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# Power and Energy Visualisation in the Home

A thesis submitted in partial fulfilment
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# Abstract

This thesis explores ways of improving the ability for households to manage their consumption of electricity, in the context of increasing concerns regarding global warming, and ever-growing demands for electricity. The thesis first explores the understanding of power and energy concepts and relationships, to establish whether poor understanding of these concepts affects people's ability to be aware of and manage their consumption. It then, given that being informed is an important contributor to awareness, proceeds to explore the effectiveness of two different styles of energy visualisation in the home: numerical detail, and a more abstract representation.

The results demonstrated that participants had a limited understanding of the relationship between the power and energy. The statistical relationship between participants' understanding and their ability to manage energy consumption in their home was a positive weak correlation. Participants believed that the abstract representation was more useful and clear than the numerical representation in visualizing home energy consumption in both studies. In representing power consumption in home, using an abstract meter was better than using a digital visualization meter because of the clarity of representation and attractive display.

# Acknowledgements

First of all, all praises are due to Allah, the Almighty, for helping me and giving me the strength, health and patience to finish this work.

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# 1 Introduction

This thesis describes a study of potential power and energy displays in the home. Increase in demand for electricity and related issues such as energy consumption impacts on the environment, increase in electricity price, misunderstanding of the concept of power and energy and energy waste have become global issues. Awareness of energy consumption is considered to be a significant factor in attempts to reduce or temper our use of energy. All these issues will be discussed in detail in the following report followed by some possible solutions.

## 1.1 Energy consumption impact on the environment:

Energy conservation has become the main concern for scientists and researchers because of the overuse of environmental resources. A large amount of energy demand is met globally by using fossil fuels such as gas and coal and this is threatening the environment because of large greenhouse gas emission throughout the world. Kirby (2004) reported that “the world will need almost 60% more energy in 2030 than in 2002, and fossil fuels will still meet most of its needs” (para. 1). In fact, using fossil fuels will bring a negative impact to the environments by increasing carbon dioxide and methane; carbon dioxide emission is considered as the main cause of global warming (People for the Ethical Treatment of Animals, 2012). The highest percentage of greenhouse gas emissions is contributed by carbon dioxide emissions (Rose, 2012).

Human activities are considered as being the main source of increasing carbon dioxide emissions in modern societies. Using heaters at home, cooking, and using lights; all these activities rely on energy which makes it one of the causes of carbon dioxide emissions because power stations are run using oil and burning coal. Another cause of carbon dioxide emissions is the industrial sector (Public Broadcasting Service, 2008: see Figure 1.1). In addition, 41 percent of all carbon dioxide emissions are caused by generating electricity in the United States (United States Environmental Protection Agency [USEPA], 2011).

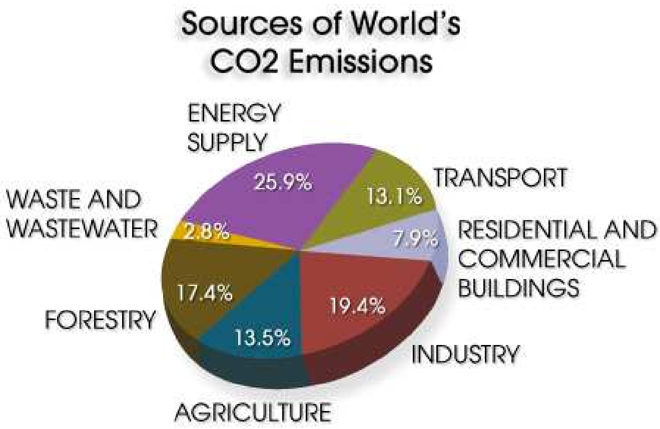



Figure 1.1: Sources of world's CO2 emissions (Reproduced from Public Broadcasting Service, 2008)

Among 27 of the Organizations for Economic Co-operation and Development (OECD) countries, New Zealand was the fifth highest for greenhouse emissions per person in 2005 (Ministry for the Environment [MfE], 2009: see Figure 1.2).

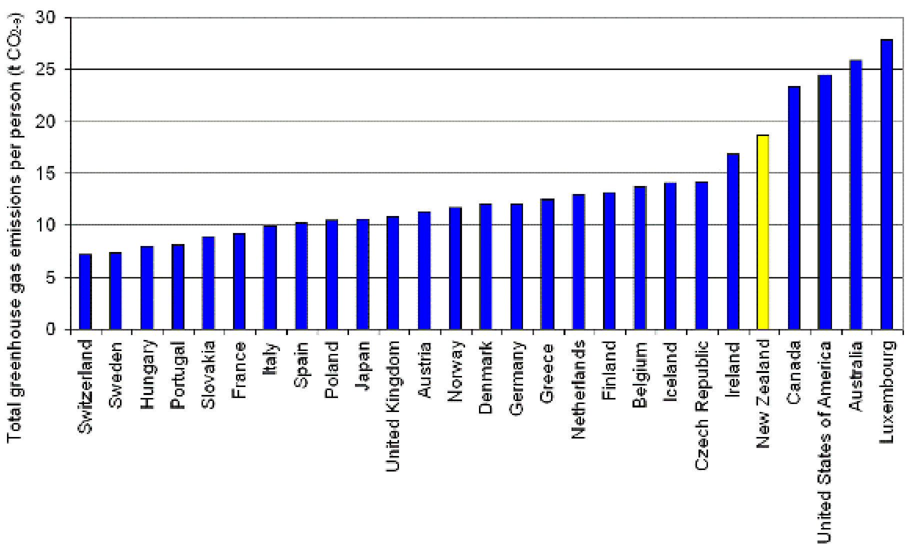



Figure 1.2: Total greenhouse gas emissions per person in 2005 (Reproduced from MfE, 2009).

In 2007, 41 percent of energy in New Zealand was generated by using coal and gas, which was the main cause for the increase in greenhouse gas emissions. Hence, due to growth in industrial businesses, electricity production played a major role in increasing the greenhouse gas emissions by about 91 percent from 1990 to 2007. The increase in greenhouse gas emissions could predictably rise by 7 percent between 2005 and 2015 (Climate Change Information New Zealand, 2011). Lockhart (2012) indicated that “almost 65% of energy delivered comes from fossil fuels. Added to that is the fact that fossil fuels are used to produce about 30% of our electricity and biomass is used for 9.5% of energy” (para. 2: see Table 1.1).

Table 1.1: Energy use in New Zealand in 2002 (Reproduced from Lockhart, 2012).

| Fuel type | Fuel use | Delivered energy (PJ) | Useful energy (PJ) | Efficiency | % of total energy |
|---|---|---|---|---|---|
| Biomass | Heat Devices: | 46.35 | 18.68 | 40.3% | |
| | Total | 46.35 | 18.68 | 40.3% | 9.5% |
| Electricity | Electronics/Lights: | 15.89 | 5.95 | 37.4% | |
| | Heat Devices: | 57.77 | 41.53 | 71.9% | |
| | Motors: | 45.32 | 41.22 | 91.0% | |
| | Total | 118.98 | 88.69 | 74.5% | 24.4% |
| Fossil Fuel (Non-Transport) | Heat Devices: | 96.49 | 51.23 | 53.1% | |
| | Motors: | 1.6 | 0.4 | 25.0% | |
| | Transport: | 21.42 | 2.79 | 13.0% | |
| | Total | 119.51 | 54.42 | 45.5% | 24.5% |
| Fossil Fuel (Transport) | Transport: | 196.21 | 28.84 | 14.7% | |
| | Total | 196.21 | 28.84 | 14.7% | 40.3% |
| Geothermal | Heat Devices: | 6.02 | 5.75 | 95.5% | |
| | Total | 6.02 | 5.75 | 95.5% | 1.2% |
| Grand total | Total | 487.07 | 196.4 | 40.3% | 100.0% |

Electricity is considered to be the backbone of the industrial, commercial and residential sector to continue meeting human needs such as lighting, heating, cooking and others. The estimation of electricity consumption in 2008 by this sector was that 44 percent of energy consumption went to the industrial sector, followed by 32 percent for the residential sector. The remaining electricity consumption was by the commercial sector. However, this estimation included all industry sectors under one energy consumption proportion which was 44 percent. Dividing this proportion among other industry sectors such as agriculture, wood, fishing and others, the result was that the highest estimation of energy consumption went to the residential sector (Powerco, n.d.). The Ministry of Economic Development [MED] (2011a) stated that residential sector in 2010 consumed 34 percent of New Zealand’s total electricity usage, followed by approximately 23 percent consumed by the commercial sector. Agriculture, forestry and fishing consumed about 4.7 percent of all electricity consumption in New Zealand (see Figure 1.3).

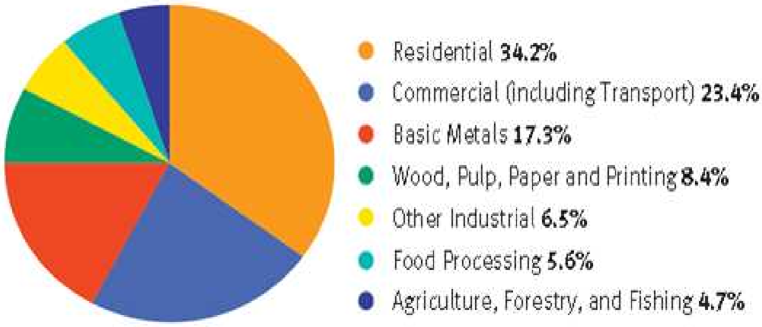



Figure 1.3: Electricity consumption by sector in 2010 (Reproduced from MED, 2011a).

Electrical devices in houses contributed to 34.2 percent of the total electricity consumption in New Zealand in 2010. This was distributed between heating water, cooking, lighting and others. Water heaters were the major utility in the houses that consumed the highest electricity, 26 percent; the second utility was miscellaneous which included TV, radio, mobile and others, consuming 22 percent; followed by 19 percent for heating. Lighting consumed 12 percent electricity, while cooking consumed 7 percent. The rest of electricity consumption was distributed between Refrigeration, Clothes dryers, Towel racks and Dishwashers (Powerco, n.d.). Efficient Home Energy Saving (2011) stated that “25% of our utility bill goes to lights and home appliances. Here, we should focus on the sensible use of lights and electronics” (para. 11).

## 1.2 Energy demand:

Energy demand is one of the main problems which have become a global issue. Rye (2009) stated that energy will be of one of the top ten problems facing people in the next five decades. ExxonMobil (2012a) predicted the increase in the energy demand between 2010 and 2040, globally, would be 30 percent. ExxonMobil (2012b) also stated that the large demand for energy comes from residential and industrial sectors and specifically in electricity. Electricity is considered to be the quicker energy source that is increased annually among developed countries owing to growth in population and rise in industrial sectors. Birol (2004) stated that “Electricity demand growth is strongest in developing countries, where demand will climb by over 4% per year over the projection period, more than tripling by 2030” (para. 7).

In general, most of the countries will face an increase in the population throughout 2040 and this rise will differ from one country to another. The main growth is expected to happen in India and China. ExxonMobil (2012a) indicated that “every region will see a net increase in households through 2040, but growth will be particularly strong in Africa, China, India and Latin America” (p.11). This growth will result in more requirements for energy specifically in two sectors: residential and commercial.

The continuous growth in the number of households will play an essential role in increasing energy demand. In 2006, the largest power consumers of New Zealand energy were households, consuming 31 percent, distributed between petrol and electricity (Statistics New Zealand, 2008). However, the demand for energy in New Zealand has been abnormal compared to other countries in the last few years. Television New Zealand (2009) indicated that the annual growth of energy demand is by 2 percent. This increase is quicker than the standard power usage in the world. Additionally, the Ministry of Economic Development [MED] (2011b) stated that, to meet the growth among residents, the demand for electricity will have increased by 25 percent in 2030.

Figure 1.4 below details the information about the total annual electricity consumption in New Zealand from 2000 to 2011. This information is represented in kilowatt-hours and excludes electricity lost in transmission and distribution processes. There was a steady increase in electricity consumption overall. The total energy consumption fluctuated between 2000 and 2003 (Index Mundi, 2012a).

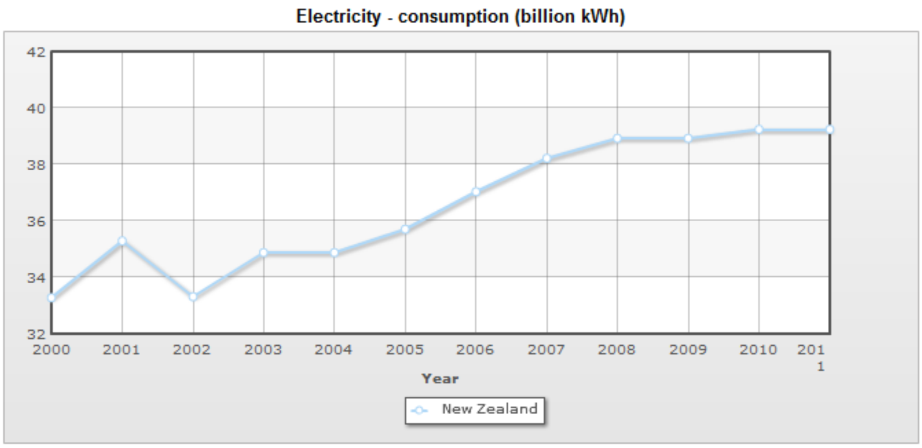



Figure 1.4: Electricity consumption in New Zealand (Reproduced from Index Mundi, 2012a).

On a personal level, Figure 1.5 shows the electricity consumption in kilowatts-hours per person in New Zealand from 1960 to 2009. Although there was a stable rise in electricity consumption per capita, this rise in electricity consumption decreased slightly after 2005 (World Bank, 2012).

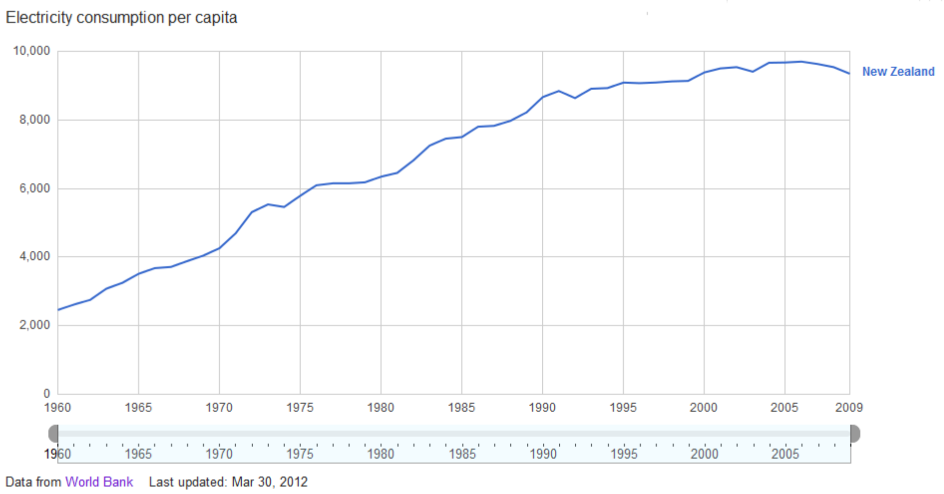



Figure 1.5: Electricity consumption per capita in New Zealand (Reproduced from World Bank, 2012).

Although electricity demand is considered a problem in many countries around the world, some countries have been able to limit their electricity demand. United Kingdom is one of these countries. They were able to diminish their demand in 2009. According to Seager (2009) “household demand has also declined – by 2% – but that was due to mild weather rather than economic reasons” (para. 2).

Electricity consumption in United Kingdom is illustrated in Figure 1.6. It can be seen that the electricity consumption reached its peak in 2008, while the lowest electricity consumption was in 2000 at approximately 330 billion kWh. Further since 2009, there has been a slight decline in electricity consumption (Index Mundi, 2012b).

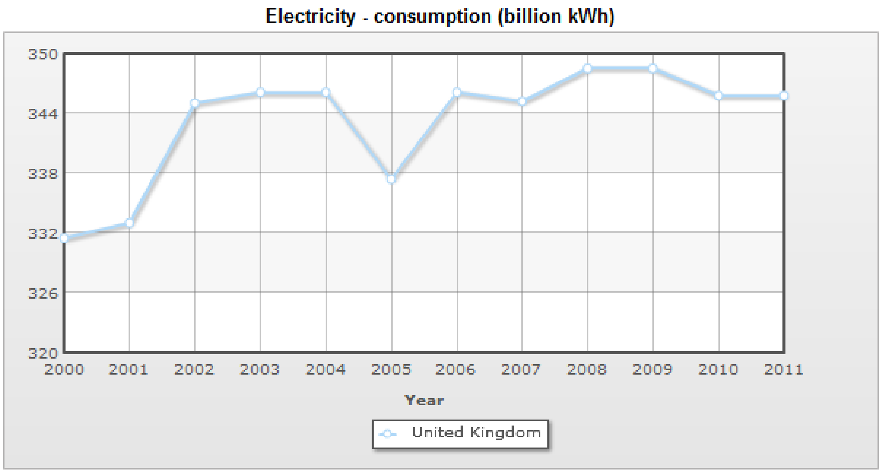



Figure 1.6: Electricity consumption in UK (Reproduced from Index Mundi, 2012b).

Not only increase in population has affected the electricity demand but also climate change is another factor that has increased the demand for electricity indirectly, specifically in New Zealand. In winter, households need more electricity for heating and lighting to keep their houses warm; while, in summer, the demand for electricity is reduced owing to mild weather and its coinciding with industrial and commercial holidays (Climate Change Office, 2003). According to Gasper and Blohm (2011) "Climate change can influence energy systems by affecting demand either through reduced heating needs or increased cooling needs" (p. 9).

## 1.3 Electricity price:

The reorganisation of the electricity sector in 1999 brought about a decrease in the price of electricity because of competition between the three generation companies: Meridian Energy, Mighty River Power and Genesis Power. Nevertheless, the price dramatically increased in 2002 and since that time the electricity price has fluctuated from year to year (Statistics New Zealand, n.d.). At the present time, households are facing increases in the electricity price. Mighty River Power (2012) indicated that “electricity prices will rise by an average of 5.8% for Mercury Energy’s residential customers from 1 April 2012” (para. 1). Additionally, this increase in electricity price will continue until all projects in electricity fields are achieved by 2015 (Radio New Zealand News, 2012).

## 1.4 Electricity company feedback:

Most of the electricity companies (Meridian Energy, Mighty River Power and Genesis Power) provide monthly information about electricity consumption via an electricity bill. This results in a lack of information about electricity feedback for households on their electricity consumption. The energy bill provides inadequate monthly feedback for households (Weiss, Mattern, Graml, Staake, & Fleisch, 2009). Roth and Brodrick (2008) stated that “current utility billing practices greatly limit the feedback that most households receive on their energy consumption. That is, they only receive monthly utility bills that summarize their energy expenditures and consumption for the prior month” (p.136).

## 1.5 Energy conservation:

People can reduce their energy bill through understanding the difference between demand and consumption (Baltimore Gas and Electric Company, 2012). However, the general lack of understanding of the difference between power and energy has led to wasting money by the consumer. For example, households might leave some lights on for the whole day and night because of the lower rate of power consumption. This leads to an increase in the electricity bill because of constant usage of electricity and rise in energy demand.

In fact, some people find difficulty in distinguishing between power and energy. People often think power and energy are similar. Hirca, Calik and Akdeniz (2008) report that “Some students think that energy can be seen by naked eye or microscope. However, energy is an abstract notion; thus, to see it by the naked eye is impossible. Some of them assert that energy is described as power or force” (p. 87).

## 1.6 Proposed Solutions:

Some policies and solutions have been undertaken to limit increases in greenhouse gas emission, under the New Zealand Emissions Trading Scheme when it was regulated in 2008 (Greenspace New Zealand, 2010). Particularly, the policy asked energy and industrial sectors to provide information about their greenhouse gas emissions, starting from 2010. Climate Change Information New Zealand (2009) stated that “The stationary energy and industrial processes sectors will have obligations to surrender units in respect of their emissions from 1 January 2010” (para. 2).

Most of energy sector depends on renewable energy resources, such as hydropower, geothermal and wind power, for generating electricity. All these resources are used to generate about 70 percent of New Zealand electricity now. And about 90 percent of electricity will be generated from renewable resources by 2025 as one of the energy strategies in the future (Energy Management Association of New Zealand, 2009). In addition, the government of New Zealand supports and promotes the investment in energy renewable resources. Mighty River Power (2011) stated that:

> In the past five years, Mighty River Power has invested more than $1billion into renewable energy project [wind and geothermal], and over 90% of our current generation capacity is from renewable generation sources. Scaling up the ETS as currently planned will provide the right incentive for continued renewable electricity development, demand management through consumer pricing and other positive energy responses. (p. 1)

Replacing the old electricity meter by a smart meter is one of the available solutions in industrial sector now and approximately 1.3 million homes are estimated to have this meter in 2012, with no extra cost to consumers in New Zealand (Deuchrass, 2009). Pullar-Strecker (2011) reported that “Contact Energy announced this month that it would roll out smart meters to 150,000 North Island customers, having already installed 60,000 in Christchurch” (para. 5). In addition, 70,000 smart meters have been installed around New Zealand in 2009 by Vector Company. This brings massive benefits to the company such as no more estimated bills and also enables the company to control the meter remotely (Vector, 2009).

## 1.7 Research Aim:

The volume of information on electricity consumption in the homes is not accessible to the households and this limits the household's ability to know where the most electricity is consumed in their homes. In addition, households might not even know how much electricity each appliance is using for operation. Since some appliances need a large amount of power to run compared to the other appliances, and the users are unaware of the consumption power of different appliances, they may be using more electricity than they realise.

With the passage of time and increasing number of issues that relates to household electricity consumption, such as shortage of environmental resources, energy demand, increase in electricity price and rise in greenhouse gas emission, this information has become more essential for all households. Thus, employing technologies with the help of computers and mobiles can provide information on their daily consumption of electricity to the households and make them aware of their electricity usage.

This study aims to find answers to the following questions:

1. How well do people understand the relationship between power and energy?
2. Does an understanding of this relationship really matter?
3. What is the vital information that people need, that will both enlighten them and allow them to make informed decisions?
4. How precisely does this information need to be described or displayed? Do the precise numbers matter? Are abstract visualisations more useful and acceptable than detailed ones?

## 1.8 Thesis outline:

The report is structured as flows:

Chapter 2 of this report explores the previous research on residential energy monitoring and display. Chapter 3 examines understanding the relationship between power and energy, and in Chapter 4 the design of power and energy visualization in the home is described. Chapter 5 describes the evaluation of power and energy visualization in the home. Chapter 6 provides detail of the implementation of the test-bed for the detailed and abstract visualization. Chapter 7 discusses the findings. Chapter 8 provides conclusions, with recommendations for future development.

# 2 Previous Research on Residential Energy Monitoring and Display:

Finding a solution for making households aware of their energy consumption is not an easy task to accomplish, due to related issues such as lack of immediate feedback in energy consumption. Initially, the electricity bill is the only feedback that is received monthly by many households. The bill does not help households much to reduce their energy consumption and also makes it difficult to act positively towards their energy usage owing to a lack of immediate feedback (Williams, Matthews, Breton, & Brady, 2006). Additionally, the electricity bill does not provide an effective motivation towards energy consumption change and does not provide any techniques or methods for changing households' behaviour. So, this may restrict households from linking their energy consumption actions with consequences (He & Greenberg, 2008). Secondly, the lack of understanding in the concept of power and energy might lead people to be unaware of their energy use, especially when their understanding of concept of energy and power is similar (Hirca et al., 2008).

Awareness of behavioural change for energy conservation is not yet considered by many households because of the lack of motivation and delayed feedback. This makes households unaware about the amount of energy that is wasted through their actions. Additionally, the monthly feedback is inefficient because it comes after the action takes place, which limits households to be informed of their actions in their home (Van Raaij & Verhallen, 1983). Furthermore, the electricity bill is represented using a traditional approach with no consideration of any cultural or social factors. This provides an unclear image of the person in house contributing the most to the usage of electricity, particularly among the family members (He & Greenberg, 2008).

Households are not aware where the energy is used in their homes. A survey of energy awareness conducted by Forrest (as cited in Abdelmohsen & Do, 2008) indicated that:

> while 91.8% of U.S. homeowners are interested in increasing their home energy efficiency and expect their home heating bills to increase by

> 76.5%, almost half of these homeowners lack understanding of how their homes consume energy, and are not clear on which home improvement projects yield the largest energy-saving benefits. (p.1)

Energy consumption in the home is a major concern in many households. This concern allows homeowners to gain more knowledge about the power consumption rate of their home electrical devices such as refrigerator and washing machine. The concern for energy conservation is one of the features that the consumers consider when they buy a new system for saving energy (Landwehr, n.d.).

The predictable decrease in domestic energy consumption ranges from 5 percent to 15 percent when the consumers obtain comprehensive and instant feedback (Weiss et al., 2009). Darby (2006) concluded that "Immediate direct feedback could be extremely valuable, especially for savings from daily behaviour in non-heating end-uses. In the longer term and on a larger scale, informative billing and annual energy reports can promote investment as well as influencing behaviour" (p.17). Allen and Janda (2006) indicated that direct feedback can enhance household awareness of energy consumption and can also cause a slight change in households' behaviour.

The effect of using direct and indirect feedback leads to a decrease in electricity consumption in houses. Many studies have been conducted to study the effect of using direct and indirect feedback of energy usage. One of the studies indicated that providing weekly feedback will cut the energy consumption down by approximately 18 percent (Lee, Pae, Kim, Kim, & Kim, 2008). Another study conducted in Canada found that displaying instant feedback via a portable energy monitoring device can save about 16.7 percent of energy consumption (Mountain, 2006). Darby (2006) indicated that the effect of the feedback is not limited to only in reducing energy consumption but it can be seen as a tool that can be used to teach consumers via the experiment.

Recently, smart devices and software applications have become an essential utility for providing real-time feedback for consumers about their electricity consumption and also for decreasing consumers' electricity bill. In the commercial sector, there are plenty of these devices for supplying vital information to consumers about the energy use by appliances or houses. The *Cent-a-Meter*, *Power Cost Monitor*, *Energy Detective* are examples of such devices that are discussed and explained briefly on some websites and also on their manufacturing business's website (Open4Energy, n.d.). A sample study indicated that installing these devices can save about 25 percent of an electricity bill and also can assist consumers to reduce their energy consumption (Stephanie, 2011).

Various commercial utilities are available in the market. Some of these facilities are used only to measure appliances whereas some of them are used to monitor the whole house. Some of these commercial devices discussed in the following sections for both for appliances and for homes.

## 2.1 Devices for monitoring individual appliances:

*Kill-A-Watt* (see Figure 2.1) is one of these devices that are used to measure the power consumption for each appliance that is plugged into it. The measurement of this device is usually presented in watt units. However, it can be displayed in kWh by aggregating the power consumption that has been used over a time (Reysa, 2007). The benefit of using *kill-A-Watt* is that consumers can eliminate the power that is consumed when the appliance is on standby or when it is left plugged in the wall by monitoring each kilowatt which is used in their homes (Leehersch, 2011).


Figure 2.1: Kill-A-Watt (Reproduced from P3 International Corporation, 2011)

*Belkin Conserve Insight* (see Figure 2.2) is another smart device which is used to measure power usage for each appliance individually. This utility has a smart monitor that displays information about the energy consumption for a plugged device. In addition, it can display the cost of the running device in dollars and in watt units. *The Belkin Conserve Insight monitor* can show the amount of carbon dioxide that result from this running device. The configuration and installation of *Belkin Conserve Insight* is very easy and in a few steps consumers can plug the appliance into *Belkin Conserve Insight device* and then into the wall (Belkin International, 2012).


Figure 2.2: Belkin Conserve Insight (Reproduced from Belkin International, 2012)

The *PeakTech Meter* (see Figure 2.3) is an electricity meter which displays the power cost of an appliance for a period of time; it is very easy to use. It is designed to encourage households to reduce their electricity bills and consumption. *PeakTech* works when the consumer plugs the meter into the power socket in the wall and then plugs the appliance into the meter. After that, the consumer can enter the power unit price and calculate the cost of the appliance's electricity consumption (PeakTeach, n.d.).


Figure 2.3: PeakTech Meter
(Reproduced from
PeakTeach, n.d.)

*Power-Mate* (see Figure 2.4) is another electricity device monitor. It was designed and developed by Computer Control Instrumentation (CCI) to monitor the electricity use for each appliance individually. *Power-Mate* users can determine the operating cost for each appliance. They can also find out the amount of green gas emission that is released by using an appliance. It is difficult for some appliances to identify their running cost due to irregular operation performance but *Power-Mate* eliminates this obstacle by showing the cost of running the appliance hourly, weekly, monthly and yearly (Computer Control Instrumentation, n.d.).


Figure 2.4: Power-Mate (Reproduced from Computer Control Instrumentation, n.d.)

Some smart devices can work with more than one appliance and control them at the same time. The *UFO Power Center* (see Figure 2.5) is one of these major power devices that can manage four home appliances concurrently. This device has many features such as supplying instant feedback, socket schedules, and socket timers. It can facilitate consumer understand the energy consumption for each appliance used and also make it easy for them to know its operation cost. The *UFO Power Center* enables consumers to switch the appliance off when it is not in use or when it is on standby state (Visible Energy, 2011). Consumers can manage their appliances energy usage in the home remotely via using iPad or iPhone with WiFi feature that is available in the *UFO Power Center*. Using *UFO Power Center* might assist consumers to save up to $150 annually (Scott, 2012).

Figure 2.5: UFO Power Center (Reproduced from Visible Energy, 2011)

*Wireless 3-Outlet Mains Power Meter* (see Figure 2.6) is another smart meter that has three separate outlets and one LCD monitor. It works by communicating through outlets to the monitor remotely using the wireless function. Consumers can only connect three appliances to three available outlets at the same time. After the connection they can see the current power, total power cost and the amount of greenhouse gas emissions in kilograms for the attached appliances (Electronic Choice, 2010).

Figure 2.6: Wireless 3- Outlet Mains Power meter (Reproduced from Electronic Choice, 2010)

## 2.2 Devices for monitoring the whole house:

*Wattson* (see Figure 2.7) is one of the many power consumption measurement devices that is used to measure electricity consumption for the whole house. It is designed to assist households to save their electricity consumption. It works with software called Holmes to store daily consumption data. *Wattson* is a portable device and it can be used anywhere at home, and also can be used with small businesses. The device works when a transmitter is attached to the electricity meter and the sensor clip is connected to the cables running from the Fuse Box. There is a small portable LCD display that communicates with the transmitter via wireless communication to show information about current consumption for appliances. This display has three types of levels of light and each level of light indicates the rate of the electricity consumption. High rate is represented by red, average by purple, and low by blue (Energeno, n.d.).

Figure 2.7: Wattson (Reproduced from Energeno, n.d.)

*EnergyHub* (see Figure 2.8) is a smart system that assists households to reduce their energy consumption and save money. This system gives information about the electricity use in the house and also assists the consumers to track every appliance. *EnergyHub touchscreen dashboard* has the facility for households to manage each appliances and devices connected to the power. Additionally, households can control their home energy consumption remotely. Working with *EnergyHub* system requires installing equipments such as smart meter with ZigBee including dashboard, temperature control unit, strip and socket (EnergyHub, 2012).


Figure 2.8: EnergyHub (Reproduced from EnergyHub, 2012)

The Efergy Company introduces variety of electricity monitors in the commercial sector. *Efergy elite2* (see Figure 2.9) is one of the utilities that constantly show the cost and the immediate power usage of the house for every six seconds. This helps households to be aware of any change in their house energy usage. In addition, households can also get to know about the average carbon emission that results from running appliances and devices in their homes. Using *Efergy elite2* is considered as one of the ways that can be used to educate all the household residents (Smart Concepts New Zealand, 2010).


Figure 2.9: Efergy elite2 (Reproduced from Smart Concepts New Zealand, 2010)

*Power-Cost Monitor* (see Figure 2.10) is a portable energy device that allows users to read their home energy in real time. The use of *Power-Cost Monitor* can assist users to know the total energy consumption for their homes at any time. It can also help them to change their attitudes toward their electricity consumption in the home as well as saving up to $250 yearly on their electricity bills. In addition, the users can explore their house's energy data via online services when they install and configure the *Power-Cost Monitor WiFi Bridge appliance* (Blue Line Innovations, 2010).


Figure 2.10: Power-Cost Monitor (Reproduced from Blue Line Innovations, 2010)

*Envi energy monitor device* (see Figure 2.11) is a multi-function energy monitor that can be used to measure the whole house and also to measure individual appliances. This device consists of three major items: the display item which is used to show the electricity consumption including the cost, temperature and time; the sensor clamp device that is used to measure the electricity consumption via connecting this sensor to the transmitter; and the transmitter item that is used to transmit data to the display. This utility brings a large number of features with it and one of these is that the households can display and extract their homes energy consumption data by installing and using Techtoniq software on their computers. When households use *Envi energy monitor*, they can reduce their total energy consumption by 15 percent to 20 percent (Steplight, 2010).


Figure 2.11: Envi Energy Monitor (Reproduced from Steplight, 2010)

## 2.3 Web-based and desktop application for monitoring energy consumption:

*Building a dashboard kiosk* is one of the projects that have been introduced to the consumers to manage their energy consumption in United States. The project displays energy and water use information in public for buildings and compares it with other buildings on the same screen. This information is represented in figures, graphs and other visualizations. This dashboard can also display the consumption expressed in intuitive or everyday units (Lucid Design Group, 2012).

One of the European projects is the Digital Environment Home Energy Management System (DEHEMS). This project is a cooperative work between more than one organization, such as private business and some universities. It also looks towards developing the efficiency of domestic energy by using technology. The aim of this project is to reduce greenhouse gas emissions and also to enable households to monitor and control their energy consumption.

Moreover, DEHEMS shows real information about appliance energy performance and consumption. It can also supply precise energy efficiency suggestions for the family (Manchester Digital Development Agency, 2008).

*Google power meter* is one of the web-based applications that was established and developed by Google. The aim of this project is to increase households' awareness about their energy usage by enabling them to access their energy information online. *Google power meter* assists households to share their energy usage information with others and recommends a personal suggestion for saving energy. In addition, *Google power meter* represents the home energy usage information via visual image which makes it easy for homeowners to easily understand their home's energy information, (see Figure 2.12) (Google, n.d.).

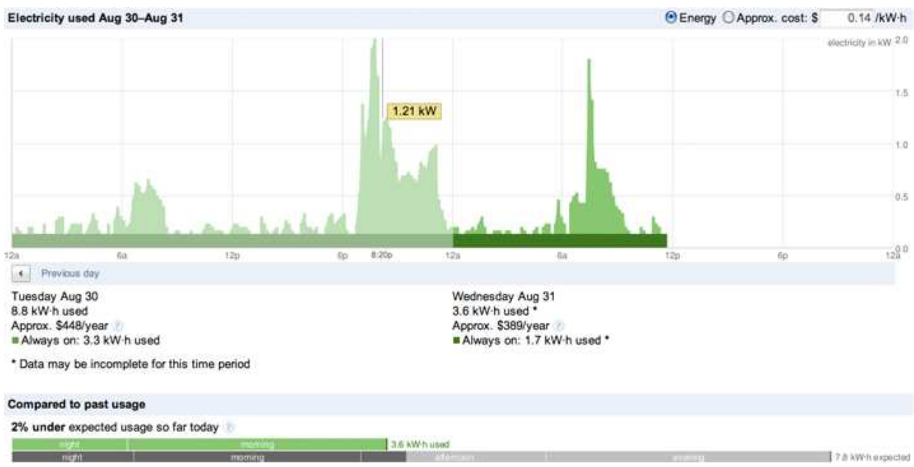



Figure 2.12: Google PowerMeter (Reproduced from Google, n.d.)

Google had partnered with Current Cost for monitoring electricity consumption in the home. This partnership will allow households in United Kingdom, New Zealand and other countries to send their home's energy data to the Google Power-Meter where it can be checked by using their accounts using iGoogle (Lardinois, 2010). Unfortunately, the *Google Power-Meter* project has become unavailable since September 16, 2011 after Google officially announced its discontinuation on June 25, 2011 (Google, 2011).

*Greenbox* is another web-based application that is similar to Google and it established in 2008 and its aim was to monitor house electricity usage. The feature of this application is that it enables the consumers to view energy information on charts and a graph for a particular time of day or for an appliance and compare it with other appliances. In addition, this web-based application can work with smart devices such as Energate and Golden Power Manufacturing. So, people who have these devices can control and manage their heating and cooling system remotely via their web-based dashboard (Kho, 2009).

*Watssup* is a web-based application that works with a Facebook application to enable users on Facebook to monitor their energy consumption. This application enables these users to compare their energy usage with their friends using their Facebook accounts. *Watssup* application works with Wattson energy monitor by reading the energy use data from this monitor and displaying it on Facebook. However, this data is presented in the form of bar graphs and tables which allow users to see their weekly energy usage and contrast it with their selected friends in order to reduce the energy consumption with the help of their social network (Foster, Lawson, Blythe, & Cairns, 2010).

*Techtoniq Energy Station* (see Figure 2.13) is one of the available desktop applications that work with the current cost energy monitor device. It enables consumers to see instant data for their home energy consumption as well as history of energy usage. The consumers will be able to export the data to an excel file and they will also be able to send alerts using email or twitter (PowerSave, 2010). *Techtoniq Energy Station* can show energy use data in a variety of outlines: live displays, live charts, historic charts and cost analysis. When users choose live display, they will acquire information about current energy use, total power usage, temperature and cost of energy in the form of figures. The users can see the same information in bar chart form when they select live chart. In addition, users can display the historic energy data in bar graph daily or monthly or yearly as they want it. However, *Techtoniq Energy Station* is not free software; the user has to purchase the software license to use it (Techtoniq, 2011).

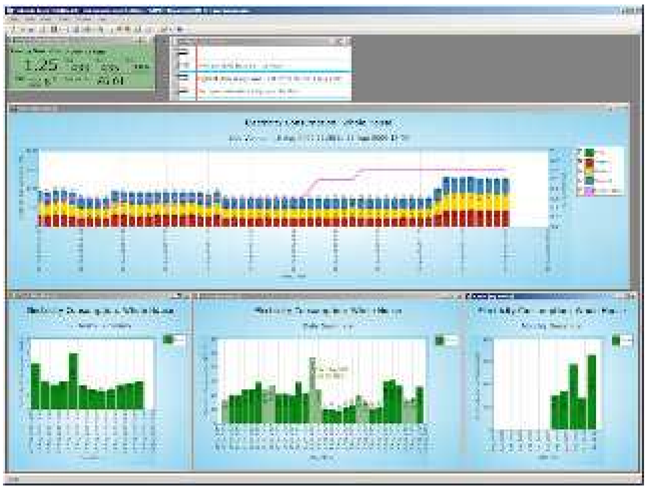


Figure 2.13: Techtoniq Energy Station (Reproduced from Techtoniq, 2011)

*Home Energy Monitor* is another desktop application that monitors home energy consumption in different operating system platforms such as Windows and Linux. This application also works with the current cost energy monitor device and represents the data in graphic form. It enables the users to explore the current energy consumption for the house and also the temperature in figures and line graph, (see Figure 2.14). *Home Energy Monitor* application facilitates users' publication of their energy consumption on twitter and its comparison with other users (Iangbell, 2010).

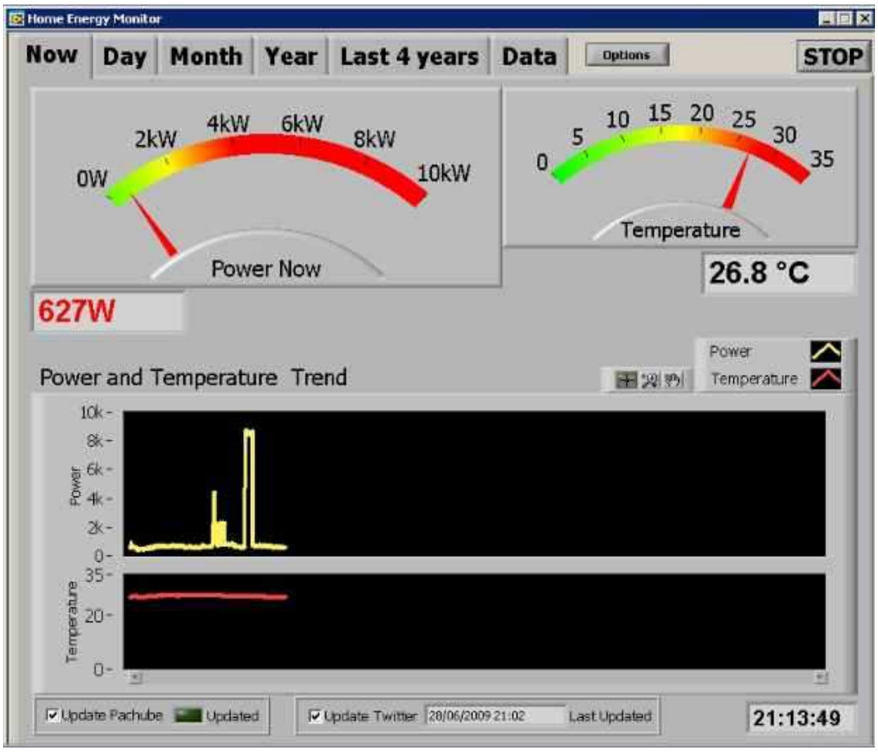



Figure 2.14: Home Energy Monitor (Reproduced from Iangbell, 2010)

## 2.4 Solutions and energy monitor devices available in New Zealand:

A range of energy monitor utilities are available in New Zealand markets at present. The most common power monitors are *Cent-a-meter Owl* and the *Current Cost device*. *Cent-a-meter Owl* was designed and developed in New Zealand. It has a variety of features such as displaying instant power consumption, calendar and accumulating cost. Using the *Cent-a-meter Owl* allows consumers to record and store their home energy consumption data for approximately 30 days. It also facilitates consumers to compare their current home energy usage with previous days, months or years. It can be used in schools, offices and small businesses. The *Cent-a-meter Owl* works by clipping the sensor over the main power box. The sensor then transmits data to the LCD monitor via wireless connection (Power Save Marketing, 2012).

*Current Cost EnviR device* is another home energy monitor available in New Zealand from SmartNow Company. It consists of three tools: sensor, transmitter and LCD EnviR display, (see Figure 2.15). It works by connecting a clamp to the home wire electricity meter and then the transmitter sends a signal to the LCD EnviR display every six seconds. Current Cost users can see their home electricity consumption and how much this electricity usage costs them in real time. These users can also manage and analyze their home energy data via connecting an LCD EnviR display to their computers using a USB connector or connecting the LCD EnviR display to their routers using a Bridge connector. The use of Bridge allows the users to upload their electricity usage and mange this data via *Google Power-Meter* or Current Cost web-based services.

Figure 2.15: Current Cost EnviR
(Reproduced from SmartNow, n.d)

In addition, the new feature of the *Current Cost EnviR device* is that it can be used to measure individual appliances in the home. It can measure nine appliances simultaneously (Current Cost, n.d.).

Nowadays, most electricity companies are replacing the old electricity meter by a new *smart meter* (see Figure 2.16). This is an electronic electricity meter that can communicate with home appliances, smart appliances and control them remotely using wireless connection. It also allows customers to buy electricity on the spot prices directly (Berry, 2011). The *smart meter* enables the electricity companies to read the electricity consumption for homes remotely. It also assists retailers to eliminate issues of estimated meter readings and estimated electricity bills. However, there is an issue facing some consumers after installing the smart meter. Some consumers said that when they want to shift to a new retailer, this retailer will be unable to connect to the smart meter remotely. So, they started to remove the existing smart meter and instead installed their own smart meter (Consumer NZ, 2010a).

Figure 2.16: Smart Meter (Reproduced from Consumer NZ, 2010a)

Some electricity retailers provide some online services such as creating accounts and browsing home energy consumption. One of these retailers is Contact Energy; this company allows consumers to access their electricity bills for last 24 bills any time. Contact Energy enables consumers to compare their energy consumption from month to month in graphic form (Contact Energy, 2012). TrustPower is another company that offers online services. TrustPower users can access their home energy consumption information as well as access their electricity bill (TrustPower, 2008).

Mercury Energy is another retailer that provides an online energy monitoring service for their customers. There are two types of online home energy monitoring introduced by this retailer. The first is the *Mercury Time-wise*; it shows home energy use in three different colours, red, orange and green, depending on the time of the day and tariff charge. This service enables consumers to see the energy consumption in slices after each 30 minutes (Mercury Energy, 2012). The second service is *Mercury advance* that enables consumers to buy power in advance with available upgrade option. Mercury consumers can access and control their energy usage through the available online dashboard (Energy Saving and Monitoring in New Zealand, 2012).

## 2.5 Visualization of energy consumption:

All the solutions and devices above use different types of information visualization. Some of them use graphs, others use figures and show this information in a small white/black display. *Cent-a-meter Owl* display is taken as an example to illustrate the idea of white and black display, (see Figure 2.17).


Figure 2.17: Cent-a-meter Owl
(Reproduced from Power
Save Marketing, 2012).

There are varieties of visualization types but the most common types of visualization are pragmatic, artistic and ambient. The differences in visualization is discussed by Kosara (2007), specifically in two types of visualization; pragmatic and artistic. Pragmatic visualization aims to explore and analyze the data as well as representing it in a technique that allows users to comprehend the information. In contrast, artistic visualization does not focus on showing data; it is more about communicating a concern. The ambient visualization is clarified by Pousman, Stasko and Mateas (2007). They stated that it is the system that gives abstract characterizations of information. It can characterize below the definition of information visualization. They also indicated that the ambient visualization produces awareness insights data that is selected by users or designers.

There are many projects using ambient display to visualize data. One of these is *Energy Orb*; this device lights up a varying degree of colour to represent significant power peak demand. When the power peak demand increases, the *Energy Orb* changes its colour to warn users of this change in power demand and price (Ambient Devices, 2012).

*Berkeley Weather Beacon* (see Figure 2.18) is another project that uses ambient display to show the weather situation via the Berkeley Building. This building consists of twenty-six storey office tower that is located in Boston. The tower displays the weather forecast in two colours; blue and bright red. When the weather forecast is clear, the weather beacon shows the steady blue colour but when the weather is cloudy the beacon shows a flashing blue. Rainy weather is indicated by steady red, while snowy weather is indicated by flashing red (CelebrateBoston, 2012).

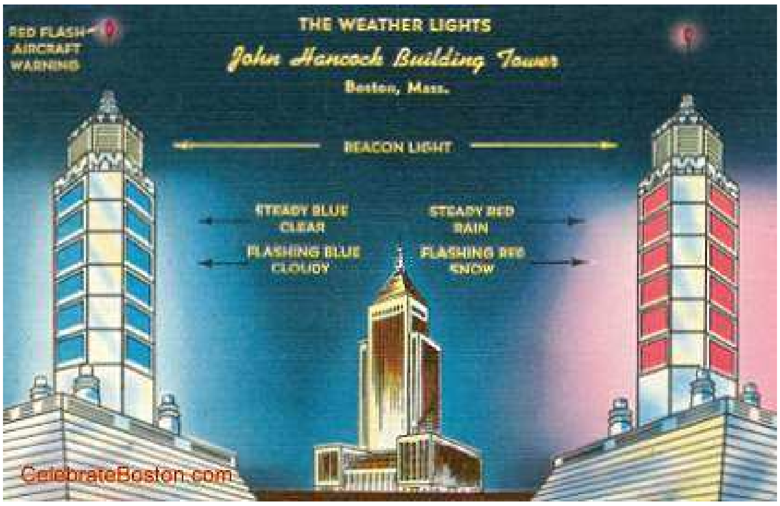



Figure 2.18: Berkeley Weather (Reproduced from CelebrateBoston, 2012)

The use of visualizing energy in an appropriate way could lead to reduction in energy consumption in the homes. Scientists McClelland and Cook (1979) conducted a study about visualization home energy consumption by using a device called *Fitch Energy Monitor*. This device showed the amount of money spent per hour during electricity use in the homes. They found that using the *Fitch Energy Monitor* assisted to decrease electricity consumption in the home by 12 percent on average.

Many studies have been done in visualizing energy in Denmark; one of these studies is ‘visualization turns down energy demand’ and it aimed to visualize heat and energy consumption in flats. This study was conducted by Ole Michael Jensen (2003), who found that visualizing the electricity consumption and heat in building can assist people to reduce electricity usage by 22 percent and can also reduce heat by 9 percent in the first year. A sample study stated that combining the energy usage with price in a single visualization has a potential effect on people behaviour toward energy consumption in the home (Pyrko, 2008 as cited by Neset, Johansson, & Linnér, 2009).

## 2.6 Understanding of Power and Energy Concepts:

The concepts of energy and power and the relationship between them are discussed in some studies around the world. One particular study defines kW and kWh by explaining the differences between kW and kWh and how these units are related to energy and power as in measurement. In addition, it states the difference between ‘power’ and ‘energy’, definitively, giving examples of devices that use power such as light bulbs, dryers and computers (BizEE Software, 2011).

Another study that discussed the concept of energy and power in more detail stated that energy is available in a variety of forms and it has the ability to be stored. In contrast, power cannot be stored. Power really only indicates the rate of energy consumption. Additionally, power is measured in watts or kilowatts and energy is measured in joules. However, they are interrelated concepts in daily life (Olivia, 2011).

Investigating peoples’ understanding of the difference between power and energy has been researched previously. The results show that people described energy as the power, and they believe that energy can be seen by microscope (Hirca et al., 2008). Naughtin (n.d.) stated that “Few people are aware that energy and power are quite different physical things. They do not know that energy is the ability to do things and that power is a measure of how fast you use the energy” (p. 2).

The concept of energy in science is more related to the physics field where it is defined as the ability to do work. The word 'energy' is derived from the Greek word 'ἐνέργεια' which means activity or operation. Energy can generally be found in a variety of forms such as chemical, electric and nuclear. These forms can be converted from one form into another by using a machine or generators. For example, it is easy to convert chemical energy that is stored in a battery directly into electric energy. Energy is expressed in multiple units but it often uses joule and kilowatt hours as its measurement (Wikipedia, 2011a; Georgia State University, n.d.-a).

Power is defined as the rate of doing work. "It is the rate at which energy is transferred, used, or transformed" (Wikipedia, 2011b, para. 1). For instance, heaters can transform electric energy into heat. Power is often measured using two units of measurement: watt and kilowatt. Power might have a variety of applications such as electrical and mechanical (Georgia State University, n.d.-b).

Understanding the concept of energy can assist households to reduce energy consumption and also help them to change those attitudes and actions that pertain to their energy consumption. Blizzard (2010) indicated that:

> Having baseline knowledge of what you consume is necessary in order to take meaningful action to reduce consumption. Some experts say that having an understanding of your energy baseline can help you modify your habits, which can lead to a 10 to 20 percent reduction in your energy consumption. (para. 6)

Understanding the difference between power and energy can reduce energy consumption. Energy (n.d.) indicated that "The difference between demand (KW) and consumption (KWH) is vital to your choices in reducing your energy costs" (para. 1). In addition, this understanding can be useful for managing home electricity usage. SCE&G (n.d.) stated that:

> The concepts of kilowatts (kW) and kilowatt-hours (kWh) are often misunderstood. The term kW (1,000 watts) refers to the rate at which energy is used (demand), while kWh measures overall consumption (usage). Understanding these concepts will provide you with important insight into how you can reduce your energy costs. (para. 1)

## 2.7 Studies of the effect of different visualisation styles:

The use of comparative experiments can assist researchers to identify which is the most effective type of visualization to help them to discover a way for changing people's attitudes. A comparative study conducted by Kim, Hong and Magerko (2010) examined the effect of using two types of visualization in users' behaviour when they used their computers. The researchers created two types of display styles, Coralog and Timelog, that showed how much time the computer was not in use when the power was on.

Coralog display was an iconic representation that related to environmental issues, showing the effect of carbon dioxide on the coral reefs in the ocean. They employed this method on the computer usage time and compared it with the previous day to see if the total computer usage was smaller: then the coral reef became healthier or unhealthier. In contrast, Timelog display was an indexical representation that showed the computer usage time with no comparison or recalculation with the previous computer usage. Bar graphs with texts and numbers were used to represent the computer usage time in this type of visualization. The researchers found that using iconic representation was more effective than using indexical representation to increase users' awareness for future attitude change (Kim et al., 2010).

Exploring ambient and artistic visualization for residential energy use feedback was another comparative experiment, conducted by Rodgers and Bartram (2011). They designed and described three types of abstract visualization: phyllotaxis, hive and pinwheel designs. All three types of displays were selected to show the instantaneous power and total energy for the home. In the phyllotaxis display, the visualization occurred in a geometric spiral so the instantaneous power was represented by vibration of the sunflower's seeds to their location in the spiral, whereas the total energy was represented by growing the size of seeds.

In the hive display, the grid of hexagonal cells was used to show the current power and total power. When the current power was low, a small number of hexagonal cells appeared slowly. When it was high, a big number of hexagonal cells appeared gradually. The total power showed by growing the cells and overlapping them. In the pinwheel display, the display of power consumption was illustrated by two points which were the figure of pinwheels and also by the pinwheels speed of rotation. They considered that the pinwheel display was similar to the hive display in its representation and in its idea (Rodgers & Bartram, 2011)

## 2.8 Summary:

Supplying an instantaneous feedback through using smart electrical monitor devices and its application such as *Current Cost device*, *Efergy elite2* and *Google power meter*, can increase awareness of energy conservation in the homes. The expected reduction of energy consumption ranges between 10 percent and 20 percent of all house energy use by these devices.

The *Current Cost EnviR device* is one of the most popular devices that have been used to monitor house energy consumption as well as enabling households to access their home energy data via smart application. This device and other facilities display energy use in the home in various formats: numbers, graph, small/large and black/white display. However, displaying numbers, text and graphs is what the households really want, as using numbers and text gives a quick message to the households. Do households understand the relationship between these numbers and graphs?

None of previous research indicates what is the best visualization and what precious data should be included in the representation of the home energy consumption that could be desirable by the household. Kim et al. (2010) indicated that "they have not yet proven what are the better ways of eco-visualization of sensed data even though there are various forms of representation methods such as text, pictures and diagrams in the field of information visualization" (p.107).

Furthermore, there is no evidence provided about the effect of understanding the relationship between power and energy in household management in their home energy use. Understanding this is an important factor for managing energy use in the home. This leads to an investigation of people's understanding of power and energy concepts and a study of the effect of different visualization styles.

# 3 Understanding the relationship between power and energy:

The daily domestic routine comprising cooking, cleaning, showering, communicating, and entertaining is considered as part of normal life. These activities, along with others, require energy. It might be assumed, therefore, that those who regularly use technologies which rely on power and energy would have a reasonable understanding of the terms ‘power’ and ‘energy’. However that may not be the case always.

Raising people’s awareness and understanding by utilizing technologies that monitor domestic and commercial energy is one option that can assist in reducing energy waste, as, with this kind of system, users are given immediate feedback on their consumption of energy. This knowledge allows the end user to make a conscious, informed choice to minimize their energy usage which will be reflected in lower energy bills. It will create a self perpetuating cycle of observation, monitoring and controlling (adTumbler LLC, n.d.).

In the science field, the difference between power and energy and the relationship between them can be easily noticed in variety of aspects. Firstly, the energy unit differs from power units, ‘‘KWh is a measure of energy, whilst kW is a measure of power’’ (BizEE Software, 2011, para. 6). Secondly, energy can be transferred into variety of forms and stored while power cannot be changed. Olivia (2011) states that “energy is present in many forms and it can be stored whereas power cannot be stored” (para. 5). Finally, energy and time are interrelated with each other while power is an immediate quantity. “Energy comes with a time component, while power is an instantaneous quantity. Power cannot vary but remains constant. Meanwhile energy accumulates predictably” (Difference Between, 2011, para. 6).

However, some people have a vague or incomplete knowledge about the concepts of energy and power and the relationship between them. They might consider energy and power as similar or interchangeable terms and it is this common use of energy and power as being synonymous that leads to misunderstanding. Simply stated, people may not know how energy and power are related, but different, terms. Does this lack of understanding create a difficulty in the management of energy consumption and does it contribute to the mismanagement of both physical and fiscal resources? (Difference Between, 2011).

Although there are many studies that examine the concepts of energy and power, few studies investigate people's understanding of their relationship. A survey questionnaire was used to investigate the understanding of people about the concepts of energy and power, and also the difference between them. It also studies the effect of this understanding on managing household electricity consumption. This survey was conducted to addresses the following questions:

- How well do people understand the relationship between power and energy?
- Does this understanding really matter for the households in managing their energy consumption?

## 3.1 Methodology:

A descriptive research methodology was used to generalize the results of this survey. This survey was conducted at various locations in Hamilton such as the City Center, the Base and the Hillcrest area.

### 3.1.1 Sample:

This survey was conducted with 30 participants selected randomly from a variety of places, ages, both genders and also different background education.

### 3.1.2 Data Collection:

Studying the relationship between energy and power and the difference between them was the initial aspect of this survey. Searching for related studies via reading books and articles online was the second aspect (adTumbler LLC, n.d.). Both these aspects contributed to finding the best method for obtaining information from the people.

A survey questionnaire was used to carry out this part of the survey which was divided into three parts:

**Part 1:** This asked eight general questions, which elicited general information about the participants, such as gender, age, taking responsibility for paying electricity bills and average cost of household electricity consumption per month.

**Part 2:** This asked eight questions, about energy consumption such as, “When cooking dinner for a period of time, would the energy consumption remain the same as usual or would more energy be used under certain conditions and also what would you expect to be more efficient; a 2 kW kettle or; a 1 kW kettle?”

**Part 3:** This asked eight questions, requesting information about managing electricity consumption such as asking people whether or not they checked the power rating of an appliance before purchase.

### 3.1.3 Procedure

Participants were given a summary of the study, then the survey questionnaire. After that, the data was gathered, analysed and reproduced in graphs based on correct responses and calculated in percentages, using Microsoft Excel.

## 3.2 Finding:

The responses were analyzed to obtain useful information about participants’ understanding of the difference between power and energy and their relationship. In addition, this analysis showed the correlation between energy consumption and managing electricity, based on the responses to the survey questionnaire.

### 3.2.1 General information:

It can be seen from Figure 3.1, that there are variety of age groups participating in this survey. The highest percentage of participants was the 20 to 29 year old group followed by the 40 to 49 year old group. The lowest percentage of participants was in the age group 20 years and lower.

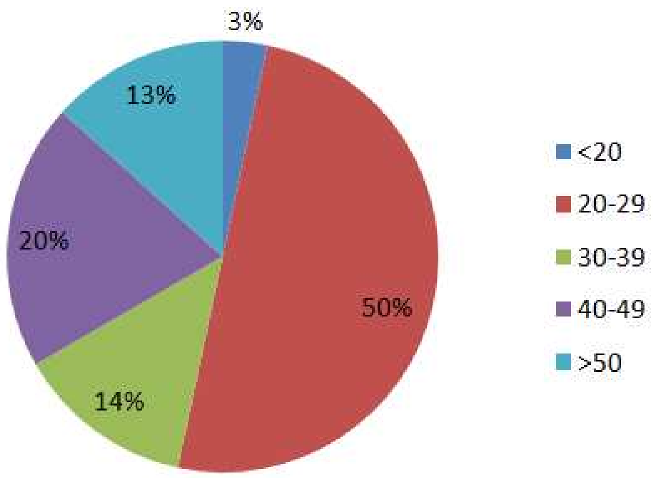



Figure 3.1: Participant’s age group

One question asked in the survey was, Who took responsibility for paying the electricity bill? Seventy-seven percent of participants said that they took responsibility for paying electricity bill: twenty three percent of participants said that they do not take any responsibility for paying electricity bills, (see Figure 3.2).

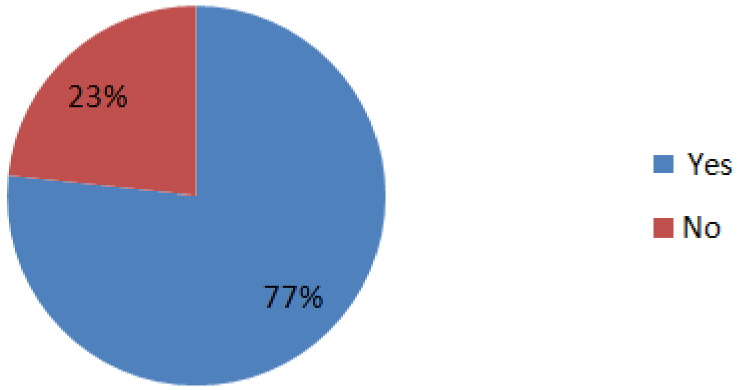



Figure 3.2: Responsibility for paying electricity bill.

Approximately 34 percent of participants stated that they paid between 100 and 200 New Zealand dollars for household electricity consumption per month. Thirty three percent of participants said that the average cost of their house electricity monthly consumption ranged between 200 to 300 New Zealand dollars. Only 3 percent of participants indicated that they paid less than 50 New Zealand dollars for their electricity bill monthly (see Figure 3.3).

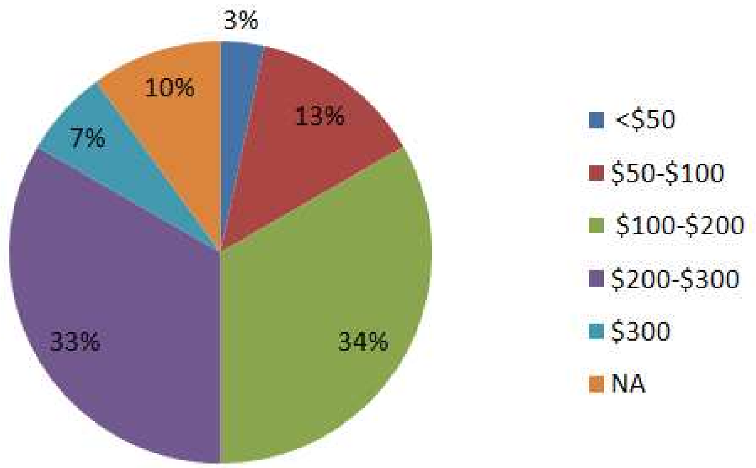



Figure 3.3: Average cost of the house electricity consumption per month.

### 3.2.2 Energy consumption:

Figure 3.4 shows the response to the question of participants putting new items into a refrigerator and whether the refrigerator uses more or less energy than usual over the next hour. Sixty-seven percent of participants expected that over the next hour the refrigerator would use more energy than usual; whereas 33 percent stated that it would use the usual amount of energy.

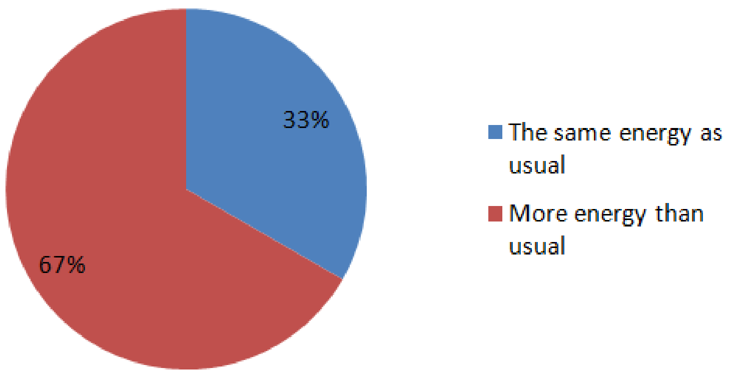



Figure 3.4: Refrigerator power consumption**.**

The following pie chart displays the participants' responses to the question as to how much energy a refrigerator with rating of 400 watts could be expected to use over a 10-hours period. Fifty-six percent of participants got the correct answer for the total consumption for that period of time, while 17 percent of participants got the wrong answer.

However, 27 percent of participants avoided answering this question, (see Figure 3.5).

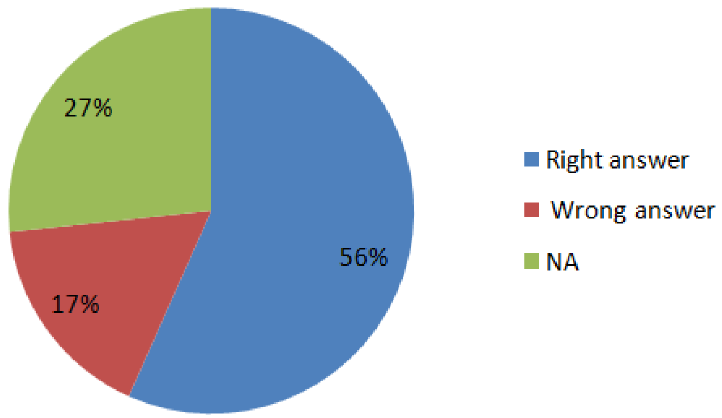



Figure 3.5: Energy consumption for refrigerator rating 400 watts working for a 10-hours period.

Figure 3.6 displays the response of all participants when asked to put appliances in ascending order, based on their total cost of operation, from largest (4) to the smallest (1). About 43 percent placed appliances in the right order according to the total cost of their operation during a specific period of time, more than half were unable to place them in the correct order.

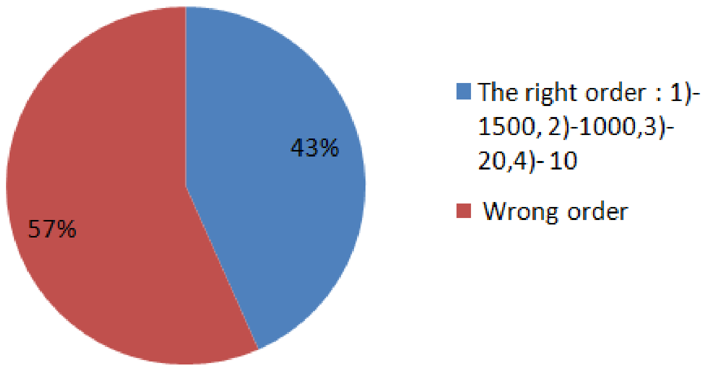



Figure 3.6: Ordering appliance based on their total cost operation.

### 3.2.3 Managing electricity:

The following pie graph (Figure 3.7) shows the responses of participants when questioned regarding their efforts to reduce electricity costs. Sixty percent stated that they made serious attempts to reduce the cost of their electricity bill, while 40 percent did not attempt to reduce their electricity bill.

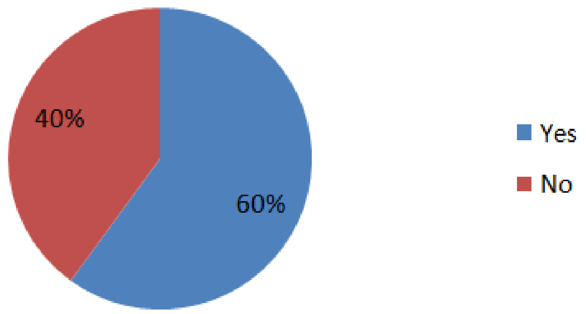



Figure 3.7: Making a serious attempt to reduce
the cost of electricity bill.

Figure 3.8 shows the reaction of participants toward appliances and lights when not in use. Seventy-seven percent of participants turned heaters, electrical appliances and lights off when they were not using them, 23 percent of participants did not.

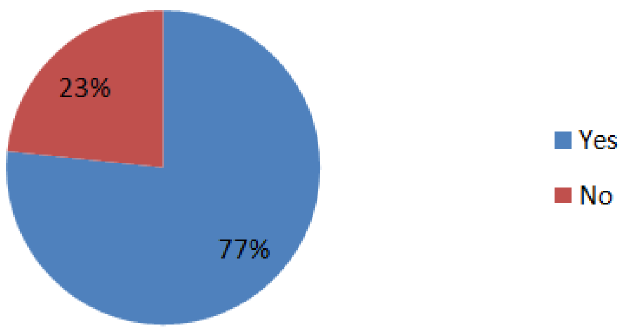



Figure 3.8: Turning appliances and lights off when
not in use.

Figure 3.9 displays information about the appliances that consume the most energy in participant’s homes. Thirty-three percent of participants believed that electric and oil heaters consumed the most energy in their homes, 27 percent stated that other appliances consumed the most energy in their houses. The lowest percentage of participants thought that the dishwasher consumed the most energy.

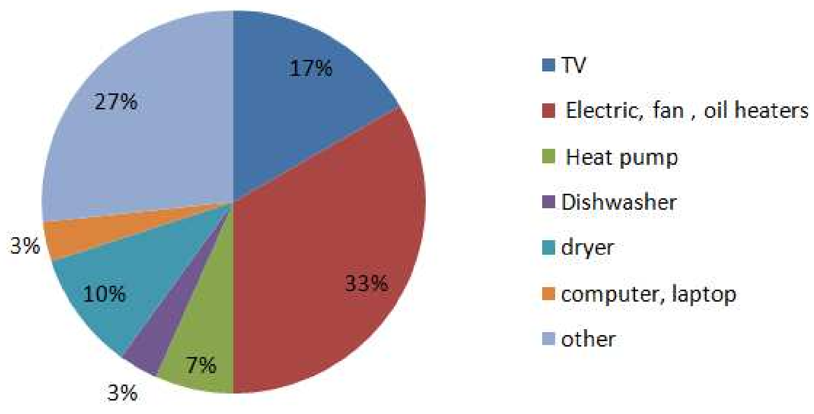



Figure 3.9: Single appliances that consume the most energy in participant's homes.

### 3.2.4 Correlation between energy consumption and managing electricity:

To verify whether or not there is any correlation between people's understanding of energy concepts and their ability to manage their energy consumption, the results of the survey were analyzed.

For each participant, the numbers of their correct answers in the energy consumption questions have been plotted against the numbers of corrected answers to the manage electricity (see Figure 3.10). This shows a weak positive correlation between the two.

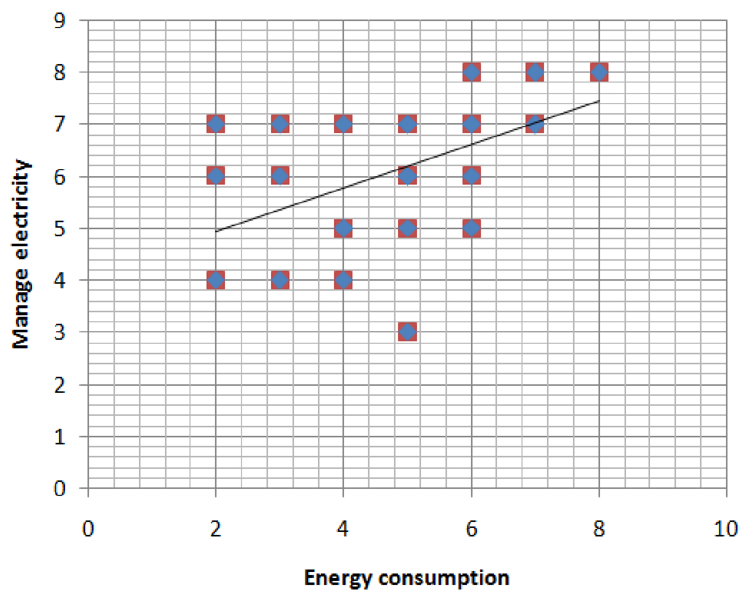



Figure 3.10: Correlation between energy consumption and managing electricity for participants.

## 3.3 Discussion:

Study participants were asked to consider the following: When a refrigerator with a rating of 400 watts works for a 10-hour period, what amount of electricity would the refrigerator use? It was interesting to note that 56 percent of participants gave the right answer while 17 percent of the participants gave the wrong answer. This showed that some participants did understand the relationship between power and energy, but they did not fully understand this relationship. When the participants were asked to order appliances based on their total cost operation, less than half of the participants were able to answer this question correctly. They were asked to order four different types of appliances from the largest total cost of operation to the smallest total cost of operation based on their running time and the power rating for each appliance, as given in the question. While 43 percent of the participants placed the appliances in the right order, more than half were not able to get the right order. Two questions looked at the total energy consumption over a period of time for some appliances, and the result of the analysis was that some participants had a limited understanding about the concept of energy and power and also of the relationship between them. This is similar to the result of Hirca et al.( 2008) who found that "students had some difficulty not only in understanding the concept of energy and related concepts, but also in relating theoretical knowledge to its practical application" (p.82).

Although half of the participants might not bother to check the appliance wattage rating, nevertheless they are still concerned about energy consumption, albeit indirectly. In other words, participants can act positively towards appliances that are not in use by turning them off. However, turning appliances off at the walls instead of leaving them on standby power was one of the questions posed in order to obtain information about the participants' awareness of energy consumption. Fifty-three percent indicated that they turned appliances off on the walls instead of leaving them on standby power; however, 43 percent did not turn appliances off at the walls; therefore half of the participants were aware of the energy consumption. This result is different from Randerson and Adam’s (2006) result. They stated that 71 percent of the users in Britain leave electrical appliances on standby.

Having baseline knowledge about energy and power will assist households to buy appliances that have high energy efficiency. It could play a major role in the reduction of household energy consumption. However, some people do not understand the relationship between energy and power; but they still attempt to reduce usage of electrical appliances in order to pay less money for their energy bills. In fact, this is similar to Chetty, Tran and Grinter (2008) who found that “householders modify their homes for resource efficiency for saving money” (p.250).

Participants were asked if they made a concerted effort to reduce the use of an appliance such as electric heater, TV, laptop, air-conditioning unit, clothes dryer or dishwasher. The results showed that 30 percent of participants said that they attempted to reduce using electric heaters, while 23 percent of participants tried to reduce using the clothes dryer. Half of the participants believed that electric heaters and clothes driers consumed more energy when in use than other appliances. When consumers avoided using electric heaters or clothes driers it did assist them to reduce their electricity bills. Consumer NZ (2010b) report supported this, saying that “heating your house accounts for 22 percent of your bill” (para. 7).

## 3.4 Conclusion:

The users of energy, the consumers, would benefit from having a basic knowledge about the concepts ‘power’ and ‘energy’ and how this knowledge plays a crucial role in the reduction of energy consumption in the house. Blizzard (2010) indicated that households can change their habits towards energy consumption if they have baseline information about energy and related concepts. This study set out to explore how well people understood the relationship between power and energy and also how this understanding affects a household’s management of energy.

The main findings were that some participants have a limited understanding about the concepts of energy and power and the relationship between them and the main motivation of reducing energy in the home is saving money.

This became evident in the different responses of the participants in the study. For instance, in the question asking participants to order four different types of appliances from the largest total cost operation to the smallest total cost operation based on their running time and their power rating, the result was about 43 percent of participants were able to place the appliances in the right order while more than half of participants were not.

Another important finding was that some participants turn appliances off when they were not in use rather than leaving them on standby. This finding is based on participants' response to the question when asked if they turn appliances off on the walls instead of leaving them on standby power. The response was that 53 percent of participants indicated that they turned appliances off at the walls instead of leaving them on standby power and 43 percent of them did not turn the appliances off at the walls.

Although there is a positive weak correlation between participants' understanding of the concept of power and energy and their attitudes towards managing their electricity, participants do manage their energy consumption even if they do not understand the power, energy relationship. For example, 77 percent of participants turn off appliances and lights when they are not in use as compared to 23 percent who do not.

Finally, this part of the study does not cover all of the issues related to it, more specifically, the question of whether people who do understand the relationship between power and energy pay less money than the people who do not understand the relationship between them. For further studies it would be necessary to identify who is better at managing energy usage by focusing on the home electricity consumption.

# 4 Design of power and energy visualization for the home:

There are plenty of power monitor tools available in the market place. Most of these tools provide feedback about the individual appliance power consumption. They also provide general feedback about the house energy consumption in different forms of representation: charts, numbers and diagrams. A survey of many of these monitoring tools was provided in Chapter 2. *Google PowerMeter* is one of the tools which provide information on house energy consumption generally for the households. In contrast, the *Kill-A-Watt* tool provides information about only the appliances that are plugged into it. However, there is no evidence which indicates what the best way of representing the data is, and also what type of data should be included in the visualization to meet the household's needs.

A comparative study has been used to examine the effect of using a variety of visualization in convincing people to change their attitude towards energy conservation. The notion of this comparative study is inspired by the Rodgers and Bartram (2011) study. They did implement variety of visualizations in their study including Hive and Pinwheel.

In our design of power and energy visualization in the home study, a comparative study was developed to examine two different formats of visualization in representing power consumption at home. One of the formats provides more numerical detail in visualization while the other provides less numerical detail. This comparative study was used to find answer for the following questions:

1. What is the vital information that people need, that will both enlighten them and allow them to make informed decisions?
2. How precisely does this information need to be described or displayed? Do the precise numbers matter? Are abstract visualisations more useful and acceptable than detailed ones?

In our comparative studies, the aim of the design is to build a realistic visualization for daily energy usage in the home for both styles of visualization. This design is made in the form of house, appliances and power consumption meters that represent a typical daily energy use in the home in order to facilitate quicker user understanding of the power consumption through using two different styles of visualization. One style of visualization, shown in Figure 4.1, uses more details in power consumption meter representation. The other, shown in Figure 4.2, is more abstract and excludes numbers and texts.

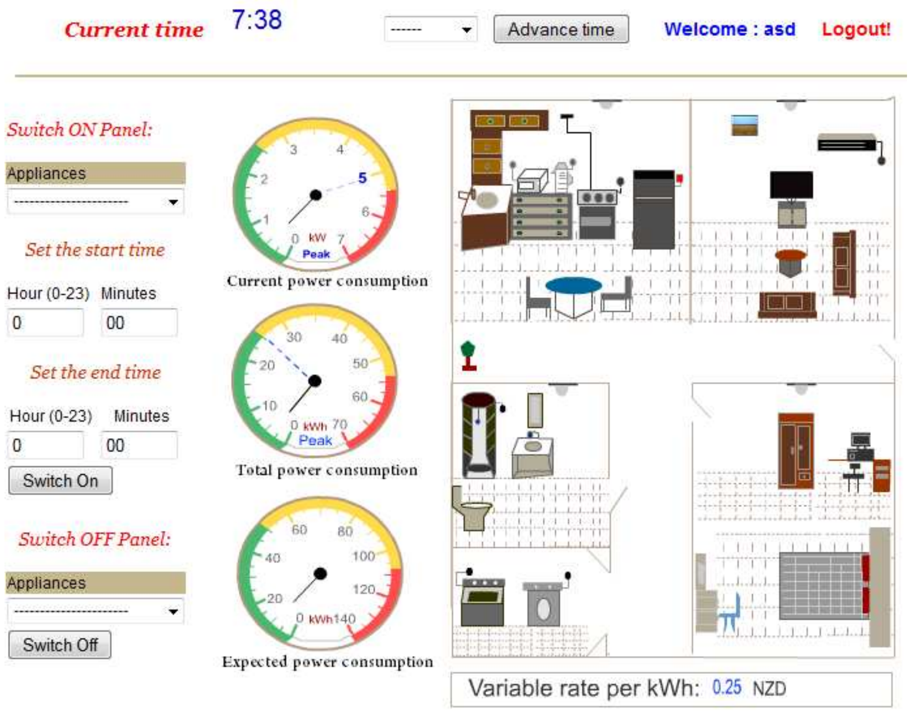



Figure 4.1: Detailed visualization


Figure 4.2: Abstract visualization

In both studies there is a similarity in two parts of the design: house representation and appliances representation. However, the difference is drawn in other parts: power consumption meter representation and variable rate per kWh representation. So, the next chapter will evaluate both styles of visualization and will indicate the methods and techniques used during this comparative study.

# 5 Evaluation of power and energy visualization in the home:

The design of power and energy visualization in the home that is hosted by University of Waikato, consists of two different styles of visualization which are detailed and abstract visualization. So, a workbench was created to evaluate and compare the effectiveness of using these two styles through building an online web-based application.

Detailed visualization is similar to abstract visualization in some aspects. The system architecture is similar in both styles, and they are both an online webpage that simulates various events such as re-running appliances, showing the power consumption for home and the decisions that a householder might need to consider. The same technique and methods to collect and analyze data is used in both styles. The same tasks are used in both the studies but there is a slight modification in the user study questionnaire specifically in abstract visualization study because of the change in the application interface.

In terms of the application interface, there are also some similarities between detailed and abstract visualization in its representation. The same control panels are used in both detailed and abstract visualization. In addition, appliances and house representation are similar for both. However, the difference occurs in the power consumption meter representation and variable rate per kWh representation as mentioned before. This chapter will give an overview of system architecture, and tasks as well as evaluating and comparing the effectiveness of detailed and abstract visualizations.

## 5.1 Detailed and Abstract System Architecture:

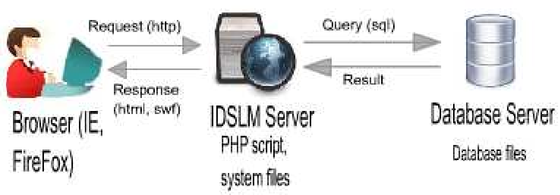



Figure 5.1: Power and energy online system architecture.

The Informed Demand-Side Load Management (IDSLM) server is used to host the project file, because power and energy visualization in the home is a part of the IDSLM project. The goal of IDSLM is to improve domestic electricity consumption (University of Waikato, 2012). The data of this power and energy project is transmitted and received over the World Wide Web via http protocol. This protocol has been used to transmit and receive all data in this online system due to the system environment (Wikipedia, 2012a). Structured Query Language (SQL) is used to store and retrieve any data from the database (Wikipedia, 2012b).

## 5.2 Running simulation for Detailed and Abstract System:

This simulation has been developed to simulate a typical daily energy use in the home using an online web-based application. It consists of background data files and application interface. The background data contains data about different types of appliances and lights, the application interface displays this data in form of picture and animation. This background data can be updated by user actions. In the other words, when the user accesses the application interface, they can switch on or off any appliance that they want to operate. And this will update the background data and the user can see the change. The user has to create an account as a requirement to access this online web-based application.

This background data contains data for nine appliances including four lights and a shower that operate over the course of the day, from 00:00 to 23:59, (see Figure 5.2). This background data was run on the MySQL database at the Waikato University server. MySQL was chosen because it is flexible and it is also suitable with PHP language which is used to create the web based application.

| constid | timee | ref | oven | Ket | micro | tv | air | comp | washM | dryer | Klight | Livinglight | bedlight | bath | shower | parttid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60971 | 08:10:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60972 | 08:11:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60973 | 08:12:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60974 | 08:13:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60975 | 08:14:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60976 | 08:15:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60977 | 08:16:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60978 | 08:17:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60979 | 08:18:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60980 | 08:19:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60981 | 08:20:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60982 | 08:21:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60983 | 08:22:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60984 | 08:23:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60985 | 08:24:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60986 | 08:25:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |
| 60987 | 08:26:00 | 450 | 0 | 800 | 900 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 10 |

Figure 5.2: The background data in MySQL.

## 5.3 Participants:

Two user studies were conducted with participants to evaluate the detailed and abstract visualizations. The user study of detailed visualization was conducted with 20 participants; 16 males and 4 females. The user study of abstract visualization was conducted with half of those participants: 8 males and 2 females. Most of them were friends and friends of my friends. Their ages ranged from 16 to 65 years old. Most of them took responsibility for paying electricity and their basic knowledge in computers was good. Many participants were students who live in a home and shared it with friends or in studio apartments.

## 5.4 Problem scenarios:

It was hard to obtain an efficient application that meets the users' needs. Additionally, it was difficult to determine which data should be included in this application. However, establishing problem scenarios were extremely beneficial to determine the objects of application interface as well as helping in the design of detailed and abstract visualization as the application interface.

**Problem Scenario 1:** Khalid was a student at Riyadh College of Technology. He paid a large amount of money for his electricity bill each month. He spent a few months avoiding using some appliances in order to reduce his electricity bill. However, he found his solution was not the best one. Khalid believes that it will be beneficial to him if there is a smart application that will provide information about his house energy usage and appliance energy consumption.

**Problem Scenario 2:** Bill is a teacher at the international school and lives in a school house. He always switches appliances and lights off if they are not in use. Although Bill's habit of managing his house energy consumption is still the same, over the last six months, the amount of his electricity bill fluctuated from one month to another. The changeability of this situation made it difficult for Bill to find a solution for his problem. Bill thinks that if there is an application that can give immediate feedback about his house energy usage it will be useful for him.

## 5.5 Tasks:

Six tasks were created based on two scenarios to examine the effectiveness of using detailed and abstract visualization in both studies. The first task requests the user to advance the current time until it becomes 8:00 am. This task is used to examine the participants' observation of any changes happening in the system, and then asking participants how many appliances are running and also to list them from the highest to lowest in terms of their power usage. In addition, the user is asked how easy is it to distinguish between appliances that are on and the appliances that are off.

The second task requires the user to switch the kettle on for thirty minutes. This task was used to test user reaction to increase the current power consumption and also their responses to other events occurring concurrently in the simulation. In addition, it was used to measure the user's satisfaction about the current, total and expected power consumption representation. The third task is similar to the second task but the difference is that the user has to advance the time till it becomes 13:00 or slightly over and then switch the microwave on for one hour. Some appliances will be running concurrently with the microwave causing a dramatic increase in the current power consumption. This task will highlight the highest power-consuming appliance and will also clarify the participant's understanding of peak demand visual representation icons.

The fourth task is to advance the current time till it becomes 18:00 or slightly over and then switch the washing machine on for two and a half hours. It was used to test user comprehension and observation of three points. The first point is that they know the number of appliances running. The second is that they can determine which three appliances consume the most power out of all the working appliances and the third is that they calculate how many watts are needed until the current power consumption reaches the peak demand which is 5 kW.

The fifth task is to switch on the dryer for two hours. This task was used to test the user awareness of preventing the power consumption from going over the peak demand of 5 kW. The user should take any action to cut down the current power consumption by switching one or two appliances off owing to the high rate of dryer power consumption. If the user does not take any action then the cost of power per kWh will increase from 0.25 to 0.30 New Zealand dollars as a consequence of not keeping the power consumption below 5kW.

The sixth task requires the user to advance the current time till it becomes 21:00 and then switch off four of the five appliances which are running. The task examines the user's reasoning in deciding which four appliances should be switched off.

## 5.6 Procedure:

Initially, participants were given a brief summary of the study. Then, the participants were asked to try using the application to become familiar with it before they performed the experimental tasks. Participants were asked to create a new account and sign in to the experiment. After creating an account, the participants were asked to answer a questionnaire about themselves. After that, participants were asked to logon to the experiment to implement tasks and complete a short questionnaire to measure both their satisfaction and performance. At the end of the study, the participants were asked to complete a post-study questionnaire on their overall satisfaction with the energy and power visualizations in the home.

## 5.7 Data Collection:

Many aspects have been involved in gathering data and building a simulation for this study. It was important, as a first step, to ascertain people's understandings about the concept of power, energy and the relationship between them. This study reviewed commonly held ideas about power and energy with the underlying purpose of increasing people's knowledge wherever there was a shortfall in their understanding. The reading and reviewing of other studies contributed to the creation of a sample design for visualizing energy in the home. The formulation of tasks and questionnaires was another aspect of collecting data. There were six tasks and forty two questions in this study. These questionnaires were divided into three parts. The first part collected data about the participants' background; the second contained questions about the tasks, and included the tasks; the final part was participants' feedback regarding the application.

## 5.8 Detailed visualization:

The detailed visualization (Figure 5.3) comprises two components: a control panel and a dashboard data image to display information about the power usage. The diagram shows an overview of the application interface and each component will be discussed further on.

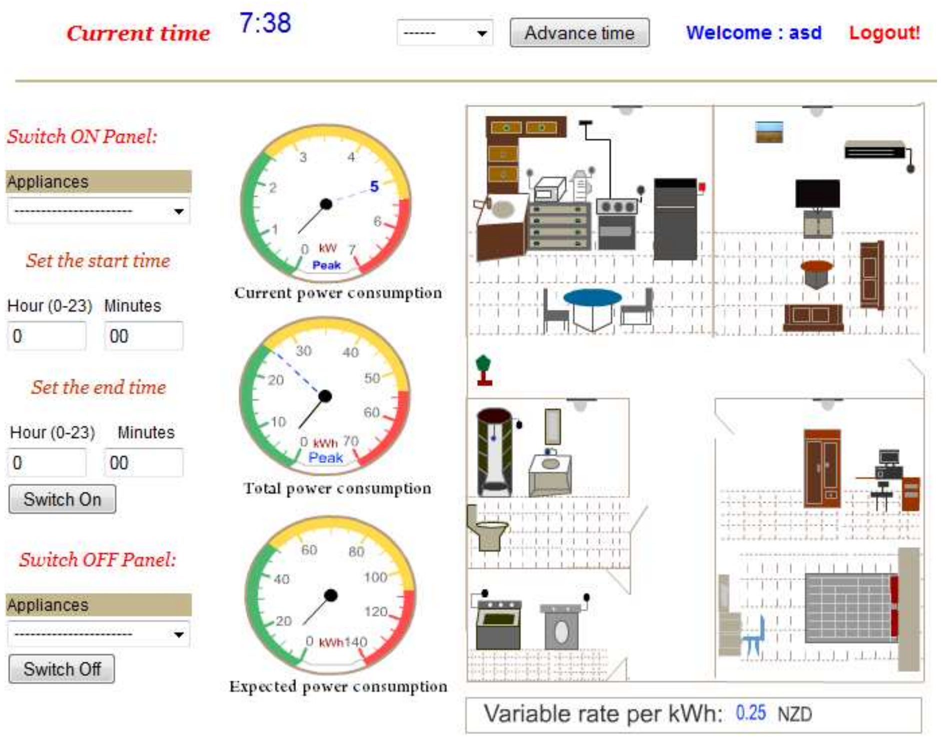



Figure 5.3: Detailed visualization

### 5.8.1 Control panels:

Three control panels are used to manage the appliance status and virtual time in this simulation. The first is a switch on panel which switches appliances on. Participants can select any appliance from the drop list and then they can set the start and end time for that appliance. To complete this process they press the switch on button, (see Figure 5.4).

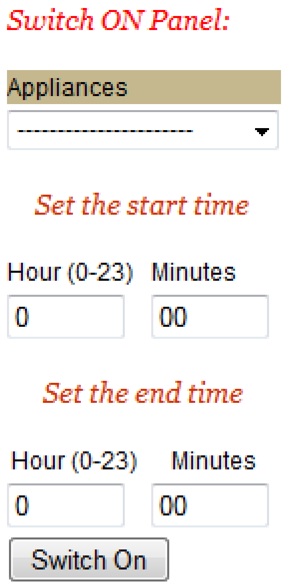



Figure 5.4: Switch on panel.

The second panel (see Figure 5.5) is for switching an appliance off. From the drop list of appliances, participants can choose the appliance that they want to turn off and then click the switch off button.

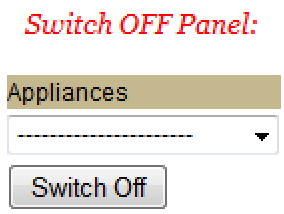



Figure 5.5: Switch off panel

The third panel, shown in Figure 5.6, is the advance time panel. It is used to add minutes and hours to current time for advancing the current time to a specific time. The current time has been included in this panel so participants can notice the change in the time. It represents the virtual time for this simulation.


Figure 5.6: Advance time panel.

## 5.8.2 Dashboard data image in detailed visualization:

The aim of this dashboard is to display the data for users, giving them feedback about their house's energy usage. The appliances, the power consumption and the variable rate are represented in this visualization.

### 5.8.2.1 Power consumption representation in detailed visualization:

The power consumption representation uses three different meters. The first meter is the current power consumption meter and it shows the consumption in kW for per minute. It also displays the amount of power that it is being used right now by aggregating the data of appliances that are currently on. It also shows the peak demand of power consumption which is highlighted by a blue dotted line, (see Figure 5.7).

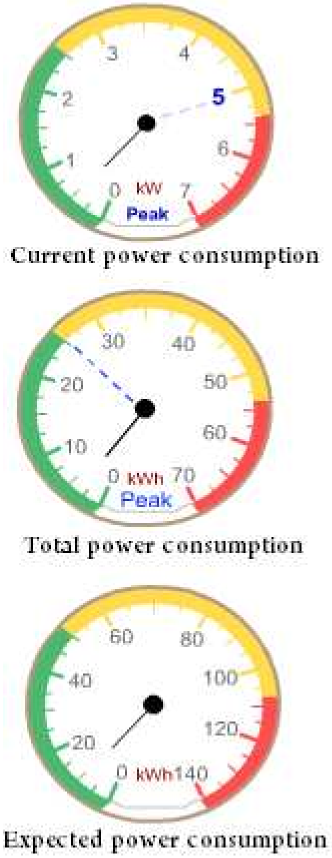



Figure 5.7: Power consumption visualization

The second meter shown in Figure 5.7 is the total power consumption meter and it displays the power used in kWh from the beginning of the day until the current time by aggregating the data of all appliances. In addition, the daily maximum energy usage has been included on this meter using a blue dotted line as indicator.

The third meter shown in Figure 5.7 is the expected power consumption meter. It shows the projected power usage for the next 24 hours based on the current power consumption.

A specific pattern of colours was used to represent the status of power consumption in all three meters. Green indicates that the power consumption is low; yellow indicates average power consumption and red indicates that the power consumption is high.

#### 5.8.2.2 Appliances representation in detailed visualization:

Nine appliances, four lights and a shower are shown in the appliances representation. Appliances that are on or off can be distinguished easily. If an appliance has a red light flashing close to it, the appliance is on and if the light is not flashing, it is off. Another way to know if this appliance is on or off is by rolling the mouse over it. A pop up window will appear and give information about the appliance: its name and power consumption. Figure 5.8 demonstrates that the two appliances which are on are the refrigerator and the microwave. In addition, the shower and the light in kitchen are also on.

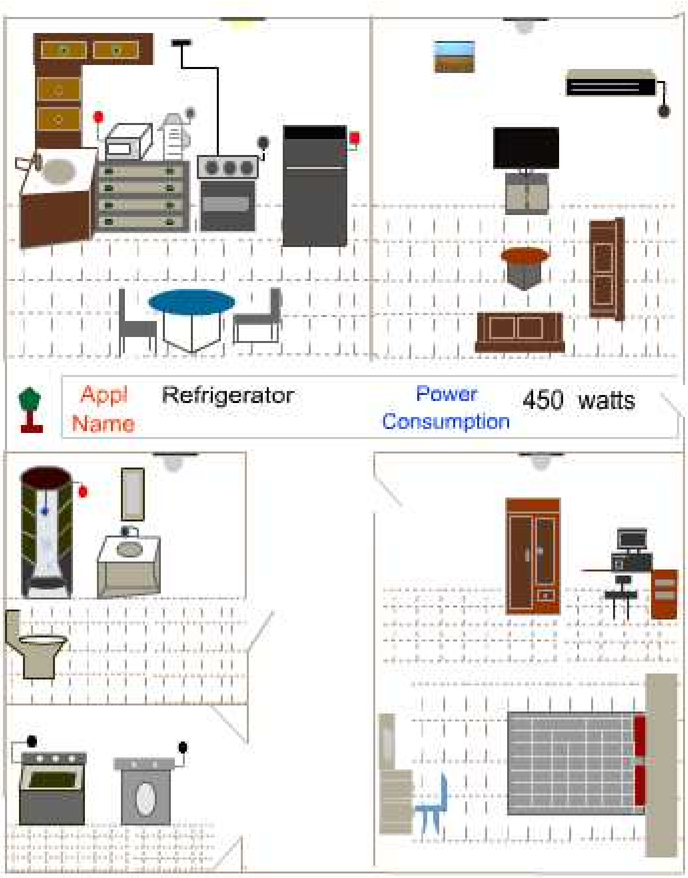



Figure 5.8: Appliances visualization

#### 5.8.2.3 Variable rate visualization in detailed visualization:

The rate of power per kWh has been represented in Figure 5.9. Two values have been used as cost of power per kWh, 0.25 and 0.30 New Zealand dollars. The normal cost of power is 0.25 per kWh but if the power goes over the peak demand the rate of power per kWh will increase to 0.30 New Zealand dollars per kWh.


Figure 5.9: Variable rate visualization

## 5.9 Results of evaluation of detailed visualization:

Participants' observation was tested in the first task by asking them how many devices were on when they advanced the current time until it became 8:00. Eighty-five percent of participants got the right answer, which was three devices: microwave, refrigerator and shower; while, 15 percent of participants were not able to provide the right answer, (see Figure 5.10).

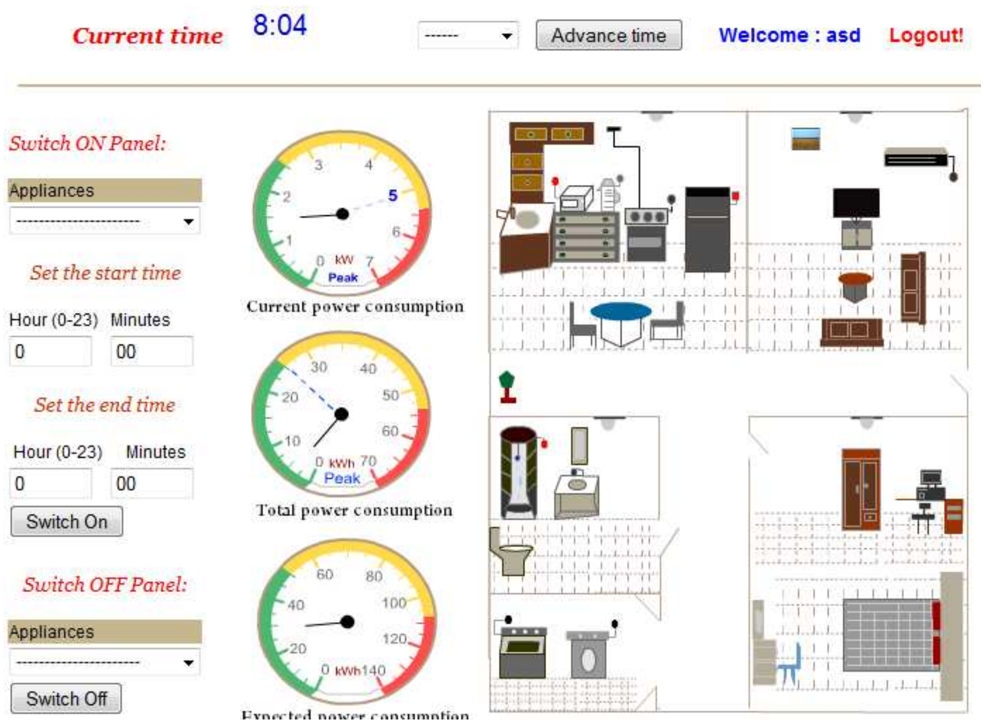



Figure 5.10: Three devices on

Asking participants to list these appliances according to their proportion of power consumption from the highest to the lowest one was another question. This question resulted in 95 percent of participants listing appliances correctly while only 5 percent of participants listed appliances incorrectly. When distinguishing between the appliances' status, 40 percent of participants said that it was very easy to distinguish between appliances that were switched on and appliances that were switched off, while, 25 percent of participants said that it was somewhat difficult to distinguish between appliances that were switched on and switched off. The remainder indicated that it was extremely easy to distinguish between appliances that were switched on and appliances that were switched off.

When asked about the clarity of the representation of the current, total and expected power consumption, over half the participants said the representation was very clear, 30 percent said it was extremely clear but 10 percent said it was somewhat unclear. Fifty-five percent indicated that using the switch on panel was extremely easy, while 45 percent indicated that it was very easy to use.

In response to a question about the clarity of the representation of peak demand in the current consumption meter 45 percent of participants' responded that the representation was very clear, 5 percent of them indicated that it was not very clear. Thirty-five percent of participants indicated that the representation was somewhat clear and 15 percent of participants stated that it was extremely clear. In addition, there was a question to determine which appliances were consuming the highest proportion of the current power consumption at the present time. The response was that all participants chose the oven. They got the right answer because the rate of power consumption for the oven was the highest rate among all the appliances that were running.

Setting the current time at 18:00 resulted in the running of many appliances in the simulation. There was a question to determine the number of appliances running. The participants' responses were as follows. Ninety-five percent got the right answer (eight appliances were on), while 5 percent were not able to get the right number. Three appliances consumed more power than all other working appliances. Asking participants to find these appliances resulted in 90 percent choosing the three appliances correctly whilst 10 percent were incorrect. Participants' understanding was tested by asking how many watts were needed until the power consumption reached 5kW. Ninety-five percent got the right answer; (between 1001 – 1500 watts), while 5 percent were not able to get the right number. A dryer rated at 2000 watts that runs concurrently with several other appliances increases power consumption to over the 5 kWh power limit. The task asked the participants to switch off one or two appliances. Ninety-five percent of participants were sufficiently aware of this principle and chose the oven, while 5 percent made no choice which showed either a lack of understanding or deliberate ignorance of the principle.

The participants' decisions were examined in the final task in the following way. At 21:00 five appliances were running. The participants were asked to select four out of these five appliances and switch them off, to prevent the energy consumption exceeding the maximum daily energy usage. All participants succeeded in this task by choosing the unnecessary appliances from the five working appliances and switched them off.

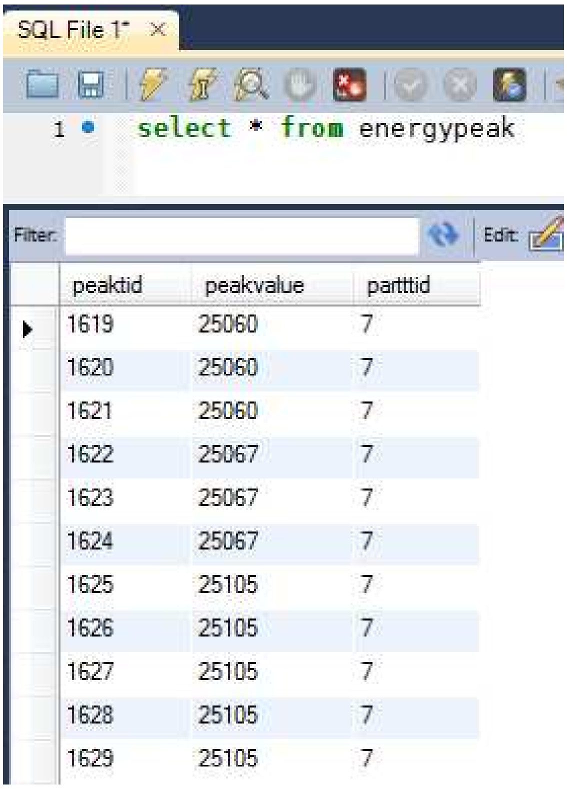
### 5.9.1 User feedback in detailed visualization:

The general user feedback is illustrated by the following points. The way of displaying information was acceptable to all participants as it was clear and easy to use the application. Some participants said that displaying information in this manner, gives a clear indication of power consumption. It also gave the consumer information about their energy consumption and raised their awareness of their household power consumption. In addition, they believed that this display provides instant information about power and energy consumption. The overall conclusion was that it helped them to be more aware of electric power usage and the ways to improve it.

Participants thought that knowing the power consumption for each appliance was very useful. They thought that it would assist them to make better decisions about economical use of energy. They said that it might also help to know which device consumes the most energy. It would also give them feedback about each appliance's power consumption.

All participants indicated that they do like abstract representation better than just numbers in the information representation. An abstract representation facilitates participants' understanding of the tasks and their purpose and, with its user friendly interface, it makes navigation easer.

In terms of analysis and observation, participants initially struggled in using application. This resulted in one of the participants failing to keep the total energy use in the home below the maximum daily target of 25000 watts, (see Figure 5.11).




| peaktid | peakvalue | partid |
|---|---|---|
| 1619 | 25060 | 7 |
| 1620 | 25060 | 7 |
| 1621 | 25060 | 7 |
| 1622 | 25067 | 7 |
| 1623 | 25067 | 7 |
| 1624 | 25067 | 7 |
| 1625 | 25105 | 7 |
| 1626 | 25105 | 7 |
| 1627 | 25105 | 7 |
| 1628 | 25105 | 7 |
| 1629 | 25105 | 7 |

Figure 5.11: Data in Database using query via
MySQL Workbench 5.2

The evidence of people struggling in using this system is shown in the first task. The first task was the easiest task; there was question for determining the number of running appliances. Some participants were not able to get the right number. However, when the participants became familiar with the application, they were able to make the right decision for controlling the appliances and the power consumption in the home. Their observation became more precise as well.

In addition, participants' awareness has increased about the appliance power consumption rate and total power consumption in the home. When the power consumption goes higher, they attempted to identify the causes of this increase. They always looked for appliances which were running in order to find which appliance consumed the highest rate of power among all appliances that were on so as to switch it off.

### 5.9.2 Issues identified in detailed visualization:

Although all participants like the power and energy visualization design, there were some design issues indicated by a few participants. One of the issues was that it would be useful to have mouse-over pop-up of the exact reading, instead of having to estimate based on the meter. Another issue was that it would be more effective if icon lights become bigger and flashed quickly. Finally, it was thought that it would be a useful idea to have one dynamic graph representing all of the appliances' power consumption.

## 5.10 Abstract visualization:

The abstract visualization is similar to the detailed visualization in control panel components. In other words, the same control panels have been used in both visualizations; detailed and abstract. The difference between abstract and detailed visualization is shown in the dashboard data visualization specifically in two components: visualizing the power consumption and variable rate visualization. Figure 5.12 gives an overview for the abstract visualization.


Figure 5.12: Abstract visualization

Power consumption visualization and variable rate visualization will be covered in this section. However, the control panels and appliances visualization will be excluded in this section owing to their similarity with detailed visualization design.

### 5.10.1 Dashboard data visualization in abstract visualization:

This part will focus more on representing the power consumption and variable rate visualization in abstract style visualization because of the similarity of dashboard data for representing home and appliances visualization.

#### 5.10.1.1 Power consumption visualization in abstract visualization:

Three types of meter were used to represent the power consumption. An abstract meter for power consumption has been used to visualize the home power consumption. In Figure 5.13, the current power consumption meter shows the current power for all appliances that are running now. The power limit is highlighted by using a blue vertical line.

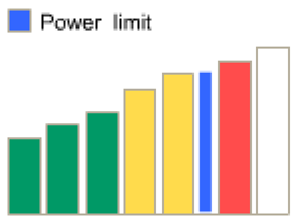



Figure 5.13: Current power
consumption
meter.

Figure 5.14 shows the meter that represents total power consumption for the whole house from mid-night until the current time by aggregating the data of all appliances. It also shows the energy limit by using a blue vertical line highlighted in the abstract meter.

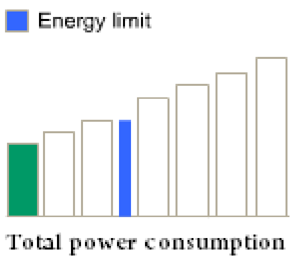



Figure 5.14: Total power
consumption
meter.

The final meter is an expected power consumption meter. This meter aims to show the expected power consumption for the next 24 hours based on the current power usage, (see Figure 5.15).

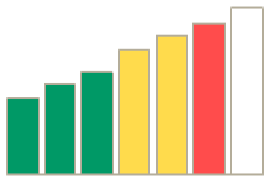


Figure 5.15: Expected
power consumption
meter.

Three colours are used to visualize the status of power consumption in all three abstract meters. Green indicates the power usage is low, while the yellow indicates average power usage and red is used to indicate the higher power usage.

#### 5.10.1.2 Variable rate visualization in abstract visualization:

A line bar was used to visualize and represent the cost of power per kWh. This bar consists of two colours with an arrow to indicate the cost of power. The green indicates the cost of power when it is normal, while the red indicates the increasing power limit or energy limit when the rate of cost of power is increased, (see Figure 5.16).


Figure 5.16: Variable rate visualization.

## 5.11 Results of evaluation of abstract visualization:

All participants in this study are familiar with this system specifically using control panels due to their participation in the prior study. Asking the participants about how many devices were on when they advanced the current time until it become 8:00 was used to examine the participants' observation. The result was that 90 percent got the right answer, which was three devices, while, 10 percent were not able to provide the right answer. Additionally, participants were asked to list these appliances according to their power usage from the highest to the lowest percentage of power usage. Ninety percent of participants listed appliances correctly while only 10 percent of participants listed appliances incorrectly.

To distinguish between the appliances' status was one of the question that was used to test participants' observation and the result of this question was that 50 percent of participants indicated it was very easy to distinguish between appliances that were switched on and appliances that were switched off; 40 percent indicated that it was extremely easy to distinguish between appliances that were switched on and appliances that were switched off; and about 10 percent said that it was not very easy to distinguish between appliances that were switched on and appliances that were switched off.

Participants were asked about the clarity of the representation of the total, the current and expected power consumption. Half of the participants said that the representation was extremely clear; 40 percent said that it was very clear; 10 percent said that it was somewhat clear. In part of the clarity of representation, there was a question about the clarity of the representation of power limit in the current power consumption meter. The result was that 20 percent indicated that it was somewhat clear; 50 percent of participants' responded that the representation was very clear; and 30 percent indicated that the representation was extremely clear.

The unit of each meter was not displayed in this study. Thus, one extra question was asked to examine participants' understanding and ability to link these units 'kW' and 'kWh' to the related current power consumption meter. Fifty percent of participants responded that kW is used to measure the current power consumption meter and they got the right answer. In contrast, there was another question to relate these units to the total power consumption meter. The outcome was that 90 percent of participants responded that kWh is used to measure the total power consumption meter and they got the correct answer.

When participants set the current time at 18:00, they were asked about how many appliances were in an on state. All of the participants got the right answer, eight appliances. Participants were also asked to select three appliances that consume more power to run among these eight appliances. All participants selected the three appliances correctly. At 18:00, eight appliances were on and the participants were asked to turn the dryer on. This needs 2000 watts to operate, so this task results in overuse of power and the current power consumption which goes over the power limit. So, participants' action was examined in this task by advising them to switch off one or two appliances to manage the power consumption, considering the appliance with the highest power consumption to run in order of priority. All participants succeeded in performing this task and they chose the oven.

Digital meter and abstract meter were two types of meters that were used to represent power consumption in the visualizations. The participants were asked which one of these meters was better for visualizing the power consumption. Seventy percent of the participants liked the idea of using an abstract meter for visualizing power consumption rather than using the digital meter; 30 percent answered that using digital meter was better than using an abstract meter.

### 5.11.1 User feedback in abstract visualization:

The representation of energy consumption in the home was clear and satisfactory for all participants. Many of the participants indicate that displaying energy usage like this will help them to monitor their power consumption. It will also assist them to become aware of the utility that consumes more power. Some of the participants believed that the representation gave them a brief idea about how much power each device is using. This encouraged them to make decisions in choosing the right appliances in the home.

Most of the participants indicated that abstract representation is more understandable and readable compared to using numbers for representing data. Few participants suggested that it would be better if the information representation combined both numerical and abstract representations, specifically in terms of representing the current, total and expected power consumption meters.

The use of abstract meters was more desirable than the use of digital meters for visualizing the power consumption. The reason was that any change in an abstract meter can be noticed more quickly than in digital power meter. Another reason was that an abstract meter attracts the user sight, while the digital meter did not catch the attention as much. The user had to rely on the needle of the meter to notice the change in the digital meter.

In the abstract study, participants were more confident in performing all tasks. This resulted in all participants succeeding in keeping the power consumption below the power limit and the maximum daily energy use targets. This also indicated that participants became more aware of their attitudes toward managing and controlling energy consumption in the home through this simulation because of the familiarity of using the system. The participants' performed better than their prior performance in the detailed visualization due to the clarity of the change these with which it could be noticed specifically in the power consumption meter representation.

### 5.11.2 Issues Identified in abstract visualization:

There were some issues indicated by the participants.

1. One of the issues was that icon lights should have been larger than their current size.
2. Another issue was that if the numerical value had combined with the abstract meter it would have given more clarity to the representation.
3. Some participants indicated that the position of the variable rate was not good; they suggested that it should be moved from its existing position and placed closer to the meters.
4. The final issue was that all devices should have been placed at the same eye level to enable user to more easily distinguish between devices that are in on and off state.

## 5.12 Summary:

Some points were covered in this chapter such as giving an overview about the system architecture, participants' feedback about each study 'detailed and abstract study' individually. In addition, this chapter provided an overview about some issues identified by participants as well as supplying the evaluation for each study. Chapter 7 will focus on comparing and contrasting these studies as well as discussing people's understanding of the concept of power and energy via the abstract study.

# 6 Implementation of the test-bed for detailed and abstract visualization:

Power and energy visualization in the home is an online web based application. It is hosted and managed by Waikato University, and was developed to evaluate and compare the effect of detailed and abstract visualization. All files, such as PHP files, flash files and database files, were uploaded to the Waikato University server. There were two phases involved in developing this webpage. The first was the development stage and it was implemented on a local machine. The second stage was the production stage and it was implemented on the Waikato University server.

## 6.1 Development stage:

### 6.1.1 Hardware:

An hp laptop was used to implement the development stage. It has a 500 GB hard drive and a 4 GB RAM and runs on Intel® Core™ i3 CPU.

### 6.1.2 Software:

The Operating System was Windows 7 Professional. In addition, apache2 was installed and used to run this machine as a server. MySQL 5 was also installed and used to manipulate the database, creating tables, inserting and querying data. Dreamweaver was used as a tool to write most of the code, PHP script and HTML. Flash CS5.5 was used to draw the visual design of the system and control it by using Actionscript3.

## 6.2 Production stage:

### 6.2.1 Hardware:

Waikato University's server was used to implement the production stage. The server has a 200 GiB hard disk and 4 GiB RAM and runs on Dual-core CPU.

### 6.2.2 Software:

The Operating System of the Waikato University server is CentOS 5.7. MySQL 5.0.7 and it was used to manipulate the database on the Linux server. Apache 2.2.3 / PHP 5.3.3 was installed on the Linux server to run

PHP files and related files. In addition, three applications were used to connect, transfer and manipulate data on the server: Putty 0.60, WinSCP 4.3.2 and MySQL Workbench 5.2 CE.

**Putty 0.60**: used to connect the server using SHH Tunnel.

**WinSCP 4.3.2**: used to transfer data form developed machine "Laptop" to the production machine known as the "Waikato University server".

**MySQL Workbench 5.2 CE**: used to create, manipulate and query the database.

## 6.3 Physical setup and data access:

The experiment was ready to use when all study files were uploaded to the Waikato University's server. It could be accessed from any location with the availability of computer and internet connection. Most participants did the user study using their own computers and they did it from their home when we had the workbench.

### 6.3.1 Tablet and Phones:

Most tablets and smart phones with Android operating systems can open and run this application. Figure 6.1 demonstrates running the power and energy visualization at home using ZEPAD Tablet with android 2 as its operation system.

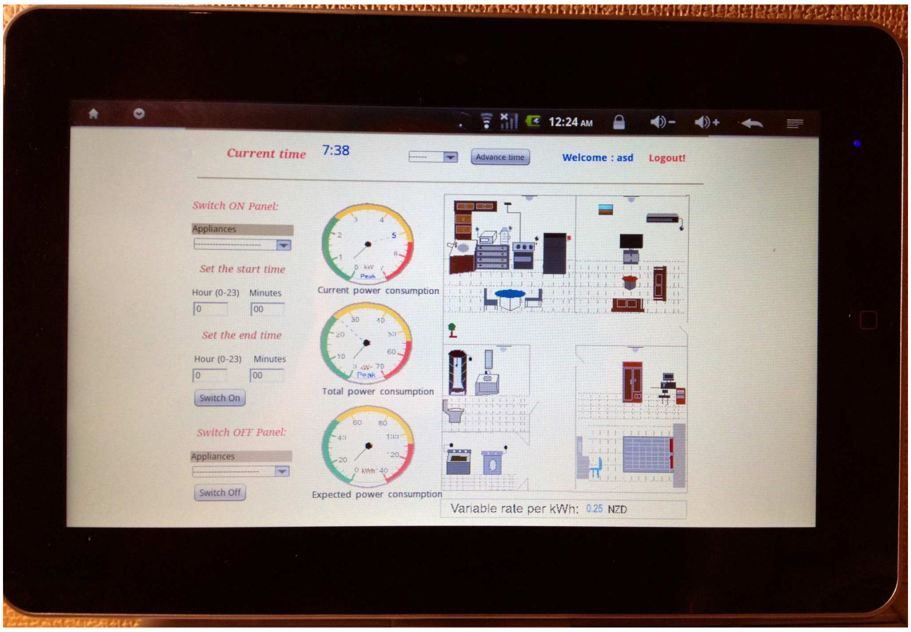



Figure 6.1: Power and energy visualization runs on ZEPAD Tablet.

However, this study cannot be run on some tablets and smart phones such as iPad and iPhone due to limitation of supporting flash contents in the project. Apple does not support flash files on its operating system.

# 7 Discussion:

This chapter reflects on the user studies carried out for the thesis and described in Chapter 5**.** It also explores the outcome of the study on people's understanding of power and energy concepts, and how an appreciation of this understanding can inform the design of energy visualizations in the home.

## 7.1 Comparing and contrasting between the detailed and abstract study:

The abstract representation of representing the data has several advantages. In both studies, detailed and abstract visualization studies, participants liked the abstract representation more than numerical representation for visualizing energy use in the home. The abstract visualization study was more attractive for participants specifically for visualizing the current, total, expected power consumption because of the attractive display, and the increase or decrease displayed in power consumption which was quickly noticeable. However, this part of the study will compare and contrast between detailed visualization and abstract visualization for participants' evaluation, the feedback and the issues that were identified by the participants.

There are a large number of similarities in participants' opinion regarding distinguishing between detailed visualization and abstract ones.

1. In the abstract visualization, almost half the participants believed that it is easy to distinguish between appliances which are switched on and the appliances which are switched off. This is similar to participants' response in the detailed visualization study, where about half the participants answered that it was very easy to distinguish between the appliances which were switched on or switched off.
2. A third of the participants in the abstract study indicated that it was extremely easy to distinguish the appliance status. This was similar to the participants' opinions in detailed study.
3. Half of the participants in the abstract study indicated that the representation of power limit was very clear, which was again similar

to participants answer in the detailed study, where almost half of participants answered that the peak demand representation was very clear.

4. Participants in the detailed study believed that the way of showing energy use data in the home was acceptable and clear. This is similar to participants' feedback in the abstract study; where they indicated that the representation of energy use in the home was also clear and satisfactory.
5. Participants' feedback in the detailed study said that knowing the power for each appliance was useful. This is similar to participants' feedback in the abstract study; where participants believed that displaying the power use for individual devices was beneficial. It made them become aware of the appliances that might consume more power.
6. In both studies, most of the participants' feedback was similar. The participants believed that the abstract representation was more understandable and readable than numerical representation.
7. Participants indicated that including a numerical value to represent the exact reading for power energy meter would have given more readable understanding and clarity for power meter representation in both studies. This was similar to the Rodgers and Bartram results (2011) which stated that "we also note the desire to have more detail on demand in the displays: participants indicated they liked the artistic feedback but wanted to 'see the numbers' in certain situations" (p.2496). The final similarity was that participants agreed that, for both studies, icon lights should have been larger than their current size.

On the other hand, there were some differences between abstract study and detailed study.

1. The belief of participants about the clarity of current, total and expected power consumption representation in each study was different. Half of the participants in the abstract study believed that using abstract meter to visualize the current, total and expected power consumption was extremely clear. In contrast, more than half of the participants thought

that using numerical detailed meter to represent the current, total and expected power consumption was very clear.

2. The participants' feedback about comparing the use of the abstract meter with the digital meter for visualizing power use in the home was that most of the participants agreed that using an abstract meter in visualizing power use was better than using a digital meter.

3. Another difference in terms of issues was identified by users was that participants in the abstract study suggested that the variable rate should have been moved from its existing position to another position which would be closer to the meter in order to see the change in the variable rate. In contrast, participants in the detailed study proposed that having one dynamic chart for representing the entire appliance' power use would enhance the application.

The analysis and observation of participants' reactions and performance in both user studies showed that only one participant was not able to keep the total energy consumption below the maximum daily energy use target. The majority of participants succeeded in keeping the current and total power consumption under the power and energy limit targets while using both styles of visualization. This indicated that, in both studies, participants were aware of managing energy in the home through the simulation and their consciousness has risen about the concept of power and energy use in the home.

## 7.2 People understanding the concept of power and energy via abstract visualization study:

The availability of a smart energy application for monitoring energy use in the home will not require users to be fully knowledgeable about the concept of power and energy to control their home energy consumption. The finding of the user study was that users acted positively and efficiently in both detailed and abstract studies. The evidence in this is drawn from one task asking participants in both user studies to switch off one or two appliances with the highest power consumption among running appliances in order to avoid power consumption going over the limit. Most of the participants targeted the oven because of its higher rate of power consumption.

However, there was a question asked to examine the participants understanding by making them choose one of the units between ‘kW’ and ‘kWh’ which would correspond to the current power consumption meter in abstract study. Only half of them were able to get the right answer. This meant that people lacked understanding the concept of power and energy in term of the scientific meaning (Hirca et al., 2008). This is similar to the main finding in the Chapter 3 reported from the first survey that studied the understanding of the relationship between power and energy, which showed that some participants had a limited understanding of the concept of energy and power and the relationship between them.

Although some participants have a limited understanding of the concept of power and energy, they were able to manage the simulation and implement the tasks effectively. The limitations did not prevent participants from achieving tasks and controlling the simulation for both applications in visualizing power use in the home. This is similar to another finding in Chapter 3, that participants can manage their energy consumption even if they do not understand the power, energy relationship. This has driven us to conclude that people can manage their home energy consumption in an appropriate way when they have an access to their home energy consumption data using smart devices or smart applications effectively, even if they do not have sufficient knowledge about the concept of power and energy use in their homes.

Although there is positive effect of understanding the concept of power and energy in changing people’s attitude toward conserving energy in the home and it might help to reduce energy consumption by 10 percent of home energy use (Blizzard, 2010), this understanding is not an essential issue to conserve the energy use in the home. One of our studies’ findings was that participants in abstract and detailed visualization acted and managed the simulation equivalently.

Some participants believed that combining the visualization with the numerical value would have provided more clarity to the representation. This is similar to Kim et als.'s (2010) findings, which were that "35.2% of Coralog users wanted to see numerical data expressed either as electricity used or monetary expenses for a further motivation toward energy conservation" (p.113). People need not be fully aware of the concept of power and energy to manage their energy use in their home especially when employing the technology to guide households to conserve their home energy usage by providing immediate feedback to increase the households' awareness.

# 8 Conclusion and Future work:

## 8.1 Conclusion:

The research described in this thesis was undertaken to investigate how well people understood the relationship between power and energy and also how this understanding affects the household's management of energy, along with the type of information which might be needed by the people for making decisions to conserve energy in the home through existing technologies. It also studies the effect of using more detailed visualization as compared to the abstract visualization for identifying the desirable information visualization that would be useful for many people to make informed decisions about energy consumption in their home.

The result was that participants had limited understanding of the relationship between power and energy. However, this limitation was not an obstacle to these participants in managing their home energy in order to save money. Additionally, the statistical relation between participants' understanding and their behavior in management of energy consumption in their home was a positive weak correlation.

Another significant result was that abstract visualization was more beneficial and acceptable than detailed visualization for most of the participants. Particularly, using abstract meter for representing power consumption in the home was better than using a digital visualization meter because of clarity and the attractive display. In addition, some participants believed that adding numerical value to the visualization would have provided more clarity to the representation. In the abstract visualization, some participants indicated that numbers were essential in specific circumstances such as during the current power consumption, display would have been precise with the combination of numbers and abstract visualization.

The result of comparing and contrasting the detailed and abstract visualizations was that there was more similarity in participants' perspectives than differences. In both studies, participants believed that abstract representation was more useful and clear than the numerical representation in visualizing home energy consumption. There were some differences were suggested by the participants. Some participants suggested that moving the variable rate to another location would have been very useful in the abstract visualization, and some participants recommended that including graphs in the detailed visualization would have given the representation more clarity.

Although abstract visualization was more attractive than the detailed visualisation, participants suggested combining it with numbers since that would give more clarity for abstract representation. This is not discussed by this research, so this new issue should be explored in further studies.

## 8.2 Future work:

Having established the base further research could be done to investigate the outcome of using abstract visualization combining it with numerical value as suggested by the participants. In addition, investigation can be made for the best place in the home to display this information, as well as finding the best media to display this information: iPhone, iPad, TV or laptop. And now armed with the knowledge that abstract seems better, perhaps there is a need to explore different abstract visualisations as well as related issues.

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# Appendices

## Appendix A

Ethical Approval

Computing and Mathematical Sciences
*Rorohiko me ngā Pūtaiao Pāngarau*
The University of Waikato
Private Bag 3105
Hamilton
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Phone +64 7 838 4021
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THE UNIVERSITY OF
WAIKATO
*Te Whare Wānanga o Waikato*

8 September 2011

Mohammed Al Mutirui
C/- Department of Computer Science
THE UNIVERSITY OF WAIKATO

Dear Mohammed

**Request for approval to conduct a user study involving human participants**

I have considered your request to conduct a user study for your Masters Thesis project "Energy and power use in the home". The project will study how people understand the concepts of energy and power and the difference between them.

The procedures described in your request are acceptable.

I note your statement that confidentiality and participant anonymity will be strictly maintained. Data gathered will be used for statistical analysis only and no names or other identifying characteristics will be stated in the final or any other reports.

Data will be confidentially stored in the FCMS data archive.

The research participants' information sheet, consent form, and questionnnaire meet the requirements of the University's human research ethics policies and procedures.

Yours sincerely,

**Mike Mayo**
Human Research Ethics Committee
Faculty of Computing and Mathematical Sciences

# Appendix B

**Participant's Workbook**

## *Research Consent Form*

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

**Ethics Committee, Faculty of Computing and Mathematical Sciences**

**(Energy and power use in the home)**

**Consent Form for Participants**

I have read the **Participant Information Sheet** for this study and have had the details of the study explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I also understand that I am free to withdraw from the study before researcher begins analyzing the collected data, or to decline to answer any particular questions in the study. I understand I can withdraw any information I have provided up until the researcher has commenced analysis on my data. I agree to provide information to the researchers under the conditions of confidentiality set out on the **Participant Information Sheet**.

I agree to participate in this study under the conditions set out in the **Participant Information Sheet**.

Signed: ________________________________________________

Name: ________________________________________________

Date: ________________________________________________

Researcher's Name and contact information:

Mohammed Al Mutirui

Email: Mohammed1022@hotmail.com

Supervisor's Name and contact information: (if applicable)

Dr Mark Apperley

Email: m.apperley@cs.waikato.ac.nz

## Initial Questionnaire

Please answer the following general questions to your best ability: (Please circle)

**1.** What is your age group?

**a.** < 20 **b.** 20-29 **c.** 30-39 **d**. 40-49 **e.** >50

**2.** Gender:

**a**. Male **b**. Female

**3.** In what type of home do you live?

**a.** Home **b.** Flat. **c.** 1Bedroom self contained unit. **d.** Studio.

**4.** What is the total number of people in your household?

**a.** 1 **b.** 2 **c.** 3 **d.** > 3

**5.** How many rooms (bedrooms, Living rooms, and kitchen) does your home have?

**a.** 1 **b.** 2 **c.** > 3 (Please specify): ---------------------

**6.** Have you ever take responsibility for paying electricity bills?

**a.** Yes **b.** No

**7.** What is the average cost of your household electricity consumption per month?

**a.** < $50 **b.** $50-$100. **c.** $100-200 **d.** $200-$300 **e.** > $300

**8.** What is the approximate total annual income of all members of your household?

**a.** <$30,000 **b.** $30,000 - $60,000 **c.** $60,000 - $90,000

**d.** $90,000 - $150,000 **e.** > $150,000

**Energy Consumption:**

**9.** While you are cooking dinner, would you expect its energy consumption to remain the same as usual or more energy to be used during that period?

**a.** The same energy consumption will be used.

**b.** More energy consumption will be used.

Could you explain your answer?

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**10.** You have just returned from the supermarket with a load of food which you immediately put into your refrigerator. Over the next hour, would you expect the refrigerator to use more energy than usual, or the same as usual?

**a.** A. The same energy as usual.

**b.** More energy than usual.

Could you explain your answer?

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**11. A.** Your refrigerator has a label that says its rating is 400watts. How much energy might you expect it to use over a 10-hour period?

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**B.** If it used significantly less than this, would you be able to explain why this might be?

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**12.** Can you place the following in order by their total cost of operation, largest (4) to smallest (1)?

**a.** A 20watt light left on for 10 hours; (-------)

**b.** A 1000watt microwave oven used for 6 minutes to heat dinner ;(---)

**c.** A 1500watt electric kettle used for 3 minutes to boil water; (--------)

**d.** A 10 watt mobile phone charger left plugged-in for 24 hours; (-----)

**13.** Consider the following list of appliances:

**a.** An electric blanket rated at 70 watts;

**b.** A vacuum cleaner rated at 1600 watts;

**c.** A laptop computer, whose charger is rated at 80 watts;

**d.** A power saw rated at 2500 watts;

In typical use, which would you expect to contribute the most to your monthly electricity bill? Which you expect to contribute the least? Can you explain your answers?

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**14.** What would you expect to be more efficient; a 2 kW kettle or; a 1 kW kettle, and why?

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**15.** A. Order the efficiency of these heaters; (1) the most efficient to (4) the least efficient.

**a.** Oil heater (…………..)

**b.** Fan heater (…………..)

**c.** Convection heater (…………..)

**d.** Heat pump (…………..)

B. Why have you chosen that ordering?

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**16.** When you raise the thermostat temperature of a heater to warm up a cold room faster; will it use more power? Will it use more energy? (Explain your answers)

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## Managing your electricity consumption:

**17.** Have you ever made any serious attempt to reduce the cost of your electricity bill?

**a.** Yes.

**b.** No.

If yes, which means have you used?

**18.** Have you installed any device or program to monitor your electricity consumption and help you manage it?

**a.** Yes.

**b.** No.

If yes, what sort of device or monitor have you used, and how effective is it?

**19.** Do you check the power rating of an appliance before you buy it?

**a.** Yes.

**b.** No.

If yes, can you explain why?

**20. (i).**What is the main type of heating you use in your home?

**a.** Central heating

**b.** Electric heaters

**c.** Fireplace

**d.** Air-conditioning / Heat pump

**e.** Other. (Please specify):---------------------------------------------------

**(ii)** Do you use any other form of heating for your home?

**a-** Yes. (Please specify): ----------------------------------------------------

**b-** No.

**21.** Do you consciously turn off heaters, electrical appliances and lights when they are not in use?

**a.** Yes

**b.** No

If yes, could you please explain your answer?

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**22.** Do you turn appliances off at the wall instead of leaving them on standby power?

**a.** Yes

**b.** No

If yes, could you please explain your answer?

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**23.** What single appliance do you think consume the most energy in your home?

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**24.** Have you made a censorious effort to reduce the use of any of the following, and why?

**a.** Electric heaters

**b.** TV

**c.** Laptop

**d.** Air-conditioning / Heat pump

**e.** Clothes Dryer

**f.** Dishwasher

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# Appendix C

Ethical Approval

**Computing and Mathematical Sciences**
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THE UNIVERSITY OF
WAIKATO
*Te Whare Wānanga o Waikato*

8 Febuary 2012

Mohammed Al Mutirui
C/- Department of Computer Science
**THE UNIVERSITY OF WAIKATO**

Dear Mohammed

**Request for approval to conduct a user study involving human participants**

I have considered your request to conduct a user study for your COMP594 research project "Power and energy visualization in the home". The project will study the effect of using more detailed information in the visualization of daily energy use in the home.

The procedures described in your request are acceptable.

I note your statement that confidentiality and participant anonymity will be strictly maintained. Data gathered will be used for statistical analysis only and no names or other identifying characteristics will be stated in the final or any other reports.

Data will be confidentially stored in the FCMS data archive.

The research participants' information sheet, consent form, and questionnaire meet the requirements of the University's human research ethics policies and procedures.

Yours sincerely,

**Mike Mayo**
Human Research Ethics Committee
Faculty of Computing and Mathematical Sciences

# Appendix D

**Participant's Workbook**

***Research Consent Form***

**Ethics Committee, Faculty of Computing and Mathematical Sciences**

**(Power and energy visualization in the home)**

**Consent Form for Participants**

I have read the **Participant Information Sheet** for this study and have had the details of the study explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I also understand that I am free to withdraw before the study is commenced on the collected data , or to decline to answer any particular questions in the study. I understand I can withdraw any information I have provided up until the researcher has commenced on my data. I agree to provide information to the researchers under the conditions of confidentiality set out on the **Participant Information Sheet**.

I agree to participate in this study under the conditions set out in the **Participant Information Sheet**.

Signed: ______________________________________________

Name: ______________________________________________

Date: ______________________________________________

Researcher's Name and contact information:

Mohammed Al Mutirui

Email: Mohammed1022@hotmail.com

Supervisor's Name and contact information: (if applicable)

Dr Mark Apperley

Email: m.apperley@cs.waikato.ac.nz

## Initial Questionnaire

Please answer the following general questions to your best ability: (Please circle)

**1.** What is your age group?

**a.** < 20 **b.** 20-29 **c.** 30-39 **d.** 40-49 **e.** >50

**2.** Gender:

**a.** Male **b.** Female

**3.** How long have you been using a computer for?

**a.** < 1 year **b.** 1-5 years **c.** 6-10 years **d.** > 10 years

**4.** For how many hours do you use computers in a typical day?

**a.** . < 1 hour **b.** 1-3 hours **c.** 4-8 hours **d.** > 8 hours

**5.** Have you ever taken responsibility of paying electricity bills?

**a.** Yes **b.** No

**6.** What is the average cost of your electricity consumption per month?

**a.** < $50 **b.** $50-$100 **c.** $100-$150

**d.** > $150

# Tasks and their questionnaires

Please perform the six tasks that are listed below:

## Task 1: Advance the time:

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

In this task, you should advance the time up until the time becomes 8 am or slightly over:

1. Go to the advance time panel at the top of the page.
2. See what the current time is and then calculate how many minutes you need to advance the time until become 8 am or slightly over.

**Questionnaire:**

**7.** How easy was this task?

- **a.** Not at all.
- **b.** Not very easy.
- **c.** Somewhat
- **d.** Very easy
- **e.** Extremely easy

**8.** How clear is the representation of device time panel?

- **a.** Not at all
- **b.** Not very clear
- **c.** Somewhat
- **d.** Very clear
- **e.** Extremely clear.

**9.** When you advance the time until it becomes" 8 am "or slightly over, how many devices are ON?

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**10.** Can you list these appliances according to their proportion of power consumption from the highest consumption (1) to the lowest consumption (3)?

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**11.** How easy was it to distinguish between appliances that were switched ON and appliances that were switched OFF?

**a.** Not at all.

**b.** Not very easy

**c.** Somewhat

**d.** Very easy

**e.** Extremely easy.

**12.** Do you notice any change occure in this representation when you advance the time until it becomes" 8 am "or slight over?

**a.** Yes. (If yes, please specify) **b.** No

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**13.** Do you have any comment about this task?

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## Task 2: Switching kettle on:

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

In this task, you are required to switch the kettle on for 30 minutes. You should do these steps to switch kettle on:

Note: The kettle consumption = 800 Watts

1. Go to the **switch on panel** at the left side of the page.
2. From appliance select **kettle**
3. For **start time** set up the time:
   - Hour = 8
   - Minute = 00
4. For **end time** set up the time:
   - Hour = 8
   - Minute = 30
5. Then click the **switch on button**.

**Questionnaire:**

**14.** How easy was this task?

- **a.** Not at all.
- **b.** Not very easy
- **c.** Somewhat
- **d.** Very easy
- **e.** Extremely easy.

**15.** Three things are affected by switching the kettle ON, could you please write two of these things down?

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**16.** How clear is the representation of the current, total and expected power consumption?

   **a.** Not at all

   **b.** Not very clear

   **c.** Somewhat

   **d.** Very clear

   **e.** Extremely clear.

**17.** How easy was it to use the switch on panel to turn the appliance on?

   **a.** Not at all
   **b.** Not very easy
   **c.** Somewhat
   **d.** Very easy
   **e.** Extremely easy.

**18.** Do you have any comment about this task?

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## Task 3: Switching microwave on

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

Before starting this task, advance the time up until the current time becomes 13:00 or slight over 13:00.

In this task, you should switch the microwave on for one hour.

Note: The microwave consumption = 900 Watts

1. Go to the switch on panel at the left side of the page.
2. From appliance select **microwave**
3. For **start time** set up the time:
   a. Hour = 13
   b. Minute = 00
4. For **end time** set up the time:
   a. Hour = 14
   b. Minute = 00
5. Then click the switch on button.

**Questionnaire:**

**19.** How easy was this task?

- **a.** Not at all
- **b.** Not very easy
- **c.** Somewhat
- **d.** Very easy
- **e.** Extremely easy

**20.** Which appliance do you think consumes the highest proportion of the current power consumption now and why?

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**21.** How many watts are needed until the current power consumption reaches the peak demand which is 5 kW after switching the microwave ON?

**a.** 500 watts

**b.** 1000 watts

**c.** 1500 watts

**d.** 2000 watts.

**22.** How clear is the representation of the peak demand in the current power consumption meter?

**a.** Not at all

**b.** Not very clear

**c.** Somewhat

**d.** Very clear

**e.** Extremely clear.

**23.** Do you have any comment about this task specifically the peak demand representation?

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## Task 4: Switching washing machine on

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

Before commencing this task, advance the time up until the current time becomes 18:00 or slightly over 18:00.

In this task, you should switch the washing machine on for two and a half hours.

Note: The washing machine consumption = 400

1. Go to the switch on panel at the left side of the page.
2. From appliance select washing machine
3. For start time set up the time:
    a. Hour = 18
    b. Minute = 00
4. For end time set up the time:
    a. Hour = 20
    b. Minute = 30
5. Then click the switch on button.

**Questionnaire:**

**24.** How easy was this task?

**a.** Not at all

**b.** Not very easy

**c.** Somewhat

**d.** Very easy

**e.** Extremely easy

**25.** How many appliances are ON?

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**26.** List the names of three appliances that consume the highest power consumption of all working appliances?

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**27.** After switching the washing machine ON, how many watts are needed until the current power consumption reaches the peak demand which is 5 kW?

**a.** 500 -1000 watts

**b.** 1001 - 1500 watts

**c.** 1501 - 2000 watts.

**28.** Do you have any comment about this task?

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## Task 5: Switching dryer ON

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

Please note that if the power goes over (5kW), it will raise the rate per kWh from 0.25 to 0.30 NZD.

Before starting this task, choose one of the appliances that consume more power during its operation and switch it off in order to keep the instantaneous peak below 5 kW.

In this task, you should switch the dryer on for two hours.

Note: The dryer consumption = 2000 Watts

1. Go to the switch on panel at the left side of the page.
2. From appliance select **dryer**
3. For **start time** set up the time:
   a. Hour = 18
   b. Minute = 00
4. For **end time** set up the time:
   a. Hour = 20
   b. Minute = 00
5. Then click the switch on button.

**Questionnaire:**

**29.** How easy was this task?

**a.** Not at all

**b.** Not very easy

**c.** Somewhat

**d.** Very easy

**e.** Extremely easy.

**30.** Which appliance did you chose to switch off and why?

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**31.** Does the current power consumption go over the peak demand of 5 kW after switching dryer on?

**a.** Yes

**b.** No

**32.** Which appliance has the highest power consumption rate of all the working appliances?

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**33.** Do you have any comment about this task?

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## Task 6: Switching four appliance off

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

Before beginning this task, advance the time up until the current time becomes 21:00 or slight over 21:00.
You should look at the appliances in the main display. You will see five appliances that are working.

In this task, you should switch four of these appliances off to keep the daily maximum energy usage at the daily target or below the daily target which is 25 kWh in order to avoid increasing the rate per kWh from 0.25 to 0.30 NZD.

1. Go to the switch off panel at the left side of the page.
2. From appliance ( select one of the appliances that is on and then switch it off)
3. Then click the switch off button

Could you please redo the second and third steps to switch the rest of these appliances off?

Note:

Please advance the time until it becomes 23:50 or slightly over?

**Questionnaire:**

**34.** How easy was this task?

**a.** Not at all

**b.** Not very easy

**c.** Somewhat

**d.** Very easy

**e.** Extremely easy.

**35.** Which four appliances did you chose to switch off?

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**36.** Do you notice any change in the variable rate per kWh, why?

**a.** Yes

**b.** No

**37.** Do you have any comment about this task?

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## Post-Study Questionnaire

**38.** Do you think a display like this would be useful?

**a.** Yes

**b.** No

Why (.......................................................................................................)

**39.** Did you find it useful to know how much power each device used?

**a.** Yes **b.** No

Why (.......................................................................................................)

**40.** Are the pictorial representations better than just number?

**a.** Yes

**b.** No

Why (.......................................................................................................)

**41.** Do you have any overall comment about the power consumption representation?

**a.** Yes

**b.** No

Comment:

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**42.** Could you please suggest other ways of representing both the power consumption and the appliance icons?

**a.** Yes **b.** No

Suggestion:

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# Appendix E

Ethical Approval

**Computing and Mathematical Sciences**
*Rorohiko me ngā Pūtaiao Pāngarau*
The University of Waikato
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Hamilton
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THE UNIVERSITY OF
WAIKATO
*Te Whare Wānanga o Waikato*

3 April 2012

Mohammed Al Mutirui
C/- Department of Computer Science
**THE UNIVERSITY OF WAIKATO**

Dear Mohammed

**Request for approval to conduct a user study involving human participants**

I have considered your request to conduct a second user study for your Masters Thesis project "Power and Energy visualization in the home". The project will study the effect of using less detailed information in the visualization of daily energy use in the home.

The procedures described in your request are acceptable.

I note your statement that confidentiality and participant anonymity will be strictly maintained. Data gathered will be used for statistical analysis only and no names or other identifying characteristics will be stated in the final or any other reports.

Data will be confidentially stored in the FCMS data archive.

The research participants' information sheet, consent form, and questionnaire meet the requirements of the University's human research ethics policies and procedures.

Yours sincerely,

LA Hunt.

pp. **Mike Mayo**
Human Research Ethics Committee
Faculty of Computing and Mathematical Sciences

# Appendix F

**Participant's Workbook**

## *Research Consent Form*

THE UNIVERSITY OF WAIKATO
*Te Whare Wānanga o Waikato*

**Ethics Committee, Faculty of Computing and Mathematical Sciences**

**(Power and energy visualization in the home)**

**Consent Form for Participants**

I have read the **Participant Information Sheet** for this study and have had the details of the study explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I also understand that I am free to withdraw before the study is commenced on the collected data, or to decline to answer any particular questions in the study. I understand I can withdraw any information I have provided up until the researcher has commenced on my data. I agree to provide information to the researchers under the conditions of confidentiality set out on the **Participant Information Sheet**.

I agree to participate in this study under the conditions set out in the **Participant Information Sheet**.

Signed: ________________________________________________

Name: ________________________________________________

Date: ________________________________________________

Researcher's Name and contact information:

Mohammed Al Mutirui

Email: Mohammed1022@hotmail.com

Supervisor's Name and contact information: (if applicable)

Dr Mark Apperley

Email: m.apperley@cs.waikato.ac.nz

## Initial Questionnaire

Please answer the following general questions to your best ability: (Please circle)

**1.** What is your age group?

- **a.** < 20
- **b.** 20-29
- **c.** 30-39
- **d.** 40-49
- **e.** >50

**2.** Gender:

- **a.** Male
- **b.** Female

**3.** How long have you been using a computer for?

- **a.** < 1 year
- **b.** 1-5 years
- **c.** 6-10 years
- **d.** > 10 years

**4.** For how many hours do you use computers in a typical day?

- **a.** < 1 hour
- **b.** 1-3 hours
- **c.** 4-8 hours
- **d.** > 8 hours

**5.** Have you ever taken responsibility of paying electricity bills?

- **a.** Yes
- **b.** No

**6.** What is the average cost of your electricity consumption per month?

- **a.** < $50
- **b.** $50-$100
- **c.** $100-$150
- **d.** > $150

# Tasks and their questionnaires

Please perform the six tasks that are listed below:

## Task 1: Advance the time:

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

In this task, you should advance the time up until the time becomes 8 am or slightly over:

1. Go to the **advance time panel** at the top of the page.
2. See what the **current time** is and then calculate how many minutes you need to advance the time until become **8 am or slightly over**.

**Questionnaire:**

**7.** How easy was this task?

- **a.** Not at all
- **b.** Not very easy
- **c.** Somewhat
- **d.** Very easy
- **e.** Extremely easy.

**8.** How clear is the representation of device time panel?

- **a.** Not at all
- **b.** Not very clear
- **c.** Somewhat
- **d.** Very clear
- **e.** Extremely clear.

**9.** When you advance the time until it becomes" 8 am "or slightly over, how many devices are ON?

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**10.** Can you list these appliances according to their proportion of power consumption from the highest consumption (1) to the lowest consumption (3)?

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**11.** How easy was it to distinguish between appliances that were switched ON and appliances that were switched OFF?

**a.** Not at all

**b.** Not very easy

**c.** Somewhat

**d.** Very easy

**e.** Extremely easy.

**12.** Do you notice any change occure in this representation when you advance the time until it becomes" 8 am "or slight over?

**a.** Yes. (If yes, please specify)

**b.** No

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**13.** Do you have any comment about this task?

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## Task 2: Switching kettle on:

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

In this task, you are required to switch the kettle on for 30 minutes. You should do these steps to switch kettle on:

**Note: The kettle consumption = 800 Watts**

1. Go to the switch on panel at the left side of the page.
2. From appliance select kettle
3. For start time set up the time:
    a. Hour = 8
    b. Minute = 00
4. For end time set up the time:
    a. Hour = 8
    b. Minute = 30
5. Then click the switch on button.

**Questionnaire:**

**14.** How easy was this task?

**a.** Not at all

**b.** Not very easy

**c.** Somewhat

**d.** Very easy

**e.** Extremely easy.

**15.** Three things are affected by switching the kettle ON, could you please write two of these things down?

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**16.** How clear is the representation of the current, total and expected power consumption by using network monitor live visualization?

**a.** Not at all

**b.** Not very clear

**c.** Somewhat

**d.** Very clear

**e.** Extremely clear.

**17.** Which of these units is relevant to the current power consumption meter?

**a.** kW

**b.** kWh

**18.** Which of these units relates to the total power consumption meter?

**a.** kW

**b.** kWh

**19.** How easy was it to use the switch on panel to turn the appliance on?

**a.** Not at all

**b.** Not very easy

**c.** Somewhat

**d.** Very easy

**e.** Extremely easy

**20.** Do you have any comment about this task?

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## Task 3: Switching microwave on

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

Before starting this task, advance the time up until the current time becomes 13:00 or slight over.

In this task, you should switch the microwave on for one hour.

Note: The microwave consumption = 900 Watts

1. Go to the switch on panel at the left side of the page.
2. From appliance select microwave
3. For start time set up the time:
    a. Hour = 13
    b. Minute = 00
4. For end time set up the time:
    a. Hour = 14
    b. Minute = 00
5. Then click the switch on button.

**Questionnaire:**

**21.** How easy was this task?

- **a.** Not at all
- **b.** Not very easy
- **c.** Somewhat
- **d.** Very easy
- **e.** Extremely easy.

**22.** Which appliance do you think consumes the highest proportion of the current power consumption now and why?

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**23.** How many bars are needed until the current power consumption reaches the peak demand which is highlighted by a blue vertical line after switching the microwave ON?

- **a.** Zero
- **b.** One
- **c.** Two
- **d.** Three

**24.** How clear is the representation of the power limit in the current power consumption meter?

- **a.** Not at all
- **b.** Not very clear
- **c.** Somewhat
- **d.** Very clear
- **e.** Extremely clear.

**25.** Do you have any comment about this task specifically the peak demand representation?

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## Task 4: Switching washing machine on

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

Before commencing this task, advance the time up until the current time becomes 18:00 or slightly over.

In this task, you should switch the washing machine on for two and a half hours.

Note: The washing machine consumption = 400

1. Go to the switch on panel at the left side of the page.
2. From appliance select washing machine
3. For start time set up the time:
   a. Hour = 18
   b. Minute = 00
4. For end time set up the time:
   a. Hour = 20
   b. Minute = 30
5. Then click the switch on button.

**Questionnaire:**

**26.** How easy was this task?

**a.** Not at all

**b.** Not very easy

**c.** Somewhat

**d.** Very easy

**e.** Extremely easy.

**27.** How many appliances are ON?

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**28.** List the names of three appliances that consume the highest power consumption of all working appliances?

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**29.** After switching the washing machine ON, how many bars are needed until the current power consumption reaches the peak demand which is highlighted by a blue vertical line?

**a.** Zero

**b.** One

**c.** Two

**d.** Three

**30.** Do you have any comment about this task?

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### Task 5: Switching dryer ON

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

Please note that if the power goes over the power limit, it will raise the rate per kWh from normal to maximum NZD.

Before starting this task, choose one of the appliances that consume more power during its operation and switch it off in order to keep the current power below the peak demand which is highlighted by a blue vertical line.

In this task, you should switch the dryer on for two hours.

Note: The dryer consumption = 2000 Watts

1. Go to the switch on panel at the left side of the page.
2. From appliance select dryer
3. For start time set up the time:
    a. Hour = 18
    b. Minute = 00
4. For end time set up the time:
    a. Hour = 20
    b. Minute = 00
5. Then click the switch on button.

**Questionnaire:**

**31.** How easy was this task?

  **a.** Not at all

  **b.** Not very easy

  **c.** Somewhat

  **d.** Very easy

  **e.** Extremely easy.

**32.** Which appliance did you chose to switch off and why?

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**33.** Does the current power consumption go over the peak demand after switching dryer on?

  **a.** Yes

  **b.** No

**34.** Which appliance has the highest power consumption rate of all the working appliances?

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**35.** Do you have any comment about this task?

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### Task 6: Switching four appliance off

**Note:**

You should check what the current time is, how many devices are ON, what the current power consumption, total power consumption and the expected power consumption are before each task.

Before beginning this task, advance the time up until the current time becomes 21:00 or slight over.

You should look at the appliances in the main display. You will see five appliances that are working.

In this task, you should switch four of these appliances off to keep the daily maximum energy usage at the daily target or below the daily target which is highlighted by a blue vertical line in order to avoid increasing the rate per kWh from normal charge to maximum charge.

1. Go to the switch off panel at the left side of the page.
2. From appliance ( select one of the appliances that is on and then switch it off)
3. Then click the switch off button

**Could you please redo the second and third steps to switch the rest of these appliances off?**

Note:

Please advance the time until it becomes 23:50 or slightly over?

**Questionnaire:**

**36.** How easy was this task?

**a.** Not at all

**b.** Not very easy

**c.** Somewhat

**d.** Very easy

**e.** Extremely easy.

**37.** Which four appliances did you chose to switch off?

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**38.** Do you notice any change in the variable rate per kWh, why?

**a.** Yes

**b.** No

**39.** How clear is the representation of the variable rate per kWh?

**a.** Not at all

**b.** Not very clear

**c.** Somewhat

**d.** Very clear

**e.** Extremely clear.

**40.** Do you have any comment about this task?

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## Post-Study Questionnaire

**41.** Do you think a display like this would be useful?

**a.** Yes

**b.** No

Why (......................................................................................................)

**42.** Did you find it useful to know how much power each device used?

**a.** Yes

**b.** No

Why (......................................................................................................)

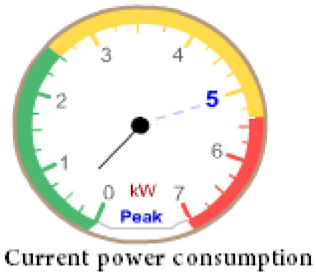
**43.** Are the pictorial representations better than just number?

**a.** Yes

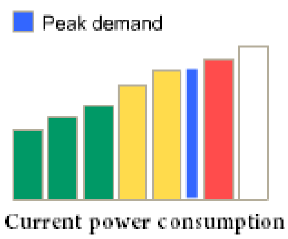
**b.** No

Why (.....................................................................................................)

**44.** Which of the two figures below is better for visualizing the power consumption, why?




**A**




**B**

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**45.** Which of two figures is better for visualizing the power rate, why?



**A** **B**

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**46.** Do you have any overall comment about the power consumption representation?

**a.** Yes

**b.** No

Comment:

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**47.** Could you please suggest other ways of representing both the power consumption and the appliance icons?

**a.** Yes

**b.** No

Suggestion:

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