NO202/4

Rotorua NOW Home® Final Performance Monitoring

Final

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About This Report

Title

Rotorua NOW Home® Final Performance Monitoring

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Reviewer

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Abstract

This report examines the sustainability performance of Beacon Pathway's second new construction research house: the Rotorua NOW Home®. The reticulated energy use, reticulated water use, indoor environmental quality and the occupancy satisfaction are examined and compared with Beacon's first new construction research project, the Waitakere NOW Home®, as well as Beacon's set of sustainability performance benchmarks, the HSS High Standard of Sustainability® (HSS®).

Reference

Pollard, A R and Jaques, R A. August 2009. Rotorua NOW Home® Final Performance Monitoring. NO202/4 for Beacon Pathway Limited.

Disclaimer

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The Rotorua NOW Home® was the second of Beacon's new construction research houses following on from the experience of the Waitakere NOW Home® (Easton, 2007). The house was built by Housing New Zealand Corporation in 2006 as part of their Community Renewal programme in the existing Rotorua suburb of Fordlands.

The rainwater system performed well in the first year. The household was able to restrict demand from the reticulated water supply to use only 57L per person per day. In the second year, the rainwater system developed a fault and was not operational for a large proportion of that year. Consequently, the reticulated water demand in the second year was high, at around 200L per person per day. Although not an ideal result, the findings from the monitoring show the significant value in having an operational rainwater harvesting system.

The reticulated energy (electricity) usage in the Rotorua NOW Home® was 6,900kWh for Year 1 and 6,500kWh for Year 2, both lower than the 8,200kWh/yr benchmark set by Beacon's HSS® for Climate Zone 2. Two items that reduced the amount of reticulated energy (electricity) required was the solar water heating (SWH) system and, more significantly, the wood pellet burner.

Overall, 36% of water heating needs were met by solar. The effectiveness of the solar hot water system would have been improved if the following performance and design criteria had been optimised.

The Rotorua NOW Home® insulation levels were much higher than Building Code requirements at the time of construction – however, they were lower than the levels chosen for the Waitakere NOW Home®. The difference in the insulation levels, along with climate and possibly user needs, meant that compared to the Waitakere NOW Home®, where heating was only required for one or two days, the Rotorua NOW Home® was heated virtually every day over winter. This heating need to provide comfortable temperatures was met using non-reticulated energy through the usage of an efficient wood pellet heater and depends on the insulation levels and design of the building.

The resulting winter indoor temperatures in the Rotorua NOW Home® had an average evening temperature of 17.5°C, slightly below the 18°C HSS High Standard of Sustainability ® benchmark. The impact of the lower thermal performance is seen in the winter overnight bedroom temperatures where the average temperature in the Rotorua NOW Home®'s master bedroom was 12.9°C, considerably cooler than the 16°C recommended in Beacon's HSS®.

The cedar louvres in the living room were included in the design to assist in lowering the relative humidity (RH) in the living areas. Evening winter humidity levels in the living room averaged 58% RH, well within the HSS® range of 20–70% RH. The average overnight winter humidity in the bedrooms was close to the upper value of this range with the master bedroom just within (69% RH) and bedroom 3 just over (72% RH) the upper limits.

There is a fair degree of satisfaction by the principal adult occupant of the Rotorua NOW Home®. Aspects of the home's space usage, airiness, aesthetics and light were very much appreciated. However, there were several aspects of its finish and day-to-day performance that the occupants thought were lacking, especially in the way that the coatings were finished. Privacy and security could have been better as well.

2 Introduction

The Rotorua NOW Home® was the second of Beacon's new construction research houses following on from the experience of the Waitakere NOW Home® (Easton, 2007). The house was built by Housing New Zealand Corporation in 2006 as part of their Community Renewal programme in the existing Rotorua suburb of Fordlands.

The house was designed to include a number of sustainability features drawing on experience gained from the Waitakere NOW Home®. It also included specific requirements of Housing New Zealand. A number of project partners donated materials and systems that were incorporated into the building. A list of these partners can be found on the Beacon website:

www.beaconpathway.co.nz/new-homes/article/our_rotorua_now_home_partners

The monitoring of the house included:

- Energy (electricity and pellet burner use)
- Water use
- Indoor temperature and humidity

Performance monitoring of the Rotorua NOW Home® was undertaken over two years using a simplification (see Appendix A) of the Waitakere NOW Home® monitoring.

In order to assess the sustainability of residential buildings, Beacon Pathway has developed a series of criteria called the HSS High Standard of Sustainability® (HSS®). Although the HSS® criteria were updated recently (Beacon Pathway, 2008), the previous 2006 version is used here, reflecting what was applied to set design targets of the NOW Homes® (see Figure 1). As can be seen in Figure 1, targets were set for reticulated energy and water use, indoor environmental quality, waste and materials.

This report examines the Rotorua NOW Home®'s performance against the readily measurable areas of energy use, water use and indoor environmental quality and uses the HSS® as a reference for measured performance.

<table>
<tr><th colspan="5">Beacon HSS-2006® benchmarks</th></tr>
<tr><td colspan="2" rowspan="2">Energy use</td><td>Benchmark in Climate Zone 1</td><td>Benchmark in Climate Zone 2</td><td>Benchmark in Climate Zone 3</td></tr>
<tr><td>New homes:
7,600 kWh/yr
Existing homes:
9,050 kWh/yr</td><td>New homes:
8,500 kWh/yr
Existing homes:
11,000 kWh/yr</td><td>New homes:
9,800 kWh/yr
Existing homes:
12,000 kWh/yr</td></tr>
<tr><td colspan="2">Water use</td><td colspan="3">180 litres/person/day (L/p/d)</td></tr>
<tr><td rowspan="4">IEQ</td><td>Temperature</td><td colspan="3">16°C bedroom mean min temp
18°C family room mean min temp</td></tr>
<tr><td>Ventilation</td><td colspan="3">New homes: 0.4-0.6 air changes per hour
Existing homes: 0.5-0.75 air changes per hour</td></tr>
<tr><td>Relative humidity (RH)</td><td colspan="3">Mean RH 20-70% in bedrooms and living space</td></tr>
<tr><td>Checklist</td><td colspan="3">Mechanical extract ventilation of kitchen, bathroom and laundry
Windows with passive venting
No unflued gas heaters
Environmental Choice certified paints and finishes
No air conditioning</td></tr>
<tr><td colspan="2">Waste</td><td colspan="3">Provision for kitchen waste composting/or space for kitchen waste
Space for recyclables storage
No in-sink waste disposal unit
New building construction or renovation in accordance with REBRI construction guidelines</td></tr>
<tr><td colspan="2">Materials</td><td colspan="3"><u>New homes</u>: materials which –
promote good indoor air quality
have minimal health risks during construction or renovation
are durable and have low maintenance requirements
incorporate recycled content or can readily be recycled
re-use existing/demolished building materials or can readily be re-used
or are made from renewable /sustainably managed resources
have low embodied energy/minimal impacts due to transport
have low impact on landfill or are biodegradable
minimal impact on the environment
have third-party certification (e.g. NZ Environmental Choice, FSC)
<u>Existing homes:</u>
intervention/renovation applies principles from materials checklist</td></tr>
</table>

Figure 1: Beacon's HSS High Standard of Sustainability® 2006

3 Rotorua NOW Home® Performance Assessment

3.1 Energy

Beacon's HSS High Standard of Sustainability® (Easton, 2006) features reticulated energy as a benchmark against which to assess buildings. Other fuel types such as solar or fuel-wood are not subject to benchmarks as they have a reduced environmental burden. The Rotorua NOW Home® features a Parkwood wood pellet burner which provides space heating, requiring a small amount of reticulated energy to operate.

This section will focus on the following areas:

- the reticulated energy use (in this case, electricity)
- the largest electrical end-uses
- the supplementary heating for the solar water heating system
- the operation of the wood pellet burner.

3.1.1 Electricity

The electricity use in the Rotorua NOW Home® was monitored from October 2006 to October 2007 and then for a second period from November 2007 to November 2008.

Over the first year the Rotorua NOW Home® used 6,900kWh of electricity. During the second year there was a slight reduction in electricity usage with 6,500kWh of electricity used. As Rotorua is located in Climate Zone 2, as defined in NZS 4218, the HSS® benchmark for reticulated energy is 8,500kWh per year. Therefore, the Rotorua NOW Home® met the HSS® benchmark for both years, in addition to using less energy than the Waitakere NOW Home®.

Table 1 provides an end-use breakdown of the electricity use over the two years. This is also shown graphically in Figure 2. The supplementary heating for the solar water heating (SWH) system is the major electricity usage in the Rotorua NOW Home® accounting for around 42% of the total electricity usage and is largely consistent from Year 1 to Year 2.

End-use	**Year 1 (kWh)**	**Year 2 (kWh)**	**Change (kWh)**
SWH heating element	2,900	2,800	-120
Lights	800	570	-230
Range	460	570	+110
Water pump	370	34*	-340
Fridge	330	350	+28
TV	180	200	+19
Pellet burner control	100	90	-15

Jug (Year 1)	360	–	–
Microwave (Year 2)	–	54	–
Total electricity	6,900	6,500	-410

(All figures to two significant figures. Figures may not add due to rounding errors)
* The water pump controller failed during the second year and was left off

Table 1: Electricity end-uses in the Rotorua NOW Home® for the two monitored years

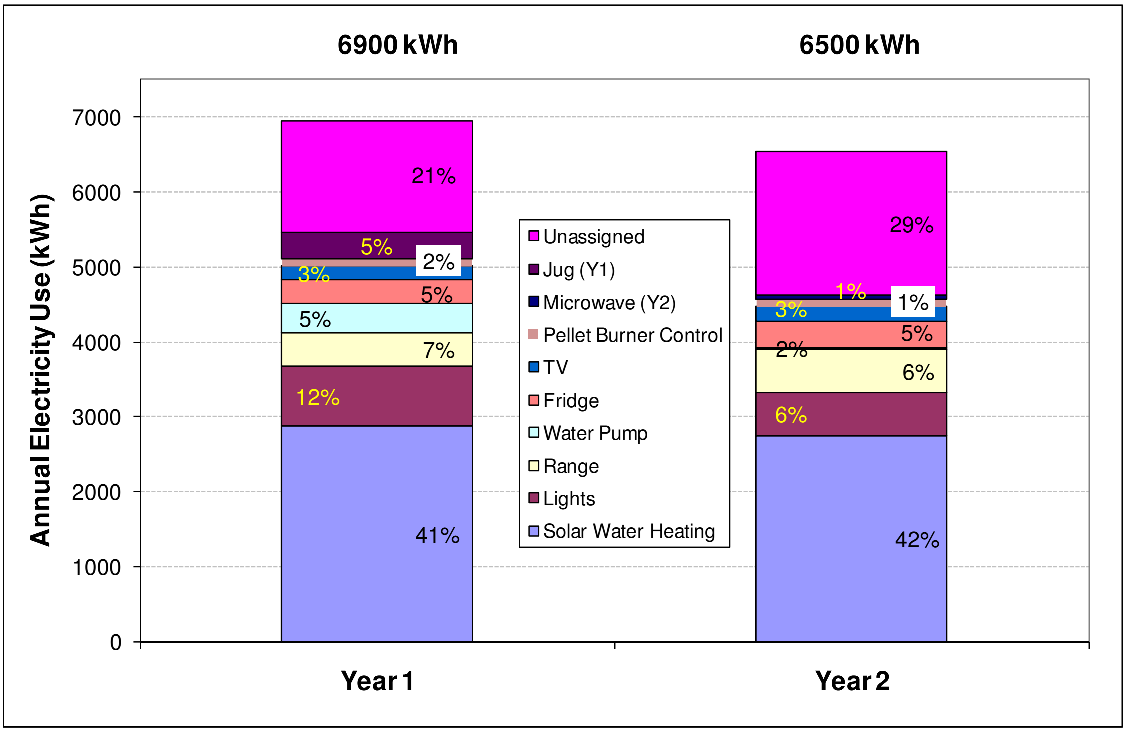

Figure 2: Electricity end-uses for the Rotorua NOW Home® for the two monitored years

The lights were also a high energy user in the first year using 800kWh or 12% of the total electricity use. The second year saw a large reduction in the lighting energy use with a 28% (230kWh) reduction resulting in a lighting use of 570kWh for the second year. It is unknown why this is the case.

The largest increase in end-uses monitored was for the range (oven and hobs) which saw a 24% (110kWh) increase during the second year to 570kWh.

The Rainbank water pump and controller used a high amount of electricity (370kWh or 5%) in the first year, more than the refrigerator freezer. Shortly into the second year, the system developed a fault and was left off as it was causing disruptions to the data collection system. Therefore, the reduction in electricity consumption for the Rainbank during the second year (340kWh) should not be attributed to any useful saving and needs to be taken into account when comparing the two years.

The overall change in total electricity use between Year 1 and Year 2, excluding the Rainbank system was negligible at around 1%.

3.1.2 Solar Water Heating

This section contains a summary of the performance of the solar water heating (SWH) system used in the Rotorua NOW Home®, which was the largest component of the electricity use. Further details can be found in Pollard (2009) which examined the SWH systems used in the Rotorua NOW Home®, the Waitakere NOW Home®, and three of the Papakowhai Renovation project houses.

The Rotorua NOW Home® included a Solar Genius low pressure thermosiphon flat plate collector SWH system. The installation is shown in Figure 3. The frame on which the SWH system sits resulted in a collector angle of 30°. This angle is shallower than the ideal angle of 38°, the same angle as latitude in Rotorua. The 30° angle was the achieved outcome because of the fixed frame provided with the system in combination with the low angle of the roof.

Figure 3: The flat plate thermosiphon SWH system in the Rotorua NOW Home®

The storage tank and collector frame is made from one moulding of polyethylene. The 2.6m^2 collector covers one fully flooded cavity with no channels or pipes and is covered by an acrylic sheet. Polyurethane is used to insulate the system. The heat losses from the system (see Table 2) are higher than many other SWH systems due to the level of insulation surrounding the tank and the outside position of the cylinder being subject to colder outside temperatures compared to a cylinder that is inside the house, within the thermal envelope.

The pressurisation of hot water is achieved by the height of the storage tank above the water delivery point. Unfortunately, additional water restriction devices that were suitable for mains pressure systems (but unsuitable for lower pressure systems) were used, resulting in shower flow rates of less than 2L/min. This is significantly lower than the typical minimum shower flow rates, and resulted in a poor quality shower. The poor performance of the shower was noted by the occupants.

It is important to control the supplementary heating element inside the cylinder to prevent the immediate (and wasteful) reheating of water and to provide the opportunity to heat the water at a later time. The control unit for the SWH system was a basic thermostat inside the storage cylinder set to 60°C. There were no timer controls used within the system and no system displays used. Controlling the cylinder therefore requires manually turning the element off from the fuse board. Not unexpectedly, this does not appear to have happened.

Table 2 shows the proportion of the water heating energy obtained from the sun by the Rotorua NOW Home® SWH system. This was disappointingly low at 36%. The data for this analysis was collected over the period 1 September 2007 to 30 August 2008, with some of the summertime data extrapolated to provide a complete data set.

System	Draw-off energy	System losses	Auxiliary energy	Total energy	Sup-plementary water heating	Renewable energy Q_{renew}		COP	Wet-back
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(% of total)		
Rotorua	2,700	1,400	-	4,200	2,700	1,500	36%	1.0	no

Table 2: Annual energy balance for each of the monitored SWH systems (from Pollard, 2009)
(All figures to two significant figures. Figures may not add due to rounding errors)

Had the performance of the Rotorua NOW Home® SWH system achieved 50% of water heating needs, then an additional 600kWh of reticulated energy would have been saved. This shows how important integrated system design (especially in terms of control design) is in a more involved setup such as SWH heating and how important the control feedback is in determining ongoing performance and costs.

3.1.3 Wood Pellet Burner

The space heating in the Rotorua NOW Home® was provided by a Parkwood 10kW wood pellet burner. This heater was located in the northwest corner of the living room as can be seen in the floor plan in Figure 8. Its position was influenced by safety (in terms of traffic flow) and practicality (in terms of seating arrangement) reasons. A photo of this pellet burner in place is shown in Figure 4.

Figure 4: The Parkwood wood pellet burner

Wood pellet burners are clean burning, efficient heaters (the model in the Rotorua NOW Home® was 82% efficient). The fuel for the heaters is commercially produced pelletised wood waste sold in 20kg bags.

Pellet burners generally require an electricity supply to power the electronic controls, the hopper to feed fuel into the burner, fans for distribution of heat, and the ignition system of the burner.

The operation of the Rotorua NOW Home® pellet burner was monitored by recording its electricity use. Figure 5 shows the electrical energy demand for a typical winter's day. The heater is off till about 3pm when it is turned on and an ignition cycle of about 250W begins. After the ignition cycle is complete, the heater requires about 100W until about 10pm when the power use drops away because it is turned off.

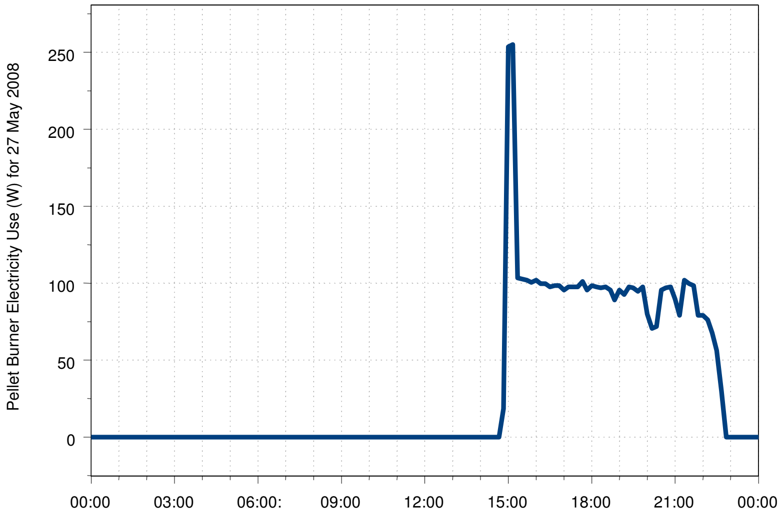

Figure 5: The typical electrical energy demand for the operation of the wood pellet burner

The data collected over the second winter was chosen for analysing the operation of the pellet burner, as its control system failed for a portion of the first year. The second year's results are shown in Figure 6. This graph shows the electrical energy use of the pellet burner by time of day (shown on the horizontal axis) and by day of year (starting from the top with each day on a separate line). The value of the electrical energy is represented by a colour according to the scale on the right hand side of the graph. The red colour is used for any value over 120W and is seen at the start of a heater operation. The orange colour is for values between 60W and 120W which is when the heater is normally operating. The blue colour is for values between 1W and 60W and can either be when the heater is used at a low setting or cooling down. Zero usage (values of 0W) is shown in white. Missing values are indicated by a grey dot with much of the data between December 2007 and March 2008 missing due to a data collection failure caused by the fault in the rainwater system (see Section 3.3).

Figure 6 shows that the pellet burner is used intensively from May 2008 to August 2008, being used on most days. Over the 2008 winter (June, July and August) the heater was on for 32% of the time which equates to over 700 hours. While there is a block of missing data from December 2007 to March 2008, there are periods of heater use in the warmer months such as two days' use in early December 2007.

Figure 7 gives an average time of day profile for the electrical energy use of the wood pellet burner which summarises some of the data from Figure 6. While there is occasional use during the day, the electricity demands for the wood pellet burner increase steeply between 3pm and 4pm suggesting this as an average time as to when it is turned on. The peak of the demand curve is more subtle, dropping away from about 8pm but having some usage in the early morning hours.

In comparison to the Waitakere NOW Home® (Pollard et al., 2008) where there was very little space heating, the Rotorua NOW Home® occupants have used the wood pellet heater extensively. The thermal performance of the Rotorua NOW Home® is discussed further in the next section (3.2) on the resulting indoor environmental conditions.

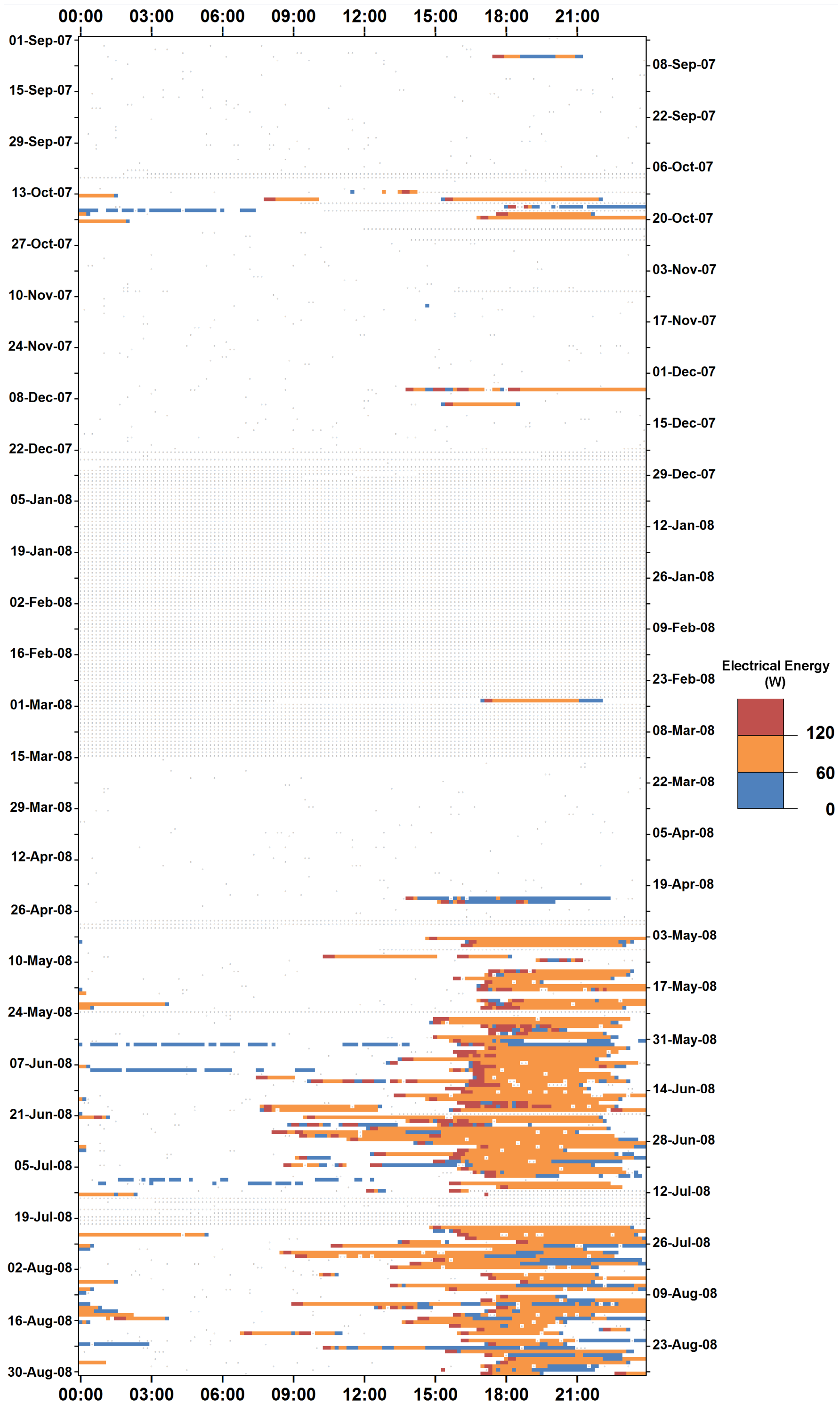

Figure 6: The electrical energy use of the pellet burner (indexed by colour according to scale on the right) by day of year and time of day (10 minutes)

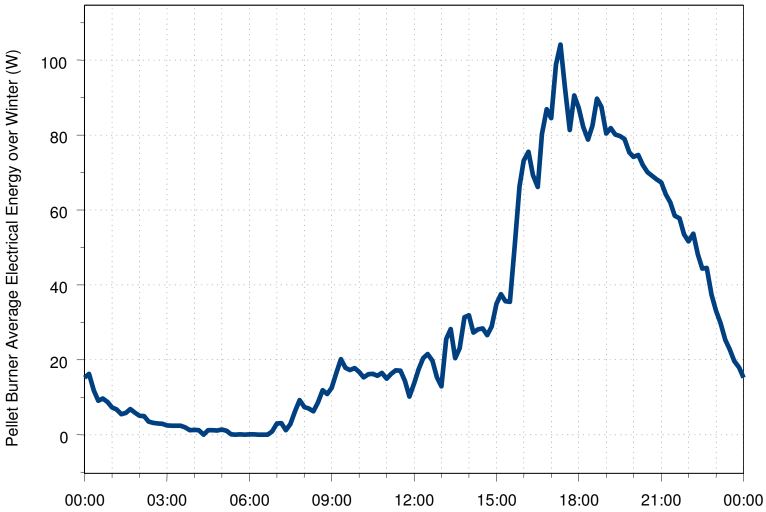

Figure 7: Average time of day use over winter for the electrical energy use of the wood pellet burner

3.2 Indoor Environment

The indoor environment is a key factor in the performance of any house. The temperatures within a space are a result of the outdoor conditions, the effectiveness of the house in terms of thermal design performance as well as how the space conditioning (heating and cooling) systems are used.

While the insulation levels in the Rotorua NOW Home® were much higher than Building Code requirements at the time of construction, they were less than the levels achieved in the Waitakere NOW Home®. Although the plans specified roof insulation to be R5.0 fibreglass insulation, only R4.0 was delivered to the site. As a comparison, the Waitakere NOW Home® used R4.6 fibreglass insulation in the roof. The external walls were also insulated with fibreglass insulation, R2.6–R2.8.

There was detailed design consideration to ensure the floor was well insulated and included an exposed concrete slab ground floor with a 40mm layer of polystyrene insulation beneath it. The floor included a foundation wall constructed from insulated concrete framework blocks. However, the occupants did not like the exposed concrete floor (they were concerned about falls onto the hard surface and the perceived coldness of the surface) and placed rugs and mats over most of it thereby limiting its ability to moderate room temperatures.

The windows were non-thermally broken aluminium framed with double glazing. Surrounding the windows in the living room were wooden louvres that could be tightly shut for increased ventilation within the house when needed (summer months). The louvres were made of cedar and have less thermal resistance (i.e. lower ability to insulate) than the wall area it substituted.

The floor plan of the Rotorua NOW Home® is shown in Figure 8. The house is constructed around a central concrete deck which means that the wall area is higher than if a simple rectangular shape was used.

Occupants will generally use a heating system to achieve a desired level of comfort. Comfort may not be realised if the occupants cannot afford to run the heating system, the system is undersized for the heating required or if there are draughts or other reasons for discomfort present. The position of the pellet burner has been questioned by some as to its efficacy in terms of the number of zones (and therefore overall area) effectively heated. The shortcomings of a point source heater (whatever the size) in this type of situation were evident here, especially when the roofline prevented the installation of a heat transfer mechanism. Ideally, a secondary heat source should be used to heat the bedrooms. Temperature and humidity are the major components of comfort and these are examined in this section.

The indoor temperatures and humidities were recorded in four locations within the Rotorua NOW Home® as indicated on the floor plan in Figure 8. The living room temperature/humidity was recorded at two heights and the average of the two sensors is reported on. The temperature/humidity in the main bedroom as well as the southernmost third bedroom was also measured, as was the outside temperature and humidity alongside the third bedroom.

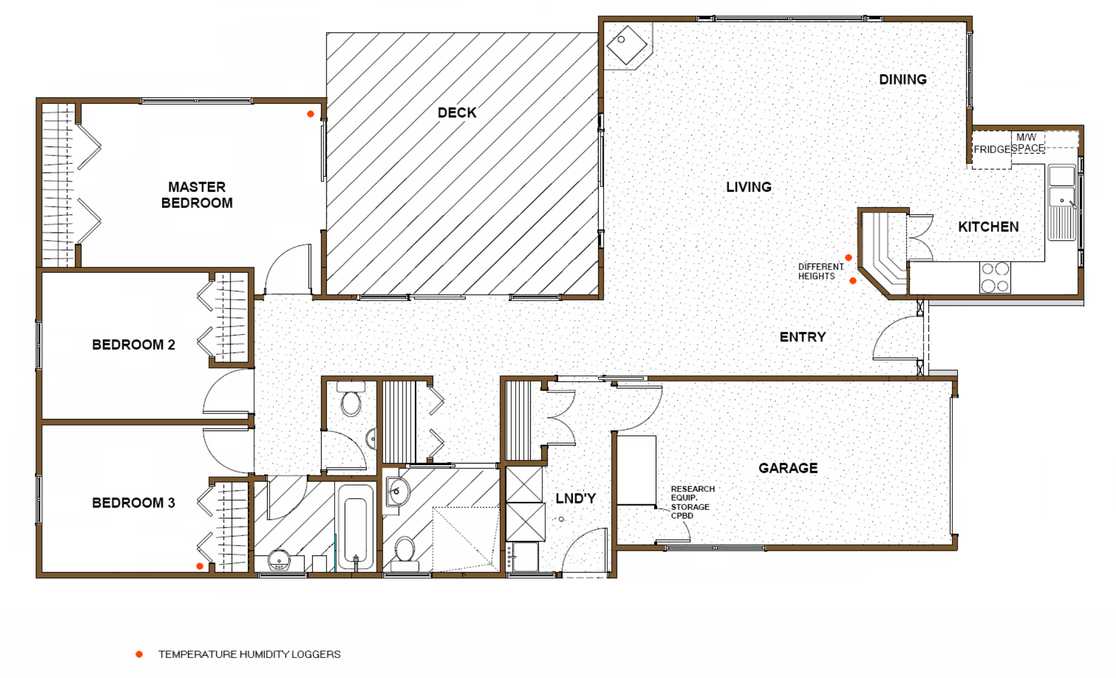

Figure 8: Floor plan of the Rotorua NOW Home® showing the location of the temperature and humidity measurement points

The HSS® (Easton, 2006) targets the indoor temperature and humidity in the evening and overnight for the winter period in the living room and bedrooms, testing the ability of the house (i.e. passive thermal design aspects) and space heating systems. The analysis of indoor conditions described below uses the data collected from the second year (June, July and August 2008).

3.2.1 Temperature

Figure 9 provides a plot of the average temperature by time of day within and around the Rotorua NOW Home® over the 2008 winter period. The average outdoor temperature drops to a low of about 5°C at around 7am, climbing to a high in the afternoon of around 11–12°C. The average living room temperature (see Table 3) is 7.6°C warmer than ambient, falling to around 13°C in the morning, climbing throughout the day and then experiencing a heating 'hump' between 5pm and 10pm when the average temperature reaches 18°C, due to the pellet burner being used in the evenings.

The temperature profile for bedroom 3 is similar to that of the living room but is at a lower level, although the evening hump is replaced by a flattening off. The average bedroom 3 temperatures are 5.5°C warmer than the outside temperature.

The master bedroom cools off in the morning more than the other rooms monitored, resulting in the lowest indoor temperatures of around 11°C at 8am. This increased cooling is due to the master bedroom being more exposed, having three external walls and a large amount of partially shaded east-facing glazing (with a low R value compared to the wall). The master bedroom temperatures increase strongly from its 8am low during the day to a peak of 16°C at around 2pm.The higher rate of temperature increase for the master bedroom is another result of the high amount of glazing.

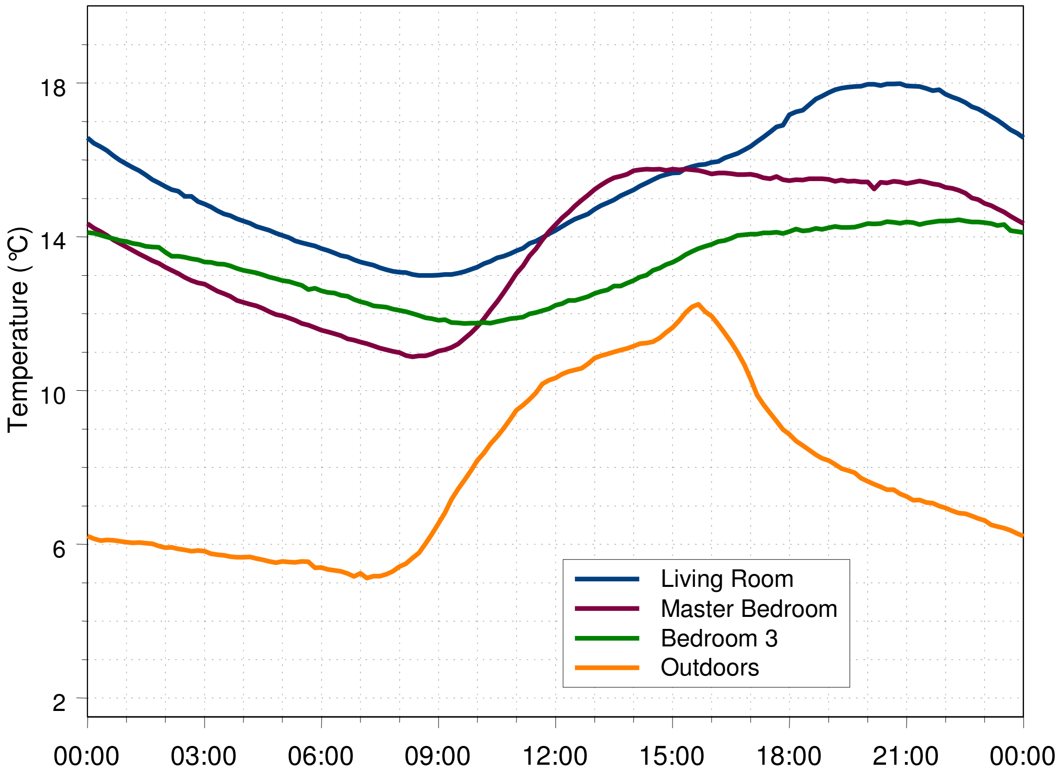

Figure 9: The time of day temperature profiles during winter for a number of rooms

Table 3 provides averages of the 2008 winter temperatures over the complete day as well as for particular time periods such as evenings (5pm–11pm), overnight (11pm–7am) and during the day (7am–5pm). The Rotorua NOW Home® falls short by 0.5°C of the HSS® (Easton, 2006) target of evening living room temperatures of 18°C. The temperatures in the master bedroom and bedroom 3 are even further below (3.1°C and 2.6°C) the 16°C overnight temperature target for bedrooms. From Figure 9 it can be seen that the average bedroom temperatures decline from between 14°C and 15°C at 11pm to a low at around 8am or 10am of 11°C–12°C. In order to achieve the HSS®, evening temperatures in the bedrooms need to be higher from a better supply of evening heat to the bedrooms (through, for example a heat transfer kit if that were possible), as well as slowing the rate of cooling for these rooms with better insulation levels.

Location	All day (24 hours) (°C)	Day (7am–5pm) (°C)	Evening (5pm–11pm) (°C)	Overnight (11pm–7am) (°C)
Living room	15.4	14.3	17.5	15.1
Master bedroom	13.8	13.7	15.4	12.9
Third bedroom	13.3	12.5	14.3	13.4
Outdoors	7.8	9.3	7.9	5.8

Table 3: Average temperatures by room during different time of day periods

A temperature of 16°C is frequently used as a threshold for health reasons (Mant and Gray, 1986). Table 4 gives the proportion of the time during the same time periods and locations, for which the temperature was below 16°C. Only in the living room during the evenings was the temperature over 16°C for more than half of the time.

Location	All day (24 hours) (%)	Day (7am–5pm) (%)	Evening (5pm–11pm) (%)	Overnight (11pm–7am) (%)
Living room	59	78	17	66
Master bedroom	74	74	55	89
Third bedroom	87	93	78	87
Outdoors	99	100	98	100

Table 4: Proportion of the time temperature is below 16°C in a number of rooms during various time of day periods

A comparison between the winter evening living room temperatures and the winter overnight master bedroom temperatures in the Rotorua NOW Home® and the Waitakere NOW Home® (Pollard et al., 2008) is shown in Table 5 and Table 6.

Location	Rotorua NOW Home® (℃)	Waitakere NOW Home® (Year1) (℃)
Living room	17.5	20.3
Outdoor	7.9	11.3
Indoor/outdoor difference	9.6	9.0

Table 5: Winter evening temperatures in the living room and outside the Waitakere and Rotorua NOW Homes®

Location	Rotorua NOW Home® (℃)	Waitakere NOW Home® (Year 1) (℃)
Master bedroom	12.9	19.1
Outdoor	5.8	8.5
Indoor/outdoor difference	7.1	10.6

Table 6: Winter overnight temperatures in the master bedroom and outside the Waitakere and Rotorua NOW Homes®

Table 5 shows that the winter evening temperatures in both houses have a similar temperature difference of 9.0°C (Waitakere) or 9.6°C (Rotorua) between the living room temperature and the outside evening temperature (Rotorua outdoor temperatures being 3.4°C colder than in Waitakere). However, the Rotorua NOW Home® is quite intensively heated to achieve its evening temperatures whereas the Waitakere NOW Home® does not use any evening heating but relies on solar gain from during the day being retained within the envelope of the home.

The indoor/outdoor difference for the master bedrooms overnight (Table 6) is higher for Waitakere (10.6°C) than it is for Rotorua (7.1°C), and results in low overnight bedroom temperatures in the Rotorua NOW Home®. As the Rotorua NOW Home® does not have any dedicated bedroom heating (like the Waitakere NOW Home®) this difference in overnight bedroom temperature is due to the combination of lower outdoor temperatures in Rotorua and differences in building design and insulation levels.

3.2.2 Relative Humidity

The cedar louvres in the living space provide a convenient means to increase passive ventilation into the house. This design concept of increased passive ventilation was intended to assist in lowering the relative humidity (RH) in the living areas of the Rotorua NOW Home®.

Table 7 and Figure 10 provide summaries of the relative humidity levels seen in the Rotorua NOW Home® over winter. The outside humidity level was measured on the fence to the south of the property and was in close proximity to much vegetation so may not accurately reflect the average humidity levels around the Rotorua NOW Home®. The Rotorua NOW Home® meets Beacon's HSS® benchmark (Easton, 2006) of 20–70 % RH for the winter evening relative humidity in the living room where the average is 58% RH. The bedrooms, however, are just within (69% for the master bedroom) and just over (72% for bedroom 3) the upper limits for the overnight relative humidity levels.

The two bedrooms, while having a similar average relative humidity, differ in the range of relative humidities experienced during the day. The third bedroom operates over a small average relative humidity range falling from a peak of around 73% RH at 7am to a value of 68% RH at 4pm. On the other hand, the average relative humidity in the master bedroom has a much wider operating range of between 59 % RH and 72% RH. The greater range of relative humidity in the master bedroom is probably due to the stronger heating (solar gains) and cooling (large window area) in this room.

Location	**All day (24 hours) (% RH)**	**Day (7am–5pm) (% RH)**	**Evening (5pm–11pm) (% RH)**	**Overnight (11pm–7am) (% RH)**
Living room	60	62	58	60
Master bedroom	66	65	63	69
Third bedroom	70	70	69	72
Outside	93	90	93	96

Table 7: Average relative humidity level by location and by time of day period

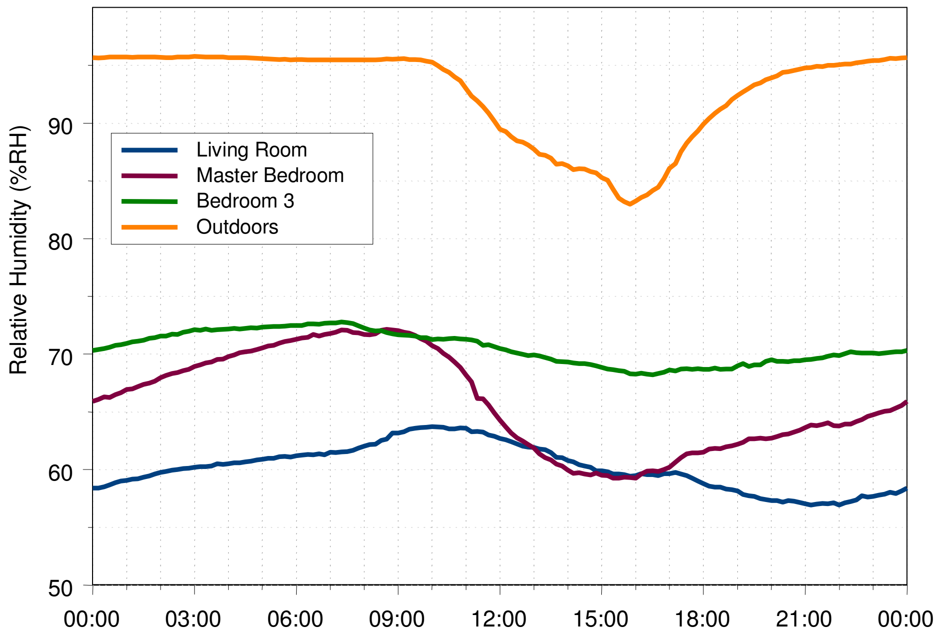

Figure 10: The time of day relative humidity profiles during winter for a number of rooms

Figure 10 provides a table of proportion of time that the measured locations have a relative humidity over 70% RH for various time periods of the day. This measure has the effect to extenuate the differences between the measurement locations. The living room is seldom over 70% RH anytime, while the third bedroom has relative humidity levels of over 70% RH for over half the time, and is consistently high for each of the sub-periods (evening, overnight and day).

Location	All day (24 hours) (%)	Day (7am–5pm) (%)	Evening (5pm–11pm) (%)	Overnight (11pm–7am) (%)
Living room	5	10	2	1
Master bedroom	36	42	19	43
Third bedroom	61	62	51	68
Outside	96	93	98	100

Table 8: Proportion of the time the relative humidity is above 70% RH in a number of rooms during various time of day periods

3.3 Water

A major sustainability feature of the Rotorua NOW Home® was the use of a 4,000L polyethylene rainwater tank for the supply of water to the outside taps and the toilets. This tank (shown on its side in Figure 11 before installation) was buried to avoid restrictive positioning (setbacks from boundaries, closeness to water services, etc.), provide more usable space, and for aesthetic reasons. A disadvantage to burying the tank is the necessity to undertake a large amount of earthworks which requires the disposal of a large quantity of earth.

Figure 11: The Rotorua NOW Home® rainwater tank before installation (photo from Beacon Pathway website)

In order to ensure continued service during dry periods, an alternate means of supply is needed. The Waitakere NOW Home® featured a bypass valve that the occupants could switch over, allowing the services normally fed by the tank water to be fed instead by water from the street. This setup did not prove effective; the tank water ran out at inconvenient times so that the occupants tended to leave the bypass valve to street water for longer periods than necessary to ensure that the tank had sufficient water. The Waitakere NOW Home® did not initially have a convenient means by which the occupants could check the level of the tank water to help decide how to set the bypass valve. A later addition to the Waitakere NOW Home® was a visible tank level gauge that extended above the tank.

The solution for the Rotorua NOW Home® was to make use of a Rainbank automatic diversion control system (see Figure 12). This system has inputs both from the street and the tank (via a water pump) and automatically switches over to the main supply when the tank is empty.

In the second year the unit developed an electrical fault that caused the residual current device connected to the laundry, the fridge freezer and the monitoring equipment in the house to be periodically turned off. As this fault had affected the monitoring system for an extended period of time during summer 2008, the Rainbank system was disabled so that data collection for winter 2008 would not be affected. This meant that the water consumption for the majority of the second year did not include any collected rainwater when the house could not access any rainwater.

Figure 12: The Rainbank rainwater tank controller during construction

Table 9 gives the total daily volumes of water from the street and tank for both of the monitored years. In Year 1, the rain tank can be seen as very effective, reducing the quantity of water required from the street by 72% to 227L per day. While the occupancy of the Rotorua NOW Home® was varied, if it is assumed that on average four occupants were usually occupying the house, then the reticulated water demand for the Rotorua NOW Home® in Year 1 is around 57L per person per day, well within the Beacon HSS® 2006 target (Easton, 2006) of 180L per person per day.

	Street	**Tank**	**Total**
	(L/day)	(L/day)	(L/day)
Year 1	227	582	809
Year 2	798	50	848

Table 9: Sources of water for the Rotorua NOW Home®

In Year 2 the overall water consumption increased 5% but with the fault with the Rainbank system, just 6% of the total water needs were met by the rain tank. The reticulated water demand for the second year was 200L per person per day, well outside of the HSS® benchmark.

Table 10 compares the total water use in the Rotorua NOW Home® with the Waitakere NOW Home® (Pollard et al., 2008). While the Waitakere NOW Home® total water consumption went down in the second year, the second year of the Rotorua NOW Home® saw an increase in total water consumption, using 23% more water than the Waitakere NOW Home® when comparing Year 2 monitoring for each home.

	Rotorua NOW Home® (L/day)	Waitakere NOW Home® (L/day)
Year 1	809	760
Year 2	848	690

Table 10: Total water use in the Rotorua NOW Home® and the Waitakere NOW Home®

The use of rainwater is quite different for the two houses, as shown in Table 11. Despite the smaller tank size of the Rotorua NOW Home® (4,000L as compared with 13,500L), the automatic switching of tank water appears to result in a much better utilisation of rainwater, with the Rotorua NOW Home® gathering 64% more water than the Waitakere NOW Home®.

	Rotorua NOW Home® (L/day)	Waitakere NOW Home® (L/day)
Year 1	582	356
Year 2	50	361

Table 11: Water source from the rain tank in the Rotorua NOW Home® and the Waitakere NOW Home®

3.4 Post Occupancy Evaluation

3.4.1 Overview

Quarterly post occupancy evaluation surveys (POE) have been carried out for the Rotorua NOW Home® in Fordlands. The same methodology used in the POE surveys conducted for the Waitakere NOW Home® was applied to the Rotorua NOW Home®. The objective is to gain additional learning on the more difficult to quantify sustainability issues which are more social and qualitative in nature. The survey should complement the intense physical (quantitative) monitoring of the building.

The issues being examined by the POE include:

- use of local transportation facilities
- use of local amenities in close proximity
- use of landscape for food
- occupants' comfort
- occupants' perceived security
- occupants' mould-risk behaviour

In addition to capturing the occupant's opinions and relating them to the measured physical performance, an additional emphasis of the POE was to create a practical, repeatable methodology that could be applied in a cost-effective manner to all future NOW Homes® or similar research-based projects.

3.4.2 Method

The questionnaire methodology was based on that developed by Aronson (1994). This approach, used by the Queensland Research House social scientists (Szokolay, 2004), was fine-tuned by Stephen McKernon,[1] using the well-recognised, social systems-based 'differences and effects'-based questions. To be suitable for the needs of the NOW Home® projects, the survey needed to make the data collection as easy as possible, while gathering maximum information and to be as minimally intrusive to the occupants as possible, e.g. ensuring the quarterly survey could be easily completed within an hour by the occupants.

The questionnaire was refined after the first interview to slipstream further interviews. The methodology and design set out to include this flexibility and refinement so it was applicable to a wide range of subjects meaning the template could be used for all NOW Home® occupants.

The first occupant interview was carried out in November 2006 approximately six weeks after occupation. Due to difficulties in contacting the occupants to arrange interviews, a decision was made to interview only the principal adult resident for the four quarterly surveys.

The interviews were usually about 35–45 minutes long, thereby fulfilling one of the design objectives of ensuring that the surveys were less than one hour in length. There was a range of questions asked of the occupants. They can be grouped into:

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

[1] ***Social scientist and research psychologist, Supplejack Consultancy.***

In all, 35 specific features were examined. The features can be grouped into the following categories:[2]

Aesthetics	Noise
Space	Security
Privacy	Running costs
Comfort	Water
Airy	Ways of dealing with rubbish
Lighting	Things that the household does

In all, four interviews were undertaken as part of this review covering a one year period.

3.4.3 Findings

In terms of how the house has been performing and the services provided by (and surrounding) it, the tenants (as represented by the principal adult) had mixed views. When asked about the house and living in it overall, a rating of 10 (out of 10) was given – representing 'extremely different'.

The differences in the house itself that were repeatedly mentioned, were:

- Good large bathroom
- Sunlight coming through the whole house
- No dampness (except for the temporary leak to the roof)
- Quite warm throughout the house when sunny
- The indoor/outdoor connection to the outside
- Aesthetic look from the outside

Of the 35 specific features examined, most features (on average) were making a positive difference for the tenants. These included:

- Aesthetics (looks from the outside, looks from the inside)
- Space use (interior layout, indoor/outdoor flow)
- Comfort (cool in summer)
- Airy (fresh/airy feel, easy to get good airflow)
- Lighting (natural light, artificial light)
- Ways of dealing with rubbish (composting, recycling)
- Other features (no step shower tray, extractor fans)
- Things that the house does (walking to shops, schools etc.)

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

The areas in which the tenant had mixed or negative feelings, in terms of making a difference, were:

- Space use (spaciousness of whole house, including adequate storage)
- Privacy (privacy from neighbours and people outside, and privacy and personal times and places within the house)
- Security (feeling safe and secure)
- Specific features (wide doorways for wheelchair access, extractor fans, concrete floor, clothes line)

Perfect or near perfect (positive) scores (i.e. a 9 or 10) for *all* of the interviews were given to the following specific features of the house:[3]

- Cool in summer
- Easy to get good air flow
- Good natural light (daytime)
- No step shower tray

The primary occupant of the Rotorua NOW Home® was more circumspect than the occupants of the Waitakere NOW Home®, rating the house perfect or near perfect (9 or 10) in only four of the 35 categories, whereas the Waitakere NOW Home® residents gave these ratings to 19 of the 35 categories. Table 12 provides an overview of the primary occupant's response to the specific features of the house, by thematic area.

Feature	Overall response
Aesthetics	positive
Space	positive
Privacy	neutral
Comfort	positive
Airy	positive
Lighting	positive
Noise	positive
Security	negative
Running costs	unknown
Water	unknown

3 It should be noted that the responses to some issues varied considerably, due to the changes made while occupying the house – e.g. the extract fan installation and the fixing of the pellet burner.

Ways of dealing with rubbish	positive
Other features	negative
Things the house does	positive

Table 12: Summary of overall response, by thematic area

The house features that were least appreciated were:

- **The overall quality of the work.** There were many finishing-related faults, probably a lot due to the very compressed nature of the construction period, potentially compounded by the perhaps overly fussy nature of the tenant. These included:
  1) Extractor fan over hob was not finished until several months after the building was occupied.
  2) An improperly cured slab floor polyurethane finish which resulted in it being easily marked, scuffed and scratched by the tenant, resulting in a worn look when, in fact, it was very new.
  3) Poorly built divider (trellis) fence which was fragile and not aesthetically acceptable, and it had not been correctly lined up with the house.
  4) Unfinished paint covering to the skirting, and blotchy paintwork in the hallway.
  5) Door handles coming loose and not working properly.
  6) A poorly positioned clothes line that was unusable *without* a step ladder and a safety hazard *with* a step ladder.

- **Other functionality issues of the house,** including:
  1) A drop in water pressure of the shower flow when someone turns the taps on.
  2) Very low water pressure in taps (taking a very long time to fill a jug or a bath).
  3) Security issues – the main road boundary fence is too low, making it too easy for people to walk over it.
  4) Restricted storage space (in this case the occupant wanted to keep and store a large amount of items).

In all, the house was liked by the occupants, but to a considerably lesser extent than the Waitakere NOW Home® tenants. Another notable feature is the more dynamic nature of the occupants of the Rotorua NOW Home® – largely a reflection of the construction-related troubleshooting that was carried out several months after occupation. Examples of this included:

- The hob air extract being connected.
- The various door handles and taps that were loose or quickly worked loose.
- The leak in the internal gutter system.
- Lack of divisional fencing between the front and back halves of the section as well as the main fencing being too low.

4 Conclusions

Overall the Rotorua NOW Home® has had a mixed sustainable performance.

The reticulated water use of the household was low in the first year using just 57L per person per day, well within Beacon's HSS® 2006 benchmark of 180L per person per day. This was due to the effective use of rainwater, which provided 72% of the household's total water needs. This amounted to 809L per day for the first year, for the household.

While the rain tank provided a large proportion of the Year 1 water, the water pump and controller also used a high amount of electricity (370kWh or 5% of the total electrical load) indicating there is a potential conflict between sustainability objectives with increasing use of rainwater requiring increased electrical pumping energy.

The overall water use in the second year increased by 5% over the first year, to 848L per day. The rainwater controller failed early in the second year, so reticulated water was used for the services that were supplied by the rainwater in the first year (outdoor taps and toilets). Overall, reticulated water use in the second year was 200L per person per day – well outside of the HSS® target, even though efficient fittings were used.

The reticulated energy (electricity) usage in the Rotorua NOW Home® was 6,900kWh for Year 1 and 6,500kWh for Year 2, both lower than the 8,500kWh target for new homes in Climate Zone 2 in the HSS® 2006.

The reduction in energy use between Year 1 and Year 2 included a 340kWh reduction in water pumping energy (due to the fault in the rainwater system), a 230kWh reduction in lighting, but a 110kWh increase in range (oven and hobs) energy use.

The two major items provided to reduce the amount of reticulated energy (electricity) required was the SWH system and the wood pellet burner. Ideally, the pellet burner would have a heat transfer kit attached to it, but the building's roofline prevented it.

The SWH system included a number of performance limitations that lowered the overall effectiveness of the system, including;

- No timer on the supplementary heating element
- Sub-optimum collector angle
- Small collector area
- High heat losses from having an externally mounted cylinder

Over the year examined, the Rotorua NOW Home® SWH system provided 1,500kWh of solar energy (36%) to the total water heating needs. Had the performance of the Rotorua NOW Home® SWH system achieved 50% of water heating needs, then an additional 600kWh of reticulated energy would have been saved bringing the reticulated energy consumption for both years within the HSS® benchmarks.

The space heating in the Rotorua NOW Home® is provided by an efficient wood pellet heater and as such, largely removes space heating from the services to be supplied by reticulated energy. The thermal performance of the Rotorua NOW Home® therefore impacts on the amount the heating system used, the amount of wood pellets purchased and what the resulting indoor environment is like.

As the Rotorua climate is cooler than the Auckland climate, the heating requirements in Rotorua, given the same insulation levels and temperature schedules, would be greater than that for Auckland. While the Rotorua NOW Home® insulation levels were much higher than Building Code requirements at the time of construction, they were below the levels achieved in the Waitakere NOW Home®. In contrast to the Waitakere NOW Home® where heating was only required for one or two days, the wood pellet heater in the Rotorua NOW Home® was operated virtually every day over winter.

The resulting winter indoor temperatures in the Rotorua NOW Home® had an average evening temperature of 17.5°C – slightly below the 18°C HSS® benchmark. The impact of the lower thermal performance is seen in the winter overnight bedroom temperatures, where the average temperature in the Rotorua NOW Home®'s master bedroom is 12.9°C, considerably cooler than the 16°C recommended in the HSS®.

The cedar louvres in the living room provide a convenient means of providing passive ventilation into the house. These louvres may be expected to assist in lowering the relative humidity in the living areas and lower humidity levels were observed in the living space as compared with the two bedrooms. Evening winter humidity levels averaged 58% RH, well within the Beacon HSS® range of 40–70% RH. The overnight winter humidity in the bedrooms was close to the upper value of this range with the master bedroom just within (69% RH) and bedroom 3 just over (72% RH) the upper limits.

There is a fair degree of satisfaction by the principal adult occupant of the Rotorua NOW Home®. Aspects of the home's space usage, airiness, aesthetics and light (amongst others) were very much appreciated. However, there were several aspects of the home's overall finish and its day-to-day performance that the occupants thought were lacking. This was especially true in the lack of quality in the coating finish, privacy issues and the home's security.

5 References

Aronson, J., 1994. '*A pragmatic view of thematic analysis*'. The Qualitative Report. Vol. 2 No. 1. Downloaded from www.nova.edu/ssss/QR/BackIssues/QR2-1/aronson.html. 20 July 2009.

Beacon Pathway Limited, 2008. *The HSS High Standard of Sustainability*®. Downloaded www.beaconpathway.co.nz/being-homesmart/article/beacons_hss_high_standard_of_sustainability 14 July 2009.

Easton L., 2006. *Defining the Benchmarks for Beacon's High Standard of Sustainability*. Confidential report PR109/2 for Beacon Pathway Limited. Auckland, New Zealand.

Easton, L., 2007. Beacon's NOW Homes®: Building and Renovating Homes for Sustainability. Sustainable Building SB07 Conference, Auckland.

Mant, D.C. and Gray, J.A., 1986. *Building Regulation and Health*. BR97 Report by the Building Research Establishment (BRE). Garston, England.

Pollard, A., French, L., Heinrich, M., Jaques, R. and Zhao, J., 2008. *Waitakere NOW Home® Performance Monitoring: Year Two Report*. Report NO102/4 for Beacon Pathway Limited.

Pollard, A.R., 2009. *Solar Water Heating in the Waitakere and Rotorua NOW Homes® and in three Papakowhai Renovation homes*. Report HR2420/8 for Beacon Pathway Limited, Auckland.

Szokolay, S., 2004. Research House Case Study. Report for the Australian Greenhouse Office, Towards Healthy & Sustainable Housing Research Project, Queensland Government, Downloaded www.build.qld.gov.au/research/library/research/AGOCase-study04.pdf 3 August 2009.

6 Appendix A: Data Collection

The Rotorua NOW Home® is a simplification of the monitoring setup from the Waitakere NOW Home®, designed to collect information useful to calculate and understand the HSS® (Easton, 2006) benchmarks for the Rotorua NOW Home®. Table 13 shows a comparison of what was monitored in the Waitakere NOW Home® and the Rotorua NOW Home®.

Feature	Waitakere NOW Home®	Rotorua NOW Home®
Temperature/humidity	Two in family room, one in living room, one in each bedroom and one in main bathroom (14 channels)	Two in family room, plus two to cover bedrooms (8 channels)
Water	Each end-use separately metered (24 channels)	Street (potable), tank or street supply if required (non-potable) and solar (3 channels)
Electricity	Total, SWH Supplementary Heating, Solar Pump, Range, Lights, Refrigerator Freezer, Dishwasher, Tank Pump, Monitoring Equipment, Washing Machine, Four Appliances (14 channels)	Total, SWH Supplementary Heating, Range, Lights, Refrigerator Freezer, Rainbank, Monitoring Equipment, Two Appliances (9 channels)
Other temperatures	Hot water, cold water, tempered, cylinder, solar feed, solar return, north and south wall framing, outside temperature and humidity, reference junction (11 channels)	Hot water, cold water, outside temperature and humidity. (4 channels)
Other measurements	Family room CO_2 levels, solar insolation, tank level, security system, south and north wall framing conductivities, hot water availability, (14 channels)	-
Total data channels	77	24

Table 13: Comparison of the monitoring between the Waitakere NOW Home® and the Rotorua NOW Home®

7 Appendix B: Water End-uses and Metering

The water services connected to the Rotorua NOW Home® rain water tank were more restricted than was the case for the Waitakere NOW Home® rainwater tank. Table 14 provides a list of the Rotorua NOW Home® water services connected to the tank, directly to the water main as well as those services connected to the hot water system, which in turn was feed directly from the water main.

Direct use of main water	Hot water (direct from main)	Tank or main water
Accessibility shower cold Shower cold Bath cold Accessibility bathroom tap cold Bathroom tap cold Basin by toilet tap cold Kitchen tap cold Outdoor sink (cold only)	Accessibility shower hot Shower hot Bath hot Accessibility bathroom tap hot Bathroom tap hot Basin by toilet tap hot Kitchen tap hot Laundry tub hot	Accessibility toilet Toilet Laundry tub cold Outside taps (×3)

Table 14: The water services connected to the various water sources

Three high resolution water meters were connected to the water services in the Rotorua NOW Home® as shown schematically in Figure 13. It was intended to feed the Rainbank system via the street water (shown by the red dotted line in Figure 13 and not including the solid blue line crossed by the red ‘x’). However, the Rainbank was connected unmetered to the street (solid blue line in Figure 13) and the proportion of the water from the tank was analysed by examining the operation of the Rainbank pump at times of water flow where it has been assumed that if the pump operates then the water is sourced from the rain tank.

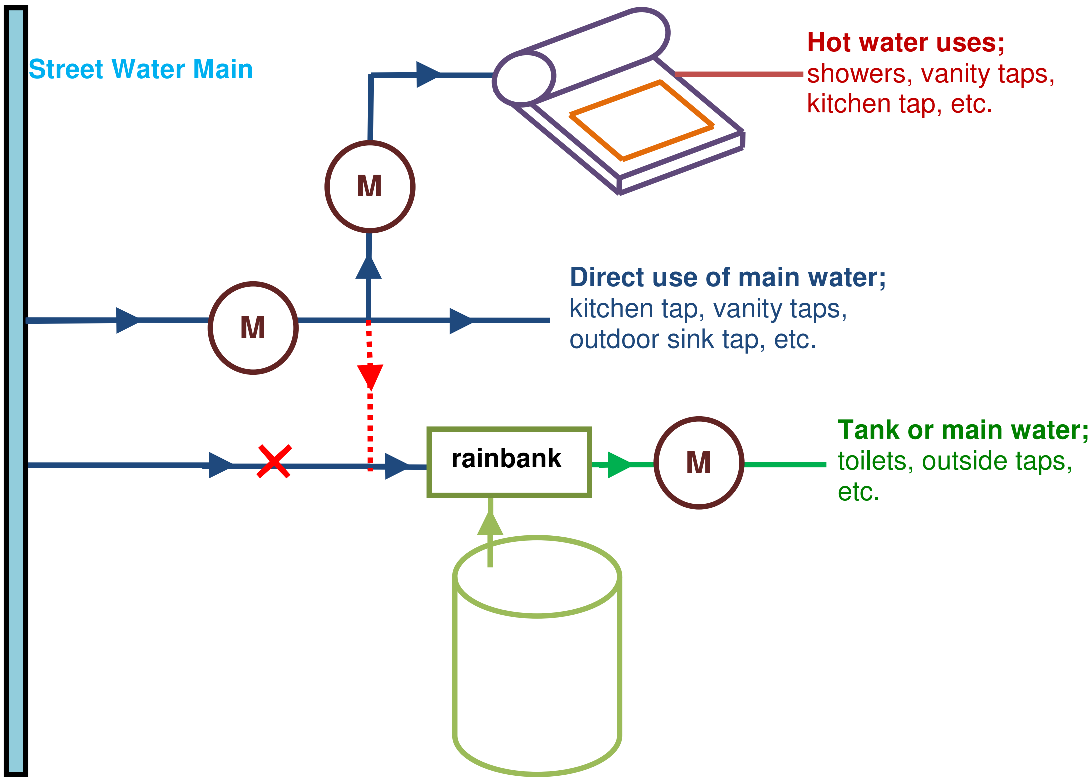

Figure 13: The water end-uses and metering locations