Report TE106/18

Papakowhai Renovations: Project Summary and Case Studies

Final

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About This Report

Title

Papakowhai Renovations: Project Summary and Case Studies

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Abstract

A project examining sustainable retrofit of existing homes in Papakowhai was undertaken from 2006-2008. Nine homes were renovated with a range of sustainable interventions and monitored to see the effects of the retrofits on dwelling performance. During the course of the project, nine reports on different aspects of the project were prepared. This report summarises these reports and presents the overall findings, with a case study for each house.

Reference

Easton, L. (ed). June 2009. Papakowhai Renovations: Project Summary and Case Studies.Report Report TE106/18 for Beacon Pathway Limited.

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- Energy use in the home
- Water use by the household
- Indoor environment quality (temperature and humidity)
- Waste (construction waste and waste produced by the households).

During the life of the project, a number of research reports have been produced at different stages and for different purposes. Reports that are publicly available are:

- McChesney, I. and Amitrano, L. (2006). *Sustainability Options for Retrofitting New Zealand Houses – Energy*. Report TE106/4 for Beacon Pathway Limited.
- Philips, M. (2007). *Sustainability Options for Retrofitting New Zealand Houses – Theoretical Cost Benefit Analysis.* Report TE106/8 for Beacon Pathway Limited
- Burgess, J. (Ed), Buckett, N., Camilleri, M., French, L., Pollard, A. and Hancock, P. (2008). *Final Performance Monitoring from the Papakowhai Renovation Project.* Report TE106/15 for Beacon Pathway Limited

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- Buckett, N., Burgess, J. and Hancock, P. (2008). *Learnings from the Papakowhai Renovation Project.* Report TE106/11 for Beacon Pathway Limited.
- Burgess, J. and Buckett, N. (2008). *Interim Performance Monitoring from the Papakowhai Renovation Project.* Report TE106/13 for Beacon Pathway Limited
- Saville-Smith, K. (2008). *Papakowhai Renovations: Impacts on Householders and Dwelling Performance.* Report TE106/9 for Beacon Pathway Limited
- Trotman, R. (2009). *Papakowhai Renovations: Householder Experiences and Perceptions.* Report TE106/17 for Beacon Pathway Limited

This Summary Report brings together the key points from the nine research reports into one document.

1.1 Key Findings from the Research

There are a number of key findings in relation to retrofit interventions which arise from the project as follows:

- Full thermal envelope insulation is likely to be needed if reticulated energy savings and temperature improvements to HSS®-2006 standards are to be made.
- Efficient heating must accompany insulation improvements.
- Hot water cylinder wraps are an excellent investment across all hot water cylinder grades.
- Optimally-sized and -installed solar hot water systems can deliver high efficiency even in winter.
- A number of retrofit measures are relatively straightforward and can easily be included within a wider renovation by competent tradespeople – although specification and correct sizing needs to be carefully undertaken.
- Some measures are slightly trickier and due to their currently uncommon occurrence (rainwater plumbed for internal uses, greywater reuse, retrofitting double glazing) need specialist installers with a high degree of competence and familiarity with good installation practices.
- Careful planning and project management are required to ensure an optimal renovation outcome – from both the consumer perspective and good function of the interventions.
- Good management of consenting issues is critical to implementing large scale renovations.

2 Introduction

Over the past three years Beacon Pathway Limited has been undertaking a research project to renovate nine homes in Papakowhai, Porirua, with a range of measures aimed to determine the best methods to enable existing homes to meet a high standard of sustainability. The key focus areas for the retrofits and their evaluation are in the areas of:

- Energy use in the home
- Water use by the household
- Indoor environment quality (temperature and humidity)
- Waste (construction waste and waste produced by the households).

The project was initiated as part of Beacon's aims to research ways to achieve the aim of bringing 90% of New Zealand's homes to a high standard of sustainability by 2012. The research project renovated nine "ordinary" houses of varying styles, sizes, constructions and occupancies with energy, waste, water reducing and indoor environment quality features. The first stage of the project involved a literature review of retrofit research previously undertaken (McChesney and Amitrano 2006) which identified that, in order for the homes to meet the HSS High Standard of Sustainability®, well above the current levels of retrofit were needed.

During the life of the project, a number of research reports have been produced at different stages and for different purposes. Reports that are publicly available are:

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This summary report brings together the key points from the nine research reports into one document. It is intended to provide an overview of the project, and to provide the reader with a summary of the methodology, and results from the project. This summary report also discusses the combined results of the individual components of the research and brings together the overall findings and conclusions from the project. The detailed research method, results and analysis can be found in the individual research reports.

2.1 Project Objectives

The project was first briefed in 2006 and, at that time, the focus was on trialling solutions packages within the retrofit homes, monitoring these and defining the benefits of the packages. As the project was scoped and put into place this was refined to two key objectives:

1) To identify the best (most cost effective and easy to implement) packages and combinations of retrofit options to significantly improve the standard of sustainability of the homes.

2) To develop the cost benefit analysis at a house level for a range of retrofit technologies in the areas of energy, water, IEQ and waste

This report deals with the research undertaken to achieve the first objective; however, it sits within the context of the second objective which is substantially informed by both the Papakowhai Renovations research and other Beacon research (e.g. Consumer surveys - Saville Smith, 2008; House typologies - Ryan et al, 2008; Page and Fung, 2008).

3 Method

3.1 House Selection

The research initially was intended as a study of ten houses, in order to get a broad range of occupancies, house type, size and construction, and to enable the elimination of some of the climate variables in the final data (Buckett et al, 2007). In addition, in order to reduce the cost of monitoring the houses, a location close to the BRANZ research station in Judgeford was considered appropriate. Because previous studies were focussed largely on low income households and in light of Beacon's focus on 90% of New Zealand homes, the suburb and houses selected were from within the "middle income" bracket and from an era when a large number of houses were known to have been built.

Accordingly, Papakowhai, a typically middle income area first developed in the mid 1960s, on the eastern side of Porirua Harbour, approximately 20 kilometres north of Wellington, was chosen to fulfil these requirements. From within the suburb houses with a rating valuation of less than $410,000 were selected, as a surrogate to eliminate those houses which were likely to be occupied by higher than average income households. A neighbourhood inspection was also carried out in order to target houses built in the 1960s and 1970s.

A letter was sent out to houses within the designated area inviting participation in the project. Interested homeowners responded by filling out a survey about the characteristics of the house and occupancy, methods of heating, and fuels used in the home. The 148 responses were then sorted by occupancy, and then 10 houses representing the range of occupancies were selected randomly for inclusion in the project.

3.2 Selected Interventions

3.2.1 Prior Research – Reports TE 106/4 and TE106/8

Prior to undertaking the interventions, two key pieces of research were undertaken to assist in choice of intervention measures. The first of these, *Sustainability Options for Retrofitting Houses – Energy*, was a review of existing retrofit programmes (McChesney and Amitrano, 2006). This report looked at a range of research into retrofit programmes including:

- Housing, Insulation and Health (HIH) study – Wellington School of Medicine
- Peak Load Reduction study - Orion
- Energy and Public Housing Study 2003 – Otago University
- Residential Energy Efficiency Retrofits – EECA
- Heat Pump / Insulation Assessment - CEA
- Private Dwelling Retrofit Study 1997-2000 - BRANZ

Key findings from the report in relation to the choice of intervention were as follows:

- Insulation alone is not enough, an efficient heat source is required to get longer term energy efficiency and reduce the incidence of takeback of energy savings
- Current (2006) insulation programmes were delivering only small improvements in temperature (approx 0.5°C improvements)– nothing like what was required for homes to meet the HSS®-2006[1]
- Despite the low level of retrofit, beneficiaries of subsidised retrofit programmes see these as effective and having improved their comfort and well-being
- There is a law of diminishing returns in relation to energy savings from insulation and this is perceived as a rationale for not promoting higher standards of retrofit.

The second report, *Sustainability Options for Retrofitting Houses – Theoretical Cost Benefit*, looked at the theoretical cost benefit of a range of different retrofit measures (Phillips, 2006). Simple paybacks (energy savings only, or water savings for water efficient technologies) were used as the basis of cost benefits. Some key findings from this report in relation to Wellington retrofits were:

- Hot water system improvements had a high IRR (Internal Rate of Return) with simple payback periods of 4.1 years (instant gas), 12.9 years (heat pump hot water) and 13.1 years (solar hot water systems)
- Double glazing, where the frames are also replaced, has very long simple payback period (48.8 years), however if glass is replaced in existing frames the payback is much better (12.1 years)
- Thick under-floor insulation has reasonable simple payback – 22.8 years for R 2, and this improves to 19.3 years for R2.8 insulation
- Wall insulation has a long simple payback (48.8 years for R3.0 where interior linings are replaced)
- Ceiling insulation has reasonable simple paybacks – 10 years for R2.8 and 12.9 years for R3.8
- Low flow showerheads have a simple payback of 3.5 years on the basis of water savings alone

While the Papakowhai project was aiming to establish what degree of renovation was required to bring homes to a HSS High Standard of Sustainability®, these simple paybacks gave some indication of the likely impact of different measures on energy efficiency gains. The data clearly indicate that the level of insulation installed should focus on what is required to bring homes up to healthy temperatures, rather than on energy savings benefits, and that hot water measures in particular may result in significant energy savings.

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[1] ***The HSS -2006 indices are outlined in Easton (2006)***

3.2.2 Thermal Packages

A key issue identified by the project team was the need to determine an optimum level of thermal retrofit – whereby temperature improvements were sufficient to meet the HSS®-2006 benchmark, with energy use kept to a level whereby the energy benchmark was also met. At the time, standard subsidised retrofit practice saw a top up of insulation in the ceiling to current code levels and installation of under-floor foil. The research of Amitrano and McChesney (2006) had already identified that this was insufficient for the required temperature increases, so a range of potential thermal improvement packages were developed for implementation in different dwellings in the study. These were:

- Basic – representing the "best practice" of 2006 subsidised retrofits (ie ECan Clean Heat) – with a ceiling insulation top up and bulky under-floor insulation
- Standard – Thick (R4 or R5) ceiling insulation and bulky under-floor insulation.
- High – Thick (R4 or R5) ceiling insulation, bulky under-floor insulation, wall insulation and double glazing

Houses were selected for the installation of these interventions; however, in the actual installation, some practical issues resulted in the installed thermal improvements being different to what was planned (Burgess and Buckett, 2008). This was as a result of a combination of factors:

- Homeowner preferences (e.g. some homeowners were unwilling to have wall linings removed and wall insulation installed)
- Physical characteristics of the dwellings (e.g. some dwellings had skillion roofs and space limitations meant the desired R value insulation couldn't be installed, one dwelling intended for wall insulation retrofit turned out to already have wall insulation when the lining removal commenced)

3.2.3 Basic Interventions

A suite of "basic" interventions were intended to be applied to all but one of the dwellings where required and physically able to be installed. These included:

- Draught stopping
- Energy efficient light bulbs
- Mechanical ventilation of kitchen and bathroom
- Polythene on ground under any suspended floors
- Replacement of single flush toilet cisterns with dual flush
- Low flow shower head if shower flow exceeded nine litres/minute
- Hot water cylinder wrap
- Worm bin

3.2.4 Hot Water Interventions

Five types of hot water heating interventions were selected for inclusion. These were:

- Hot water cylinder wraps
- Instant gas hot water
- Solar hot water
- Combined solar/wetback hot water
- Heat pump hot water

A heat pump hot water system was not included in the study as when it came to installing the system a suitably-sized household with an optimum hot water setup wasn't available.

3.2.5 Heating Interventions

Three types of efficient heating interventions were applied in some of the dwellings. In the case of one of the wood burners and the heat pump, these were choices installed by the owners, however they fitted with the intended interventions:

- Pellet burner
- Efficient low emission wood burner
- Heat pump

Central heating systems were not considered due to cost issues; however, one of the households decided to replace their two heat pumps with a ducted heat pump central heating system, so this intervention has been included in the study.

3.2.6 Changes from Intended Interventions to Actual Interventions Undertaken

The actual interventions varied from those originally selected. There were a range of reasons for this, including:

- Aspirations of the homeowners differed from the proposed methodology. For example, recent redecoration meant reluctance in some cases for wall insulation and different interventions were sought rather than those proposed. This was partly a result of expectations being raised early in the project.
- Difficulties arose with defining the thermal envelope to insulate as many of the homes were split level and included a rumpus room/office in the lower level. It was intended that insulation interventions focussed on the living areas of the home, not storage or garages.
- Cost escalations resulting in cut backs to the packages.
- Time delays with the consenting process and getting suitable tradespeople meaning that some interventions were not included.
- One of the houses was sold and the new owners declined to participate in the project.
- Wall insulation was discovered in homes where it was not expected.

3.3 Physical Monitoring

The physical monitoring programme (which was undertaken by BRANZ Ltd) was set up to capture key data in relation to energy and water efficiency, indoor environment quality and waste generation (Buckett et al, 2007). In order to track the effects of the anticipated changes to the 10 Papakowhai houses, monitoring began in July 2006 before the renovation allowing the performance of the homes to be directly compared to the performance after the renovation.

At the time of the design of the monitoring programme, Beacon had yet to define its HSS High Standard of Sustainability®. This meant an early focus was placed on energy use, and associated end uses and temperature.

Extra monitoring was added in December 2006 (relative humidity and water use), and a waste audit of domestic refuse was undertaken pre-retrofit (March/April 2007) and post-retrofit (October 2008).

An initial survey, based on the HEEP survey was undertaken. This documented all the major appliances within the home, the type and location of the hot water system, heating devices and insulation. Household data including number of occupants, showering habits, normal hours of occupation, heating season and peak energy use times were collected. In addition, detailed plans were made of the houses and the houses were modelled in ALF 3.1 and eventually AccuRate.

3.3.1 Indoor Environment Quality

In order to monitor the interior environmental quality (IEQ) of the homes, temperature loggers were installed into the master bedroom and family room(s) and relative humidity (RH) loggers into the master bedrooms. Temperature and relative humidity were monitored at 10 minute intervals. Temperature monitoring began in July 2006 with two loggers in the living room at different heights and one in the bedroom. Relative humidity monitoring in the master bedroom began in December 2006 (after House 4 was sold).

The external temperatures were monitored at two homes in the sample. External temperatures were monitored at House 4 until it was sold, with the transfer taking place at the beginning of January 2007. On 1 December 2006, an external temperature logger was placed at House 10, with this becoming the primary external temperature logger after the equipment was removed from House 4 in mid December 2006. Comparisons of temperature profiles in a deliberate overlap period showed that the temperatures were very similar.

The time periods used for the data analysis are as shown in:

Table 1: Heating Schedule Definitions for Analysis
(Source Buckett et al, 2007)

Heating Schedule Definitions	
24hr	24 hours
Evening	5pm to 11pm
Morning	7am to 9am
Daytime	9am to 5pm
Night	Midnight to 7am

In determining mean winter temperatures for homes pre- and post-retrofit, normalised data (whereby the impact of differing outdoor temperatures is removed) was used. All other temperature data presented in this report is not normalised. When looking at the temperature data, the influence of outdoor temperature needs to be considered. A comparison of the outdoor temperatures across the three years indicates that the 2006 and 2008 had very similar temperature winters. As outdoor temperature has a strong influence on indoor temperature some of the increases in temperature seen between 2006 and 2007 may be due to warmer outdoor temperatures.

3.3.2 Energy

Totals of all fuels being used in the houses were monitored (electricity, natural gas, solid fuel, LPG, and post-renovation solar water heaters).

Large loads such as the hot water heating and fixed wired electric heating were monitored separately. Energy monitoring data was collected at two minute intervals.

3.3.3 Water

Water meters were installed in seven of the 10 houses in December 2006 and January 2007 to assess the water usage over the driest time of the year in the area. It was impractical to monitor House 6 and House 7 due to difficulty installing a meter on the line of water pipe where it entered the property. House 4 was not monitored having been sold.

The water meters were read at each download visit to measure the consumption in the preceding weeks.

3.3.4 Waste

The waste audit was performed by EnergySmart, and measured the waste of eight of the 10 homes in the sample. Several months before the audit the households had been told that their household waste would be audited at some point. They were informed it would take place two days before the audit was undertaken.

The method of the waste audit followed the categories of Ministry for the Environment's (MFE) Solid Waste Analysis Protocol, and samples were collected over two weeks in late March and early April 2007. The post-retrofit audit was undertaken in October 2008. Samples were stored in a cool place and audited within 24 hours of disposal.

Waste put out as recycling was audited separately from rubbish. Waste was measured in kilograms (kg).

3.3.5 Downloading of Data

Downloads of all data were performed every four to six weeks, and the data processed. 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.

3.4 Process of Retrofit

As part of the process of capturing learnings from the project, the process of retrofit and accompanying issues were documented through regular Project Control Meetings and Minutes, and also through a spreadsheet held by BRANZ. A post-retrofit workshop was held where the experience of the retrofit and learnings were discussed, and these were written up in a report (Buckett et al, 2008).

3.5 Occupant Interviews

Occupant interviews were undertaken, pre-project by BRANZ as part of recruiting the homeowners, post-retrofit by CRESA in February 2008, and post-project by Rachael Trotman in March 2009. The post-retrofit and post-project interviews are included in detailed reports (Saville Smith, 2008 and Trotman, 2009). Both of these interviews were semi-structured, conversational interviews. All households were interviewed in the CRESA post-retrofit February 2008 interviews; however, only House 3, House 9 and House 10 were interviewed in the Trotman post-project March 2009 interviews.

3.5.1 Key Topics – Post-Retrofit Interviews

The post-retrofit interviews focussed on a number of key topics:

- Motivations and expectations around involvement and retrofit benefits
- Knowledge of the retrofit undertaken in their dwelling
- Perceived impacts of the retrofit on dwelling performance
- Perceived achievements of the retrofit – both expected and unexpected
- Issues around process and/or failure to achieve benefits
- Taste for retrofit procedure and retrofit expenditure.

3.5.2 Key Topics – Post-Project Interviews

The post-project interviews were focussed on a number of key topics:

- Experience of the retrofits – including positive and less positive aspects
- Impact of the retrofits on the occupant behaviour, use and experience of the home
- Probing issues which arose from the detailed physical monitoring of the homes.

4 Case Study Findings

4.1 House 1

House 1 is a typical 1970s split-level three bedroom house with a living area of approximately 120m^2 and a total dwelling area of approximately 190m^2. It has a skillion corrugated iron roof throughout, and a mixture of sheet and weatherboard cladding around the outside. The lower storey has a concrete slab floor, while the upper floors have a timber suspended floor with a concrete perimeter wall. The house was occupied by a young family of two adults and two children.

4.1.1 Interventions Undertaken

House 1	Pre-Retrofit Condition	Intervention
Thermal	■ Timber framed single glazed draughty windows ■ Un-insulated skillion roof ■ Draughts from downstairs sliding door by garage ■ Un-insulated under-floor ■ Un-insulated walls ■ Bare ground under-floor	■ Lowered ceiling and insulated to R4.6 (R2.6 in places) ■ Draught stopped sliding door ■ Insulated under-floor with R2 Batts ■ Laid polythene on ground
Hot Water	■ Poorly insulated B grade (2003) hot water cylinder and un-insulated hot water pipes	■ Hot water cylinder wrap and pipe lagging
Heating	■ Old wood burner ■ Oil column heaters	■ Replaced wood burner with pellet burner ■ Installed ducted heat transfer system to bedrooms

Other Energy	▪ Inefficient lighting ▪ Thermal drapes through part of the house	▪ 5 CFL light bulbs installed
Ventilation	▪ Extract fan in shower room ▪ No extract ventilation in bathroom	
Water	▪ Low flow shower and taps ▪ Full flush toilets	▪ Plumbing checked
Waste	▪ No composting facilities	▪ Installed worm bin
Total Cost of Interventions		$23, 610

4.1.2 Dwelling Performance

4.1.2.1 Summary

This dwelling received a standard thermal retrofit, minor energy and waste efficiency measures and a change in heating method from wood (old wood burner) to pellets in a new low emission pellet burner combined with a heat transfer system. Overall, the physical benefits of this retrofit were significant but relatively minor, for a significant cost.

Key dwelling performance improvements which occurred in the house were:

- A significant reduction in hot water use during winter of ~ 12%
- A significant reduction in reticulated energy use of ~7% over winter
- A significant reduction in annual reticulated energy use of ~13% from 12,700 kWh/year to 11,000 kWh/year
- A statistically significant increase in average winter temperatures in the family room of 1.1°C
- A statistically significant increase in average winter temperatures in the main bedroom of 1.5°C
- A ~2°C increase in the most common temperature experienced in winter in the family room and bedroom

These improvements are largely attributed to the following interventions

- Heavy ceiling and under-floor insulation
- Hot water cylinder wrap
- Heat transfer system taking heat to bedrooms
- Increased efficiency of pellet burner versus old wood burner

When the post-retrofit house performance is examined against the HSS High Standard of Sustainability®; however, the house is deemed to still perform poorly. Total reticulated energy use remains high, and non reticulated space heating energy use was increased. With regard to temperature, despite the increases, both the family room and the main bedroom remain below HSS®-2006 standards. While the occupants reported being happy with the family room temperatures, they felt that the bedrooms were still too cold. The average minimum winter overnight temperature was 13.2°C in the main bedroom. The average 24 hour winter temperature was only 14.7°C and these temperatures are considered to be cold. Humidity levels remained high in the dwelling and outside the range considered optimum.

4.1.2.2 Energy

Table 2 below shows the winter energy data by end use for House 1. Highlighted figures are statistically significant at the 95% confidence level.

Table 2: House 1 Winter Energy Use Data By End Use (May – Sept)

House 1 Winter Energy Use (May – Sept)				
Period	**Space Heating (kWh)**	**Reticulated Hot Water (kWh) – electricity**	**Total Reticulated Energy (kWh)**	**Total Energy (kWh)**
Pre-Retrofit (06)	820 (wood)	3,290	6,410	6,870
Intermediate (07)	640 (pellets)	3,390	6,370	6,740
Post	970 (pellets)	2,900	5,930	6,540

4.1.2.3 Indoor Environment Quality[2]

Table 3 and Table 4 show the percentage of time the dwelling main bedroom and family room exceeded HSS®-2006 indoor environment quality indices in July. As can be seen from these tables, despite the retrofits, the rooms remain cold and damp for the majority of the time in July.

Table 3: Percentage of Time House 1 Main Bedroom Exceeded 70% Relative Humidity in July

Period	**House 1 Main Bedroom July Relative Humidity**	
	% Time Above 70%, 24 hr	**% Time Above 70%, night**
Intermediate (07)	51%	40%
Post (08)	74%	49%

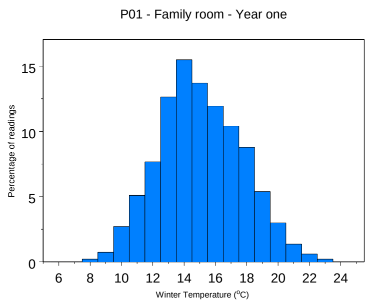
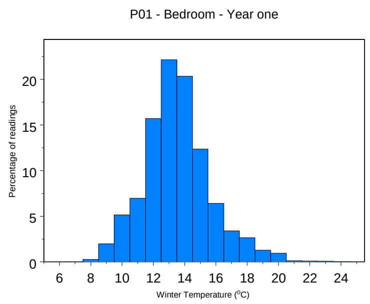
[2] *A comparison of the outdoor temperatures across the three years indicates that the 2006 and 2008 had very similar temperature winters. As outdoor temperature has a strong influence on indoor temperature some of the increases in temperature seen between 2006 and 2007 may be due to warmer outdoor temperatures*

Table 4: Percentage of Time House 1 Family Room and Bedroom Were Below Healthy Temperatures in July

House 1 July Temperatures - % Time Below Healthy Temperatures				
Period	**Family Room**		**Main Bedroom**	
	% time below 18°C, 24 hr	**% time below 18°C, evening**	**% time below 16 °C, 24 hr**	**% time below 16 °C, night**
Pre-Retrofit (06)	85%	58%	66%	88%
Intermediate (07)	73%	39%	40%	67%
Post	89%	69%	64%	85%

Figure 1 shows the frequency of different temperatures for the 3 winter months. These give a degree of subtlety that the other information doesn't provide and show that there has been an improvement in terms of in particular a reduction in the frequency of very low temperatures in both the family room and the main bedroom. Pre-retrofit the most common winter temperature in the family room was 14°C, whereas post-retrofit 16°C was the most common winter temperature. The lowest temperatures experienced in the family room also moved from 8°C to 10°C. When the main bedroom histograms are considered, a similar picture occurs, with the most frequent bedroom temperature being 13°C in winter 2006 pre-retrofit to becoming 15-16°C in winter 2008.

Figure 1: House 1 Winter Temperature Histograms

<table>
<tr><th colspan="3">House 1 Winter (June – August) Temperature Histograms</th></tr>
<tr><th>Period</th><th>Family Room</th><th>Main Bedroom</th></tr>
<tr><td>Pre (06)</td><td>
</td><td>
</td></tr>
</table>

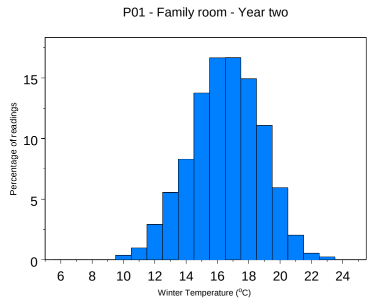
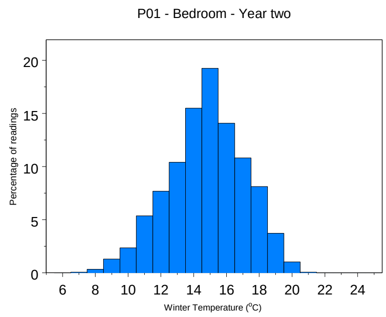
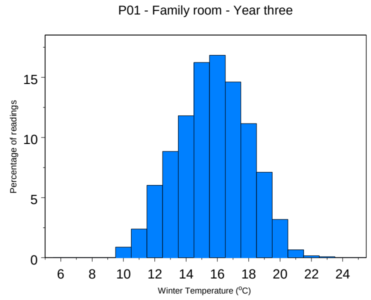
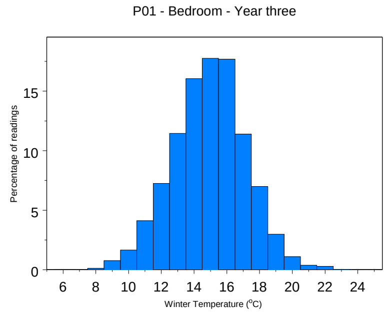
House 1 Winter (June – August) Temperature Histograms		
Period	**Family Room**	**Main Bedroom**
Intermediate (07)		
Post (08)		

Table 5 and Table 6 show the detailed winter temperature data for the family room and main bedroom. From Table 5 the impact of the main heating device (wood burner pre-retrofit and pellet burner post-retrofit) can be seen, with evening heating. This is likely to be linked to the improvements in evening temperatures in the main bedroom, however common sense would suggest that not long after the pellet burner is turned off, heat transfer benefits to the bedrooms will cease, and overnight bedroom temperature improvements are much smaller than those seen in the evening.

Table 5: House 1 Winter Temperature Data in Family Room

House 1 Family Room Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	14.7	12.5	12.6	12.7	16.3	12.9
Intermediate (07)	15.5	14.0	14.1	14.6	17.7	14.3
Post (08)	15.8	13.3	13.4	14.1	17.5	13.7

Table 6: House 1 Winter Temperature Data in Main Bedroom

House 1 Main Bedroom Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	13.2	11.6	11.8	11.7	14.0	12.4
Intermediate (07)	14.2	12.6	12.7	12.8	15.5	13.3
Post (08)	14.7	12.2	12.5	12.4	15.7	13.2

4.1.2.4 Water

Apart from the plumbing check, no measures were undertaken in this dwelling which would be expected to impact on water use. Average per capita water use for this four person household was a fairly high 287 l/pp/day.

4.1.3 Occupant Experience

The occupants of this dwelling were interviewed post-retrofit. Their interest in the renovation project was around the opportunities to increase the value of their home while increasing its sustainability. They had some specific concerns about the performance of their house and household health. In particular, they found the house cold in winter – particularly in the children's bedrooms – and 'unbearably hot' in summer. They saw retrofitting as a way of saving money and a means by which they could better manage the conditions for family members suffering from asthma.

The occupants noted that they had increased the level of warming in the family room and saw the wood pellet burner as extraordinarily efficient, convenient, 'guilt free' and safe. The household reported typically running the pellet burner from 4 pm to 10.30 pm in winter. They did, however, find that the pellet burner was noisy and commented that costs associated with it were high. The householders reported that they used 60 bags of pellets at $12/bag over winter.

Despite the considerable investment and range of interventions the householders still perceived the house as having performance problems post-retrofit. The householders felt that both the family room and bedroom temperatures have risen during winter. Indeed, they were entirely satisfied with the winter family room temperatures despite the winter average still be substantially lower than the HSS®-2006 temperatures (18°C in living space and 16°C in bedrooms) at 15.8°C as a winter average – although evening temperatures in winter averaged a more acceptable 17.5°C.

However, they found the thermal performance in summer was poor, with excessive heat. In addition the bedrooms were still described – correctly given that the winter temperature is an average of 14.7°C and 13.2°C overnight, – as cold.

These householders clearly believed that double glazing would have been a useful and effective intervention. They saw the pellet burner as providing the most benefits and would choose that intervention above all others. They also identified the worm farm as giving them very real benefits.

When asked about willingness to pay for improvements, overall, the householders saw themselves as expending around $20,000 on retrofit if it improved indoor temperature management.

4.2 House 2

A two-storied colonial-style house, this four-bedroom home has a coated metal tile roof and a mixture of weatherboard and sheet cladding. The lower storey appears to have been an addition put in soon after the house was built. It is smaller than the upper storey, and backs onto a bank. The upper story has timber suspended floors, while the lower storey has a concrete slab floor. The living areas and three of the four bedrooms are upstairs. The living area is approximately 140m^2 with a total floor area of approximately 160m^2. The house was occupied by a semi-retired couple.

4.2.1 Interventions Undertaken

House 2	Pre-Retrofit Condition	Intervention
Thermal	■ Old thin fibreglass batts in ceiling, ■ Wall and under-floor insulation in master bedroom. ■ Bare ground under-floor ■ Timber and aluminium single glazed windows ■ Broken cat flap causing draughts	■ Ceiling insulation re-laid and topped up to R2.6 ■ Floor insulated with R2 foil backed bulk insulation ■ Polythene vapour barrier installed over ground ■ New cat door installed
Hot Water	■ Original low pressure D grade hot water cylinder in ceiling cavity.	■ Hot water cylinder wrap and pipe lagging

Heating	■ Old wood burner ■ Oil column heaters in rumpus room ■ Electric blanket in bedroom	
Other Energy	■ Inefficient lighting ■ No thermal linings on windows	■ 5 CFL light bulbs installed
Ventilation	■ Broken mechanical extract in bathroom ■ Rangehood in kitchen	■ Extract fan fixed
Water	■ Low flow shower head and taps ■ Dual flush toilets	■ Plumbing check
Waste	■ No method of composting kitchen waste	■ Worm bin installed
Other	■ No smoke alarm	■ Smoke alarm installed
Total Cost		$2120

4.2.2 Dwelling Performance

4.2.2.1 Summary

This dwelling received a relatively basic thermal retrofit and minor energy and waste efficiency measures. However for the low cost, reasonable performance benefits were gained.

Key dwelling performance improvements which occurred in the house were:

- A significant reduction in total winter reticulated energy use ~6%
- A significant reduction in winter hot water energy use ~11%
- A significant increase in average winter temperature in the family room – 1.6°C
- A significant increase in the average winter temperature in the main bedroom –1.1°C
- Temperature increases occurred with no overall increase in heating energy used in the home.
- A significant 35% reduction in annual reticulated energy use – bringing a house which already met the HSS®-2006 energy benchmark from 7500 kWh/year down to a modest 4900 kWh/year.
- A ~1°C increase in the most common temperature experienced in winter in the family room

These improvements are large attributed to the following interventions

- Moderate ceiling and under-floor insulation
- Hot water cylinder wrap

However, some of the reticulated energy savings cannot be attributed to the interventions made. Occupancy changes occurred in the household as two of the adult children who had lived in the home left home.

When the post-retrofit house performance is examined against the HSS High Standard of Sustainability®; however, the house is deemed to still perform sub-optimally. With regard to temperature, despite the increases, the main bedroom remains below HSS®-2006 standards. The average minimum overnight temperature in the main bedroom was 13.4°C and the average 24 hour winter temperature was only 14.2°C. Humidity levels in the home still exceed optimum levels at times, although the homeowners reported they had given away their dehumidifier – which could be a significant factor in the reticulated energy use reduction.

4.2.2.2 Energy

Table 7 below shows the winter energy data by end use for House 2. Highlighted figures are statistically significant at the 95% confidence level.

Table 7: House 2 Winter Energy Use Data By End Use (May – Sept)

House 2 Winter Energy Use (May – Sept)				
Period	**Space Heating (kWh) -wood**	**Reticulated Hot Water (kWh) – electricity**	**Total Reticulated Energy (kWh)**	**Total Energy (kWh)**
Pre-Retrofit (06)	3010	1140	2350	6130
Intermediate (07)	2370	1020	2370	4720
Post	2850	1010	2380	5140

Key points to note from this data are that the intermediate year (2007) winter saw a substantial decrease in heating energy which was then "taken back" in the second winter (2008). Unlike some of the homes in the study, the family room in this house was already heated above HSS®-2006 minimum levels. Takeback in increased family room comfort however still occurred.

4.2.2.3 Indoor Environment Quality

Table 8 and Table 9 show the percentage of time the dwelling main bedroom and family room exceeded healthy indoor environment quality indices in July. As can be seen from these tables, while in the evening the family room is approaching healthy temperatures, the bedroom remains cold and damp for the majority of the time in July.

Table 8: House 2 Percentage of Time Main Bedroom Exceeded 70% Relative Humidity in July

Period	House 2 Main Bedroom July Relative Humidity	
	% Time Above 70%, 24 hr	% Time Above 70%, night
Intermediate (07)	16%	17%
Post (08)	36%	25%

Table 9: House 2 Percentage of Time Family Room and Bedroom Were Below Healthy Temperatures in July

House 2 July Temperatures - % Time Below Healthy Temperatures				
Period	Family Room		Main Bedroom	
	% time below 18°C, 24 hr	% time below 18°C, evening	% time below 16 °C, 24 hr	% time below 16 °C, night
Pre-Retrofit (06)	75%	27%	59%	93%
Intermediate (07)	69%	14%	55%	79%
Post	65%	14%	52%	76%

Figure 2 shows the frequency of different temperatures for the three winter months. These show that there has been a minor improvement in terms of the frequency of very low temperatures in both the family room and the main bedroom. Pre-retrofit the most common winter temperature in the family room was 15°C, whereas for the 2008 winter 16°C was the most common winter temperature. 15°C remains the most common temperature in the bedroom, although there is a reduction in the frequency of lower temperatures.

Figure 2: House 2 Winter Temperature Histograms

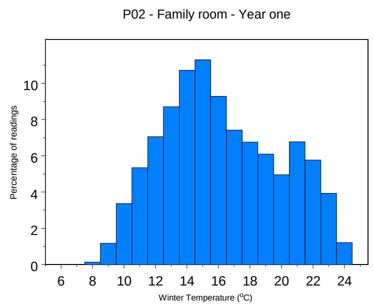
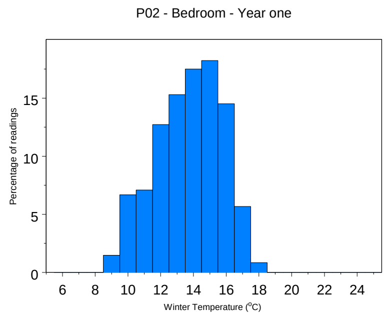
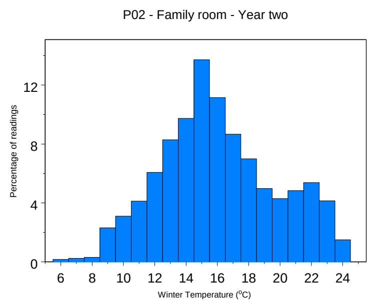
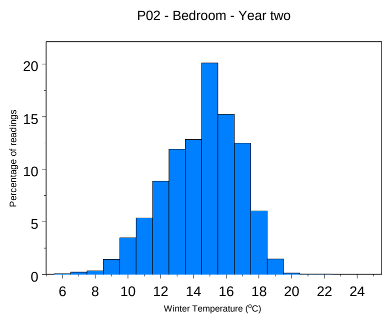
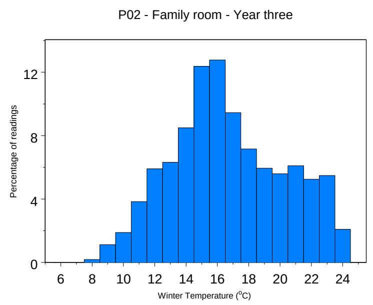
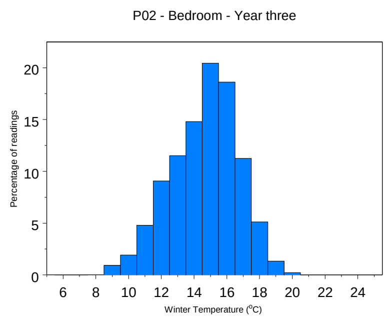
House 2 Winter (June – August) Temperature Histograms		
Period	**Family Room**	**Main Bedroom**
Pre (06)		
Intermediate (07)		
Post (08)		

Table 10 and Table 11 show the detailed winter temperature data for the family room and main bedroom. From Table 10 the impact of the main heating device can be seen, with evening heating.

Table 10 : House 2 Winter Temperature Data in Family Room

House 2 Family Room Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	14.9	12.5	12.7	13.0	18.6	12.9
Intermediate (07)	16.5	13.3	13.5	13.6	19.3	13.7
Post	16.5	12.8	13.0	13.1	19.4	13.3

Table 11: House 2 Winter Temperature Data in Main Bedroom

House 2 Main Bedroom Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	13.1	12.8	12.9	13.1	15.0	13.3
Intermediate (07)	14.4	13.4	13.9	14.3	15.9	13.8
Post	14.2	12.9	13.0	13.3	15.6	13.4

4.2.2.4 Water

Apart from the plumbing check, no measures were undertaken in this dwelling which would be expected to impact on water use. Average per capita water use for this two person household was 220 l/pp/day.

4.2.2.5 Waste

Like all households in the study, this home was supplied with a worm bin. Pre-retrofit and 2008 waste audits indicate no significant change in the composition of this household's solid waste. Post-occupancy interviews indicate the worm farm was abandoned early on when the worms were accidentally killed.

4.2.3 Occupant Experience

The occupants of this dwelling were interviewed post-retrofit. These householders were attracted to the renovation project to both reduce expenditure on energy and become more 'eco-friendly'. They had no interest in the notion of increasing the capital value of their dwelling as they had been living in the house 28 years and saw themselves living in it well into the foreseeable future.

The major performance problem that they had with the house was high levels of humidity and the necessity of using a dehumidifier. From this perspective the retrofit was seen by them as being successful as they were able to give away their dehumidifier. Humidity levels however in the home continue to be above that considered optimum by Beacon.

Despite the very low renovation investment ($2,120) there have been statistically significant decreases in energy use which were sustained over the two year period. The change in household occupancy is likely to have contributed substantially to this however. There have also been statistically significant increases in temperature in both the family room and the master bedroom. These rooms are still, however, relatively cold at 16.5°C and 14.5°C on average. The householders' view is that the temperature increases are more significant than average measurements. They suggest that the family room is heated to 25°C in winter despite leaving doors open. They believe that they are receiving more benefit from their enclosed wood burner in which they burn pine, manuka and blue gum which has been seasoned for a year or more. They have found the basement drier and can walk around the house in bare feet without becoming chilled.

4.3 House 3

The house was built in the 1970s, and was constructed of mainly rimu framing. The house contains a large open plan living and dining area, and kitchen on the upper floor. The bedroom wing contains three bedrooms, a large foyer, bathroom and toilet upstairs. Downstairs there is a laundry, toilet, small and large offices, and part way through the project an additional office was put into the rear of the garage. The addition of the large office at the rear of the house took place in the early 1980s.

The exterior cladding is a mainly weatherboard and sheet cladding, with concrete block around the addition, and a small stone veneer façade at the front of the garage. The total dwelling area is approximately 175m^2, with 120m^2 upstairs living area. The lower floor has a concrete slab floor, while the upper floor has timber suspended floors. The corrugated iron roof was in poor condition at the time of entry into the project. The roof is partly skillion, partly cavity. The house is occupied by a young family of five, and at the time of retrofit, as an employee in the small business run from the home was there during the day.

4.3.1 Interventions Undertaken

House 3	Pre-Retrofit Condition	Intervention
Thermal	■ Single glazed aluminium windows in poor condition ■ Wall insulation installed at the time of construction in office part of the dwelling ■ New R2.6 ceiling batts in cavity over bedrooms; remaining roof un-insulated ■ No pelmets ■ Un-insulated under-floor ■ Bare ground under-floor	■ New aluminium frame clear IGU double glazing units ■ Walls insulated with R2.4 batts ■ Skillion ceiling lowered and insulated with R3.6 batts, remaining insulation re-laid and overtopped with R2.6 blanket ■ Pelmets installed ■ Under-floor insulated with R2 foil backed batts ■ Polythene vapour barrier installed
Hot Water	■ 135 litre B grade hot water cylinder and un-insulated pipes ■ Jigh flow rate in shower	■ new evacuated tube solar hot water system with 300 litre hot water cylinder ■ Flow restrictor on shower head
Heating	■ Heat pump and old wood burner in living room with unused heat transfer system ■ Two heat pumps and fan heater in downstairs office ■ Oil column heater in child's bedroom	■ Wood burner replaced with NES compliant burner ■ Ducted heat pump system installed late 2007
Other Energy	■ fridge inefficient ■ no thermal linings on windows ■ inefficient lighting	■ 5 CFL light bulbs installed
Ventilation	■ Kitchen extraction fan broken ■ No mechanical ventilation bathroom	■ New rangehood
Water	■ Two full flush toilets	■ Dual flush cisterns ■ Plumbing check
Waste	■ No method of composting	■ Worm farm installed
Other	■ No smoke alarm ■ Leaking roof past useful life	■ Smoke alarm installed ■ Roof replacement
Total Cost		$76, 590

4.3.2 Dwelling Performance

4.3.2.1 Summary

This dwelling received a substantial retrofit to the thermal envelope, hot water and heating aspects as well as some indoor environment quality, water and waste efficiency measures. It was the most expensive of the retrofits undertaken, with the double glazing and new window frames the most expensive single component of the retrofit.

As a result of these substantial measures, very significant improvements in the house performance occurred. These include:

- A significant reduction in total winter reticulated energy use ~33%
- A significant reduction in energy required for space heating ~ 62%
- A significant reduction in total winter energy use (all sources) ~37%
- A significant reduction in winter hot water energy use ~ 55%
- A significant increase in average winter temperature in the family room -1.7°C
- A significant increase in average winter temperature in the main bedroom – 3.8°C
- Almost total elimination of sub 16°C (bedroom) and sub 18°C (family room) temperatures in the house in winter during occupied times
- A ~5°C increase in the most common temperature experienced in winter in the main bedroom
- A 9% reduction in annual reticulated energy use – bringing a house which already met the HSS®-2006energy benchmark from 10,000 kWh/year down to an improved 9024 kWh/year

In addition this house exhibited substantial takeback in terms of hot water use. As a result:

- Total winter hot water use increased by 21% with takeback exhibited between the 2007 and 2008 winters

4.3.2.2 Energy

Table 12 below shows the winter energy data by end use for House 3. Highlighted figures are statistically significant at the 95% confidence level.

Table 12: House 3 Winter Energy Use Data By End Use (May-Sept)

House 3 Winter Energy Use (May – Sept)				
Period	**Space Heating (kWh)**	**Reticulated Hot Water (kWh)**	**Total Reticulated Energy (kWh)**	**Total Energy (kWh)**
Pre-Retrofit (06)	2,120	2,130	7,550	8,970
Intermediate (07)	1,410	860	6,460	7,590
Post (08)	810	970	5,070	5,670

Key points to note from this data are as follows:

- Space heating energy substantially decreased between the '07 and '08 winters. This is probably because of the change in heating method. In 2007 a combination of heat pumps and the efficient wood burner were both used. In winter 2008 the newly installed ducted central heating system was used in preference to the wood burner, the usage of which reduced substantially. The efficiency of a ducted central heating system is more than double that of a wood burner, so less energy is needed to generate the same amount of heat.
- Like House 2, the family room in this house was already heated above minimum levels. Takeback in increased family room comfort still occurred; however, the energy impact was absorbed by the improvement in thermal performance of the dwelling and increased efficiency of heat source. It is possible to have your cake and eat it too!
- Take back of about 10% of the energy savings from the solar hot water system seems to have occurred between the '07 and '08 winters.
- Changes to the household occurred, which are likely to have impacted on reticulated energy use. At the start of the project a small home office, with one employee was located in the downstairs part of the house. As the business became more successful, employee numbers expanded to 3. However the business moved to other premises early in 2008. These changes are likely to impact most on the total reticulated energy (from computers, lighting and office electronics) and reticulated heating energy component as the office was heated with heat pumps and a portable electric heater. The office area itself was outside of the thermal envelope treated in the retrofit, so physical changes would be limited.

4.3.2.3 Indoor Environment Quality

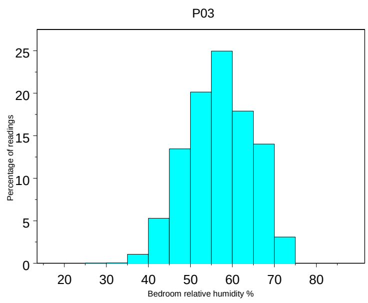
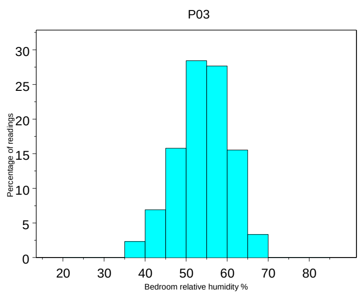
Table 13and Table 14 show the percentage of time the dwelling main bedroom and family room fell below healthy indoor environment quality indices in July. Figure 4 and Figure 3 supplement this information by showing the frequency of temperatures and relative humidity within the homes over winter.

As can be seen from Table 13 and Figure 3, humidity levels were very satisfactory for the home post-retrofit – the pre-retrofit condition is unknown. Given the lower temperatures in the dwelling pre-retrofit however we can expect relative humidity was significantly higher pre-retrofit. The reduction in frequency of the higher humidity levels in the bedroom in 2008 could be an indicator of the house drying out as a result of the improvements made.

Table 13: Percentage of Time House 3 Main Bedroom Exceeded 70% Relative Humidity in July

Period	**House 3 Main Bedroom July Relative Humidity**	
	% Time Above 70%, 24 hr	**% Time Above 70%, night**
Intermediate (07)	2%	1%
Post (08)	0%	0%

Figure 3: House 3 Histograms of Winter Relative Humidity

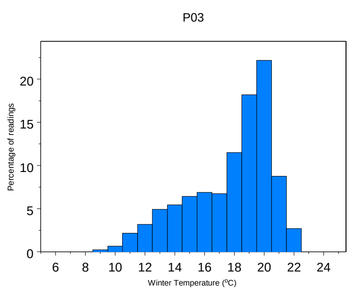
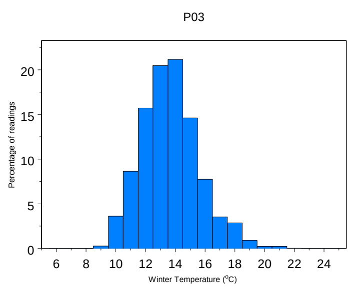
House 3 Winter (June – August) Relative Humidity Histograms	
Period	**Main Bedroom**
Intermediate (07)	
Post (08)	

As can be seen from Table 14 and Figure 4, between winter 2006 and winter 2008, there were significant improvements in the proportion of time the family room and main bedroom exceeded healthy temperatures. The increase in percent of time the house fell below health temperatures in July in 2007, and this being substantially reversed in 2007 is probably largely due to the changes in heating method in the two years. As can be seen from Figure 4, 2007 saw a very large reduction in the frequency of very low temperatures in both the family room and bedroom with both heat pumps and a wood burner combined with heat transfer to bedrooms used in 2007. However the mean and median temperatures were still below the desired healthy levels. The change to a ducted heat pump system as the primary source of heating in 2008 resulted in further temperature improvements, to the point where very low temperatures were eliminated and the % time below healthy minimums was substantially reduced.

Table 14: Percentage of Time House 3 Family Room and Bedroom Were Below Healthy Temperatures in July

House 3 July Temperatures - % Time Below Healthy Temperatures				
Period	**Family Room**		**Main Bedroom**	
	% time below 18°C, 24 hr	**% time below 18°C, evening**	**% time below 16 °C, 24 hr**	**% time below 16 °C, night**
Pre-Retrofit (06)	42%	15%	30%	84%
Intermediate (07)	63%	51%	38%	41%
Post	29%	4%	8%	20%

Figure 4: House 3 Histograms of Winter Temperatures

House 3 Winter (June – August) Temperature Histograms		
Period	**Family Room**	**Main Bedroom**
Pre (06)		

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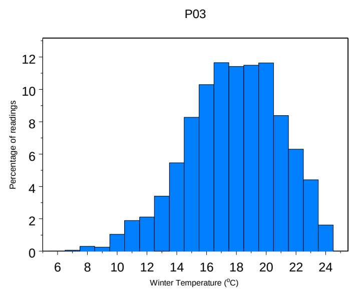
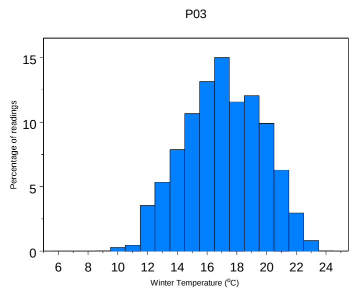
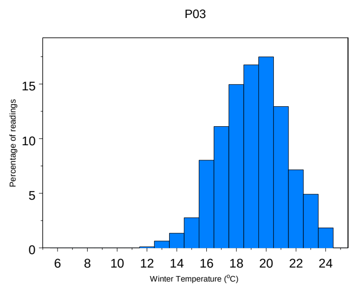
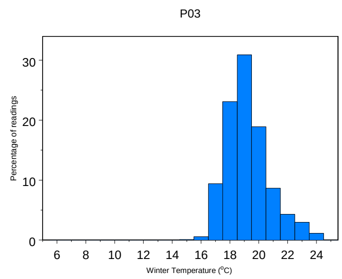
<tr><td>Intermediate (07)</td><td></td><td></td></tr>
<tr><td>Post (08)</td><td></td><td></td></tr>
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Table 15 and Table 16 show the detailed winter temperature data for the family room and main bedroom. Of note are the increases in mean minimum temperatures in the family room during the evening from healthy, to very comfortable temperatures over the life of the project. The reduction in mean minimum temperatures in the main bedroom overnight between winter 2007 to winter 2008 could be a result from changed heating methods. In 2007 a combination of heat transfer from the wood burner in the family room, and oil column electric heating in the bedroom was in place. In the 2008 winter the main heat source was the ducted central heating system – presumably set at a standard temperature for the whole house.

Table 15: House 3 Winter Temperature Data in Family Room

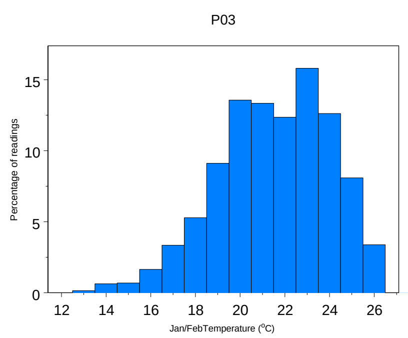
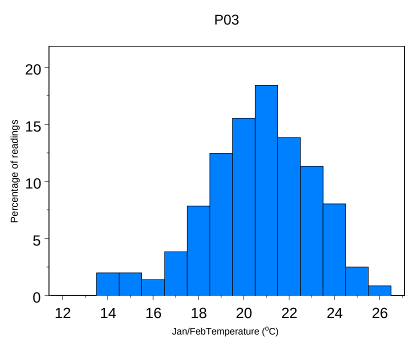
House 3 Family Room Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	17.8	13.3	15.8	17.2	18.4	13.5
Intermediate (07)	17.5	16.8	17.2	17.6	19.3	17.7
Post (08)	19.5	16.4	16.6	17.9	20.5	16.8

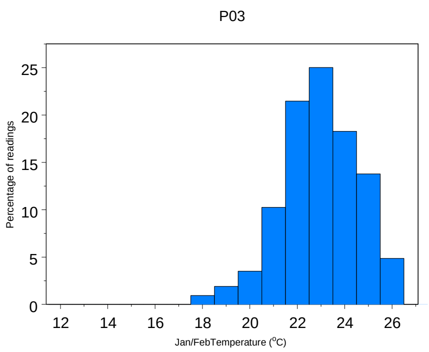
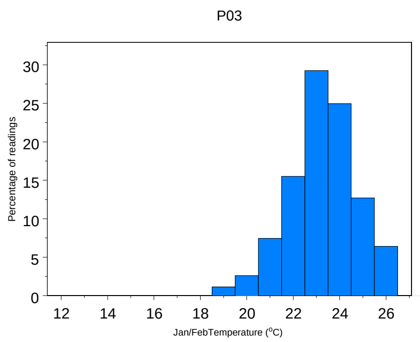
Table 16: House 3 Winter Temperature Data in Main Bedroom

House 3 Main Bedroom Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	15.8	12.7	12.8	13.1	14.2	12.9
Intermediate (07)	16.8	15.6	16.3	16.0	16.9	16.7
Post	19.5	17.8	18.8	18.2	19.3	18.4

In addition to winter temperatures, the extent of thermal retrofit in this dwelling warranted an investigation into the impacts on summer temperatures. It can be seen from Figure 5 that a significant change occurred. The frequency of higher temperatures increased substantially and lower temperatures were eliminated. Higher temperatures were also significantly more common in the bedroom overnight. The highest temperatures in the home experienced were around 27°C and this did not change, however the occupants advise that they used the heat pumps (pre-retrofit) and ducted central heating system for space cooling in the dwelling. Cooling behaviour was fairly limited pre-retrofit and has increased through the duration of the project. In response to overheating concerns sunshades were installed in the family room in 2008.

Figure 5: House 3 Summer Temperature Histograms

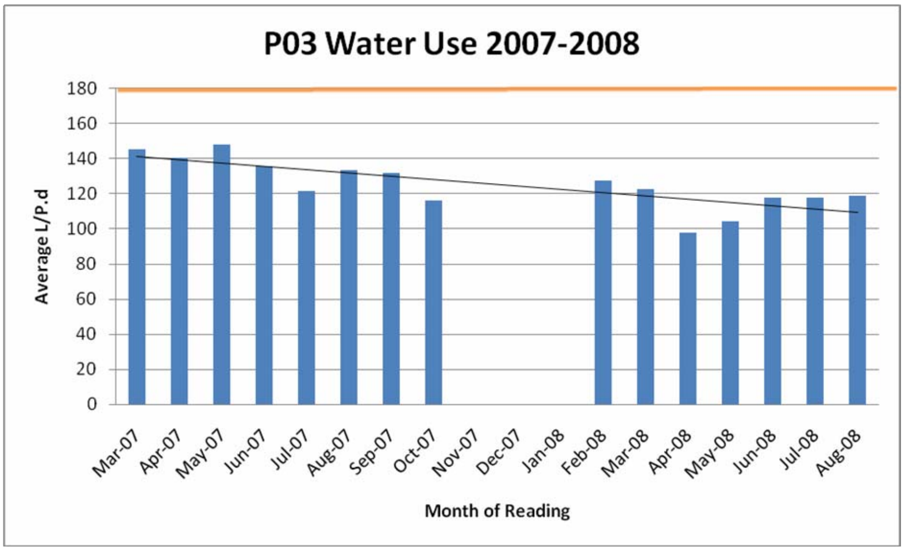
<table>
<tr><th colspan="3">House 3 Summer (Jan –Feb) Temperature Histograms</th></tr>
<tr><th>Period</th><th>Family Room</th><th>Main Bedroom</th></tr>
<tr><td>Pre (2007)</td><td>
</td><td>
</td></tr>
</table>

House 3 Summer (Jan –Feb) Temperature Histograms		
Period	**Family Room**	**Main Bedroom**
Post (2008)		

4.3.2.4 Water

In addition to the plumbing check, dual flush cisterns (September 07) and a solar hot water system (May 07) were installed in this house. These measures could be expected to have an impact on per capita water use in the dwelling. Figure 6 shows the monitored water use for the dwelling.

Figure 6: House 3 Water Use – March 2007 – Aug 2008



As noted above, the installation of the solar hot water system resulted in an increase of hot water energy use by the household of 21% between the 2007 and 2008 winter periods. Though data is not available this is likely to be paralleled with an increase in hot water as the hot water heating method was much more efficient. This combined with the presence of business staff of varying numbers during the life of the project, and the very short period of pre-retrofit data means a clear picture of water use is not available.

There are no statistically discernible trends in water use which can be attributed to the interventions, apart from the increased hot water use. However, like all houses where water monitoring occurred, there was a discernible downward trend in water use between the 2007 and 2008 years. The occupancy interviews identified that outdoor water use in the dwelling was minimal and that no particular water saving behaviours had been put in place, therefore the reduced water use can probably be attributed to the ceasing in use of the dwelling as an office in early 2008 and the installation of the dual flush toilets.

This five person household were relatively low water users through the duration of the project, averaging 125 l/pp/day.

4.3.2.5 Waste

Like all households in the study, this home was supplied with a worm bin. Pre retrofit and 2008 waste audits indicate no significant change in the composition of this household's solid waste, which was generally quite low. Post occupancy interviews indicate the worm farm was diligently used until mid 2008, when accidental death of the worms occurred. After that its use was abandoned.

4.3.3 Occupant Experience

The occupants of this house were interviewed twice – post-retrofit (early 2007) and post-project (March 2008).

These householders were attracted to the renovation project because it offered them opportunities to increase heat efficiency and saw a professional and personal interest in monitoring for increased warmth and energy efficiency. They saw it as an opportunity to modernise the house with lowered ceilings and new (recessed) lighting as well as improve dwelling performance. Noise, cold and excessive condensation issues were of concern to the householders.

In the post-retrofit interviews the householders cited the solar hot water system as the main reason for their fall in energy consumption and the double glazing as the major reason for temperature increases – although they saw this in particular in relation to draught reduction. In the post-project interviews the solar gain in the lounge with heat being trapped in by the double glazing was seen as a major reason for winter temperature increases – although there were associated concerns about summer overheating.

In both sets of interviews, the household were concerned about potential overheating and intended to install sunscreens, and did so for the lounge windows in early 2008.

In the post-retrofit interviews the householders believed (incorrectly) that their hot water use was decreasing – though acknowledging that because it was costing less to heat they no longer worried about the hot water running out, or felt the need to ask the children to get out of the shower. In the post-project interviews the occupants weren't really aware that their hot water use was still increasing, although suggested that one cause may be the older age of the children resulting in a desire by them to shower more.

In the post-retrofit interviews, the changes exceeded the expectations of the householders. They stated that the wood burner combined with the heat transfer system heated the whole house – though they subsequently installed a ducted heat pump central heating system with cold bedrooms and the avoidance of continuing use of the oil column heaters being the main reason given for this in the post-project interviews.

The problems with condensation and mould have been entirely eliminated.

In the post-retrofit interviews they identified the following unexpected benefits:

- Noise reduction of sounds generated inside the house and sounds generated outside the house.
- A feeling that the house is healthier.
- The modernised look of the house.

The householders reported that they would be prepared to pay up to 20 percent of the house value in improvements. In the post-retrofit interviews they identified that of particular benefit was the solar water heating and insulation. At that time, the householders saw double glazing as appropriate in new houses but had doubts about their retrofit value. In the post-project interviews however this opinion was reversed and the occupants said they felt they could recommend double glazing to people. They also felt if building a home they would install the highest R value insulation as a result of their experience.

In the post-project interview the family noted improved health in relation to colds and flu since the retrofits, and that the asthmatic child was able to use an inhaler less frequently. They also noted as significant benefits the ability to be warm in and use the whole house rather than the previous experience of having to "huddle around the fire".

4.4 House 4

This home was built in 1976, and was the only house in the study with a fully concrete slab floor. The roof is concrete tile, and the walls are mostly stucco on sheet material, with a partial brick veneer on the front of the home. The house contains three bedrooms, ensuite, separate laundry, toilet, bathroom, and a living room, dining and kitchen area with a living area of 130m^2. It has a detached double garage.

Part way through the project there was a change of occupancy of this house. The former inhabitants were a retired couple, one with serious health conditions. The house was sold and the new family declined to participate further in the project.

4.5 House 5

This house is single-storied with three bedrooms, sunken living room, and open plan dining and kitchen. The house was constructed in 1978 and has 130 m^2 approximate living area, with 150m^2 approximate total floor area.

There is an ensuite, a separate toilet, bathroom and laundry. The house is clad with brick in the east, and weatherboard on the rest of the house. The timber framed windows were in good condition apart from the stays, leading to draughts. The house has a metal tile roof. The majority of the floor of the living areas is suspended timber, apart from the concrete slab floor of the lounge and the attached garage. The occupants are a retired couple.

4.5.1 Interventions Undertaken

House 5	Pre-Retrofit Condition	Intervention
Thermal	■ Timber framed single glazed windows: draughty ■ Original 1978 ceiling insulation[3] ■ original wall insulation ■ Draughty sliding door ■ Floor un-insulated ■ Bare ground under-floor	■ Ceiling insulation topped up with R 1.8 blanket ■ Door draught stopped ■ Under-floor insulated with R2 foil backed batts ■ Polythene vapour barrier installed

[3] ***Wall insulation was discovered at the time of physical intervention, it was originally thought no wall insulation existed.***

Hot Water	■ Wrapped D grade hot water cylinder	■ Two instant gas hot water systems ■ Low flow shower head
Heating	■ Flued gas fireplace in living room ■ Convection heater. ■ Electric blanket	■ Ducted heat transfer system installed to hallway near bedrooms
Other Energy	■ No thermal linings on windows in half of the house ■ Large old recessed down-light in kitchen ■ Other inefficient lighting	■ Installation of two CA rated halogen downlights ■ 5 CFL light bulbs installed
Ventilation	■ Kitchen and bathroom unventilated	Bathroom extract ventilation installed
Water	■ Low flow taps	■ Plumbing check
Waste	■ No method of composting	■ Worm farm installed
Total Cost		$10,690

4.5.2 Dwelling Performance

4.5.2.1 Summary

This dwelling, which was already fully insulated to 1978 standards, received a moderate level of retrofit to the thermal envelope, a hot water upgrade and minor energy and waste efficiency measures.

Overall the improvements which resulted to the house performance were relatively minor. No statistically significant improvements in winter reticulated energy use, space heating, hot water heating or average family room temperatures occurred although there was a 0.6°C increase in the main bedroom temperatures and a reduction in the frequency of the lowest temperatures was seen in both the family room and bedroom. Takeback was evidenced from both the space heating and hot water energy savings made in the intermediate (2007) winter and this may partly explain the minor upward trend in bedroom temperature experienced in the 2008 winter.

The change to instant gas hot water system did result in a significant reduction of ~35% in winter electricity use, however this was replaced by a similar quantity of gas, meaning the change was a fuel switching, rather than energy efficiency measure.

4.5.2.2 Energy

Table 17 below shows the winter energy data by end use for House 5. There are no statistically significant changes.

Table 17: House 5 Winter Energy Use Data By End Use (May-Sept)

House 5 Winter Energy Use (May – Sept)				
Period	**Space Heating (kWh)**	**Reticulated Hot Water (kWh)**	**Total Reticulated Energy (kWh)**	**Total Energy (kWh)**
Pre-Retrofit (06)	7,870	1,070	10,970	10,970
Intermediate (07)	6,950	970	10,150	10,150
Post (08)	7,470	1,050	10,270	10,270

Key points to note from this data are as follows:

- In the 2007 post-retrofit winter, a reduction in space heating energy was seen – likely as a result of the thermal improvements making the home easier to heat. However this efficiency was largely taken back in the second winter.
- In the 2007 post-retrofit winter ,a reduction in hot water heating energy was also observed. This is likely to be a result of the improved efficiency of the hot water system (instant gas is more efficient than a D grade electric cylinder), however again these savings were taken back in the 2008 winter. The amount of hot water used in this home was not monitored, but it seems likely that an increased amount of hot water was also used.
- No changes in heating efficiency were made in this home, which post-retrofit should have performed quite well thermally – with (old) wall insulation, moderate ceiling insulation and heavy under-floor insulation. This case study appears to confirm the hypothesis that alongside insulation an efficient heating system is needed, otherwise long term energy efficiency and healthy temperatures are unlikely to occur.
- Total annual reticulated energy consumption remained a high 12,500 kWh/year.

Total Annual Reticulated Energy kWh/year	Pre-retrofit	Post-retrofit
S-House 5	12,500	12,500

4.5.2.3 Indoor Environment Quality

Table 18 and Table 19 show the percentage of time the dwelling main bedroom and family room fell below healthy indoor environment quality indices in July. As can be seen, from these tables, relative humidity remains a significant issue within this dwelling. Table 18 shows that there was an increase in the amount of time the family room fell below 18°C in the evening in winter between the pre-retrofit (2006) and intermediate (2007) winters. This aligns with other data which shows a reduction in heating energy, as the occupants felt that the house was warmer and heated less, with the 2008 winter reversing this trend as takeback in the form of warmer temperatures occurred.

Table 18: House 5 Percentage of Time Main Bedroom Exceeded 70% Relative Humidity in July

Period	House 5 Main Bedroom July Relative Humidity	
	% Time Above 70%, 24 hr	% Time Above 70%, night
Intermediate (07)	50%	57%
Post (08)	52%	56%

Table 19: House 5 Percentage of Time Family Room and Bedroom Were Below Healthy Temperatures in July

House 5 July Temperatures - % Time Below Healthy Temperatures				
Period	Family Room		Main Bedroom	
	% time below 18°C, 24 hr	% time below 18°C, evening	% time below 16 °C, 24 hr	% time below 16 °C, night
Pre-Retrofit (06)	68%	7%	53%	93%
Intermediate (07)	79%	40%	60%	81%
Post	74%	20%	51%	86%

Figure 7 shows the frequency of different temperatures for the three winter months. These show that there has been an improvement in terms of a reduction in the frequency of very low temperatures in both the family room and the main bedroom between the 2006 and 2008 winters. Pre-retrofit the most common winter temperature in the family room was 14°C, whereas post-retrofit 15°C was the most common winter temperature. The lowest temperatures experienced in the family room also moved from 8°C to 10°C. When the main bedroom histograms are considered, a similar picture occurs: the most frequent bedroom temperature being 13°C in winter 2006 pre-retrofit and becoming 14°C in winter 2008.

Figure 7: House 5 Winter Temperature Histograms

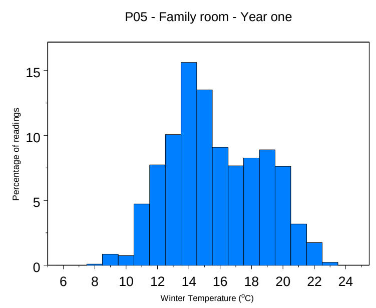
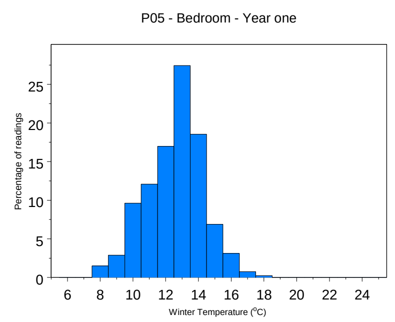
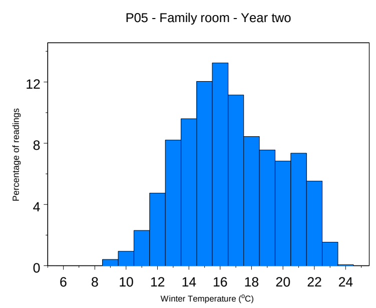
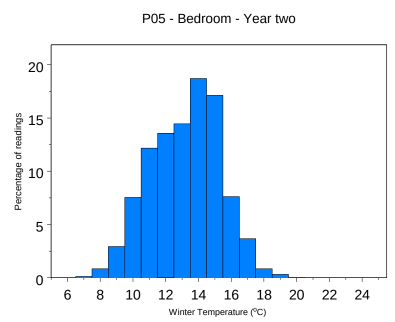
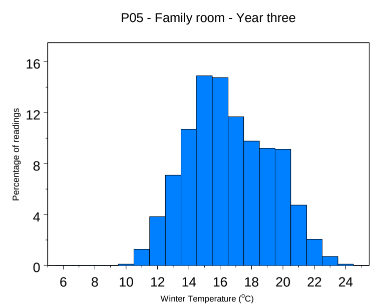
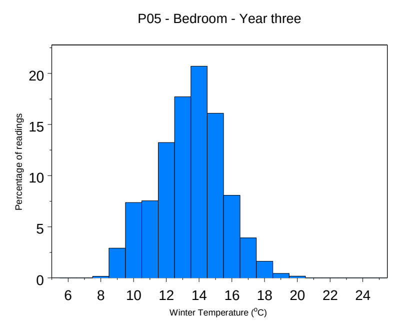
House 5 Winter (June – August) Temperature Histograms		
Period	**Family Room**	**Main Bedroom**
Pre (06)		
Intermediate (07)		
Post (08)		

Table 20 and Table 21 give the detailed temperature data for the winter months (May – September). The evening heating in the family room is evident, although the rest of the time the family room remains cold. A heat transfer system was included in this retrofit; however it appears to have had minimal impact on the bedroom temperatures – probably because the heating method (flued gas) and habits generated insufficient temperatures in the family room for significant excess heat to be produced to transfer to the bedroom.

Table 20: House 5 Winter Temperature Data in Family Room

House 5 Family Room Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	16.6	13.1	13.1	13.3	17.8	13.4
Intermediate (07)	16.7	14.3	14.3	14.7	18.9	14.5
Post (08)	16.5	13.6	13.6	14.1	18.4	13.9

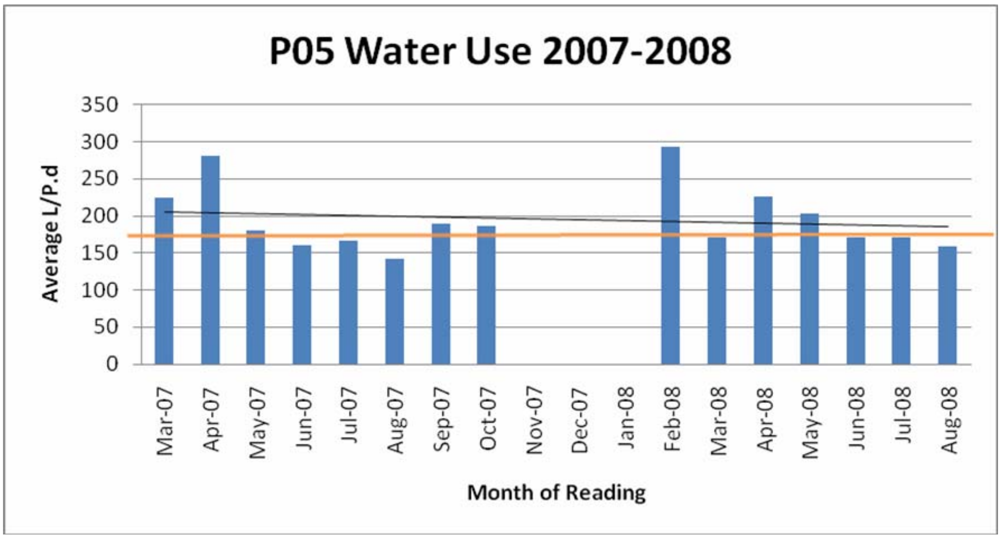
Table 21: House 5 Winter Temperature Data in Main Bedroom

House 5 Main Bedroom Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	12.7	12.1	12.2	12.4	13.4	12.4
Intermediate (07)	13.0	12.8	13.0	13.3	14.1	13.1
Post	13.3	12.2	12.5	12.8	13.5	12.6

4.5.2.4 Water

The installation of two instant gas hot water systems (July 07) was the main retrofit measure which could be expected to impact on water use in this dwelling. A low flow showerhead and flow restrictors were installed at the same time to help offset the impact of moving to a mains pressure system. Figure 8 shows the water use data for this dwelling. This shows no discernable trend for total water use. Hot water use was not separately monitored in this home so it is not known whether the instant gas hot water systems resulted in an increase in hot water use.

Figure 8: House 5 Water Use Data : March 07 – Aug 08



4.5.2.5 Waste

Like all households in the study, this home was supplied with a worm bin. Pre-retrofit and 2008 waste audits indicate no significant change in the composition of this household's solid waste.

4.5.3 Occupant Experience

The occupants of House 5 were interviewed post-retrofit. These householders were attracted to the retrofit project to increase the warmth of their house. They had no interest in the notion of increasing the capital value of their dwelling as they saw themselves living in their current dwelling well into the foreseeable future. At the time of interviews, the householders believed the house to be warmer and the physical monitoring data indicates these changes were marginal and the result is not statistically significant. Post-retrofit they also believed that their hot water use was less, since the time of interview; however, the hot water use increased according to the monitoring data.

In terms of effectiveness of retrofit, the householders felt that the insulation of under-floor and ceiling areas had made the most difference. They also associated the reduction of noise with draught stopping of the sliding door. The householders reported being prepared to expend up to $30,000 on retrofit.

Despite this apparent willingness to pay for retrofit at relatively high levels, the householders expressed dissatisfaction with the performance of some installed items. The installation of the bathroom duct was believed to be faulty by the householders and they associate this with mould and condensation problems in the shower. The new lighting was considered too dim. The dual flush toilet proved unsatisfactory on the half flush. The water pressure in the shower was also seen as inadequate.

4.6 House 6

This house was built in the 1970s, and has a living area of approximately 190m^2 and a total area of approximately 220m^2. The house is mainly of timber-framed weatherboard construction, with some sheet cladding around the lower part of the house and concrete block around the family room extension. The roof is concrete tiles, and the foundations are concrete slab beneath the garage and family room, and timber suspended floors under the rest of the house. The house was occupied by an adult family of three professionals, with another two adults living there intermittently.

4.6.1 Interventions Undertaken

House 6	Pre-Retrofit Condition	Intervention
Thermal	■ Mix of new and old aluminium and wooden windows, all with single glazed panes ■ Patchy ceiling insulation, with numerous downlights intruding. ■ Under-floor poorly insulated beneath the lounge, rest of floor un-insulated ■ Un-insulated walls	■ Ceiling insulation topped up with R 2.6

Hot Water	▪ B grade hot water cylinder, pipes unlagged ▪ Fridge inefficient with leaky seals	
Heating	▪ Wood burner in family room ▪ Oil column heaters in bedrooms ▪ Portable LPG heater	
Other Energy	▪ No thermal linings on windows in half of the house	
Ventilation	▪ Extractor fan in bathroom ▪ No mechanical extraction in kitchen	
Water	▪ Low flow rate in shower and taps due to low pressure water system	
Waste	▪ No method of composting	
Total Cost		$1380

4.6.2 Dwelling Performance

4.6.2.1 Summary

With a very minor insulation top-up, this dwelling was expected to see little improvement in performance. Some energy savings did occur, but these are most likely to be as a result of occupancy changes within the household, as the number of household members varied considerably throughout the duration of the project. Total annual reticulated energy reduced from 7100 kWh/year to 6300 kWh/year.

As expected, relative humidity and temperatures remained below healthy levels within this dwelling remained poor, and this dwelling performed worst of all of those in the study in relation to these indices.

4.6.2.2 Energy

Table 22 below shows the winter data by end use for House 6. While some of the changes are statistically significant, due to occupancy changes in the home, and the low level of intervention they cannot be attributed to the retrofit. The household were already relatively low reticulated energy users, and as a result of their reduced occupancy this dropped further by the end of the project.

Table 22: House 6 Winter Energy Use Data By End Use (May-Sept)

House 6 Winter Energy Use (May – Sept)				
Period	**Space Heating (kWh)**	**Reticulated Hot Water (kWh)**	**Total Reticulated Energy (kWh)**	**Total Energy (kWh)**
Pre-Retrofit (06)	1,530	1,070	3,400	4,710
Intermediate (07)	1,580	770	2,750	4,040
Post (08)	1,460	650	2,570	3,750

4.6.2.3 Indoor Environment Quality

Table 23 and Table 24 show the percentage of time House 6 fell below healthy Indoor Environment Quality indices. In the case of relative humidity – a serious problem in this house, this was almost all the time. In the case of temperature the house also performed very poorly, with the ceiling insulation making no appreciable difference, with the low heating regime in the household meaning that little temperature gains were likely.

Table 23 : House 6 Percentage of Time Main Bedroom Exceeded 70% Relative Humidity in July

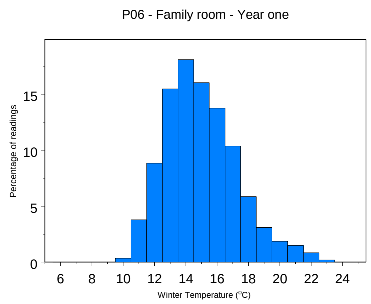
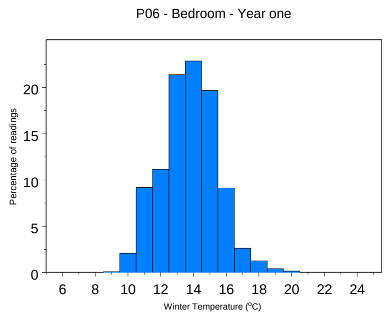
Period	**House 6 Main Bedroom July Relative Humidity**	
	% Time Above 70%, 24 hr	**% Time Above 70%, night**
Intermediate (07)	97%	95%
Post (08)	100%	100%

Table 24: House 6 Percentage of Time Family Room and Bedroom Were Below Healthy Temperatures in July

House 6 July Temperatures - % Time Below Healthy Temperatures				
Period	**Family Room**		**Main Bedroom**	
	% time below 18°C, 24 hr	**% time below 18°C, evening**	**% time below 16 °C, 24 hr**	**% time below 16 °C, night**
Pre-Retrofit (06)	89%	72%	71%	87%
Intermediate (07)	88%	66%	72%	91%
Post	89%	73%	75%	91%

Figure 9 shows the frequency of different temperatures for the 3 winter months. These show that there has been an increase in the frequency of very low temperatures in both the family room and the main bedroom between the 2006 and 2008 winters. While the most frequent temperature experienced in winter in the family room remains 14°C, lower temperatures have become more frequent. This picture is similar in the bedroom, except that the most common temperature has dropped from 14°C to 13°C. This is likely linked to the reduction in both space heating and total energy use within the home.

Figure 9: House 6 Winter Temperature Histograms

<table>
<tr><th colspan="3">House 6 Winter (June – August) Temperature Histograms</th></tr>
<tr><th>Period</th><th>Family Room</th><th>Main Bedroom</th></tr>
<tr><td>Pre (06)</td><td>
</td><td>
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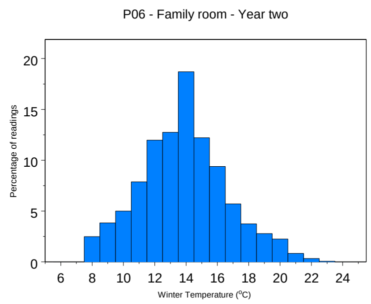
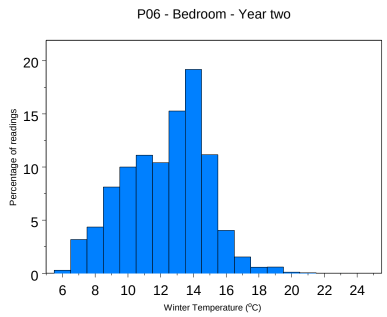
<tr><td>Intermediate (07)</td><td>
</td><td>
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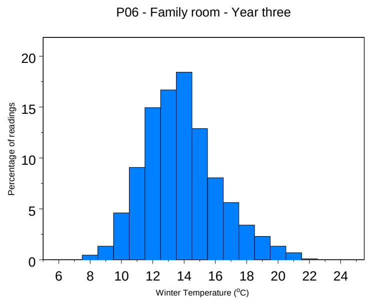
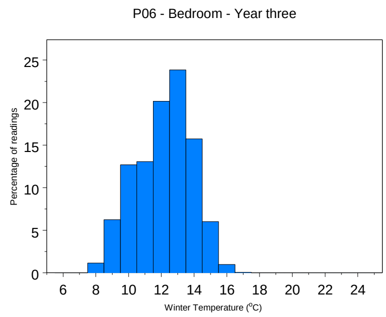
<table>
<tr><th colspan="3">House 6 Winter (June – August) Temperature Histograms</th></tr>
<tr><th>Period</th><th>Family Room</th><th>Main Bedroom</th></tr>
<tr><td>Post (08)</td><td>
</td><td>
</td></tr>
</table>

Table 25 and Table 26 show the detailed winter temperature data for the family room and main bedroom. It is interesting to note that this household significantly under-heats the family room even in the evening, with only minor increases in temperature. This may be as a result of a combination of factors including: sizing and type of heating device; homeowner preferences; poorly performing thermal envelope with high heat loss.

Table 25: House 6 Winter Temperature Data in Family Room

House 6 Family Room Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	14.4	13.2	13.2	13.2	15.4	13.5
Intermediate (07)	14.4	12.8	13.0	13.0	14.9	13.2
Post (08)	13.7	11.7	11.9	12.1	13.9	12.1

Table 26: House 6 Winter Temperature Data in Main Bedroom

House 6 Main Bedroom Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	12.9	13.0	13.2	13.0	14.9	13.6
Intermediate (07)	12.6	12.3	12.7	12.5	13.6	12.7
Post (08)	12.0	11.5	11.8	11.8	12.7	12.0

4.6.3 Occupant Experience

These householders were interviewed immediately following the retrofits. The householders stated were attracted to the retrofit project because it offered them opportunities to increase heat efficiency and saw their own house as typical of the area. They saw the project as addressing the warmth and dryness of the house and increasing its liveability into their retirement. They also saw the project as giving them ideas on what they could do to with the house to both increase its thermal performance and to increase its value.

The house was seen as being in good condition but with some persistent performance problems. In particular, they had one bedroom which was persistently damp and cold. They realised the impact of damp and cold on their own and other people's health when they had a daughter who was prone to illness sleeping in the cold, damp, mouldy bedroom. The installation undertaken as part of the project was basic but was supplemented by the householders wrapping the hot water cylinder and lagging the hot water pipes.

At that time the householders believed that hot water use had increased and this supports a conclusion that the benefits of hot water cylinder wraps are significant. The householders also reported that occupancy levels have varied significantly over the monitoring period. While the householders were away for an extended period of they report both very low levels of occupancy over that time and very high levels of occupancy subsequently. It is difficult to establish, then, whether energy consumption improvements are being under or over stated in the monitored energy measurements. However, indoor temperatures have fallen slightly and are unhealthily cold.

The households felt that the house was still cold and damp post-retrofit –which is very true. They were relying on electric blankets and spot heating as they felt they couldn't heat the house adequately. They saw persistent sickness among household members as reflecting poor house performance. The householders reported that they would be prepared to spend the equivalent cost of moving house to 'putting the house right'. They estimate that sum to be in the region of $15,000. However, they were concerned that they do not have the information they need to make decisions about appropriate, quality and affordable interventions and saw the provision of credible information as a desirable key outcome of the project.

4.7 House 7

The older part of this house was built in the 1970s, and the living areas insulated, relined and new windows put in during the last few years. A lounge was added on top of the garage and met 2006 code insulation requirements. There are four bedrooms, a bathroom, toilet, open plan kitchen/dining/family room/lounge area upstairs with an area of approximately 160m^2, and a rumpus room, bathroom, toilet, laundry, workshop, storage and garage downstairs, making a total floor area of approximately 260 m^2.

Prior to the study, the occupants replaced most of the older aluminium windows in the upper part of the house with 10mm laminated glass and new frames with the intention of reducing noise and providing better insulation. Downstairs, (which is not part of the living spaces of the home) the windows are a mixture of timber and aluminium frames, all in poor condition. The house is mainly clad in weatherboard. The house has a ventilated concrete perimeter wall, suspended timber floor upstairs, and an un-insulated concrete slab floor downstairs. The house has a coated metal tile roof. The occupants are a middle-aged couple, both employed full-time. One occupant does contract work overseas at times.

4.7.1 Interventions Undertaken

House 7	Pre-Retrofit Condition	Intervention
Thermal	■ Insulated ceiling to 2006 Code (R2.6) in living areas, poor condition insul-fluff in the rest of the house ■ Large numbers of halogen downlights in living areas penetrating ceiling insulation ■ Walls of living areas and one bedroom insulated ■ No under-floor insulation ■ Bare ground under-floor ■ Mix of new and old aluminium windows, all with single panes	■ Ceiling insulation topped up with R 2.6 blanket ■ R 2.4 wall insulation installed in rest of bedrooms ■ Under-floor insulated with R2 foil backed batts ■ Polythene vapour barrier installed ■ Remaining old aluminium windows replaced with modern frames
Hot Water	■ A grade hot water cylinder, un-insulated pipes	■ Cylinder wrapped and pipes lagged
Heating	■ Large new enclosed wood burner ■ Broken heat transfer system	■ Heat transfer system fixed, ducting extended to bedrooms
Other Energy	■ No thermal linings on windows in half of the house ■ Fridge inefficient with leaky seals ■ Large numbers of halogen lights throughout the house and penetrating thermal envelope	
Ventilation	■ Bathroom moisture extracted to ceiling cavity ■ Extract ventilation in place from kitchen	■ Extract fan ducted to outside ■ Showerdome installed
Water	■ High flow showerhead and taps	■ Plumbing checked
Waste	■ No method of composting	■ Worm farm installed
Total Cost		$7640

4.7.2 Dwelling Performance

4.7.2.1 Summary

This dwelling received a fairly significant thermal retrofit, albeit at a modest overall cost – largely due to the significant labour input from the homeowners. Minor improvements were also made to hot water, heating, indoor environment quality and waste components within the home.

Improvements in house performance were significant and appeared to deliver good performance value for the modest cost. These include:

- A significant reduction in total winter electricity use ~20%
- A significant reduction in winter hot water energy use ~30%
- A significant increase in family room average winter temperatures of ~1.1°C
- A significant increase in main bedroom average winter temperatures of ~1.0°C
- A reduction in total reticulated energy use from 8400 kWh/year pre-retrofit to 7000 kWh/year post-retrofit.

Despite the energy savings and temperature increases, this house still didn't meet healthy indoor environment quality indices for much of the time post-retrofit.

4.7.2.2 Energy

Table 27 below shows the winter energy data by end use for House 7. Highlighted figures are statistically significant at the 95% confidence level.

Table 27: House 7 Energy Use Data By End Use (May – Sept)

House 7 Winter Energy Use (May – Sept)				
Period	**Space Heating (kWh)**	**Reticulated Hot Water (kWh)**	**Total Reticulated Energy (kWh)**	**Total Energy (kWh)**
Pre-Retrofit (06)	1,540	990	3,860	5,070
Intermediate (07)	1,890	850	3,490	5,120
Post (08)	1,670	700	3,110	4,570

Key points to note from this data are as follows:

- The hot water cylinder wrap seems to be the main driver of energy efficiency from the retrofits with approximately 15% energy savings in the first winter, although occupancy changes (one occupant being away a lot) will also have contributed.
- % energy savings from the hot water cylinder wrap were high, however this is partly because a low amount of hot water energy was used in this house – therefore relatively high standing losses occurred.

4.7.2.3 Indoor Environment Quality

Table 28 and Table 29 show the percentage of time the dwelling main bedroom and family room fell below healthy indoor environment quality indices in July. Table 30 and Table 31 show the detailed temperature data.

While some improvement in relative humidity levels seems to have occurred, perhaps from the house drying out as a result of improvements made (removal of bathroom moisture, polythene vapour barrier), levels are still high, probably because of the cold temperatures normally found in the house. With regard to temperature, the 2007 winter saw an improvement and an associated increase in heating energy used; however, temperatures and heating energy have fallen back in 2008 and, despite improvements, the house remains cold in both the family room and main bedroom.

Table 28: House 7 Percentage of Time Main Bedroom Exceeded 70% Relative Humidity in July

Period	House 7 Main Bedroom July Relative Humidity	
	% Time Above 70%, 24 hr	% Time Above 70%, night
Intermediate (07)	80%	98%
Post (08)	63%	74%

Table 29: House 7 Percentage of Time Family Room and Bedroom Were Below Healthy Temperatures in July

House 7 July Temperatures - % Time Below Healthy Temperatures				
Period	Family Room		Main Bedroom	
	% time below 18°C, 24 hr	% time below 18°C, evening	% time below 16 °C, 24 hr	% time below 16 °C, night
Pre-Retrofit (06)	84%	86%	82%	95%
Intermediate (07)	62%	62%	61%	71%
Post	88%	88%	85%	91%

Figure 10 shows the frequency of different temperatures for the three winter months. These show that there has been an increase in the frequency of very low temperatures in both the family room and the main bedroom between the 2006 and 2008 winters, although there was an initial improvement in 2007. The most frequent temperature experienced in winter in the family room remains 13°C and low temperatures occurred a similar amount of the time pre and post-retrofit. This picture is similar in the bedroom, except that the most common temperature has dropped from 13°C to 12°C, although the mean minimum temperatures have increased by 0.6°C. This is likely linked to the further reduction in both space heating and total energy use within the home.

Figure 10: House 7 Winter Temperature Histograms

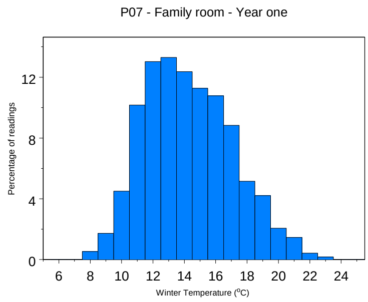
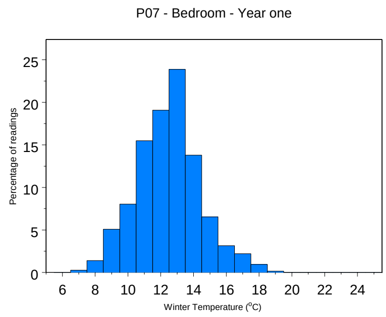
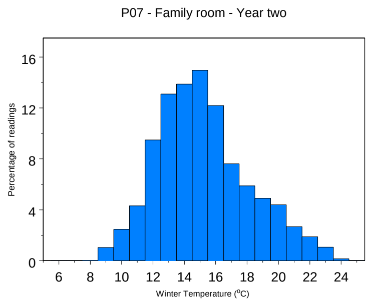
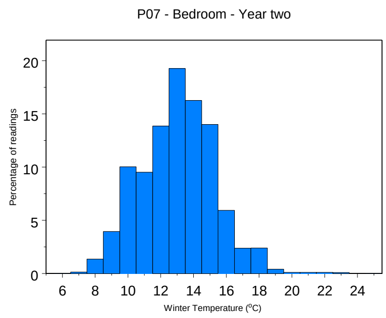
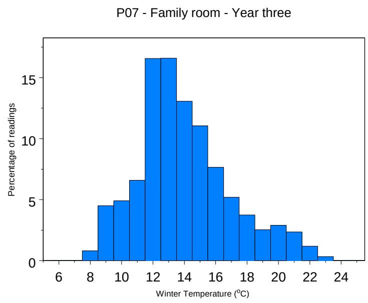
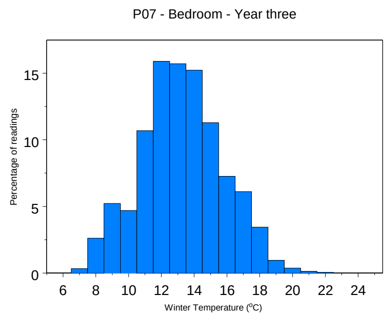
House 7 Winter (June – August) Temperature Histograms		
Period	**Family Room**	**Main Bedroom**
Pre (06)		
Intermediate (07)		
Post (08)		

Table 30: House 7 Winter Temperature Data in Family Room

House 7 Family Room Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	13.6	12.7	12.7	12.8	15.7	13.0
Intermediate (07)	14.7	14.0	14.1	14.3	16.8	14.3
Post (08)	14.7	13.1	13.3	13.3	15.8	13.6

Table 31: House 7 Winter Temperature Data in Main Bedroom

House 7 Bedroom Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	12.4	11.6	11.7	12.1	13.4	11.9
Intermediate (07)	12.9	12.1	12.3	12.7	14.1	12.4
Post (08)	13.4	12.0	12.2	12.5	14.0	12.4

4.7.2.4 Waste

Like most of the households in the study, this home was supplied with a worm bin. Pre-retrofit and 2008 waste audits indicate no significant change in the composition of this household's solid waste. The home has an in-sink waste disposal unit and it is not clear how much that is used in preference to the worm farm.

4.7.3 Occupant Experience

The occupants of this dwelling were interviewed in 2008 post-retrofit. These householders were attracted to the retrofit project because they were already considering renovations. They wanted to achieve a warmer house which they describe as being like a 'fridge'. They had already undertaken insulation of half of the house and installed 10 meters of what they described as 'thick glass' and had perceived a significant difference in thermal comfort from doing so.
The householders perceived a fall in electricity consumption which was consistent with the monitoring data, and this trend continued. At the time of interviewing householders ascribed the fall in energy consumption to not having to use a dehumidifier in winter. The heat transfer system was seen as spreading warmth into the bedrooms; however, the householders reported that the family room temperature was much the same.

The householders identified a number of expected and unexpected benefits. In relation to expected benefits, the householders found the house drier and warmer with less condensation in the bathroom. They used the worm farm and associated this with a decrease in rubbish. The warmth in the master bedroom was higher than expectation. The musty smell had disappeared and they had ceased using a dehumidifier.

4.8 House 8

This house was one of the first homes built in Papakowhai, having been constructed around 1965. The gym part of the downstairs area of the split level was added around the year 2004, and the two windows in this area are double-glazed and the exterior walls insulated. The floor in this area is part concrete slab, and part timber suspended floor on an enclosed concrete block footing. The lower part of the split-level downstairs area has timber framed windows and a timber suspended floor. It contains the fourth bedroom, a rumpus room and the laundry. Upstairs is an open plan lounge, dining, and family room. In the upper part are three bedrooms, a bathroom and a toilet. Upstairs has a timber suspended floor, with the exception of the foyer. The garage has a concrete slab floor and is attached to the upper split level on the upper storey, but is not internally accessible. The living area is approximately 195m^2 and the total floor area of the house approximately 220m^2.

The upper part of the house is clad mainly in weatherboards, with some sheet materials below the apex of the long-run iron roof. The lower part of the house is clad in sheet material, and the back wall of the gym is un-insulated concrete block. The occupants of the home are an adult couple and their university student daughter. Both adults work full time with one working from home.

4.8.1 Interventions Undertaken

House 8	Pre-Retrofit Condition	Intervention
Thermal	■ Mostly new single glazed tinted aluminium framed windows ■ Two double glazed windows, insulated exterior walls in downstairs gym ■ Some timber framed single glazed windows ■ Un-insulated under-floor ■ Bare ground under-floor ■ Un-insulated walls except for exterior walls in downstairs gym ■ Ceiling insulation throughout (approx R2.6) with recessed halogens in the bathroom and living areas	■ Clear double glazed units installed in existing aluminium frames ■ R2 foil backed under-floor insulation installed ■ Polythene vapour barrier installed ■ Wall between gym and under-floor insulated ■ Ceiling insulation re-laid and topped up with R2.6 blanket
Hot Water	■ B grade hot water cylinder, pipes unlagged	■ Solar hot water system installed with new cylinder/ flow restrictor
Heating	■ Two night-store heaters – one in hallway of bedroom wing upstairs, one in rumpus room downstairs ■ Underfloor heating in the family room	
Other Energy	■ Seals on fridge in need of replacement ■ No washing line ■ no thermal linings on windows in half of the house	■ washing line installed
Ventilation	■ No extract ventilation in bathroom ■ Extract ventilation in kitchen	■ Showerdome installed
Water	■ High flow shower and taps	■ Plumbing checked
Waste	■ No method of composting	■ Worm farm installed
Total Cost		$24,610

4.8.2 Dwelling Performance

4.8.2.1 Summary

This house received a significant thermal upgrade in the form of heavy ceiling and under-floor insulation and double glazing – but no wall insulation. It also received substantial hot water improvements in the form of a solar hot water system and new hot water cylinder. Minor energy efficiency, indoor environment quality and waste measures were also undertaken.

Improvements in house performance were significant, with the solar hot water system making the most significant difference to energy efficiency within the home. Energy efficiency gains were also made as a result of the thermal envelope improvements, and unlike other homes, they were not taken back in comfort. The most significant changes in performance in the home were:

- A significant reduction in total winter electricity use ~33% in this all electric house
- A significant reduction in winter hot water electricity use~70%
- A significant increase in family room and bedroom temperatures over the 2007 winter – which were then were reversed in the 2008 winter as the family reduced their heating energy, resulting in an overall 0.9°C decrease in the mean family room temperature
- A significant decrease in total hot water use of ~32%
- A substantial reduction in total annual reticulated energy use from 19,800 kWh/year to 13,400 kWh/year

Some of the improvements are likely to be partly as a result of occupancy changes with an adult child moving out early on in the project, and significant use of the batch during the post-retrofit period.

4.8.2.2 Energy

Table 32 below shows the winter energy data by end use for House 8. Highlighted figures are statistically significant at the 95% confidence level.

Table 32: House 8 Energy Use Data by End Use (May – Sept)

House 8 Winter Energy Use (May – Sept)				
Period	**Space Heating (kWh)**	**Reticulated Hot Water (kWh)**	**Total Reticulated Energy (kWh)**	**Total Energy (kWh)**
Pre-Retrofit (06)	4,620	1,630	12,980	12,980
Intermediate (07)	4,280	340	10,510	10,510
Post (08)	3,900	480	8,760	8,760

Key points to note from this data are as follows:

- The solar hot water system has been the main driver of energy efficiency. There appears to be a slight takeback effect between the 2007 and 2008 winters from this.
- Significant space heating savings were also observed, and these increased between the 2007 and 2008 winters. No changes were made to space heating method in the dwelling, which had two electric night store heaters and an under-floor heater. The data indicate night store heater use reduced between 2007 and 2008 – with commensurate decreases in temperatures in the home. The reasons for this are unknown, but may have been a conscious effort by the homeowner to conserve electricity and money in the face of escalating prices.
- Despite the savings, the energy use in this house remains high and the house fails to meet the HSS®-2006 benchmark for energy. The dwelling has a significant number of appliances and the occupants work from home and these are likely to be contributory factors in the high energy use.

4.8.2.3 Indoor Environment Quality

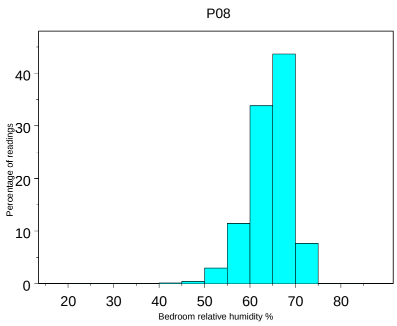
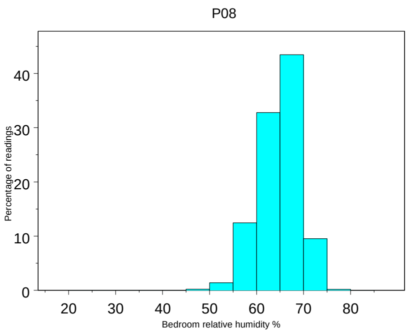
Table 33 and Table 34 show the percentage of time the dwelling main bedroom and family room fell below healthy indoor environment quality indices in July. Table 35 and Table 36 show the detailed temperature data. These tables are augmented by Figure 11 and Figure 12 which show the frequency of temperatures and relative humidity over winter.

As can be seen from Figure 11 and Table 33 humidity levels remained outside a healthy range for a large amount of time in House 8. Given the significant proportion of time that cold temperatures were experienced as shown in Table 34 and Figure 12, and that the significant moisture sources in the home (bathroom, kitchen and under-floor) were being managed, these relative humidity levels can be explained by the low temperatures. If the home had been adequately heated, and clothes drying behaviour modified (commonly clothes were dried indoors) then relative humidity levels would be expected to improve.

Table 33: House 8 Percentage of Time Main Bedroom Exceeded 70% Relative Humidity in July

Period	**House 8 Main Bedroom July Relative Humidity**	
	% Time Above 70%, 24 hr	**% Time Above 70%, night**
Intermediate (07)	9%	19%
Post (08)	13%	21%

Figure 11: House 8 Winter Humidity Histograms

House 8 Main Bedroom Winter (Jun – Aug) Humidity Histograms	
Period	**Main Bedroom**
Intermediate (07)	
Post (08)	

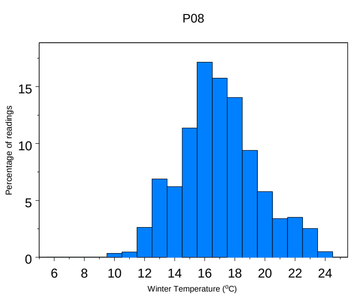
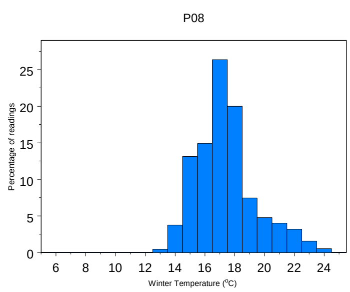
Between the 2006 pre-retrofit winter and the 2007 post-retrofit winter higher minimum temperatures are seen, and the frequency of lower temperatures decreased (Table 35 and Figure 12). This is likely to be due to a combination of improved thermal performance as well as slightly warmer 2007 winter temperatures. Heating energy use actually decreased at this time. In the 2007 winter mean minimum temperatures increased, particularly in the family room (refer Table 35) but there was also an improvement in the main bedroom (refer Table 36).

However these improvements were reversed in the winter of 2008, almost certainly because of a reduction in heating within the home. It is not known whether personal circumstances within the home changed over time, creating, for example, economic pressures to save electricity, but certainly this household were very high energy users even post-retrofit. This change could be a type of "reverse takeback", where the occupants decided to revert to the pre-retrofit temperatures and comfort and gather further energy and cost savings from reduced heating. A clear recommendation for further retrofit to this dwelling would be to make changes in heating method, to a low emission wood burner, or as it is currently an all electric house, perhaps a heat pump. This would result in significant heating energy efficiency, and consequently quite probably improved temperatures within the home.

Table 34: House Percentage of Time the Family Room and Bedroom Were Below Healthy Temperatures in July

House 8 July Temperatures - % Time Below Healthy Temperatures				
Period	**Family Room**		**Main Bedroom**	
	% time below 18°C, 24 hr	**% time below 18°C, evening**	**% time below 16 °C, 24 hr**	**% time below 16 °C, night**
Pre-Retrofit (06)	61%	30%	31%	42%
Intermediate (07)	48%	39%	20%	22%
Post	64%	51%	29%	29%

Figure 12: House 8 Winter Temperature Histograms

House 8 Winter (Jun – Aug) Temperature Histograms		
Period	**Family Room**	**Main Bedroom**
Pre (06)		

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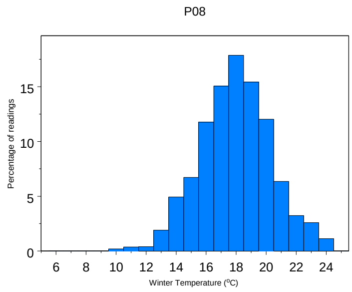
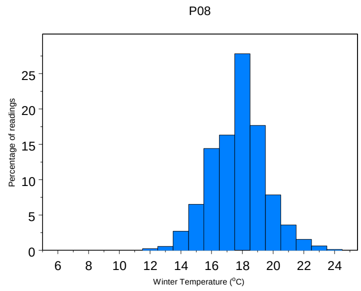
<tr><td>Intermediate (07)</td><td>
</td><td>
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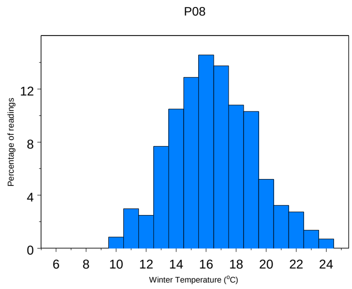
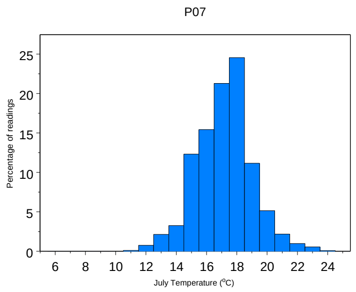
<tr><td>Post (08)</td><td>
</td><td>
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Table 35: House 8 Winter Temperature Data in Family Room

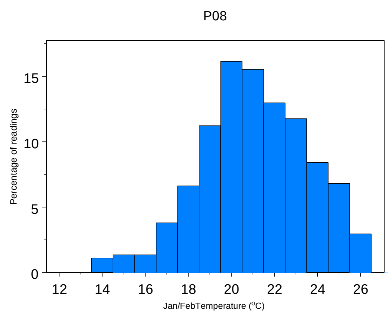
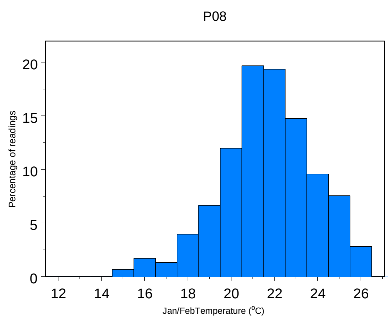
House 8 Family Room Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	18.0	14.6	14.6	15.0	17.4	14.8
Intermediate (07)	19.1	16.0	16.1	16.3	18.2	16.5
Post (08)	17.1	13.9	14.2	14.4	16.2	14.4

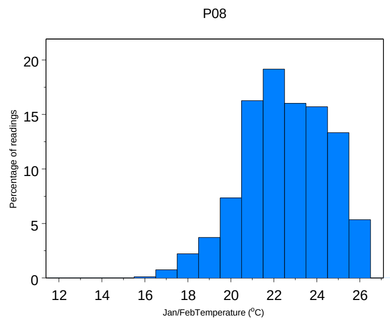
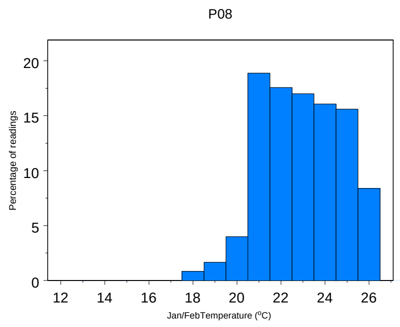
Table 36: House 8 Winter Temperature Data in Main Bedroom

House 8 Main Bedroom Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	17.2	16.3	16.5	16.4	18.3	16.7
Intermediate (07)	17.9	16.9	17.1	17.0	18.8	17.4
Post (08)	17.1	15.8	16.1	16.0	17.8	16.3

In addition to winter temperatures, the extent of thermal retrofit in this dwelling warranted an investigation into the impacts on summer temperatures. It can be seem from Figure 13 that a marked increase in warmer temperatures in both the family room and main bedroom is evident post-retrofit. The frequency of higher temperatures increased substantially and lower temperatures were eliminated. While the highest temperatures in the home experienced were around 27°C and this did not change, the frequency in the main bedroom, increased substantially. The design of this house means there is largely no shading of northern or western windows, and the house was not mechanically cooled with window opening being the main cooling behaviour.

Figure 13: House 8 Summer (Jan - Feb) Temperature Histograms

House 8 Summer (Jan - Feb) Temperature Histograms		
Period	**Family Room**	**Main Bedroom**
Pre (2007)		

House 8 Summer (Jan - Feb) Temperature Histograms		
Period	**Family Room**	**Main Bedroom**
Post (2008)		

4.8.2.4 Water

Apart from the plumbing check, no measures were undertaken which would impact on water use. Average per capita water use for this two person household was 265 l/pp/day.

4.8.2.5 Waste

Like all but one of the households in the study, this home was supplied with a worm bin. Pre retrofit and 2008 waste audits indicate no significant change in the composition of this household's solid waste. The home has an in-sink waste disposal unit and it is not clear how much that is used in preference to the worm farm.

4.8.3 Occupant Experience

The occupants of this house were interviewed early in 2008, following the retrofits. They reported that they wanted to achieve capital gain on their property as well as reduce their energy costs through solar water heating. Despite the extent of the retrofits at that time the household still operated three dehumidifiers - although the frequency with which the dehumidifiers are emptied is reported to have reduced. Post-retrofit the householders reported a marked improvement in the comfort of the dwelling – and that they had reduced their heating hours. They noticed the reduced electricity bills – despite their increased use of hot water. In terms of electricity consumption reductions, however, it is noted that there have been changes in occupancy. One daughter moved out about the time that the project started, and one household member was increasingly spending weekends at the couple's second house. At least some of the fall in electricity use could therefore be due to household, rather than dwelling changes.

For these householders thermal comfort benefits were supplemented by unexpected benefits around sound control. Members of the household no longer heard train noise filtering up from the main trunk line. The impact of insulation has been particularly impressive for the householders. If confronted with undertaking a renovation in their house, this experience has meant that the householders would prioritise insulation in the roof and the floor and the installation of solar water heating. They reported that they would not undertake double glazing in an existing house.

4.9 House 9

This house is a typical two-storied townhouse, built in 1976 and around 115m^2 in total floor area, 95m^2 living area. The downstairs is clad in sheet material and has a concrete slab floor, while the upstairs is clad in fibre cement weatherboards and has a timber suspended floor. There is a concrete block firewall between the two townhouses on the western wall. The roof is concrete tiles.

Upstairs contains an open plan kitchen, dining and family room area as well as two bedrooms, a bathroom and a laundry. Downstairs has a single internal garage below the master bedroom, a large rumpus room and an unused sauna. The occupant of the house works full time.

4.9.1 Interventions Undertaken

House 9	Pre-Retrofit Condition	Intervention
Thermal	■ Windows single glazed with older aluminium frames ■ Draught from sliding door between garage & living area ■ Walls and ceiling insulated with older batts (approx R2.6) ■ Under-floor un-insulated ■ Bare ground under-floor	■ Sliding door draught stopped ■ R 2.4 insulation laid over joists ■ Wall between rumpus room and garage insulated with R2.4 batts ■ R2 foil backed insulation installed under-floor ■ Polythene vapour barrier laid over ground
Hot Water	■ B grade hot water cylinder and unlagged pipes	■ Hot water cylinder wrap and pipe lagging installed
Heating	■ Family room heated with heat pump ■ Fan heater in master bedroom ■ A portable halogen radiant heater and a fan heater downstairs in the rumpus room.	
Other Energy	■ Inefficient lighting used ■ Old fridge/freezer and old chest freezer all with inefficient seals ■ No thermal linings on windows in half of the house	■ 5 CFL bulbs installed in high use fittings
Ventilation	■ Extract fan in bathroom – but mould still evident ■ Extract ventilation in kitchen	■ Showerdome installed
Water	■ Low flow shower and taps	■ Plumbing checked
Waste	■ No method of composting	■ Worm farm installed
Total		$7830

4.9.2 Dwelling Performance

4.9.2.1 Summary

This dwelling received a modest retrofit addressing thermal, hot water and indoor environment quality aspects. It also received a minor waste efficiency measure. The house was already insulated to 1978 Building Code levels prior to the retrofit.

Some improvements to the home's performance were evidenced as a result of these measures, although temperature improvements were relatively minor. Post-project occupancy interviews indicate the homeowner was satisfied with temperatures within the home, although they fall below minimum healthy levels.

Key improvements in the house performance are as follows:

- A significant reduction in total winter electricity consumption of ~20%
- A significant reduction in hot water energy consumption of ~21%
- A significant increase in mean family room and main bedroom temperatures of 0.4°C
- A 12.5% reduction in annual reticulated energy use, bringing a house which was already a low energy user and met the HSS®-2006 energy benchmark to an improved, and very modest 4900 kWh/year.

4.9.2.2 Energy

Table 37 below shows the winter energy data by end use for House 9. Highlighted figures are statistically significant at the 95% confidence level.

Table 37: House 9 Winter Energy Use Data By End Use (May – Sept)

House 9 Winter Energy Use (May – Sept)				
Period	**Space Heating (kWh)**	**Reticulated Hot Water (kWh)**	**Total Reticulated Energy (kWh)**	**Total Energy (kWh)**
Pre-Retrofit (06)	400	980	3,530	3,530
Intermediate (07)	390	820	2,890	2,890
Post (08)	480	770	2,820	2,820

Key points to note from this data are as follows:

- Space heating energy fluctuated across the three years, with no statistically significant changes.
- The hot water cylinder wrap was the main retrofit driver of energy efficiency, other reductions in energy use occurred which appear to be behaviour related, and these have resulted in more energy being saved than the hot water cylinder wrap achieved.

- Because this household was a one person low energy user prior to the project, there is probably a limit to the amount of energy savings which can be achieved in relation to dwelling aspects (hot water, space conditioning) and the impact of appliance use will be a major factor.

4.9.2.3 Indoor Environment Quality

Table 38 and Table 39 show the percentage of time the dwelling main bedroom and family room fell below healthy indoor environment quality indices in July. As can be seen, from Table 38, relative humidity levels in the home, while at times elevated, were normally within an acceptable range in the main bedroom. Table 39 shows that there was a significant reduction in the proportion of time the home the family room and main bedroom fell below minimum healthy temperatures, but it was still a relatively frequent occurrence, particularly in the bedroom.

Table 38: House 9 Percentage of Time Main Bedroom Exceeded 70% Relative Humidity in July

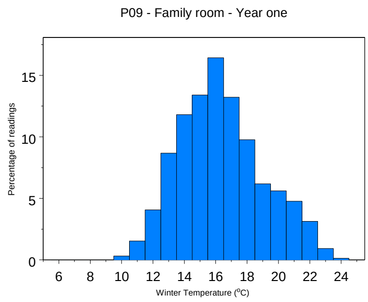
Period	**House 9 Main Bedroom July Relative Humidity**	
	% Time Above 70%, 24 hr	**% Time Above 70%, night**
Intermediate (07)	3%	7%
Post (08)	9%	16%

Table 39: House 9 Percentage of Time Family Room and Bedroom Were Below Healthy Temperatures in July

House 9 July Temperatures - % Time Below Healthy Temperatures				
Period	**Family Room**		**Main Bedroom**	
	% time below 18°C, 24 hr	**% time below 18°C, evening**	**% time below 16 °C, 24 hr**	**% time below 16 °C, night**
Pre-Retrofit (06)	80%	37%	60%	81%
Intermediate (07)	73%	35%	42%	55%
Post	71%	21%	48%	54%

Figure 14 shows the frequency of different temperatures for the three winter months. These show that there has been very little change in the frequency of very low temperatures in both the family room and the main bedroom between the 2006 and 2008 winters, although there was an initial improvement in 2007. The most frequent temperature experienced in winter in the family room remains 16°C, and the most frequent temperature experienced in winter in the main bedroom remains 15°C.

Figure 14 : House 9 Winter Temperature Histograms

<table>
<tr><th colspan="3">House 9 Winter (Jun – Aug) Temperature Histograms</th></tr>
<tr><th>Period</th><th>Family Room</th><th>Main Bedroom</th></tr>
<tr><td>Pre (06)</td><td>


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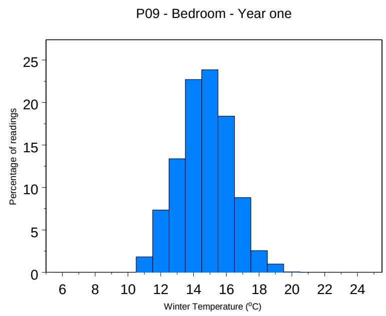

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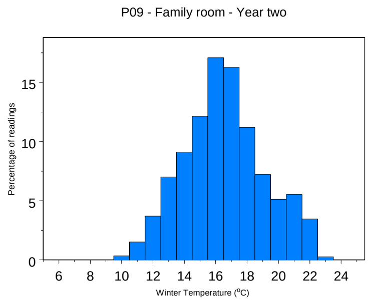
<tr><td>Intermediate (07)</td><td>


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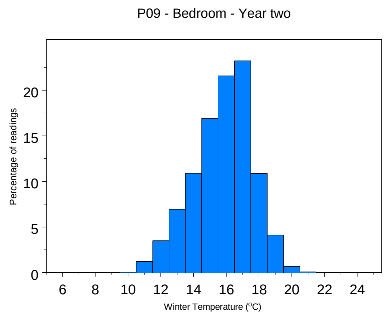
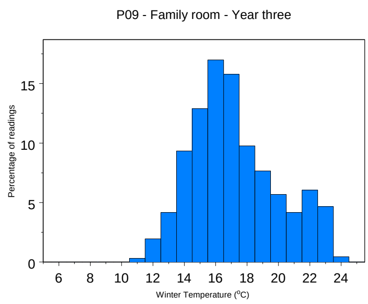


</td></tr>
<tr><td>Post (08)</td><td>


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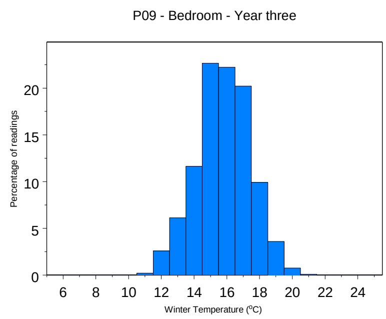


</td></tr>
</table>

Table 40 and Table 41 give the detailed temperature data for the winter months (May – September). Of particular note is the relatively small fluctuations in temperature within the home – likely to be a result of the ceiling, wall and floor insulation keeping the temperature relatively even throughout the day and night. Efficiency of heating method doesn't appear to be an issue, with a heat pump the main heating source used. From the data it is clear that heating energy used in this home is very modest, and that is the major reason why the home does not meet healthy indoor environment quality indices. Occupancy interviews indicate that the homeowner does not feel that the home is inadequately heated and that it is perceived as comfortable.

Table 40: House 9 Winter Temperature Data in Family Room

House 9 Family Room Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	16.5	14.2	14.7	15.4	16.9	14.5
Intermediate (07)	16.4	14.7	14.7	15.4	16.7	15.0
Post (08)	16.9	14.2	14.5	14.8	17.4	14.8

Table 41: House 9 Winter Temperature Data Main Bedroom

House 9 Main Bedroom Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	15.1	14.2	14.6	14.8	15.0	14.4
Intermediate (07)	15.6	14.9	15.1	16.1	16.0	15.2
Post	15.5	14.3	14.6	15.2	15.5	14.7

4.9.2.4 Water

Apart from the plumbing check, no measures were undertaken in this dwelling which would be expected to impact on water use. Average per capita water use for this one person household was 193 l/pp/day.

4.9.2.5 Waste

Like all households in the study, this home was supplied with a worm bin. Pre-retrofit and 2008 waste audits indicate no significant change in the composition of this household's solid waste.

4.9.3 Occupant Experience

The occupant of this dwelling was interviewed twice – post-retrofit in summer 2008 and again post-project in summer 2009. The householder was attracted by the project because of a broader interest in energy, energy efficiency and a concern about rising costs. This householder was not interested in capital gains because the householder has no intention of moving. The attraction of renovation lay in increasing the warmth of the dwelling, reducing cold related health problems and reducing energy costs.

The main factor affecting how the occupant used his home was the fact that he was home a lot when not at work. Little had changed in the way he used the house over the three years of the renovations project.

In the first interview the householder attributed lower electricity consumption to lower hot water energy use. The householder was satisfied that winter temperature problems have been resolved but found that the house overheats in summer. Cooling actions undertaken were mainly opening windows; the heat pump was not used for cooling.

In terms of heat pump use, the heat pump is situated in the lounge and during the week it was set to start 15 minutes before he was due to arrive home from work. Unless it was really cold in the weekends it was not reportedly used. The occupant considered that the house was warm enough in winter and he only used a fan heater in the mornings in the bedroom (rather than switching the heat pump on in the mornings).

Energy use was recorded as low in this house through the monitoring undertaken and in the second interview the respondent was asked whether there was any reason causing him to under-heat the house, to which he replied no, and that the heat pump had made a major difference to the heating he needed to use.

In terms of changes in dampness the occupant noted that there was still some condensation on the windows, although the shower dome had reduced mould in the bathroom and he didn't need to use as much hot water. He did note that his tall nephew had come to stay and had some trouble breathing in the shower with the shower dome. The respondent was happy however with the shower dome, especially when combined with the fan in the bathroom, which resulted in little to no mould in the bathroom. Dehumidifiers are not used in this house.

The occupant used water outdoors every couple of weeks on average, although a bit more than this in summer. He did not consciously change his water use habits over the 2007-2008 drought and did not change his water use habits over the period of the renovations.

When asked whether he changed his waste disposal behaviour as a result of putting in worm bins, he responded that he put out less rubbish for collection and commented that the worm farm was easy to use with no smell, although he did forget sometimes to use it.

In terms of further retrofit, the householder reported a preparedness to pay an additional $5,000 to put in double-glazing upstairs. In the post-retrofit interview insulation was seen as the most effective option by the householder and this was confirmed in the post-project interview.

In terms of any physical health benefits noticed the respondent noted that he seemed to have fewer colds; but that he had only been getting flu jabs in the last few years as well. He did not notice any impact from the renovations on his general wellbeing.

An unexpected benefit was the insulation and relining the garage, and features he particularly liked were insulation out the back of the garage under the floor (including the polythene) and extra insulation in the ceiling.

Based on this experience, features that he would look for in future homes were:

- Double glazing
- Good insulation

He commented that his experience had taught him the value of trapping the sun.

4.10 House 10

House 10 was bought a couple of years before the project started as a renovation project. The house was as it had originally been built in the early 1970s, and had been poorly maintained, with timber window frames rotten through in places, drainage problems, and leaks in the building envelope. The current owners had been progressively been relining parts of the house, and installed double glazed window units in the bedroom wing during the summer of 2006-2007.

The upper level of the house contains an open plan kitchen, dining and family room wing, connected by a sunken foyer to the bedroom wing containing three bedrooms, a laundry and a bathroom. The lower level of the house contains a fourth bedroom or rumpus room, a storage room, and an internally accessible garage. The upper level of the house is clad in sheet materials with timber framed windows. The floor of the living areas is unusual in that it is concrete, while the rest of the upper level has timber suspended floors. The lower level has a concrete slab floor, and concrete walls. The roof of the house is concrete tiles. The living area is approximately 150m^2 and the total floor area is 170m^2. The occupants of the house are a working couple with three children aged between 6 and 13.

4.10.1 Interventions Undertaken

House 10	Pre-Retrofit Condition	Intervention
Thermal	■ Bedrooms double glazed in aluminium frames ■ Rest of house poor quality wooden frames with single glazing ■ Poor quality older ceiling insulation ■ Skillion roof un-insulated ■ Walls un-insulated ■ Under-floor un-insulated ■ Bare ground under-floor ■ Draughty door to garage	■ Double glazed windows in aluminium frames installed ■ Two layers of R2.6 insulation installed in ceiling ■ R3.6 insulation installed in skillion roof ■ R2.4 wall insulation installed ■ R2 foil lined batts installed under-floor ■ Polythene vapour barrier laid on ground ■ Draught proofing garage door
Hot Water	■ B grade hot water cylinder with hot water cylinder wrap	■ Solar hot water system, wetback and new 300 litre cylinder installed
Heating	■ Older recessed enclosed wood burner in the family room ■ Oil column heater in the hallway ■ Radiant heater in living area	■ New NES compliant wood burner with wetback installed
Other Energy	■ Inefficient lighting used ■ No thermal linings on windows in the house	■ 5 CFL bulbs installed in high use fittings
Ventilation	■ No extract ventilation in bathroom or laundry ■ Extract ventilation in kitchen	■ Extract fans installed in bathroom & laundry
Water	■ Leak in bathroom vanity ■ High flow rate on shower and taps ■ Existing rainwater tank for garden use	■ Plumbing checked ■ Leak fixed
Waste	■ No method of composting ■ No method of recycling	■ Worm farm installed ■ Recycling bin installed
Total Costs		$74,070

4.10.2 Dwelling Performance

4.10.2.1 Summary

This dwelling received a substantial retrofit to the thermal envelope, hot water and heating aspects, as well as some indoor environment quality, water and waste efficiency measures. It was the second most expensive of the retrofits undertaken, with the double glazing and new window frames the most expensive single component of the retrofit.

As a result of these substantial measures, very significant changes in the house performance occurred. These include:

- A significant reduction in total winter reticulated energy use of ~23%
- A significant reduction in total winter reticulated hot water electricity consumption decreased by ~70%. During May-September almost all the hot water heating energy was being supplied by the wetback and solar connections
- A significant increase in mean winter family room temperatures of 1.4°C
- A significant increase in mean winter main bedroom temperatures of 2°C
- A significant ~30% reduction in annual reticulated energy use – bringing a house which already met the HSS® -2006 energy benchmark down to an improved 5600 kWh/year.

In addition this house exhibited substantial takeback, both in terms of hot water use, and space heating. As a result:

- Total monitored winter space heating energy (wood) increased by ~ 9%
- Total monitored hot water heating energy (i.e. including solar + wood) increased by ~19%
- Total winter hot water use increased by ~29%
- Total winter energy use increased by ~9%

4.10.2.2 Energy

Table 42 below shows the winter energy data by end use for House 10. Red highlighted figures are statistically significant at the 95% confidence level.

Table 42: House 10 Winter Energy Use Data by End Use (May – Sept)

House 10 Winter Energy Use (May – Sept)				
Period	**Space Heating (kWh)**	**Reticulated Hot Water (kWh)**	**Total Reticulated Energy (kWh)**	**Total Energy (kWh)**
Pre-Retrofit (06)	1,650	2,050	4,090	6,460
Intermediate (07)	1,750	420	2,280	5,760
Post (08)	1,940	600	3,160	7,040

Key points to note from this data are as follows:

- Space heating energy (wood) has steadily increased over the period of the project. This has not resulted in concurrent increases in dwelling temperature and it may be that the operation of the wood burner was less than optimal.
- Reticulated hot water energy use, after having a substantial 80% reduction in 2007 when compared to the 2006 winter, increased in the 2008 winter - partly as a result of the substantial increases in hot water use between 2007 and 2008, but also the occupancy interviews identified that a larger number of appliances were being used, particularly by the children as they grew up.
- Total reticulated energy use in 2007 was substantially lower than 2008. Between the 2006 (pre-retrofit) and 2007 winters there was a ~45% reduction in total reticulated energy use. This was reversed in the 2008 winter with a ~39% increase in total reticulated energy use. The vast majority of this reticulated energy came from end uses which were not specifically monitored, including portable heaters and appliances. As a result, a significant component of electricity savings from the change in hot water heating methods was taken back in other electrical services within the home.

4.10.2.3 Indoor Environment Quality

Table 43 and Table 44 show the percentage of time the dwelling main bedroom and family room fell below healthy Indoor Environment Quality indices in July.

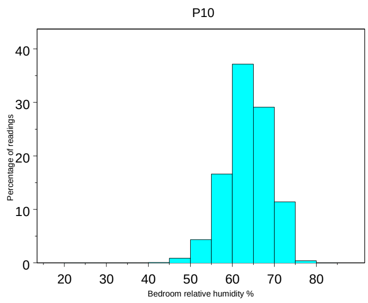
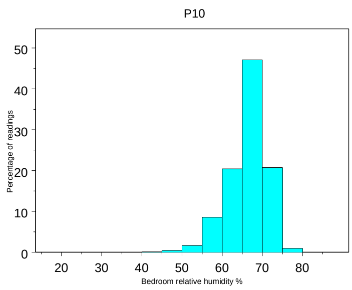
Figure 15 and Figure 16 supplement this information by showing the frequency of temperatures and relative humidity within the homes over winter.

As can be seen from Table 43 and Figure 15, humidity levels at times exceeded HSS®-2006 levels. Given the measures taken to reduce moisture in the home this may be largely due to under-heating of the home leading to elevated relative humidity levels.

Table 43: House 10 Percentage of Time Main Bedroom Exceeded 70% Relative Humidity in July

Period	House 10 Main Bedroom July Relative Humidity	
	% Time Above 70%, 24 hr	**% Time Above 70%, night**
Intermediate (07)	12%	15%
Post (08)	25%	33%

Figure 15: House 10 Histograms of Winter Relative Humidity

House 10 Winter (June - August) Relative Humidity Histograms	
Period	**Main Bedroom**
Intermediate (07)	
Post (08)	

As can be seen from Table 44 and Figure 16, between winter 2006 and winter 2007 there were significant improvements in the proportion of time the family room and main bedroom exceeded healthy temperatures. These figures were however reversed in 2008 in the family room, but the trend continued positively in the main bedroom – possibly as a result of supplementary heating from the oil column heaters. It is interesting that this reversal of temperature improvement in the family room has occurred despite an increase in space heating energy. Comments from the homeowners on the difficulty of keeping the temperatures down to a comfortable level in the first year post-retrofit, perhaps suggest sub optimum operation of the wood burner may be an issue.

This house does not have a heat transfer system, so supplementary space heating in the bedroom (not separately monitored) paired with increased insulation levels are the most likely cause of the increasing overnight temperatures in the main bedroom.

Table 44: House 10 Percentage of Time Family Room and Main Bedroom Were Below Healthy Temperatures in July

House 10 July Temperatures - % Time Below Healthy Temperatures				
Period	**Family Room**		**Main Bedroom**	
	% time below 18°C, 24 hr	**% time below 18°C, evening**	**% time below 16°C, 24 hr**	**% time below 16°C, night**
Pre-Retrofit (06)	70%	18%	50%	62%
Intermediate (07)	48%	8%	21%	14%
Post	87%	83%	57%	45%

Figure 16: House 10 Histograms of Winter Temperatures

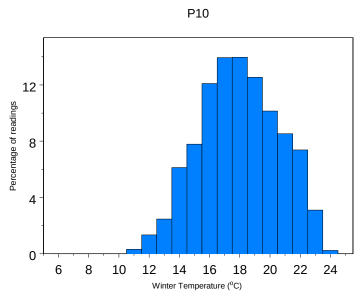
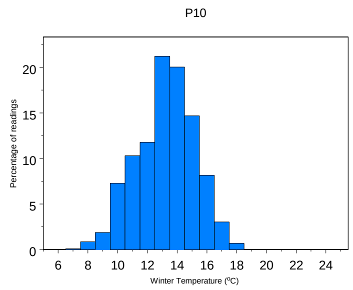
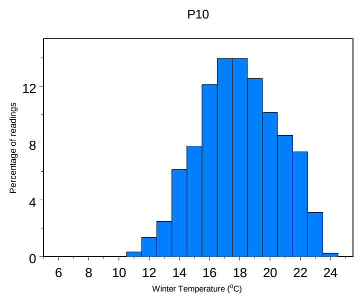
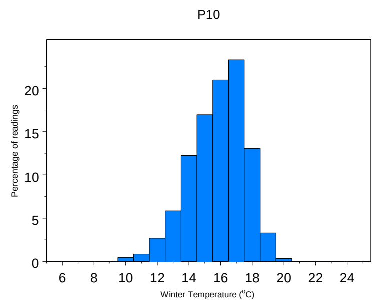
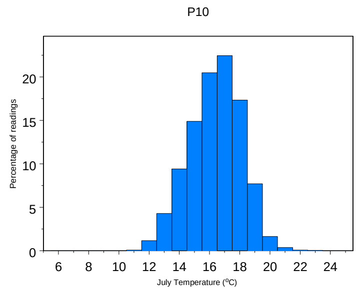
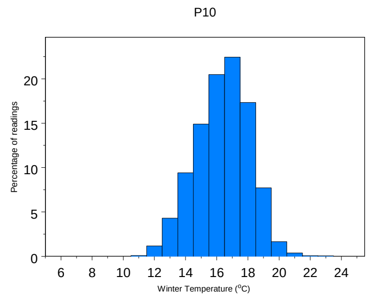
<table>
<tr><th colspan="3">House 10 Winter (June - August) Temperature Histograms</th></tr>
<tr><th>Period</th><th>Family Room</th><th>Main Bedroom</th></tr>
<tr><td>Pre (06)</td><td></td><td></td></tr>
<tr><td>Intermediate (07)</td><td></td><td></td></tr>
<tr><td>Post (08)</td><td></td><td></td></tr>
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Table 45: House 10 Winter Temperature Data in Family Room

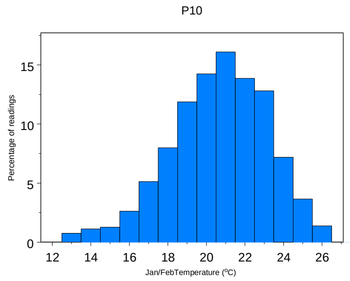
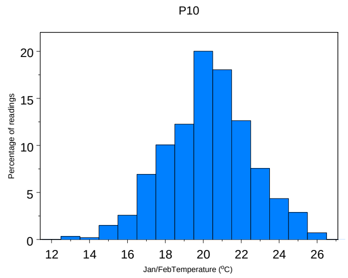
House 10 Family Room Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	16.3	13.6	13.7	13.8	17.7	14.0
Intermediate (07)	17.6	15.4	15.7	15.4	19.0	16.3
Post (08)	17.7	15.3	15.9	15.4	17.8	16.5

Table 46: House 10 Winter Temperature Data in Main Bedroom

House 10 Main Bedroom Temperatures Winter (May – September)						
Period	**Mean 24 Hr Temp (°C)**	**Mean Minimum Temp (°C) 24 Hr**	**Mean Minimum Temp (°C) Morning**	**Mean Minimum Temp (°C) Day**	**Mean Minimum Temp (°C) Evening**	**Mean Minimum Temps (°C) Night**
Pre-Retrofit (06)	14.0	12.2	12.3	12.2	14.4	12.8
Intermediate (07)	15.8	14.8	15.2	14.8	16.6	15.8
Post	16.0	14.7	15.2	14.7	16.4	15.7

The extent of thermal retrofit in this dwelling warranted an investigation into the impacts on summer temperatures. It can be seen from Figure 17 below that some increases in temperature occurred, although these were less than experienced in either House 3 or House 8. The changes were most notable in the main bedroom, where a large reduction in the prevalence of lower temperatures and large increase in the higher temperatures occurred. The highest temperatures in the home experienced were around 27°C and this did not change. No significant shading of windows or mechanical cooling was used in this home.

Figure 17: House 10 Summer Temperature Histograms

<table>
<tr><th colspan="3">House 10 Summer (Jan - Feb) Temperature Histograms</th></tr>
<tr><th>Period</th><th>Family Room</th><th>Main Bedroom</th></tr>
<tr><td>Pre (2007)</td><td>
</td><td>
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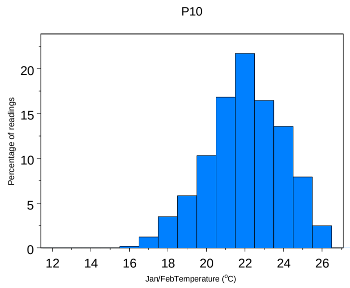
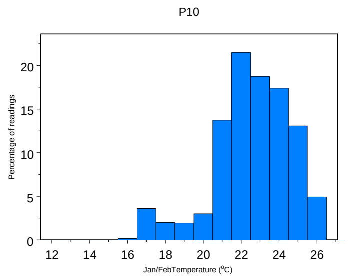
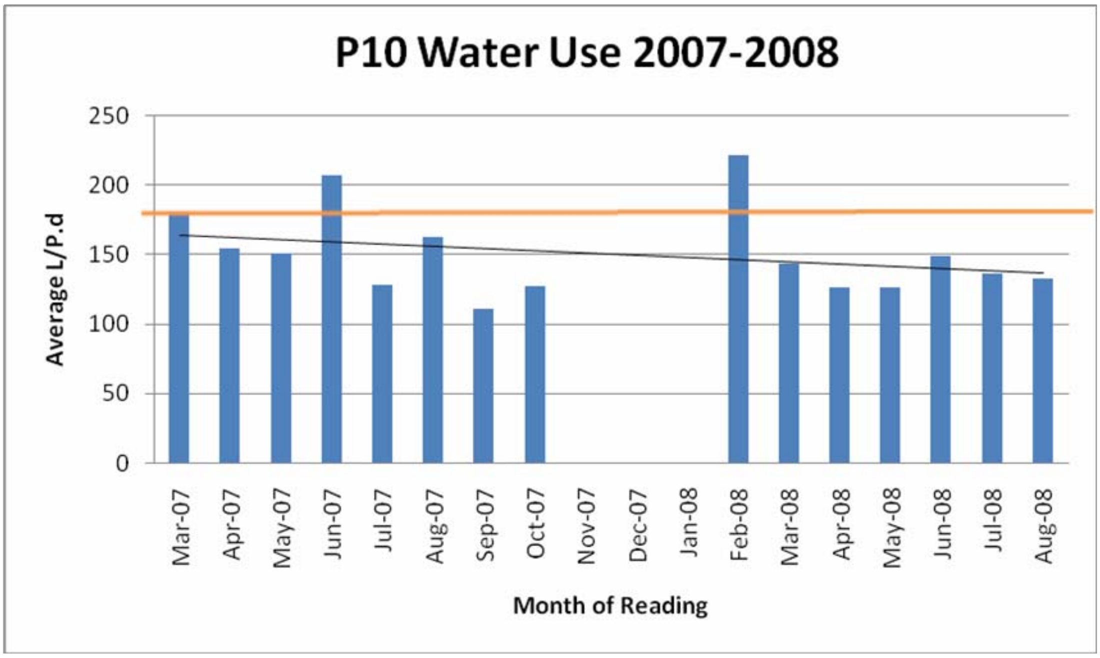
<tr><td>Post (2008)</td><td>
</td><td>
</td></tr>
</table>

4.10.2.4 Water

The installation of a solar hot water system/ wetback (May 07) and the fixing of a leak found during the plumbing check (May 07) were the main retrofit measures which could be expected to impact on water use in this dwelling. Figure 18 shows the water use data for this dwelling. This shows no discernable trend for total water use. When the hot water data is considered, an increase of 21% was found between winter 2007 and winter 2008.

Figure 18: House 10 Water Use Data



The average per capita water use for this five person household during the project was a relatively low at 151 l/pp/day.

4.10.2.5 Waste

Like all households in the study, this home was supplied with a worm bin. Pre retrofit and 2008 waste audits indicate no significant change in the composition of this household's solid waste.

4.10.3 Occupant Experience

The occupants were interviewed twice, post-retrofit in summer 2008 and post-project in summer 2009. The householders had been intending extensive renovations prior to the project but were severely constrained by their low income. They were attracted to the project because it gave them the opportunity to 'kick-start' things that they had already planned on doing.

This couple bought the house knowing it needed major renovation and have worked "non-stop" on it: "The house became our life". This project reportedly moved the renovations ahead significantly and "jump started" the rest of the renovation work. Around mid 2007 the male adult in the house went back to work full time, which significantly increased the household income.

Their primary concerns with the house were:

- cold
- damp
- mould

Because of their concern about the cold in their children's bedrooms they had already started to double glaze the children's rooms prior to the project.

Although the householders were prompted by a desire to increase the warmth of their dwelling, they found the cost savings associated with reduced energy consumption a very real benefit. They attributed the fall in electricity consumption to the solar water heating and wetback on the installed wood-burner. In the post-retrofit interviews the householders reported that they had increased their use of hot water and that their previous small cylinder had provided a very poor hot water service.

Increased hot water use was also matched by the householders reported increase in water use generally. This was associated with the family establishing an extensive vegetable garden and planting trees in September and October 2007. They expected to reduce their outdoor water use once the trees were established. In the initial interview the householders were particularly pleased with the fertiliser derived from the worm farm.

The renovations met their expectations around improved warmth. The unexpected benefits were the very considerable cost reductions they were able to achieve with solar water heating and the wetback. They had originally been sceptical about solar water heating but at the first interview they stated that if they were faced with the same situation again they would place solar water heating at the top of their priority list. The heating combined with insulation they saw as having the most impact on temperatures. The double glazing, while welcomed, they saw as a secondary issue.

The most unexpected consequence of the renovation for the householders was the enormous sense of well-being derived from being able to progress the work and improve their living conditions. The warmth in particular and the reduction of noise from the double glazing and window repair have been particularly important for the family.

When asked if they had run their wood burner in the 2008 winter more consciously they replied that they had, running it from March to September, but that they always did this as they get free wood through work: “We have the fire going 20 hours a day”.

The bedrooms no longer feel cold to the occupants; although when it gets really cold they do run supplementary heating in the bedrooms. They commented that while the wood burner was very efficient it can’t get heat down to the other end of the house, so a heat transfer system is needed and this is something they plan to do at some stage. Overall they noticed that temperatures have risen in the house during winter, with the morning temperature “much higher”.

Respondents noted that it did get too hot in the house over several weeks in summer, but they opened the windows and the heat was not considered to be a problem. Cooling actions undertaken in general were opening windows and doors, including the sliding doors in the main bedroom.

In terms of changes in dampness within the home, respondents noted that the dampness had gone in the main living areas and that, with everyone using the fan in the shower, dampness had decreased by 80%. They did use dehumidifiers when they first moved in but thought they were “useless” and did not continue with them. They found the extractor fans in the bathroom and laundry to be “excellent”, especially when combined with new windows.

In terms of outside water use they fill the swimming pool up twice in the summer and water the garden every two to three days in summer, although they estimate their water use dropped by half over 2008. This was related to the drought over 2007 to 2008. The vegetable garden was still active, on a par with the year before.

In terms of general water use this household noted that their hot water tank was too small before the renovations and hot water use was a major issue for the household, with monitoring of showers, fewer showers and sharing of bath water. “As the family have grown we don’t have to worry about the water – we used to boil water on the fire and share the bath with the kids”.

They considered now that they tended to have more showers: “We don’t feel so guilty about having showers now, before the renovations we worried about the water in the tank; our water consumption has gone up”. Their daughters were also considered to be showering more over the last year.

When asked whether they changed their waste disposal behaviour as a result of putting in a worm bin, they responded that they had emptied out the worm bin as they had overfed them and had a problem with bugs and flies. The female adult expressed a wish to resurrect the worm farm, and they are still using the worm fertiliser on the garden.

In terms of any physical health benefits noticed the adults remarked that they had “A lot less colds; kids always had runny noses, less colds and flu”. They commented that they all felt more relaxed, and that being warmer makes them happier; that they “were on edge before, and cold, it was a nightmare, this has taken a weight off us”. They felt that if this project hadn’t come along they would have “either bailed out [of this house] or sold our other house and put the money into this one”.

In terms of general impact on wellbeing they noted that the renovations created mental benefits as they felt more relaxed and that they had significantly progressed their upgrading of the house.

They remarked that “We didn’t think it [the renovations] would be as good as it has been; we are surprised at how warm the house is, the double glazing and insulation have been great”.

In terms of benefits for the adults in the house, they noted that they felt happier, felt less stress as there was less to fix and the house was warmer. The project also meant they had to borrow less money for renovations, the kids can use more hot water and they can put the washing machine on warm not cold: “We are doing our job as parents by keeping the house healthy for the kids”.

The children saw the main benefits as being warmth, in that it was nicer to come home in winter and it is warm in the mornings, it is quieter and they can open windows in their bedrooms (these weren’t able to open previously).

Family life has improved through less noise from parties in the neighbourhood as a result of the double glazing and through increased warmth. They noted that they had been pleased with everyone involved in the project, who they considered had really made an effort and gone out of their way to assist. They were listened to on several key occasions as to their preferences (including the wood burner and double glazing).

The features that have made the most perceived difference to their lives are the fire and double glazing. The latter was noted as being the biggest cost “that you couldn’t afford yourself”.

Based on this experience, features they would look for in future homes were:
- Double glazing, they would cost in the purchasing of double glazing
- Warmth features, they would check for insulation in floors and ceiling (“We know what a warm house is now”)
- Low maintenance
- Low renovation needed

They commented that their experience had reinforced their existing focus on the importance of warmth and practical comfort.

5 Overall Results

5.1 HERS Assessments

The nine homes were evaluated using the recently released New Zealand Home Energy Rating Scheme (HERS) using the AccuRate tool. Both a pre-retrofit evaluation and a post-retrofit evaluation were undertaken. At this stage the HERS evaluation only rates the thermal envelope of the home, however it is proposed to be expanded to include hot water and fixed heating in the future.

Table 47 shows the pre and post-retrofit results of the HERS Rating. As can be seen from Table 1 there is no apparent relationship between the investment in thermal envelope improvements and the increased star rating under the HERS scheme. In particular it is worth noting that where partial (but inadequate) insulation exists, "topping up" appears to have a low effect on the star rating.

Table 47: Interventions and Effect on HERS Rating

House ID	Thermal Envelope Intervention	Approx Market Value of Thermal Retrofit	HERS Star Rating Before Retrofit	HERS Star Rating After Retrofit
House 1	Skillion ceiling lowered in 40% of upper level, and R-3.6 insulation installed to achieve R-3.6. R-2 insulation installed under-floor (excluding mid-floor) Heavy draught stopping –garage door Polythene laid on ground	$15 900	1	1.5
House 2	Re-laid and topped up existing R-2.6 ceiling insulation to achieve R-2.6. R-2 insulation installed under-floor Cat door replacement (draughts)	$1 450	2.5	2.5
House 3	Insulated walls with R-2.4 insulation Skillion ceiling lowered, (in 40% of upper level) and R-3.6 insulation installed, below existing R-1 layer to achieve R-4.6. Original R-2.6 re-laid, extra R-2.6 laid over ceiling joists in cavity ceiling to achieve R-5. Old aluminium windows replaced with clear double glazed units in 16 new frames R-2 insulation installed under-floor Polythene laid on ground	$62 300	2.5	5

House 5	R-1.8 blanket laid over existing R-1.5 insulation to achieve R-3.2. R-2 insulation installed under-floor Polythene laid on ground	$4 270	2.5	3.5
House 6	Ceiling insulation top-up to achieve R-2.6	$1 380	1.5	1.5
House 7	Ceiling insulation topped up over existing macerated paper insulation to R-3.6 in half the ceiling area; top up with R-2.4 over other half bringing insulation to R-5 R-2.4 insulation installed in bedroom walls R-2 insulation installed under-floor Polythene laid on ground	$6 130	2	3
House 8	Existing ceiling insulation topped-up to R-2.6, additional layer of R-2.6 put over ceiling joists to achieve R-5. R-2.4 insulation added to rear wall of bedroom R-1.2 masonry insulation added to rear wall of gym R-2 insulation installed to 75% of suspended floor R-1.3 to rest. Polythene laid on ground Clear double glazing units inserted into 16 existing aluminium frames.	$14 190	2	3
House 9	Layer of R-2.6 put over existing insulation and ceiling joists to achieve R-4.2. R-2 insulation installed under-floor Polythene laid on ground R-3.6 insulation installed to ceiling/floor of garage/main bedroom. R-2.4 wall insulation installed into internal garage wall to stairwell, and on under-floor side of rumpus. Sliding door to garage draught-stopped	$4 010	4.5	5
House 10	R-2.6 insulation laid over existing ceiling insulation, then additional layer of R2.6 put over ceiling joists to achieve R-5. R-2 insulation installed under-floor Polythene laid on ground in sub-floor Flat roof of foyer insulated with R-3.6 insulation R-2.4 wall insulation to all walls except 1ower bedroom Clear double glazing units in 25 new window frames installed throughout house.	$59 060	1.5	4.5

5.2 Management of Intervention Installation

This research found that all the householders that participated in the interviews appreciated the opportunity to be involved in the retrofit project. Most householders identified a number of problems associated with participation, however. The most important of those were:

- uncertainty, and in some case unmet expectations, regarding the nature of the package installed
- poor specification and sequencing of installation leading to:
  - extended disruption of the household
  - unexpected requirements to provide a 'sweat' contribution, and
  - difficulties around managing the quality of work.

In addition there were a number of implementation problems that arose. Prior to interventions being undertaken, all the homes were the subject of a detailed BRANZ House Condition Survey and detailed drawings undertaken in order to provide information for modelling the expected performance of the homes.

These pre-retrofit evaluations identified that the homes were of varying levels of maintenance – with some homes needing urgent maintenance to items such as roofs and windows. In some cases full replacement of rotting materials was required. In addition, it became clear that some of the homes had probably been the subject of unauthorised building work undertaken in the past, by previous owners. In all cases, council plans were inaccurate and incomplete, when the actual built form of the homes was examined. One house had part of the home a mirror image of the plan, and other houses had missing elements (including whole floors) in the plans or in the construction. This is not an uncommon feature in New Zealand's housing stock, with a large proportion of older homes having both poor council documentation and work not authorised under the Building Code.

While these unauthorised building renovations (many of which were undertaken prior to the current compliance framework) were not the subject of the Papakowhai project they created difficulties for the project when it came to applying for Building Consent for the proposed retrofits. At one point in time it appeared that the Council was considering requiring BRANZ and Beacon to retrospectively consent/legalise all unauthorised building work on the homes (a requirement which would have quickly resulted in the project being cancelled), rather than just the retrofits proposed as part of the project.

Good management of consenting issues and a good relationship with local authorities are critical to implementing large scale renovations.

5.3 Key Findings

5.3.1 Thermal Insulation

Homes, where windows, walls, ceiling and floors were insulated and efficient heating installed, saved the most electricity and had the biggest temperature gains. In two homes which received the "high" thermal packages there were substantial reticulated energy savings as well as major increases in temperatures in both the family rooms and bedrooms.

Most of those homes which received insulation of ceiling and under-floor only did achieve reticulated energy savings and temperature improvements, however the temperatures and humidity levels in the homes did not meet the HSS® -2006 minimums.

It's important therefore to insulate the full thermal envelope if good reticulated energy savings and temperature improvements to HSS® -2006 standards are to be made.

5.3.2 Heating

Four of the nine homes were fitted with an efficient heat pump, low-emission pellet or wood burner. When coupled with good levels of insulation the potential exists to experience good temperature and energy efficiency gains. However, it was notable that most homeowners with less efficient heating devices chose not to increase their heating. As a result, while they did achieve some reticulated energy savings, they were not accompanied by increases in temperature to HSS®-2006 minimums. Heat transfer systems did appear to have an effect on improving bedroom temperatures when significant heating was done in the source room.

A key finding is that efficient heating must accompany insulation improvements.

5.3.3 Hot water cylinder wraps

In terms of value for money, hot water cylinder wraps and pipe lagging remain an excellent investment. While cylinders ranged in age (1970s-2005), wrapping proved worthwhile in all cases (even for the A grade cylinders), boosting efficiency between 11% and 30%.

5.3.4 Solar hot water systems

Optimally-sized and -installed solar hot water systems provided an impressive 55-70% of the hot water needs to the three homes – in winter. Analysis of the summer data is yet to come, but this is expected to show even better performance.

5.3.5 Water and Waste

The interventions undertaken in the homes around water and waste did not result in any significant changes to the water and waste indices. While the water and waste aspects of the project were relatively minor, it is clear that more significant interventions, and homeowner engagement around water efficiency and waste minimisation is needed if significant change is to result.

5.3.6 Retrofit Intervention Development

This project demonstrated that some retrofit components are easier than others to install and this varies according to both the intervention and the dwelling itself. This has cost implications and may affect householder take up.

In terms of physically doing the job, the following retrofits can be regarded as being straightforward to **a competent and suitably qualified tradesperson who has had experience with installing this type of feature**:

- Ceiling insulation in a cavity ceiling
- Skillion ceiling lowering and insulating
- Under-floor insulation
- Wall insulation and replacement of internal linings
- Mid-floor insulation
- Replacement of non CA rated downlights with CA rated lights
- Installation of low flow devices (shower head, cistern, taps)
- Installation of bathroom and kitchen ventilation systems (vented to the outside)
- Replacement of solid fuel heating devices
- Installation of pellet burners
- Installation of heat pumps
- Installation of heat transfer systems
- Replacement of single glazing with IGUs in existing, modern, aluminium frames
- Worm farms/compost bins/washing lines/recycle bins/compact fluorescents/draught stopping/Showerdomes and other minor interventions
- Rainwater tanks for outdoor use
- Installing water meters
- Solar hot water system

In all these instances the correct specification of the system for a sustainable outcome is still required – under sizing/under specifying seems to be a common theme in almost all instances, with over sizing a common problem with solid fuel burners.

The project also showed that there are slightly trickier retrofits. Those require a specialised installer who is familiar with the system.

- replacing windows with double glazed IGUs and frames
- rainwater tank plumbed to toilet/washing machine
- greywater systems.

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