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Final Monitoring Report from the Papakowhai Renovation project

Final

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About This Report

Title

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Abstract

The Papakowhai Renovation Project has monitored indoor environment, waste, water and energy parameters in nine homes in the Porirua suburb of Papakowhai before and after renovation packages were applied to the homes. This report presents an analysis of monitored data from three consecutive years (2006, 2007 and 2008). The first year included the period before the renovation, the second year included the period after the renovation, and the third year captured the effect of 'take back' in a second year after the renovation. Results showed that all homes had some improvements in energy use and/or space temperatures. Analysis against the Beacon HSS™ showed that most renovations were not sufficient to lift the homes to the HSS™, and suggested that other drivers such as occupant choice and behavior limited the outcomes.

Reference

Burgess, J.C. (Ed), Buckett, N.R., Camilleri, M.J.T., French, L.J., Pollard, A.R. & Hancock, P.J. (2008). Final Monitoring Report from the Papakowhai Renovation project. Report TE106/15 for Beacon Pathway Limited.

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1 Executive Summary

The Project

The Papakowhai Renovation Project has renovated 10 existing 1970s homes in the suburb of Papakowhai, Porirua. Each of the renovations was different although the renovations fell into the three categories of ‘Basic’, ‘Standard’ and ‘High’.

The Aim

The project had the dual aim as follows: first to assess the validity of several renovation assumptions developed in previous work; and secondly, to compare the pre-renovation performance of the homes with the post-renovation performance, and hence determine the effectiveness of these renovations against the HSS High Standard of Sustainability™ (HSS™). At the beginning of the project, the winter period was seen as the key season for assessment with the summer period used for renovations.

The Method

The performance of these 10 homes was assessed against the five Beacon performance areas of energy, water, IEQ, waste and materials.

Monitoring equipment was installed in these homes in July 2006 to measure the energy use of the homes, as well as the temperature in the main bedroom and the family room. In late December 2006, sensors were installed to measure the main bedroom relative humidity (RH) and in January-February 2007 meters were installed for total reticulated water use. Data was monitored for the winter of 2006 (July to September), before renovations were made between February and June of 2007. Then data was monitored for the 2007 winter period (May to September) immediately after the interventions, and again for the 2008 winter period to allow the performance of the interventions to settle, and to account for any take back in comfort. The data were analysed and reported as follows. Waste audits on the available homes were performed in March 2007 and October 2008. The 10 homes in the study were reduced to nine when P04 was sold in January 2007, and this home was removed from the sample, an unfortunate occurrence in real life monitoring.

The Results

The results showed that the renovations had improved many of the performance areas measured. The table below shows the changes in the energy and temperature performance areas for winter (see column headings) from before the renovation to after the renovation.

In this table ‘Less’ means less energy has been used after the renovation than before the renovation, ‘More’ means more energy has been used. ‘Unchanged’ (for both energy and temperatures) means that there was no statistically significant difference between the use before and after the renovations. In the two temperature columns, ‘Higher’ indicates that the average winter temperatures in the family room were warmer after the renovation and ‘Lower’ that the temperatures were cooler.

Winter result summary						
Home Number	**Total Reticulated Energy**	**Space Heating**	**Total Energy**	**Total Reticulated Hot Water Energy**	**Family Room Temps**	**Bedroom 1 Temps**
'High' package homes						
H-P03	Less	Less	Less	Less	Higher	Higher
H-P10	Less	More	More	Less	Higher	Higher
H-P08	Less	Less	Less	Less	Lower	Unchanged
'Standard' package homes						
S-P01	Less	Unchanged	Unchanged	Less	Higher	Higher
S-P05	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Higher
S-P09	Less	Unchanged	Less	Less	Higher	Higher
S-P07	Less	Unchanged	Unchanged	Less	Higher	Higher
'Basic' package home						
B-P02	Less	Unchanged	Less	Less	Higher	Higher
'Contrast' package home						
C-P06	Less	Unchanged	Less	Less	Lower	Lower

The Key Findings

The study showed that although not all of the HSS™ benchmarks were achieved, all of the Papakowhai homes had improved sustainability and comfort after the renovations.

Three of the five renovation assumptions[1] assessed in this work were supported, being:

- "Insulation alone is not enough – you need to include an efficient heating device to get significant energy savings and temperature improvements". **Supported**.
- "Current retrofit standards will not achieve a HSS™; much higher levels of retrofit are needed". **Supported.**
- Wall insulation on top of ceiling and under floor insulation may be required, combined with efficient heating, to get homes to the HSS™"**. Supported.**

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[1] ***The renovation assumptions are presented in the paper by Walford et. al., as noted in the references.***

One renovation assumption was not supported:

- *“Heavy insulation of ceiling and under floor may be sufficient to bring homes up to a HSS™”*. **Not supported.** The work showed that none of the homes receiving heavy insulation of just the ceiling and under floor reached the HSS™ benchmarks, although this does not prove that it is impossible.

And one renovation assumption could not be tested:

- *“Removing moisture sources will improve the relative humidity conditions in the homes”*. **N/A**. This renovation assumption could not be tested since the project did not make RH measurements before the renovations, although the RH measurements after the renovations are discussed.

Other key findings of this work were as follows:

- Solar water heating systems (SWH) installed into three homes gave very large reductions in the reticulated water heating energy ***during winter*** of between 55% and 70%, even though the ***consumption of hot water increased*** by over 20%. The summer performance of the SWH has not been assessed in this work. However typically summer performance is better than winter performance, and the winter performance was significantly improved.
- The insulation of existing storage electric hot water cylinders reduced their energy need by between 11% and 21%, although this is more than is expected just from the reduction in standing losses.
- Since, or accidentally, in which case it is an example of comfort take back. Other occupants maintained the same air temperatures, and used less space conditioning energy, in which case there were cost savings.
- Instant gas water heaters (replacing a storage electric system in one home) improved the availability of heated water, but had no effect on the water heating energy demand.
- Heat transfer kits (drawing heated air from the living rooms of the homes) may have assisted the thermal envelope improvements to increase the air temperatures in the main bedroom. It is suggested that the operation of heat transfer kits be looked at in greater detail, since their operation and performance is not well understood.
- RH levels in bedroom 1 can often be over 70% – it was only regular space heating of the main bedroom in one of the homes that allowed the RH level to stay below 70%.
- The renovations could not be shown to significantly affect organic waste handling or potable water management, but there was little incentive and no requirement for occupants to improve waste management practices or water consumption in this work.
- The introduction of worm farms for waste management purposes may reduce the use of the in-sink waste disposal systems, resulting in less reticulated water use, and less load on the municipal sewage treatment system. This study did not provide any conclusions, but further work in this area is warranted.

2 Introduction

This report is the final technical report of a pilot study involving the sustainable renovation and data logging of 10 homes over three years (2006-2008) in the Wellington suburb of Papakowhai.

The 10 homes, described elsewhere (Burgess & Buckett, 2008), were treated as individual case studies and instrumented to assess the performance against the benchmarks provided by the HSS™ concerning their normal use with their normal occupants over three years, focussing on the winter periods. The effect of the renovations was also assessed to determine the improvements in a variety of sustainability parameters as well as the performance areas that are the subject of the HSS™ benchmarks. The energy use, internal space temperatures, water use, internal RH and solid waste produced by the homes were measured with data logging instruments. Significant renovations were designed and installed part-way through the project, and included such diverse interventions as double-glazing, wall insulation, low-flow water devices, SWH systems, polythene-sheet ground cover, a pellet burner and worm farms. Logging continued after these renovations, allowing the impact of changes in the HSS™ performance areas of reticulated energy use, water use, indoor environment quality (IEQ) and waste to be assessed, and improvements to be discerned.

3 Aim

This work presents the data from a set of case studies, undertaken to test the validity of a set of assumptions (Walford et al., 2005) about home renovation sustainability issues.

The renovation assumptions are:

- "Insulation alone is not enough – you need to include an efficient heating device in conjunction with insulation to get significant energy savings and temperature improvements".
- "Current retrofit standards will not achieve a HSS™; much higher levels of retrofit are needed".
- "Heavy insulation of ceiling and under floor may be sufficient to bring homes up to a HSS™".
- Wall insulation on top of ceiling and under floor insulation may be required, combined with efficient heating, to get homes to the HSS™".
- "Removing moisture sources (polythene on ground, extract fans, shower domes) will improve the relative humidity conditions in the homes".

A concurrent aim has been to reveal how the renovations have helped the homes to achieve the Beacon HSS™ and improve other sustainability parameters.

The benchmarks of the HSS™ performance areas are currently (December 2008) being updated, and so the version that has been used for comparison is reproduced in Table 1.

HSS High Standard of Sustainability™ benchmarks				
		Benchmark in Climate Zone 1	Benchmark in Climate Zone 2	Benchmark in Climate Zone 3
Energy use		New homes: 7,600 kWh/yr Existing homes: 9,050 kwh/yr	New homes: 8,500 kWh/yr Existing homes: 11,000 kwh/yr	New homes: 9,800 kWh/yr Existing homes: 12,000 kwh/yr
Water use		180 litres/person/day (L/p/d)		
IEQ	Temperature	16°C bedroom mean min temp 18°C family room mean min temp		
	Ventilation	New homes: 0.4-0.6 air changes per hour Existing homes: 0.5-0.75 air changes per hour		
	Relative humidity (RH)	Mean RH 20-70% in bedrooms and living space		
	Checklist	Mechanical extract ventilation of kitchen, bathroom and laundry Windows with passive venting No unflued gas heaters Environmental Choice certified paints and finishes No air conditioning		
Waste		Provision for kitchen waste composting or storage space for kitchen waste collection Space for recyclables storage No in-sink waste disposal unit New building construction or renovation in accordance with REBRI construction guidelines		
Materials		<u>New homes</u>: materials which – promote good indoor air quality have minimal health risks during construction or renovation are durable and have low maintenance requirements incorporate recycled content or can readily be recycled re-use existing or demolished building materials or can readily be re-used are made from renewable or sustainably managed resources have low embodied energy including minimal impacts due to transport have low impact on landfill or are biodegradable minimal impact on the environment (air, water, land, habitats and wildlife) have third-party certification (e.g. NZ Environmental Choice, Forest Stewardship Council) <u>Existing homes:</u> intervention or renovation applies principles from materials checklist where appropriate		

Table 1: HSS High Standard of Sustainability™ benchmarks (Easton 2006)

For the temperature benchmarks used in this report the analysis sections show how these were further defined

4 Methodology

The renovations made in the 10 homes were referred to as 'Basic', 'Standard' or 'High' packages, as described in a previous report (Burgess & Buckett, 2008) and shown in Table 2. Three homes received 'High' renovation packages, four homes received 'Standard' packages, and one home received a 'Basic' package. One home was sold, and one was left without renovations to provide a 'Contrast' home, although this home did eventually receive ceiling insulation late in the renovation period, and also accidentally received a hot water cylinder wrap. The renovation packages were not identical, being tailored to suit each home, and intended to lift the homes to higher levels of sustainability.

Renovation packages	
H-P03	High + Solar Hot Water
H-P10	High + Solar Hot Water + Wetback
H-P08	High + Solar Hot Water
S-P01	Standard + Pellet Burner
S-P05	Standard + Gas Hot Water
S-P09	Standard
S-P07	Standard + High Insulation
B-P02	Basic
P04	SOLD[2] – No Renovations
C-P06	Contrast

Table 2: Renovation packages

The value of the generic renovations provided here has been summarised in a separate report (Page, 2008). The actual interventions have been categorised under the five performance areas see Appendix (Section 9.2), although four have been used in this analysis. These performance areas are as follows: water, waste, energy (sub-categorised into space heating and lighting, and water heating), and IEQ. Results are grouped in all further tables by the type of intervention shown in Table 2 as 'High', 'Standard' or 'Basic', with the results from the 'Contrast' home also included. The homes are referred to as follows – the 'High' package homes (H-P03, H-P10, H-P08), the 'Standard' package homes (S-P01, S-P05, S-P07, S-P09), the 'Basic' package home (B-P02) and then P04 (Sold), and the 'Contrast' home (C-P06).

[2] ***Since P04 was sold, it will not be included in further analysis.***

Renovation summary – 'High' package homes						
Home	Thermal	Hot Water	Heating	Water	Waste	Moisture Control
H-P03	Heavy ceiling and under floor, full wall insulation Double-glazing	Solar hot water system	New wood burner. Existing two heat pumps replaced April 2008 by ducted heat pump	Plumbing check Two dual flush toilets	Worm farm	Vapour barrier on ground
Costs	$64,290	$10,060	Included in thermal	$170	$160	$1,910 (IEQ)
H-P10	Heavy ceiling and under floor insulation Full wall insulation Double-glazing	Combined solar hot water wetback system	New wood burner	Plumbing check and leaks fixed	Worm farm	Extractor fans in bathroom and laundry Vapour barrier on ground
Costs	$59,925	$12,065	Included in thermal.	$300	$160	$1,620
H-P08	Ceiling and heavy under floor insulation Wall insulation added against gym wall, rest of walls un-insulated Double-glazed units inserted into existing frames	Solar hot water system	None	Plumbing check	Worm farm	Shower dome Vapour barrier on ground
Costs	$13,110	$9,870	Included in thermal	$80	$160	$1,390

Table 3 Renovation summary and costs for 'High' package homes

Renovation summary – 'Standard' package homes						
Home	Thermal	Hot Water	Heating	Water	Waste	Moisture Control
S-P01	Heavy ceiling + Under floor insulation	Hot water cylinder wrap and lagging	Pellet burner replaced wood burner Heat transfer kit	Plumbing check	Worm farm	Vapour barrier on ground
Costs	$19,180	$90	Included in thermal section	$80	$160	$4,100
S-P05	Ceiling insulation top-up, heavy under floor insulation (Note: existing wall insulation in home)	Two gas instant hot water systems replaced electric cylinder Low-flow shower head	Heat transfer system	Plumbing check Low flow shower head	Worm farm	Bathroom extract ducted outside Vapour barrier on ground
Costs	$2,895	$4,520	Included in thermal	$80	$160	$3,035
S-P09	Ceiling insulation top-up Heavy under floor insulation and mid floor insulation Wall insulation added to one wall	Hot water cylinder wrap	Heat pump	Plumbing check	Worm farm	Shower dome Vapour barrier on ground
Costs	$6,905	$90	Included in thermal	$80	$160	$595
S-P07	Heavy ceiling and under floor insulation Partial wall insulation (bedrooms)	Hot water cylinder wrap and pipe lagging	Heat transfer system upgraded and fixed	Plumbing check	Worm farm	Bathroom extract ducted outside Shower dome Vapour barrier on ground
Costs	$5,245	$90	Included in thermal	$80	$160	$2,065

Table 4 Renovation summary and costs for 'Standard' package homes

Renovation summary – 'Basic' and other package homes						
Home	Thermal	Hot Water	Heating	Water	Waste	Moisture Control
B-P02	Re-laid and topped up low level ceiling insulation Heavy under floor insulation	Hot water cylinder wrap and lagging	None	Plumbing check	Worm farm	Vapour barrier on ground, shower vent fan system extended
Costs	$785	$90	Included in thermal	$80	$160	$1,005
P04 (Sold)	None	None	None	None	None	None
C-P06	Ceiling insulation top-up	Hot water cylinder wrap and lagging	None	None	None	None
Costs	$1380	Nil	None	None	None	None

Table 5: Renovation summary and costs for 'Basic', 'Sold' and 'Contrast' package homes

4.1 Overview

The Sustainability – by performance area section (Section 5) presents the results that were obtained in this work, looking first (Section 5.1) at the improvements obtained in energy use and internal temperatures in winter. This includes Section **5.1.4** which assesses the effect of installing water heating systems using non-reticulated energy in several of the homes, and Section **5.1.6** which assesses the energy use against the HSS™. Section **5.2** assesses the other IEQ performance areas against their HSS™ benchmarks. Section **5.3** presents the water consumption data and analysis, and Section **5.4** the waste data and analysis, both assessed against the HSS™.

A summary of the achievement of the HSS™ benchmarks in all the performance areas is then presented in Section **6.1**, with the improvements against the non-HSS™ performance areas included in the Appendix (Section **9.5**).

The integrity of the data is covered in Section **6.1**, before considering the effect of the renovations in a section on the testing of the renovation assumptions (Section **6.2**).

The 'materials' and 'ventilation' HSS™ performance areas do not have separate sections in this report. The Resource Efficiency in Building and Related Industries (REBRI) principles (Clark, 2007) were followed for the material use in the renovations (construction and demolition), but no assessment was made of the existing material use. In the ventilation area, it had been intended to perform blower door tests of the homes before the renovations but this was not scheduled. The other ventilation interventions are discussed under the IEQ section.

5 Sustainability – by performance area

5.1 Energy and temperatures – winter

The analysis of the energy use and temperatures of the Papakowhai homes is reported comparatively here for the pre-renovation winter period (June to September 2006) and the post-renovation period for the winter heating season (May to September 2008). The early parts of this section (up to Section **5.1.5**) do not address performance against the HSS™, which is discussed in Section **5.1.6**. The five month winter heating season of May to September was chosen on the basis of the results from the HEEP work (Isaacs et. al., 2003).

Where there is useful information in the analysis of the 2007 heating season (the intermediate period) – previously reported in the Interim report (Burgess & Buckett, 2008) – this has also been added.

5.1.1 Method

To enable year-to-year comparisons between the pre- and post-renovation periods for energy-use and space temperatures, an adjustment has been made to the analysis to account for climate variability year-on-year. This was achieved by correlating the energy consumption of the various end uses (total electricity, total energy, and space and water heating) with the average weekly external air temperature. Previous HEEP (Isaacs et. al., 2003) analysis has shown that the average external air temperature is an important driver of household energy consumption, and generally has a strong correlation to household energy consumption for total heating, hot water heating, and for average 24 hr internal temperatures. The data were interpolated for the May-September period. This interpolation effectively compensates for any periods of missing data, and minimises the effect of any atypical period, for example, if the occupants were away.

An example of the correlation of average external temperature to electricity consumption is given in Figure 1, where a pair of lines has been fit to the data of interest (up to 16°C) – in this example for the pre-renovation and the post-renovation situation. Here it can be seen that at higher external air temperatures there is less total electricity consumption for this home.

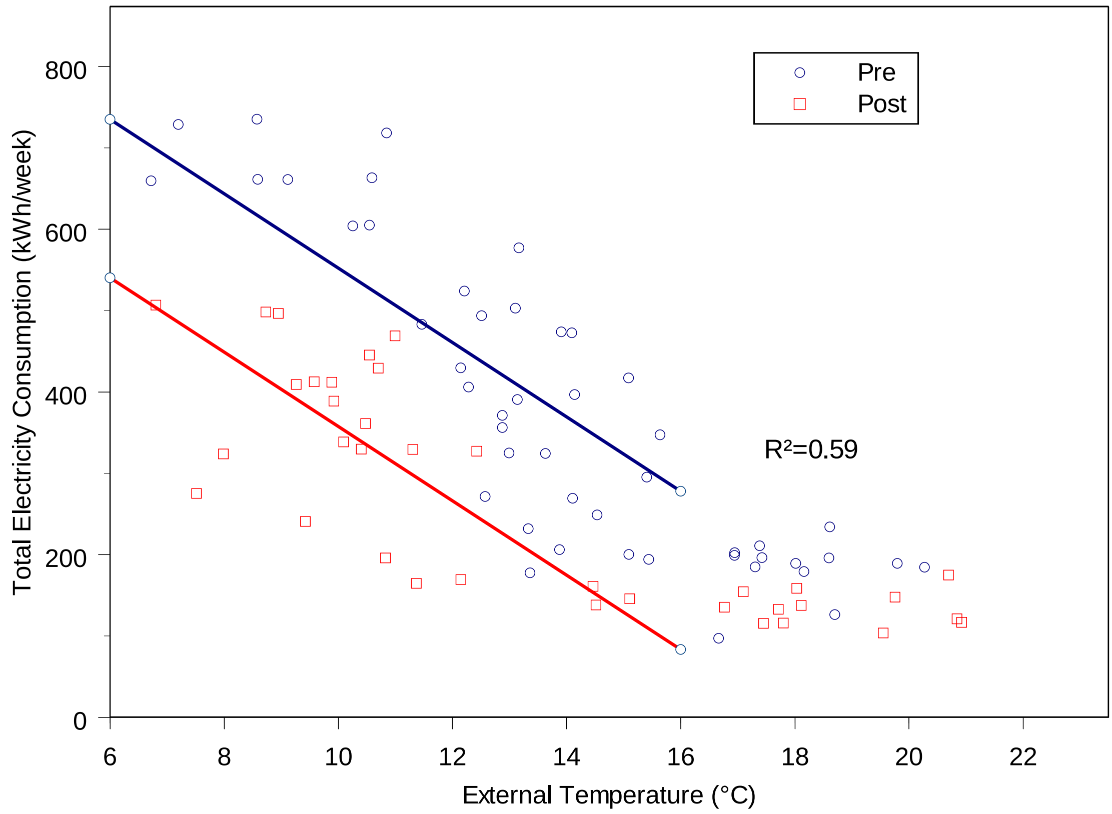

Figure 1: Example of the pre- and post-intervention total electricity consumption by weekly average external temperature

5.1.2 Heating season results

The normalised average energy consumption and normalised temperatures are reported in Table 6 for the pre-renovation, the intermediate, and the post-renovation winter heating season, interpolated to the May-September months within each year.

More data was available for this report in the post-renovation period than for the Interim report (Burgess & Buckett, 2008), and this extended data has been analysed. This means that numbers reported here may be different from the Interim report, for both before and in the intermediate year after the intervention. The Interim report (Burgess & Buckett, 2008) compared the pre-renovation data with the incomplete post-renovation data from the 2007 year, whereas this report has compared the pre-renovation data with the post-renovation data from the 2008 year, which includes the effect of any comfort take-back – a key requirement of this work. See the Appendix (Section 9.6) for the executive summary of this Interim report.

Heating season energy and temperatures by end use							
Home No.	**Pre-renovation Intermediate or Post- renovation**	**Total Reticulated Energy[3] (kWh)**	**Space Heating (kWh)**	**Total Energy (kWh)**	**Total Reticulated Hot Water Energy (kWh)**	**Average 24 Hr Family Room Temps (°C)**	**Average 24 Hr Bdrm 1 Temps (°C)**
'High' package homes							
	Pre	7,550	2,120	8,970	2,130	17.8	15.7
H-P03	Intermed.	6,460	1,410	7,590	860	17.5	16.8
	Post	5,070	810	5,670	970	19.5	19.5
	Pre	4,090	1,650	6,460	2050	16.3	14.0
H-P10	Intermed	2,280	1,750	5,760	420	17.6	15.8
	Post	3,160	1,940	7,040	600	17.7	16.0
	Pre	12,980	4,620	12,980	1,630	18.0	17.2
H-P08	Intermed.	10,510	4,280	10,510	340	19.1	17.9
	Post	8,760	3,900	8,760	480	17.1	17.1
'Standard' package homes							
	Pre	6,410	820	6,870	3,290	14.7	13.2
S-P01	Intermed.	6,370	640	6,740	3,390	15.5	14.2
	Post	5,930	970	6,540	2,900	15.8	14.7
	Pre	10,970	7,870	10,970	1,070	16.6	12.7
S-P05	Intermed.	10,150	6,950	10,150	970	16.7	13.0
	Post	10,270	7,470	10,270	1,050	16.5	13.3
	Pre	3,530	400	3,530	980	16.5	15.1
S-P09	Intermed.	2,890	390	2,890	820	16.4	15.6
	Post	2,820	480	2,820	770	16.9	15.5
	Pre	3,860	1,540	5,070	990	13.6	12.4
S-P07	Intermed.	3,490	1,890	5,120	850	14.7	12.9
	Post	3,110	1,670	4,570	700	14.7	13.4
'Basic' package home							
	Pre	2,530	3,010	6,130	1,140	14.9	13.1
B-P02	Intermed.	2,370	2,370	4,720	1,020	16.5	14.4
	Post	2,380	2,850	5,140	1,010	16.5	14.2
'Contrast' home							
	Pre	3,400	1,530	4,710	1,070	14.4	12.9
C-P06	Intermed.	2,750	1,580	4,040	770	14.4	12.6

[3] *See text for what is covered in these columns.*

	Post	2,570	1,460	3,750	650	13.7	12.0

Table 6: Energy and temperatures by end use (pre-renovation winter 2006 and post-winter 2008)

Table 6 has three line entries for each home, listed by the 'P' number assigned to each home. (P04 was *removed* from the analysis when it was sold in January 2007.) The first line for each home presents the data for the pre-renovation period (2006 winter). The second line for each home presents the data for the intermediate period (2007 winter), and the third line is for the post-renovation period (2008 winter).

The first data column is labelled 'Total reticulated energy', and is the sum of the electricity and gas provided to the home in kWh during the heating season. Reticulated gas was only provided to S-P05, so in all other cases this column presents just electricity. (Bottled LPG was used in C-P06 and is included in the space heating and total energy columns.)

The second data column is headed 'Space heating' and includes all the **monitored** space heating used in the five month heating season in kWh from the major heating sources i.e. electricity, solid fuel and bottled gas. Since 'plug-in' electric heaters were not monitored (these were available in all the homes), nor was the effective space heating contribution from the operation of other appliances (lighting, refrigeration etc) – this column is not the sum of all the space heating. (A rough assessment of the space heating used in the heating season can be obtained from subtracting the total hot water energy column from the total energy column, which will leave you with the sum of space heating and appliance energy consumption.)

The third column is labelled 'Total energy' and includes in kWh the sum of the reticulated energy (electricity and gas), and the energy from solid fuel burners for the heating season (including wetback contribution), but does not include energy provided from solar sources (H-P03, H-P08, H-P10).

The fourth column is labelled 'Total reticulated hot water energy' and includes in kWh the total of the reticulated (electricity and gas) energy used to heat water in the heating season. The solar energy contribution will be calculated in a separate report.

The 'Average 24 hr family room' and 'Average bedroom 1 temperatures' in columns five and six of this table are an average of all the data over the heating season, and are discussed in relation to the HSS^{TM} in the IEQ section (Section **5.2**).

Table 7 uses the same column headings, and interprets Table 6, to summarise the statistically significant changes (these are at a 95% confidence level) made in the consumption of energy and in the temperatures found in the family room and bedroom 1 of the homes. The contribution from solar is not addressed in this table, but is discussed in Section 5.1.4. Energy was supplied both from reticulated sources (electricity and gas) and as bottled gas, solid fuel and harvested solar energy (SWH systems).

The notation in Table 7 of 'Unchanged' means that the difference between the variable in the pre-renovation period (see Table 6) is not statistically significantly different from the value for the variable in the post-renovation period. 'Less' indicates that less energy has been consumed, and 'Lower' that the temperature is lower in the post-renovation period compared with the pre-renovation period.

‘More’ indicates that more energy has been used, and ‘Higher’ that the temperature is higher in the post-renovation period than in the pre-renovation period.

Summary of winter changes in energy and temperatures							
Energy						Temperatures	
Home No.	Energy Intervention Cost (NZ$ exc GST	Total Reticulated Energy[3]	Space Heating	Total Energy	Total Reticulated Hot Water Energy	Average 24 Hr Family Room Temps	Average 24 Hr Bdrm 1 Temps
‘High’ package homes							
H-P03	$74,350	Less	Less	Less	Less	Higher	Higher
H-P10	$71,990	Less	More	More	Less	Higher	Higher
H-P08	$22,980	Less	Less	Less	Less	Lower	Unchanged
‘Standard’ package homes							
S-P01	$19,270	Less	Unchanged	Unchanged	Less	Higher	Higher
S-P05	$7,415	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Higher
S-P09	$6,995	Less	Unchanged	Less	Less	Higher	Higher
S-P07	$5,335	Less	Unchanged	Unchanged	Less	Higher	Higher
‘Basic’ package home							
B-P02	$875	Less	Unchanged	Less	Less	Higher	Higher
‘Contrast’ home							
C-P06	$1,380	Less	Unchanged	Less	Less	Lower	Lower

Table 7: Statistically significant changes in energy and temperatures

The table also shows by the shading, where light green is an improvement and light red a poorer result. (Note that a ‘Higher’ result for internal temperature in winter in this table is a good result, while a ‘Less’ result in the energy use is a good result.)

There have been statistically significant changes in the usage of some of the measured parameters in all of the homes.

5.1.3 Winter performance discussion

The following results are presented for the energy analysis above for the five month heating season, and concern statistically significant changes in the parameters measured:

- H-P03 – For this ‘High’ package home, the family room temperatures increased by 1.7°C compared to the post-renovation period, and bedroom 1 temperatures by 3.8°C. Despite these large increases in temperatures the energy consumption actually decreased for space heating (62%), total reticulated energy (electricity (33%)) and total energy (37%). There were major changes in the space heating system after the renovations in April 2008, and major changes in the heating usage also. The heat pump in the lounge was removed, and a ducted central heating heat pump system installed. From examination of the data it appears that the solid fuel burner was used much less in 2008 than in 2007, and the heat pump-driven central heating system used instead. The decrease in total energy consumption was probably due to the higher efficiency of the heat-pump central heating system (likely ~200-300%) compared to the solid fuel burner (likely 60-70%), together with the higher insulation of the home envelope. Total electricity consumption has also dropped, which might be caused in part by the central heating system being used to heat the bedrooms rather than portable electric heaters, together with the higher envelope insulation. Reticulated hot water energy consumption in H-P03 decreased by ~55%, due to the SWH system installed. There was no change in the electric energy consumption of the SWH system between 2007 and 2008 after the renovation. This home received insulation to the complete thermal envelope, from the highly insulated ceiling, to the insulated walls with double-glazing, and the insulated floor. The office operating from the downstairs area in the daytime had an unknown effect on this home. Staff numbers varied from one to three during the analysis period. Given the changes to the space heating system in this home, coupled with the change in daytime occupancy due to the commercial premises downstairs, it is difficult to attribute benefit in this home. It is clear however that this home has had significant improvements in its indoor environment, and the joint effect of the thermal envelope improvements and the space heating improvements has been very good in this ‘High’ package home, with all the parameters in the tables (Table 6 and Table 7) improving.

- H-P10 – In this ‘High’ package home, total electricity (reticulated energy) consumption decreased by ~23%, monitored space heating energy increased by ~18% and total energy consumption (not including solar) increased by ~9% in the heating season. Reticulated hot water electricity consumption decreased by ~70%, although if the energy harvested from the wetback is included, the energy used by the hot water system increased by 19%. A further report will assess the energy utilised by the solar collectors, which will show that the energy used to heat water (reticulated and harvested) increased significantly. During the May-September period almost all the energy was being supplied by the wetback and solar connections. Family room temperatures were 1.4°C higher after the renovation, and the bedroom 1 temperature was 2°C higher, indicating that the bedroom 1 was probably still being heated with an oil column heater since there was no heat transfer system. Both the total energy and the monitored space heating energy increased. Much of the interim energy savings found in the Interim report (Burgess & Buckett, 2008) have been taken up as increased service, although the space air temperatures did not change significantly between the intermediate and post-renovation years. The social analysis in the CRESA report (Saville-Smith, 2008) shows that this household made a conscious decision to benefit from the ‘free’ hot water provided by the SWH system and wetback. This home received high levels of ceiling, floor and wall insulation together with double-glazing, a new solid-fuel burner with a wetback and SWH system. These interventions (fully insulated envelope and solid-fuel burner change) resulted in significant improvements to the space temperatures. The combined wetback/SWH system also provided significant improvements to the use of reticulated energy for water heating.

- H-P08 – This 'High' package home showed a total electricity consumption (which was also total energy in this home) decrease of ~33% after the renovation. The energy consumption for the night store heater was not shown to be significantly different in the 2007 winter immediately after the 2007 renovation. However, the difference in energy consumption between the 2008 season and the 2006 pre-renovation period for this heater is significant, at 16% lower. Temperatures increased in 2007 after the renovation by 1.1°C in the family room and 0.7°C in the bedroom 1, but then decreased in the 2008 winter season. The end result was a temperature 0.9°C lower in the family room, and no statistically significant difference in the bedroom 1 temperature. This drop in temperature in the 2008 winter season is likely to be partly due to the decrease in use of the night store electric heater. Reticulated hot water energy consumption decreased by ~70% after the renovation, due to the installation of the SWH system, with the total energy use not statistically significantly different between the 2007 and 2008 heating seasons. This home received high ceiling and floor insulation, together with double-glazing, but no wall insulation. One interpretation of these results is that wall insulation is necessary to significantly improve indoor temperatures, and that double-glazing by itself may not be sufficient. However, this is only a result from one home, and also does not account for social factors.

- S-P01– There was a statistically significant decrease of ~7% in reticulated electricity (reticulated energy) consumption after the renovation. There was no statistically significant change in either monitored space heating (solid fuel) or total energy consumption. Hot water energy consumption decreased by ~12%, although the only intervention in the water heating was the installation of a hot water cylinder wrap. The temperatures in the family room increased by 1.1°C, and by 1.5°C in bedroom 1. These higher temperatures have been achieved without increasing energy consumption. This home had changes to both its space heating (a pellet burner and a ducted heat transfer system) and to its thermal envelope, where the ceiling was highly insulated, and R-2 under floor foil-backed insulation was installed, although no wall insulation was installed. The heating system allowed bedroom 1 to be heated, helping to achieve the higher winter air temperatures.

- S-P05 – In this 'Standard' package home, there was no change after the renovation in space heating energy use, or in hot water energy use (see Table 6 and Table 7). While the total electricity consumption decreased by ~35%, this was replaced by an approximately equal amount of gas energy consumption, resulting in no change in total reticulated energy consumption. There was no statistically significant difference in family room temperatures, although bedroom 1 temperatures increased by 0.6°C. This 'Standard' package home received two instant gas water heaters, had ceiling insulation topped up and floor insulation added, together with a ducted heat transfer system, but no wall insulation.

- S-P09 – Total electricity consumption (which was also total energy in this home) decreased by ~20% after the renovation. There was no statistically significant difference in monitored space heating energy consumption, which was the lowest space heating energy use total for any home in this work (although plug-in heaters were not assessed). Hot water energy consumption decreased by ~21% after the renovation. Family room temperatures increased by 0.4°C, and the bedroom 1 temperature increased by 0.4°C. This home received a wrapped cylinder and lagged pipes, together with some ceiling and floor insulation, plus a small amount of wall insulation, where a wall was adjacent to a sub-floor area. While there has been a good improvement in the water heating energy use, it appears that the heat pump in this home was not performing as well as expected. It is possible that the occupant was not operating the heat pump efficiently, and still using a portable heater in the bedroom 1. There is also a large downstairs area that is not directly heated by the heat pump – if this area was used in the evenings (not reported) then this could help account for the unchanged space heating results. This home had low levels of wall insulation before the renovation.

- S-P07 – The analysis in this report has resulted in a change in the conclusions from the Interim report (Burgess & Buckett, 2008). Some small changes which were not statistically significant between the pre-renovation and the 2007 renovation periods have now been found to be statistically significant with the comparison from the pre-renovation to the 2008 post-renovation data. Total electricity consumption was about 20% lower. There was no statistically significant change in space heating use, or in total energy. Hot water energy consumption was about 30% lower after the renovation. Family room temperatures increased by ~1.1°C after the renovation, and the bedroom 1 temperatures by ~1.0°C. This home received ceiling insulation top-ups and floor insulation, together with a relocated heat transfer unit, and their old hot water cylinder was wrapped and the pipes lagged. This renovation shows the benefit of performing space heating improvements in conjunction with envelope insulation improvements.

- B-P02 – In this 'Basic' home, total reticulated energy consumption decreased by ~6% and total energy consumption by ~16% after the renovation. Heating energy consumption was unchanged (although was lower in the 2007 winter). Hot water energy consumption decreased by ~11%, helped by a hot water cylinder wrap and pipe lagging. The temperatures in the family room increased by 1.6°C, and by 1.1°C in the bedroom 1. These higher temperatures have been achieved without increasing space heating energy consumption. The home received a highly insulated floor, slightly improved ceiling insulation, and the existing shower extract fan was extended and repaired. This home has shown very good improvements for very little intervention.

- C-P06 – The analysis of the data from the pre-renovation situation to the 2008 analysis has resulted in a change in the conclusions from the Interim report (Burgess & Buckett, 2008), which analysed the difference between the pre-renovation and the immediate 2007 winter. The 2008 heating season analysis shows a significant decrease in total electricity consumption (~24%), total energy consumption (~20%), and total hot water consumption (~40%), with no change in space heating energy use (see Table 6 and Table 7). The temperatures decreased by 0.7°C in the family room and 0.9°C in the bedroom 1 which was unexpected, but may be explained by the absence of three family members, and subsequent change to comfort expectations. There was an unplanned addition of a hot water cylinder wrap to the hot water storage cylinder system, which coupled with the occupancy reduction from five to two, resulting in the reduction in hot water energy use. It is possible that there were some unrecorded holiday, weekend and overnight visits by the three adult children, which reduced in frequency during the study period, and which will have influenced the hot water energy use. This thermal envelope of this home only received a ceiling insulation top-up, so the renovations cannot be claimed to be the cause of the space heating changes.

Homes S-P01, S-P05, and S-P07 all had heat transfer units installed or modified in this project (the modifications to B-P02 were to the moisture extract system in the shower). These systems took heat from the main heated room and distributed it to other rooms in the house. (Note: these are not the DVS/HRV/Moisture Master type systems which draw air from the ceiling space.) While the improvement in these homes cannot be solely attributed to the heat transfer systems, these appliances assisted these homes in achieving higher bedroom 1 temperatures. A specific study of heat transfer kits needs to be performed since it is assumed that the quantity of heat energy that can be carried in these situations is not large.

5.1.4 Water heating with non-reticulated fuel

This section assesses the performance of the water heating systems which were primarily heated with non-reticulated fuels (three using solar energy, with one of these also incorporating a wetback). This analysis is for the five month heating season. The annual performance of the SWH systems will be addressed in a separate report. The water heating systems fuelled with reticulated energy (electricity and reticulated gas) have already been discussed in Section 5.1.3, with an overview of all water heating systems presented in Section 5.1.5.

5.1.4.1 Method

As a major renovation for water heating, the storage electric water heating systems in H-P03, H-P08 and H-P10 were replaced with SWH systems with electric back-up. The system in H-P10 also had a wetback connection to a solid fuel burner.

The location and orientation of the solar collectors was designed by a solar engineer (retained by the system supplier) to maximise the output of the systems, and the same large collector was installed in each home. Consequently, some of the choices made (e.g. the collector area was double the typical area) may be different from the parameters recommended in other SWH programs.[4]

The water heating analysis for the solar and wetback heated homes uses results from meters that were installed at the time of the renovation, so there are no data available for the volume of hot water consumption before the renovation.

A full examination of the performance of the SWH systems will be carried out in a separate study, so only an overview is presented here.

[4] ***For example the EECA Energywise solar water heating grant has a threshold for financial assistance for each brand of packaged solar water heating system. It is possible that the collector area was increased on the systems provided to this project, since the system cost was above the threshold for receiving the EECA subsidy, and would result in more solar energy harvesting.***

5.1.4.2 Results

Table 8 shows the change in reticulated energy consumption for water heating during the heating season, alongside the cost of the interventions.

Energy needed for water heating in winter		
Home	Decrease In Reticulated Water heating Energy Need (%) (May-Sep)	Cost of Water Heating Intervention ($)
H-P03	55	$10,060
H-P10	70[5]	$12,065
H-P08	70	$9,870

Table 8: Solar hot water system reticulated energy change

There were major reductions in reticulated energy need for the water heating in these three homes, but all three increased their use of hot water in the year after the systems were installed (see Table 9). No measurement of the hot water volume was made before the renovations.

Table 9 shows the change in the volume of water heated after the installation of the renewable water heating systems.

Volume of water heated in winter		
Home	Change In Average Monthly Heated Water Consumption (litres/month) (May-Sep[6] Average, 2007-2008)	Change In Average Monthly Heated Water Consumption (%) (May-Sep[6] Average, 2007-2008)
H-P03	+1,600	+21%
H-P10	+2,300	+29%
H-P08	-1,000	-32%

Table 9: Heated water consumption after renovation

5.1.4.3 Discussion

The SWH systems resulted in large reticulated energy savings, even with the increased water use in H-P10 and H-P03. These systems: were well-sized (featuring two 12 collector arrays connected together); had the collectors installed at a steep angle (at the latitude angle, 41°); were connected to

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[5] *This includes the effect of the wetback and the solar hot water system.*

[6] *Data for the water meters was not available in May or June of 2008, so the average for 2008 is a three month average value, not a five month average.*

cylinders designed for additional heat input; and had a controller that managed the operation of the heating element.

In H-P10, the occupants made a conscious decision to make use of the 'free' hot water (Saville-Smith, 2008), and greatly increased (29%) their use of hot water. This may indicate that there was a deficit in the supply previously compared with the household desired hot water use. However due to the fuel-switching from reticulated to renewable (solar and wetback), the increase in hot water demand was met, and reticulated energy consumption decreased by 70%.

The amount of energy the SWH systems saved can be examined by comparing the electrical energy used for water heating before the intervention with the electrical energy use of the SWH system (which includes supplementary heating and operation of the pump and controller) after the renovations. This type of comparison has been used in this report over winter to study the effectiveness of the SWH systems.

The systems were monitored in such a way (including water flow into the system as well as the inlet and outlet system temperatures) to allow a complete system measure to be made of the effectiveness of the SWH systems. This method allows the energy balance of the systems to be examined, like the assessment for the Waitakere NOW Home® shown in Figure 2 (Pollard et. al., 2008).

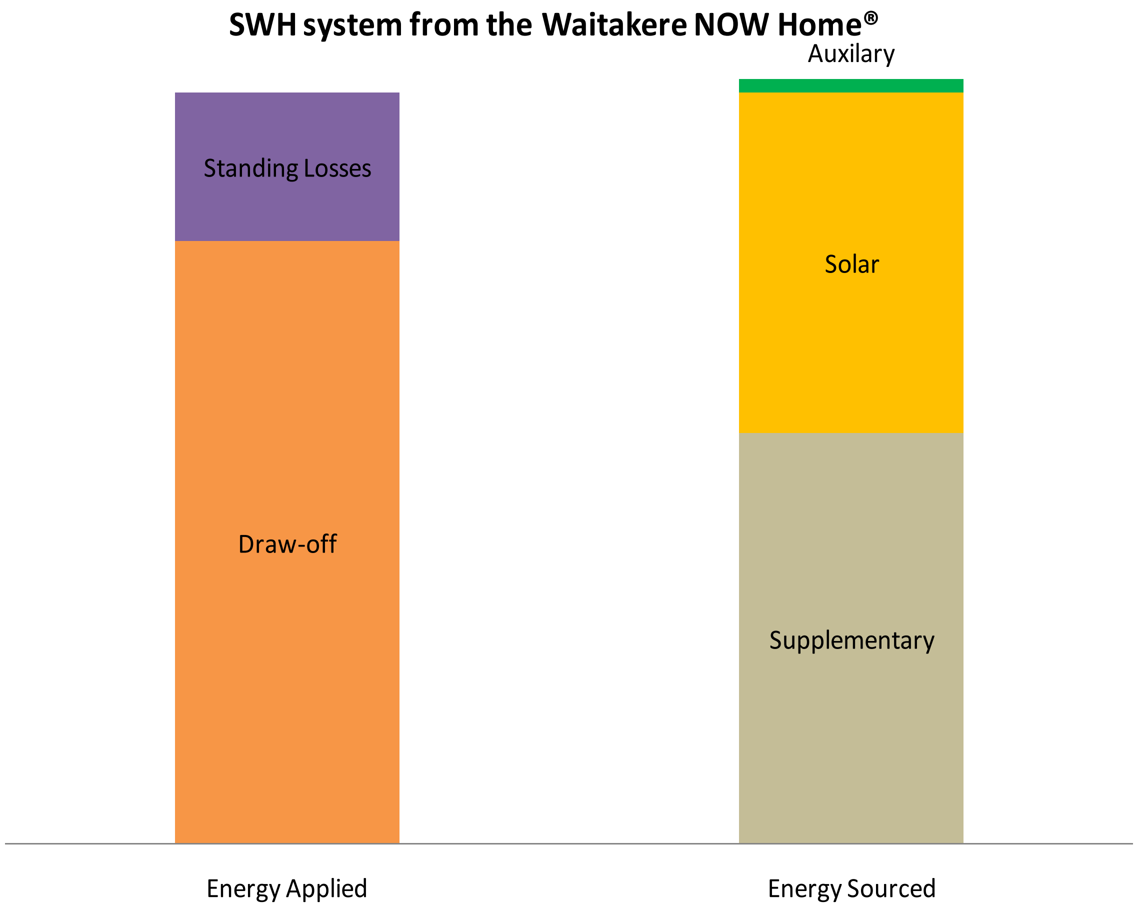


Figure 2: SWH system from the Waitakere NOW Home®

This balance allows confirmation that a good level of service is provided from the SWH system and that heated water is delivered efficiently so that both the supplementary heating and the heat (standing) losses in the system are small.

This process is not used in this report for the full year, but a separate report will analyse the annual performance of the SWH systems. This separate report will allow the well-performing Papakowhai systems to be compared against a wider variety of systems such as those examined in the BRANZ SWH research programme (Pollard & Zhao, 2008).

5.1.4.4 Wetback water heating – discussion

A wetback water heating system was installed in H-P10, to operate in conjunction with the SWH system. A small solid fuel burner was chosen that had a lower than usual space heating output, and a much higher than usual water heating output. A typical solid fuel burner would have overheated the now well-insulated space, whilst producing little or no water heating output.

During the May-September 2008 post-retrofit period the wetback water heating system supplied 2,000 kWh. Electricity consumption over the same period was 600 kWh, compared to 2,050 kWh of electric energy consumed during the heating season of the pre-retrofit period, a reduction of ~70%. The wetback provided a large amount of useful energy and, in combination with the SWH system, provided most of the May-September hot water energy, even though the hot water consumption of the home increased by nearly 30%. If the household demand for hot water had not increased, then the electricity consumption for water heating in the May-September period would have been very low, possibly even zero. The combination of wetback and SWH has been very effective at reducing reticulated energy consumption for water heating.

5.1.5 Water heating – discussion

This section summarises the water heating energy results from Section 5.1 using reticulated fuels, and the water heating energy results from Section 5.1.4 using non-reticulated fuels.

The wrapping of the hot water cylinders and the lagging of the pipes has had very good results.

Of the five homes that received cylinder wraps, Table 6 shows there were 11% (B-P02, 1970s), 12% (S-P01, 2003), 21% (S-P09, 2000), 30% (S-P07, 2005) and 40% (C-P06, 1970's) reductions in electric energy consumption for water heating – with the age of the cylinder being noted in the brackets. This suggests that this relatively low-cost intervention is particularly useful.

The Year 9 HEEP report (Isaacs et. al, 2005) found an average of around 10% reduction in energy use due to cylinder wrapping (it is the standing losses that are reduced by the insulation of cylinders), but that this was dependent on hot water demand and age of cylinder.

The cylinders in this report that were wrapped with extra insulation varied in age from five to 30 years old. The use of the 2005 cylinder (S-P07) showed a large energy saving, although it already had higher levels of insulation than the older cylinders (Isaacs et. al., 2003) and the home had no other water heating interventions. This cylinder had low use, (Table 6 shows it had 700 kWh for the heating season of 2008) which accentuates the % change in standing loss, although this is not sufficient to explain all the improvement. We suspect that some of this change in use at S-P07 is due to undisclosed occupancy variation.

The 40% reduction in hot water heating energy in C-P06 was due to both the increased cylinder insulation, and the reduction in occupancy from five to two persons over the period of the study, so the results from S-P07 and C-P06 have been ignored in further reporting.

Of the three homes receiving SWH systems, there were 55% (H-P03), 70% (H-P08) and 70% (H-P10 – in conjunction with the wetback) reductions in electric energy consumption for water heating. This is a superb result given that this is the winter performance.

One home (S-P05) received two instant gas water heating systems to replace an aging storage electric water heater, and had no statistically significant reduction in water heating energy use. One of the heaters served the bathroom (shower), and the other unit served the laundry and kitchen. It has been reported anecdotally that the installation of instant gas water heaters can result in an increase in the consumption of hot water, although this was not found here – probably since a low-flow shower head was also installed.

5.1.6 Reticulated energy HSS™ performance

In this section, the energy results have been extrapolated to a complete year, to assess against the annual total reticulated energy HSS™ benchmark of 11,000 kWh/annum, appropriate for existing homes in climate zone 2 (SNZ, 2004).

The results from the 12 month extrapolation for the comparison of the energy end-use between the years of 2007 and 2008 (for total reticulated energy use for H-P03, H-P08, S-P01 and S-P05), were inconclusive until the total energy meter readings were analysed for the September 2007 to September 2008 year.

Conclusions could then be made for all but S-P01 which was still inconclusive,[7] although likely to be a fail. See Table 10.

Six of the nine homes met this HSS™ benchmark after the renovations, but two did not. The ninth had an inconclusive result, although is likely to also fail to meet the level. It is likely (although statistical tests have not been performed)[8] that at least five of the six homes that met the HSS™ for total reticulated energy use after the renovation were **already** meeting the HSS™ for total reticulated energy before the renovation. However, none of the homes were concurrently meeting the other energy HSS™ benchmarks before the renovation. The following section (Section 6.1) will show that

[7] Results from the actual meter readings were still inconclusive for S-P01 since the first and last results were taken one year and 12 days apart, and a correction had to be applied, which introduced sufficient uncertainty to prevent a conclusion being made.

[8] Resources were not available to complete these statistical tests, which are not vital to the outcomes.

some of the homes were able to meet both the HSS™ for total reticulated energy and other energy-related HSS™ benchmarks after the renovation.

HSS™ total annual energy consumption	
Home	**Total Reticulated Energy**
H-P03	Meets benchmark
H-P10	Meets benchmark
H-P08	Fails
S-P01	Inconclusive
S-P05	Fails
S-P09	Meets benchmark
S-P07	Meets benchmark
B-P02	Meets benchmark
C-P06	Meets benchmark

Table 10: Assessment of 12 month performance against the HSS™ 'total reticulated energy' benchmark

5.2 IEQ performance

5.2.1 Method

This section (5.2) examines the temperatures and RH against the HSS™ for all the homes, and also looks also at the range of internal temperatures for the 'High' package homes only. The values in this section have not been normalised for the annual variation in outside air temperature, nor have the results been interpolated to add missing data. Although no statistically significant comparisons can be made between years, the outdoor air temperatures in Papakowhai in the winter of 2008 were slightly colder than the winter of 2007, while the 2006 and 2008 winters had similar average temperatures. The mean temperature for the 2006 winter was 9.9°C, for the 2007 winter 10.6°C and for the 2008 winter 9.8°C. The outdoor RH was not monitored in this work.

The IEQ HSS™ benchmark for temperature (Easton, 2006) does not have a defined analysis period, so for this work the HSS™ benchmark for temperature has been developed to be the 24 hr mean minimum temperature for the heating season (May to September) – 16°C in bedroom 1 and 18°C in the family room. This means that the coldest temperature recorded for each day in the heating season has been averaged across days to present our result. This has been performed for three sequential years – being the pre-renovation period (2006), the intermediate period (2007), and the post-renovation period (2008), and has been examined in a number of ways to reveal different conclusions.

Data from the warmest month of summer (February) of two sequential years (the pre-renovation 2006-2007 summer period and the post-renovation 2007-2008 summer period) were examined against a maximum temperature of 24°C.[9]

Since the HSS™ currently has no maximum temperature, 24°C was used as it is the maximum value recommended for optimum indoor temperatures (WHO, 2003).
Note: RH measurements started in December 2006, meaning that there was no pre-renovation RH data for the 2006 winter period.

5.2.2 *Winter – temperature and relative humidity*

In this section, the internal air temperatures and RH have been examined during winter in both the family room and bedroom 1 against both the HSS™ and other benchmarks for several time periods.

5.2.2.1 Family room

In this section, the data for the winter temperatures in the family rooms are examined in four different ways, as seen in the tables below.

The minimum mean air temperature regarded as viable for maintaining occupant health in living spaces within homes is given as 18°C in the HSS™. The room nominated as the 'family room', often recognised as the 'living room' in the Papakowhai homes in this study, was assessed for the proportion of time during which the air temperature fell below this temperature. Results for before the renovations (pre), immediately after the renovations (intermediate) and after the renovations (post), are given in Table 11. This shows the percentage of time in which the air temperature in the family room was below 18°C during July.

Family room temperatures – July, 24 hr				
Home No.	**Package**	**2006 (Pre)**	**2007 (Intermediate)**	**2008 (Post)**
H-P03	High	42%	63%	29%
H-P10	High	70%	48%	87%
H-P08	High	61%	48%	64%
S-P01	Standard	85%	73%	89%
S-P05	Standard	68%	79%	74%
S-P09	Standard	80%	73%	71%
S-P07	Standard	94%	72%	94%
B-P02	Basic	75%	69%	65%
C-P06	Contrast	89%	88%	89%

Table 11: Percentage of time below 18°C – family room, July

[9] ***Note that the project was timed to allow a winter and a summer before the interventions, and two winters and one summer after the interventions.***

The air temperature in all the homes in July fell below 18°C at some time, with all homes (except one 'High' package home – H-P03) having more than half of the time below 18°C in July 2008. The data can be seen to be variable, with behaviour that cannot all be attributed to the interventions.

Table 12 shows the percentage of time the family room air temperature was below 18°C in the evening.

A comparison of the results for the full July analysis (Table 11) and the evening analysis (Table 12) show that the family rooms of all the homes are spending a lower proportion of time below 18°C in the evening, which suggests that the homes are being heated in the evenings. Half of the homes are spending more time below 18°C during the 2008 winter evening compared to the 2007 winter. Some of this can be explained given that the 2007 winter was warmer than the 2008 winter and the 2006 winter (NIWA, 2008).

The statistical significance of the temperature differences between the 2006 and 2008 recordings for the winter period are shown in Table 7, along with the energy results.

Family room temperatures – July, evening				
Home No.	**Package**	**2006 (Pre)**	**2007 (Intermediate)**	**2008 (Post)**
H-P03	High	15%	51%	4%
H-P10	High	18%	8%	83%
H-P08	High	30%	39%	51%
S-P01	Standard	58%	39%	69%
S-P05	Standard	7%	40%	20%
S-P09	Standard	37%	34%	21%
S-P07	Standard	86%	62%	88%
B-P02	Basic	27%	14%	14%
C-P06	Contrast	72%	66%	73%

Table 12: Percentage of time below 18°C – family room, July, evening

The energy used for space heating in the family rooms has decreased in H-P03 and H-P08 but in H-P10 has increased (these are the 'High' package homes – see Table 7). This indicates that in H-P03 and H-P08 occupants have reduced the space heating purchased and are choosing **not** to heat to higher levels, or the 18°C temperature of the HSS™ benchmark. This is not comfort take-back (where the same energy use is used to maintain warmer temperatures), but it is an example of the desirable behaviour where similar 'comfort' levels are maintained for less energy use, albeit based on a lower temperature than the HSS™.

Table 13 shows the mean minimum air temperatures (HSS™ benchmark) that were recorded for the family room in May to September, including additional 'morning' and 'day' periods, which are defined as 7am-9am for the morning and 9am-5pm for the day. Red text in the table indicates a temperature above 18°C has been met for that time period, although the HSS™ for family room temperature has only been met when assessed against a 24 hr period. Table 13 shows that the 18°C temperature is only being met in the evening for many of the homes. The variation in external air temperatures explains some of the variation in internal temperature, since the HEEP work has shown that there is significant coupling between the indoor and outdoor air temperatures (Isaacs et. al., 2006).

Mean minimum family room temperatures – winter						
	Home No.	**24 hr (°C)**	**Morning (°C)**	**Day (°C)**	**Evening (°C)**	**Night (°C)**
2006 – Pre-renovation (Note that the 2006 year monitoring only stated in July)	H-P03	13.3	15.8	17.2	18.4	13.5
	H-P10	13.6	13.7	13.8	17.7	14.0
	H-P08	14.6	14.6	15.0	17.4	14.8
	S-P01	12.5	12.6	12.7	16.3	12.9
	S-P05	13.1	13.1	13.3	17.8	13.4
	S-P09	14.2	14.7	15.4	16.9	14.5
	S-P07	12.7	12.7	12.8	15.7	13.0
	B-P02	12.5	12.7	13.0	18.6	12.9
	C-P06	13.2	13.2	13.2	15.4	13.5
2007 – Intermediate	H-P03	16.8	17.2	17.6	19.3	17.7
	H-P10	15.4	15.7	15.4	19.0	16.3
	H-P08	16.0	16.1	16.3	18.2	16.5
	S-P01	14.0	14.1	14.6	17.7	14.3
	S-P05	14.3	14.3	14.7	18.9	14.5
	S-P09	14.7	14.7	15.4	16.7	15.0
	S-P07	14.0	14.1	14.3	16.8	14.3
	B-P02	13.3	13.5	13.6	19.3	13.7
	C-P06	12.8	13.0	13.0	14.9	13.2
2008 – Post-renovation	H-P03	16.4	16.6	17.9	20.5	16.8
	H-P10	15.3	15.9	15.4	17.8	16.5
	H-P08	13.9	14.2	14.4	16.2	14.4
	S-P01	13.3	13.4	14.1	17.5	13.7

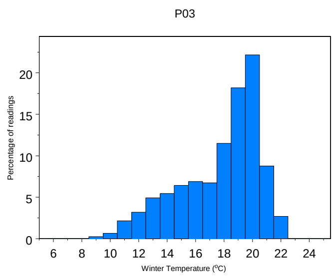
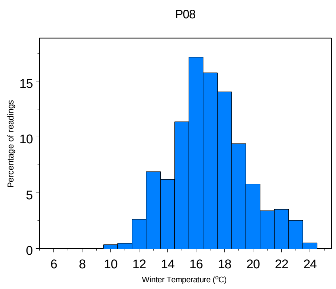
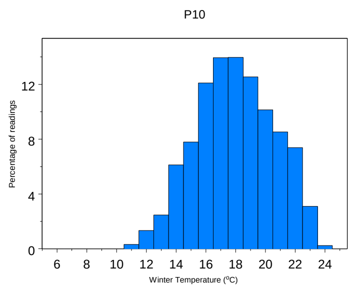
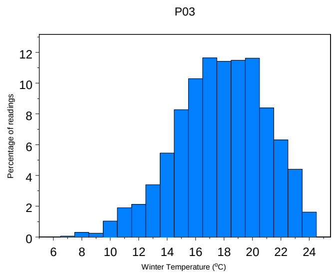
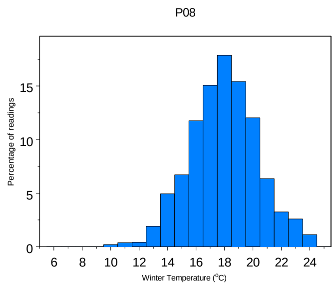
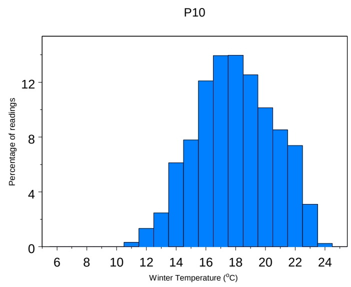
	S-P05	13.6	13.6	14.1	18.4	13.9
	S-P09	14.2	14.5	14.8	17.4	14.8
	S-P07	13.1	13.3	13.3	15.8	13.6
	B-P02	12.8	13.0	13.1	19.4	13.3
	C-P06	11.7	11.9	12.1	13.9	12.1

Table 13: Mean minimum temperatures in the family room during May-September

The variation in temperature in bedroom 1 of the ‘High’ package homes was of particular interest in this work, and so data is presented in alternative ways for these three homes – H-P03, H-P08 and H-P10. The following histograms (Figure 3) show the distributions of temperatures in the family rooms over the three months of winter – June, July and August. Note the scale on the y-axis varies to enhance readability; the x-axis scale is consistent throughout the histograms.

The histograms for H-P03 show that the lowest temperature in the family room in 2008 was 12°C compared with 9°C in 2006. The highest temperature has also increased from 22°C to 24°C, and the range of temperatures has reduced slightly, from a 13°C spread to a 12°C spread. Much less time is now spent at (or under) 17°C in 2008. For H-P08, the profile is similar for the three analysis periods

‘High’ package homes family room winter temperature histograms

	P03	**P08**	**P10**
Pre (2006)			
Inter-mediate (2007)			

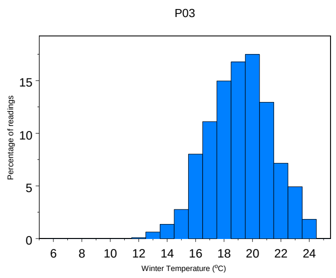
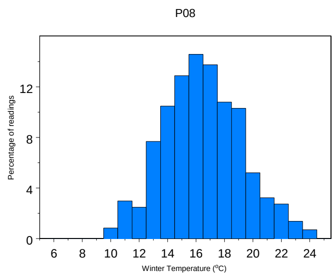
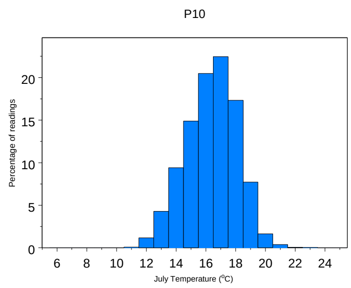
Post (2008)			

Figure 3: Histograms of winter temperatures (June, July and August) separated by year – family room (average of two sensors)

For the H-P10 family room, the lowest temperature is still 11°C and the highest is now 21°C, down from 24°C. There is a lower spread of temperatures, although this home is now using 20% more space heating energy to help achieve these temperatures.

5.2.2.2 Bedroom 1

In this section, the data for the winter temperatures and RH in bedroom 1 are examined in five different ways, as in the tables and figures below.

The minimum mean air temperature regarded as viable for maintaining occupant health in sleeping spaces within homes is given (WHO, 1990) as 16°C. The room nominated as 'bedroom 1' in the Papakowhai homes in this study was usually the 'master bedroom'. In this room, the data have been assessed for the proportion of time during which the air temperature fell below 16°C. RH has been assessed against the HSS™ top limit of 70%. Excursions below the lower RH limit of 20% have not been assessed as the RH in the bedroom 1 in the homes did not fall below this level. Table 14 displays the percentage of time during which the air temperature of bedroom 1 during July was below 16°C, and in the far right columns the percentage of time during which the RH was above 70%. A high percentage in the table indicates more time at low temperatures – or more time at high RH – both of which are non-desirable.

For statistically significant comparisons between years please see Table 7. The data in this section have not been normalised for the outside temperature or outside RH.

Bedroom 1 time below 16°C and RH above 70% – July, 24 hrs						
		Temperature Below 16°C			Relative Humidity Above 70%	
Home No.	**Package**	**2006 (Pre)**	**2007 (Intermediate)**	**2008 (Post)**	**2007 (Intermediate)**	**2008 (Post)**
H-P03	High	30%	38%	8%	2%	0%
H-P10	High	50%	21%	57%	12%	25%
H-P08	High	31%	20%	29%	9%	13%
S-P01	Standard	66%	40%	64%	51%	40%
S-P05	Standard	53%	60%	51%	50%	52%
S-P09	Standard	60%	42%	48%	3%	9%
S-P07	Standard	82%	61%	85%	80%	63%
B-P02	Basic	59%	55%	52%	16%	36%
C-P06	Contrast	71%	72%	75%	97%	100%

Table 14: Percentage of time below 16°C and above 70% RH – bedroom 1, July

With the exception of C-P06, S-P07 and H-P10, the homes have a lower percentage of time where the air temperature is below 16°C when comparing the pre- and post-renovation periods in the winter in bedroom 1. However, the variation in the intermediate year shows no distinct trend and suggests that these results should be treated carefully. Pre- and post-renovation RH is not able to be assessed since these RH measurements were started in December 2006. The time spent above 70% RH in C-P06 is of concern. This home was the 'Contrast' home and received a ceiling insulation top-up, and a hot water cylinder insulation, however had occupancy reduction from five to two persons, limiting the conclusions that can be made about the performance of the home.

H-P03 began consistently heating their bedroom 1 in the winter of 2008 with a heat pump. This decreased the amount of time below 16°C to just 8% from 30% in 2006 with the RH below 70% for the entire month of July 2007.

The pattern of temperatures and RH in bedroom 1 in winter are similar during the night time, with the % of time below 16°C being slightly higher and the % of time above 70% RH being higher, as can be seen in Table 15, by comparison to Table 14.

Table 15 displays the percentage of time during which the air temperature of bedroom 1 during the July night was below 16°C, and the RH was above 70%. It can be seen that bedroom 1 in all the homes is not getting as cold in 2008, given that the amount of time spent below 16°C in bedroom 1 during a winter night has decreased in the 'High' package homes – by 64%, 17% and 13% for H-P03, H-P10 and H-P08.

Bedroom 1 time above 16°C and RH above 70% – July, night						
		Temperature Below 16°C			**Relative Humidity Above 70%**	
Home No.	**Package**	**2006 (Pre)**	**2007 (Intermediate)**	**2008 (Post)**	**(Intermediate)**	**(Post)**
H-P03	High	84%	41%	20%	1%	0%
H-P10	High	62%	14%	45%	15%	33%
H-P08	High	42%	22%	29%	19%	21%
S-P01	Standard	88%	67%	85%	74%	49%
S-P05	Standard	93%	81%	86%	57%	56%
S-P09	Standard	81%	55%	54%	7%	16%
S-P07	Standard	95%	71%	91%	98%	74%
B-P02	Basic	93%	79%	76%	17%	25%
C-P06	Contrast	87%	91%	91%	95%	100%

Table 15: Percentage of time below 16°C and above 70% RH – bedroom 1, July, nigh

The 'Standard' package homes have also not been as cold after the renovation as before, although they have improved by a lesser amount.

Table 16 gives the mean minimum air temperatures for the months of May to September in bedroom 1. Red text indicates the **temperature** of 16°C has been met, although the temperature HSS™ is only met when assessed against a 24 hr period. H-P03, H-P08 and H-P10 (all 'High' package homes) exceed the 16°C temperature at some time in bedroom 1 in the post-renovation period, although H-P10 only meets the 16°C temperature of the HSS™ during the evenings. It must be recognised that the occupants are not necessarily aiming to achieve the HSS™ levels of temperature in bedroom 1 (and in fact are unlikely to even know what these levels are), but are behaving in ways that cannot be explained solely through this physical analysis. Consequently, failing to achieve the HSS™ for temperature is not a failure of the program, but recognition that this is not just a home modelling program, but a program incorporating an amalgam of physical, behavioural and social interactions.

Table 16 has shown that bedroom 1 in all of the homes (except in C-P06 and H-P08) have higher mean temperatures over winter as a result of the renovations.

Mean minimum bedroom 1 temperatures – winter						
	Home No.	**24 hr (°C)**	**Morning (°C)**	**Day (°C)**	**Evening (°C)**	**Night (°C)**
2006 – Pre-renovation	H-P03	12.7	12.8	13.1	14.2	12.9
	H-P10	12.2	12.3	12.2	14.4	12.8
	H-P08	16.3	16.5	16.4	18.3	16.7
	S-P01	11.6	11.8	11.7	14.0	12.4
	S-P05	12.1	12.2	12.4	13.4	12.4
	S-P09	14.2	14.6	14.8	15.0	14.4
	S-P07	11.6	11.7	12.1	13.4	11.9
	B-P02	12.8	12.9	13.1	15.0	13.3
	C-P06	13.0	13.2	13.0	14.9	13.6
2007 – Intermediate	H-P03	15.6	16.3	16.0	16.9	16.7
	H-P10	14.8	15.2	14.8	16.6	15.8
	H-P08	16.9	17.1	17.0	18.8	17.4
	S-P01	12.6	12.7	12.8	15.5	13.3
	S-P05	12.8	13.0	13.3	14.1	13.1
	S-P09	14.9	15.1	16.1	16.0	15.2
	S-P07	12.1	12.3	12.7	14.1	12.4
	B-P02	13.4	13.9	14.3	15.9	13.8
	C-P06	12.3	12.7	12.5	13.6	12.7
2008 – Post-renovation	H-P03	17.8	18.8	18.2	19.3	18.4
	H-P10	14.7	15.2	14.7	16.4	15.7
	H-P08	15.8	16.1	16.0	17.8	16.3
	S-P01	12.2	12.5	12.4	15.7	13.2
	S-P05	12.2	12.5	12.8	13.5	12.6
	S-P09	14.3	14.6	15.2	15.5	14.7
	S-P07	12.0	12.2	12.5	14.0	12.4
	B-P02	12.9	13.0	13.3	15.6	13.4
	C-P06	11.5	11.8	11.8	12.7	12.0

Table 16: Mean minimum temperatures in the bedroom 1 during May to September

As for the winter period in the family rooms, histograms are shown for the three ‘High’ package homes – H-P03, H-P08 and H-P10 – for winter in bedroom 1. The following histograms (see Figure 4) show the distributions of temperatures in bedroom 1 over the three months of winter – June, July and August – for the ‘High’ package homes.

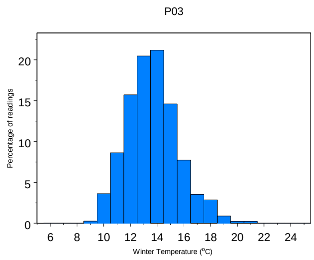
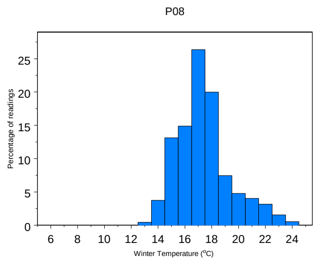
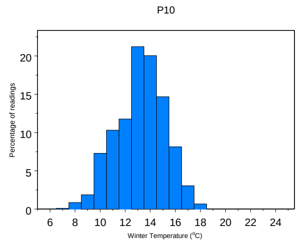
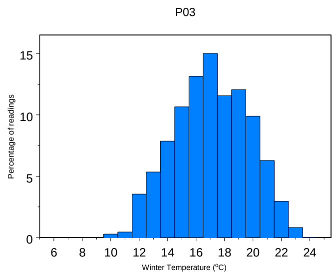
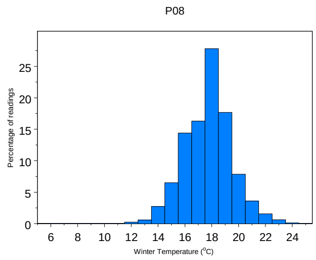
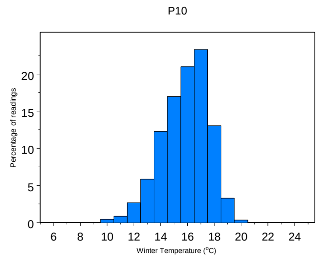
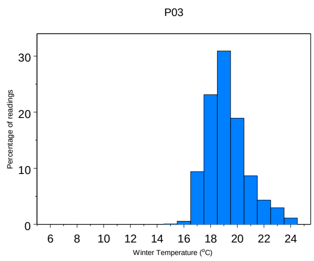
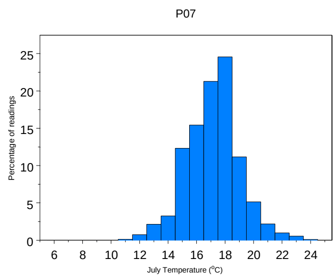
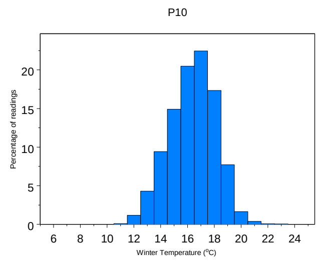
‘High’ package homes bedroom 1 winter temperature histograms			
	P03	**P08**	**P10**
Pre (2006)			
Intermediate (2007)			
Post (2008)			

Figure 4: Histograms of winter temperatures (June, July and August) separated by year – bedroom 1

The shape of the histograms for bedroom 1 in winter can be seen to change over the three years analysed, with a shift up in temperatures for H-P03 clearly visible. This is positive, where the most frequent temperature is no longer 14°C, but is now 5°C higher at 19°C, which is experienced for over 30% of the time. The temperatures also vary less, with a range of 8°C (from 16°C to 24°), instead of a range of 12°C (from 9°C to 21°C). Similarly for the family room of H-P08, the most frequent temperature in bedroom 1 of H-P08 is up 1°C from 17°C to 18°C, with a similar range of temperatures. This is confirmed in Table 14 and Table 15 for a longer analysis period, where it can be seen that the bedroom 1 temperatures are statistically unchanged, although 16% less space heating energy is being used in the home.

The histograms for H-P10 in Figure 4 also show that the bedroom 1 is much warmer, although the 16°C HSS™ is not being achieved. The bedroom 1 minimum temperature had been 7°C and after the renovations the minimum temperature is now 4°C warmer at 11°C. The highest temperature in winter before the renovation in the bedroom 1 had been 18°C, and after the renovation was a comfortable 21°C. The most common temperature in bedroom 1 is now 17°C instead of 13°C.

While not specific to the RH in bedroom 1, the occupants in B-P02 removed the ground cover polythene (installed to improve the RH in the home), since it seemed to be accumulating water on top of it. This was unfortunate, although is a reality of such work where occupants are not restricted in their behaviour.

The following histograms (see Figure 5) show the distributions of RH during winter (June, July and August) in the bedroom 1 for the three 'High" package homes.

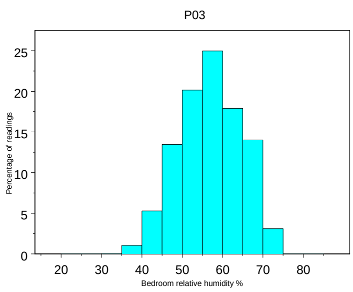
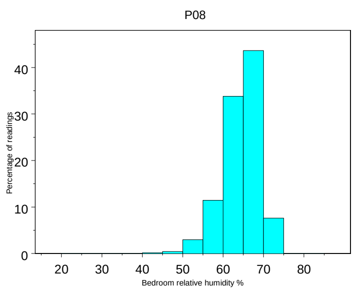
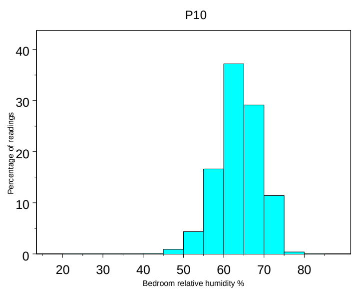
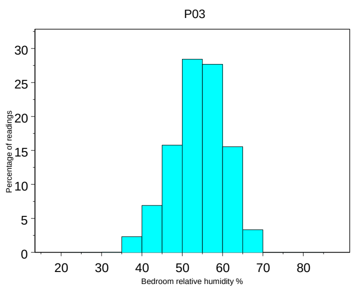
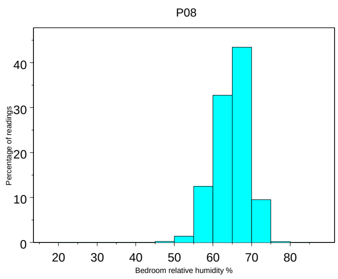
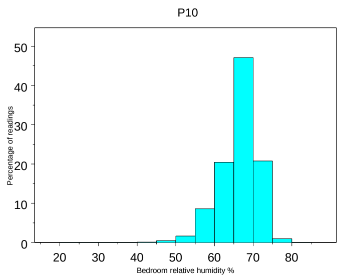
'High' package homes bedroom 1 winter RH histograms			
	P03	P08	P10
Intermediate (2007)			
Post (2008)			

Figure 5: Histograms of RH during winter (June, July and August) – bedroom 1

The RH relates to the temperature, such that when the indoor temperature increases the RH will decrease unless moisture is added from elsewhere. The indoor RH is also dependent on the external RH, although the external RH was not monitored in this work.

The bedroom 1 of H-P03 has shown a shift to lower RH levels (a favourable outcome) in the second year, with a narrower spread, but the other two homes have very little difference between the intermediate year and the post-renovation year. No conclusions can be drawn from the change since there was no monitoring during the pre-renovation year.

The histograms in Figure 5 show that the most frequent result in the RH for H-P03 is about 55%, ranging from 35% to 70%, falling within the HSS™ range. It is interesting to note that in the previous year the bedroom 1 RH in H-P03 had been higher. It is expected that the ground cover polythene placed as part of the IEQ renovations has reduced the evolution of moisture from the ground, such that the indoor RH has been reduced, although there can be a time lag before the effect is seen. This coupled with increased internal space temperatures will have the effect of reducing the RH since RH and temperature are inversely related. This was the assumption at the start of the program, although there are many other factors which affect the RH of the living space, so this cannot be proven. The type of heating has also changed from electric resistance heaters to a heat pump in the bedroom 1. H-P03 is the only home where the RH in the bedroom 1 does not rise above 70% in the 2008 winter, and is the only home where occupants maintained a significant heating regime.

In H-P08 the RH now varies over a smaller range, from 45 to 80%, with a peak at 68%. This home was heating the bedroom 1 before the renovation to the same temperature (17°C) and is now continuing to do so, but using 16% less space heating energy. It is unlikely that the RH will drop further to within the HSS™ for RH unless the occupant heating behaviour changes.

H-P10 shows a RH range from 45% to 80%, with a peak at 68%. This home continues to have RH levels which are above the HSS™, again with a similar pattern to the intermediate year.

5.2.3 Summer temperatures

In this section, the internal air temperatures have been examined during summer in both the family room and bedroom 1 against both the HSS™, and other aspects for several time periods.

The first summer in which air temperatures were monitored was the 2006-2007 summer before the renovation took place (pre). The second (and last) summer monitored (post) is the first summer post-renovation (2007-2008). The summer analysis has no intermediate period, unlike the winter period.

- The family room temperatures are shown by the percentage of time during which the air temperature in the family room was over 24°C during February, and also just for the evening period (6pm to 10pm) in February.
- Bedroom 1 temperatures are shown by the percentage of time during which the air temperature was above 24°C during February, and also just for the night (1am to 7am) in February.

The monthly average external air temperature for February 2007 was 18.6°C and in February 2008 was 19.1°C. Temperature averages were calculated from the external temperature data collected at H-P10. The outdoor air temperature is not the only climatic influence on indoor temperature. Other influences include sunshine hours, solar access and penetration and ventilation rates, which can all have a large effect on the summer temperatures.

Two homes have the capacity to cool using reverse-cycle heat pumps. One is choosing to cool (H-P03), the other is not (S-P09).

5.2.3.1 Family room

In this section, the data for the summer temperatures in the family rooms are examined in three different ways.

The issue of overheating has been addressed, in which the temperature of 24°C has been chosen to indicate overheating.

The February analysis of the family room temperatures can be seen in Table 17.

In this section, the data for the summer temperatures in the family rooms are examined in three different ways.

The issue of overheating has been addressed, in which the temperature of 24°C has been chosen to indicate overheating.

The February analysis of the family room temperatures can be seen in Table 17.

Family room time above 24°C – Feb, 24 hrs			
Home No.	**Package**	**2007 (Pre)**	**2008 (Post)**
H-P03	High	33%	30%
H-P10	High	15%	13%
H-P08	High	35%	46%
S-P01	Standard	22%	24%
S-P05	Standard	15%	9%
S-P09	Standard	30%	35%
S-P07	Standard	21%	21%
B-P02	Basic	11%	9%
C-P06	Contrast	6%	8%

Table 17: Percentage of time above 24°C – family room, February, 24 hrs

During February all of the family rooms in both 2007 and in 2008 are showing time spent with air temperatures over 24°C. The occupants of H-P03 do have the capacity to cool with their heat pump and are doing so; the time spent above 24°C is likely to have been higher if cooling was not performed.
Time spent above 24°C for the family room in the evening period is shown in Table 18.

During the evening period shown in Table 18 the time above 24°C is higher in 2008, compared to the 24 hr analysis shown in Table 17 (in all but C-P06).

Family room time above 24°C – Feb, evening			
Home No.	**Package**	**2007 (Pre)**	**2008 (Post)**
H-P03	High	57%	31%
H-P10	High	38%	28%
H-P08	High	75%	79%
S-P01	Standard	71%	68%
S-P05	Standard	41%	19%
S-P09	Standard	54%	60%
S-P07	Standard	62%	66%
B-P02	Basic	28%	19%
C-P06	Low	15%	3%

***Table 18**: Percentage of time above 24°C – family room, February, evening*

The following histograms (Figure 6) show the distribution of temperatures over January and February in the family room for the three 'High' package homes.

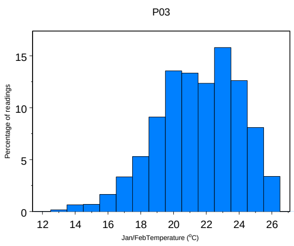
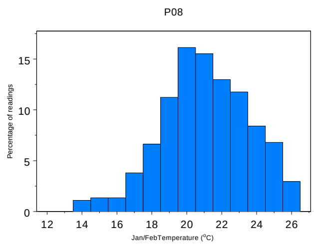
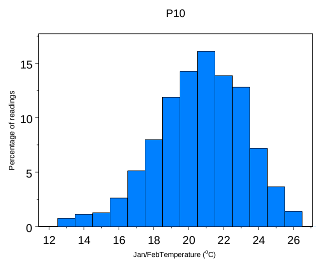
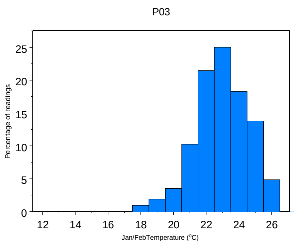
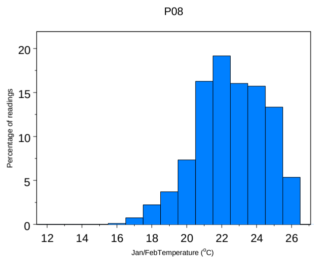
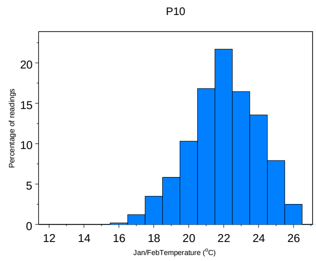
'High' homes family room summer temperature histograms			
	P03	**P08**	**P10**
Pre (2007)			
Post (2008)			

Figure 6: Histograms of summer temperatures (January/February) separated by year – family room (average of two sensors)

All three of the homes show a shift toward higher temperatures in the family room in summer, commensurate with lower thermal losses from better insulated envelopes.

H-P03 had a maximum temperature of 26°C before the renovations, and a 13°C spread of temperatures experienced, from 13°C to 26°C. After the renovation the minimum temperature in the family room was 18°C, with an 8°C spread to the same peak of 26°C. This is not significant overheating, but indicates that the renovations have reduced the heat loss from the family room considerably. When the summer data is normalised for variation in the outside temperature (by the method used for Section 5.1.1) a statistically significant change can be seen – an increase of 1.1 °C.

H-P08 and H-P10 show the same very similar patterns to H-P03 in Figure 6, with a reduction in the frequency of low summer temperatures, the same maximum temperature of 26°C, and the most frequent temperature of 22°C. When normalising for the outside temperature there is no statistically significant change for H-P08. However H-P10 is found to be 0.25°C warmer in the post retrofit year.

5.2.3.2 Bedroom 1

In this section, the data for the summer temperatures in the bedroom 1 rooms are examined in three different ways.

Table 19 shows the time the percentage of time during which bedroom 1 is above 24°C during February over a 24 hour analysis period.

Bedroom 1 time above 24°C – Feb, 24 hrs			
Home No.	**Package**	**2007 (Pre)**	**2008 (Post)**
H-P03	High	17%	76%
H-P10	High	15%	39%
H-P08	High	34%	66%
S-P01	Standard	12%	15%
S-P05	Standard	7%	10%
S-P09	Standard	19%	57%
S-P07	Standard	10%	11%
B-P02	Basic	9%	34%
C-P06	Contrast	16%	11%

Table 19: Percentage of time above 24°C – bedroom 1, February, 24 hrs

Eight out of the nine homes have increased the amount of time spent above 24°C in the bedroom 1 between the 2007 summer (pre) and the 2008 summer (post), with one reduction (the 'Contrast' home), although in two cases the increase has been marginal.

H-P03's bedroom 1 temperatures have increased with 76% of the time spent over 24°C, up from 17% in the pre-renovation condition. This bedroom 1 faces north-east (from where it would receive morning solar gains) and the double-glazing and high insulation levels will be serving to trap this solar heat, as well as the heat conducted or convected into the bedroom 1 during the day. Four other homes have also had large increases in the amount of time spent over 24°C (all three of the homes receiving 'High' packages and one home receiving a 'Standard' package). Some of these homes do have substantial areas of west-facing glazing, which will contribute significant solar gains in the evening, although the amount of glazing has not changed during the work.

Table 20 shows the amount of time over 24°C in February during the night time.
H-P03 and H-P08 had the largest increase in the amount of time spent over 24°C

The same pattern of increasing amounts of time spent over 24°C is evident in both tables (Table 19 and Table 20), except for S-P09 which has had a significant increase in overheating in the 24 hr analysis, but not in the night-time analysis.

Bedroom 1 time above 24°C – Feb, night			
Home No.	**Package**	**2007 (Pre)**	**2008 (Post)**
H-P03	High	1%	68%
H-P10	High	1%	19%
H-P08	High	12%	53%
S-P01	Standard	0%	2%
S-P05	Standard	1%	2%
S-P09	Standard	10%	19%
S-P07	Standard	0%	3%
B-P02	Basic	3%	10%
C-P06	Contrast	7%	1%

Table 20: Percentage of time above 24°C – bedroom 1, February, night

The following histograms (see Figure 7) show the distribution of temperatures for the 'High' package homes over January and February in bedroom 1. As for the family rooms, the temperature range of bedroom 1 has reduced, with the maximum temperature not increasing, although the time spent above 24°C has increased. Although any temperature over 24°C is viewed as overheating, the maximum temperature of 26°C for the small proportion of time shown above is not believed to be overly concerning.

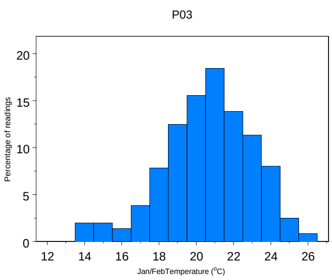
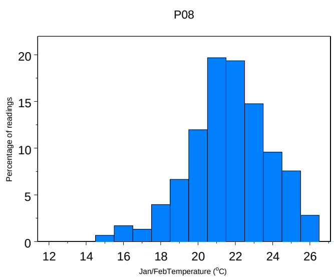
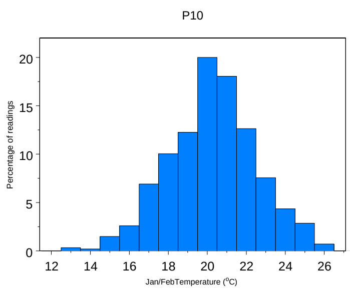
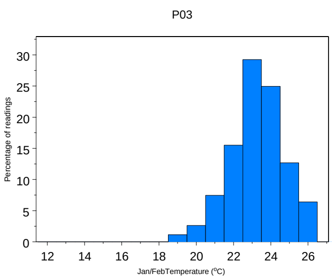
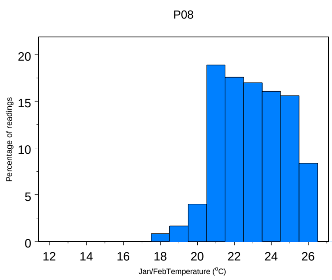
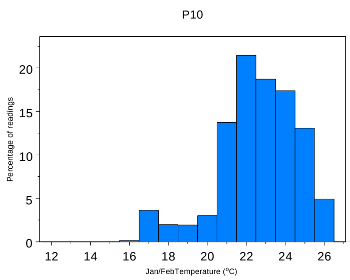
‘High’ package homes bedroom 1 summer temperature histograms			
	P03	**P08**	**P10**
Pre (2007)			
Post (2008)			

Figure 7: Histograms of summer temperatures (January/February) separated by year – bedroom 1

H-P03 and H-P10 were both found to be statistically significantly warmer over summer in the bedroom 1 - H-P03 by 2.6°C and H-P10 by 1°C. There was no significant difference found in H-P08 over the summer, although the temperature profile is markedly different, indicating changed behaviour.

5.2.4 Temperatures and RH – conclusions and discussion

These conclusions relate to the assessment of the hottest summer and coldest winter month comparison with the HSS™ benchmarks, with the achievement of these benchmarks summarised in the tables in Section 6.1.

5.2.4.1 Winter

From the one month winter analysis, all of the homes except C-P06 and H-P08 have had increases in the mean minimum temperatures in both the family rooms and bedroom 1. This is an expected result (other than for H-P08) given the levels of envelope insulation provided in the renovation. However, no homes are meeting the HSS™ for temperature in both rooms. H-P03 now meets the 16°C HSS™ in bedroom 1, and H-P08 is very close, but the family rooms of all homes fall short of the 18°C HSS™.

RH levels are high in many of the homes. However no pre-renovation monitoring was performed to quantify the changes. C-P06 has RH levels that are of concern, although this home had a very low level of intervention (partial ceiling insulation and hot water cylinder wrap). H-P03 is the only home that meets the HSS™ for RH, which is partly because bedroom 1 is heated.

It is clear that before the renovations the occupants (except perhaps H-P08) were not conditioning their homes to a healthy or comfortable temperature, as is done in many other western nations (Cunningham et. al., 2004). This has a significant influence on the performance of the home. The renovations applied to Papakowhai homes have been modelled (Burgess & Buckett, 2008) and results indicate they are sufficient to achieve HSS™ energy and temperature benchmarks. These findings show that to achieve the IEQ benchmarks for temperature and RH requires renovation of the complete thermal envelope of the home and sufficient heating to optimise the outcome.

This work showed that since the occupants have a large effect on their living environment (Isaacs, 2006) it is possible that their influence can swamp the beneficial results expected from renovations, and this appears to have occurred here. From the data and results it can be seen that the houses are capable of achieving many of the HSS™ parameters, so the fact that they do not always do this cannot be explained by physical factors alone. This leads to the suggestion that a tailored combination of a behavioural and physical renovation set may be a more appropriate driver to the achievement of the HSS™ in New Zealand homes.

Since there was little incentive and no requirement in this study to modify the home space air temperatures to that required by the HSS™ parameters for temperature, it was not surprising that they were not met. However, the achievement of the HSS™ for space air temperatures or any of the performance benchmarks is not necessarily the intention of individual homeowners, and they may make different choices dependent on their own expectations and requirements.

It has been reported (Isaacs, 1993) that New Zealand homeowners do not tend to maintain a specific space conditioning regime in their homes, nor do they maintain specific internal temperatures. The recent heat pump report (French, 2008) concurs, and reports that of the 19% of New Zealand homes with heat pumps only 15% of the sample was conditioning their homes with a 24 hr heating schedule, although 93% used a heating schedule that included the evening period. It is possible that in future work like this, if the occupants were informed about their level of achievement of the HSS™ parameters on a regular (monthly) basis, and encouraged to achieve the HSS™, that the outcomes may differ.

5.2.4.2 Summer

The examination of temperatures indicates that the renovations have not had much effect on the summer family room temperatures, but that the amount of time spent above 24°C in bedroom 1 has been increased in the ‘High’ package homes, as well as in B-P02 and S-P09. The temperatures are only reaching 26°C (and for a relatively short time) which may not be viewed as overheating in countries with warmer climates.

Heat built-up in the home is less able to be lost through the improved thermal envelope. This can be addressed by increasing ventilation and/or reducing the solar gains. No interventions to improve summer conditions were made in this work (e.g. external shading or fans, except in houses fitted with heat pumps, and even then only house H-P03 used the heat pump for summer cooling).

5.2.5 IEQ checklist

Beacon has a HSS™ performance checklist as part of the measurement of the IEQ performance of a home. This is contained within Table 21. Table 21 records how the Papakowhai homes compare against this benchmark for the renovation of these homes.

HSS™ IEQ checklist									
IEQ checklist	H-P03	H-P10	H-P08	S-P01	S-P05	S-P09	S-P07	B-P02	C-P06
Element									
Mechanical ventilation of kitchen, bathroom and laundry	N	N	N	N	N	N	N	N	N
Windows with passive venting	N	N	N	N	N	N	N	N	N
No unflued gas heaters	Y	Y	Y	Y	Y	Y	Y	Y	N
Environmental choice paints and finished used in the renovation	Y	Y	Y	Y	Y	Y	Y	Y	Y
No air conditioning	N	Y	Y	Y	Y	N	Y	Y	Y

Table 21: Assessment of achievement against HSS ™ IEQ checklist benchmark

None of the homes meet the IEQ performance benchmark, partially since there was little emphasis on ventilation in the renovation work.

5.3 Water performance

The consumption of reticulated potable water is one of the components of the HSS™, and so is assessed in this section. The HSS™ benchmark for water consumption per occupant of existing homes is 180 L/p/d.

Seven of the 10 homes in the Papakowhai Renovation Project have had their water use monitored since early 2007. The timing of the installation of meters did not allow data for the pre-renovation water consumption to be obtained. All homes had checks of the plumbing system integrity, while H-P03 had two dual flush toilet cisterns installed and a SWH system and water meter. S-P05 had two instant gas water heaters installed with a flow restrictor, and a low-flow shower head. H-P08 and H-P10 also had SWH systems installed.

5.3.1 Water methodology

Water meters were installed on the reticulated potable water lines between December 2006 and January of 2007, with reliable readings obtained from February 2007. Water meters were installed on the three SWH systems in June 2007, with the reticulated water meters also measuring the water used by the SWH water meters. Data was collected approximately monthly, with information not collected over the 2007-2008 summer. Figure 8 shows all the data obtained from the reticulated water meters in this study, and gives an overview of the consumption of all the homes as a group, before the later graphs assess water use per home, while the water use of the SWH systems is discussed in Section 5.1.4.2 The Appendix (

Figure 10 to Figure 16) has the individual home water use graphs.

Although there were significant changes to the water heating systems of four homes, there were minimal interventions made to the reticulated potable water demand to reduce water use.

This section assesses the reticulated water use of the homes in relation to the HSS™ and looks at the trends in water use, but cannot compare the water use before and after the renovation since the water meters were only installed part-way through the project.

5.3.2 Water results

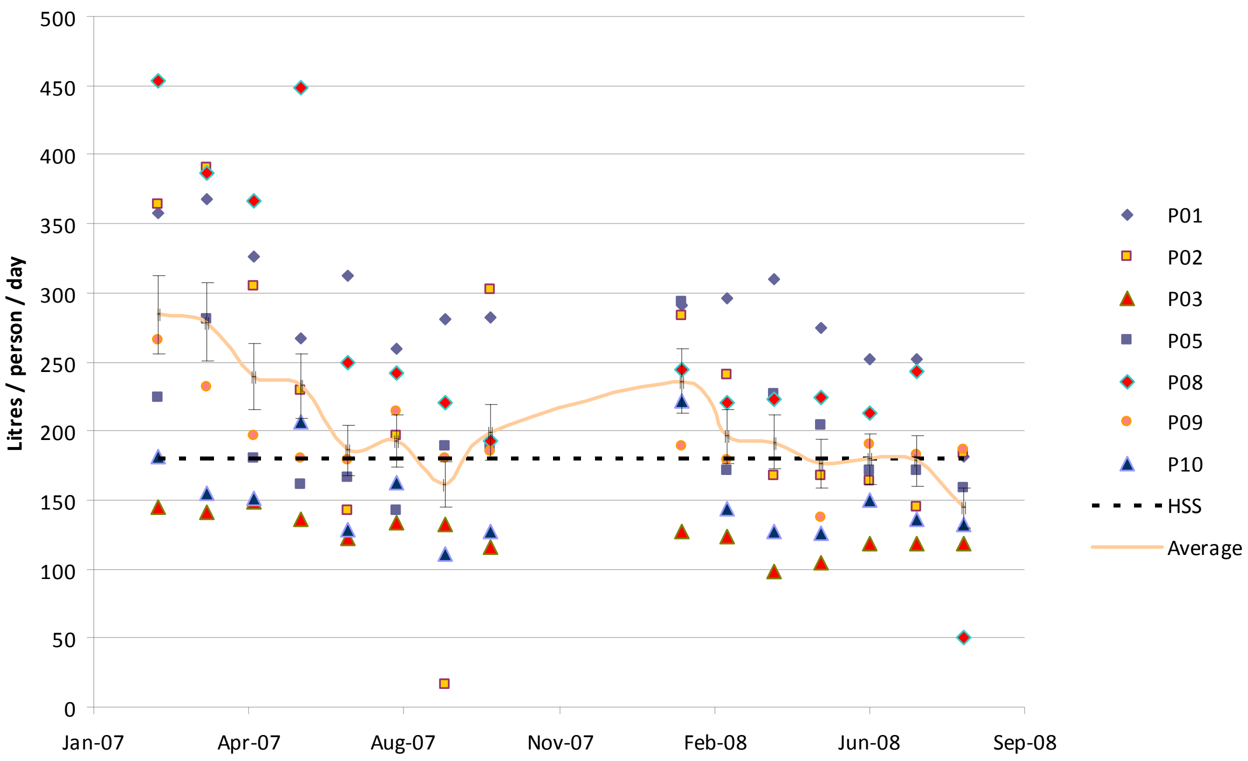


Figure 8: Monthly reticulated water use (all purposes) for all homes

Note: data was not read from the accumulative water meters from November 2007 to January 2008. The results from the first reading in January 2008 were therefore averaged over the three months, and the average attributed in this graph to January, but not to November or December, explaining the gap in the data above.

From the figures in the Appendix (

Figure 10 to Figure 16) it can be seen that there was a systematic reduction in water use between 2007 and 2008 for all homes, which is difficult to discern in Figure 8.

Table 22 includes a summary of the water interventions placed in the homes (with reticulated water metering), and displays the change in water use and cost by individual home.

5.3.3 Water analysis

Water interventions				
Home	**Interventions**	**Cost**	**Usage Drop Between 2007 and 2008 (L/p/d)**	**Drop in water Usage (%)**
H-P03	Plumbing check (SWH panels and 280 L cylinder costs included under energy section) Two dual flush toilets	$178	24	18%
H-P10	Plumbing check and leak fixed (SWH panels and 300 L cylinder with flow restrictor, wetback on new solid fuel burner costs included in energy section)	$88	28	17%
H-P08	Plumbing check (SWH panels and 280 L cylinder, with flow restrictor costs included in energy section)	$88	162	45%
S-P01	Plumbing check	$88	54	17%
S-P05	Plumbing check (two instant gas water heaters, and flow restrictors costs included in energy section) and low-flow shower head installed	$218	9	5%
S-P09	Plumbing check	$88	65	31%
B-P02	Plumbing check	$88	93	34%

Table 22: Scope of water interventions in homes

The cost of the renovations in the table above does not include the costs of interventions performed for energy purposes, such as the SWH systems, since these are included in the energy analysis in Section 5.1.4. Table 23 shows the average water usage per person for each of the Papakowhai homes, together with the average occupancy.[10] As can be seen in Table 23, five of the seven homes monitored exceeded the HSS™ for water during the monitoring period, with only two of the homes averaging below the HSS™ for reticulated water use. This is the same result as in the Interim report (Burgess et. al., 2008).

Water use per person		
Home ID	**# People**	**Average L/p/d**
H-P03 [1,3,5]	5	125
H-P10 [1,3]	5	151
H-P08 [1,3]	2	265
S-P01	4	287
S-P05 [2,3,4]	2	195
S-P09	1	193
B-P02	2	220

[1] = SWH system and 280-300 L cylinder installed
[2] = Low-flow shower head installed
[3] = Flow restrictor installed
[4] = Instant gas water heaters (two) installed
[5] = Two dual flush toilets installed

Table 23: Average water use per person (L/person/day) per home

The trend of reduction in water use in 2008 may be due to increased irrigation after an autumn drought in early 2007 (NIWA, 2008), and consequent reduction in irrigation due to council-imposed watering restrictions.

The individual home water demand graphs are shown in the Appendix (see Section 9.4).

5.3.4 Water conclusions and discussion

- H-P03 – The five occupants of this home had the lowest per person water use of any home in the study, with 125 L/p/d water use over the monitoring period, well below the HSS™ of 180 L/p/d. The home had a SWH system and flow restrictor installed as part of the renovation. However, it was suspected that this would increase water consumption due to the increased availability of hot water, since discussions with the occupants indicated that the family had previously been short of hot water with an under-sized hot water cylinder. The major reason for this low water use is due to the half-flush toilet cisterns. Research from the water end-use study in Kapiti, Wellington, New Zealand (Heinrich, 2007) found that the average occupant flushes just over five times per day. Information from the Auckland water use study (Heinrich, 2008) found that the average

[10] ***The occupancy in some of the homes fluctuated during the period of study. However, unless this change was significant and permanent it was not included in the analysis.***

Aucklander flushes just under five times per day. If this is true for H-P03, then this home is saving around 170 L of water per day (assuming that an average of four people are in the home per day and there are 20 flushes of 4.5 L instead of 20 flushes, each at 13 L). Since no pre-renovation water measurements were made, improvements cannot be seen due to the renovation. This is now a good low-water use home, with the average water consumption falling in the 2008 monitoring periods compared to the same periods in 2007 (both after the renovations).

- H-P10 – The five occupants of this home had average daily water use per person of 151 L/p/d over the 2007 and 2008 water monitoring periods. This consumption was one of only two below Beacon's HSS™ of 180 L/p/d (the other being H-P03). As with H-P03, H-P10's five member household appears to be able to make highly efficient use of their potable water resources due to the household size. Water use fell slightly between 2007 and 2008, but this is more likely to have been due to social than physical changes. Peaks of use can be seen in June 2007 and February 2008. As the family has a large vegetable garden, it is possible that the February 2008 peak in use (similar to those observed in B-P02 and S-P05) were due to watering during drier than normal weather in Wellington's summer (NIWA Climate Centre, 2008), and subsequent water restrictions. A SWH with a water flow restrictor was installed into the home during June 2007, so this may have contributed to the spike in water use at this time as the family tested the capabilities of the system.

- H-P08 – The water use of the two occupants in this home reduced between 2007 and 2008. It appears that this is due to several reasons, including a worm farm reducing the use of the sink waste disposal unit, the installation of a SWH system with water flow restrictor in June 2007, and the absence of one occupant during part of the week throughout the 2008 year. The home, occupied much of the time, averaged potable water use of 265 L/p/d throughout the water monitoring period – the second highest in the study. The average daily water consumption per person did not fall below the HSS™ of 180 L/p/d while the home was occupied for a full metered 'month'. Daily per person water use in H-P08 reduced between 2007 and 2008. Other contributing factors are that one of the two occupants began spending more time at their holiday home in the weekends, and the occupants were away for most of the July to August water monitoring period, leading to low average daily water use per person (51 L/p/d).

- S-P01 – The family of four in S-P01 were consistently amongst the highest water users on a per person basis throughout the study, and used the most water overall per person and the most water as a household during the course of the water monitoring period. There were no water intervention measures installed during the renovations, and this home did not meet the HSS™ benchmark of 180 L/p/d. An average of 287 L/p/d of reticulated potable water was used in this home throughout the monitoring period. This home had occupants in it for much of the day, with the adults working shifts at different times of the day in order to look after the young children. Also, both adult occupants had careers which led to frequent clothes washing and bathing at least twice a day. In the last month of the study one adult occupant left the home.

- S-P05 – The average per person potable water use did not change significantly between 2007 and 2008 for the two occupants of this home. Meter readings have revealed water use spikes during late summer and early autumn in both years, expected to be due to garden watering during dry spells. Two instant gas water heaters and flow restrictors were installed, with a low-flow shower head. The home, occupied much of the time, averaged potable water use of 195 L/p/d throughout the study, and averaged just below the HSS™ for water use during approximately half the months for which water was monitored at the home. Occupants were away for 10 days in the July to August water monitoring period, accounting for the slightly lower than usual water usage of 143 L/p/d.

- S-P09 – Water use in S-P09 fell slightly between the 2007 and 2008 water monitoring periods. The sole occupant of the home was responsible for an average water consumption of 192 L/p/d. This is lower than expected (Heinrich, 2007) due to the reduced per person water efficiency of one person homes (as explained further below. This water consumption is lower than in the two person homes in the study (B-P02, S-P05 and H-P08), as well as a four person home (H-P10), but did not meet the HSS™.

- S-P07 – The consumption of water in this home was not measured.

- B-P02 – The two occupants of this home had water use averaging 220 L/p/d over the whole water monitoring period. However, on a monthly basis this was often at levels below the HSS™ of 180 L/p/d, and in the 2008 monitoring period met the water HSS™. There were no water intervention measures installed during the renovations. It is suspected that the substantial drop in water consumption between 2007 and 2008 was partially due to occupants working away from home more often. Spikes observed in water consumption for the home are suspected to be due to visitors staying, as well as garden watering in dry months, although our records do not capture this information.

- C-P06 – The consumption of water in this home was not measured.

The two homes which used less water per occupant were homes with five occupants, three of them being children in each case. Homes with a larger number of occupants tend to have a lower per person use, as events like using the washing machine or dishwasher might be more frequent, but use less volume per person (Heinrich, 2007). Also outdoor uses, such as irrigation, are lower on a per person basis, as the total use is divided by a larger number of people, whereas events such as toilet flushing and showers are dependent on the number of people.

The young family of four in S-P01 remained the highest potable water users between February 2007 and August 2008, both per person and in overall measurement. Initial and post-renovation BRANZ interviews discovered that two members of the home have at least two showers per day, while another two have at least one shower per day. Both adult occupants have had jobs which require frequent clothes washing (fisherman and nurse).

In comparison, the occupants of the Waitakere NOW Home® decreased their water use by 8% in the second year of occupation (Pollard et. al., 2008), while all the Papakowhai homes also showed reductions. However it is expected that these reductions are less due to demand-side management than to natural variation.

There was no incentive or requirement in this study to modify the household consumption for water, and although there was a systematic reduction in potable water use found in these homes in the two monitored periods after the renovations, this is not due to the interventions.

5.4 Waste performance

Beacon has developed a checklist for the performance area of waste as part of the HSS™ as follows:

- Providing facility for kitchen waste composting or storage for kitchen waste collection;
- Space for recyclable storage;
- The absence of an in-sink waste disposal system; and
- Renovation in accordance with REBRI (Resource Efficiency in Building and Related Industries) construction guidelines.

5.4.1 Method – waste

Worm farms[11] were provided to all the homes together with incidental education on recycling and waste management, but it was not possible to facilitate the removal of any in-sink waste disposal systems. The renovation work was performed within the REBRI guidelines (Clark, 2007).

Pre-renovation and post-renovation solid waste audits were conducted as part of the renovation programme on the Papakowhai homes. Each home was trained in the use of the worm farm and its use as a specific means to reduce their volume of organic (mainly kitchen) waste. In six of the homes, direct comparisons of pre- and post-renovation audits were feasible. Since one home withdrew after the first audit (P04), the 'Contrast' home (C-P06) was originally not audited, and two other homes had changes to the occupancy such that meaningful direct comparisons could not be made, although the results are presented and discussed.

While the full waste audit results are presented below, the discussion centres on the management of organic waste, since this is the only area where physical interventions were made.

5.4.2 Process – waste

All homes have kerbside access to Porirua City Council's weekly rubbish bag collection and recycling bin (45 L) collection, although several homes chose to use a contracted 'wheelie bin' rubbish service in lieu of the Council operation. No homes were found to use alternative recycling facilities.

A summary of the refuse options available to the residents follows:

- Council funded weekly recyclable collections (1 x 45 L black bin, plus unlimited supermarket bags).
- Council funded weekly rubbish collection (pay per use 70 L bag).

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[11] ***A compact organic composting system where worms are housed within a bin to digest organic waste and produce vermicast.***

- Wheelie bin services – at least three different service providers each supplying 240 L wheelie bins for all household waste. Some collections coincided with the Council collection day while others were on different days.
- Council operates an excellent recycling and resource recovery operation (Trash Palace – www.trashpalace.co.nz) which is approximately 7 km from the sample homes.
- Several homes (C-P06, S-P07, and H-P08) have inbuilt kitchen waste disposal systems.
- Some residents operated compost bins (to varying levels of sophistication; however these have been replaced with the worm farms).

While no homes appear to regularly access a large ‘company’ rubbish bin, at the pre-renovation audit one home (H-P03) was running a business from their home with several staff, and another home (S-P01) ran an owner-operated business but had no other staff on their premises. H-P08 had a weekly wheelie bin collection while S-P01 emptied their wheelie bin ‘as required’ making auditing difficult. In both these cases, the pre-renovation refuse sampled included waste which was of a ‘household’ origin and also waste that was clearly business related e.g. shredded paper, staff catering etc.

It was decided to audit these ‘households’ because as the owner-operators of the business they were clearly capable of influencing the way their business behaves. Also it is impossible to completely differentiate between the two highly integrated operations of running a household and running a business from the home. Unfortunately, in both these cases, the business operation had been removed from the premises by the time the post-renovation audit was conducted. Furthermore, in the case of S-P01, the household was also one member less in number when the post-renovation waste audit was carried out. (This occupant left the home after the final energy monitoring.)

5.4.3 Waste audit

Both audits followed MfE’s standardised SWAP2 categories (MfE, 2002) with measurements recorded in kilograms (to 1/1,000). Pre-renovation samples were taken over two weeks in late March and early April 2007. Post-renovation samples were taken in early October 2008.

For each audit, collection of the samples was coordinated so as to cause minimal disruption to the household. Homes were asked to make made minimal alteration to their routine although they were aware their refuse was being collected. To mitigate any conscious or sub-conscious behaviour change, homes were told several months in advance that their refuse would be audited and then given only two days’ notice that the auditor was collecting ‘this week’s’ refuse.

All samples were kept cool and weighed using 5 kg kitchen scales (accurate to 1 g) before being recorded within 24 hrs of being ‘put out’ for collection. The completed audit sheets can be found in the Appendix (Section 9.4).

5.4.4 Waste results

5.4.4.1 Pre-renovation cumulative results of eight homes

A one week breakdown of pre-renovation waste (by weight) produced by eight homes can be seen in Figure 9 and was approximately 160 kg, which equates to an average of 20 kg per home per week or one tonne per year. This suggests this sample is reasonably 'typical' of New Zealand homes in their overall waste (MfE, 2002). Equally the composition is within the 'normal' bounds of domestic waste (MfE, 2002). Within the graph in Figure 9, just one home (B-P02) contributed 65 kg to the 94 kg 'organic' portion.

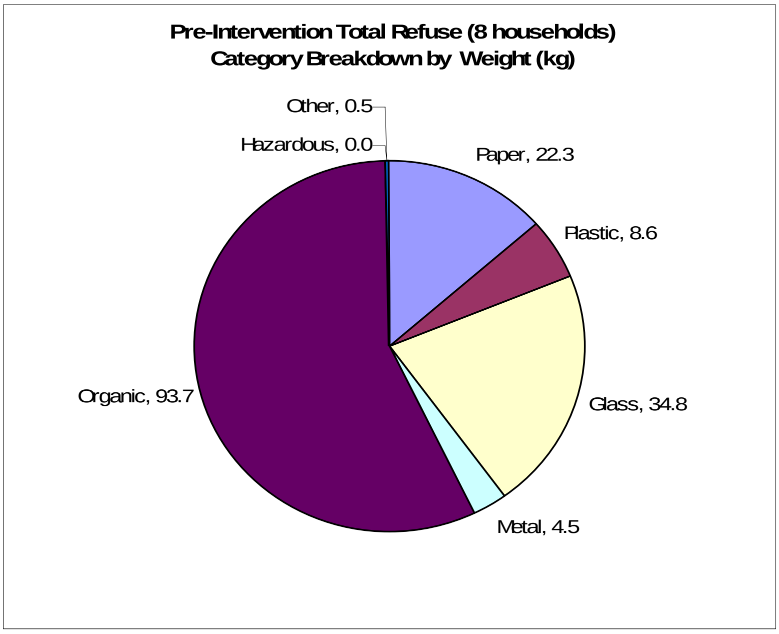

Figure 9: Pre-renovation total refuse category breakdown by weight

As only six homes (H-P10, H-P08, S-P09, S-P05, S-P07 and B-P02) could have the post-renovation audit compared with the pre-renovation audits, from here forward combined results relate to these homes only and focus on the organic waste.

The fate of such organic material as lawn clippings has not been resolved, since it cannot be assumed to be composted on-site. It is also worth noting that several homes (H-P08, S-P07 and C-P06) have in-sink waste disposal units for the disposal of kitchen waste which makes it extremely difficult to ascertain the volume of refuse put through the worm farms before and/or after the renovation.

5.4.5 Waste conclusions and discussion

- There is no clear evidence that any significant alteration has been made to the solid organic waste disposed of from any of these homes. However the waste audits suggest that there has been a higher recognition of the household contribution to the waste stream.
- H-P10 – This home met the HSS^{TM} benchmark for waste, although total waste volume stayed the same between the audits. This home is not recycling much of it waste stream.

- H-P08 – The waste management at this home was the best of all the homes assessed. While there was no change in the kitchen waste volumes, there were low overall refuse volumes and high rates of recycling. This home did not meet the HSS™ benchmark for waste, (due to the in-sink waste disposal unit) and had improvements in the management of its waste stream.
- S-P05 – The results of the waste audits show that this home appears to be a consistent and stable home with good rates of recycling and low volumes of refuse overall. The results possibly show an increase in recycling, but these results are inconclusive. This home met the HSS™ benchmark for waste.
- S-P09 – This home had an inconclusive result in meeting the waste HSS™, although it did have lower waste after the renovation and high recycling rates.
- S-P07 – No construction waste was found in the 2007 audit even though the home was clearly being renovated at the time. We suspect trips to the 'dump' have been contributing to low waste volumes. This is a home showing low overall refuse levels and high rates of recycling, although it fails the HSS™ due to having an in-sink waste disposal unit. It is unclear how the worm farm is contributing to the management of organic waste.
- B-P02 – Large amounts of green waste were evident in the wheelie bin on both audits yet this home runs a working compost heap. They managed to drown the first batch of worms and more were ordered as replacements. Apparently these never showed up although it was only in carrying out the second audit this 'failure' was discovered. Kitchen waste is significant as are newspapers, despite the owners reporting that they burn most paper in their fire. This home fails the HSS™ benchmark for waste, although the waste volume reduced between audits.

There was little incentive, and no requirement in this study, to improve the management of the household organic waste streams – which did not significantly improve. However two homes met the Waste HSS™ (one of these was a 'High' package home – see Table 24) and four homes had improved performance (see Table 46 to Table 52).

The introduction of worm farms to facilitate the on-site disposal of organic kitchen waste was intended to reduce the use (in two homes – the third home did not receive a worm farm) of the in-sink kitchen waste disposal systems installed in three homes. This has the triple benefit of: reducing reticulated water consumption to flush debris from the kitchen sink into the sewage system; reducing reticulated energy use to operate the electric motors on the waste disposal units; and reducing the nutrient content of the waste, potentially reducing the municipal sewage treatment requirements. The project was not able to remove any waste disposal units or confirm any change in usage patterns of these appliances, but further work in this area is warranted.

See Appendix (Section 9.4) for a full breakdown of the pre-renovation and post-renovation waste stream audits.

6 Discussion

6.1 HSS™ summary by home

This section summarises an assessment of Beacon's HSS™ benchmarks against all the performance areas:

- Total reticulated energy;
- Water use;
- The IEQ parameters of
  - Mean minimum bedroom 1 and family room temperatures;
  - Ventilation (not assessed);
  - Winter RH;
  - The IEQ checklist;
- Waste; and
- Materials.

'High' package homes summary of HSS™ benchmarks								
Home	**Total Reticulated Energy**	**Water**	**Winter Bedroom 1 Temps**	**Winter Family Room Temps**	**Bedroom1 RH**	**IEQ Check**	**Waste**	**Material**
H-P03	Met	Met	Met	Fails	Met	Fails	N/A	Met
H-P10	Met	Met	Fails	Fails	Fails	Fails	Met	Met
H-P08	Fails	Fails	Fails	Fails	Fails	Fails	Fails	Met

Table 24: Summary of HSS™ achievement for 'High' package homes

'Standard' package homes summary of HSS™ benchmarks								
Home	**Total Reticulated Energy**	**Water**	**Winter Bedroom 1 Temps**	**Winter Family Room Temps**	**Bedroom 1 RH**	**IEQ Check**	**Waste**	**Material**
S-P01	Fails	Fails	Fails	Fails	Fails	Fails	N/A	Met
S-P05	Fails	Inconc[12]	Fails	Fails	Fails	Fails	Met	Met
S-P09	Met	Inconc	Fails	Fails	Fails	Fails	Inconc	Met
S-P07	Met	N/A	Fails	Fails	Fails	Fails	Fails	Met

Table 25: Summary of HSS™ achievement for 'Standard' package homes

[12] *'Inconc' is used as a contraction of 'inconclusive'.*

The results for the ‘Basic’, ‘Sold’ and ‘Contrast’ homes are not tabulated here.

The energy assessments have been made on the basis of all the data available, as shown in Table 10 for total reticulated energy (not just the five month winter data reported in Section 5.1) while statistical techniques have been used to address gaps in the data and to ensure significance of the data. The other HSS™ benchmarks of mean minimum temperatures (May-September) and the RH values (July) are taken from Section 5.2 since the winter months are expected to contain the periods with minimum external air temperatures. The water data come from Section 5.3 and the waste from Section 5.4.

The summaries in the two tables below are drawn from the tables for each home contained in the Appendix (Section 9.5).

6.1 Data integrity

The maximum amount of data possible has been used in this work. However, as with any experimental work, there are unintentional periods of data loss. Where this has occurred, recognised techniques have been used and missing data has been interpolated.

- In the Interim report (Burgess & Buckett, 2008) there was a problem with the gas monitoring at S-P05. When the instant water heating equipment was being installed in S-P05, the gas metering equipment was restored to the wrong meters, and the Interim report erroneously reported that there had been a significant increase in reticulated energy used for water heating. In that previous work, S-P05 was inadvertently recognised as the only home which used more reticulated energy for water heating after the renovation. This was incorrect, and the corrected analysis is presented here.
- There were also periods where resources did not permit the collection of data. This included the November 2007 – January 2008 period where water meters were not read.
- The energy and temperature data had gaps over the November 2007 – December 2007 period.
- Some homes were not able to receive waste audits.
- There was no assessment of the RH before the renovations.
- There was no assessment of reticulated water use before the renovations.
- There was no water measurements made at S-P07 or C-P06 since meters were not easy to install at these properties.
- There was no waste measurement before the renovation for C-P06, and no waste measurement after the renovation for H-P03.
- Ventilation was not assessed.
- The performance of the SWH systems in summer was not analysed.
- The IEQ checklist was used for the renovation only.
- Some of the renovations were augmented by material installations at the user’s own cost – including a roof replacement and insulation, and heat pumps at H- P10 as well as the heat pump at P09. Hence the value of these is not included in the cost tables.

6.2 Validity of renovation assumptions

The TE101 report (Walford et. al., 2005) presents a set of assumptions regarding the package choices that were implemented as interventions in this work.

The case studies presented here do not have the scientific rigour to conclude the validity of the renovation assumptions. However our observations are sufficient to provide the following realisations, where the term ‘Supported’ is used to indicate that the findings of this work have been in general agreement with the assumptions.

- “Insulation alone is not enough – you need to include an efficient heating device in conjunction with insulation to get significant energy savings and temperature improvements”. **Supported**. The results in this work have indicated general agreement with this assumption, although the support is not strong. None of the ‘Standard’ package homes (where no wall insulation and no significant space heating was provided) showed reduced space heating energy consumption, while two of the ‘High’ package homes (where both envelope insulation and space heating interventions were made) showed lower space heating energy consumption. While our records show that only H-P03 and S-P07 had wall insulation before the renovations, some wall insulation was found in P05 during the renovations. The fact that some of the homes already had some wall and ceiling insulation before the renovation (whether disclosed or not), was not a major problem where the aim was to compare the performance before and after the renovations.

- *“Current retrofit standards will not achieve a HSS™; much higher levels of retrofit are needed”*. **Supported**. Previous work (Buckett et. al., 2008) has shown that while the insulation of the ‘High’ and ‘Standard’ package homes is sufficient to enable many of the homes to meet the Energy and IEQ HSS™ performance benchmarks, none of the homes monitored in this work actually met all of them. This indicates that there are other factors than the physical interventions operating here, and that it would be very unlikely for any renovation that did not include full thermal envelope insulation and a high output space heating system to meet the thermal HSS™. The HSS™ are high compared to typical New Zealand standards (Isaacs et. al., 2003). It is likely that behaviour change is also necessary to achieve the HSS™ performance benchmarks.

- *“Heavy insulation of ceiling and under floor may be sufficient to bring homes up towards a HSS™”*. **Not supported**. This work has shown that the heavy insulation of the **complete** thermal envelope (including walls) provided to two homes (the ‘High’ package homes) in conjunction with improved space heating systems and double-glazing has lifted the performance of the homes towards the HSS™, but not achieved all the HSS™ performance benchmarks. The four ‘Standard’ package homes did not receive wall insulation, and while only two homes achieved one of the HSS™ performance benchmarks, the four homes all showed improved thermal performance. It is clear that heavy insulation of the ceiling and under floor without insulation of the walls or windows (and without an efficient space heating appliance) is unlikely to elevate homes to a HSS™ energy-use benchmark, without also changing user behaviour.

- "Wall insulation on top of ceiling and under floor insulation may be required, combined with efficient heating, to get homes to the HSS™". **Supported**. The performance of H-P03 and H-P10 indicates that it is unlikely for a home to reach an energy-related HSS™ performance, without the inclusion of wall insulation and efficient space heating. It must be noted that some of the homes in this work already had some levels of wall insulation, and all had some ceiling insulation, so the comparison was not from a 'zero-level' regarding the insulation of the thermal envelope. The study was unable to prove whether wall and window insulation are necessary to achieve the Beacon HSS™ levels for space heating. However four of the five homes that did not receive wall and/or window insulation, met the HSS™ for total energy (B-P02, C-P06, S-P07, S-P09), but not for space heating energy. The energy used for space heating in the family rooms has decreased by 60% in both H-P03 and H-P08, but in H-P10 has increased. This indicates that in H-P03 and H-P08 occupants have reduced the space heating purchased and are choosing **not** to heat to the HSS™ levels. Occupants are maintaining similar temperatures with **lower** energy use i.e. the occupants are choosing not to heat to the HSS™ temperature benchmarks, which may be an economic decision, could be accidental, or might be due to lifestyle expectations.

- "Removing moisture sources (polythene on ground, extract fans, shower domes) will improve the relative humidity conditions in the homes". **N/A**. There was no pre-renovation assessment of the RH levels in the homes, so this assumption could not be tested. We are concerned at the high RH levels in all the homes (except P03)[13], and particularly the 'Contrast' home, C-P06. (It is noted that the examples in this italicised assumption are not actually relevant to the **removal** of moisture sources, but to mitigation of the effect of moisture sources that are difficult to remove.)

7 Key observations

Since this work dealt with a diverse set of case studies, with the number of studies being less than that required for a valid statistical review, it is difficult to draw reliable overall conclusions. Consequently this section is titled 'Key observations' and draws together the main findings from the discussion sections of all the other analyses.

This work assessed the validity of a set of renovation assumptions (Walford et. al., 2005) and concurrently assessed the achievement of renovation sustainability benchmarks. In the following section (7.1), the renovation assumptions from the previous section (6.2) are summarised.

[13] ***The combination of bedroom heating and high insulation levels in H-P03 have allowed the RH in the bedroom of this home to fall within the performance benchmarks of the HSS™ for humidity.***

7.1 Testing renovation assumptions

- "Insulation alone is not enough – you need to include an efficient heating device in conjunction with insulation to get significant energy savings and temperature improvements". **Supported**.
- "Current retrofit standards will not achieve a HSS™; much higher levels of retrofit are needed"**. Supported**.
- Wall insulation on top of ceiling and under floor insulation may be required, combined with efficient heating, to get homes to the HSS™"**. Supported**.

One renovation assumption was not supported:

- "Heavy insulation of ceiling and under floor may be sufficient to bring homes up to a HSS™"**. Not supported**.

And one renovation assumption could not be tested:

- "Removing moisture sources (polythene on ground, extract fans, shower domes) will improve the relative humidity conditions in the homes"**. N/A**.

7.2 Beacon sustainability packages

- Homes which received the Beacon 'High' package renovation had the greatest improvements in their sustainability outcomes.
- The Beacon 'High' package was more successful than the Beacon 'Standard' package at improving outcomes for occupants.
- Occupants of the homes in this study made choices about their living environments which over-rode the effect of some of the physical renovations.
- All the homes were improved in at least one measurable parameter by the 'High', 'Standard' and 'Basic' renovation packages.
- A social/behavioural/physical renovation set may be as strong a driver to the achievement of the HSS™ in New Zealand homes as the physical renovations piloted here.

7.3 HSS™ achievements

- Physical interventions alone are not necessarily sufficient to lift the performance of homes to the Beacon benchmarks for all the five performance areas of the HSS™.
- Occupants do not necessarily operate their homes at the HSS™, even if provided with the ability to do so.
- All of the Beacon renovation packages improved the performance of homes against the HSS™ benchmarks.

7.4 Energy achievements

- Solar water heating in winter (and in one case wetback heating) resulted in 55% to 70% reductions in the use of reticulated energy, even though there were increases in heated water use.
- Physical intervention packages upgrading the insulation of the thermal envelope and space and water heating appliances can result in significantly less reticulated energy use in homes.
- None of the ‘Standard’ package homes had reductions in space heating energy use, and only one home had reduced total energy need.
- All the standard homes had improved bedroom 1 temperatures, and two of the three ‘High’ homes had improved bedroom 1 temperatures.
- Hot water cylinder wraps resulted in between 11% and 21% reductions in water heating energy use.
- Six homes met the total reticulated energy consumption HSS™ after the renovation, but five of these already met the HSS™ (although no statistical tests were performed) before the renovation, so the interventions have probably only resulted in one extra home meeting the reticulated energy consumption HSS™ benchmark.
- Two of the ‘High’ package homes, and all of the standard package homes do not get as cold as before, although no homes meet the HSS for temperature in both rooms. Only one home meets the HSS™ for temperature in the bedroom 1 and no homes meet this HSS™ in the family room.
- Instant gas water heaters may have improved the availability of heated water, but did not change the reticulated water heating energy use.
- Heat transfer kits may have assisted to increase the air temperatures in bedroom 1 of the homes, although this potential benefit cannot be extracted from the data and further research is recommended.

7.5 IEQ achievements

- RH levels are high in bedroom 1 of all but one home.
- Regular heating of bedroom 1 is necessary to reduce RH levels, but more work needs to be done in this area.
- The frequency at which summer air temperatures rise above 24°C in the bedroom 1 and the family room has increased, but the peak temperature in the ‘High’ package homes is 26°C, indicating that overheating has not been made significantly worse by the insulation of the thermal envelope of the homes.
- None of the homes met the IEQ checklist since none have passively vented windows, and no homes have all of the kitchen, bathroom and laundry actively ventilated.

7.6 Water achievements

- Three of the homes meet the HSS™ for reticulated water.
- Since there were no pre-renovation measurements of potable water use, improvements cannot be quantified.

7.7 Waste achievements

- Three homes met the waste HSS, and four homes had better waste management practices after the renovation, although there was little incentive and no requirement to improve organic waste management practices.
- The introduction of worm farms to facilitate the on-site disposal of organic kitchen waste was intended to reduce the use of the in-sink kitchen waste disposal systems installed in three homes. This has the triple benefit of: reducing reticulated water consumption to flush debris from the kitchen sink into the sewage system; reducing reticulated energy use to operate the electric motors on the units; and reducing the nutrient content of the kitchen waste, potentially reducing the municipal sewage treatment requirements. The project was not able to remove any waste disposal units or confirm any change in usage patterns of these appliances, but further work in this area is warranted.

7.8 Materials achievements

- The materials HSS™ benchmark for the renovations was met for all homes.

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9 Appendices

9.1 Renovation selection tools

While the previous reports on the Papakowhai renovation study have discussed the development of renovations, the use of the Healthy Housing Index (HHI), the House Condition Survey (HCS) and the International Health Assessment (IHA – self-reported) has not been discussed.

In the development of the options of renovations for assessment, it was recognised that there was significant overlap between the various tools. It was also found that the HEEP home assessment tool (Isaacs et. al., 2007) already contained aspects of the HCS tool that were relevant in this work. Unfortunately the HHI lacked a benchmarked assessment protocol. Consequently, the HEEP home assessment tool was modified with input from the IHA, and implemented as a survey performed on the households of interest. This tool is proprietary to BRANZ, so is not presented below. However the outcome of applying the instrument to the homes is presented in the intervention list in Section 9.3.

9.2 Renovation categorisation

The renovations included in each of the following categories are listed below.

9.2.1 Energy

9.2.1.1 Space heating and lighting

The 'Space heating and lighting' subcategory of the 'Energy' category includes: lowered and insulated ceilings; plastered, re-gibbed and insulated walls (including the restoration of pelmets); installation of masonry batts; the installation of midfloor and underfloor batt insulation and foil; the installation and modification of heating appliances (including heat pumps and solid fuel burners); the installation of energy efficient luminaires and fixtures; the replacement of old single-glazed aluminium windows with new double-glazed aluminium windows, and the replacement of single-glazed panes with double-glazed panes in existing windows.

9.2.1.2 Water heating

The 'Water heating' subcategory of the 'Energy' category includes: the wrapping of existing hot water cylinders with insulation blankets; the lagging of hot water pipes; the installation of SWH systems; the replacement of a storage electric cylinder with an instantaneous gas hot water unit and a condensing instantaneous gas hot water unit; the installation of a low-flow shower head; and the installation of a wetback.

9.2.2 IEQ

The IEQ category includes: draught-stopping of doors, windows and other openings in the exterior envelope; the placement of polythene on sub-floor ground; the installation and modification of heat transfer systems; the installation of smoke alarms; the installation and modification of extraction fans (including a rangehood); and the installation of shower domes.

9.2.3 Water

The 'Water' category includes anything regarding potable reticulated water, and includes plumbing checks, and the installation of water-saving dual-flush toilet cisterns. The installation of a low-flow shower head and flow restrictors in S-P05 is included in the energy section (9.2.1.2).

9.2.4 Waste

The 'Waste' category includes the installation of worm farms, and incidental education provided to the homeowners about recycling and organic waste management while contractors were on-site.

9.3 Full renovation list by home

9.3.1 H-P03

H-P03				
Issues	**Interventions**	**Date**	**Approx. Market Value (exc GST)**	**Intervention Package**
Old wall insulation in unknown state	Stripped, re-insulated and re-lined walls to R-2.4 pelmets rebuilt	Sep 07	$10,050	
Old skillion ceiling insulation in unknown state – assume R-1	Lounge, dining and kitchen skillion ceilings lowered and insulated with R-3.6 glass fibre insulation	Feb 07	$5,930	
	Plasterboard for walls (10 mm) and ceiling (13 mm)	Feb/Sep 07	$1,450	
No underfloor insulation	Floor insulated with R-2 foil-backed bulk insulation, polythene put on ground	Feb 07	$2,020	
135 L B grade electric hot water cylinder – family of five	SWH system with 300 L cylinder	May 07	$10,060	
Old woodburner past useful life	Occupant installed new NES[14] compliant woodburner		$3,000	
Ceiling insulation in cavity needing to be re-laid	New ceiling insulation over existing. Insulation re-laid, R-2.6 insulation put over top and over ceiling joists to remove thermal bridging	Feb 07	$1,080	
Plumbing in unknown state	Plumbing checked	May 07	$80	
No smoke alarm	New smoke alarm installed	May 07	$30	
Food waste not being reused	Worm farm installed	Sep 07	$160	
Kitchen fan not working	New rangehood in kitchen	Aug 07	$870	
High water use toilets	Two dual flush toilet cisterns installed	Sep 07	$90	
Old aluminium window frames past useful life	Windows replaced with double-glazing and standard frames	Oct 07	$41,770	
	(Occupants replaced roof)	Feb 07	N/A	High
	TOTAL		$76,590	

Table 26: H-P03 – issues, interventions and costs

[14] *Ministry for the Environment's (MfE) National Environmental Standards (NES) for Wood burners*

9.3.2 H-P10

H-P10				
Issues	**Interventions**	**Date**	**Approx. Market Value (exc GST)**	**Intervention Package**
Ceiling insulation thin and patchy	Two layers of R-2.6 put over old insulation, top layer put over ceiling joists to remove thermal bridging	Feb 07	$2,100	
No under floor insulation	Timber suspended floors above sub-floor and garage insulated with R-2 foil-backed bulk insulation, polythene put on ground in sub-floor	Apr 07	$2,380	
Flat roof above foyer uninsulated	Flat roof insulated with R-3.6 mid floor glass fibre insulation and lined (13 mm)	Feb 07	$540	
No wall insulation	Walls stripped, insulated with R-2.4 and re-lined (10 mm) throughout thermal envelope, except downstairs bedroom	Apr 07	$7,810	
	Plasterboard for flat roof and walls	May 07	$1,230	
Original electric hot water cylinder (wrapped) losing excess heat	SWH system installed on foyer roof	May 07	$10,040	
Old inbuilt wood burner past useful life	New high efficiency wood burner installed with wetback pumped to hot water cylinder	May 07	$4,050	
Old timber window frames in poor condition and rotted through in places	Double-glazing units and window frames installed throughout home by homeowner	Nov 07	$45,000	
Standard incandescent bulbs in high-use fittings	Compact fluorescent bulbs put into high-use fittings	Jul 07	$30	
No extraction fans in bathroom and laundry	Householders installed extraction fans into bathroom and laundry	Apr 07	$380	
Draughty door to garage losing heat	Garage door draught-proofed	Jul 07	$50	
Plumbing in unknown state	Plumbing checked, vanity moved for re-lining, leaky tap fixed	May 07	$300	
Food waste not effectively dealt with	Worm farm installed	Sep 07	$160	High
	TOTAL		$74,070	

Table 27: H-P10 – issues, interventions and costs

9.3.3 H-P08

H-P08				
Issues	**Interventions**	**Date**	**Approx. Market Value (exc GST)**	**Intervention Package**
Ceiling insulation at moderate level but needs re-laying in places	Ceiling insulation re-laid, second layer of R-2.6 put over existing and across ceiling joists, removing thermal bridging, raising insulation to approximately R-5	Feb 07	$940	High
No wall insulation	Rear wall of bedroom 4 (R-2.4 batts) and gym backing onto underfloor (R-1.2 masonry) insulated	May 07	$390	
No underfloor insulation	Floor insulated with R-2 foil-backed bulk insulation, or foil, polythene put on ground	Mar /May 07	$2,160	
B grade electric hot water cylinder with excessive heat loss	SWH with 300 L cylinder installed	May 07	$9,870	
New aluminium framing with single-glazed panes does not provide good insulation	Double-glazing panes retrofitted into existing aluminium frames (including scaffolding)	Jun 07	$10,700	
Condensation and mould in bathroom	Shower dome installed	May 07	$310	
Plumbing in unknown state	Plumbing checked	May 07	$80	
Food waste going into the bin	Worm farm installed	Sep 07	$160	
	TOTAL		$24,610	

Table 28: H-P08 – issues, interventions and costs

9.3.4 S-P01

S-P01				
Issues	**Interventions**	**Date**	**Approx. Market Value (exc GST)**	**Renovation Package**
Skillion ceilings throughout with inadequate insulation	Lowered and insulated ceiling to R-4.6 (R2.6 in places)	May 07	$13,270	**Standard**
	Plasterboard (13 mm) for ceiling	May 07	$570	
Draughts from downstairs around sliding door	Heavy draught-stopping around door to garage	May 07	$100	
Uninsulated under floor	Insulated floor with R-2 foil-backed bulk insulation, polythene put on ground	Feb 07	$1,960	
Older wood burner	Pellet burner installed	July 07	$4,330	
Inadequately heated bedrooms	Ducted heat transfer kit with three outlets installed	May 07	$3,020	
Food waste not being composted	Worm farm installed	Sep 07	$160	
Energy inefficient lighting	Compact fluorescent bulbs put into high-use fittings	May 07	$30	
Plumbing quality unknown	Plumbing checked		$80	
Poorly insulated B grade electric hot water cylinder	Hot water cylinder wrapped and pipes insulated with lagging	May 07	$90	
	TOTAL		$23,610	

Table 29: S-P01 – issues, interventions and costs

9.3.5 S-P05

S-P05				
Issues	**Interventions**	**Date**	**Approx. Market Value (exc GST)**	**Intervention Package**
Original D grade (wrapped) electric hot water cylinder poorly insulated	Replaced electric storage hot water cylinder with gas instant hot water units, one a high efficiency condensing model, at the two service areas Low-flow shower head installed	Jul 07	$4,520	Standard
Lack of wall insulation making heat losses high	Plastering repairs to walls	Feb 07	$50	
Older ceiling insulation in unknown state	Ceiling insulation topped up with R-1.8 blanket	Feb 07	$1,190	
No under floor insulation making heat losses high	Timber suspended floors insulated with R-2 foil-backed bulk insulation, polythene put on ground	Feb 07	$3,030	
No active heating in bedrooms	Ducted air transfer system installed to move warm air into hallway by bedrooms	Jun 07	$1,400	
Extraction fan vents moisture into roof cavity	Bathroom extraction fan ducted to outside	Jun 07	$70	
Plumbing in unknown state	Plumbing checked	May 07	$80	
Draughty windows and sliding door in dining room contributing to heat loss	Sliding door draught-stopped	Jun 07	$50	
Large old recessed down light in kitchen resulting in poor energy use and loss of insulation value	Two x CA-rated halogen down lights installed in kitchen	Jul 07	$110	
Energy inefficient lighting	Compact fluorescent bulbs put into high-use light fittings	May 07	$30	
Food waste going into the bin	Worm farm installed	Sep 07	$160	
	TOTAL		$10,690	

Table 30: S-P05 – issues, interventions and costs

9.3.6 S-P09

S-P09				
Issues	**Interventions**	**Date**	**Approx. Market Value (exc GST)**	**Intervention Package**
Ceiling insulated to a low-moderate level	Layer of R-2.6 put over top of existing insulation, and over ceiling joists to remove thermal bridging, raising insulation to approximately R-4	Feb 07	$710	Standard
No under floor insulation	Floor insulated with R-2 foil-backed bulk insulation, polythene put on ground	Mar 07	$490	
Floor of main bedroom is above uninsulated garage	Mid floor insulation installed between garage and main bedroom	Mar 07	$2,270	
	Plasterboard (13 mm) for garage ceiling	Mar 07	$320	
Wall between garage and stairwell/rumpus, rumpus/under floor uninsulated	Wall insulation on rear of wall to under floor and garage installed	Apr 07	$180	
Slight mould in bathroom	Shower dome installed	May 07	$310	
No fixed heating	Homeowner installed heat pump	Mar 07	$3,000	
	Heat pump rewired	Mar 07	$150	
Draught from garage sliding door into living area	Sliding door to garage draught-stopped	May 07	$40	
B grade electric hot water cylinder with poor insulation performance	Cylinder wrapped, pipes lagged	Feb 07	$90	
Energy inefficient lighting used	Compact fluorescent bulbs put into high-use fittings	Apr 07	$30	
Plumbing in unknown state	Plumbing checked	May 07	$80	
Food waste is not recycled	Worm farm installed	Sep 07	$160	
	TOTAL		$7,830	

Table 31: S-P09 – issues, interventions and costs

9.3.7 S-P07

S-P07				
Issues	**Interventions**	**Date**	**Approx. Market Value (exc GST)**	**Intervention Package**
Low to medium levels of insulation in ceiling	Ceiling insulation topped up with R-2.6, existing insulation tidied up	Apr 07	$1,940	Standard
No wall insulation in bedroom wing	R2.4 wall insulation installed by occupants in bedroom wing	May 07	$1,940	
	Plasterboard for walls	Jun 07	$480	
No under floor insulation	Timber suspended floors insulated with R-2 foil-backed bulk insulation, polythene put on ground	Feb 07	$1,770	
B grade electric hot water cylinder not insulated	Hot water cylinder wrapped, pipes lagged	Feb 07	$90	
Heat transfer system not working, bedrooms not actively heated	Relocated heat transfer thermostat into lounge, extended ducting to bedrooms	Jun 07	$810	
Extraction fan vents moisture into roof cavity	Bathroom extraction fan ducted to outside Shower dome installed	May 07	$370	
New single-glazed aluminium windows throughout family areas offer poor insulation value	Occupants retrofitted rest of home with single-glazed tinted laminated aluminium windows	Dec 06	N/A	
Plumbing in unknown state	Plumbing checked	May 07	$80	
Food waste going into the bin	Worm farm installed	Sep 07	$160	
	TOTAL		$7,640	

Table 32: S-P07 – issues, interventions and costs

9.3.8 B-P02

B-P02				
Issues	**Interventions**	**Date**	**Approx. Market Value (exc GST)**	**Intervention Package**
Original D grade electric hot water cylinder is poorly insulated	Hot water cylinder wrapped and pipes lagged	July 07	$90	Basic
No under floor insulation	Floor insulated with R-2 foil-backed bulk insulation, polythene put on ground	Feb 07	$1,290	
Dislodged ceiling insulation	Ceiling insulation re-laid, extra added where necessary	Feb 07	$110	
Wall insulation only in master bedroom walls				
Food waste not being re-used	Worm farm installed	Sep 07	$160	
Extractor fan not working well	Extra fan added to shower extract fan system, ducting shortened	Jul 07	$280	
Broken cat flap causing draughts from garage	New cat door installed	Jul 07	$50	
Energy inefficient lighting	Compact fluorescent bulbs put into high-use fittings	Jul 07	$30	
Plumbing of unknown quality	Plumbing checked	May 07	$80	
No smoke alarm	New smoke alarm installed	May 07	$30	
	TOTAL		$2,120	

Table 33: B-P02 – issues, interventions and costs

9.3.9 C-P06

C-P06				
Issues	**Interventions**	**Date**	**Approx. Market Value (exc GST)**	**Intervention Package**
Poor insulation in ceiling	Ceiling insulation topped up with R-2.6	Jul 07	$1,380	Contrast
	Accidental addition of hot water cylinder wrap	Jul 07	Nil	
	TOTAL		$1,380	

Table 34: C-P06 – issues, interventions and costs

9.3.10 P04

No renovation.

9.4 Water and waste results per home

This appendix contains the reticulated water use measurements from the homes where water meters were installed, and the data from the waste audits, where these were carried out.

The orange line in

Figure 10 to Figure 16 represents the HSS™ for water (180 L/p/d as defined in Easton, 2006), while the black line is a linear trend line. The data is not shown for November 2007 to January 2008 in any of the water use figures below, although a reading of the cumulative water use from November-January was taken in January 2008 and is shown in Table 23.

There were no pre-renovation water-use measurements.

9.4.1 H-P03

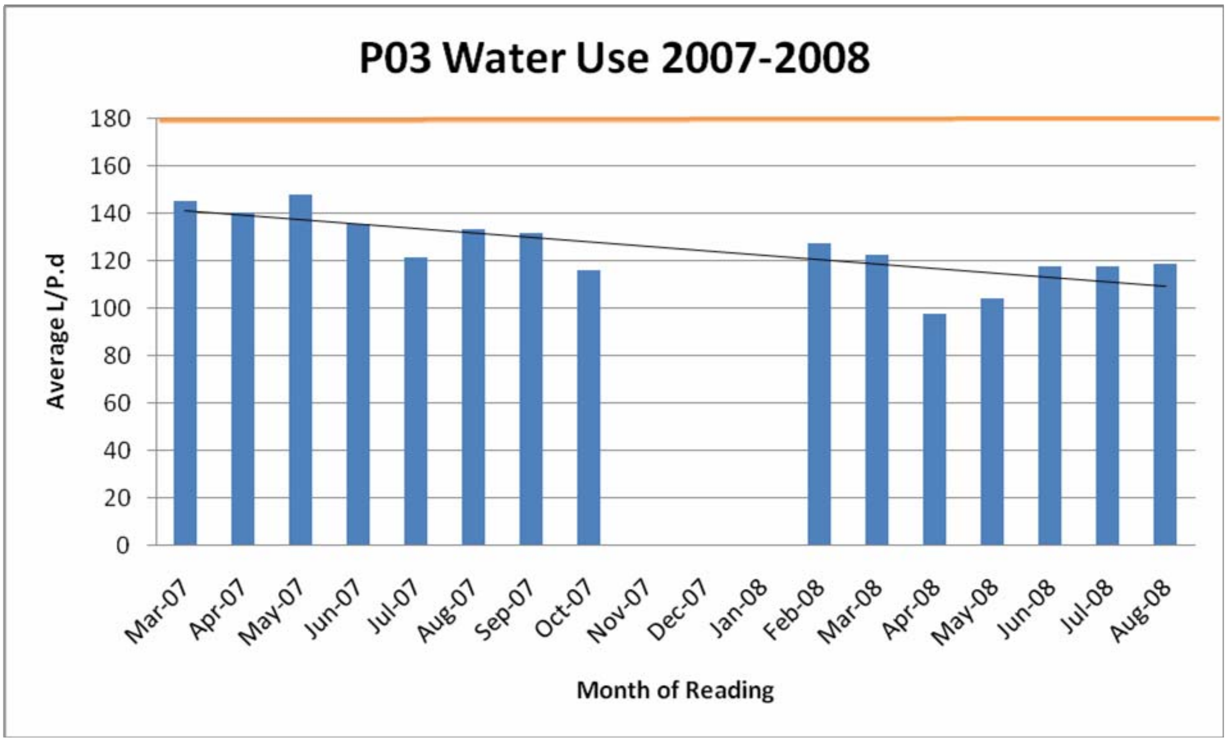
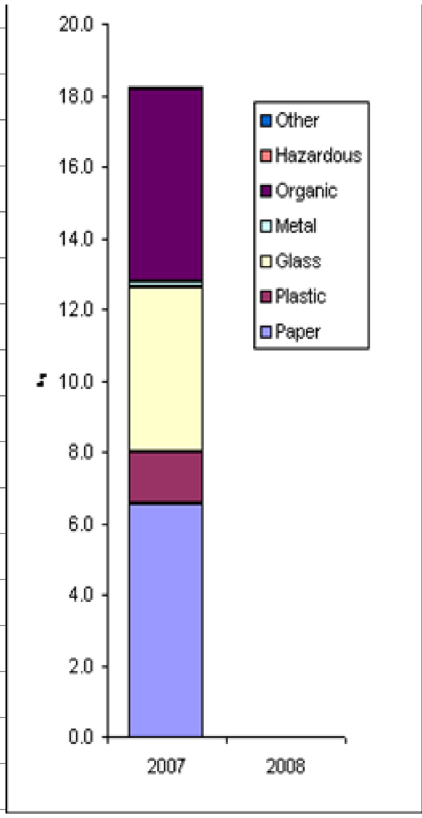


Figure 10: The water use in H-P03 from March 2007 to August 2008

H-P03	2007		2008		
Category		Wheelie + rec Bin			
1 2	Recycled	Rubbish	Recycled	Rubbish	Comments
Newspaper	0.05	0.1			Operated a business from "home".
Magazines	2.98	0.14			
Office paper		0.2			
Drink containers					
Cardboard	0.085	0.4			
Other packaging	0.157	0.55			
Sanitary					
Other paper	0.808	1.087			
Paper	4.08	2.477	0.0	0.0	
Rigid 1	0.052				
Rigid 2	0.05				
Rigid 5		0.1			
Rigid 6					
Other rigid		0.06			
Flexible 2					
Flexible 45					
Other flexible		0.61			
All other		0.58			
Plastic	0.102	1.35	0.0	0.0	
Reusable bottles					
Other drink	2.64	2			
Food jars					
All other					
Glass	2.64	2	0.0	0.0	
Steel cans	0.105				
Aluminium cans	0.015				
Other ferrous					
Other non-ferrous					
Appliances					
Metal	0.12	0	0.0	0.0	
Kitchen food		5.4			Office food scraps – cakes etc.
Soft garden waste					
Harder garden waste					
Soil					



Other					
Organic	0	5.4	0.0	0.0	
Construction	0	0	0.0	0.0	
Aerosols					
Hazardous	0	0	0.0	0.0	
Leather					
Clothing		0.055			
Other					
Other	0	0.055	0.0	0.0	No post-audit performed as business no longer operated from home.
Total	6.942	11.282	0.0	0.0	Based on numbers of people on-site – reduced by four.

Table 35: Waste assessment instrument from H-P03

9.4.2 H-P10

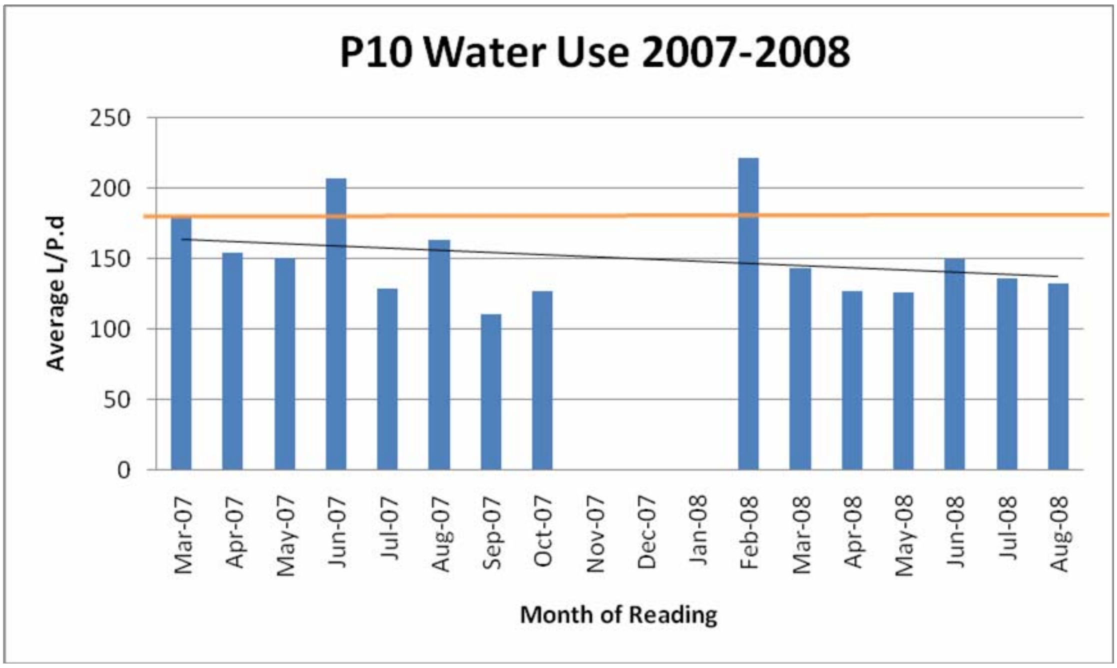
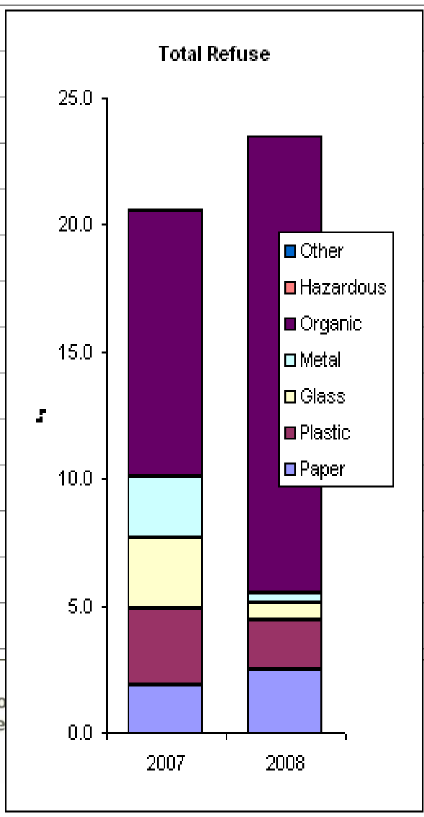


Figure 11: The water use in H-P10 from March 2007 to August 2008

H-P10	**2007**		**2008**		
Category		**Wheel +r bin**		**rubbish bag X 3**	
1 2	Recycled	Rubbish	Recycled	Rubbish	Comments
Newspaper		0.7		1.3	No discernable change although wheelie bin not used.
Magazines		0.5		0.9	
Office paper					
Drink containers				0.3	
Cardboard	0.5				
Other packaging	0.2				
Sanitary					
Other paper					
Paper	0.7	1.2	0.0	2.5	
Rigid 1	0.4			0.1	
Rigid 2	0.3			0.5	
Rigid 5				0.4	
Rigid 6				0.2	
Other rigid		0.6			
Flexible 2				0.2	
Flexible 45					
Other flexible		1.2			



All other		0.6		0.6	
Plastic	0.6	2.4	0.0	1.9	
Reusable bottles				0.7	
Other drink	1.9				
Food jars	0.9				
All other					
Glass	2.7	0.0	0.0	0.7	
Steel cans		1.8		0.4	
Aluminium cans		0.6		0.0	
Other ferrous					
Other non-ferrous					
Appliances					
Metal	0.0	2.4	0.0	0.4	
Kitchen food		10.5		18.0	
Soft garden waste					
Harder garden waste					
Soil					
Other					
Organic	0.0	10.5	0.0	18.0	
Construction	0.0	0.0	0.0	0.0	
Aerosols					
Hazardous	0.0	0.0	0.0	0.0	
Leather					
Rubber					
Clothing		0.1			
Other					
Other	0.0	0.1	0.0	0.0	
Total	4.1	16.6	0.0	23.5	Family of four who clearly are not big on recycling.
Recycled Portion	20%		0%		Total refuse unchanged but now recycling rate dead.

Table 36: Waste assessment instrument from H-P10

9.4.3 H-P08

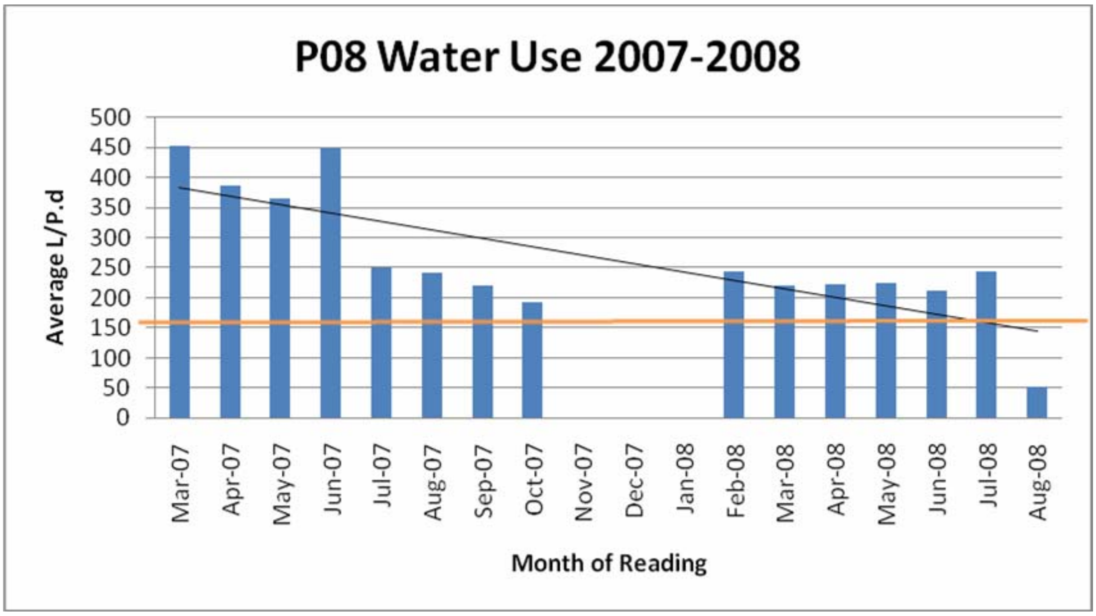
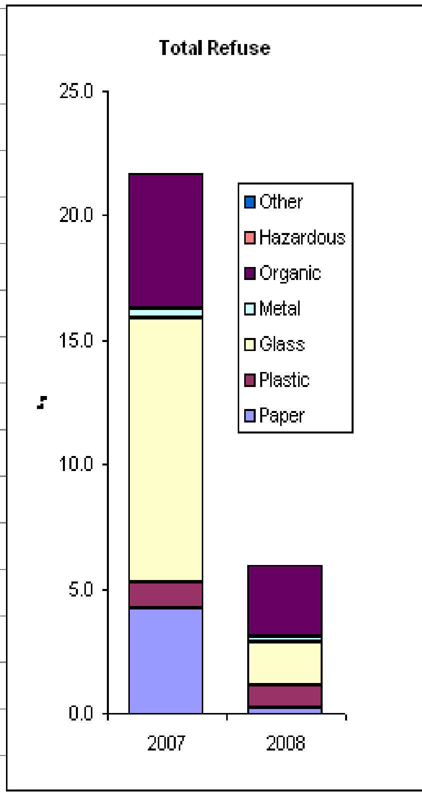


Figure 12: The water use in H-P08 from March 2007 to August 2008

H-P08	**2007**		**2008**		
Category		**Wheel + recyc Bin**		**Rubbish + Recycling Bag**	
1 2	**Recycled**	**Rubbish**	**Recycled**	**Rubbish**	**Comments**
Newspaper					
Magazines	1.0				
Office paper	0.8		0.1		
Drink containers	1.0				
Cardboard		0.2			
Other packaging		0.3			
Sanitary		0.3		0.1	
Other paper		0.6			
Paper	2.8	1.4	0.1	0.1	
Rigid 1	0.1				
Rigid 2	0.1		0.3		
Rigid 5					
Rigid 6			0.0		
Other rigid		0.3			
Flexible 2					
Flexible 45		0.2			
Other flexible	0.1	0.2	0.5		



All other		0.1	0.0		
Plastic	0.3	0.8	0.9	0.0	
Reusable bottles			0.6		
Other drink	8.9	0.2			
Food jars	1.2				
All other		0.4	1.1		
Glass	10.1	0.6	1.7	0.0	
Steel cans	0.1		0.2		
Aluminium cans	0.2		0.1		
Other ferrous					
Other non-ferrous					
Appliances					
Metal	0.3	0.0	0.2	0.0	
Kitchen food		1.8		2.9	Potentially a star performer but kitchen waste
Soft garden waste		3.7			unchanged. Decrease in recyclable paper and glass probably a lifestyle cycle.
Harder garden waste					
Soil					
Other					
Organic	0.0	5.5	0.0	2.9	
Construction	0.0	0.0	0.0	0.0	
Aerosols					
Hazardous	0.0	0.0	0.0	0.0	
Leather					
Rubber					Low overall refuse rates and high rates of recycling.
Clothing					
Other					
Other	0.0	0.0	0.0	0.0	
Total	13.5	8.2	3.0	3.0	Best contender for "star performer" award.
Recycled Portion	62%		50%		

Table 37: Waste assessment instrument from H-P08

9.4.4 S-P01

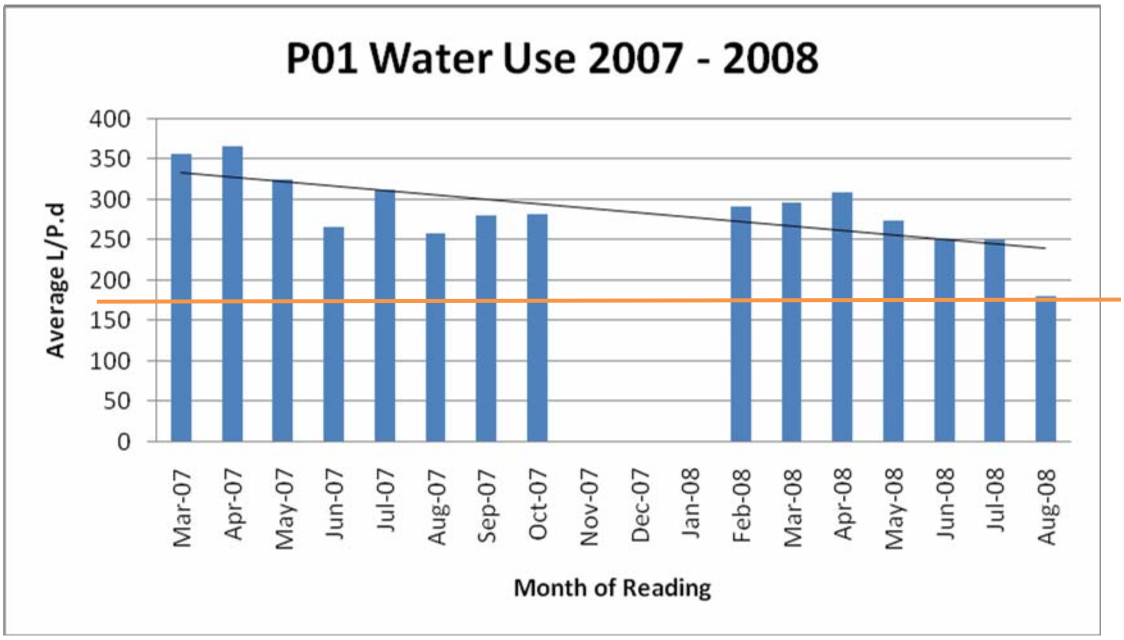


Figure 13: The water use in S-P01 from March 2007 to August 2008

S-P01	2007		2008		
Category		R Bin only		Rec Bin only	
1 2	Recycled	Rubbish	Recycled	Rubbish	Comments
Newspaper	0.25		0.061		Wheelie bin not collected in either audit.
Magazines	0.29				
Office paper	0.42				
Drink containers					
Cardboard	0.61		0.528		
Other packaging	0.355				
Sanitary					
Other paper	0.1				
Paper	2.025	0	0.589	0	
Rigid 1	0.15		0.148		
Rigid 2	0.55		0.122		
Rigid 5					
Rigid 6					
Other rigid					
Flexible 2					

Flexible 45					
Other flexible	0.05				
All other	0.02		0.1		
Plastic	0.77	0	0.37	0	
Reusable bottles			4.5		
Other drink	10.37				
Food jars	0.35				
All other	0.13		0.235		
Glass	10.85	0	4.735	0	
Steel cans	0.2		0.059		
Aluminium cans	0.07				
Other ferrous					
Other non-ferrous					
Appliances					
Metal	0.27	0	0.059	0	
Kitchen food					
Soft garden waste					
Harder garden waste					
Soil					
Other					
Organic	0	0	0	0	
Construction	0	0	0	0	
Aerosols					
Hazardous	0	0	0	0	
Leather					
Rubber					
Clothing					
Other					
Other	0	0	0	0	
Total	13.915	0	5.753	0	Pre- includes four people plus a business
Recycled Portion	100%		100%		Post- includes three people only

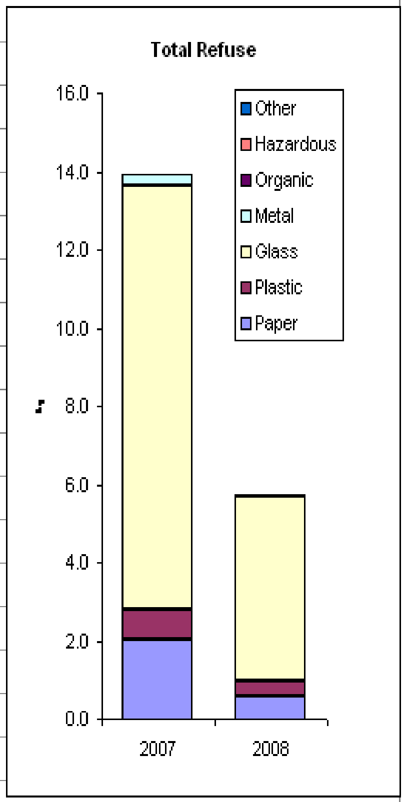


Table 38: Waste assessment instrument from S-P01

9.4.5 S-P05

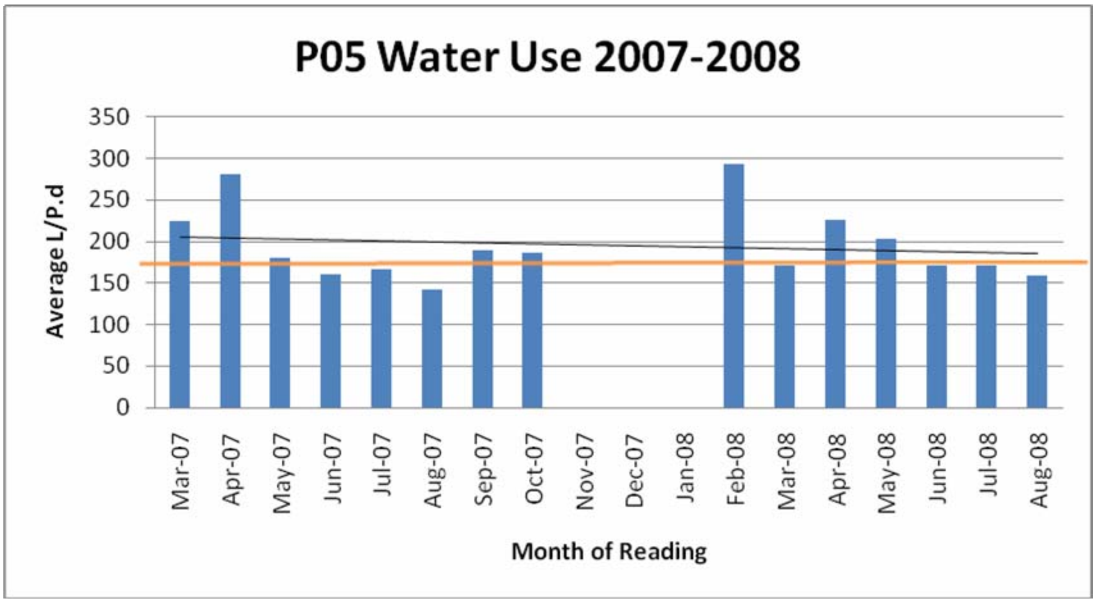
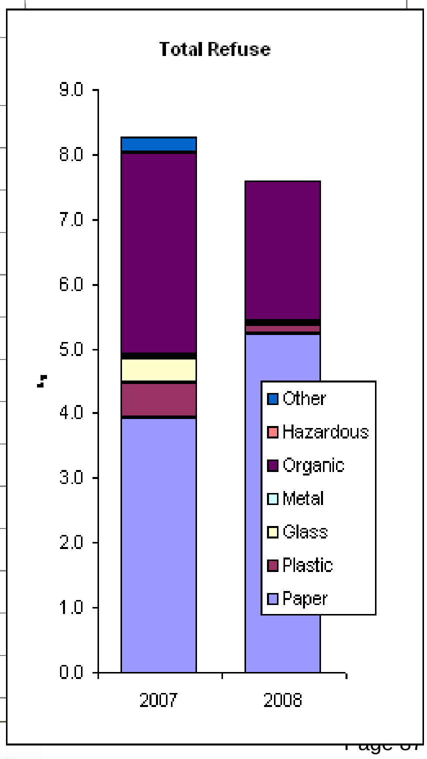


Figure 14: The water use in S-P05 from March 2007 to August 2008

S-P05	**2007**		**2008**		
Category		**Bag +r bin**		**Rub Bag + rec bag**	
1 2	**Recycled**	**Rubbish**	**Recycled**	**Rubbish**	**Comments**
Newspaper	2.15	0.06	4.796		
Magazines	1.077				
Office paper					
Drink containers					
Cardboard	0.51		0.275		
Other packaging	0.136		0.171		
Sanitary					
Other paper					
Paper	3.873	0.06	5.242	0	
Rigid 1		0.057	0.078		
Rigid 2	0.07		0.038		
Rigid 5					
Rigid 6					
Other rigid		0.02			
Flexible 2					
Flexible 45					
Other flexible	0.151	0.245			



All other					
Plastic	0.221	0.322	0.116	0	
Reusable bottles					
Other drink	0.245				
Food jars	0.133				
All other					
Glass	0.378	0	0	0	
Steel cans			0.056		
Aluminium cans	0.027				
Other ferrous	0.013				
Other non-ferrous					
Appliances					
Metal	0.04	0	0.056	0	
Kitchen food		2.83		1.94	Possible decrease but inconclusive.
Soft garden waste					
Harder garden waste					
Soil					
Other		0.3		0.236	
Organic	0	3.13	0	2.176	
Construction	0	0	0	0	
Aerosols					
Hazardous	0	0	0	0	
Leather					
Rubber					
Clothing		0.245			
Other					
Other	0	0.245	0	0	
Total	4.512	3.757	5.414	2.176	Nothing notable.
Recycled Portion	55%		71%		

Table 39: Waste assessment instrument from S-P05

9.4.6 S-P09

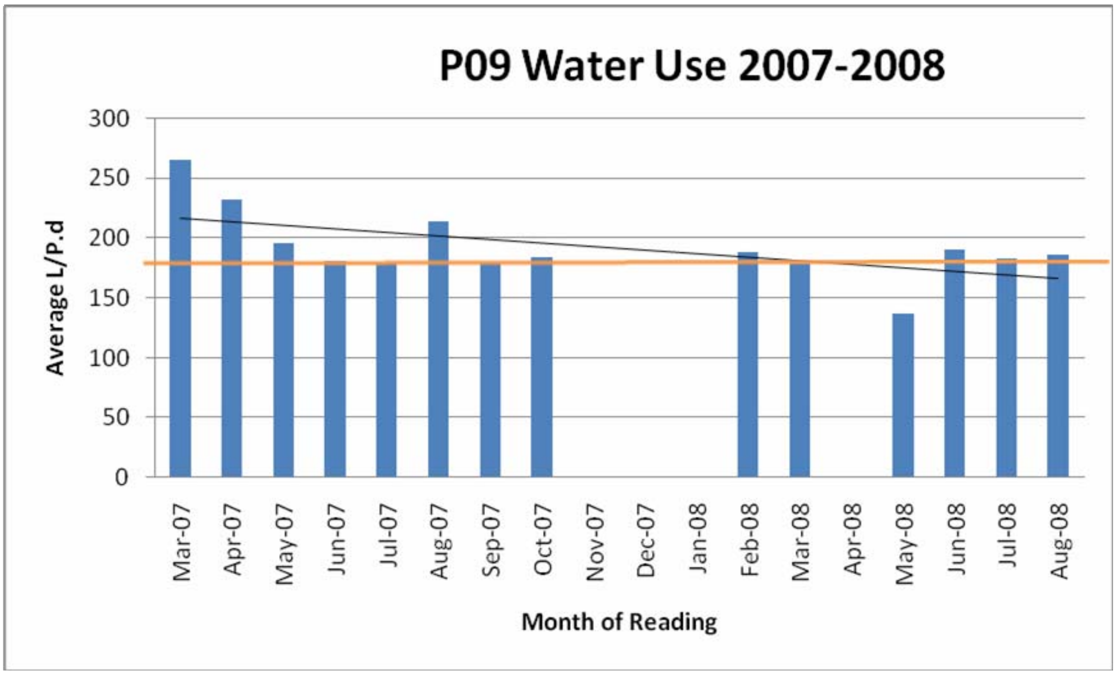


Figure 15: The water use in S-P09 from March 2007 to August 2008

S-P09	2007		2008		
Category		Bag +r bin		Bag +r bin	
1 2	Recycled	Rubbish	Recycled	Rubbish	Comments
Newspaper	0.6	0.13	0.2		Possible decrease in paper waste.
Magazines					
Office paper			0.2		
Drink containers					
Cardboard					
Other packaging	0.03	0.08			
Sanitary		0.03			
Other paper		0.08			
Paper	0.6	0.31	0.4	0.0	
Rigid 1	0.1	0.02	0.1		
Rigid 2	0.2				
Rigid 5					
Rigid 6					
Other rigid					
Flexible 2		0.05			
Flexible 45					

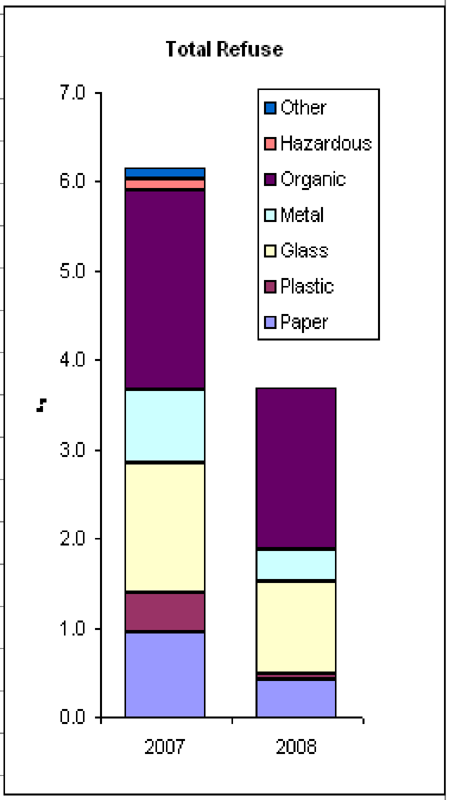
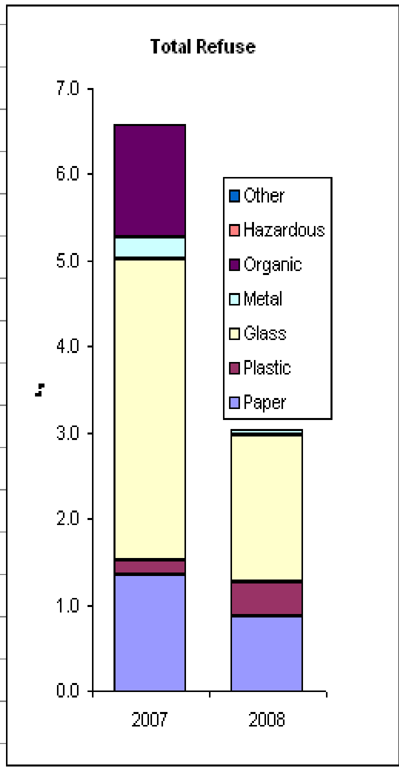
Other flexible		0.11			
All other		0.02			
Plastic	0.2	0.2	0.1	0.0	
Reusable bottles					
Other drink	1.5		0.6		
Food jars			0.1		
All other			0.3		
Glass	1.5	0.0	1.0	0.0	
Steel cans	0.1	0.6	0.4		
Aluminium cans	0.02	0.02			
Other ferrous					
Other non-ferrous					
Appliances					
Metal	0.2	0.7	0.4	0.0	
Kitchen food		2.2		1.8	
Soft garden waste					
Harder garden waste					
Soil					
Other					
Organic	0.0	2.2	0.0	1.8	
Construction	0.0	0.0	0.0	0.0	
Aerosols		0.1			
Hazardous	0.0	0.1	0.0	0.0	
Leather					
Rubber					
Clothing		0.1			
Other		0.1			
Other	0.0	0.1	0.0	0.0	
Total	2.5	3.7	1.9	1.8	Single person but still reasonably low volumes.
Recycled Portion	41%		51%		With good rates of recycling. Possible improvement.

Table 40: Waste assessment instrument from S-P09

9.4.7 S-P07

No water data.

S-P07	2007		2008		
Category		Bag+ Rbin		Rec only	
1 2	Recycled	Rubbish	Recycled	Rubbish	Comments
Newspaper	0.15				
Magazines	0.5				
Office paper	0.1		0.729		
Drink containers					
Cardboard	0.2		0.129		
Other packaging	0.3				
Sanitary					
Other paper	0.1				
Paper	1.35	0	0.858	0	
Rigid 1	0.067				
Rigid 2					
Rigid 5			0.052		
Rigid 6			0.031		
Other rigid	0.102				
Flexible 2					
Flexible 45					
Other flexible			0.075		
All other			0.254		
Plastic	0.169	0	0.412	0	
Reusable bottles			1.7		
Other drink	3.5				
Food jars					
All other					
Glass	3.5	0	1.7	0	
Steel cans			0.065		
Aluminium cans	0.25				
Other ferrous					
Other non-ferrous					
Appliances					
Metal	0.25	0	0.065	0	
Kitchen food		0.25			
Soft garden waste		0.55			In-sink waste disposal unavailable so unsure how worm farm contributing.
Harder garden waste		0.5			
Soil					
Other					



Organic	0	1.3	0	0	
Construction	0	0	0	0	
Aerosols					
Hazardous	0	0	0	0	
Leather					
Rubber					Low overall refuse rates and high recycling.
Clothing					Household has lifestyle which gives significant savings in refuse collection and general resource use.
Total	5.269	1.3	3.035	0	
Recycled Portion	80%		100%		No rubbish! Too good to be true?

Table 41: Waste assessment instrument from S-P07

9.4.8 B-P02

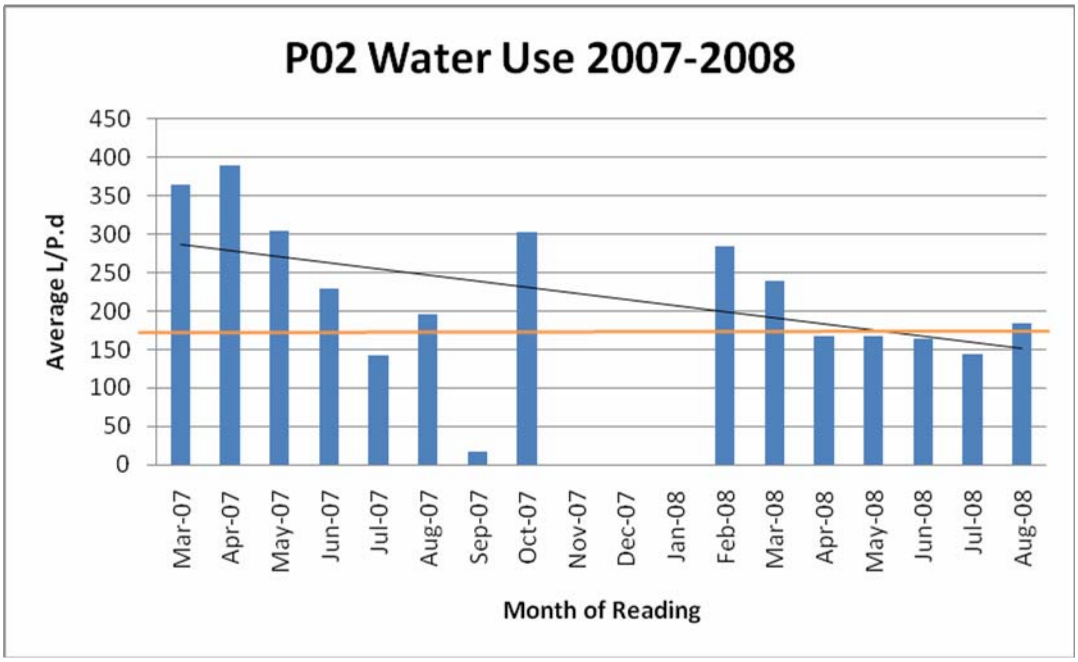
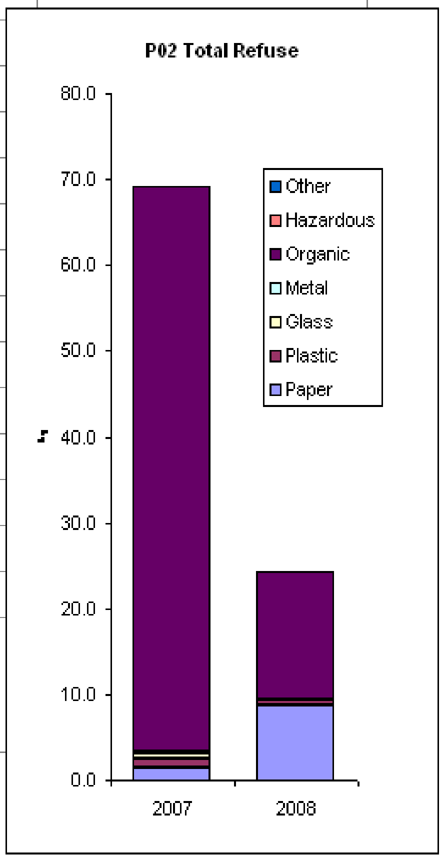


Figure 16: The water use in B-P02 from March 2007 to August 2008

B-P02	2007		2008		
Category		**Wheelie + recycle Bin**	**Wheelie Bin + recycle bin**		
1 2	**Recycled**	**Rubbish**	**Recycled**	**Rubbish**	**Comments**
Newspaper	0.1		7.5		"Burns a lot of paper in fire".
Magazines	0.5		1.2		
Office paper	0.1				
Drink containers	0.0				
Cardboard	0.1				
Other packaging	0.3				
Sanitary	0.1				
Other paper		0.3			
Paper	1.2	0.3	8.7	0.0	
Rigid 1	0.5				
Rigid 2	0.1			0.1	
Rigid 5					
Rigid 6					
Other rigid	0.4				
Flexible 2					
Flexible 45					

Other flexible				0.1	
All other		0.1		0.4	
Plastic	1.0	0.1	0.0	0.5	
Reusable bottles					
Other drink	0.4				
Food jars	0.2				
All other					
Glass	0.6	0.0	0.0	0.0	
Steel cans					
Aluminium cans	0.1				
Other ferrous	0.1				
Other non-ferrous	0.0				
Appliances					
Metal	0.2	0.0	0.0	0.0	
Kitchen food		0.2		5.0	Worms "drowned" with too much tea, replacements ordered but didn't arrive.
Soft garden waste		60.0		10.0	Large amount of lawn clippings.
Harder garden waste		5.0			Volumes of garden trimmings.
Soil		0.5			
Other					
Organic	0.0	65.7	0.0	15.0	
Construction	0.0	0.0	0.0	0.0	
Aerosols					
Hazardous	0.0	0.0	0.0	0.0	
Leather					
Rubber					
Clothing					
Other					
Other	0.0	0.0	0.0	0.0	
Total	3.0	66.1	8.7	15.5	

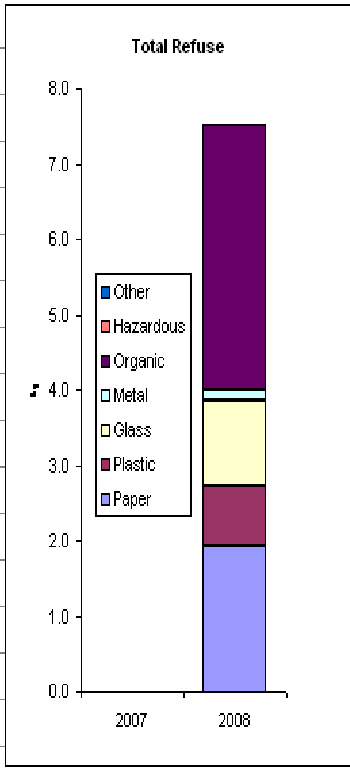
Table 42: Waste assessment instrument from B-P02



9.4.9 C-P06

No water data.

C-P06	2007		2008		
Category		Bag +r bin	P06	1 rubbish 1 rec bag	
1 2	Recycled	Rubbish	Recycled	Rubbish	Comments
Newspaper				0.268	
Magazines					
Office paper			0.948		
Drink containers					
Cardboard			0.191		
Other packaging			0.025		
Sanitary					
Other paper			0.5		
Paper	0	0	1.664	0.268	
Rigid 1			0.138		
Rigid 2			0.057		
Rigid 5					
Rigid 6					
Other rigid					
Flexible 2			0.2		
Flexible 45					
Other flexible					
All other			0.387		
Plastic	0	0	0.782	0	
Reusable bottles			0.915		
Other drink					
Food jars			0.218		
All other					
Glass	0	0	1.133	0	
Steel cans			0.065	0.1	
Aluminium cans					
Other ferrous					
Other non-ferrous					
Appliances					
Metal	0	0	0.065	0.1	
Kitchen food				3.5	Potential to reduce kitchen waste:



Soft garden waste					no worm bin supplied as this was
Harder garden waste					'no intervention' home.
Soil					No pre-intervention audit carried out.
Other					
Organic	0	0	0	3.5	
Construction	0	0	0	0	
Aerosols					
Hazardous	0	0	0	0	
Leather					
clothing					
Other	0	0	0	0	
Total	0	0	3.644	3.868	Nothing notable.
Recycled Portion	#DIV/0!		49%		

Table 43: Waste assessment instrument from C-P06

9.5 Home sustainability performance summary

While the performance against the HSS™ benchmarks and the energy use results are all significant (to a 95% confidence interval), no statistical tests have been applied to the proportion of time the rooms are above 24°C (or below 16°C or 18°C) or to the waste and water outcomes. The outcome is noted as 'Better' if there has been a change of two or more in the percentage of time spent over a threshold in the value of the temperature or RH values from the tables from Table 11 to Table 20, and similarly for water and waste.

The cells in the tables following (Table 44 toTable 52) are greyed out if there is no assessment possible e.g. since there was no pre-retrofit assessment of the RH parameter made.

While not the subject of the HSS™, other important outcomes in this work have been included in these tables as follows:

- Monitored space heating energy use
- Total energy use (not just reticulated, but not including the solar contribution)
- Reticulated hot water energy use
- The proportion of time during which the bedroom and the family room spend above 24°C.

The summarised results of the tables in this section are included in Section 6.1 (Table 24 and Table 25).

H-P03 performance summary			
Performance Area	**Specific Benchmark** **(HSS™ Performance Areas In Bold, With Benchmark Levels Bracketed)**	**HSS™ Benchmark Achievement (Met/Inconclusive /Fails/Not Assessed)**	**Outcome** **(Non -HSS™ Performance) (Better/Worse/ Inconclusive/N/A)**
Energy	Total reticulated energy (11,000 kWh/year)	Met	Better
	Monitored space heating		Better
	Total energy use		Better
	Reticulated water heating energy		Better
Water Use	(Less than 180 L/p/d)	Met	
IEQ	Mean minimum May-Sep 24 hr winter bedroom 1 temps (above 16°C)	Met	Better
	Bedroom 1 time above 24°C		Worse
	Mean minimum May-Sep 24 hr winter family room temps (above 18°C)	Fails	Better
	Family room time above 24°C		Better
	Ventilation	N/A	
	Relative humidity – RH in bedroom 1 in July (in range of 20-70%)	Met	
	Checklist – see Table 1	Fails	
Waste	See Table 1	N/A	N/A
Materials	See Table 1	Met	

Table 44: H-P03 Summary of performance against HSS™ and other benchmarks

H-P10 performance summary			
Performance Area	**Specific Benchmark** **(HSS™ Performance Areas In Bold, With Benchmark Levels Bracketed)**	**HSS™ Benchmark Achievement (Met/Inconclusive /Fails/Not Assessed)**	**Outcome** **(Non -HSS™ Performance) (Better/Worse/ Inconclusive)**
Energy	Total reticulated energy (11,000 kWh/year)	Met	Better
	Monitored space heating		Worse
	Total energy use		Worse
	Reticulated water heating energy		Better
Water Use	(Less than 180 L/p/d)	Met	
IEQ	Mean minimum May-Sep 24 hr winter bedroom 1 temps (above 16°C)	Fails	Better
	Bedroom 1 time above 24°C		Worse
	Mean minimum May-Sep 24 hr winter family room temps (above 18°C)	Fails	Better
	Family room time above 24°C		Better
	Ventilation	N/A	
	Relative humidity – RH in the bedroom 1 in July (in range of 20-70%)	Fails	
	Checklist – see Table 1	Fails	
Waste	See Table 1	Met	Inconclusive
Materials	See Table 1	Met	

Table 45: H-P10 Summary of performance against HSS™ and other benchmarks

H-P08 performance summary			
Performance Area	**Specific Benchmark** **(HSS™ Performance Areas In Bold, With Benchmark Levels Bracketed)**	**HSS™ Benchmark Achievement (Met/Inconclusive /Fails/Not Assessed)**	**Outcome** **(Non -HSS™ Performance) (Better/Worse/ Inconclusive)**
Energy	Total reticulated energy (11,000 kWh/year)	Fails	Better
	Monitored space heating		Better
	Total energy use		Better
	Reticulated water heating energy		Better
Water Use[15]	(Less than 180 L/p/d)	Fails	
IEQ	Mean minimum May-Sep 24 hr winter bedroom 1 temps (above 16°C)	Fails	Worse
	Bedroom 1 time above 24°C		Worse
	Mean minimum May-Sep 24 hr winter family room temps (above 18°C)	Fails	Worse
	Family room time above 24°C		Worse
	Ventilation	N/A	
	Relative humidity – RH in the bedroom 1 in July (in range of 20-70%)	Fails	
	Checklist – see Table 1	Fails	
Waste	See Table 1	Met	Better
Materials	See Table 1	Met	

Table 46: H-P08 Summary of performance against HSS™ and other benchmarks

[15] *No intervention was made in this area to this home.*

S-P01 performance summary			
Performance Area	**Specific Benchmark** **(HSS™ Performance Areas In Bold, With Benchmark Levels Bracketed)**	**HSS™ Benchmark Achievement (Met/Inconclusive /Fails/Not Assessed)**	**Outcome** **(Non -HSS™ Performance) (Better/Worse/ Inconclusive)**
Energy	Total reticulated energy (11,000 kWh/year)	Inconclusive	Better
	Monitored space heating		Inconclusive
	Total energy use		Inconclusive
	Reticulated water heating energy		Better
Water Use[15]	(Less than 180 L/p/d)	Fails	
IEQ	Mean minimum May-Sep 24 hr winter bedroom 1 temps (above 16°C)	Fails	Better
	Bedroom 1 time above 24°C		N/A
	Mean minimum May-Sep 24 hr winter family room temps (above 18°C)	Fails	Better
	Family room time above 24°C		Worse
	Ventilation	N/A	
	Relative humidity – RH in the bedroom 1 in July (in range of 20-70%)	Fails	
	Checklist – see Table 1	Fails	
Waste	See Table 1	N/A	Inconclusive
Materials	See Table 1	Met	

Table 47: S-P01 Summary of performance against HSS™ and other benchmarks

S-P05 performance summary			
Performance Area	**Specific Benchmark** **(HSS™ Performance Areas In Bold, With Benchmark Levels Bracketed)**	**HSS™ Benchmark Achievement (Met/Inconclusive /Fails/Not Assessed)**	**Outcome** **(Non -HSS™ Performance) (Better/Worse/ Inconclusive)**
Energy	Total reticulated energy (11,000 kWh/year)	Fails	Inconclusive
	Monitored space heating		Inconclusive
	Total energy use		Inconclusive
	Reticulated water heating energy		Inconclusive
Water Use	(Less than 180 L/p/d)	Inconclusive	
IEQ	Mean minimum May-Sep 24 hr winter bedroom 1 temps (above 16°C)	Fails	Inconclusive
	Bedroom 1 time above 24°C		N/A
	Mean minimum May-Sep 24 hr winter family room temps (above 18°C)	Fails	Better
	Family room time above 24°C		Better
	Ventilation	N/A	
	Relative humidity – RH in the bedroom 1 in July (in range of 20-70%)	Fails	
	Checklist – See Table 1	Fails	
Waste	See Table 1	Met	Inconclusive
Materials	See Table 1	Met	

Table 48: S-P05 Summary of performance against HSS™ and other benchmarks

S-P09 performance summary			
Performance Area	**Specific Benchmark** **(HSS[TM] Performance Areas In Bold, With Benchmark Levels bracketed)**	**HSS™ Benchmark Achievement (Met/Inconclusive /Fails/Not Assessed)**	**Outcome** **Non -HSS™ Performance) (Better/Worse/ Inconclusive)**
Energy	Total reticulated energy (11,000 kWh/year)	Met	Better
	Monitored space heating		Inconclusive
	Total energy use		Better
	Reticulated water heating energy		Better
Water Use[15] above	(Less than 180 L/p/d)	Inconclusive	
IEQ	Mean minimum May-Sep 24 hr winter bedroom 1 temps (above 16°C)	Fails	Inconclusive
	Bedroom 1 time above 24°C		N/A
	Mean minimum May-Sep 24 hr winter family room temps (above 18°C)	Fails	Inconclusive
	Family room time above 24°C		Worse
	Ventilation	N/A	
	Relative humidity – RH in the bedroom 1 in July (in range of 20-70%)	Fails	
	Checklist – see Table 1	Fails	
Waste	See Table 1	Inconclusive	Better
Materials	See Table 1	Met	

Table 49: S-P09 Summary of performance against HSS[TM] and other benchmarks

S-P07 performance summary			
Performance Area	**Specific Benchmark** **(HSS™ Performance Areas In Bold, With Benchmark Levels Bracketed)**	**HSS™ Benchmark Achievement (Met/Inconclusive /Fails/Not Assessed)**	**Outcome** **(Non -HSS™ Performance) (Better/Worse/ Inconclusive/N/A)**
Energy	Total reticulated energy (11,000 kWh/year)	Met	Better
	Monitored space heating		Inconclusive
	Total energy use		Inconclusive
	Reticulated water heating energy		Better
Water Use[15]	(Less than 180 L/p/d)	N/A	
IEQ	Mean minimum May-Sep 24 hr winter bedroom 1 temps (above 16°C)	Fails	Better
	Bedroom 1 time above 24°C		N/A
	Mean minimum May-Sep 24 hr winter family room temps (above 18°C)	Fails	Better
	Family room time above 24°C		Inconclusive
	Ventilation	N/A	
	Relative humidity – RH in the bedroom 1 in July (in range of 20-70%)	Fails	
	Checklist – see Table 1	Fails	
Waste	See Table 1	Fails	Better
Materials	See Table 1	Met	

Table 50: S-P07 Summary of performance against HSS™ and other benchmarks

B-P02 performance summary			
Performance Area	**Specific Benchmark** **(HSS™ Performance Areas In Bold, With Benchmark Levels Bracketed)**	**HSS™ Benchmark Achievement (Met/Inconclusive /Fails/Not Assessed)**	**Outcome** **(Non -HSS™ Performance) (Better/Worse/ Inconclusive)**
Energy	Total reticulated energy (11,000 kWh/year)	Met	Better
	Monitored space heating		Inconclusive
	Total energy use		Better
	Reticulated water heating energy		Better
Water Use[15]	(Less than 180 L/p/d)	Met	
IEQ	Mean minimum May-Sep 24 hr winter bedroom 1 temps (above 16°C)	Fails	Inconclusive
	Bedroom 1 time above 24°C		N/A
	Mean minimum May-Sep 24 hr winter family room temps (above 18°C)	Fails	Better
	Family room time above 24°C		Better
	Ventilation	N/A	
	Relative humidity – RH in the bedroom 1 in July (in range of 20-70%)	Fails	
	Checklist – see Table 1	Fails	
Waste	See Table 1	Fails	Better
Materials	See Table 1	Met	

Table 51: B-P02 Summary of performance against HSS™ and other benchmarks

C-P06 performance summary

Performance Area	Specific Benchmark (HSS™ Performance Areas In Bold, With Benchmark Levels Bracketed)	HSS™ Benchmark Achievement (Met/Inconclusive /Fails/Not Assessed)	Outcome (Non -HSS™ Performance) (Better/Worse/ Inconclusive)
Energy	Total reticulated energy (11,000 kWh/year)	Met	Better
	Monitored space heating		Inconclusive
	Total energy use		Better
	Reticulated water heating[16]		Better
Water Use[15]	(Less than 180 L/p/d)	N/A	
IEQ	Mean minimum May-Sep 24 hr winter bedroom 1 temps (above 16°C)	Fails	Worse
	Bedroom 1 time above 24°C		N/A
	Mean minimum May-Sep 24 hr winter family room temps (above 18°C)	Fails	Worse
	Family room time above 24°C		Worse
	Ventilation	N/A	
	Relative humidity[17] – RH in bedroom 1 in July (in range of 20-70%)	Fails	
	Checklist – see Table 1	Fails	
Waste	See Table 1	N/A	N/A
Materials	See Table 1	Met	

Table 52: C-P06 Summary of performance against HSS™ and other benchmarks

[16] No intervention was made in this area to this home.

[17] No polythene was laid on the ground under this home.

9.6 Executive summary of Interim report (June 2008)

9.6.8 Preface

The Papakowhai Renovation Project has renovated nine existing homes in the suburb of Papakowhai, Porirua. The project goal was to identify the most cost-effective and easy to implement packages and combinations of renovation options that would significantly improve the standard of sustainability of the homes. This report presents the interim monitoring results, while the companion report (Saville-Smith 2008) presents the social analysis of this data and the project's impacts on the households.

9.6.9 The project

The suburb of Papakowhai, Porirua was chosen since it contained a large number of homes constructed in the same era (1970s) and was close to BRANZ Ltd. The choice of the same era was important so that similar issues would be faced in interventions. Ten homes were randomly selected from letters sent out to 355 homes in this suburb, after the homes had been sorted by occupancy types. The homes were labelled from S-P01 to H-P10.

Monitoring equipment was installed in these 10 homes in 2006 to measure the energy use, and the temperature in the bedroom 1 and family room. In 2007, equipment to measure the bedroom 1 RH and the water use by the household was installed. Data was monitored for a year before renovations were made in 2007. Subsequently the performance of the homes was monitored after the renovations. Ten homes were reduced to nine when P04 was sold, and this home was removed from the sample in January 2007.

9.6.10 The interventions

These renovations were designed to improve the sustainability of the homes. A range of renovation packages were used with effects that were designed to be from minimal to significant:

- The Low[18] renovation included improvements such as hot water cylinder wraps and ceiling insulation
- The 'Basic' renovations included the 'Low renovations', and also used compact fluorescent lights, RH reduction measures, and water and waste minimisation strategies
- The 'Standard' used the same as the 'Basic', and added higher levels of ceiling insulation and floor insulation
- The 'High' used all the 'Standard' renovations and added wall and window insulation, and some other more costly improvements including SWH and space heaters.

The impact of interventions have been assessed against Beacon's HSS™, which sets the performance expectations for temperature, energy use, water use, ventilation, RH, waste and material use. The monitoring was continued after these renovations were completed. The differences in the winter performance before and after the renovations were analysed.

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18 The 'Low' intervention was not used in the study, although is discussed in previous work, so has been retained here

9.6.11 The monitoring results

Reticulated energy consumption for all metered purposes was found to be the same or less after the renovations in all but one case.[19] The only monitored increase in reticulated energy consumption was for the water heating in S-P05, where two instant gas hot water systems had been installed. The HSS™ for the total energy use was met in B-P02 and H-P03 using the 15% reduction in energy use that was initially used as the metric for the energy HSS™.

The largest reductions in reticulated energy demand were for SWH systems. In all cases the family room or bedroom temperatures were the same or higher after the renovations. The HSS™ was met for the temperatures in the bedroom 1's of H-P03 and C-P06, and for the family room temperatures of H-P03, H-P08 and H-P10 for this winter period.

The largest energy and comfort improvements came from the homes with the most extensive renovations, labelled 'High'.

All homes have improved thermal comfort levels, and in most cases also increased temperatures.

9.6.12 The HERS results

The home performance was modelled with the AccuRateNZ software used as part of the new HERS, both before and after the renovations. The HERS modelling results all show the same trend in improvement for the energy parameters from before to after the renovations, as seen in the actual monitoring work.

9.6.13 The conclusions

The HSS™ was achieved for some of the HSS™ performance areas investigated for the winter period.

Insulation of the complete thermal envelope had the greatest effect on energy consumption and/or temperatures.

SWH systems provided large reductions in reticulated hot water energy demand.

The 'High' renovation package incurred very high capital costs ($75,000) in two of the three cases.

[19] ***Reticulated energy is electricity supplied by the electricity network and natural gas supplied by underground pipe.***

9.5 EDA graphs

9.5.1 Energy results in EDA graphs

During HEEP, with the extensive amount of data processed it became necessary to develop Exploratory Data Analysis (EDA) graphs to allow the data to be quickly examined.

A series of these HEEP EDA graphs have been generated for the Papakowhai NOW Home® and are included in a separate document.

9.5.2 Explanation of EDA graphs

The following edited description of the format of the plots has been taken from a HEEP homeowner report and is relevant to a generic ‘appliance’, which needs to be interpreted as any of the logged equipment, including appliances, meter boards, loggers etc. Reference should be made to the example plot provided in Figure 17 below.

The home label and monitored parameter appear in the title of the graph. Underneath the title is summary information. This reports: the number of days monitored; the number of days of N/As (missing values); then the percentage of valid data points with power in the ranges – equal to zero W, greater than zero and less than 20 W, and greater than 20 W; and finally either the mean temperature or the energy use (kWh) over a year (one average day x 365).

These percentage ranges correspond roughly to the proportion of the time the appliance was drawing no power, the proportion of time in ‘standby’ mode (if that applies to the appliance), and the proportion of time in operation. As the time resolution is only 10 minutes, this description will not be valid for appliances with switching cycles shorter than 10 minutes.

Each individual EDA graph (see Figure 17) contains three plots: a ***histogram*** of the power recorded every 10 minutes; a ***time-series plot*** of the power every 10 minutes; and time-series plots of the ***seven-day moving average*** power consumption (solid line, left axis) and ***daily profile*** (dashed line, right axis).

The ***histogram*** shows how often the power was in a given range. The power range in watts is on the horizontal axis and the counts are on the vertical axis. For appliances that have too many values in the ‘zero’ bin, this bin is replaced by a number, otherwise the remaining bins would be too small to see clearly.

The ***time series plot*** has the date (start of month) on the horizontal axis, and the appliance power in watts on the vertical axis. As there is so much data, the lines sometimes overlap slightly, causing a solid block of black. This indicates rapid switching between high and low values. If a solid block has an apparent straight edge on the top or bottom, this indicates that it is switching to a constant value. If the solid block has a ragged edge, it is switching to a changing value. Periods of missing values are indicated by a straight horizontal line near the top of the time-series plot. These may occur if there was a problem with the monitoring, a power cut, or the appliance was not monitored during a given period.

The third plot contains the ***seven-day moving average plot*** and ***daily profile***. The two lines provide an average ***daily profile*** (dot-dash line) running from midnight to midnight, and a ***seven-day moving average*** running from the start to the end of the data (solid line). In the example of Figure 17 the average ***daily profile*** for this total load channel shows a low overnight base load, stepping up at 5am to a morning peak at 7am, stabilising for the day with a slight fall off in the early afternoon, and then rising to a peak of 1500 W at 7pm, which falls off into the later evening. The ***seven-day moving average*** removes the fluctuations over the day, and shows any seasonal pattern. The winter peak (June through September) shows clearly, suggesting the use of electric space heating in this home.

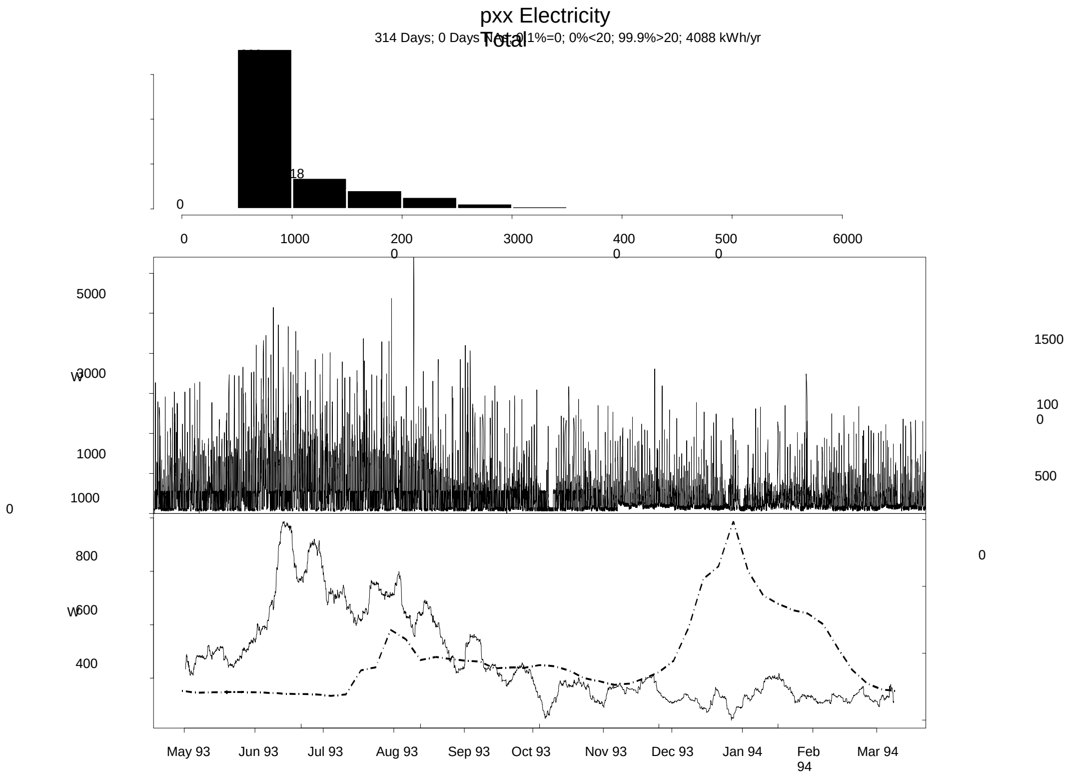

Figure 17: Example of an EDA plot for a single appliance

While the graphs for the Papakowhai work are not all appliances the format is the same as discussed above.