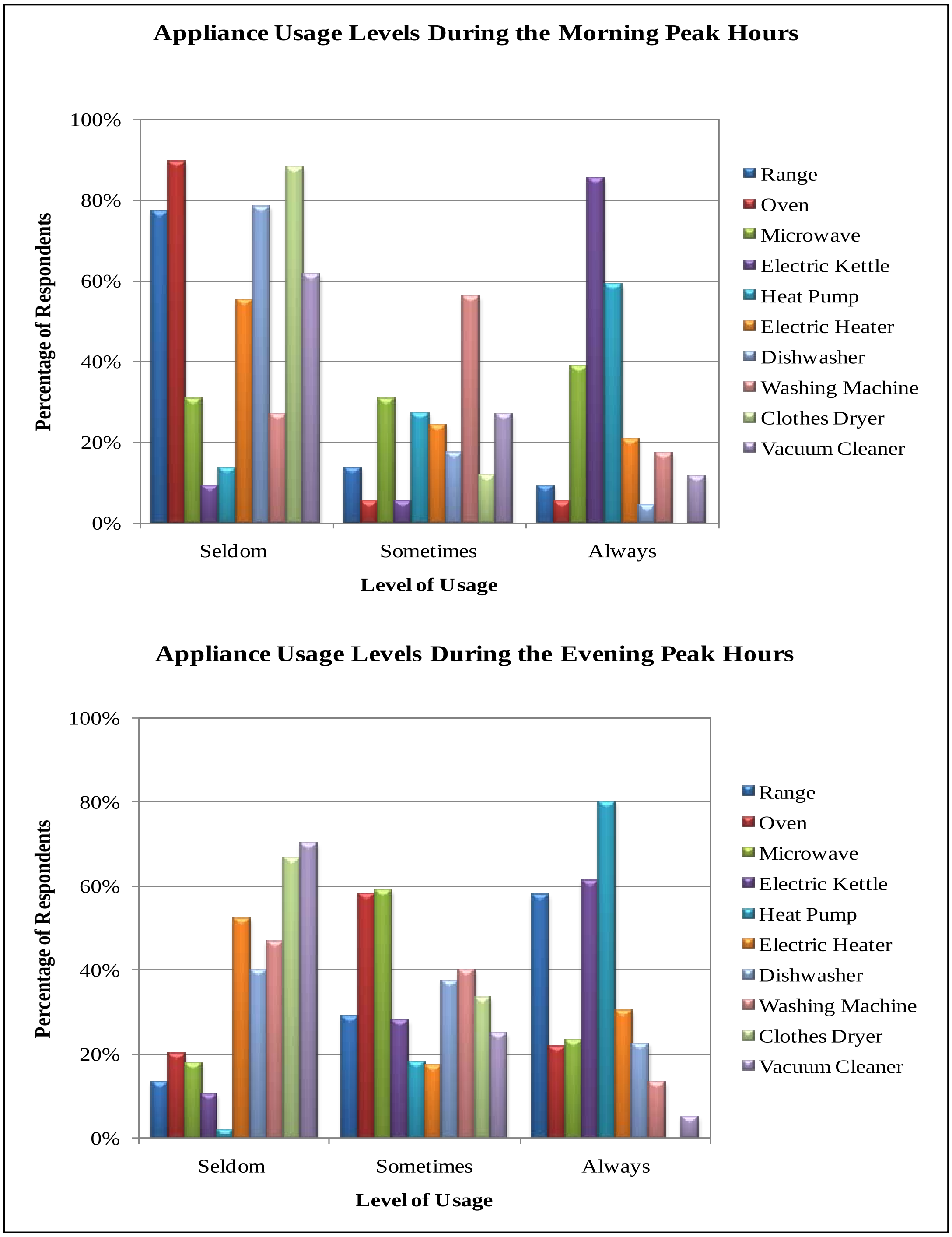

Figure 6.2: Participants response to question of appliance usage during peaky times.

The participant's responses to the level of usage of each appliance was converted into a single factor by applying the following weighting factors to the three levels: seldom: $w1 = 1$, sometimes: $w2 = 2$ and always: $w3 = 3$. The probability factor, P_i, was referred to as the likelihood of appliance usage at peak hours. This factor is defined in equation 6.2.

$$P_i = \frac{n_{i1} \times w1 + n_{i2} \times w2 + n_{i3} \times w3}{n \times w3} \qquad \text{Equation 6. 2}$$

where n_{i1}, n_{i2}, and n_{i3} are the number of customers indicating the use of an appliance, as "seldom", "sometimes", and "always" respectively, and $w1$, $w2$, and $w3$ are the respective weights assigned to the levels. n represents the total number of households that respondent to survey (i.e. n=63). This factor is a probability that a particular appliance will be used, out of the pool of possible appliances during the peak times.

Figure 6.3 shows the result of appliance usage probability (Pi) calculated from the responses of participants. The appliances that have over one in two chance of being used during the morning peak hours were the electric kettle (80%), heat pump (57%), and microwave (54%). In the evening peak hours, they were the electric kettle (76%), heat pump (74%), microwave (61%), and range (58%).

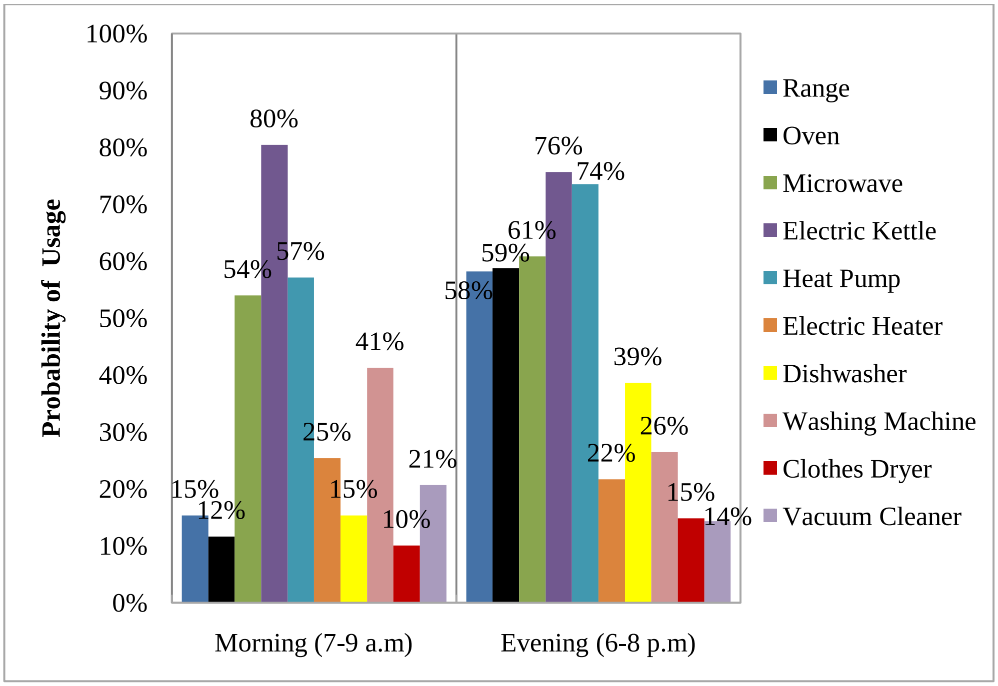

Figure 6.3: Probability of appliance usage (P_i) during peak times.

6.2.6 Response to Future Changes

This section of the questionnaire was designed to explore customers response to possible future changes that might result from increasing peak demand. These changes have to do with increased price, increased environmental emissions and reduced security of supply. Figure 6.4 shows the responses to the factor sensitivity questions that were asked of participants. It is clear that people are sensitive to price increase. Their level of concern is quite high, with 60% of participants indicating that a 10% price increase would be considered as a large increase. A further third said a 20% price increase would be considered to be a large increase. Generally, the result shows that customers would be concerned about a raise of prices by more than 20%.

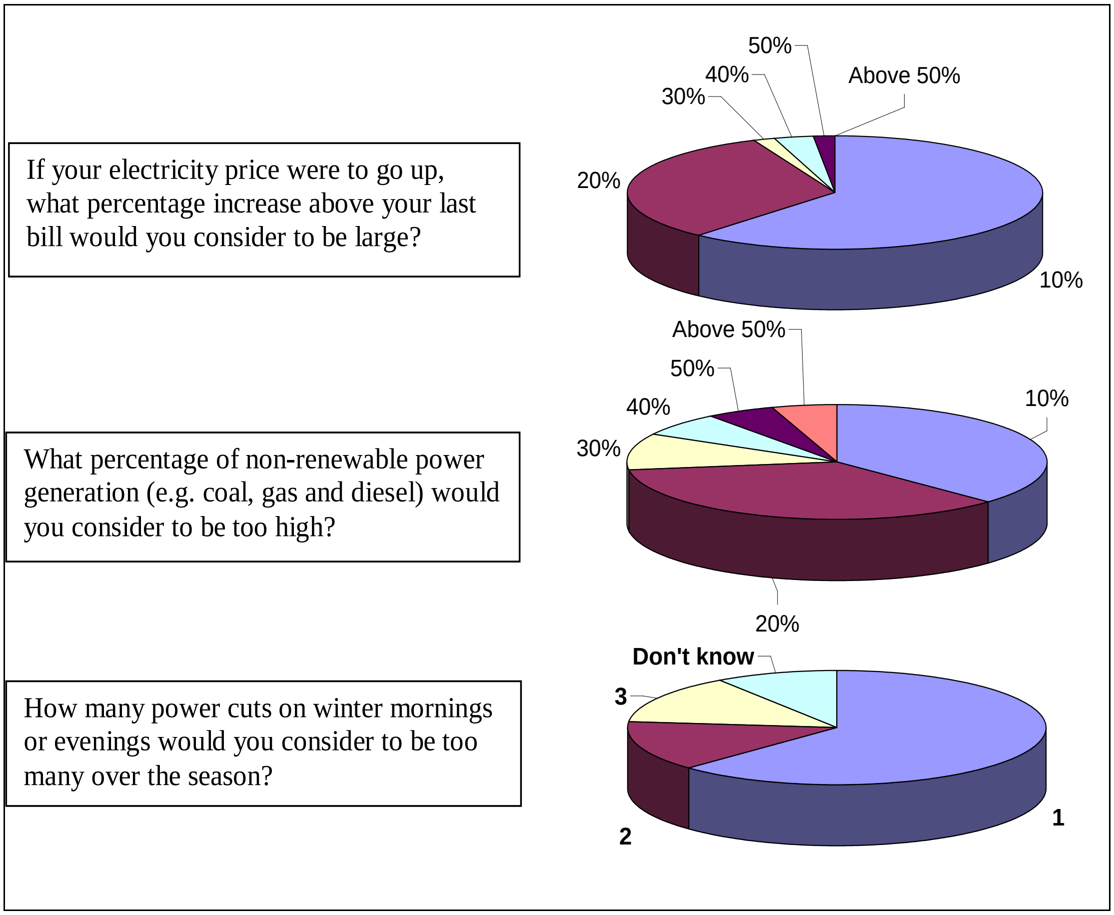

Figure 6.4: Households response rates to the three factors.

Respect for the environment is one of the ethical principles that guides human behaviour and governs decision-making at its various levels. Environmental protection might also be based on a cost-benefit calculation (as a bad environment may cause health problems). Currently, environmental problems such as global warming and threats to biodiversity are among the main reasons for which people adopt conservation behaviour (Gardner and Stern 2002). The second question in this section was aimed at getting an idea about the attitude toward CO_2 emissions. What level of increase in non-renewable generation would people accept? More than a third of the respondents said they would consider 10% electricity generated from non-renewable sources to be too high. A further third said a 20% increase would be considered too high. As with price, respondents do not want more than 20% of their electricity to be supplied from non-renewable sources. Their tolerant level with environmental could be similar to what they indicated as their level of tolerance with electricity price increase.

With respect to the question on security of supply, more than half said one power cut in a winter season would be considered too many. Obviously, people do not want to experience power cuts. The question is; will people be willing to participate in demand response to avoid any power cuts when they are given clear information to do so? The next sections show the behaviour change motivation of customers to the three factors and their willingness to alter the use of some major household appliances during the peak hours.

6.2.7 Electricity Allocation Scenario and Demand Response Behaviour

A further question was asked of the participants about what behaviour changes they would make during the peak demand period. Participants were asked to consider a hypothetical situation where they are allocated a certain amount of power during peak times which is less than what they would normally use. They were then asked to tell us how they would alter their electrical appliance usage in response to such a situation (see source questions Q18 – Q25 in appendix A). This question was asked to get an idea about household customer's flexibility in their appliance usage when they are given a ceiling on their demand during critical peak hours. Figure 6.5 shows the percentage of households that indicated they would adjust the usage of a particular appliance in response to peak demand allocation.

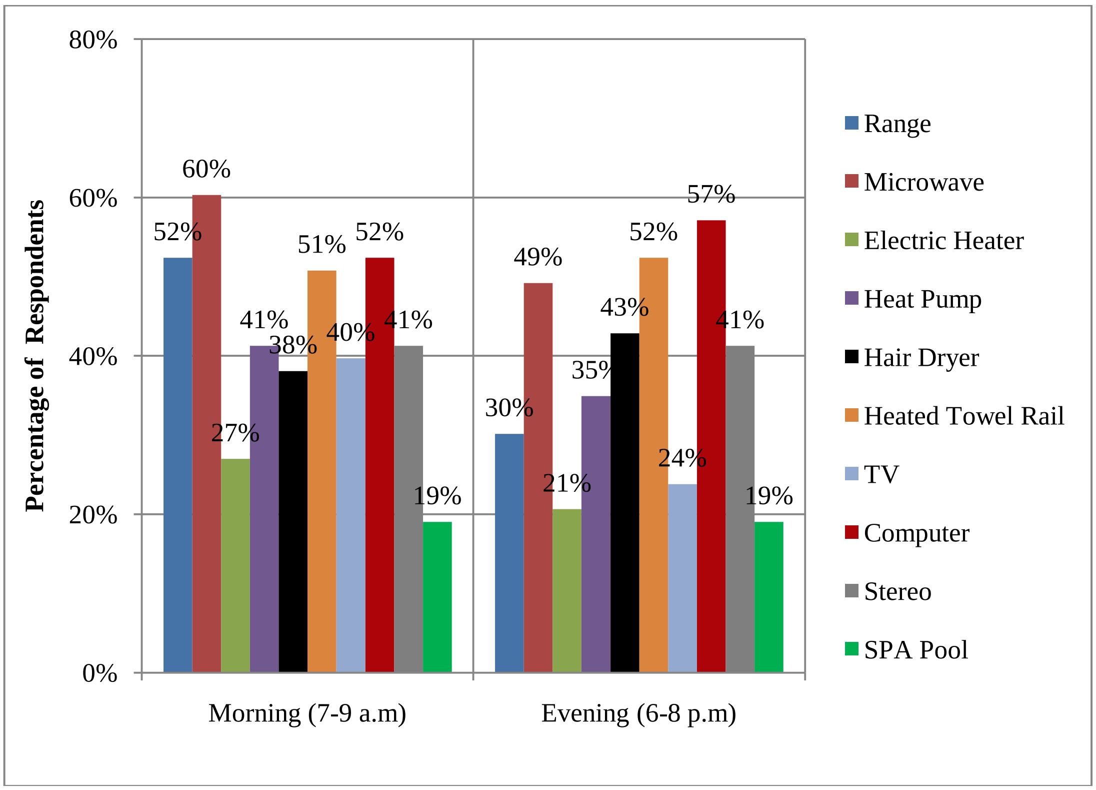

Figure 6.5: Percentage of households that indicated they would adjust the usage of particular appliances in response to a situation where they are allocated a limited amount of power than they need during the peak hours.

The figure shows that more than half of the respondents would alter the use of their microwave (60%), range (52%), computer (52%) and heated towel rail (51%) during the morning peak hours. A similar proportion would alter the usage of their computer and heated towel rail during the evening peak periods.

Figure 6.6 shows the shifting of flexible appliances (washing machine, clothes dryer and vacuum cleaner) from the peak period. More than half of the respondents would shift their washing machine usage from both the morning and the evening peak hours. It can be seen from figures 6.5 and 6.6 that demand response potential could be very large if the appliances such as heated towel rails, vacuum cleaners, washing machines, and clothes dryers are used during the peak demand hours.

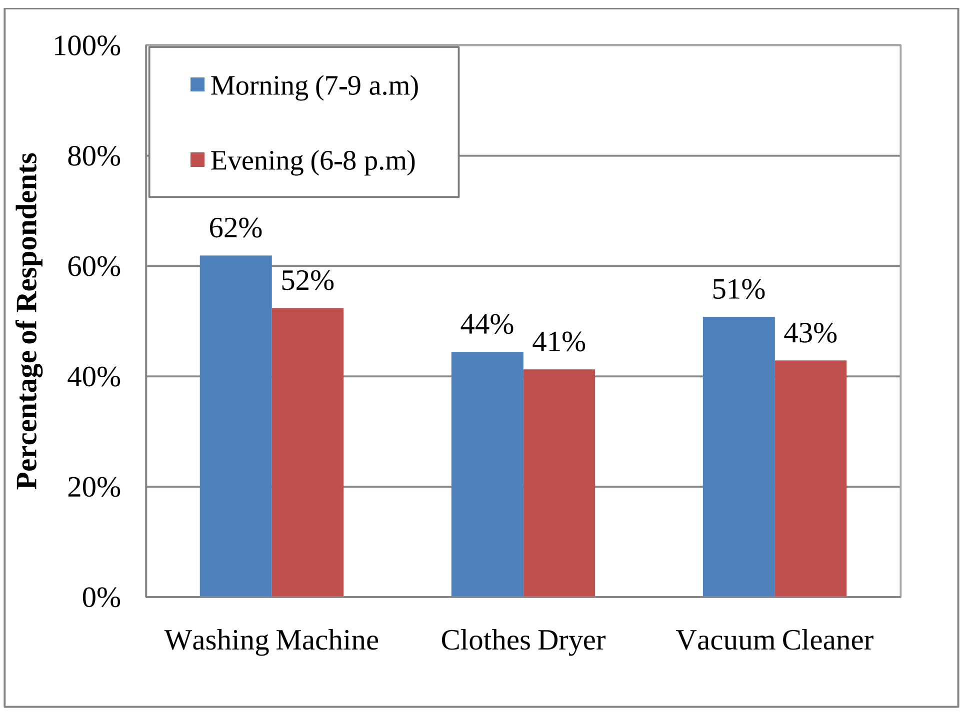

Figure 6.6: Shifting of some flexible loads away from peak hours.

The response of participants to an earlier question about appliance usage during the peak demand hours shows that households seldom use some of the appliances that they have also indicated a high potential to alter usage during the peak hours. To get an idea of achievable appliance demand response potential, the likelihood that an appliance will be used during the peak hours was combined with the likelihood that the usage of that same appliance would be altered during the peak hours. Achievable appliance demand response participation, dx_i is defined as the product of the likelihood that an appliance usage would be altered at the peak demand period and the likelihood that the same appliance would be used during the peak hours. Table 6.5 shows that achievable appliance demand response participation during morning peak hours ranges from 3% for clothes dryer to 18% for hair dryer. During the evening peak hour it ranges from 1% for SPA pool and hair dryer to 23% for oven. Table 6.6 shows the results of the number of light bulbs that are usually on during the peak hours compared with the number that can be switched off by participants due to limited allocated power to households.

Table 6.5: Likelihood of household appliance usage at the peak times and the corresponding demand response participation.

	Likelihood of Peak Usage (%)		Likelihood of Demand Response Participation		Achievable Demand Response Participation, dx_i	
Appliances	Morning	Evening	Morning	Evening	Morning	Evening
Cloth Dryer	10	15	44	41	4	6
Computer	19	44	52	57	10	25
Dishwasher	15	39	37	26	6	10
Electric Kettle	80	76	13	19	10	14
Hair Dryer	38	43	38	43	15	18
Heat Pump	57	74	41	35	24	26
Heated Towel Rail	51	52	51	52	26	27
Microwave	54	61	60	49	33	30
Electric Heaters	25	22	27	21	6	5
Oven	12	59	49	40	6	23
Range	15	58	52	30	8	18
Spa Pool	2	5	19	19	0	1
Stereo	12	8	41	41	5	3
TV	20	86	40	24	8	21
Vacuum Cleaner	21	14	51	43	10	6
Washing Machine	41	26	62	52	26	14

Table 6.6: The Number of light bulbs per household that are usually on during the peak hours compared with the number that can be switch off as a result of limited allocated power.

	Morning	**Evening**
Average number of light bulbs on during the peak hours	8.2	9.0
Average demand response participation	2.50	3.40

6.2.8 Behaviour Change Motivation

To determine which of the three factors could have a significant influence on behaviour; participants were asked 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 6.7 shows the response of the participants. The figure shows that customers are highly motivated by price and security factors. The number of people motivated by environment at the highest level (scale =5) is about half that of price and security.

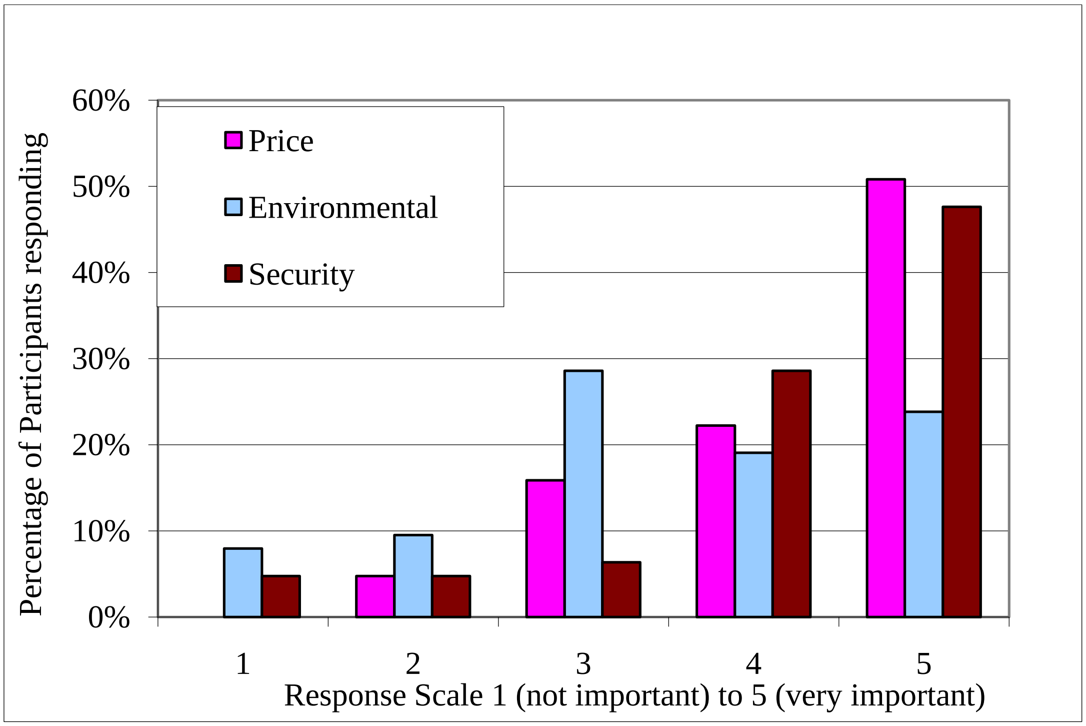

Figure 6.7: Household response rate to the three motivation factors, at each importance level.

The means responses to the factors were compared to see if there are significant differences between them. This was done by using SPSS software, a Statistical Package for the Social Sciences. The test of significance difference between the means of the factors was done using Analysis of Variance (ANOVA) test. ANOVA is a collection of statistical models that is used to test whether or not the means of three or more groups are the same (Norusis 1998). In this analysis, the factors were the independent variables and the levels of importance attached to the factors were the dependent variables. Table 6.7 provides the multiple comparison results using the Tukey HSD test. Significant differences (according to the 0.05 criterion) are indicated by an asterisk.

Table 6.7: Multiple comparisons of the factors using the Tukey HSD test.

(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

The result shows no significant difference between price and security as motivation factors. It means that people would respond to a security signal at peak demand hours with the same attention as they would do with price. The importance attached to the environment was different than the other two factors (price and security). The difference in mean between environment on one hand, and price and security on the other hand was significant, i.e. less than 0.05 significant level.

A further analysis was done to determine the weight of each factor as a motivation factor. The total score of each of the three factors was determined from the equation 6.3.

$$W_f = \sum_{j=1}^{n} w_{fj} \qquad \text{Equation 6. 3}$$

Where W_f represents the numerical importance of the factor f and w_f is the score given by the j^{th} customer to that factor. Table 6.8 shows the scores of the factors as a percentage of the maximum possible score (i.e. if all the respondents had given the factor the highest rating). Price obtained the highest score (82%) followed by security (79%) and then environment (64%).

Table 6.8: Scores of motivation factors for the Halswell survey

Motivation Factors	**Total Score**	**% Score**
Price	259	82%
Environmental	203	64%
Security	248	79%
Maximum Possible for each	315	100%

In order to assess the behaviour characteristics of the respondents, analysis of the weight of motivation factors by gender was carried out. Figure 6.8 shows the cross tab analysis of the weights of the factors by gender.

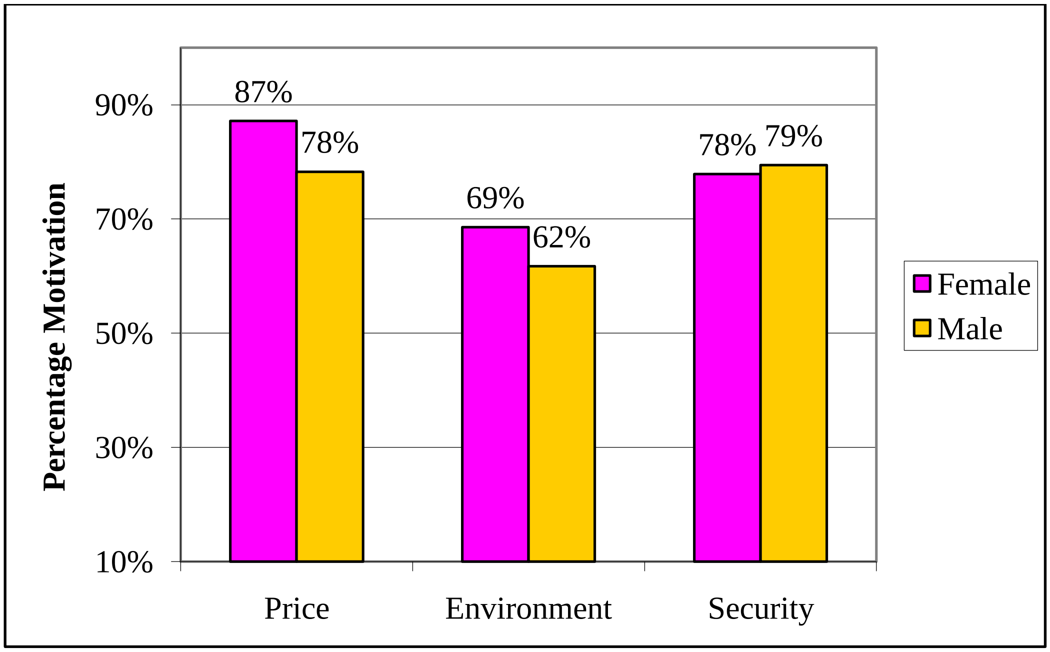

Figure 6.8: Weight of the motivation factors by gender.

For security, males and females scores were almost the same; 79% and 78% respectively. In contrast, females scored higher on environment (69%) than males (62%). Also the females score significantly higher on price (87%) than males (78%). Although the low number of respondents makes comparison limited, it can be said that females are more responsive to price and environmental factors compared to males in the Halswell survey.

6.3 Random Survey

6.3.1 Sample Representativeness

Gender, family size and income profiles of respondents were compared with the 2006 census data for Christchurch obtained by Statistics New Zealand using chi-square test. For Gender and family size, there was no significant difference between the sample and population. There was a significant difference between the income which was basically due to an over representation of households with annual income greater than $1000,000 NZD in the demand response survey. As in the Halswell survey, this is due to the survey targeting only single family homes. Table 6.9 show a comparison of the demand response survey with that statistics New Zealand for Christchurch.

Table 6.9: Comparison of the household income obtained from demand response survey with that of Statistics New Zealand for Christchurch.

Annual Household Income before Tax (in NZD)	**Demand Response Survey**		**Statistics New Zealand Survey (2006)**	
	Households (Number)	**Households (Percent)**	**Household (Number)**	**Households (Percent)**
<30,000	11	14	36,135	25
30,001 - 50,000	11	14	23,328	16
50,001 - 70,000	7	9	18,021	14
70,001- 100,000	16	21	18,021	13
>100,000	24	31	18,486	16
Not Stated	9	12	18,543	16

6.3.2 Demographic Information

Participants in the random survey were made up of people from the neighbourhoods as shown in table 6.10. A total of 78 out of the 400 surveys distributed were completed and returned by participants. Although there were large numbers of participants from Ilam and Fendalton compared to the other neighbourhoods, there is a wide mix of home construction in these older neighbourhoods. All the households together give a general idea of the characteristics of houses in Christchurch. The demographic distribution of the households in the random survey was dominated by couples, as in the Halswell survey. Figure 6.9 gives some demographic information of the households. While the chart shows two-person household as the most dominant family size (37%), most households (75%) have more than two bedrooms.

Table 6.10: Location of Household that Participant in Random Survey.

Household Location	Households (number)	Households (percent)
Merivale	7	9
Avonside	3	4
Fendalton	17	22
Ilam	38	49
St Albans	3	4
Upper Riccarton	3	4
Linwood	1	1
Location unspecified	6	8

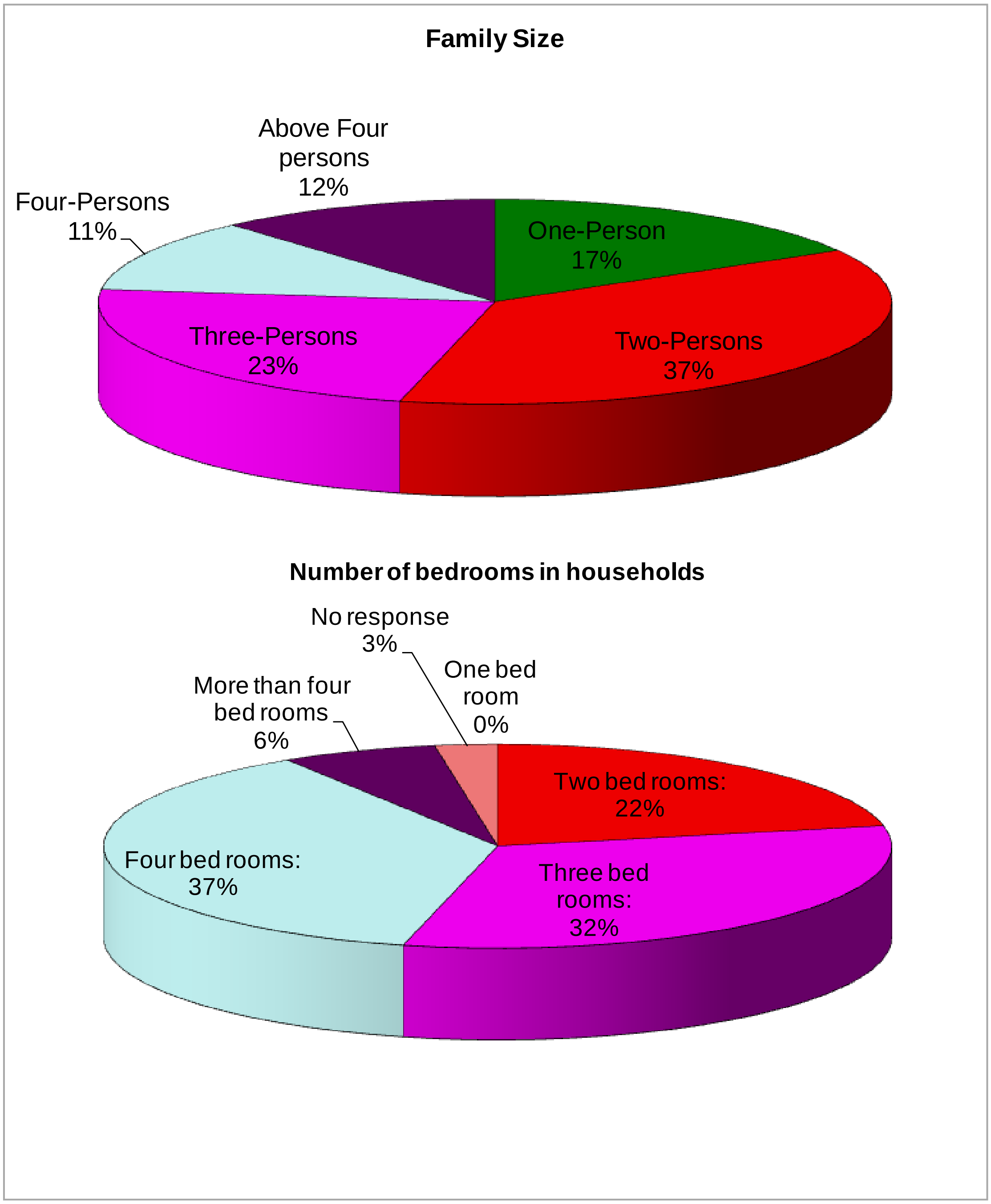

Figure 6.9: Demographic distribution of household respondents.

6.3.3 Winter Power Cost

The distribution of the monthly power cost was similar to that of the Halswell suburb. Figure 6.10 shows the monthly power bill of the participants in the random survey.

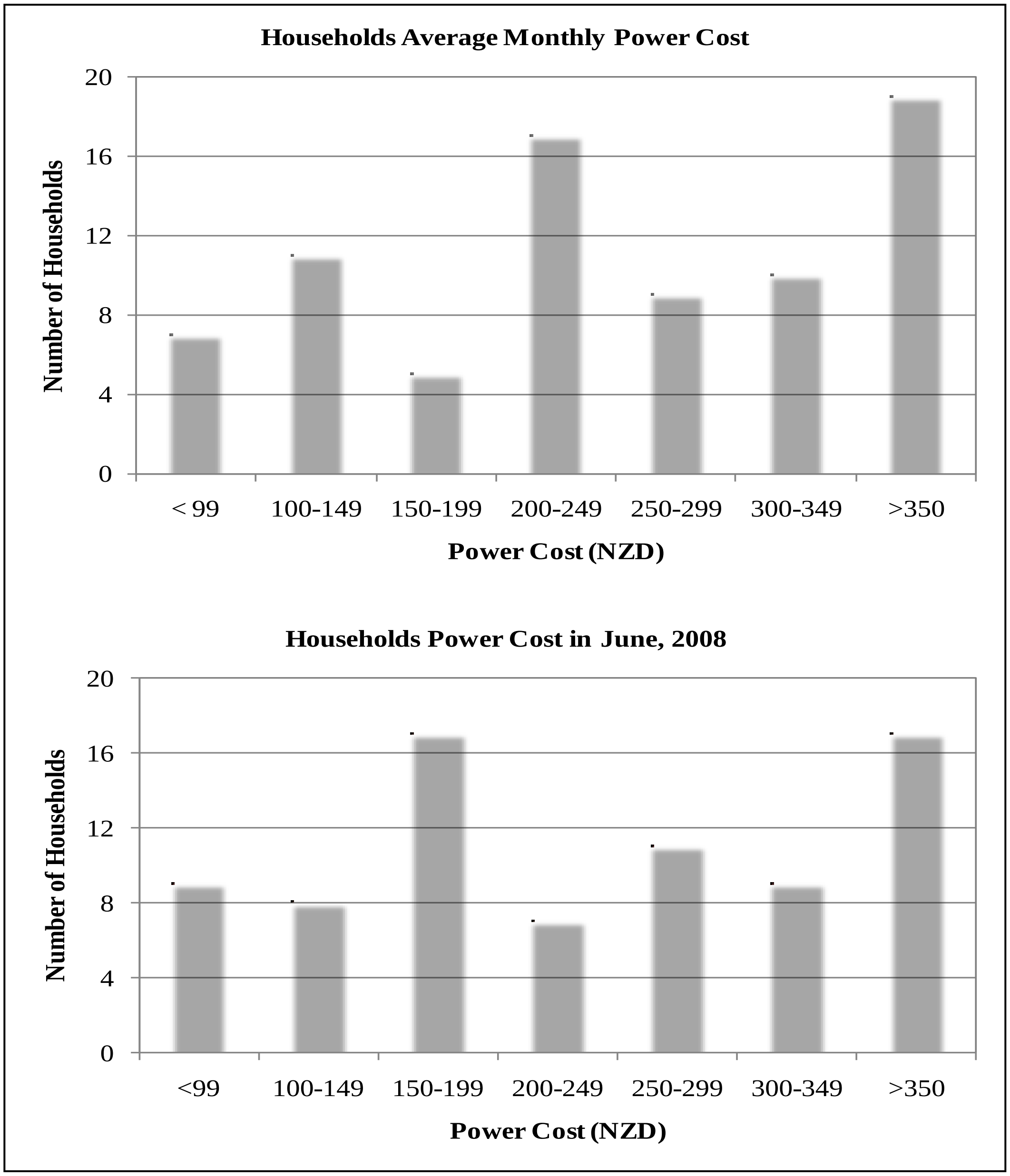

Figure 6.10: Average winter monthly household electricity cost in Christchurch.

While only 8% of the households in Halswell pay more than 350 NZD per month for power, 23% of households that participated in the random survey pay more than 350 NZD per month in winter for power. The household winter power cost range from 99 NZD to 600 NZD per month with the average of 252 NZD across all households and standard deviation of 120. It should be taken into account that about half of the households receive split rate tariff: night (or lower) and day (higher) rate. The end-uses on night-rate meter are water heating cylinder (37%) and night-store heater (29%). Table 6.11 shows the number of households with split meter.

Table 6.11: Number of households that receive split rates: night and day rates.

Source Question: Do you have night-rate power?		
	Households(Number)	**Households(Percent)**
Yes	36	46
No	37	47
Don't know)	5	6
If yes, which appliance(s) are on the night rate?		
Hot water heater	29	37
Night-store heater	23	29
Other	5	6
Don't know	7	9

6.3.4 Household Energy Features

The insulation status of the households that participated in random survey was lower compared to that of the new suburb of Halswell. This may partly explain why a significant proportion of the households in the random survey pay a higher cost per month for power in winter. Many houses in New Zealand are not fully insulated (Clark, Jones et al. 2005) and this was reflected in the random survey. Figure 6.11 shows the insulation level of the houses as indicated by the participants. Majority of the houses (78%) have insulated ceilings while about a third have wall insulation. Houses with floor insulation were also about a third. Ceiling is the easiest part of the house to insulate, while giving the highest benefits, and this is reflected in the high level of ceiling insulation.

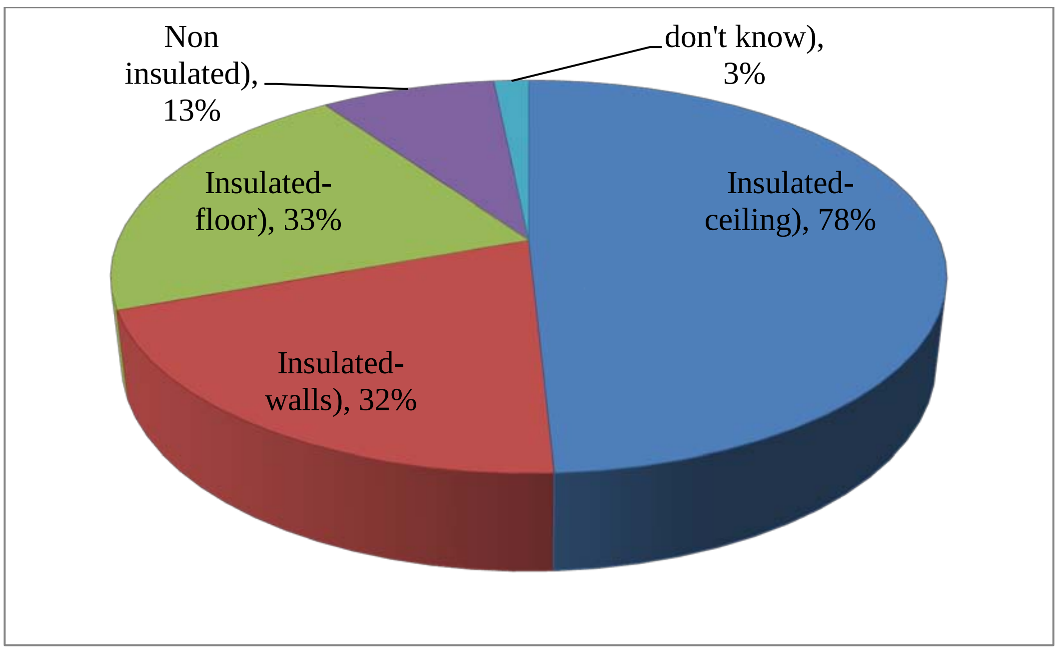

Figure 6.11: Insulation levels of the households in Christchurch showing the parts of house that are insulated.

This result is in line with the insulation status of the houses in New Zealand. The BRANZ 2005 House Condition Survey (Clark, Jones et al. 2005) found that 69% of houses in New Zealand had fully insulated ceiling, while about one in every five houses had partially insulated ceiling. Only 29% of houses have all walls insulated. Floor insulation is not very common in New Zealand with 64% of houses having completely un-insulated floors.

The BRANZ Household Energy End-use Project (HEEP) report (Isaacs, Camilleri et al. 2007) shows that electricity constitutes about 69% of energy use in homes in New Zealand and about 32% of space heating delivered energy. Low thermal performance due to poor insulation would require more heat input to maintain thermal comfort. This would result in increased power cost for non-insulated households that use electricity for space heating.

A further question was asked of the householders about the energy source for cooking. As shown in table 6.12, electricity is the main source of energy for cooking in the majority of the households: 59% of the households use only electricity as a source of energy for cooking, while 35% use both electricity and gas. If this number (i.e. the 35%) would do cooking with gas during the peak demand hours, it could help reduce the peak load substantially. Obviously, insulating homes could substantially reduce peak winter demand in Christchurch, but this would be a demand side management project rather than a demand response project.

Table 6.12: Source of energy for cooking in the households.

Fuel Switching	Household (Number)	Household(Percent)
Gas Only	5	6
Electricity Only	46	59
Gas and Electricity	27	35
Other	1	1

6.3.5 Future Changes

The response to possible future changes such as increase in price at peak times and increase in insecurity of supply, were similar to the responses of participants in the Halswell survey. The response of participants to the three questions related to the three factors is shown in figure 6.12. The majority of participants would be concerned if the price of electricity would increase above 20%. Householders are also not prepared to accept power cuts. In the case of the environment, the question was modified to help understand if people are aware of the current electricity generation mix in New Zealand. Instead of asking about the non-renewable additions that participants would consider as a big increase, they were rather asked for their opinion about a good renewable electricity generation target for New Zealand. At the time of this survey, the national government energy strategy had been released that had a stated target to 90% renewable electricity generation by the year 2050, and there had been widespread coverage in the media (MED-a 2007). No respondents indicated that a level lower than 50% would be acceptable. The largest answer group (24%) said they would consider 50% renewable generation as a good target for New Zealand. 15%, 15% and 18% of the respondents answered 60%, 70% and 80% respectively as a good renewable generation target for New Zealand.

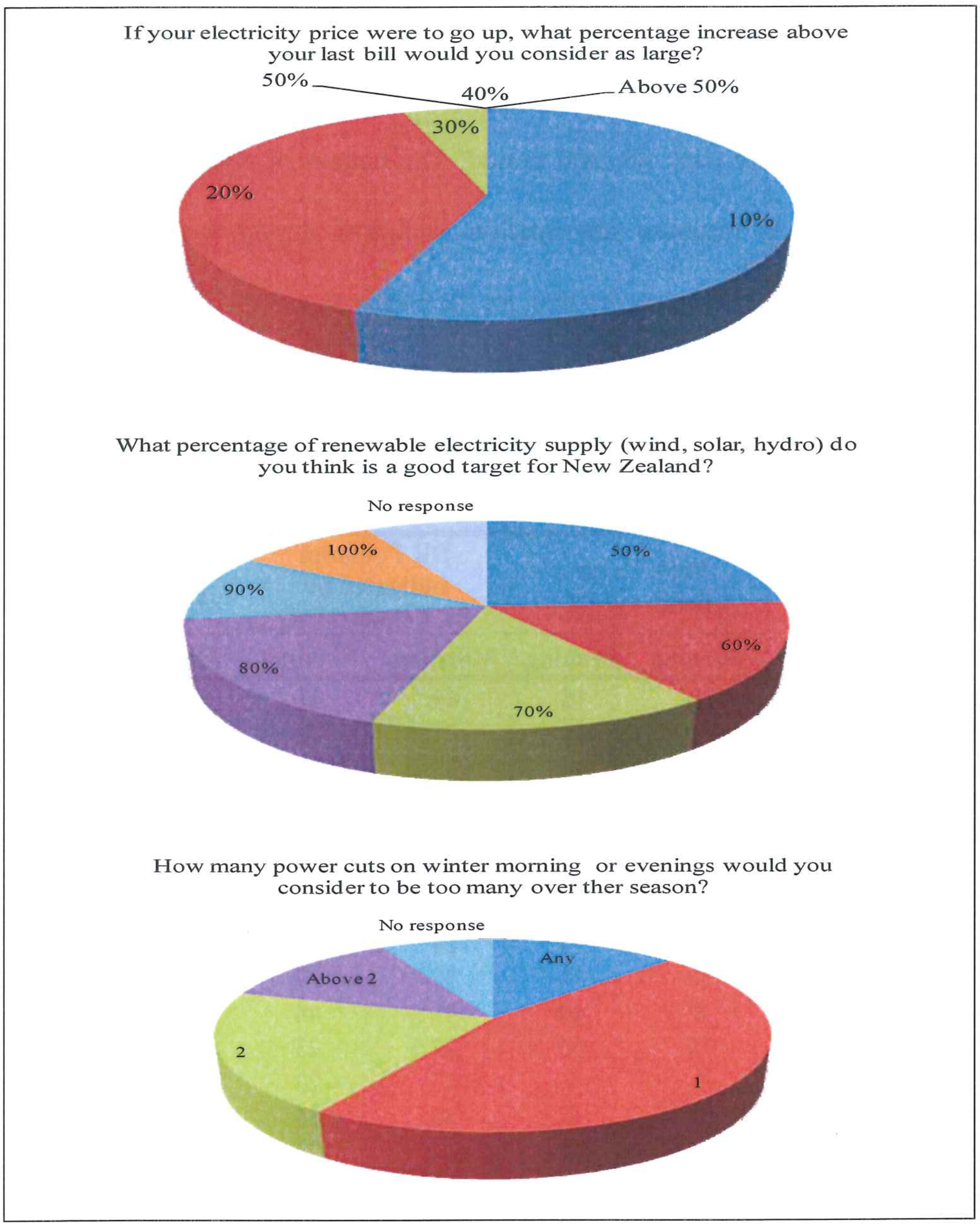

Figure 6.12: Households response to questions related to the three factors

6.3.6 Electricity Allocation Scenarios and Demand Response Behaviour

Table 6.13 shows the electricity usage during winter morning and evening peaks hours in Christchurch. It is important to note that according to the current survey and the HEEP study, flexible appliances like dish washers and clothes dryers are already mostly being largely used outside the peak demand period. The pattern of appliances used and the likelihood of demand response participation calculated during the peak hours were slightly higher for the random survey than for the Halswell survey.

Table 6.13: Likelihood of appliance usage at the morning and evening peak hours and the corresponding demand response participation.

Appliances	Peak Usage Likelihood (%)		DR Potential indicated by Participants (%)		Achievable DR Participation (%)	
	Morning	Evening	Morning	Evening	Morning	Evening
Cloth Dryer	10	15	44	41	4	6
Computer	18	44	41	42	7	18
Dishwasher	17	36	38	38	6	14
Electric Kettle	79	64	19	26	15	17
Hair Dryer	41	6	31	37	13	2
Heat Pump	49	51	26	21	13	11
Heated Towel Rail	46	37	45	44	21	16
Microwave	45	58	24	19	11	11
Electric Heater	37	34	32	32	12	11
Oven	8	49	42	44	3	22
Range	22	56	27	23	6	13
Spa Pool	1	1	23	23	0	0
Stereo	6	9	38	35	2	3
TV	16	78	41	23	7	18
Vacuum Cleaner	22	13	50	38	11	5
Washing Machine	41	24	58	53	24	13

6.3.7 Behaviour Change Motivation

An interesting finding was that the importance of three factors as behaviour change motivation was similar for the random survey as for the Halswell survey. Figure 6.13 shows the response of participants to each of three motivation factors at each importance. Price was the dominant motivating factor, followed by the security factor, and then environment. Table 6.14 shows the score of the factors as a percentage of the maximum possible score (i.e. if all the respondents had given the factor the highest rating.

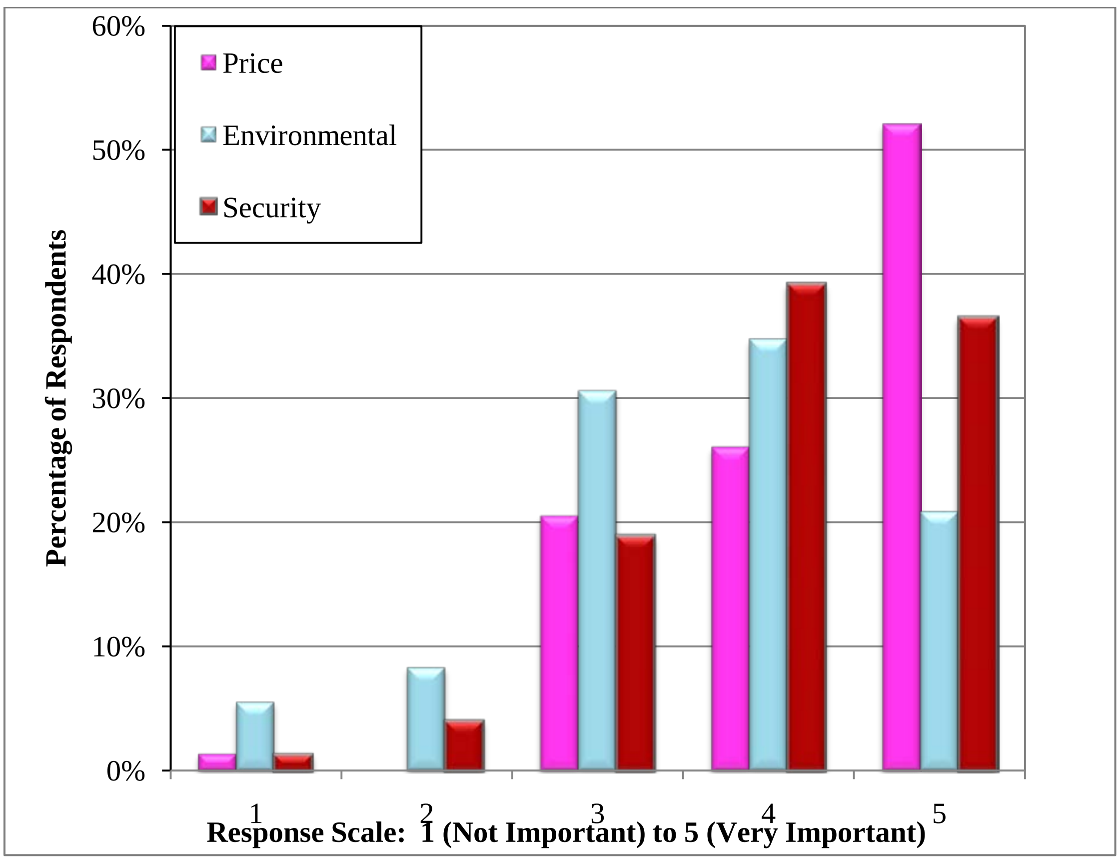

Figure 6.13: Households response rate to the three motivation factors, at each importance level.
Table 6.14: Score of motivation factors for the random survey.

Factors	Total Score	% Score
Price	312.00	80%
Environmental	257.00	66%
Security	300.00	77%
Maximum Possible for Each	390.00	100%

6.4 Focus Group

6.4.1 Awareness, Attitude, and Willingness to Participate in Demand Response

Focus group responses to questions were anonymously registered by use of electronic answer selection equipment as explained in the method section. The focus group response is presented in the list of points below.

- When given the option of either paying more for power or paying the normal rate and reduce their demand during critical peak hours, eight out of thirteen participants said they prefer the later.
- All the participants agreed that utility companies should charge their customers high prices during the peak hours if they wouldn’t agree to reduce their demand at those hours.
- Eleven out of the thirteen participants were prepared to adjust their electricity demand to ensure security of supply and lower the cost to all participants.

- Another key motivation included environmental benefits – 10 out of the 13 participants were prepared to reduce their demand in order to lower the impact of peak electricity generation on the environment, if they are informed of the effective response times.
- The idea of using smart tools and technologies to identify the opportunity to reduce demand during peak hours was welcomed by almost all the participants.
- The participants disagreed on whether demand response should be mandatory or voluntary. 40% of the focus group participants felt that demand response should apply equally to all customers while the rest (60%) felt that it should be applied to customers based on their electricity consumption level.

6.4.2 Behaviour Response in the Context of Dry Year Conditions

New Zealand generates more than 60% of its electricity from hydro power plants. During severe dry seasons, or "dry years", which usually occur in the winter, the output from the hydro power plants could drop greatly to the extent that the government sometimes has to initiate an energy conservation campaign. The last dry year occurred in 2008 and coincided with the time of the survey. The focus group participants were asked about what energy conservation actions they took during the dry year conservation campaign. The most common action taken by the participants was taking shorter showers (54% of respondents), followed by switching-off light bulbs (38%). Actions such as installing energy efficient light bulbs or cooking less were not taken by any of the participants.

Only one participant reported lowering his space heating temperature setting. None of the participants reported doing nothing during the dry year in 2008.

6.4.3 Comments and Suggestions from the Individual Participants

There were a range of ideas, suggestions, and concerns from participants when the floor was opened for comments. The following were ideas, suggestions and concerns given by participants.

- "Demand response should use an already existing technology in homes" (participant, 2008). Mobile/cell phone as a smart device that can receive peak demand warning messages from the utilities was suggested by this participant. This, according to the participant, would eliminate the cost of installing new meters in homes.
- "Power companies should identify the most caring user, those that are able to reduce their demand at peak time when called to do so, and reward them; and should find notorious users and big users who wouldn't want to change their usage behaviour and punish them" (participant, 2008).
- "The cost of power should be a big motivator to let people change their behaviour" (participant, 2008).
- One participant suggested an improvement in New Zealand Insulation Standard (R-Value). High standards will reduce the amount of heat loss in homes and will therefore reduce heating loads in the winter. According to this participant R-value in New Zealand is low compared to countries like Switzerland.

- "At least some degree of decentralization will be required to solve the peak demand problem" (Participant, 2008). This, according to the participant, would make the cost of power cheaper; as the losses in transmission and distribution will be reduced.
- "Using price to induce behaviour change will not be the best way to solve the peak load problem because of the low income households; it will introduce more social problems" (Participant, 2008). He suggested re-arranging or shifting working times for businesses – some shifted forward 2 hours and some shifted backwards 2 hours, as domestic peak demand is due to working patterns.
- New technologies like the "WHISPERGEN™" should be used in households to supply heating needs and also generate part of the households' electricity. Whispergen is a micro Combine Heat and Power (CHP) machine designed to produce up to 12 kW of heat for water and space heating in households and up to 1kW of electricity which can be used in the house or fed into the grid.
- Society transition was also suggested, where children are given education about peak demand and other sustainability issues in schools.
- A bigger range of ripple control is needed. Street lighting should be ripple controlled.
- Communities should use solar and gas systems.

6.5 Discussions of Survey Results

The results show that it is possible, with the right education and enhanced information, to effectively manage residential peak demand. The demand response surveys have provided some insight into residential energy use behaviour during the peak demand hours in Christchurch, perhaps giving some insight into why some researchers have pointed to the insufficiency of peak pricing programs to bring about an effective residential customer response. One of the interesting findings is the strength of security as a response factor. The statistical test revealed that there is no significant difference between price and security as motivating factors, suggesting the use of security as feedback information could achieve similar results to those reported for price in the literature. While customers' motivation tends to be more inclined to the cost of power and supply security, environmental benefits also seem to drive a significant proportion of consumers. The variations in the weight of the factors between respondents suggest that the combination of all three factors as feedback information could enhance customer response.

Residential customers in New Zealand lack important information that could influence people's peak demand behaviour. Even the monthly power bills given to the residential customers do not indicate the percentages of the different generation mix and the different levels of emissions. Providing customers this sort of information is a requirement in European Union countries (Darby 2006). An energy service directive that ensures that end-use customers are provided with a reasonable amount of information to help them make informed decisions could help to achieve energy conservation and peak demand reduction

Another interesting finding is the likelihood of customers adopting any peak demand reduction strategy (changing time of usage or using less). Demand response surveys usually report a large percentage of customers that are willing to shift the usage of some appliances away from peak to the off-peak hours (Lutzenhiser, Peters et al. 2009). This study shows that survey of usage of appliances during the peak demand hours is important in determining the potential load reduction. When this is taken into account, the achievable demand response potential could be lower than what is usually reported in the literature.

Solving peak demand through time-varying pricing in the residential sectors has been criticized for equity reasons (Alexander 2007). According to Alexander (2007) price response would disproportionately affect low income households who do not have the capacity to take action to avoid paying high peak prices. If low income households would be able to reduce their demand, they would do so at the expense of their comfort and wellbeing as well as convenience. This equity problem would be avoided if demand response was introduced as a voluntary exercise with different information packages (e.g. price, environment and security) targeted to sub-groups of residential customers. The result of the focus group, for instance, shows that if people are given improved peak demand information, they would be willing to reduce their electricity demand if they have the capacity to do so.

Another issue that often comes up in the discussion of demand response and Advanced Metering Infrastructure (AMI) or “smarter meter” is whether customer response to time-varying pricing would be sufficient to offset the investment in AMI. Even if it is assumed that investment in this technology has the potential to lower prices in the long-run, most utilities will not choose to or agree to absorb the additional costs in the short-run. Analysis shows that at least part of the cost would have to be *borne* by the residential customers (Faruqui and Sergici 2009), possibly in the form of monthly fixed charges. Higher monthly fixed charges may have a more adverse impact on lower use customers where the fixed charges represent a higher percentage of the total monthly bill. This issue was brought up by a participant during one of the focus group discussions. According to that participant, “demand response should use an already existing technology in homes”. An example is a mobile/cell phone as a smart device that will receive text messages from the utilities about an approaching peak time. This will eliminate the cost of installing new meters in homes.

Chapter 7: Demand Response Impact Modelling

7.1 Introduction

This chapter begins with a general introduction to the problem of residential demand response impact estimation. It discusses the methods that are used to estimate demand response impact in the residential sector. This is followed by presentation of a generalized model to estimate the magnitude of residential demand reduction. The approach adopted for this chapter is a combination of published literature reviews and resources and own research work.

7.2 Demand Response Resource Estimation

Demand response resource is simple the magnitude of load reduction that occur when demand response signal is given. One of the main objectives of demand response analysis is to determine this resource during demand response event for the purpose of the event analysis and settlements, program evaluation and investment potential. Two key measurement components are essential to the determination of demand response resource.

- **Baseline –** the consumption or demand that would have occurred, if the demand response had not taken place.

- **Responsive load** – the observed consumption or demand that occurs when the demand response signal is given and the anticipated participation is achieved.

Since the responsive load during demand response event is usually known, the key challenge is how to accurately estimate the baseline. If the baseline and responsive load could be modelled, then demand response resource would simply be the mathematical difference between the baseline and the responsive load, as illustrated in figure 7.1.

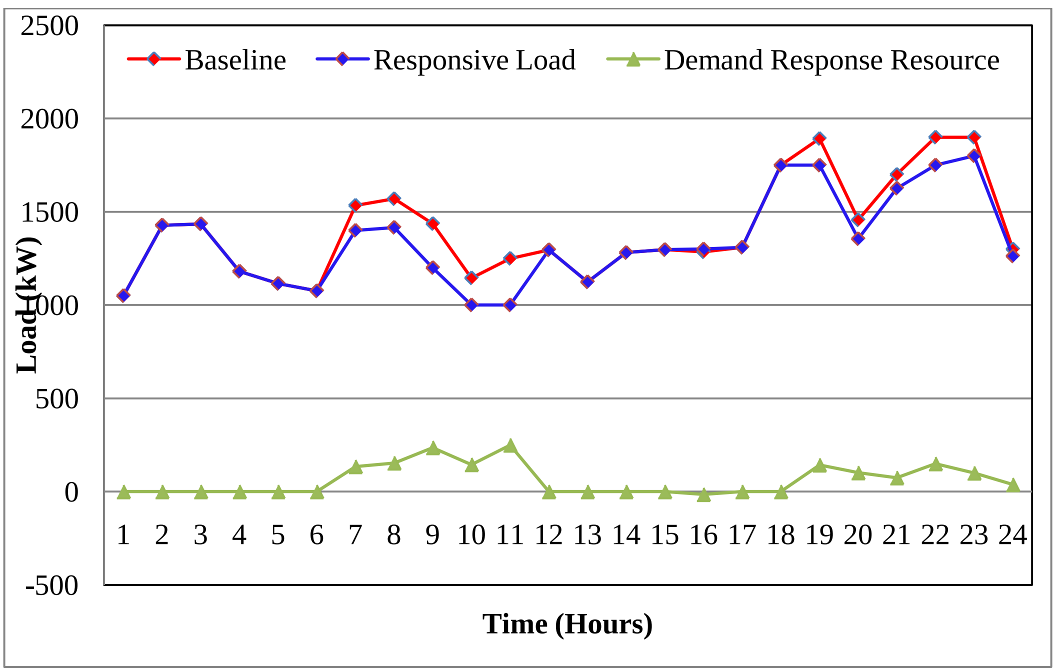

Figure 7.1: An illustration of demand response resource estimation problem

In the residential sector, customer diversity and the random nature of their demand make it difficult to estimate appropriate baseline for the purpose of demand response programme investment analysis. “Policy makers are of the concern that any method that would be used to estimate customer baseline should lead to a fair and accurate compensation, and provide useful information to resource planners and system operators who wish to incorporate demand response into their resource planning" (Coughlin 2008). The design of an appropriate baseline methodology is one of the important topics in demand response research. Different baseline criteria and methodology have been presented by different groups in recent times (KEMA-XENERGY 2003 ; Quantum&SummitBlue-Consulting 2006.). The most common baseline quality criteria include:

- **Accuracy –** the baseline must provide customers credit for their actual load reduction
- **Integrity –** the baseline calculation must not encourage nor be influenced by manipulation
- **Simplicity –** the baseline and the response calculation must be simple for all stakeholders to understand
- **Alignment –** the baseline design must facilitate performance in line with the goals and interest of stakeholders

7.3 Existing Baseline Methods

The existing approaches to estimate demand response baseline in the residential sector fall under one of the following four categories: (1) averaging method, weather matching approach (3) regression method and (4) econometric demand analysis. These methods are discussed in more detail in section 7.3.1 through 7.3.4.

7.3.1 Averaging Method

With this method, the baseline is estimated from two factors: most recent non-event days' average and an event-day adjustment factor that could move the calculated average up or down to better fit a specific event-day's load. The adjustment factor is designed to match the baseline load shape to the event's day loads, hours prior to the start of the event, thereby partially correcting for weather effects. Most studies recommend the calculation of the baseline from the average (at hourly level) of the 10 most recent load patterns prior to the event day, excluding weekend and holiday (KEMA-XENERGY 2003). A recent study (Quantum&SummitBlue-Consulting 2006.) recommends the calculation of the baseline from the average of the 3 highest loads selected from the 10 most recent non-event days' loads. The averaging method is straight forward and easy for customers to understand. However there are customers who have extreme variations in their day-to-day demand. For such customers, different method will be required to estimate their baseline demand since no averaging across non-event days will produce a reasonable baseline for a specified event-day.

7.3.2 Regression Method

The regression method uses a multivariate statistical regression model with as many days load data as possible together with a series of customer specific information, weather data and other characteristics to estimate the customer baseline. The regression method provides a more accurate baseline prediction but at the expense of model simplicity.

This method is popular for forecasting future demand response potential. The regression method can be used to estimate a single model that can be applied to all customers. However, Woo and Heter (Woo and Herter 2006) recommend the use of the regression method to estimate customer specific baselines as it allows more details to be built into the model; and also eliminates the need for customer demographic information as this would not change significantly within a short period.

7.3.3 Weather Matching Approach

The weather matching approach (Herter 2006) estimates the baseline from the average of non-event days with weather conditions closely matching those of the event day in question. The direct difference between the average of non-event day load, with weather data comparable to that of the event day, and the load data of the event day in question gives the impact of customer demand response. This method is straightforward, but the estimated baseline may not be credible enough, as non-event day with weather data comparable to that of the event day may not exist. If days with similar weather conditions do exist, then it might be expected that demand response event were called on those days as well.

7.3.4 Econometric Demand Analysis

Econometric demand analysis is based on the microeconomic theory of consumer behaviour. Unlike the other methods described above, this method is not directly used to estimate customer baseline but rather used to assess how electricity consumers respond to price change. It is more suited for price response programs. The econometric demand analysis can be used to estimate an electricity demand function for either households or businesses. For households the demand function is estimated based on utility maximization theory. The output of such a model is price elasticity that tells how consumers respond to price changes. These elasticity values can further be used to estimate the load impact. Examples of econometric demand analysis study include Caves for Wisconsin and Reiss and White for California (Caves, Christensen et al. 1984; Reiss and White 2002).

7.4 Residential Demand Response Modelling

The magnitude of demand response is usually estimated at an aggregate level. This method is suitable for the industrial and the commercial sectors. In the residential sector a better understanding of the customer behaviour is required. One of the main barriers to residential demand response is the lack of proper understanding of residential customers' behaviour in responding to demand response requests (DRRC 2007). There is a concern among demand response practitioners that demand response 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 will be required to study this problem, especially the effect of load shifting models on the aggregate load. However, unavailability of appliance level load makes it difficult to study this problem. The load data that is usually presented by the electric utilities for the residential sector do not contain much information about its nature. In the following sections, a generalized model to generate the load curve from the individual components of the residential load is presented. These data allow one to identify the relative contribution of the different components of the residential load to the sector's peak demand. This will allow a further analysis of effectiveness of the individual households' appliances in reducing the peak load on utility network.

7.5 Development of a Generic Appliance-based Load Curve

The appliance-load curve model is a "bottom –up" approach of generating the aggregate load profile of residential customers in which the pattern of usage of individual appliances are represented. The bottom-up approach has been used, for example, in the load model by Capasso et al. (Capasso, Grattieri et al. 1994), where probability functions representing the relationship between the demand of a residential customer and the psychological and behavioural factors typical of households were established through the use of a Monte Carlo method. Estimating these relationships at the individual household level makes the Capasso et al. model highly complex because these factors are extremely subjective and not easily defined with any certainty at that level. Paatero et al. (Paatero and Lund 2006) also developed a simplified bottom-up-model, quite similar to that of Capasso et al., but used representative data sample and statistical averages. The random nature of consumption was generated by using stochastic processes and probability distribution functions.

In this study, the load curves of the major household appliances whose aggregate defines the load profile of residential customers were generated using the method of diversified demand. This method was developed by Arvidson in 1940 (Gönen 2008) to estimate the load on distribution transformers when measurements of the actual load are limited. The diversified demand method has seen increased interest in recent times due to the revived interest in residential demand response and the need for component by component analysis of residential load. The method is straightforward and makes use of standard behaviour of the various types of household appliances as applied to a group of residential customers through the use of statistical correlations. According to the diversified demand method, 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. If the same technique is used for other classes of customers, similar load curves can be prepared (Gönen 2008). The construction of the appliance load curve requires certain load information to be available. Load saturation and load diversity data are needed for the class of customers whose load curve is to be generated. The diversified demand takes into account the fact that households may not be using all the electrical appliances that constitute the connected load of the house at the same time or to their full capacity. The load curve is constructed from the most probable load – the load that creates demand on the distribution facility.

7.5.1 Definition of Terms

The following terms relating to the power supply and demand are worth defining before the method of diversified demand is introduced.

Diversified demand –the demand of the composite group, as a whole, of somewhat unrelated loads over a specified period of time (Gönen 2008). It describes the variation in the time of use (or the maximum use) of two or more loads.

Maximum diversified demand – the maximum sum of the contribution of the individual demand to the diversified demand over a specific time interval.

Demand factor – the ratio of the maximum demand of a system to the total connected load of the system.

Connected load – the sum of the continuous ratings of load-consuming apparatus connected to the system.

Feeder – the circuit which carries a large block of power from the service equipment to some points at which it is broken into smaller circuits.

Residential feeder- a feeder that serves only residential customers i.e. households

Distribution transformer – the device use to converts electrical energy of higher voltage to a lower voltage, with frequency identical before and after the transformation.

Non-coincident demand –the demand of a group of load with no restriction on the interval to which each demands is applicable.

Hourly variation factor –the ratio of demand of a particular type of load co-incident with the group maximum demand to the maximum demand of that particular type of load

(Gönen 2008). It is simply the percentage of appliance load that coincides with the group maximum load.

Appliance saturation rate – the percentage of households that own at least one of a given appliance category.

7.5.2 Modelling Approach

Figure 7.2 illustrates the approach used to estimate the load curves of the individual household appliances. F_1, F_2, F_3 and F_4 represent typical residential feeders. H_1, H_2 …H_m are houses on a distribution transformer which are fed by the feeder F_4. A_1, A_2 … A_n represent the different household appliances in the individual houses. The average maximum diversified demand of the appliance categories is calculated from equation 7.1

$$MDD(_{av,\max})_i = MDD_i * n_i \qquad \text{Equation 7. 1}$$

where $$n_i = m * s_i \qquad \text{Equation 7. 2}$$

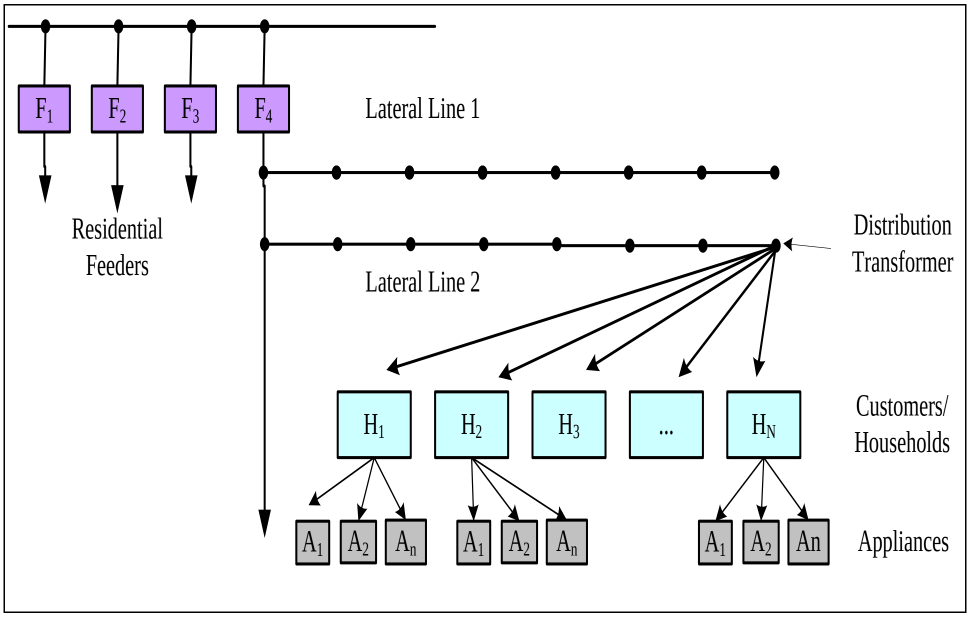

Figure 7.2: Illustration of the Modelling Approach for a group of customers

$MDD(_{av,\,max})_i$ 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 a given category, m represents the total number of households under consideration and s_i represents the saturation rate of appliance of a given category. *MDD* depends on the total number of appliance *n*. The *MDD* corresponding to different *n* for some household appliances is presented in table 3 (Gönen 2008). As the number of appliances (n_i) increases the maximum diversified demand per customer (MDD_i) decreases until it becomes a constant at large n values.

Table 7.1: Maximum 30 minutes diversified demand per customers (in kW) for given number (n) of appliance (Gönen 2008)

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 7.3

$$MDD_{(t,\,\max)i} = MDD_{(av,\,\max)i} * f_i(t) = MDD_i * n_i * fi(t) \qquad \text{Equation 7. 3}$$

$f_i(t)$ is the hourly variation factors of the appliance categories. $f_i(t)$ depend on the living habits of the individuals in a particular are and may differ from location to location. These factors define the pattern of the load curves. The maximum load on the distribution transformer at any time is given by the sum of the maximum diversified demand of the individual appliances and is determined from equation 7.4.

$$MLT(_{t,\max}) = \sum_{i=1}^{N} MDD(t,\max)_i = \sum_{i=1}^{N} MDD_i * n_i * f_i(t) \qquad \text{Equation 7.4}$$

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.).

An Illustrative Example of the method

Assuming a distribution transformer serves five houses, through five service drops and two spans of secondary lines. Suppose that there are a total of 20 distribution transformers and 100 residences supplied by the primary feeder. If a typical residence contains clothes dryer, range, refrigerator, and lighting and miscellaneous appliances, then the following calculation can be performed.

1. The 30 minutes maximum diversified demand on the distribution transformer can be found from table 7.1.The number of houses, n=5. The average maximum diversified demands of appliances per customer are:

$$MDD,_{per,\ customer} = \begin{cases} 1.80 & clothes\ dryer \\ 0.07 & refrigerator \\ 0.90 & range \\ 0.65 & lighting\ \&\ Mics \end{cases}$$

The maximum load on the distribution transformer is given by

$$MLT = \sum_{i=1}^{N} MDD_i * n = (1.80 + 0.07 + 0.90 + 0.65) * 5 = 17.1kW$$

2. Assuming the hourly variation factors of the appliances from 4 p.m to 6 p.m on a typical weekday are as shown in the table below:

Time	Hourly Variation Factors			
	Clothes Dryer	**Range**	**Refrigerator**	**Lighting and Misc.**
4 P.M	0.38	0.24	0.90	0.32
5 P.M	0.30	0.80	0.90	0.70
6 P.M	0.22	1.00	0.90	0.92

Then the portion of daily demand curve on the distribution transformer or the total maximum hourly diversified demand can be calculated as:

$$MLT(t)i = \sum_{i=1}^{N} MDD_i * n_i * f_i(t)$$

The results are as presented the table below.

Time	Demand Contribution				Total=MLT
	Clothes Dryer	**Range**	**Refrigerator**	**Lighting and Misc.**	
4 P.M	3.42	0.084	4.05	1.04	8.594
5 P.M	2.7	0.28	4.05	2.275	9.305
6 P.M	1.98	0.35	4.05	2.99	9.37

3. The maximum load on the entire feeder (n=100) is calculated as follow:

$$MDD,_{per,\,customer} = \begin{cases} 1.00 & clothes\ dryer \\ 0.05 & refrigerator \\ 0.50 & range \\ 0.52 & lighting\ \&\ Mics \end{cases}$$

Hence

$$MLT = \sum_{i=1}^{N} MDD_i * n = (1.00 + 0.05 + 0.50 + 0.52) * 100 = 207kW$$

However, if the answer for the 30-minutes diversified demand on one distribution transformer found in part I is multiplied by 20 to determine the 30-minutes maximum diversified demand on the entire feeder, the answer would be 20*17.1=342, which is greater than 207 found in III. The discrepancy is due to the application of the appliance diversity.

Chapter 8: Case Study in Christchurch, New Zealand

8.1 Introduction

The generic household appliance load curve methodology developed in the previous chapter was applied in a case study in Halswell, a small neighbourhood in Christchurch, New Zealand, with approximately 400 households. This chapter presents the results of the case study.

8.2 Variables Estimation for the Case Study

The generic household appliance load curve methodology described above was applied in a case study in Halswell, a small neighbourhood in Christchurch, New Zealand, with approximately 400 households. The Halswell neighbourhood was selected as a location for the case study due to its unique nature as the only area in Christchurch which has its own residential feeder. There is no retail, commercial or industrial load on this feeder. It was selected to make it possible to compare the modelling results with the actual load measured by the utility.

The total number of each appliance category (n_i) was determined by multiplying the total number of households (n = 400 in this case) by the appliance saturation rates (s_i). The appliance saturation rates for New Zealand (Electricity-Commission 2007) were used for the location. 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 situation at the Halswell area. Halswell is a relatively new suburb in Christchurch with high penetration of heat pumps. The saturation rate of electric heaters is expected to be lower than the New Zealand average as space heating is done mainly with heat pumps. Table 8.1 Shows the maximum diversified demand estimated for the 400 households in Halswell.

Table 8.1: Maximum diversified demand calculated for 400 households

Appliances	**Appliance saturation rate (%)**	**Total number of appliance**	**Diversified demand per customer (kW)**	**Maximum diversified demand (kW)**
Domestic Water Heater (DWH)	87	348.00	0.72	250.56
Heat Pump*	35	140.00	2.60	364.00
Electric Heater**	93	372.00	3.00	1116.00
Clothes Dryer	34	136.00	1.20	163.20
Washing Machine	95	380.00	1.20	456.00
Freezer	64	256.00	0.08	20.48
Refrigerator	31	124.00	0.06	6.82
Fridge/Freezer	80	320.00	0.08	25.60
Microwave/Oven	78	312.00	0.50	156.00
Range	93	372.00	0.55	204.60
Lighting & Misc.	100	400.00	0.54	216.00

The appliance saturation rates were all taken from a recent electricity commission study (Electricity-Commission 2007) except * which was taken from a recent BRANZ study (French 2008). ** Saturation of electric heater has been adjusted to reflect the situation at Halswell.

Estimation of the hourly variation factor, $f_i(t)$

The hourly variation factors, $f_i(t)$ reveal the behaviour characteristics of appliance usage and depends on the living habits of the individuals in a particular location. These living habits in turn are affected by the socio-economic factors such as the number of occupants in the individual households, their age and income. The hourly variation factors for New Zealand were estimated from the results of the second year report of New Zealand Household Energy End-Use Project (HEEP) (Stoecklein, Pollard et al. 1998), and data from Orion Networks (OrionNetwork 2006), the distribution company in the Christchurch area. The HEEP study measured interval electricity demand of household appliances in winter in some regions in New Zealand. The data from the HEEP pattern of usage and the information from Orion Network were used to estimate the hourly variation factors shown in figure 8.1. Figure 8.2 shows the load profile estimated for the 400 households on the Halswell residential feeder compared with the actual profile measured by the utility in some selected days in winter 2006. The shape of the estimated load curve compares very well with the load profile measured by the utility. While the shape of the load curve measured by the utility in different days remains largely the same, the magnitude of the curve may vary greatly from day to day. It is therefore important that the estimated load profile compares well with that measured by the utility in shape rather than in magnitude.

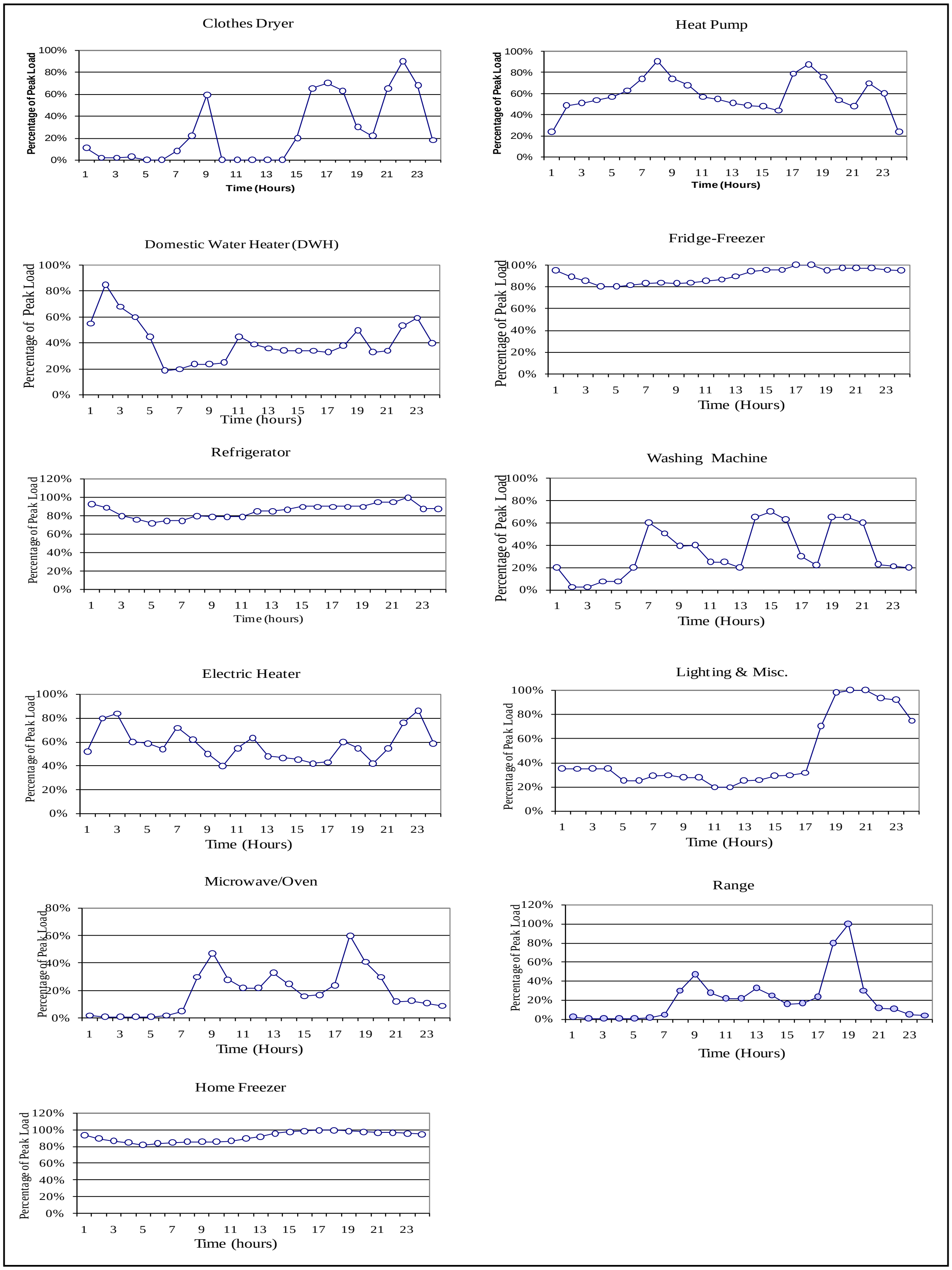

Figure 8.1: Hourly variation factors determined for winter in New Zealand

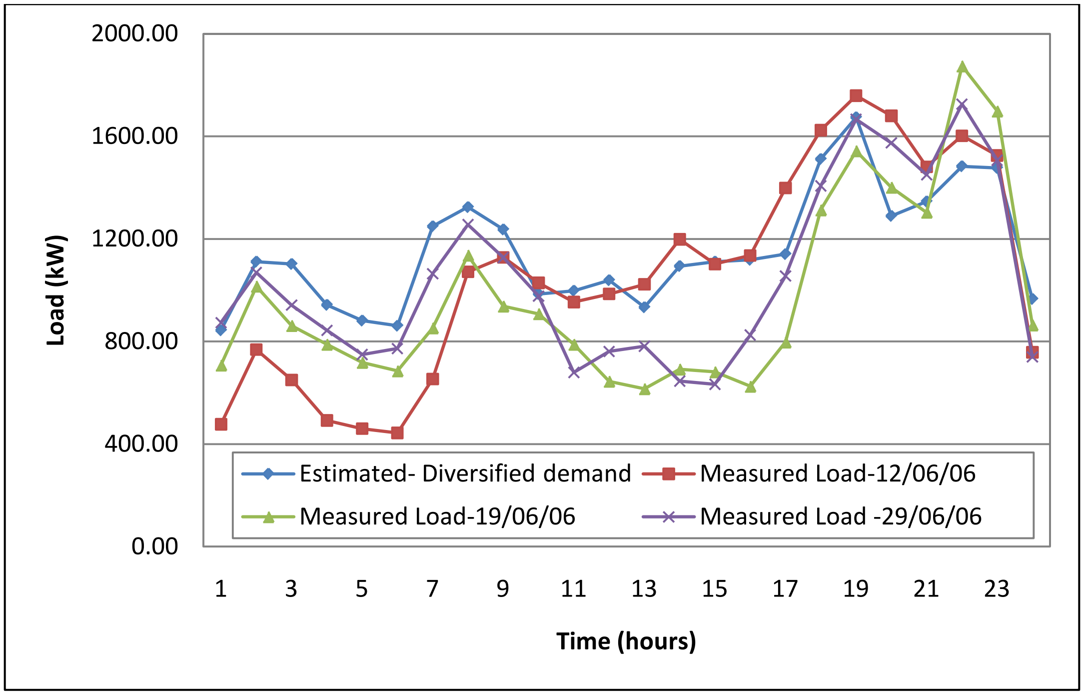

Figure 8.2: Estimated load curve for the 400 households in Halswell compared with the measured load by the utility in winter, 2006.

8.3 The Impact of Demand Response in Halswell

In order to calculate the magnitude of demand response for Halswell, the households' willingness to adjust their demand in a hypothetical supply constraint situation in winter obtained through survey in the area was combined with the appliance load data obtained through modelling (see table 6.5). Customers' activity demand response (ADR) was calculated from equation 8.1. The 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.

$$ADR_{i(t)} = MDDi(t) * dx_i \qquad \text{Equation 8.1}$$

$ADR_i(t)$ represents customer activity demand response, 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 likelihood 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 constraint situation during the peak hours. These survey results were presented in table 6.5.

The average activity demand response for the Halswell neighbourhood is shown in figure 8.3. The average activity demand response during the morning peak hours (07 – 09) ranges from 2.6 kW for clothes dryer, representing 0.2% of the average morning peak load to as high as 72 kW from heat pump, representing 4.8% of the morning peak load. The second highest activity demand response at the morning peak hours was from washing machine, representing a reduction of 53.4 kW or 3.5% of the morning peak load. The highest activity demand response during the evening peak hours (18:00 – 20:00) was 49.2 kW obtained from heat pump, followed by 33.2 kW from washing machine, and 21.7 kW from electric heater. The average total activity demand response was higher during the morning peak hours at 192 kW, representing about 13% of the morning peak load, than 139 kW of the evening peak reduction, representing 8% of the evening peak load. Table 8.3 shows the detail activity demand response during the peak hours.

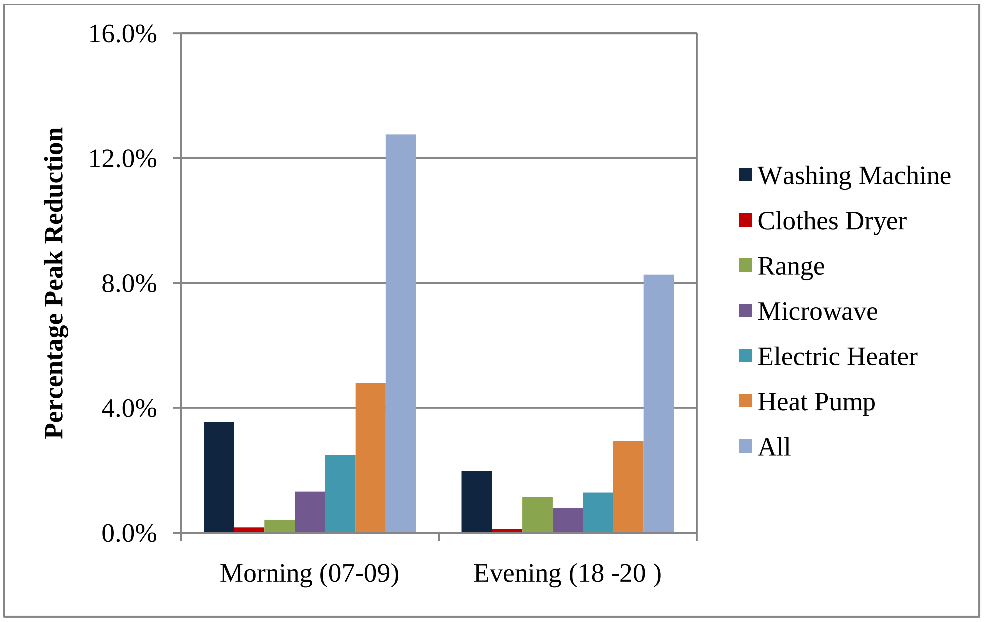

Figure 8.3: Average activity demand response for 400 households at the morning and the evening peak hours

Table 8.2: Detail average activity peak demand response for 400 households (in kW) in Halswell, Christchurch

Peak Time	Washing Machine	Clothes Dryer	Range	Microwave	Electric Heater	Heat Pump	All
07-08	60.5	1.4	4.9	15.4	41.5	79.5	203.3
08 -09	46.2	3.9	7.7	24.2	33.5	64.6	180.1
Morning Average	53.4	2.6	6.3	19.8	37.5	72.1	191.7
% of Morning Peak	3.5%	0.2%	0.4%	1.3%	2.5%	4.8%	12.8%
18:00-19:00	41.5	2.9	36.8	19.2	30.7	71.9	203.1
19:00- 20:00	24.9	1.1	1.5	7.4	12.6	26.5	74.0
Evening Average	33.2	2.0	19.2	13.3	21.7	49.2	138.5
% of Evening Peak	2.0%	0.1%	1.1%	0.8%	1.3%	2.9%	8.3%

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 peaks. The result of this comparison is shown in figure 8.4. 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 use behaviour in accordance with their stated behavioural intensions (during the survey), then such change would be enough to maintain system reliability.

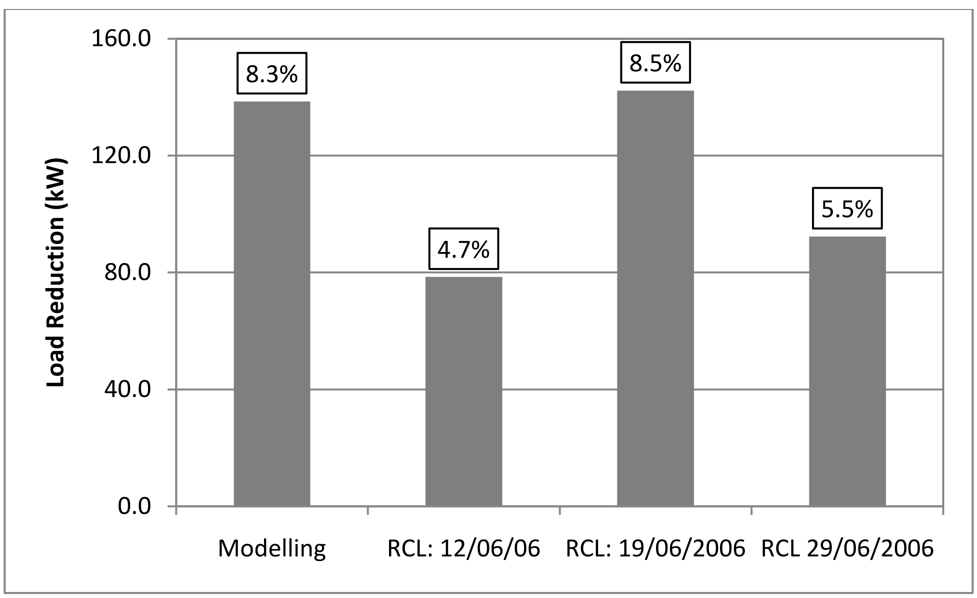

Figure 8.4: Comparison of the modelling results to ripple-controlled load (RCL) by utility company during the evening peak hours in some selected days in winter 2006.

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8.4 Potential of Peak Demand Response in Christchurch

In order to calculate the potential activity demand response for Christchurch, the peak demand reduction obtained for the 400 households in Halswell was projected onto the number of all households in the Christchurch city (approximately 131,833). The resulting load curve after activity demand response redistribution was compared with the actual load curve on the entire Orion's distribution network on the 19^{th} of June 2006. 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). It was shown that the average morning (07:00 – 09:00) peak load could be reduced with the voluntary activity demand response by 63 MW, representing 10.5% of the morning peak, while the evening peak load (18:00-20:00) could be reduced by 46 MW, representing 7.4%. Figure 8.5 shows the reduction in the entire Orion network peak load, if the results obtained for the Halswell neighbourhood is projected onto the total number of households in Christchurch. This result is based on the assumption that all the households in Christchurch will behave the same way as those in Halswell. Indeed demand response of the random survey of households in Christchurch gave results similar to that of the Halswell neighbourhood.

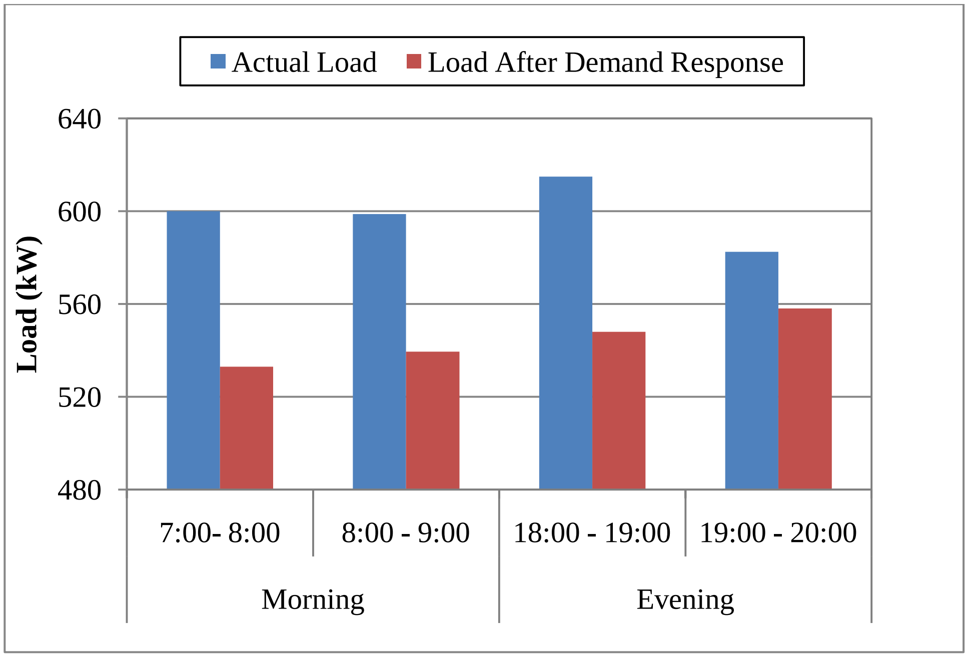

Figure 8.5: Voluntary activity demand response potential in Christchurch

8.5 Determining the Value of Demand Response

The value of demand is often calculated by comparing costs per kW of demand reduction provided to increase system reliability to the costs of a new gas combustion turbine or diesel generator and/or to spot market electricity prices, if the later would have been used to provide the system reliability. This is often referred to as the avoided cost methodology or the Standard Practice Methodology. The unit cost of providing the additional system peak load requirement with ‘peaking’ plants is used to assign value to the kilowatt (kW) load reduction obtained through a demand response program. The avoided supply cost includes:

- Generation cost (\$/kWh)
- Transmission cost (\$/kWh)
- Distribution (\$/kWh)
- Transmission and distribution Losses
- Emissions costs (\$/kWh)
- Market price effect of reduced demand (% by time-of-use period)

The other popular method of assessing the value of demand response is by considering demand response as an emergency resource that reduces the number, the scope and the size of forced outages. The value of demand response is expressed as the the product of the *Expected Outages times the Expected Disconnected Load times the Value of Lost Load (VOLL) (\$/kWh)* as shown in equation 8.2. “The accepted industry practice is to adopt a VOLL of \$2-5/kWh, which represents an average value across the entire market” (USDOE 2006).

$$Value\ of\ Demand\ \mathrm{Re}sponse = Expected\ Outages(hours/year) \times Expected\ Disconnected\ Load(MW) \times VOLL(\$/kWh) \qquad \text{Equation 8. 2}$$

8.6 The Value of Demand Response in Christchurch

The value of demand response in Christchurch was estimated based on avoided cost methodology described in section 8.5. Readily quantifiable costs and benefits of peak demand reduction were assessed. This is a more conservative estimate and excludes customer environmental benefit, societal cost, risks, and other benefits which are not easy to quantify, such as the market effect of reduced peak demand.

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 of around NZD $50/kW and a distribution LRAIC of NZD $100/kVA[1] per annum (IEADSM 2008). Adopting these values, the 46 MW average evening peak load reduction translates into approximately NZD 2.30 million per annum of transmission capacity and NZD 4.60 million per annum of distribution capacity.

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

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

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. The generation cost of the reduced load at the morning peak hours translates into approximately NZD $0.76 million per annum and that of the evening translate into approximately NZD $0.55 Million per annum. The avoided cost of the different components of the electricity supply is shown in figure 8.4.

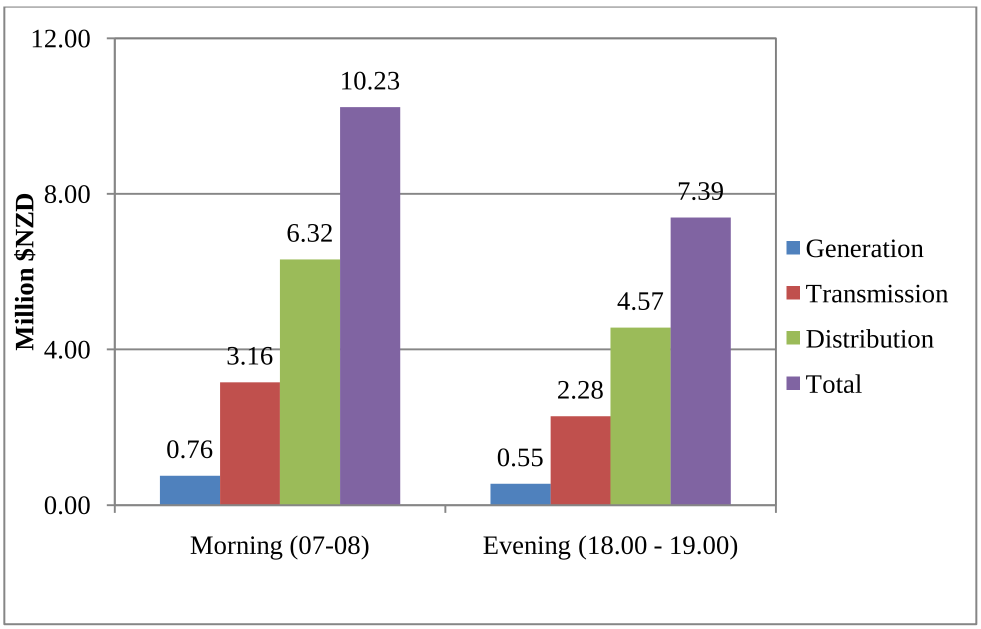

Figure 8.6. Component cost of the avoided peak load during the morning and the evening peak hours.

8.7 Cost Effectiveness of the Reduced Load

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 55 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 discount rate of 5%

The demand response program cost includes the device cost with installation, direct mail solicitation, media campaign etc. Table 8.6b compares the cost of the reduced peak load against the benefit of such a demand response project over a 15 year time horizon. The cost per kW of the reduced load for given year was calculated from equation 9.

$$FC_n = \frac{TPC(1+i)^n}{\sum_{n=1}^{n} DR} \qquad \text{Equation 8. 3}$$

FC_n is the cost per kW for a given year, TPC is the total project cost, n is the year under consideration, DR is the reduced demand. These analyses were made by adopting the Long Run Average Incremental Cost (LRAIC) of new transmission addition of NZD $50/kW and distribution LRAIC of NZD $100/kVA per annum. The results show that the benefit of demand response project will exceed the cost after the 5th year, assuming a persistent demand reduction.

Table 8. 3: Value of the demand response compared with the avoided cost over a 15 year time horizon, assuming a persistent saving.

Cost Components	**Cost in NZD $**				
	Year I	**Year 2**	**Year 5**	**Year 10**	**Year 15**
Value of Reduced Demand (NZD/kW)	615.22	322.99	149.56	95.44	81.21
Generation Cost (NZD/kWh)	0.21	0.22	0.26	0.33	0.42
Transmission cost (NZD/kW)	52.50	55.13	63.81	81.44	103.95
Distribution Cost (NZD/kW)	105.00	110.25	127.63	162.89	207.89

Chapter 9: Conclusions and Recommendations

9.1 Conclusion

Demand response is expected to play an important role in the supply of power in the future. In a resource or transmission and distribution constrained power system where the option of increasing supply to balance demand is limited and/or available at high cost, demand response can contribute highly to supply-demand balance, by ensuring that voltage and most especially frequency remain within their required operational values. The potential of demand response in the residential sector can be huge, but its' exploration still remains a challenge. Information barriers and lack of proper understanding of customer behaviour are among the factors that limit the extension of demand response programs to the residential customers. The objective of this PhD Work: "Demand response assessment and modeling for the residential sector, information and communication requirements" was to contribute to advancing the state of knowledge in residential demand response by exploring the behaviour dynamics upon which a successful residential demand response depends. The specific key research objectives are repeated here as:

- Investigate the state of demand response program in the residential sector and their limitations.

- Investigate behaviours that are prevalent during the peak hours and behaviour modifications likely to be adopted by households.
- Investigate the impact of broadening demand response information scope to households to include environmental and security factors.
- Investigate customer behaviour motivation levels to three factors: price environment and security.
- Model the impact of the stated residential behaviour modification on the load curve of the utility.

These investigations were done with a case study in Christchurch, New Zealand. A review of power system in New Zealand was also carried out to understand the extent of the peak load problem in the country and the possible contribution of demand response. The main achievements of the work described in this thesis are summarized in the following sub-sections.

9.1.1 Review of Power System in New Zealand

This thesis has given a thorough review of the electricity supply system in New Zealand. It has also given a brief review of demand trends and the implication of these trends on the supply infrastructure. The focus was more on peak demand and its implication on the security of supply. The outcome of this review showed the peculiar nature of New Zealand and its power supply system that may necessitate the need for demand response.

These include large renewable generation (about 60%), mainly from hydro resources which is sometimes “out of step” with the time of high demand, the isolated nature of the country that makes it impossible to import power from other countries, and high government target (90%) of renewable generation by the year 2050. The residential sector in New Zealand consumes about a third of annual electricity generation energy but responsible for more than half of the peak demand. This shows that demand response strategy in the residential sector can contribute immensely in reducing the system peak load.

9.1.2 Demand Response in the Residential Sector and Limitations

This thesis has described the peak load problems that sometimes occur on utility network. It was established that demand side management of the 1980’s and current demand response programs in the commercial and industrial sectors have contributed to reducing peak load in many countries. The peculiar nature of the peak problem in New Zealand has also been described. The demand response programs in the residential sector fall under either direct load control or time-varying pricing. Demand management in the form of direct control of water heating load is a typical example of demand response program in the residential sector in New Zealand. Utilities in Christchurch, for example, directly control domestic water heating load during the peak demand hours using ripple control signal to maintain system reliability. This is done to reduce demand during the peak hours and to shift load from peak to off-peak hours. In other countries (e.g. U.S.A and Australia) direct control of air-conditioning load is a typical demand response program. The limitations of the direct load control program, which include fixed financial incentive for unmeasured load (i.e. all customer in the program receive the same incentive from their retailer regardless of magnitude of load reduction they contribute to system) were also addressed. Demand response programs in the form of time varying pricing is currently not available to the residential customers in New Zealand. Residential customers pay flat rate or split rate (day and night rate) for electricity. In the U.S.A., Canada, France, Japan, and other countries, time-varying pricing have been experimented and some have been implemented in the residential sector. Most of the programs that have been implemented in the residential sector are time of use programs and critical peak pricing programs. The drawbacks of time-varying pricing were researched including its inconsistency with all the principles of rate design such as equity and affordability to low income households.

9.1.3 Energy Use Behaviour Motivation and Response in the Residential Sector

This thesis established from behavioural literature the need for researchers in demand response to recognize that high prices alone will not necessarily create the conditions needed to achieve effective peak demand management that could be reliably deployed to reduce the need for generation and transmission infrastructure. This thesis proposes that a range of factors could be used to influence people's energy use behaviour. The objective of demand response is to reduce electricity demand during peak hours. The reductions are temporary and may represent simply shifting load to an off peak time, conservation or change of activity. The benefits of demand response to consumers in all sectors include lower peak price, market discipline, reliable electrical service and possibly lower environmental emissions. It was established that better explanation of all these benefits to the consumer is necessary to achieve effective demand response in the residential sector. The form of the response will depend on the information conveyed to the customer. In other words, getting a high response would mean sending clear information to the right responders. Also, whatever method we use to reduce peak load should satisfy the three sustainable conditions as proposed by Barbier (Barbier 1987): economic viability, social acceptability and environmentally sustainable. The core objective of demand response should therefore be focused on reducing peak load and should be consistent with the sustainable goal of achieving environmental quality, economic efficiency and system reliability. It was proposed that demand response could effectively be achieved by broadening the scope information that is conveyed to households to include environmental and security constrains that limit delivery of electricity at peak times.

9.1.4 Broadening Demand Response Information Scope

A case study was done in Christchurch to assess the effectiveness of broadening the demand response information scope to include the cost (price), environment (CO_2 intensity), and security (blackout) that may result from peak supply using stated preference survey method. The results showed that people would be motivated to reduce their electricity demand at peak times if they are informed about the consequences of meeting demand at those times. There was no significant difference between customers' response to price and security as demand response motivation factors, suggesting that people may reduce their electricity demand for security reason in much the say way as they would do for price reasons. While there was a significant difference between price and security factors on one hand and the environmental factor on the other hand, the motivation of customer to adjust their demand for environmental reason was quite substantial (see figure 6.7 and 6.13). The findings suggest that if the information that is communicated to households is broadened to include all these factors, demand response could be increased.

9.1.5 Prevalent Behaviour during the Peak Hours and their Modifications

The result shows that households already shift some load out of the peak periods but there is still great potential for further load reduction. Appliances that are mostly used during the peak hours include Heat Pump, Electric Kettle, TV and Range/Oven, and Heated Towel Rail. The results further show that customers will be willing to adjust their demand at peak times. There is a great potential to reduce lighting load at peak times. The survey results show that about 1 out of every 5 light bulbs that is switched on during the peak hours is likely to be switched off by customers during the peak hours. The findings that the new suburb (Halswell) and the random survey produced essentially the similar results indicate that the behaviours could be modelled and their impact on the load curve of the utility estimated.

9.1.6 Demand Response Modelling

This thesis reports a generic methodology developed to estimate the impact of residential demand response on the load curve of the utility. The results of the survey conducted in Christchurch were used as input into the model together with appliance saturation and load diversity to estimate the voluntary demand response on a typical residential feeder. The results show that nearly 13% reduction in the morning (07.00-09.00) peak load could be achieved. The evening (18.00-20.00) peak load could be reduced by just over 8%. The breakdown of this figure into the individual activity demand response is also reported. The cost effectiveness of demand response program in Christchurch was estimated. Based on the assumptions, the results show that the benefit of the demand response could be realized after the 5th year of implementation of such program in the residential sector.

9.2 Highlights of the study

- Review research on various demand side management and demand response issue have been conducted establishing the context and the need for this research.
- Extensive field research has been undertaken in some suburbs in Christchurch
- The generic model to estimate the impact of demand response in the residential sector has been developed.
- Cost benefit analysis of demand response program in the residential sector has been conducted.

9.3 Recommendations

Demand response programs in the residential sector have been demonstrated to be effective and affordable means to control demand growth. Numerous examples both overseas and in New Zealand show that demand response alternatives can have a better cost/benefit outcome than investments in new generation or transmission upgrades to support peak demand. The research and literature review has shown that most programs to-date have focused charging high per unit of electricity used at the peak time, payment of incentives to customer to reduce demand (peak time rebate) and automatic controls such as ripple control of water heaters and air conditioners.

The hypothesis of this research is that if they had information about the electricity supply system provided with clear signals about what to do;

- People would participate in demand response to achieve benefit of lower cost
- People would participate in demand response to ensure secure power supply
- People would participate in demand response to reduce carbon emissions

The survey and focus group results clearly support the above hypothesis. The modelling results are clear; demand response in the residential sector is an un-tapped, yet promising component of DSM. I recommend that any future studies or pilot programs of demand response be informed by this research, and include other value options such as environmental and security factors for effective peak management. The developed residential demand response model provides a new analysis tool for assessing the residential demand response impact.

9.4 Potential future Work

Multi-Modal Signal Process and Delivery: It would be interesting to extend this research further by investigating how the multi-modal price, environmental and security signals could be processed and convey to household.

Balancing of Intermittent Renewable

Intermittent renewable energy is expected to play an important role in the future supply of electricity. For example, renewable generation is expected to reach about 90% in New Zealand by the year 2050, with high wind power penetration. Studies analyzing intermittent renewable generations like wind power systems emphasize that with increasing penetration of this power in the supply mix, additional efforts are necessary to balance and control the supply variability. This balancing is currently done through supply-side interventions and/or introduction of storage options or power imports. In an isolated and power constraint country like New Zealand where the availability of these options may be limited, it would be interesting to investigate how much of this balancing need could be achieved (in time) with residential demand response.

Extension of value preposition and Social Responsibility to other Sectors

The link between the value preposition of demand response participation and social response to the service providers and participants of demand response is a challenging and complex subject. The different market structures, tariffs and market designs make it difficult to treat this as a generic case when describing the value and understanding demand response economics. However, as a result of this study it will be good to answer the question: what value preposition has demand response to offer to the public and other stakeholders? This can be an important topic for future study.

Finally there are certain kinds of end-use sectors, for example, companies with environmental awareness and Corporate Social Responsibilities (CSR) which may find value in participating in demand response. Many large companies have significant stake and investment in finding environmental solution to the global problem. These companies may be happy to participate in demand response if shown the value as a part of corporate CSR. Further research to find out how these companies can be shown these value can be topic for future study.

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Appendix A:

Demand Response Residential Household Survey

Developed by Samuel Gyamfi, PhD student
Department of Mechanical Engineering
University of Canterbury

UC Ethics Committee Approval Granted
1 February 2008

PHD project survey – electricity consumption during peak periods

Samuel Gyamfi, Student and Associate Professor Susan Krumdieck, Supervisor

This survey is being undertaken for a PHD project, with the aim being to understand the ability and willingness of household consumers to potentially adjust their power consumption during local peak demand periods (cold winter evenings and mornings).

A prospect for the future, given technology advances, is for information to be made available to households to alert them when peak demand periods are occurring. Survey results will be used by the PhD student to develop models for reducing electricity use during peak demand periods (called 'demand response') in the residential sector.

Our survey results will also help to develop new technologies for communicating the critical peak demand conditions to households.

Please note, there are some questions in this survey relating to electricity allocation. These are hypothetical scenarios only and your answers are important to help us to develop the demand response models mentioned above.

Why reduce electricity during peak demand?

Like roads, electricity networks have limited capacity. The 'rush hour' on New Zealand electricity networks typically occurs on very cold winter evenings when people arrive home from work and turn on their lights and heaters. If electricity demand is higher than planned for, then there is a risk of power cuts.

One solution to these high loads is to expand the electricity network's capacity - much like making roads bigger to handle the traffic. However this solution is very expensive and would lead to an increase in the price of electricity. It could also mean an increase in environmental pollution through the use of high carbon emission sources of generation.

Because electricity 'rush hours', or 'peak demand periods', only occur for a few hours each year, the other cheaper solution is for customers to reduce their demand during these peak demand periods. Typically customers will reduce their electricity use during peak demand periods when they are given a price incentive to do so.

Morning Evening

Earth Hour
Response

A.1 Survey Questions

Household Information

1) Please indicate how many people live in your household.

[ ] One [ ] Two
[ ] Three [ ] Four [ ] Other (specify) ___________

2) In which location (suburb) in Christchurch do you live? ______________________
3) How many bedrooms does your house have? ____________
4) How many living rooms does your house have? ____________

Winter Power Costs

5) Approximately how much is your winter monthly electricity bill?
6) How much was your last electricity bill?

5)	**$**
6)	**$**

Household Energy Features

7) Do you have night-rate power?

[ ] Yes [ ] No [ ] Don't know

If yes, which appliance(s) are on the night rate?

[ ] Hot water heater [ ] Night-store heater
[ ] Others [ ] Don't know

8) Which of the following best describes your house?

[ ] Insulated house: Ceiling ☐ Walls ☐ Floors ☐
[ ] Non insulated house
[ ] Don't know

9) Which of the following is/are source(s) of energy for cooking in your house?

[ ] Gas
[ ] Electricity
[ ] Other: Please specify___________________________________

Future Change Issues

10) 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%

11) What percentage of renewable electricity supple (e.g. coal, gas and diesel) do you think is a good target for New Zealand.

[ ] 50%	[ ] 60%	[ ] 70%
[ ] 80%	[ ] 90%	[ ] 100

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

An Ordinary Winter Week Day Scenario *(Questions 13-17)*

Tell us how you use electricity to carry out your daily household activities on a typical winter week day.

13) Which of the following appliances do you normally use in your kitchen/laundry during peak times for food preparation, heating, cleaning during the week?

Tick boxes that apply and circle — *seldom* ***1*** *sometimes* ***2*** *always* ***3***

	Morning **7:00-9:00 am**		Evening **6:00-8:00 pm**	
Range	**[ ]**	**1 2 3**	**[ ]**	**1 2 3**
Oven	**[ ]**	**1 2 3**	**[ ]**	**1 2 3**
Microwave	**[ ]**	**1 2 3**	**[ ]**	**1 2 3**
Electric Kettle	**[ ]**	**1 2 3**	**[ ]**	**1 2 3**
Heat Pump	**[ ]**	**1 2 3**	**[ ]**	**1 2 3**
Other Electric Heater	**[ ]**	**1 2 3**	**[ ]**	**1 2 3**
Dishwasher	**[ ]**	**1 2 3**	**[ ]**	**1 2 3**
Washing Machine	**[ ]**	**1 2 3**	**[ ]**	**1 2 3**
Clothes Dryer	**[ ]**	**1 2 3**	**[ ]**	**1 2 3**
Vacuum Cleaner	**[ ]**	**1 2 3**	**[ ]**	**1 2 3**

14) Indicate (approximately) the number of light bulbs that are typically on at any moment throughout your house during peak hours?

	Morning **7:00-9:00 am**	Evening **6:00-8:00 pm**
Number of Light Bulbs	___________	__________

15) If a shower is normally taken in your house/flat during the peak times, what is the estimated number?

	Morning **7:00-9:00 am**	Evening **6:00-8:00 pm**
Number of Showers taken	___________	__________

16) In your bathroom, do you use any of the electrical appliances below during the times specified?

Tick in boxes that apply

	Morning **7:00-9:00 am**	Evening **6:00-8:00 pm**
Hair Dryer	**[ ]**	**[ ]**
Heated Tower Rail	**[ ]**	**[ ]**
Electric Heater	**[ ]**	**[ ]**

Others: Please specify____

____

17) Do you ever use any of the following appliances during the peak times?

	half hour	*one hour*	*the whole time*
Tick in boxes that apply and circle	***1***	***2***	***3***

	Morning **7:00-9:00 am**	Evening **6:00-8:00 pm**
TV	**[ ] 1 2 3**	**[ ] 1 2 3**
Computer	**[ ] 1 2 3**	**[ ] 1 2 3**
Stereo	**[ ] 1 2 3**	**[ ] 1 2 3**
SpaPool	**[ ] 1 2 3**	**[ ] 1 2 3**
Heat Pump	**[ ] 1 2 3**	**[ ] 1 2 3**
Other Electric Heater	**[ ] 1 2 3**	**[ ] 1 2 3**

Electricity Allocation Scenario

(Questions 18 – 25)

Consider a hypothetical situation, where you are 'allocated' a certain amount of power during peak times which is less than you would normally use. In the following questions, tell us how you would alter your electrical appliances usage in response to the situation.

Morning Peak	Evening Peak
7:00-9:00 am	**6:00-9:00 am**

18) Which appliances would you turn down or not use until after the peak period?

Tick in boxes that apply

	Morning **7:00-9:00 am**	Evening **6:00-8:00 pm**
Range	**[ ]**	**[ ]**
Oven	**[ ]**	**[ ]**
Microwave	**[ ]**	**[ ]**
Electric Heater	**[ ]**	**[ ]**
Heat Pump	**[ ]**	**[ ]**

19) How many un-necessary light bulbs in each of the following rooms/places would you switch off in the times specified?

Write the number (if any)

	Morning **7:00-9:00 am**	Evening **6:00-8:00 pm**
Lounge/Dining Room	___________	__________
Kitchen	___________	__________
Bedrooms/Study	___________	__________
Hall/Outdoor/Rec. Room	___________	__________

20) If you normally take showers in the peak time, would you take any of the following actions?

[ ] Shift the shower time from morning peak to another time in the morning
[ ] Shift the shower time from evening peak to another time in the evening
[ ] No change
[ ] Not applicable as I have night rate water heating

21) Which appliances would you avoid using during peak times?

	Morning **7:00-9:00 am**	Evening **6:00-8:00 pm**
Hair Dryer	**[ ]**	**[ ]**
Heated Tower Rail	**[ ]**	**[ ]**
Electric Heater	**[ ]**	**[ ]**

Others: Please specify____

22) Which appliances would you ***switch off or turn down*** during the peak times?

Tick in boxes that apply

	Morning **7:00-9:00 am**	Evening **6:00-8:00 pm**
TV	**[ ]**	**[ ]**
Computer	**[ ]**	**[ ]**
Stereo	**[ ]**	**[ ]**
SPA Pool	**[ ]**	**[ ]**
Electric Heater	**[ ]**	**[ ]**

23) Which appliances would you shift to use outside the peak time?

Tick in boxes that apply

	Morning **7:00-9:00 am**	Evening **6:00-8:00 pm**
Washing Machine	**[ ]**	**[ ]**
Cloth Dryer	**[ ]**	**[ ]**
Dishwasher	**[ ]**	**[ ]**
Vacuum Cleaner	**[ ]**	**[ ]**

24) If you have a beer fridge, would you take any of the following action(s)?

[ ] Switch it off between 7:00 – 9:00 in the morning

[ ] Switch it off between 6:00 – 8:00 in the evening

[ ] Switch it off between 7:00 – 9:00 in the morning and between 6:00 – 8:00 in the evening

[ ] Other____

25) Given the electricity allocation scenario at peak times, indicate how willing are you to switch from electricity to gas for cooking

[ ] I would be willing to switch from electricity to gas but with incentive
[ ] I would be willing to switch from electricity to gas even without incentive
[ ] I would not be willing to switch from electricity to gas because I prefer to cook with electricity

Energy Saving Motivation

26) 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

Personal Information

27) Please indicate your gender.

[ ] Male
[ ] Female

28) Please *tick* which of the following approximately represents your *household's* annual earnings (before tax).

[ ] under $30,000
[ ] $30,001 - $50,000
[ ] $50,001 - $70,000
[ ] $70,001 - $90,000
[ ] $90,001 - $110,000
[ ] $110,001 - $130,000
[ ] Above 130,000

29) Please indicate your electricity provider.

[ ] Meridian Energy
[ ] Other ______________
[ ] Contact Energy
[ ] Don't Know
[ ] Empower

30) If you know your rate plan, please indicate by ticking one of the following boxes.

[ ] Meridian Energy Economy 24
[ ] Meridian Energy Low User Economy 24
[ ] Meridian Energy day/night rate
[ ] Contact Energy All Day Economy
[ ] Contact Energy All Day Economy Low
[ ] Contact Energy night rate
[ ] Other ______________________________

31) Considering your household or flat, would you take any other strategy to save electricity apart from the ones specified in the questions above?

____
____
____
____
____
____
____
____
____
____
____
____
____

A.2 Information Sheet

Samuel Gyamfi, PhD Candidate
Department of Mechanical Engineering
Advanced Energy and Material Lab.
Private Bag 4800
Christchurch
New Zealand

Information Sheet

You are invited to participate in the research project **"Demand Response in the Residential Electricity Sector: New ICT Solution".** The aim of the project is to develop innovations for electricity supply security. Our information communication technology (ICT) concept would provide information to households to alert people to critical electricity demand hours. This survey is to understand the willingness and ability of households to adjust their power consumption during critical winter peak demand hours.(Clark, Jones et al. 2005)

We invite your involvement in this project by completion of the questionnaire, which is attached to this information sheet. The questionnaire will take approximately 20 minutes to complete. Explanation of the issues of winter peak demand is given on the front page of the questionnaire. Though there are no direct benefits to you for participating, the outcome of the research will benefit society by improving the cost-effective and secure production and supply of electricity.

The questionnaire is anonymous and you can decide to withdraw information you provide until it is mixed up with other questionnaires. The data provided will be accessible to *Samuel Gyamfi and Dr. Susan Krumdieck* who are carrying out the study.

If you wish to be in the draw to win one of 10 CENTAMETERS™ ($150 value www.centameter.co.nz) then tick the box on the consent statement and fill in your phone number. Your phone number will not be used for any other purpose.

The project is being carried out *as a requirement for degree of Doctor of Philosophy in Mechanical Engineering* by Samuel Gyamfi under the supervision of Dr. Susan Krumdieck who can be contacted at +64 3 364 2987 Ext 7249 or by electronic mail on susan.krumdieck@canterbury.ac.nz. We will be pleased to answer any questions you may have about the project or your participation in the survey. Please note that the project has been reviewed ***and approved*** by the University of Canterbury Human Ethics Committee

A.3 Statement of Consent

Samuel Gyamfi
Department of Mechanical Engineering
Advanced Energy and Material Lab.
Private Bag 4800
Christchurch
(03) 364 2987 extn. 7243

Withdrawal Date: 20.10.2008

CONSENT FORM

Demand Response in the Residential Electricity Sector: New ICT Solution

I have read the information sheet and understand the description of the above-named project. On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.
I understand also that I may withdraw from the project, including withdrawal of any information I have provided up until the date shown above by calling the researcher.

NAME (please print): ……………………………………………………………….
Signature:
Date:

10 CENTAMETERS™ will be provided as prizes to ten participants randomly selected at the end of the survey project. If you wish to be in the draw, tick the box below and provide your phone number.

☐ Yes, I would like to be entered into the draw

Phone Number: ______________________

We are working on developing new technology to help residents meet their needs by keeping prices down and keeping the grid from overloading. We are looking for a small group of residents who would be willing to participate in a round-table discussion or focus group on the issues of security of supply, peak demand management, and affordability of supply or to provide feedback about new technology concepts.

☐ Tick the box and supply your contact details (any of the following) if you would be willing to participate.

E-Mail:____
Post: Address___________________________________
Phone____

Appendix B

Demand Response Residential Household Focus Group

Developed by Samuel Gyamfi, PhD student and Associate Professor Susan Krumdieck
Department of Mechanical Engineering
University of Canterbury

UC Ethics Committee Approval Granted
1 February 2008

B.1 Presentation at the Focus Group

Demand Response in the Residential Electricity Sector: New ICT Solutions

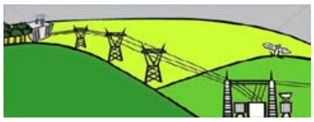
Samuel Gyamfi, PhD Student

Department of Mechanical Engineering
University of Canterbury,
Christchurch, New Zealand

Supervisors: Dr. S. Krumdieck and Dr. L. Brackney

Overview

- **Background of the Problem**
- **Demand Response**
- **Your Reactions**
- **Discussion**



Using the Response Clicker

Practice Question A

1. Male
2. Female

Using the Response Clicker

Practice Question A

1. Male
2. Female

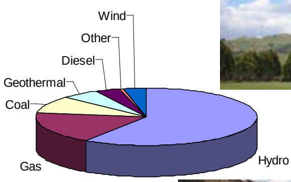
Pre-Discussion Question

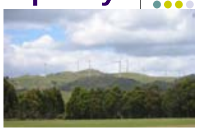
Residential Electricity Customers

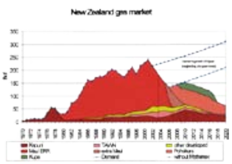
- People are not willing and/or able to adjust their power use for any reason.

1. Agree Completely
2. Agree in Some Cases
3. Disagree In General
4. I don't know

Electricity Generation Capacity







Problem 1: Dry Year

- 64% of generation
- 60 days of storage

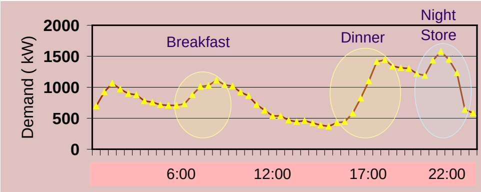
- High Spot Price
- Risk of "Cold Showers"
- Risk of Power Cuts

Demand Response

What was your Dry Year Response?

1. Shorter Shower
2. Turn off Lights
3. Install Fluorescent Lights
4. Turn Heat Lower
5. Less Cooking

Problem 2: Peak Demand



Supply

Demand

High Cost of Peak Demand

Transmission Capacity

Ripple Control, Industry Shut Down 40¢ kWh

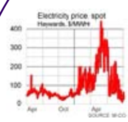
Diesel 40¢ kWh

Peak Capacity

Gas 25¢ kWh
Peaking Hydro 12 ¢ kWh

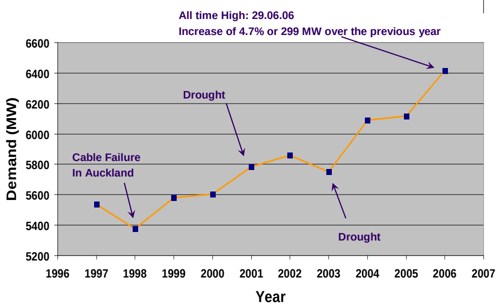
Base-Load Capacity

Hydro 5¢ kWh



Dinner Time
Power Demand

Growing Peak Demand



What Causes Peak Demand?

Sector	Consumption	Peak
Residential	33%	52%
Industrial	45%	31%
Commercial	22%	17%
Total	100%	100%

Source: NZ Electricity Commission

Meeting Peak Demand

- Peak Generation is met by burning Fossil Fuels.
- New Zealand's Carbon Emissions have been growing because of growing peak demand.

Environmental Concerns

- Should power, transmission, and distribution companies ask their customers if they would rather adjust their peak demand in order to reduce pollution?

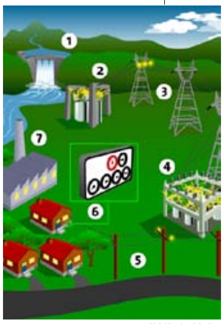
1. Yes
2. No

Solution 1: Invest in More Supply

More costs More

Projected Electricity Generation by Fuel Type 2005-2025 (Reference Scenario)

www.med.govt.nz



www.mercury.co.nz

Cooperation

- Should power, transmission, and distribution companies ask their customers if they would rather adjust their peak demand or pay a higher price?

1. Yes
2. No

Solution 2: Do Nothing

- Power Outages
- Let Residents provide their own power

Self Sufficiency

- Would you rather not pay more for power and just deal with power outages yourself?

1. Yes
2. No

Solution 3: Smart Residents

Demand Response

Residences keep power demand below the critical limit

Mutual Benefit

- Would you be willing to adjust your power use in response to signals in order to maintain a secure supply and lowest possible cost for everyone?

1. Yes
2. No
3. As Much as Needed

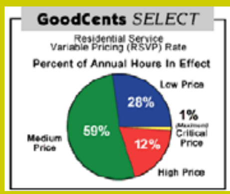
Automatic Demand Response

Ripple Control

Electricity de France
Tempo Tariff

Night Store

Advanced Automatic Response



Pricing Periods

Average Rate:	8.9 cents/kWh
Low Rate:	6.8 cents/kWh
Medium Rate:	8.0 cents/kWh
High Rate:	12.6 cents/kWh
Critical Rate:	33.5 cents/kWh

Customer control of demand response to price

Does this appeal to you?

- Would you be interested in new technology that lets you set up automatic control of different appliances?

1. Yes, if it saves me money
2. No, it seems too complicated
3. Maybe, if it's not too hard

Voluntary Demand Response

- Lets residents choose their response
- Much lower cost technology
- Also lets people know when renewable power is plentiful and low cost

Smart Residential Consumers

People who have their own generation systems, manage their peak power demand

Our Technology Idea

- Smart Grid
- Smart Meters
- Smart Residential Customers

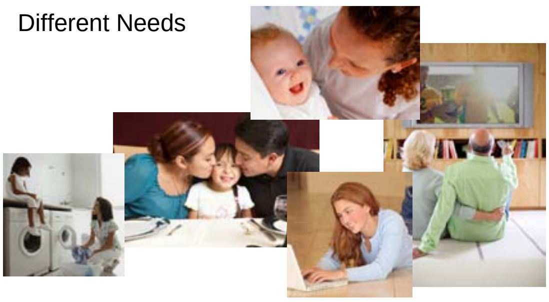
Who should be smart?

- Should demand response technology be mandatory for all households or voluntary participation?

1. Mandatory
2. Voluntary

Residential Households

Smart Consumers have
Different Needs

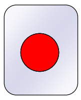


Who should be Smart?

- Which statement do you agree with regarding a Demand Response Programme?

1. Any programme should apply equally to all residences
2. The programme should apply differently according to consumption, income, and need.

Security of Supply Warning



- Low Cost Device
- No Direct Price Savings
- Indirect Cost Benefit

Could this work?

- Do you agree that most people could understand what this signal means?

1. Strongly Agree
2. Agree
3. Disagree
4. Strongly Disagree

Smart Centometer

- Security of Supply Warning
- Peak Demand Indicator
- Current Price Indication
- Your Power Use Target
- Your Smart Resident Bonus

Thesis:

Demand Response

People would participate in demand response to achieve benefits of lower power costs

People would participate in demand response to ensure secure power supply

People would participate in demand response to reduce carbon emissions

If they had clear information and signals about what to do

Do you agree with the Thesis?

Some people will adjust their demand, if they can, if they are informed of the situation

1. Strongly Agree
2. Agree
3. Disagree
4. Strongly Disagree

Discussion

Thank You

B.2. Participants Responses to Specific Questions

People are not willing and/or able to adjust their power use for any reason

Completely Agree 1
Agree in Some Cases 8
Disagree in General 5
Don't Know 0

What was your Dry Year Response?

Shorter Shower 7
Turn Lights Off... 5
Install Compact Fluorescent Lights 0
Turn Heater Lower.. 1
Less Cooking 0

Should power, transmission, and distribution companies ask their customers if they would rather adjust their peak demand in order to reduce pollution?

Yes 10
No 2

Should power, transmission, and distribution companies ask their customers if they would rather adjust their peak demand or pay a higher price?

Yes 14
No 0

Would you rather not pay more for power and just deal with power outages yourself?

Yes 2
No 8

Would you be willing to adjust your power use in response to signals in order to maintain a secure supply and lowest possible cost for everyone?

Yes 11
No 0
As much as needed 3

Would you be interested in new technology that lets you set up automatic control of different appliances?

Yes, if it saves me money 10
No, it seems to complicated.. 1
Maybe if it's not too hard 3

Which statement do you agree with regarding a Demand Response Programme?

Any programme should apply equally to all residences 5
The programme should apply differently according
to consumption, income and need...8

Do you agree that most people could understand what this signal means?

Strongly Agree..6
Agree 8
Disagree 0
Strongly Disagree 0

Some people will adjust their demand, if they can, if they are informed of the situation.

Strongly Agree..6
Agree 8
Disagree 0
Strongly Disagree 0