NO102/3

Waitakere NOW Home® Performance Monitoring: Year One Report

Final

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About This Report

Title

Waitakere NOW Home® Performance Monitoring: Year One Report

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Reference

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1 Introduction

This report summarises the learning from the first full year of occupancy of the first NOW Home® in Olympic Place, Waitakere City. The intent of the project is discussed, and findings presented, under broad categories of Resource Use and Indoor Environment and Occupant Perspectives. Analysis is presented giving insight into how this positions the NOW Home's performance in a national context. The mechanics of the project monitoring are also discussed.

1.1 The Waitakere NOW Home®

Developed during 2003-2004 by a co-operative team, key members of which later went on to catalyse the formation of Beacon, the NOW Home® is a house building approach or concept for sustainable houses (specifically targeted at the 'post-Kyoto' era of 2012-2015). However, it was constrained in that it could only utilise materials/technologies which were currently available or able to be achieved today. Costs were also to be in alignment with current new construction costs or below.

During the design of the Waitakere NOW Home®, the design process and key sustainability balancing factors were captured and distilled into a Design Protocol, which formed the basis of subsequent NOW Homes®. The essence of this Protocol is to enable the shaping of each NOW Home® to its owner's specific priority while ensuring that it remains sustainable.

The Waitakere NOW Home® is not a show home, but physically demonstrates current best knowledge and practice (with current proven technologies) in one possible solution. It is designed with the 'average' New Zealander in mind, rather than as a social housing project or for the higher income customer who could use the expertise of an architect or expert in this field. The first NOW Home®, although affordable, is an aspirational 'stretch' target. It is something which is within reach for the median household income (at the time of building) of $NZD48,500, but prospective owners would still need to save and work quite hard towards obtaining the 10-20% deposit required for a mortgage.

1.1.1 The dwelling

Figure 1: The Waitakere NOW Home®

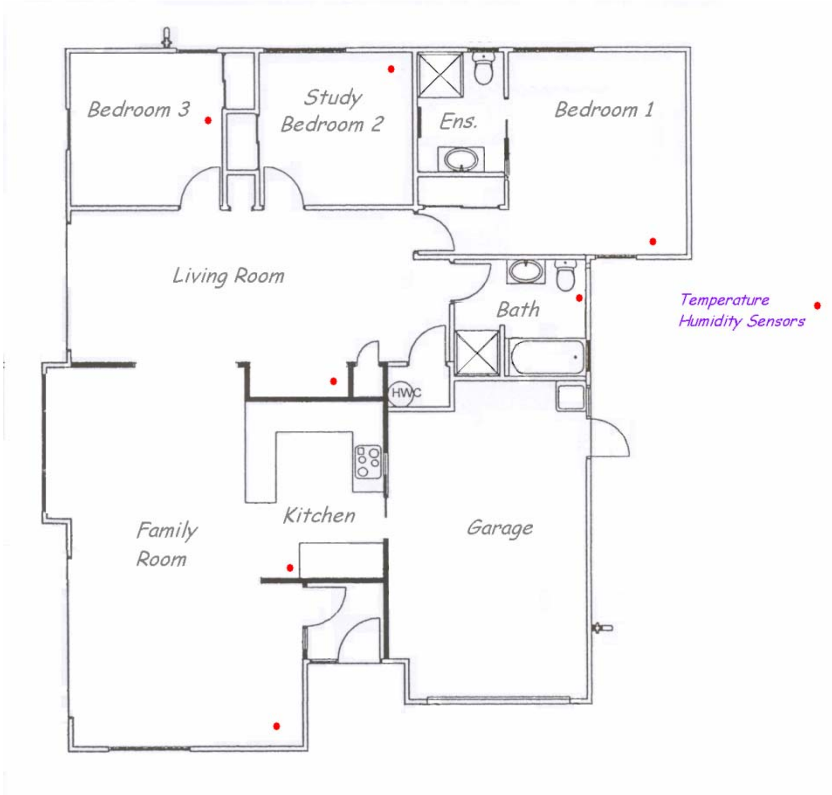


Figure 2: Floor plan of the Waitakere NOW Home® (north is to the left)

The Waitakere NOW Home® uses timber weatherboards fixed to a timber frame on a heavily-insulated concrete slab. The roof is concrete tile and the ceilings and walls are heavily insulated. The entire building is double glazed.

The building is sited to maximise the benefits of passive solar heating, using the highly insulated envelope to trap and retain the sun's warmth – mainly via the polished (no carpets) concrete slab. Passive ventilation is incorporated in the design to facilitate air changes without creating draughts, which is important for a healthy indoor environment.

A solar water heater is installed on the roof and a water tank collects from the roof. The tank water is used for non-potable water needs within the house. All light fittings are high-efficiency compact fluorescent types (where possible – for some fittings they are not available).

The majority of the appliances belong to the tenants. However the range, fridge, dishwasher and washing machine are new efficient items supplied as chattels.

1.1.2 The household

The Waitakere NOW Home® has been occupied since September 2005 by a family of four (two adults, two children). The two children are of pre-school age.

There have been quarterly post-occupancy evaluation (POE) survey visits which take about half to three-quarters of an hour. These are to capture the occupants' experiences compared to the previous house they lived in.

2 Monitoring the NOW Home®

2.1 Objectives

The NOW Home® Design Protocol broke down the process of rating the sustainability of the residential built environment into the following key attributes, which could be balanced with the owner's priorities:

- **Affordability** – capital cost, fuel and electricity costs over life of building, water and waste-water cost, maintenance and operating costs
- **Desirability** – ergonomics, aesthetics, resale potential, functionality, marketability
- **Performance** – structure, durability, quality, weatherproofing, ability to meet future needs – design flexibility
- **Personal well-being** – injury prevention, indoor pollution, moisture, crime prevention, temperature, light, noise, air quality, fire protection, accessibility
- **Community well-being** – urban design, privacy, transport, employment, neighbourhood character
- **Environmental well-being** – air emissions, waste generation, material manufacture, resource renewability, resource sustainability, toxicity, water and waste resource management
- **Energy** – amount of energy used in the home, amount of energy used in materials manufacture and transportation, and type of energy used (renewable versus non renewable).

The monitoring programme reported upon here is intended to verify (or otherwise, which will lead to further opportunities for development) the design solutions arrived at during the process of establishing the NOW Home® protocol. At that time, targets were set for the operational performance of the Waitakere NOW Home®, aligned wherever practicable with the seven key sustainability attributes given above. These have since been modified to draw out some of the less obvious issues such as adaptability for future use.

Table 1: Key performance areas which are monitored

Key Performance Area	Features (examples)	Benefits (examples)	Measurable Indicator (examples)
Energy	Passive solar design Solar hot water Ceiling, wall & floor insulation Multi-pane windows Low-energy light bulbs Energy-efficient appliances	Health Warmth Comfort Affordability (in terms of lowering running costs)	Indoor temperature Measured energy consumption Power bills
Water	Rainwater tank Dual-flush toilet Water-efficient appliances	Future security Lower cost	Water – litres consumed per person per dwelling
Indoor Environment Quality	Natural ventilation Low VOC levels	Health Comfort	Rates of asthma
Waste	Minimise building waste Recycling	Cost efficiency	Construction waste to landfill % of home waste to landfill
Materials	Recycled timber	Cost efficiency Health	Life-cycle assessment

The results of the monitoring and information gained can be useful to a wide range of building industry groups including manufacturers, to provide information on the marketability and benefits of sustainable products and systems and for the regulator, to gain a glimpse of what may be achievable when sustainability is implemented at Building Code level.

2.2 Other Information Sources

No other studies of sustainability in houses cover the full range of issues that are being examined in the NOW Homes® and few studies which include measured, verifiable data. There are however some very important studies which assess aspects of the sustainability of houses, in particular the Household Energy End-Use Project (HEEP) study which provides important information on residential energy use and indoor temperatures. A brief introduction to HEEP is provided below

The HEEP project is a multi-year, multi-discipline research project that has involved detailed energy and temperature monitoring, occupant surveys and energy audits of some 400 randomly selected New Zealand houses.

All fuel types encountered within each house were monitored and included electricity, natural gas, LPG, coal and wood.

The method of monitoring for HEEP involved the installation and monthly downloading of electronic dataloggers to record the energy and temperature patterns at 10 minute intervals.

Measurements were undertaken on the random set of 400 houses between 1999 and 2005. The majority (74%) of houses had the total for each fuel and the domestic hot water (DHW) heater monitored. In the remaining 26% of houses, detailed end-use monitoring of all significant fuel use was undertaken. For more detailed information on the HEEP study Appendix A.

2.3 Data Collection

Measurements for the Waitakere NOW Home® include:

- Surveyed items such as inspections of the physical properties of the house (area of windows, wattage of water heater etc);
- Post occupancy evaluations of the occupants;
- Dynamic physical measurements of resource use (electricity and water use);
- Environmental factors affecting the house (outdoor temperature, humidity and solar radiation);
- The use of services within the house (for example, the use of lights, hot water for showering, or use of the dishwasher); and
- The resulting environment within the house (room temperature and humidity, family room CO_2 levels).

It was decided to collect end-use information for both the electricity and water use. An electricity meter was assigned to each major electrical channel (eight meters in total) and a water meter for each water end-use (24 meters). Temperature and humidity were measured in each room as well as CO_2 in the living room. The water temperatures, solar radiation and water flows for the solar water heater were also measured.

The large range of physical information obtained makes collecting individual channels (or even groups of channels) with self-contained data loggers impractical as the process of collecting and merging data together is very difficult. Instead a central data acquisition system (comprising a desktop computer, an Agilent datalogger and a Point 6 radio sensor network) was used. The components of this system were predominantly located in the hot water cupboard. This system is described in detail in Appendix B: Data Collection.

2.4 Analytic Approach

There is a considerable amount of information collected from the Waitakere NOW Home® so it has been important to collect the data and put in place a good management structure to the database holding all the measurement data. An overall approach to the data analysis has been to examine the data over differing time periods to highlight any differences due to differing physical and social factors.

To ensure the measurements and information from the analysis have context, the Waitakere NOW Home® protocols initially, and more recently Beacon's HSS High Standard of Sustainability® (HSS®) (Easton 2006), have been used to provide targets against which to assess this NOW Home®. They will also be used for the Rotorua NOW Home® and other future NOW Homes®.

There are measurements in the Waitakere NOW Home® which can be compared to other studies but there are also a number of measurements which are unique. HEEP data and information has extensively measured residential energy use and temperatures. The method used to examine the Waitakere NOW Home® performance for this report uses this data (see section 2.4.1).

Water use is a topic with a high degree of interest at present. Data sources, against which the Waitakere NOW Home® can be assessed in future, while not yet available, are being created. The BRANZ, Water End-Use and Efficiency Project (WEEP) (Heinrich 2006) will improve the understanding of water end-uses. However, the best overall water use information is from water services companies and local and regional government.

The occupant survey was built upon the findings of the Queensland Research House (Barnett and Buys) and looked to employ a minimally intrusive quarterly survey. The survey looks to examine the occupants' experiences with the Waitakere NOW Home® using social systems-based 'differences and effects' questions.

Information on the indoor environment is limited. While HEEP has included the measurements of indoor temperature (and these are compared in this report), there have been limited studies of relative humidity (RH) or CO_2 concentrations in New Zealand houses and this work is largely exploratory.

Standard statistical approaches were applied to the dataset to address any gaps in the data prior to analysis. Care was taken when interpreting results so as to not exceed the capacity of the dataset in reporting of findings. The challenges the project addressed in monitoring an occupied home so intensely have been documented elsewhere (Pollard (2007))

2.4.1 Matched samples

The HEEP data provides a range of data on energy and temperatures. One way to compare the energy and temperatures measured in the Waitakere NOW Home® with those measured in HEEP is to identify groups of the HEEP houses which have similar characteristics to the NOW Home®. Comparing the different groups with the Waitakere NOW Home® data, the relative performance of the NOW Home® can be assessed.

The following characteristics would be useful to examine:

- Dwelling size
- Dwelling location
- Dwelling age
- Household size
- Household income
- Household life stage (expressed as age of youngest occupant).

The contrast for the dwelling age was between new and recently constructed houses compared to the current stock. The house age information in HEEP was asked in two questions: one which provided age bands (before 1978, 1978-1996 etc); the other was the actual age. As the actual age was frequently unknown, the recently constructed group was taken as built since 1996.

While a multitude of combinations of these characteristics can be constructed, five groups were examined for this report

- Group 1 houses constructed after 1996
- Group 2 houses constructed after 1996 with a household of four occupants with pre-school age children
- Group 3 houses with a household of four occupants with pre-school age children
- Group 4 houses constructed after 1996 located in Auckland
- Group 5 houses constructed after 1996 located in a wider Auckland area (including the Awhitu, Orewa and Parawai HEEP clusters).

3 Resource Use

Minimising resource use is a cornerstone of sustainability. In the Waitakere NOW Home® the use of energy and water is carefully measured. In order to improve understanding, the contributing end-uses are separated out.

3.1 Energy Use

Figure 3 shows the mean daily purchased energy (which was electricity) consumption used by the Waitakere NOW Home® along with a smoothed curve through the data. Overall the annual purchased energy consumption for the NOW Home® is estimated at 20.3 kWh per day which is equivalent to 7400 kWh per year.

Figure 3: Mean daily purchased energy (electricity) consumption for the Waitakere NOW Home®

In addition to the energy usage shown in Figure 3, the monitoring equipment used in the Waitakere NOW Home® used another 4.0 kWh per day. While this energy is not attributable to the energy services used by the occupants, it does provide an appreciable heating load into the hot water cupboard within the house. The benefit of this heating load generated by the monitoring equipment is minimal, so has not been taken into account in the energy analysis reported.

The occupants of the Waitakere NOW Home® provided their electricity company records for the previous year of the house they rented before moving into the NOW Home®. Figure 4 provides a comparison of the electricity use between the Waitakere NOW Home® and the previous home. It shows a significant reduction in the amount of electricity used, with the NOW Home® using 45% less electricity than the previous home.

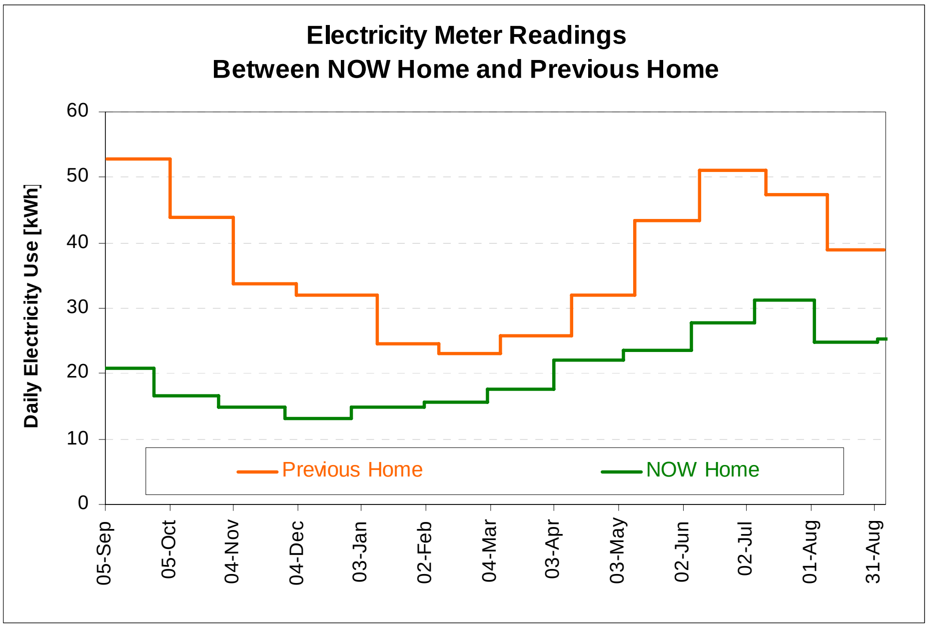


Figure 4: Comparison of daily electricity consumption between the Waitakere NOW Home and previous residence

The daily electricity consumption calculated from the monthly meter readings from the Waitakere NOW Home® and the preceding year at the previous property rented by the NOW Home occupants

The difference between the highest monthly consumption and the lowest monthly consumption in the Waitakere NOW Home® is 18.2 kW per day, whereas for the previous home it was 29.7 kWh per day. The ratio of the maximum (winter) to the minimum (summer) of the monthly consumption for both the NOW Home® and the previously occupied home was surprisingly similar, being approximately 2.4 and 2.3 kWh.

These ratios are so similar because the passive solar design and solar water heater of the Waitakere NOW Home® are contributing influences on the seasonal energy use. However, they work in opposite directions. The passive solar design in the NOW Home® has primarily been designed to reduce the winter-time space heating, a task which it has been performing well. The solar water heating provides its best performance in summer with the electric boosting of the water heating occurring predominantly in winter.

This is important from a national perspective because energy demand and the risk of supply constraints (due to low inflows into the hydro lakes) are high in winter, raising an interesting question of how best to minimise increased winter residential energy use. The Waitakere NOW Home® indicates that solar hot water systems may not greatly improve the winter-based scenario.

Beacon's HSS® (Easton 2006) provides a range of reference marks against which to assess the performance of the Waitakere NOW Home®. The HSS® energy performance benchmarks are for reticulated energy use (electricity and natural gas) rather than total energy use and, as such, do not include solid fuel heating or portable LPG gas heating so an initial comparison with reticulated energy is made.

For the Waitakere NOW Home®, the only energy type used is electricity so the value for the reticulated energy use and total energy use is the same. The measured energy use of the Waitakere NOW Home® has been higher than initially expected and lies between the level for the HSS®(2006) and the NOW Home® target as seen in Table 2.

Target	Annual Reticulated Energy Use (kWh)
NOW Home	6000
HSS High Standard of Sustainability®	7600
Current Building Code	10000
Measured NOW Home	7400

Table 2: Benchmarks from the draft Beacon High Standard of Sustainability for reticulated energy use for new construction in climate zone 1
(Easton 2006)

To examine the energy performance of the Waitakere NOW Home® against measured data, a number of matched sample groups of HEEP data were examined. The groups discussed in section 2.4.1 were used, the sample size of which are shown in Table 3. Figure 5 displays the individual reticulated energy use for each house in these groups along with the group mean. The benchmarks of Table 2 are also shown as horizontal lines.

Group	Description	Size
Group 1	houses constructed after 1996	29
Group 2	houses constructed after 1996 with a household of four occupants with pre-school age children	2
Group 3	houses with a household of four occupants with pre-school age children	23
Group 4	houses constructed after 1996 located in Auckland	8
Group 5	houses constructed after 1996 located in a wider Auckland area (including the Awhitu, Orewa and Parawai HEEP clusters)	13

Table 3: HEEP subset group definitions

Group 1, houses constructed after 1996, has the most cases and is quite widespread. The Waitakere NOW Home® is in the low to middle range of this group. Group 2, which is the group of houses constructed after 1996 with a household size of four with pre-school aged children (a similar household to the NOW Home®), has only two cases and both are of similar value – much higher than the Waitakere NOW Home®. Group 3, which is all ages of houses which have a similar household to the NOW Home®, has one case which is very high but the remaining group is more clustered. The Waitakere NOW Home® is again in the lower to middle part of this group. Groups 4 and 5 reflecting houses built after 1996 in the Auckland or near Auckland regions are widespread and similar to the Group 1 cases.

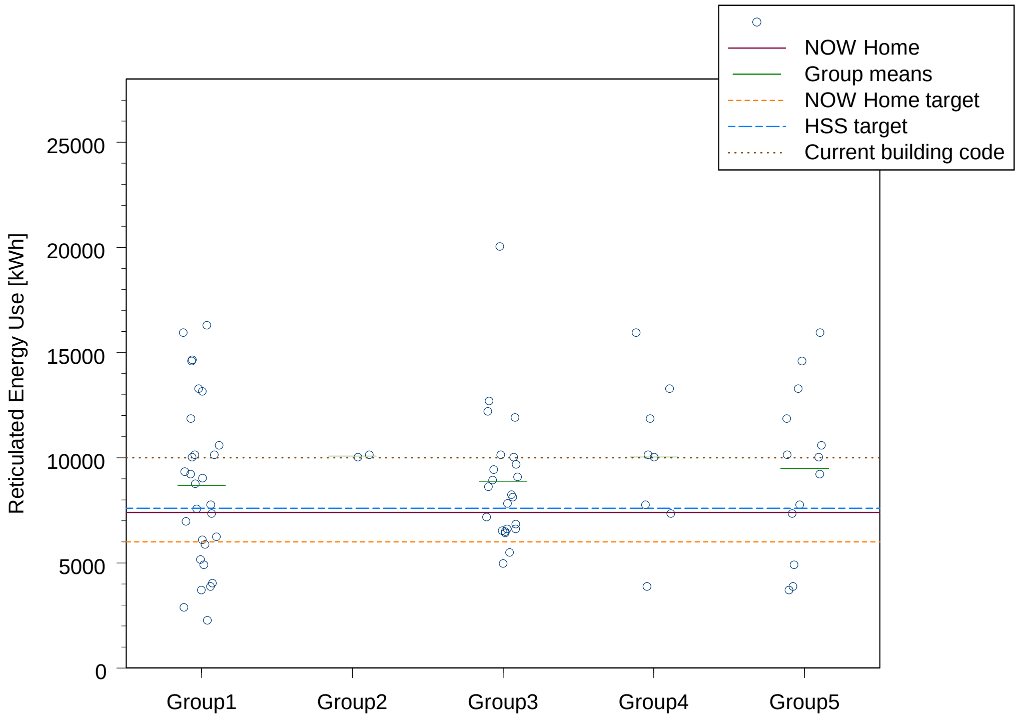


Figure 5: Total reticulated energy use for the Waitakere NOW Home® compared to the reticulated energy use of a number of groupings of HEEP data.
The data for each grouping has been 'spread' out in the x-axis direction so that points with similar values are more easily distinguished

When all fuel types are considered (Figure 6), the total energy distributions for each group are more varied, presumably due to the large variation in space heating energy use which is frequently from non-reticulated energy sources such as solid fuel burners. The Waitakere NOW Home's measured total energy usage is unchanged (because it is solely electric) from the reticulated energy use.

However the total energy use of the HEEP groups has increased, improving the relative performance of the NOW Home® into the lower ranges of each of the groups. The improvement against Group 3 (similar household regardless of age) is the most apparent. The Waitakere NOW Home® energy use is now at the bottom of the range of two groups, one being Auckland houses built after 1996, and the other being houses with a similar household to the NOW Home® also built after 1996. There are a number of houses built after 1996 which have lower energy consumption than the Waitakere NOW Home®. The likely reason for this is lifestyle and occupancy choice rather than performance.

Based on the HEEP data, the Waitakere NOW Home®'s total energy consumption could be said to perform well against new houses in the Auckland region (Group 4) as well as against four person households with pre-school age children (Group 3) where the average savings are approximately 33%.

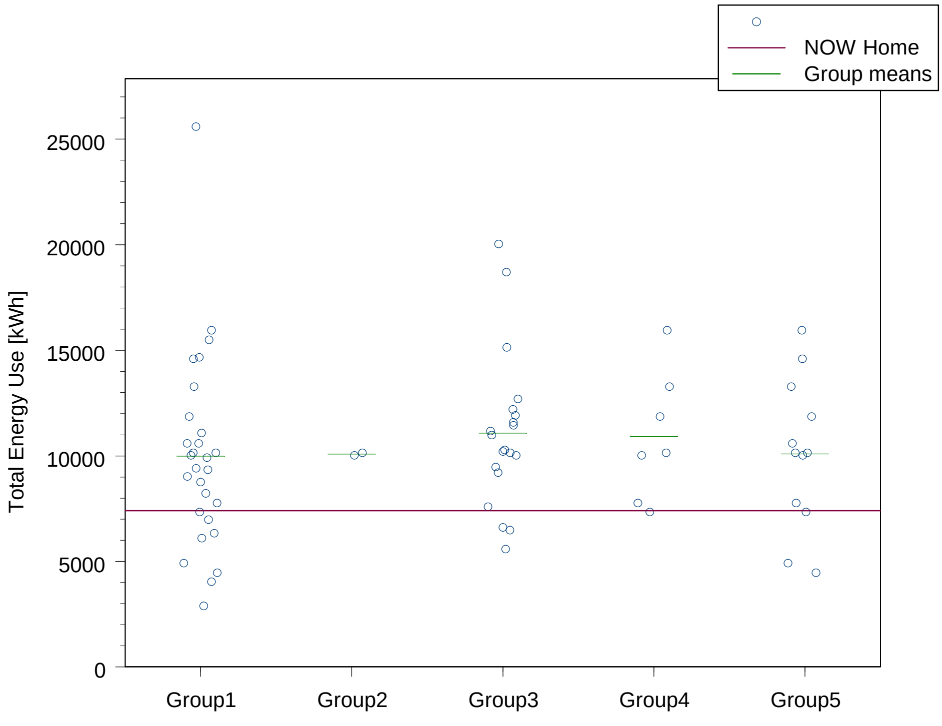


Figure 6: Total energy use for the Waitakere NOW Home® compared to the total energy use (i.e. includes solid fuel) for a number of groupings of HEEP data

3.1.2 Energy end-uses

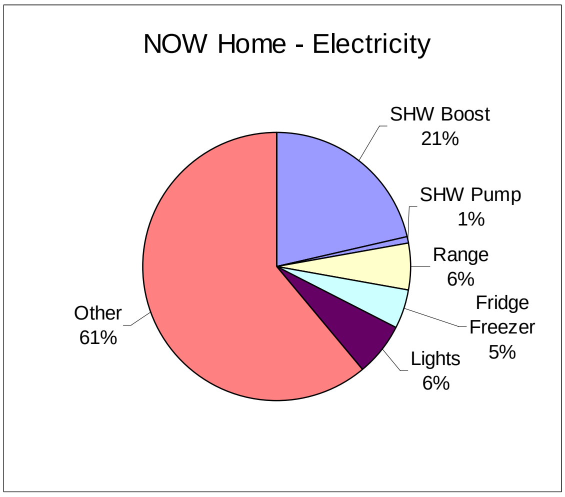
The focus on the monitoring of energy end-uses was on the 'fixed' appliances and services such as the solar water heating, range, lights, refrigerator freezer, dishwasher and the water pump for the rain tank water. This was primarily because it was anticipated the fixed appliances would be the higher users of energy and hence energy efficient appliances were installed.

Figure 7 shows the purchased electricity breakdown for the Waitakere NOW Home® alongside the average breakdown of energy use for appliances taken from the HEEP Year 10 report (Isaacs et al 2006). For the sake of comparison only the end-uses matching the HEEP categories have been used. A more complete end-use breakdown for the NOW Home® is shown in Figure 8.

The fridge freezer only used 5% of the total energy – one-third of the electricity compared to the HEEP sample. The reason for this significant difference is likely to be the fact there is only one refrigeration appliance in the Waitakere NOW Home® compared to the HEEP national average of 1.7 appliances per home. Also, it is a new fridge so is unlikely to be one of the 20% of fridges in New Zealand that are faulty or about to fail. The low energy consumption of refrigeration in the Waitakere NOW Home® shows that while particular appliance groups (i.e. refrigeration) may be important nationally, other appliances may be of similar energy importance for specific houses. For the Waitakere NOW Home® the dishwasher in the house used 6% of the total energy, more energy than the refrigerator.

While the ‘range’ energy use in the Waitakere NOW Home® is similar in proportion to the HEEP sample, the hot water (using solar water heating) heating (no measured electrical heating), lighting and refrigeration are all reduced in proportion in the NOW Home®. This has consequently increased the ‘other’ category to a very large proportion – 61% of electrical energy use.

The more complete breakdown in Figure 8 provides some reduction in this ‘other’ category by including the dishwasher, the water pump and the washing machine. However the remaining ‘unknown’ energy use is still over half of the energy use (53%).



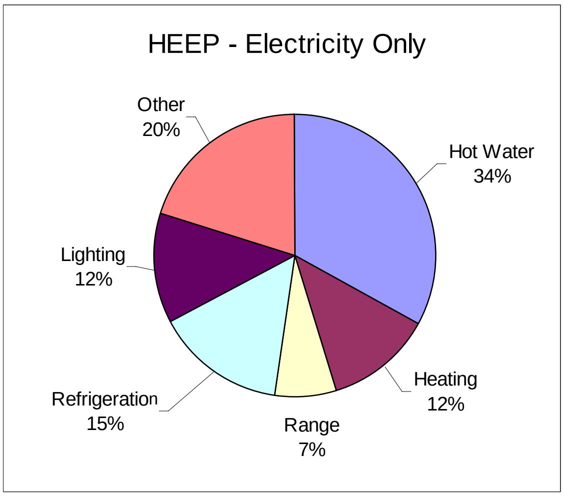


Figure 7: Breakdown of electrical energy for the Waitakere NOW Home® and for HEEP

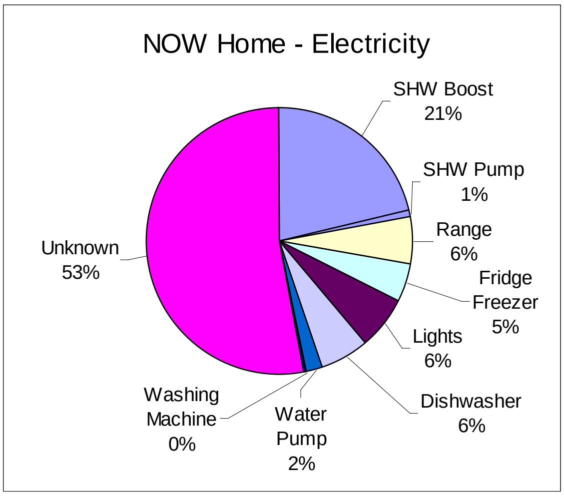


Figure 8: All electrical energy end-uses in the Waitakere NOW Home®

The large size of the 'unknown' category is of concern and more work is required to examine this. The occupants of the Waitakere NOW Home® have a number of computer and entertainment appliances that will be contributing to this 'unknown' load.

High seasonal variation in purchased energy use is typically expected from appliances such as water heating and lighting. Figure 9 shows this seasonal variation and the daily energy use for lighting over the course of a year. The scatter in the data about the smoothed line is high, indicating that there is much day-to-day variation in the lighting use.

For future reporting, statistical analysis of the lighting usage and, in particular, the large variation will be examined in greater detail.

Figure 9: Daily energy use for the Waitakere NOW Home® lighting

3.1.3 Solar water heating

The Waitakere NOW Home®'s solar hot water (SHW) system is saving a significant amount of energy. The HEEP houses used, on average, 3260 kWh of their electricity for hot water, while the Waitakere NOW Home® used half that amount (1640 kWh including the pump energy).

Figure 10 shows the estimate for the solar water heater boost element alongside the total electrical energy use for the Waitakere NOW Home®. This shows that little electrical boosting is required during summer, but that a large proportion of the increased winter energy use is likely to be attributed to the increased water heating need.

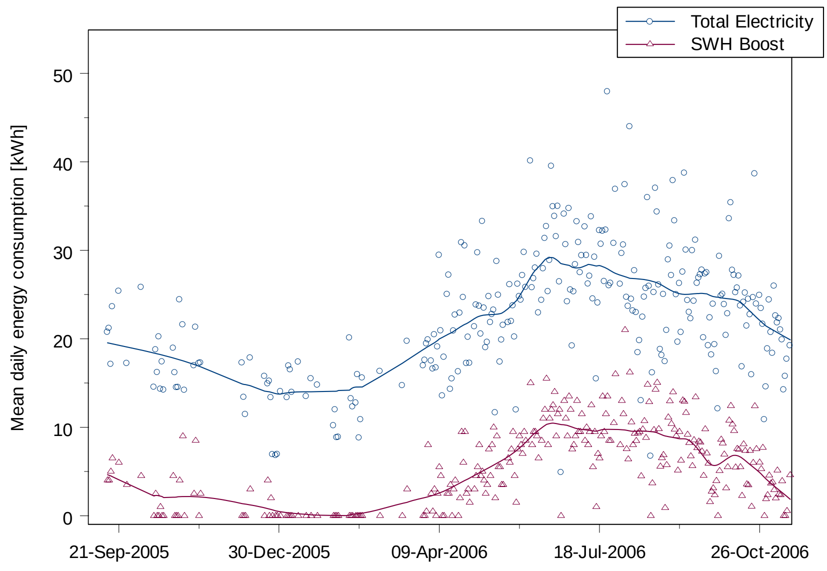


Figure 10: Comparison of the total electricity use and the energy use by the SWH boost element

The next step to further analyse the solar hot water heating is to calculate an energy balance of the system to determine the solar contribution as distinct from the standing losses and water draw-off. This will be completed and reported on at the completion of Year 2

3.2 Water Consumption

The Waitakere NOW Home® water data is a valuable source of information despite being a single home.

The Waitakere NOW Home® has each water end-use directly metered (see the arrangement of water meters in 10). This means a total of 24 separate meters are being monitored in the Waitakere NOW Home®, which was the best solution at the time it was built. However, since the construction of the Waitakere NOW Home®, BRANZ has carried out a pilot study WEEP project already mentioned (Heinrich 2006). This project uses high accuracy water meters and disaggregation software to estimate the water end-uses so only one meter is needed per house.

3.2.1 Total use

The following table (Table 4) shows the amount of water used in the Waitakere NOW Home® from the two different sources – the street water main and the rainwater tank for the first year of monitoring.

Water Use		
	L/day	**L/person/day**
Street main	402	100
Water tank	353	88
Total (L/p/d)	**755**	**189**

Table 4: Total amount of water used in the first year of the Waitakere NOW Home®

The rainwater tank is therefore providing for approximately 47% of the water needs of the Waitakere NOW Home® occupants. Beacon's HSS® (Easton 2006) provides a target of 180 litres per person per day (L/p/d) so that the NOW Home®'s reticulated water use of 100 L/p/d is well below this figure and only one-third of the Ministry of Health's (Easton 2006) estimate of 300 L/p/d.

If total water usage is considered the Waitakere NOW Home®'s 189 L/p/d is still 37% below the Ministry of Health's average estimates.

3.2.2 Time of day profiles

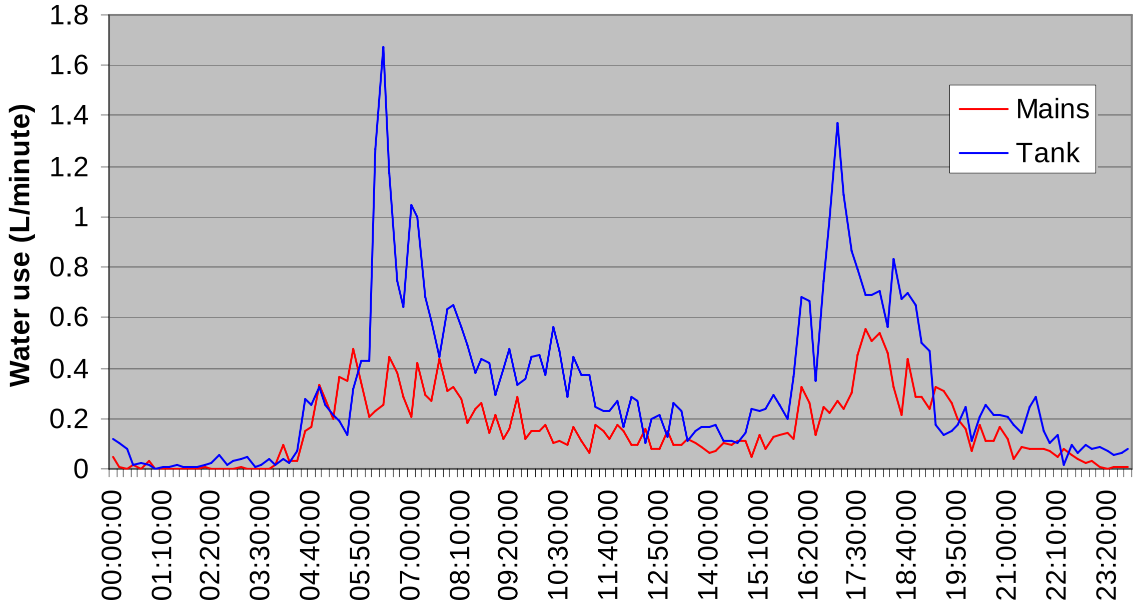


Figure 11: Time of day profile

From Figure 11, it can be seen that the majority of water from both sources (tank and mains) is highest in the morning between 5:30 and 8:30 and in the afternoon from 16:00 to 20:00. Not surprisingly minimal flow is observed after midnight.

3.2.3 *Proportion of end-use*

Figure 12 shows the daily distribution of end-uses for the whole monitoring period. It can be seen that the main uses of showering occur predominantly in the morning from 4:00 to 8:00 and in the evening from 16:00 to 18:00. The peak use for the shower occurs during 6:00 and 6:30.

The use of water for irrigation, which is the second highest use in the summer period, occurs mainly during the evening from 17:00 until 20:00. The kitchen tap is mainly used in the evening from 16:00 to 18:00 and the main use of the bathroom tap also occurs during this time. Around 17:00 is the peak use for the dishwasher and the bath. This does not mean the bath and shower are both being used at the same time. The more likely scenario is sometimes one or some of the occupants (most likely the children) have a bath instead of a shower.

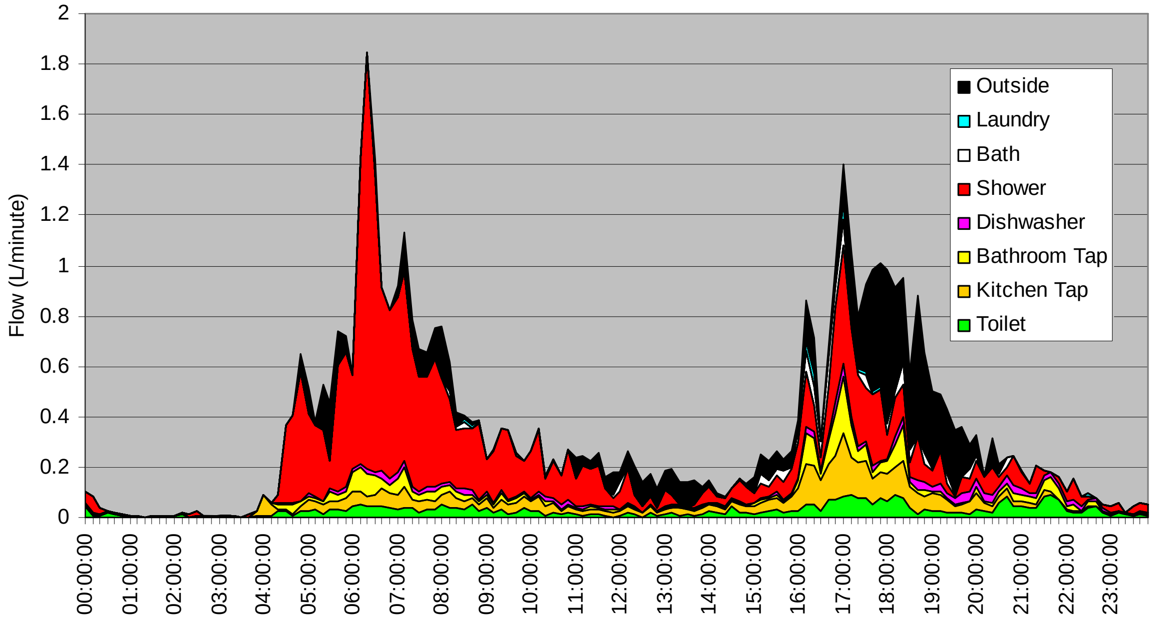


Figure 12: Daily profile of end-uses – stacked

3.2.4 Seasonal end-use distribution

The end-uses for each of the two seasons are given in the graphs below. The highest summer end-use is the shower (37%), followed by outside uses (34%). The total tap use of 15% (6% bathroom and 9% kitchen) makes up the third highest use. The toilet accounts for only 7% of the total uses.

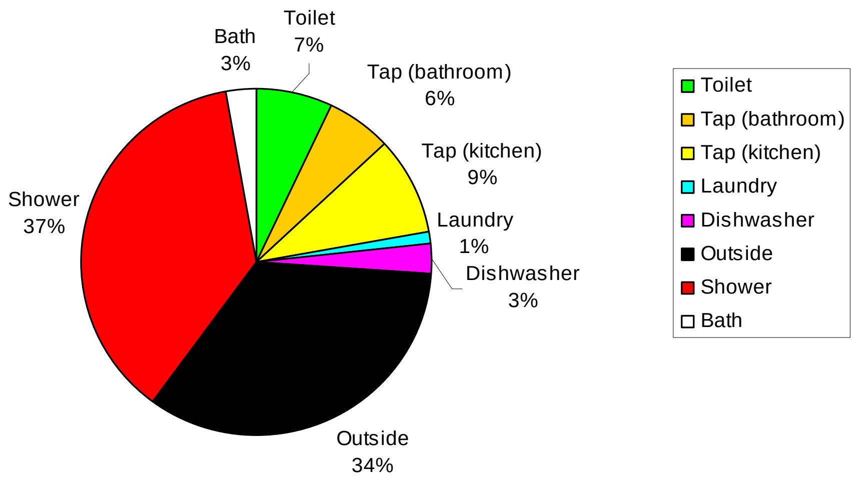


Figure 13: Summer end-uses

The highest winter use is the shower with 36%, followed by 32% inside tap use (26% kitchen, 6% bathroom). Baths make up 11% of the total winter uses, followed by the toilet with 9%.

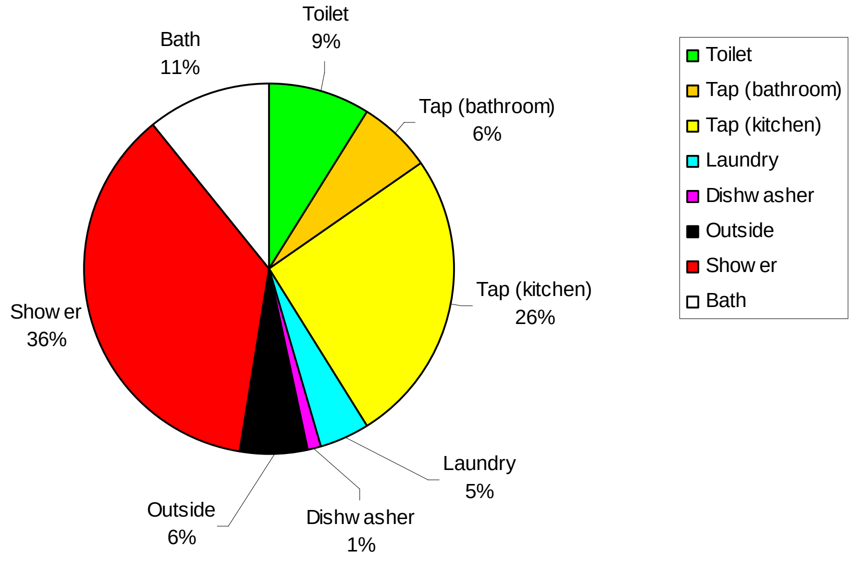


Figure 14: Winter end-uses

During the winter the amount of water used from the kitchen tap, the laundry and the bath increased, while the volumes of the other end-uses decreased. The greatest decrease was for water used outside, followed by the shower.

The next step for analysing the water data is to effectively show the different volumes of water used seasonally.

3.3 Rainwater Collection

3.3.1 Inflows into tank

The amount of rainwater captured depends on the roof area and the annual rainfall, so total rainfall is only an estimate of captured rainfall which will vary from year to year. The formula below provides a good estimate of the amount of rainfall harvested. In reality this will vary depending on how often the tank overflows due to the longevity and intensity of the rainfall.

$$\text{Amount of Rainwater Captured } (m^3) = 85\% \text{ Efficiency} \times \text{Plan View Roof Area } (m^2) \times \text{Annual Rainfall (m)}$$

Equation 1: Simple Rainwater harvesting formula

The total rainfall from 01 January 2006 until 17 November 2006 was 918 mm. The average mean annual rainfall in Auckland is 1301 mm. The plan view roof area of the Waitakere NOW Home® during this time is 194 m^2.

Harvested Volumes				
	Rainfall (mm)	**(m^3)**	**Litres**	**Litres/day**
Jan-06	94.0	15.5	15497	499.9
Feb-06	30.2	5.0	4984	166.1
Mar-06	50.0	8.3	8251	266.2
Apr-06	216.2	35.6	35644	1188.1
May-06	123.7	20.4	20398	658.0
Jun-06	66.0	10.9	10890	363.0
Jul-06	36.6	6.0	6031	194.6
Aug-06	77.0	12.7	12691	409.4
Sep-06	44.7	7.4	7372	245.7
Oct-06	145.8	24.0	24042	775.5
Nov-06	33.5	5.5	5529	325.2
Total	**917.7**	**151.3**	**151329**	

Table 5: Harvested rainwater

The amount of rainwater that can be harvested off the roof during 2006 (January until November 17) was on average 463 litres per day (L/d). This amount is sufficient to cover all the end-uses that are connected to the rain tank (including hot water) during both the summer and winter period.

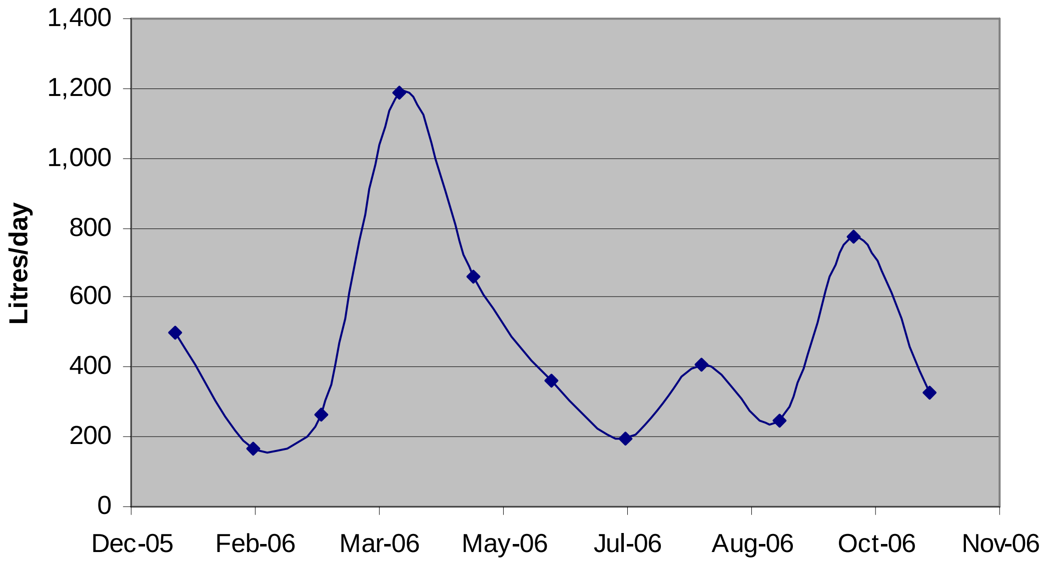


Figure 15: Monthly amount of harvested rainwater

Figure 15 shows the monthly variations of rainwater that can efficiently be harvested off the roof. During dry months like February or July, only a limited amount of rainwater can be collected. However, due to the large storage capacity of the tank – 13 500 L – it is possible to use the water captured during wetter months, for months with a lower amount of rainfall.

3.3.2 Rainwater use

Figure 16 shows the amount of rainwater in the tank. This is derived by balancing the inputs (harvested rainwater) with the out-takes (consumption). As the rain tank has a maximum capacity of 13 500 L, any excess water cannot be stored in the tank, but has to go into the storm water system. During dry periods, when the amount of out-take exceeds the amount of input (rain), the level in the tank drops. If this deficit continues to accumulate, the tank may eventually run dry, as can be observed in the graph (from 27 July). As supply exceeds demand, the level in the tank rises again. When there is no water in the tank, the occupants can switch to mains water via a bypass. This has occurred in this case. However five days later, after a period of rain the tank had enough volume to deliver the required amount of water, but the residents forgot to switch over to tank water again for another four days. An automatic switch could be installed, which switches between mains and tank, depending on the water level in the tank.

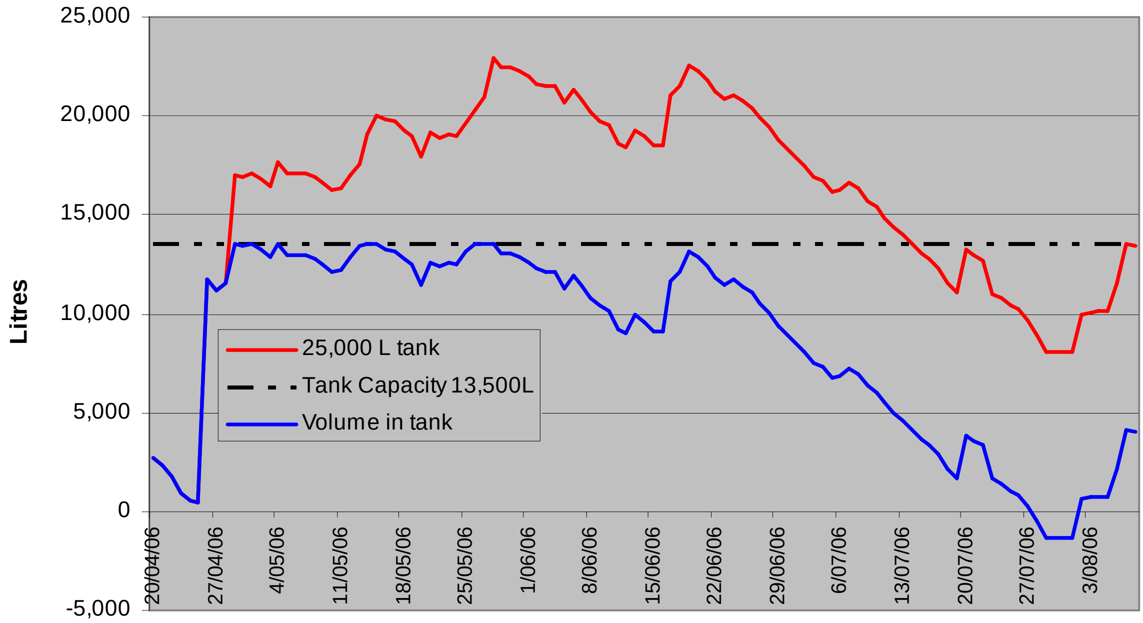


Figure 16: Volume in rainwater tank

If the volume of the tank had been larger, e.g. a 25 000 L, the tank would have carried enough water and would not have run dry. Captured water lost through the overflow could have been used within the home instead.

4 Indoor Environment

Temperatures and RH are being measured in the bedrooms, study, family room, living room and the bathroom in the Waitakere NOW Home®. Carbon dioxide levels have been measured in the family room. The following section gives an overview of the temperatures, RH and CO2 levels experienced in the NOW Home® so far. Where possible the measurements are related back to comfort or health.

4.1 Temperature

Temperatures have been examined separately over the summer and winter periods as there are seasonal differences. Where possible the temperatures have been compared to the HEEP research.

Through HEEP (Isaacs et al 2006) it has been found that newer houses in New Zealand have much higher indoor temperatures in both summer and in winter. It is not unexpected therefore that the Waitakere NOW Home®, being a new house, has high temperatures compared to most of the HEEP sample.

4.1.1 Winter temperatures

Winter temperatures are examined from June through to the end of August in the following section.

Location	Mean °C	Median °C	Min °C	Max °C	NA's
Family room (low)	19.4	19.0	13.5	27.0	95
Study	19.4	19.5	13.0	24.0	95
Family room (high)	19.1	19.0	14.0	26.0	95
Living room	18.5	18.5	14.0	24.0	95
Bedroom 3	18.1	18.0	12.0	24.5	95
Main bedroom	17.2	17.5	12.5	22.0	95
Bathroom	15.1	15.0	9.5	21.0	95
Ambient	9.7	10.5	-1.0	18.0	95

Table 6: 24 hr winter temperatures

Table 6 gives the mean, median, minimum and maximum temperatures reached during winter for each of the rooms in the Waitakere NOW Home® and the ambient temperature. The temperatures inside the house are much warmer than outside, with no heating being done in the house. This must be due to the house construction, solar gains, internal gains from the occupants and the equipment running inside the house. The rooms that were warmest in summer are also warmest in winter.

Figure 17 compares the average winter evening temperature in the Waitakere NOW Home® with a range of average winter evening temperatures taken from the HEEP sample. The groupings are the same as for the energy analysis in section 3.1.

The Waitakere NOW Home®, with an average winter evening temperature of 19.4°C, is high in comparison to the other groupings despite using minimal energy for heating. Again Group 3 houses, with a four person household with pre-school children, shows an interesting contrast with a wide range of temperatures in comparison to the other groups.

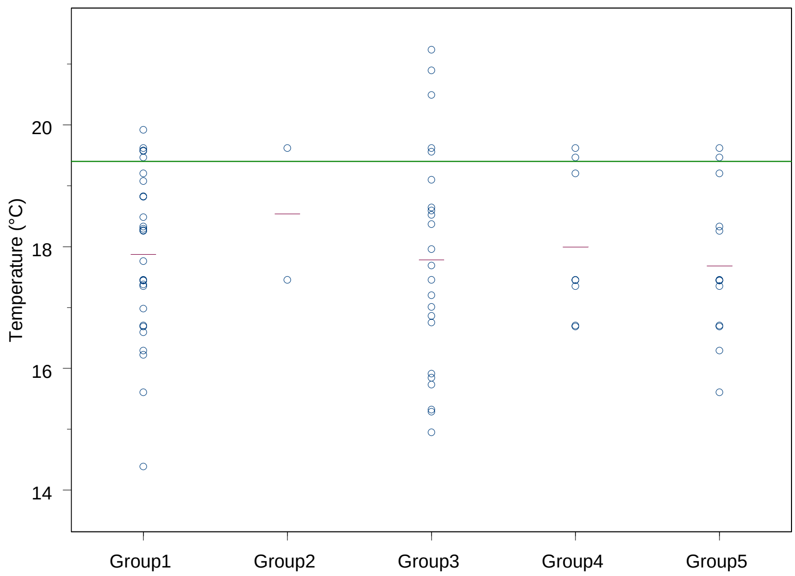


Figure 17: Waitakere NOW Home® average winter evening temperature (horizontal line) compared with HEEP average winter evening temperatures for a number of groups

4.1.1.1 Comfortable temperatures?

Room	**Below 20°C**	**20-25°C**	**Above 25°C**	**Hrs Measured**
Family room	63%	36%	0%	2144.5
Study	56%	44%	0%	2144.5
Living room	80%	20%	0%	2144.5
bedroom 3	83%	17%	0%	2144.5
Main bedroom	97%	3%	0%	2144.5
Bathroom	100%	0%	0%	2144.5

Table 7: Proportion of time in each temperature range over 24 hrs - Winter

As noted earlier, a general comfort range in New Zealand for temperatures can be considered to be between 20°C and 25°C. Table 7 and Table 8 show the proportion of time the Waitakere NOW Home® is in this comfort range and below and above it. The temperature never goes above the comfort range, but during the evening in the family room and study temperatures are primarily between 20°C and 25°C.

Room	Below 20°C	20-25°C	Above 25°C	Hrs Measured
Family room	31%	69%	0%	539.67
Study	33%	67%	0%	539.67
Living room	64%	36%	0%	539.67
Bedroom 3	81%	19%	0%	539.67
Main bedroom	94%	6%	0%	539.67
Bathroom	100%	0%	0%	539.67

Table 8: Proportion of time in each temperature range during the evening – winter

4.1.1.2 Healthy temperatures?

The time period shown in Table 8 for each of the rooms is during a period when the room is likely to be occupied. Table 9 shows the proportion of time spent above 18°C, a recommended minimum for health. Most of the Waitakere NOW Home® rooms spend most of the time above 18°C. The main exception is the bathroom where people generally spend little time anyway. The bedrooms are also colder than ideal during the night when they are occupied.

Location	Below 16°C	16-18 °C	Above 18°C	Hrs Measured	Time Period
Family room	4%	23%	73%	2144.5	24 hr
Family room	1%	3%	96%	539.67	evening
Study	4%	15%	82%	2144.5	24hr
Bedroom 3	15%	58%	27%	614.83	during night
Living room	3%	27%	70%	2144.5	24 hr
Living room	1%	6%	93%	539.67	evening
Main bedroom	24%	59%	16%	614.83	during night
Bathroom	60%	30%	9%	2144.5	24hr

Table 9: Healthy winter temperatures

4.1.1.3 Temperatures by time of day

Figure 18 gives the average winter temperature profile. The internal temperatures can be seen to rise and fall at the same time as the external temperature, although less steeply. There is no heating taking place in the house so therefore there are no steep rises in temperature.

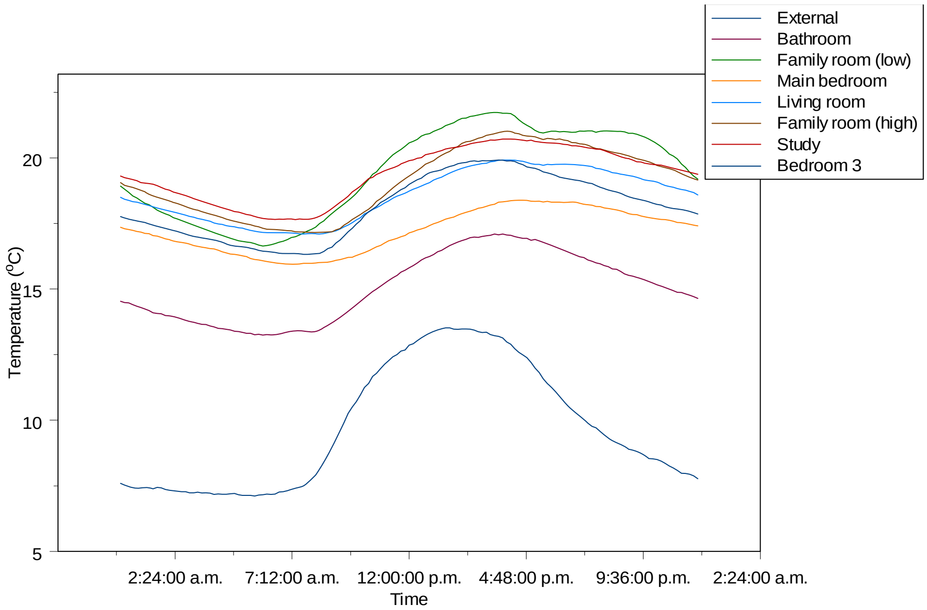


Figure 18: Winter temperature profiles

4.1.2 Summer temperatures

Location	Mean °C	Median °C	Min °C	Max °C	NA's
Family room (low)	24.9	25.0	19.5	31.0	1067
Study	24.9	24.5	19.0	31.0	1067
Family room (high)	24.5	24.5	20.0	30.0	1067
Bedroom 3	24.3	24.0	17.0	40.0	1067
Living room	24.0	24.0	19.0	28.5	1067
Main bedroom	23.4	23.5	18.0	28.5	1067
Bathroom	22.6	22.5	16.0	37.5	1067
Ambient	19.46	19.42	8.17	30.62	1067

Table 10: 24 hr temperature summaries for summer

Table 10 gives the mean 24 hr temperatures for the Waitakere NOW Home® over the summer (December to February) arranged by the highest mean temperature (family room) down to the lowest (bathroom).

The NA's in Table 10 and other tables through this section are the number of missing temperature (or humidity) measurements during the period being examined, which has a total number of measurements just over 13 000.

The maximum temperatures reached in the houses show that all rooms experience some overheating, with bedroom 3 experiencing temperatures as high as 40°C. The living room and the main bedroom have the lowest maximum temperature at 28.5°C; these temperatures are considered uncomfortable for the occupant. Normally you would expect the low sensor in the family room to have a lower temperature (due to heat rising), but occasionally other factors (radiant heat sources – sun, appliances) have more of an influence especially in summer.

The comparison of the average Waitakere NOW Home® summer evening temperature (25.4°C) with the HEEP groups (Figure 19) again shows that the NOW Home® is at the higher end of the temperature ranges of each of the groups. However the preference is to be at the other end of the ranges during this time.

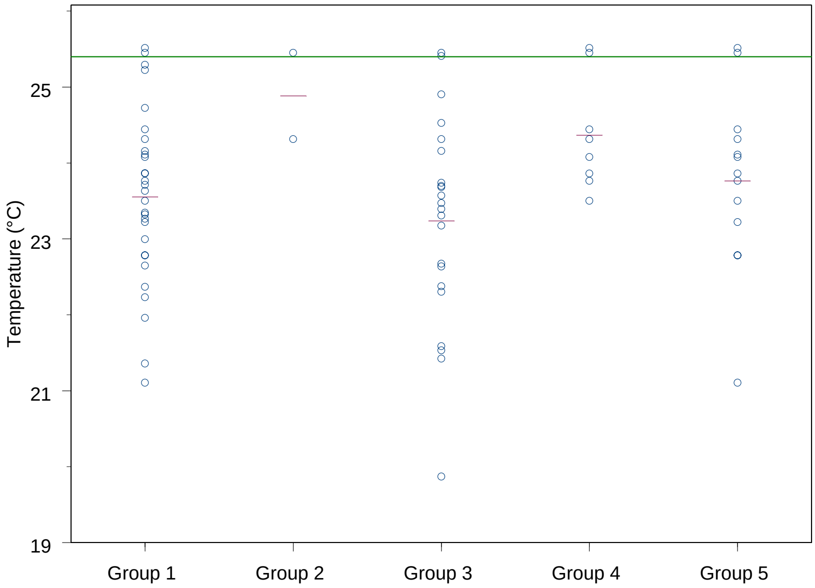


Figure 19: Waitakere NOW Home® average summer evening temperature (horizontal line) compared with HEEP average summer evening temperatures for a number of groups

4.1.2.1 Comfortable temperatures?

Room	Below 20°C	20-25°C	Above 25°C	Hrs Measured
Family room	0%	54%	46%	1365
Study	0%	49%	51%	1365
Bedroom 3	0%	70%	30%	1365
Living room	1%	58%	41%	1365
Main bedroom	2%	74%	24%	1365
Bathroom	11%	70%	19%	1365

Table 11: Comfort temperatures Jan-Feb 24 hrs

Comfort is dependent on the occupants' preference, clothing level, activity levels and the outdoor temperatures. In previous work in New Zealand, 20-25°C (Jaques 2000) has been used as the comfort range. Using the 10 minute data from the Waitakere NOW Home® the proportion of time spent above 25°C, below 20°C, and between 20°C and 25°C can be calculated. In the post-occupancy surveys it has been indicated by the occupants that it can be uncomfortably warm at times causing them to have trouble sleeping. Due to traffic noise and security, it is understood the occupants are not keen on having the windows open during the night or while they are away from the house. The occupants commented that the house was warmest when they have been away for the day. From the temperatures being achieved, there looks to be a lack of cross-ventilation in the house.

The Waitakere NOW Home® temperatures are primarily between 20°C and 25°C but there is a significant amount of time spent above 25°C over 24 hrs.

Table 11 shows the proportion of time in each temperature range in the evening when the occupants are most likely to be at home. Again the temperatures are primarily between 20°C and 25°C, with the exception of the family room which spends nearly 60% of the time above 25°C.

Room	Below 20°C	20-25°C	Above 25°C	Hrs Measured
Family room	0%	41%	59%	569
Study	0%	57%	43%	569
Bedroom 3	0%	73%	26%	569
Living room	0%	59%	41%	569
Main bedroom	2%	71%	27%	569
Bathroom	6%	70%	24%	569

Table 12: Comfort temperatures Jan-Feb during evening

Table 12 shows the proportion of days during January and February where the temperature over the day reaches a maximum temperature of 20°C, 25°C, 26°C, 27°C and 30°C for both the ambient and indoor temperatures measured in the Waitakere NOW Home®. As there is no recommended upper limit for health, and the limit for comfort is subjective, a range of temperatures has been given. Generally the upper limit for comfort in New Zealand is accepted to be 25°C or 26°C (Camilleri 2000, Jacques 2000, Donn and Thomas 2001).

Room	Proportion of days above:				
	20°C	25°C	26°C	27°C	30°C
Ambient	100%	44%	32%	18%	4%
Family room (low)	100%	91%	81%	66%	8%
Family room (high)	100%	75%	54%	33%	0%
Main bedroom	100%	48%	28%	11%	0%
Living room	100%	56%	33%	13%	0%
Study	100%	81%	62%	47%	4%
Bedroom 3	100%	76%	65%	52%	34%
Bathroom	100%	77%	59%	44%	10%

Table 13: Proportion of days above specified temperatures during summer

The proportion of days where the temperature is above 26°C is high for all rooms except the main bedroom which is higher than the ambient. Ideally on these hot days the house would be cooler than outside. It is a concern that bedroom 3 exceeds 30°C on 34% of the days during January and February.

4.1.2.2 Average temperatures

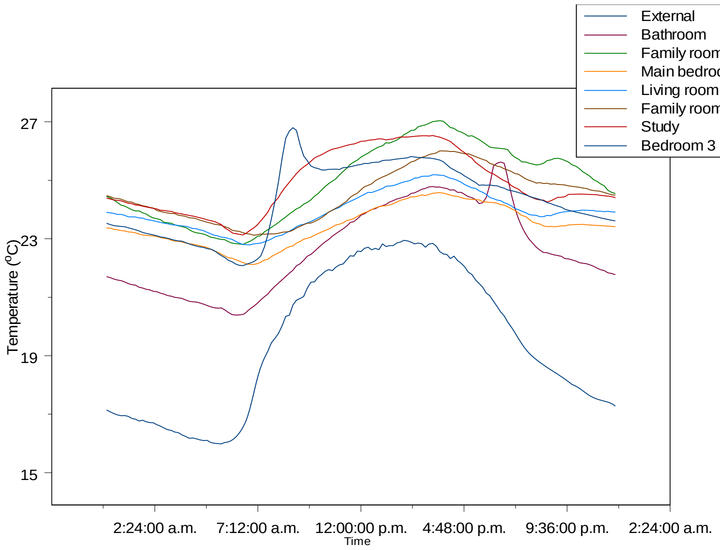


Figure 20: Temperature profiles for summer months

The temperature profiles show the average temperatures during a day for the three summer months. The bathroom on average is the coolest room, although there is a quick rise in temperature in the evening and this is likely due to the bathroom being used at this time. Bedroom 3 has a sharp rise in temperature in the morning – this room has high solar gains in the morning. All rooms average warm temperatures, with the bathroom the only room below 22°C. The family room, bedroom 3, the study and bathroom all reach temperatures above 25°C on average each day from approximately 12 noon through to at least 5 pm. The family room does not go below 25°C until 8 pm.

Mean Temperatures for Waitakere NOW Home®				
	Morning 7 am to 9 am	Day 9 am to 5 pm	Evening 5 pm to 11 pm	Night Midnight to 7 am
Family room (°C)	23.4	25.5	25.4	23.6
Bedroom (°C)	22.5	24.0	23.8	22.8
Ambient (°C)	19.4	22.3	19.3	16.5

Table 14: Mean temperature during time periods for Waitakere NOW Home®

Table 14 gives the mean temperatures for the main bedroom and the average of the two family room sensors in the Waitakere NOW Home®. These temperatures can be compared to the HEEP sample for the whole of New Zealand in **Error! Reference source not found.**.

Mean Temperatures for all Houses (HEEP)				
	Morning 7 am to 9 am	Day 9 am to 5 pm	Evening 5 pm to 11 pm	Night Midnight to 7 am
Family room (°C)	19.2	21.8	23.1	20.3
Bedroom (°C)	19.1	21.2	22.6	20.1
Ambient (°C)	15.8	20.1	17.9	14.5

Table 15: Mean temperature during time periods New Zealand sample

(French et al 2006)

Table 15 gives the mean temperatures for the different periods of the day from 400 houses in HEEP. These houses are a representative sample of New Zealand houses and all except two can be considered to be of light-weight construction. The Waitakere NOW Home® has concrete thermal mass floors so is considered to have higher thermal mass than most houses in New Zealand.

Time of Day	Room	Temperature ^{o}C
Morning	Family room	23.4
	Study	24.4
	Bedroom 3	24.7
	Living room	23.1
	Main bedroom	22.5
	Bathroom	21.4
	Ambient	19.4
Day	Family room	25.5
	Study	26.2
	Bedroom 3	25.6
	Living room	24.6
	Main bedroom	24.0
	Bathroom	24.0
	Ambient	22.3
Evening	Family room	25.4
	Study	24.7
	Bedroom 3	24.4
	Living room	24.1
	Main bedroom	23.8
	Bathroom	23.3
	Ambient	19.3
Night	Family room	23.6
	Study	23.8
	Bedroom 3	22.9
	Living room	23.4
	Main bedroom	22.8
	Bathroom	21.0
	Ambient	16.5

Table 16: Mean temperatures at different times of the day

Table 16 gives the mean temperatures for all of the measured rooms in the house at different periods of the day.

All rooms are always above ambient; the hottest time in the house is during the day-time period (9 am to 5 pm). During this time for most of the week the house is likely to be shut up with the occupants away from home. The night-time period is when there is the biggest difference between the ambient and the indoor temperatures – for all rooms it is a difference of over 4°C. During the night the thermal mass would be expected to release heat into the house. This could explain the high temperature difference between inside and outside along with the internal gains from the occupants and the equipment in the house.

4.2 Relative Humidity (RH)

RH has been examined separately over the summer and winter periods as there are seasonal differences.

As very little monitoring of RH has been done in New Zealand houses, the measurements are therefore compared to suggested acceptable levels for health and comfort. Beacon's Papakopwhai Renovation houses in Porirua are currently having the humidity levels monitored in the master bedrooms. This will be continued over the next 12 months and comparisons will be able to be made during this time. There is not enough data from the Papakowhai Renovations to make comparisons yet.

Humidity measurements taken on a one minute basis by the same loggers recorded the temperatures with the Waitakere NOW Home®. RH affects the comfort and health of the occupants within the houses. Acceptable levels of humidity for comfort vary by the temperature in the house. WHO (1987) recommends for indoor temperatures between 18-24°C an RH between 20% and 70% is compatible with health. However WHO go on to say 70% RH is generally sufficient to sustain mould growth once started.

4.2.1 Summer humidity

Location	Mean %	Median %	Min %	Max %	NA's
Family room (low)	54.5	54.1	31.0	93.5	1128
Study	55.6	54.9	32.9	86.5	1128
Family room (high)	56.0	55.7	34.0	88.6	1128
Bedroom 3	57.9	57.6	27.5	82.6	1128
Living room	57.0	55.9	34.9	85.5	1128
Main bedroom	60.0	59.8	36.8	90.3	1128
Bathroom	61.6	61.7	26.7	98.1	1128

Table 17: 24 hr RH summary for summer

Table 17 has been arranged by the highest mean temperature down to the lowest (from Table 16); the humidity varies differently for the temperatures but the rooms with the higher temperatures generally have a lower mean RH. The mean RHs are at the upper end of the acceptable range but they are all within the range. The bathroom has the highest mean at 61.6%; less than 10% below the upper recommended level. The minimums recorded are all above the recommended minimums with the bathroom recording the lowest RH out of the measured rooms. The maximum reached in the house does exceed the upper limit for health by as much as 23.5% in the living room.

4.2.1.1 Acceptable RH levels

24 hr		Evenings (5-11 pm)		Night (11 pm-7 am)		Location
20-70%	>70%	20-70%	>70%	20-70%	>70%	
99%	1%	100%	0%	99%	1%	Family room
100%	0%	100%	0%	100%	0%	Study
95%	5%	95%	5%	92%	8%	Bedroom 3
99%	1%	100%	0%	100%	0%	Living room
98%	2%	100%	0%	96%	4%	Main bedroom
84%	16%	90%	10%	72%	28%	Bathroom

Table 18: Proportion of time RH is within acceptable levels

Table 18 shows the proportion of time RH is between 20-70% and above 70% over 24 hrs during the evening and night. Below 20% has not been included in the table as the minimum for all rooms is above 20% RH. As seen in Table 18 the RH levels only exceed 70% for 1% of the time over the day in the family room, 2% in the master bedroom and 5% in bedroom 3 (children’s bedroom). The period of day when the RH is highest is during the night, with the room spending the most time above being the bathroom. By the temperature and water use of the bathroom, there looks to be high use of the bathroom in the evenings so this is not surprising. Bedroom 3 spends 8% of the time during the night above the acceptable range; this room has two children sleeping in it.

Humidity was not measured in HEEP so we are unable to compare the values with a representative New Zealand sample.

4.2.1.2 RH by time of day

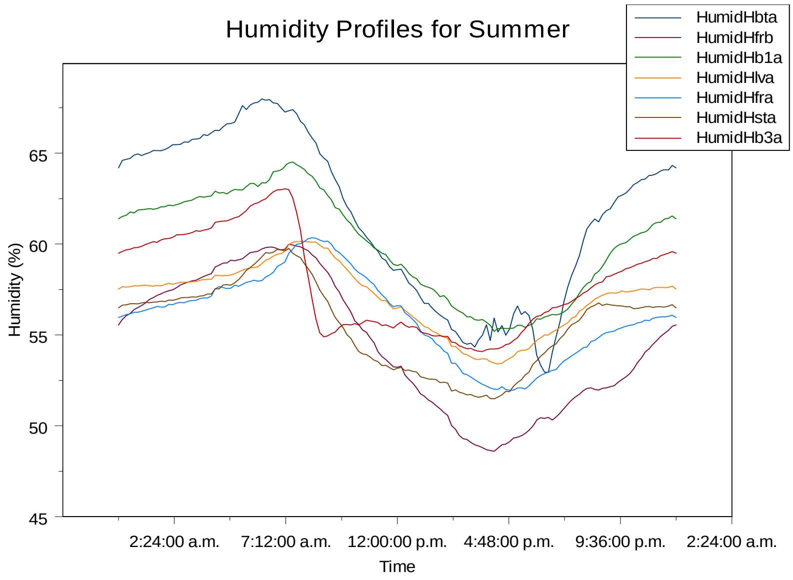


Figure 21: Humidity profiles for summer

The humidity profiles show the average humidity for each room during 24 hrs for the three summer months. The bathroom is the only room where it gets above 70% consistently. No rooms have a summer profile of RH below 20%. The average maximum is reached early in the morning before the occupants leave the house. The biggest drop is in bedroom 3

4.2.2 Winter humidity

Location	Mean RH %	Median RH %	Min RH %	Max RH %	NA's
Family room (low)	59.5	59.3	36.8	83.0	3
Study	61.7	61.5	42.5	79.4	3
Family room (high)	60.7	60.1	42.4	90.3	3
Living room	63.0	62.2	48.4	84.2	3
Bedroom 3	67.4	66.7	46.4	93.0	3
Main bedroom	71.6	70.8	53.4	95.1	3
Bathroom	76.9	77.6	46.7	99.1	3

Table 19: 24 hr winter RH

RH has been examined for the three months of winter (June, July and August). The RHs are a lot higher than during summer, as seen in Table 19. The means and the median are within the suggested acceptable level for health. There is a lack of New Zealand data on RH in humidity so it is not possible to compare the Waitakere NOW Home® with other New Zealand houses at this stage. Although the RH is on the high side it is expected that the house is performing better than most in Auckland's humid climate. The higher the indoor temperature, the lower the RH. Improving the ventilation in the bathrooms (especially the bathroom off the main bedroom) and heating the house are likely to decrease the RH in the NOW Home®.

4.2.2.1 Acceptable RH levels?

Location	24 hr		Evenings (5-11 pm)		Night (11 pm-7 am)	
	20-70%	>70%	20-70%	>70%	20-70%	>70%
Family room	92%	8%	94%	6%	91%	9%
Study	93%	7%	93%	7%	94%	6%
Living room	89%	11%	88%	12%	91%	9%
Bedroom 3	71%	29%	75%	25%	66%	34%
Main bedroom	44%	56%	58%	42%	37%	63%
Bathroom	21%	79%	20%	80%	11%	89%

Table 20: Proportion of time at acceptable levels of RH – winter

No rooms have an RH below 20%. The RH levels in the house are exceeding the maximum acceptable range for health in all rooms. The bedroom is a concern with 63% of the night-time during winter being spent over 70% RH; bedroom 3 spends 34% of the night over 70%. The bathroom is the highest and mould growth could be a problem in this room.

4.2.2.2 RH by time of day

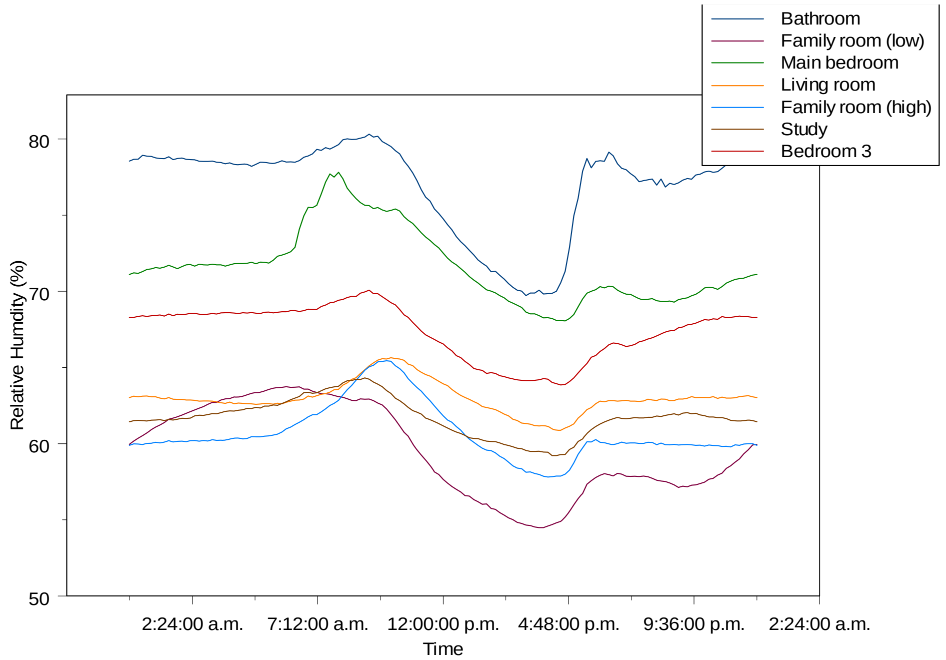


Figure 22: Winter RH profiles

4.3 Carbon Dioxide

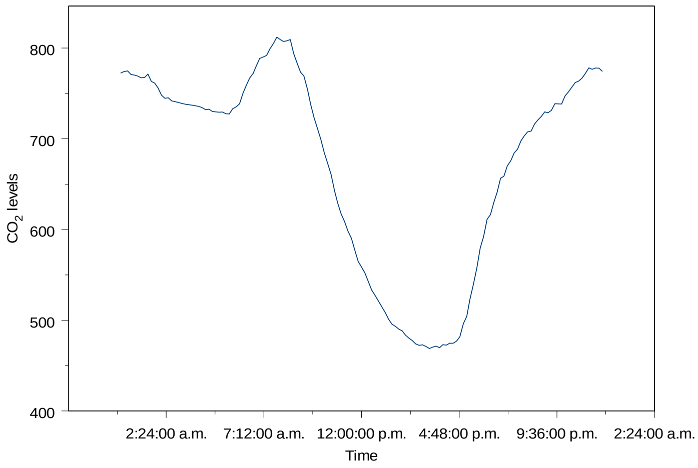


Figure 23: Winter carbon profile in the family room (March to November)

Month	CO_2 Average
Mar	458
Apr	522
May	567
Jun	651
Jul	729
Aug	632

Table 21: Mean CO_2 levels through the year

Time of Day	CO_2 Levels
Morning	685
Day	468
Evening	587
Night	676
24 hr	583

Table 22: CO_2 levels at different times of the day (March to November)

The CO_2 monitoring data started in March 2006. CO_2 levels vary both by occupants and the level of ventilation/infiltration in the space. The CO_2 appears to be affected by occupancy of the space as the levels drop during the morning (when the occupants are away) and rise again at about 5 pm (when they return). Survey responses from the occupants suggest that they do not leave the windows open while they are away so the reduction through the morning is due to infiltration and having no CO_2 producers in the house. During summer the occupants open the windows when they arrive home to reduce the temperature inside the house, so it may be possible to examine the seasonal influence on the CO_2 levels.

5 Household Perspectives

5.1 Overview

Quarterly POEs are being carried out for the Waitakere NOW Home® as part of the two-year longitudinal (monitoring) investigation. The study seeks to determine the more difficult to quantify issues which are more social and qualitative in nature and complement the intense physical (quantitative) monitoring of the building. Issues being examined by the POE include:

- Use of local transportation facilities
- Use of local amenities in close proximity
- Use of landscape for food (i.e. a vegetable garden)
- Occupants' comfort
- Occupants' perceived security
- Occupants' mould-risk behaviour.

For a full listing of the survey questionnaire see Appendix D: Post-Occupancy Evaluation Survey.

In addition to capturing the occupants' opinions and relating them to the measured physical performance, the emphasis of the POE for the Waitakere NOW Home® is also on ensuring that we have a practical, repeatable methodology which can be applied in a cost-effective manner to all future NOW Homes®.

5.2 Approach

There were several key goals that the research project wanted to achieve including:

- To build upon the research methodology and findings of the Queensland Research House[1]
- To make the data collection as easy as possible, while gathering maximum information.
- To be minimally intrusive to the occupants as possible e.g. ensuring the quarterly survey could be easily completed within an hour by the occupants
- To be able to be refined after the first interview to slipstream further interviews with a particular set of interviewees, yet initially applicable for a wide range of subjects so that the template can be used for all NOW Home® occupants.

The questionnaire methodology was based on that by: Aronson J. (1994). *A Pragmatic View of Thematic Analysis*'.[2] This approach, used by the Queensland Research House social scientists, was fine-tuned using the well-recognised social systems-based 'differences and effects' questions.

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[1] See www.housing.qld.gov.au/initiatives/researchhouse/tour/index.htm and also: Buys, Laurie et al. (2005). 'Smart Housing and Social Sustainability: Learning from the Residents of Queensland's Research House'. Australian Journal of Emerging Technology and Society (3): 1.
2 The Qualitative Report (2): 1. (www.nova.edu/ssss/BackIssues/QR2-1/aronson.html)

The first occupant interview was carried out in early December 2005, with both the adult residents of the Waitakere NOW Home® being interviewed together. The next interviews were carried out at quarterly intervals during 2005-2006. Only the adult occupants were interviewed as both children are currently considered to be too young (at 5 and 3 at the start of the process). The surveys were conducted in a relaxed manner, with a tape recorder being present for three of the four interviews. This was mainly to ease the collection of the open-ended data. Notes were also made on the survey forms, but by the interviewer only. Both adults were usually interviewed. In one case, only the adult male was interviewed. A typical interview time (disregarding the first one) was approximately 30 minutes.

5.3 Details

The first interview was a little over an hour long – the longest by far, in order to provide the tenants with a comprehensive overview of the process and their roles. The following interviews averaged at 30 minutes, therefore fulfilling one of the design objectives of keeping the interview period short. There were a range of questions asked of the occupants. They can be grouped into:

1) Straight factual e.g. “How many people have lived in your household for the last 3 months?”
2) Generic and open-ended i.e. “How do you feel about the house and living in it overall”. A longer answer expected here as an introduction to the next set of questions.
3) Specific and quantitative, assessing the differences and effects i.e. “Which specific features are making a difference for you and how do you rate them on a scale”. A short scale (1-10) was used as an indicator.

In all, 35 specific features were examined. The features can be grouped into the following categories:[3]

3 Unlike the University of Queensland approach, where recurring themes were combined and catalogued into sub-themes, the NOW Home research had already identified 12 categories.

ISSUE / CATEGORY	Specifics
Aesthetics	both internal and/external
Space	layout and flow
Privacy	both internal and external
Comfort	thermal only
Airy	perception of air freshness
Lighting	both day (natural) and night (artificial) lighting
Noise	external and internal sources
Security	the perception of security
Running costs	ongoing utility bills
Water	solar hot water and roof-collected rainwater
Ways of dealing with rubbish	recycling and composting
Things that the house 'does'	e.g. clothesline, public transport, vegetable garden etc

Table 23: Issues examined in post occupancy evaluations

It should be noted that many of the questions are comparative in that they ask the interviewee to compare aspects of the Waitakere NOW Home® with previous houses they have been in. Thus, the tenants are asked to compare general physical attributes, overall living aspects (the 'experience'), and specific features of the NOW Home® with their previous houses.

5.4 Findings

There was an overwhelming vote of confidence for the way the house is performing i.e. in the comfort and utility both it and its surrounding services provide. Of the 35 specific features examined (see Q. 8), for example, only two were seen as making a negative difference for them (there were three others that were termed 'not applicable'). The responses for the other features were either very positive or perfect, and this is true over the duration of their first year of tenancy.

Although both adults were interviewed together, agreement in both generic and specific views on any elected issue was very good. With only one exception (Feature #35 'growing your own vegetables'), did their scores vary by more than one point.

In terms of overall rating of the house:

The tenants consistently gave a perfect rating of '10' (i.e. Extremely Different), in terms of the experience for living in the Waitakere NOW Home® (Q. 2), compared to houses lived in previously.

In terms of how much better living in the house was overall, a perfect '10' was given, compared to previous houses (Q. 3). In terms of how much worse living in the house was overall, compared to previous houses, a '1' (i.e. 'Not at all') was given (Q. 4).

The house features which were most appreciated were:

The specific features of the house that were originally given a perfect '10' score were: comfort (thermal, fresh air, lighting, sound insulation), physical attributes (concrete floor), utility (spaciousness, interior layout and flow), and service provision (electricity bills and hot water heating, recycling, security,4 clothes line). These changed very little during the first year of monitoring. However, there were many (around 11) other features that received a high score (rated as 7.5 out of 10 or greater), both initially and throughout the duration of the first year.

In terms of the features that were repeatedly discussed as being exemplary, the three that stood out were:

- The layout of the rooms and good use of space
- The thermal performance of the house, in terms of stability and (almost) negating the necessity for winter-time space heating
- The concrete floor, in terms of its ability to keep clean.

The tenants thought that the overwhelmingly positive features of the house and its surroundings made a significant positive contribution to their inter-family relationships.

The house features which were least appreciated were:

The tenants thought the following performance aspects of the house could have been improved:

- Tracking the small pathway stones into the house
- The 'breakfast bar' being too high
- The lack of privacy from neighbours
- Condensation on the master bedroom window in the winter-time.[5]

However, the tenants recognised that these issues were of a more trivial nature compared to the benefits.

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[4] ***This rating is somewhat artificial, as their views were based on a private security firm checking the area at regular periods, which would not happen in more standard situations.***

[5] ***A large contributor to this problem is thought to be due to user behaviour i.e. not venting the ensuite bathroom properly, drying clothes inside the house and the closure of the (passive) window vents in the bedrooms.***

The house features and experiences that changed with time were:

The spaciousness of the house – originally given a perfect rating, this top score was tempered as the tenants felt that, in the ‘perfect house’, an extra metre or two of space on the north wall would have made things even better.

The vegetable garden – the tenants admitted that they did not have the greenest of fingers from the outset, but soon started to put effort into growing vegetables. However, with the onset of winter, efforts in this area declined.

The ‘house’ features that reduced their environmental loading/impact (as perceived by the occupants rather than measured):

- The amount of non-decomposable recycled at a local level
- The amount of decomposable recycled
- Reduced cleaning of floors
- Reduced space heating
- Reduced reticulated water use
- Reduced hot water heating
- Reduced vegetable purchases in the summer
- Reduced water bill
- Reduced energy bill
- Reduced artificial lighting requirements.

6 Conclusions and Recommendations

6.1 Key Facts and Information from the Waitakere NOW Home® Monitoring

Energy

The Waitakere NOW Home® in its first year of occupation had an energy consumption (electricity) of 7400 kWh. Based on the HEEP data the NOW Home®'s total energy consumption could be said to perform well against new houses in the Auckland region (Group 4) as well as against four person households with pre-school age children (Group 3) where the average savings are approximately 33%. The Waitakere NOW Home® used 45% less energy than the previous house the NOW Home® occupants rented. The seasonal variation of energy usage in absolute terms was smaller for the Waitakere NOW Home®; however it was similar in relative terms.

The water heating, refrigeration and lighting electrical end-uses were seen to use a smaller proportion of the total household electricity use than was the case for an average house in HEEP.
Over half of the electrical energy could not be assigned to an end-use category.

The solar water heating is providing a high proportion of the water heating needs in summer but in winter is less effective. Further analysis of the solar water heating will be carried out.

Water

The Waitakere NOW Home® used 100 L of water person per day from the street water main, 44% less than the 180 L/p/d in Beacon's HSS® (Easton 2006). The rainwater tank provided an additional 88 L/p/d or 47% of the total water needs.

The Waitakere NOW Home® has extensively monitored water end-uses. Showering was seen to be the major water use within the house with approximately 36% of water being used for this purpose. In summer the use of the outdoor taps was a large contributor making up 34% of summer-time water use. Despite the large size of the rainwater tank (13 500 L) there will still occasions when the system overflowed.

Comfort and Utility

There was an overwhelming vote of confidence from the Waitakere NOW Home® occupants: the way the NOW Home® was performing in the both comfort and utility. The tenants consistently gave a perfect rating of '10' (i.e. Extremely Different) in terms of the experience for living in the NOW Home®, compared to houses lived in previously.

The features the occupants repeatedly highlighted as positives were:

- The layout of the rooms and good use of space
- The thermal performance of the house, in terms of stability and not needing to heat in winter
- The concrete floor, in terms of its ability to keep clean.

The features the occupants thought could have been improved were:

- Tracking the small pathway stones into the house
- The 'breakfast bar' being too high
- The lack of privacy from neighbours
- Condensation on the master bedroom window in the winter-time.

There was in general no movement in the perception of how features of the house made a difference for the occupants. This was true even for those issues for which there were expected to be some seasonal variations.

The summer temperatures in the Waitakere NOW Home® are warm (above comfort range). The temperature in the family room spends nearly 60% of the time above 25°C over summer. During the night-time period the difference between the ambient and the indoor temperatures is at its highest with the high thermal mass of the NOW Home® slowing the drop in room temperatures.

Despite not having any regular heating, the winter temperatures in the Waitakere NOW Home® are good. The mean winter evening temperature in the living room was 19.4°C.

The mean summer RH in the living room was approximately 55% and 60% in the main bedroom. In winter the RHs were higher, with a mean living room value of approximately 60% and a main bedroom value of 72%, which did cause some comment from the occupants.

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8 Appendix A: Additional HEEP Information

HEEP has used a population weighted sampling framework based on major urban areas ('strata') and the rest of the country ('clusters'). The strata included 221 households from Auckland, Manukau, North Shore, Waitakere, Tauranga, Hamilton, Wellington, Upper Hutt, Lower Hutt, Porirua, Christchurch, Dunedin and Invercargill. The remaining 178 households were selected from 19 area unit clusters of eight, nine or 10 houses drawn at random, with a probability proportional to the number of households from those New Zealand households not covered by the major population regions – from the far north to the deep south (see Section 3, Isaacs et al 2005, for a more detailed description).

The HEEP sample was designed to produce estimates of New Zealand residential energy consumption. The sample size of 400 houses was determined from early monitoring and designed to produce an acceptable error for the total New Zealand residential energy use. The errors, when using subsets of the HEEP data (i.e. houses in Auckland), have increased errors associated with them. Once more than a few factors are considered, the sample size of the resultant subset is too small to produce useful statistical estimates. For example, once the HEEP database is filtered for Auckland houses (97 households) that were recently constructed (within five years), the size of the resulting subset is only two households.

9 Appendix B: Data Collection

The physical data collection arrangement for the Waitakere NOW Home® considered of a Pentium computer connected to an Agilent datalogger and a Point 6 radio sensor network, The Agilent datalogger was a new product on the market and allows for data collection from the pulsed output of electricity meters and water meters in addition of a number of other analog channels such as the thermocouples measuring the solar water heating. These sensors were wiring back to the Agilent data logger located in the hot water cupboard. See Table 24 for a full list of channel assignments

The other new technology used was a Point 6 radio sensor network which primarily collected temperature and humidity but also data from the CO_2 sensor and the three portable electricity meters. The quantity of data arriving at BRANZ is considerable. Each day the 80 channels of data (shown in Table 24) being collected at one minute intervals results in over 115 000 data points. The one minute data collection interval is required due to the Point 6 radio sensors.

The management of such as large dataset has been challenging. Initially the one minute data was loaded into S+, a statistical analysis environment. However after two months of data collection the data objects in S+ became too large and stopped functioning. The one minute data was instead loaded into a Microsoft Access database which could pass data through to S+. Again the large volume of data placed a strain on the software and after about 10 months of data collection, once the Access database was about 820 Mb and 35 million records long, this system stopped working

Rather than working with the one minute data, the data was processed into 10 minute blocks before moving into a database. Furthermore a more flexible indexing system was used in S+ which will allow the data to be more easily examined.

ID	Source	Type	Measuring	Name	ID	Source	Type	Measuring	Name
1	Agilent	Pulse	Electricity	Total	41	Agilent	Thermistor	Temperature	Ref. Junction
2	Agilent	Pulse	Electricity	Hot Water	42	Agilent	Thermistor	Temperature	Outdoor
3	Agilent	Pulse	Electricity	Range	43	Agilent	RH Sensor	Humidity	Outdoor
4	Agilent	Pulse	Electricity	Lights	44	Agilent	Pyranometer	Insolation	Solar Radiation
5	Agilent	Pulse	Electricity	Refrigerator Freezer	45	Agilent	Voltage	Voltage	5 Volt Reference
6	Agilent	Pulse	Electricity	Solar Pump	46	Agilent	Voltage	Conductivity	Moisture N. Wall
7	Agilent	Pulse	Electricity	Dishwasher	47	Agilent	Voltage	Conductivity	Moisture S. Wall
8	Agilent	Pulse	Electricity	Tank Pump	48	Agilent	Voltage	Availability	Hot Water
9	Agilent	Pulse	Water Use	Street	49	Agilent	Voltage	Voltage	5 V to Digital Inp
10	Agilent	Pulse	Water Use	Tank	50	Agilent	Voltage	Voltage	12 Volt Supply
11	Agilent	Pulse	Water Use	Tank Bypass	51	Agilent	Voltage	Motion	Kitchen
12	Agilent	Pulse	Water Use	Outside	52	Agilent	Voltage	Motion	Entry
13	Agilent	Pulse	Water Use	Outside Garage	53	Agilent	Voltage	Motion	Family
14	Agilent	Pulse	Water Use	Cold Tempered	54	Agilent	Voltage	Motion	Bedroom1
15	Agilent	Pulse	Water Use	Warm Tempered	55	Agilent	Voltage	Motion	Bed2 (Study)
16	Agilent	Pulse	Water Use	Dishwasher	56	Agilent	Voltage	Motion	Bedroom3
17	Agilent	Pulse	Water Use	Bathroom Vanity C	57	Agilent	Voltage	Voltage	Not Used
18	Agilent	Pulse	Water Use	Bathroom Vanity H	58	Agilent	Current	Water Level	Tank
19	Agilent	Pulse	Water Use	Bath Cold	59	Point6	Humidity	Humidity	Bathroom

ID	Source	Type	Measuring	Name	ID	Source	Type	Measuring	Name
20	Agilent	Pulse	Water Use	Bath Hot	60	Point6	Temperature	Temperature	Bathroom
21	Agilent	Pulse	Water Use	Bathroom Toilet	61	Point6	Humidity	Humidity	Family Room L
22	Agilent	Pulse	Water Use	Ensuite Vanity Cold	62	Point6	Temperature	Temperature	Family Room L
23	Agilent	Pulse	Water Use	Ensuite Vanity Hot	63	Point6	Humidity	Humidity	Bedroom1
24	Agilent	Pulse	Water Use	Ensuite Toilet	64	Point6	Temperature	Temperature	Bedroom1
25	Agilent	Pulse	Water Use	Kitchen Sink Cold	65	Point6	Humidity	Humidity	Living Room
26	Agilent	Pulse	Water Use	Kitchen Sink Hot	66	Point6	Temperature	Temperature	Living Room
27	Agilent	Pulse	Water Use	Ensuite Shower C	67	Point6	Humidity	Humidity	Family Room H
28	Agilent	Pulse	Water Use	Ensuite Shower H	68	Point6	Temperature	Temperature	Family Room H
29	Agilent	Pulse	Water Use	Laundry Cold	69	Point6	Humidity	Humidity	Study Bedroom2
30	Agilent	Pulse	Water Use	Laundry Hot	70	Point6	Temperature	Temperature	Study Bedroom2
31	Agilent	Pulse	Water Use	Bathroom Shower C	71	Point6	Humidity	Humidity	Bedroom3
32	Agilent	Pulse	Water Use	Bathroom Shower H	72	Point6	Temperature	Temperature	Bedroom3
33	Agilent	Thermocouple	Temperature	Cylinder Cold	73	Point6	Temperature	Temperature	Fan Heater
34	Agilent	Thermocouple	Temperature	Cylinder Hot	74	Point6	Temperature	Temperature	Wash. Machine
35	Agilent	Thermocouple	Temperature	Solar Cold	75	Point6	Temperature	Temperature	Monitor. Equip
36	Agilent	Thermocouple	Temperature	Solar Hot	76	Point6	Voltage	CO_2 conc	Family Room
37	Agilent	Thermocouple	Temperature	Tempered	77	Point6	Counter	Electricity	Fan Heater
38	Agilent	Thermocouple	Temperature	Cylinder	78	Point6	Counter	Electricity	Wash. Machine

ID	Source	Type	Measuring	Name	ID	Source	Type	Measuring	Name
39	Agilent	Thermocouple	Temperature	South Wall	79	Point6	Counter	Electricity	Monitor Equip
40	Agilent	Thermocouple	Temperature	North Wall					

Table 24: Channel assignments for the Waitakere NOW Home® data collection

10 Appendix C: Arrangement of Water End-Uses

The following diagram (Figure 24) shows how the various water end-uses are metered in the Waitakere NOW Home®. Twenty-four meters are installed in total. In addition to a mains water supply, rainwater is collected off the roof and stored in a 13 500 litre tank. This tank supplies several end-uses in the home as well as the solar water heater.

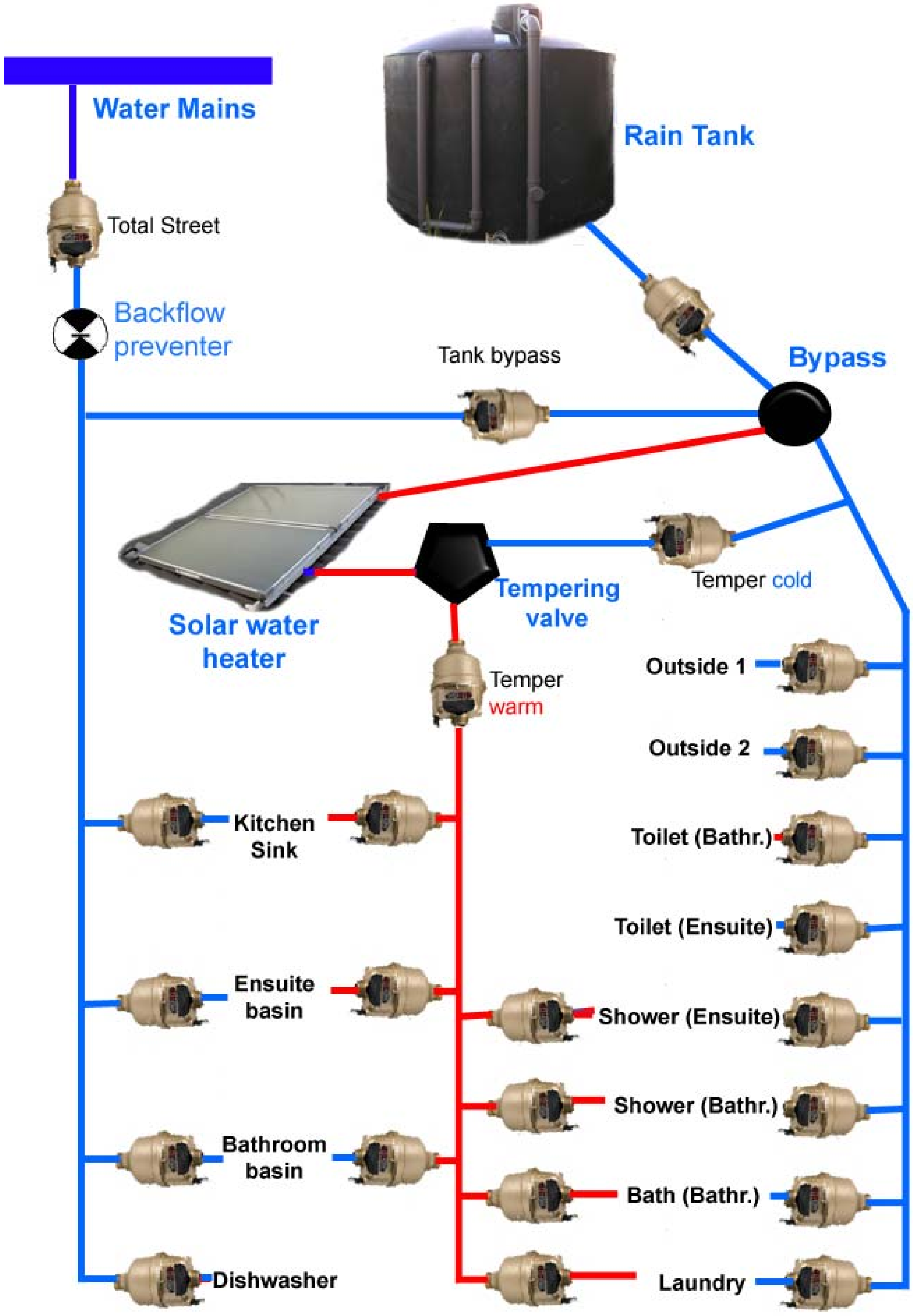

Figure 24: The arrangement of the water end-uses in the Waitakere NOW Home®

11 Appendix D: Post-Occupancy Evaluation Survey

Questions

Your Household

1. How many people (both adults and children) have lived in your household for **all of** the last 3 months? How many adults (over 18)? How many teenagers (13 – 17)? How many children (under 13)? [NOTE ANY CHANGES ETC]

Your Overall Rating

2. Thinking about the house and living in it overall, on a scale from 1 to 10 (SHOW SCALE), where 1 is 'not at all' and 10 is 'extremely' different, how does **living in this house** compare to other houses you have lived in overall? [ANSWER AS HOUSEHOLD]

3. And on the same scale from 1 to 10, overall how much better or worse is it living in this house? [ANSWER AS HOUSEHOLD]

[IF HOUSE IS RATED '1' or '2' FOR Q. 2 or Q. 3 (I.E. MINIMAL DIFFERENCE), SAY YOU'D LIKE TO ASK SOME QUESTIONS TO EXPLORE ANY DIFFERENCES THEY CAN THINK OF, EVEN VERY SMALL ONES.]

The House

4. Comparing this house to other houses you have lived in: what specifically makes **the house itself** different in any way for you and your household (as a house)?

Living in this House

5. What specifically makes **living in this house** different in any way for you and your household?

6. Thinking about these differences. What are the effects of these differences for you and your household? [PROMPT ON DIFFERENCES MENTIONED IF THIS HELPS]. The effect of having [DIFFERENCE] is ....

7. So what do you gain by living in this house? What do you lose by living in this house?

Specific Features of This House

8. Which of these features (SHOW CARD) are making a difference for you?

9. Of those you chose, what difference does each make – what are the positives and negatives?

10. On the same scale, how much difference is this? [ONLY RATE ONES THAT ARE MAKING A DIFFERENCE]

Data

Your Household

1.	Total people ______	Adults ______	Teenagers ______	Children ______

Your Overall Rating

2.	Different ______	3.	Better ______	Worse ______

The House

4. Differences in the house itself

Living in this House

5. Differences in living in house	6. Effects	7. Gain	7. Lose

Specific Features of Living in this House

Aesthetics

1. The looks from the outside
2. The look from the inside

Space

3. The spaciousness
4. The interior layout
5. The indoor-outdoor flow

Privacy

6. Privacy from neighbours and people outside
7. Privacy and personal times and places within the house

Comfort

8. Cool in summer
9. Warm in winter
10. Heating needs

Airy

11. Fresh, airy feel
12. Easy to get good air flow

Lighting

13. Natural light (day time)
14. Lighting (night time)

Noise

15. Road noise
16. Noise from people inside the house
17. Noise from appliances

Security

18. Feeling safe and secure

Running Costs

19. Water bills
20. Electricity bills
21. Phone bills

Water

22. Solar water heating
23. Tank water

Ways of dealing with rubbish

24. Recycling
25. Composting

Other Features

26. Grab rails
27. Wide doorways
28. No-step shower tray
29. Extractor fans
30. Concrete floor

Things the Household Does

31. Using the clothesline
32. Using public transport for shops, schools or work etc
33. Walking to shops, schools or work etc
34. Cycling to shops, schools or work etc
35. Growing your own veges

Features	Positives	Negatives	Score
1.The looks of the outside			
2. The looks of the inside			
3. The spaciousness			
4. The interior layout			
5. The indoor-outdoor flow			
6. Privacy from neighbours and people outside			
7. Privacy and personal times and places within the house			
8. Cool in summer			
9. Warm in winter			
10. Any other heating or cooling needed			
11. Fresh, airy feel			
12. Easy to get good air flow			
13. Natural light (day time)			
14. Lighting (night time)			
15. Road noise			
16. Noise from people inside the house			
17. Noise from appliances			
18. Feeling safe and secure			
19. Water bills			
20. Electricity bills			
21. Phone bills			
22. Solar water heating			
23. Tank water			
24. Recycling			
25. Composting			
26. Grab rails			
27. Wide doorways			
28. No-step shower tray			
29. Extractor fans			

Features	Positives	Negatives	Score
30. Concrete floor			
31. Using the clothesline			
32. Using public transport for shops, schools or work etc			
33. Walking to shops, schools or work etc			
34. Cycling to shops, schools or work etc			
35. Growing your own veges			

Not all all									**Extremely**
1	2	3	4	5	6	7	8	9	10