HN2800/6

Performance of the New Zealand Housing Foundation's Home*Smart* Home

Final

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About This Report

Title

Performance of the New Zealand Housing Foundation's HomeSmart Home

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Abstract

This report examines the performance of the NZHF HomeSmart Home with regard to the energy and water use and indoor environment. The home was assessed against Beacon's HSS High Standard of Sustainability® (HSS®) benchmarks for reticulated energy use and reticulated water use. It pays particular attention to the technologies not used in other Beacon demonstration homes.

Reference

Roberti, J., Pollard, A., Buckett, N. & Burrough, L. July 2011. Performance of the New Zealand Housing Foundation's HomeSmart Home.Report HN2800/6 for Beacon Pathway Limited.

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1 Overview

The New Zealand Housing Foundation (NZHF) HomeSmart Home is the result of a partnership between Beacon Pathway Limited (Beacon) and the NZHF.

This research project examines the performance of the NZHF HomeSmart Home with regard to the use of photovoltaics and the grey water system. The home was assessed against Beacon's High Standard of Sustainability® (HSS®) benchmarks for reticulated energy use and reticulated water use.

The aim of this project was focus on the sustainability features not previously examined in Beacon's research homes.

The outcome of the research project was that the use of photovoltaics and the grey water system did benefit the sustainability performance of the NZHF HomeSmart Home.

While the photovoltaics produced 2,000 kWh of electricity, only 50% of this energy was able to be utilised in the household. Surplus energy was exported back into the national grid. The grey water system enabled reticulated water usage to be reduced by approximately 20% annually.

2 Background

The NZHF is a not-for-profit trust which aims to provide access to affordable and sustainable housing for low income persons and households. Subdivisions are developed around repeated designs and houses made available to purchasers on a shared equity basis.

Beacon is a research consortium focused on improving the sustainability of New Zealand housing. Beacon has developed the HomeSmart Home procedures for houses to have lower resource use and be more sustainable. Beacon's philosophy is that sustainable homes are not just about energy efficiency; they are about using water wisely, creating a healthy indoor environment, selecting renewable and recyclable materials, and reducing construction and household waste.

Beacon recognised the need to verify that the HomeSmart Home procedures are effective and so developed benchmarks called the HSS High Standard of Sustainability® (HSS®).

2.1 The HSS® benchmarks

The HSS®[1] covers five key performance areas:

a) Energy
b) Water
c) Indoor environment quality
d) Waste
e) Materials

The HSS® benchmarks relevant to this research are:

Criteria	*Benchmark*
Energy use (Climate Zone 1[2]) - New home	5800 kWh/yr
Reticulated water use	125 litres / person / day
Living room average temperature	>18°C - 5-11pm in Winter▫
Bedroom average temperatures	>16°C - 11pm-7am in Winter▫
living room average RH	40-70% - 5-11pm in Winter▫
Bedroom average RH	40-70% - 11pm-7am in Winter▫

3 House design and applied technologies

The NZHF HomeSmart Home used in this project was built in Waitakere in 2009. A standard type 4a NZHF design was used as a basis with additions and modifications made to the design to align with HomeSmart Home procedures[3]. These variations cost around $43,500; about 20% of the total construction budget. This included a $20,000 photovoltaic (PV) system. Monitoring equipment was installed into the house at the end of 2009. The energy generation, energy use, water use, indoor temperatures and relative humidity were measured throughout 2010.

The NZHF HomeSmart Home was designed to showcase several options that homeowners can consider to save energy and water costs. The home has two storeys with four bedrooms and a bathroom upstairs with the dining, kitchen, lounge and toilet on the ground floor. The total floor area is 160 m^2. There is single story double garage attached on the south side which also includes a laundry. The home has good solar orientation and a high standard of insulation, having a HERS thermal rating of 8.5 stars.

[1] *http://www.beaconpathway.co.nz/being-homesmart/article/the_benchmarks*
[2] *http://www.beaconpathway.co.nz/being-homesmart/article/the_benchmarks*
[3] *Trotman (2010)*

Table 1 gives an overview of the key features in the home:

Table 1: Key systems and appliances featured in the NZHF HomeSmart Home[4]

Performance area	Features
Energy generation	Photovoltaic energy production system
Energy efficiency	Insulated concrete slab R-4.6 ceiling insulation R-2.6 external wall insulation U-PVC framed double glazing Heat pump water heating system 4 star washing machine Induction cook top 3.5 star dishwasher 4 star fridge/freezer (although occupants have another older fridge/freezer they are using as well) LED and compact fluorescent lighting Stand by easy reach switches Window coverings
Water efficiency	Low flow shower heads and taps 4 star dual flush toilets 4500 L rainwater tank for external use Grey water recycling system for toilets 4 star water efficient washing machine 4 star water efficient dish washer Rain garden to reduce stormwater run-off
Indoor environment quality	Low environmental impact paints Linoleum rather than vinyl used in bathrooms Extraction fans vented to outside in bathroom and laundry Opening windows for good ventilation Low profile, roof-mounted, solar powered ventilation vent
Waste	Good construction waste management practices Multiple waste bins in the kitchen Recycled plastic carpet

NZHF HomeSmart Home features that are of particular interest in this project are the photovoltaic energy production system and the greywater recycling system.

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4 ***http://www.beaconpathway.co.nz/new-homes/article/nz_housing_foundations_homesmart_home***

3.2 Photovoltaic system

The photovoltaic (PV) energy system produces electricity and has the ability to feed excess energy back into the national grid. The home does not feature any in-home storage capacity for electricity such as batteries. Batteries can contain corrosive liquids and require appropriate space for storage. Not having a storage system reduces the on-going maintenance and cost of the system.

The PV system consists of eight roof-mounted photovoltaic panels (Figure 1) and a Sunny Boy™ controller\inverter unit next to the fuseboard (Figure 2). The PV panels have a total surface area of 10.4 m². They are mounted at an angle of 28° on the side of the roof that faces North-west-west (NWW) – the most suitable of the available orientations.

Figure 1: PV panels on the NWW facing roof side

Figure 2: The Sunny Boy™ grid connection inverter

The PV array produces electricity in proportion to the solar radiation incident on it. Solar radiation incident tends to peak in the middle of the day but can be reduced by cloud cover or by external shading. It is not possible to align the output of the PV array to when the household is requiring electricity.

Should the PV array output exceed the household demand at any given time then this surplus electricity is available to be exported back into the national electricity grid.

3.2.1 Exporting to the grid

Exporting electricity back to the grid is subject to a connection agreement between the household and the electricity supply company. Unlike many overseas countries, New Zealand regulations do not permit net metering[5]. Net metering is where the electricity meter measures the difference between the electricity supplied to the household and what is exported back. In New Zealand, excess electricity produced by a PV system cannot reverse flow through the meter and instead bypasses it. No recording device was installed in the NZHF HomeSmart Home to measure the exported electricity; therefore, the occupants do not receive an incentive for allowing this to occur. A further result is that no data was collected as to the amount of excess electricity generated by the PV system.

3.3 Grey water system

The NZHF HomeSmart Home features a grey water system, rainwater tank (4,500 L), and water efficient appliances to reduce use of the reticulated water supply. The rainwater tank is exclusively used for the garden and the grey water system flushes the two toilets.

The grey water system was an Ecoplus™ water recycling system (Figure 3). It receives waste water from the laundry and bathroom, which is decontaminated and stored within the system for reuse as grey water to flush the two toilets in the building. Supply to each toilet is controlled by a separate water pumps taking water from the system internal reservoir. Grey water piped through the house in purple colour-coded pipes conform local regulations.

Figure 3: Eco-plus grey water system

[5] *Watt (2009)*

The toilets are connected both to the grey water system and the mains water supply feeding point. The mains water supply feed is intended to function as a back-up for the grey water system. The toilets are water efficient, having a rating of 4-stars according to New Zealand's Water Efficiency Labelling Scheme (WELS). They are rated to use 4.5 litres of water per full flush and 3 litres per half flush.

A standard 230/12 volt transformer provides the power the 12-volt supply pumps of the grey water system. It was placed outside in a separate wall-mount waterproof container behind the grey water system (Figure 4).

Figure 4: AC/DC Transformer for grey water system

4 Monitoring

Monitoring was undertaken for a period of 12 months, starting in December 2009 and running for 2010.

4.1 Indoor environment

To gain some general insight into the performance of the NZHF HomeSmart Home information about the indoor environment was collected. Monitoring of the temperature and relative humidity in the living room and the main bedroom was carried out using two Hobo U10 loggers[6] (Figure 5).

Figure 5: Hobo Temperature and humidity data logger

The Hobo is a two-channel temperature and relative humidity logger with 10-bit resolution. The logger can measure and store up to 52,000 samples with a sampling frequency down to one per second. Both Hobo's were placed in non-intrusive locations (one in the living room and one in the main bedroom) that were not exposed to direct sunlight (Figure 6). Sampling was performed at a rate of one measurement every 10 minutes.

Living room   Bedroom

Figure 6: Location of Hobo loggers in the living room and bedroom

[6] ***http://www.onsetcomp.com/products/data-loggers/U10-data-loggers***

4.2 Electricity use and the PV system

The set up for the monitoring of electricity flows for the NZHF HomeSmart Home is shown in Figure 7.

Location 1 identifies the meter used by the electricity retailer. This meter was read every two months.

Within the home, a three channel electricity meter was used to understand the household energy use. The three channels were assigned to:

- the electrical output of the PV array (Location 2)
- the electricity input required by the grey water system (Location 3), and
- the electricity input required by the rest of the house (Location 4).

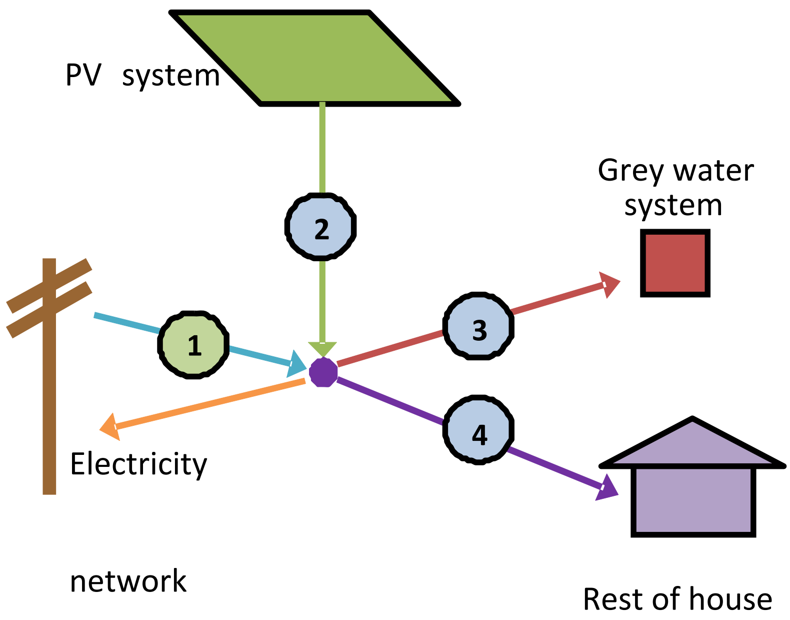

Figure 7: Set-up of electricity use monitoring

The three channel electricity meter used was a VM series Direct Connect Meter – VMP3120-230[7] from Energy Intellect™ (Figure 8). This device allows for remote communication using the cellular network. Daily data was retrieved by Energy Intellect and sent to BRANZ on a monthly basis.

[7] *http://www.energyintellect.com/index.php/smart-metering/vm-smart-meter-series*

Figure 8: Installation of the Energy Intellect™ meter

The three channel meter has a large measurement range of 500 mA-120 A with a nominal start current of 40 mA. The output signal is a discrete pulse signal with one pulse per Watt-hour (Wh). The sampling period can be programmed over a range of discrete settings from one second (lowest) to one hour (highest) intervals. For this research project the sampling period was set at five minute intervals.

4.3 Grey water use

In monitoring the grey water system, both the energy and the amount of grey water used were of interest. Measuring the grey water flow at the outlet with multiple water meters was not a feasible option due to the water being contaminated. Therefore the measurement approach chosen was grey water consumption measured by proxy based on the energy use of the pump. Given the consistent flow rate of the pump, it was anticipated that a linear relationship existed between the amount of water used and the energy required to pump the water through the system. Toilet flushing and refilling of the fixed volume cistern creates repeating patterns in energy use link to a particular volume water displaced from the grey water reservoir to fill the cisterns of the toilets.

All reticulated water used in the NZHF HomeSmart Home passes through a Kent/Elster meter (Figure 9), located along the driveway to the garage. Owing to a lack of space it was not possible to connect a pulse probe and a data logger to this standard water meter. Instead a manual reading was taken at the start of monitoring and billing records from Watercare Services Limited were used for the estimation of average water usage by the household over the monitoring period.

Figure 9: Water meter

5 Results

5.1 Indoor environment

Figure 10 and Figure 11 provide average daily profiles by month of the indoor temperature and relative humidity in the NZHF HomeSmart home.

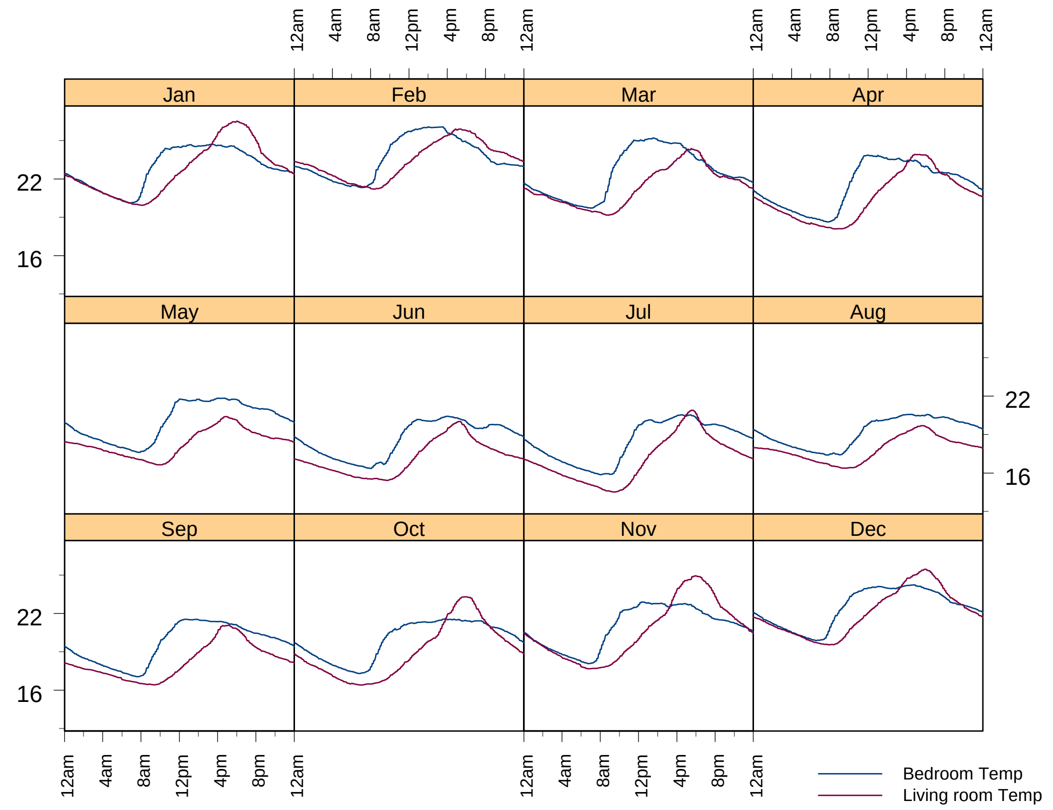

Figure 10: Average daily profile for temperature (˚C) by month

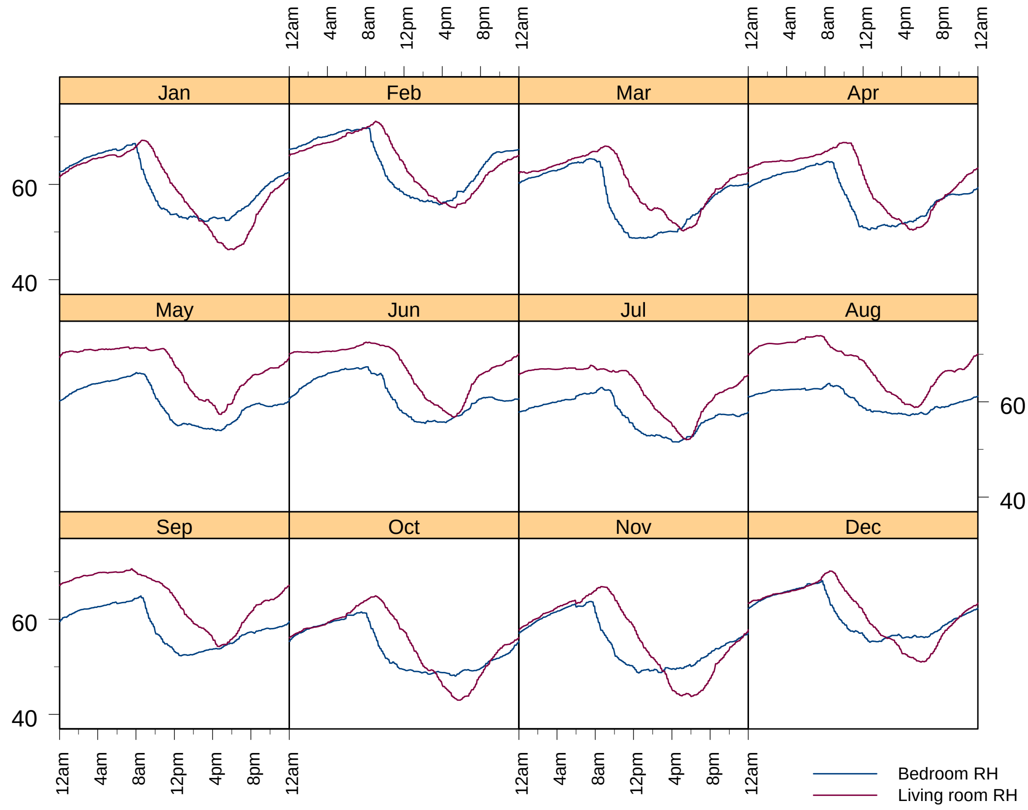

Figure 11: Average daily profile for relative humidity (%) by month

The main bedroom's temperatures were consistently higher than in the living room. This may reflect the reduction in solar gain in the living room due to a retaining wall and high fence close to the living room's eastern wall and the occupants often keeping the curtains shut on the northern wall for security reasons. The upstairs positioning of the bedrooms may play a role in elevating the bedroom temperatures due to stack effects.

During the winter months, the temperatures were sufficiently warm. During summer both the living room and main bedroom had temperatures above 25°C. In an interview, the occupants stated that they found overheating to be a problem[8]. While they would have liked to open the windows more, they were limited by security latches on both levels. They were not comfortable opening the lounge doors, possibly due to security concerns after a burglary soon after they moved in. Some external shading may assist. The extraction fan in the hallway was used to help with the airflow.

The relative humidity levels in the home are on the higher side of what is ideal, due in part to the humid Auckland climate. The relative humidity in the living room is higher than the relative

[8] *Trotman (2010)*

humidity in the bedroom. Over winter the early morning relative humidity in the living room appears consistently high. The lack of an externally-vented rangehood in the kitchen to extract steam from cooking directly together with the open plan design would increase the moisture levels in the living room.

5.2 Electricity use and the PV system

From the data collected, the NZHF HomeSmart Home sourced a combined total of 6,890 kWh of electricity from the grid supply (from electricity company meter records) and the PV system (from monitored data). Actual household use accounted for approximately 5,890 kWh of energy. The difference between these two amounts (1000 kWh) is the amount of surplus electricity produced by the PV system that was not immediately able to be used by the home and was exported back to grid. This is shown graphically in Figure 12. The PV system produced 2,000 kWh of electricity so the exported amount equals half of the electricity produced by the PV system.

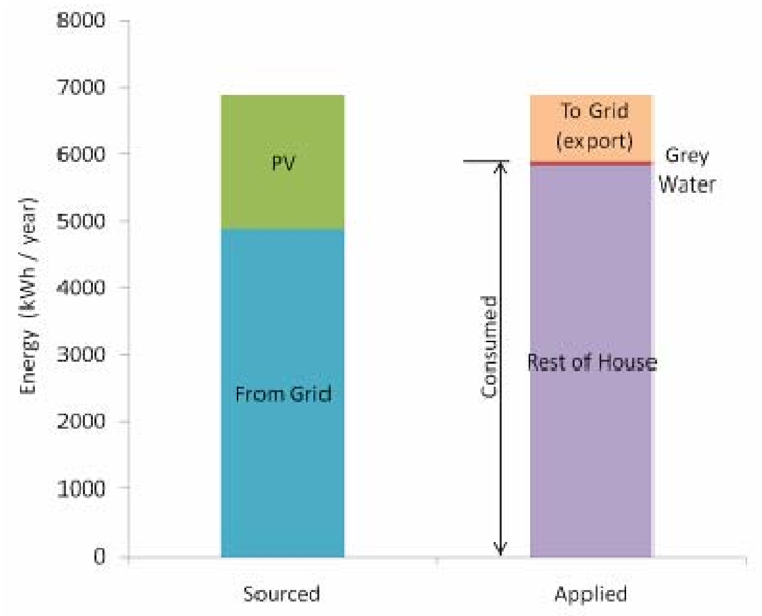

Figure 12: Total energy balance of the NZHF HomeSmart Home

Figure 13 shows the monthly energy consumption and generation for the home. The seasonality of both the total energy consumption and the PV system can be seen. The grey water system is only a very small proportion of the total energy of the household.

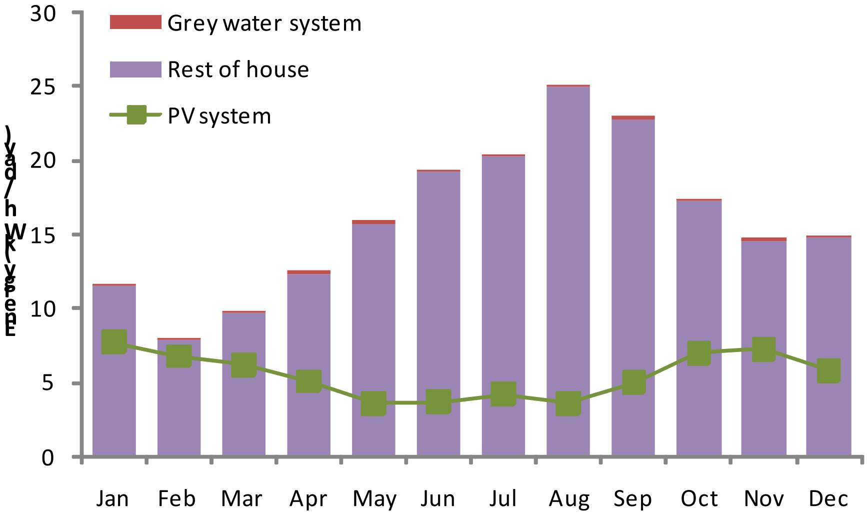

Figure 13: Average monthly energy used and PV system output

Figure 14 shows the monthly percentage contribution of electricity produced by the PV system to total energy use of the household. As expected the output of energy from the PV system peaks in the summer months when solar radiation is highest. Conversely, the highest energy demand from the household is during the winter months due to increased heating (space and water) and lighting requirements.

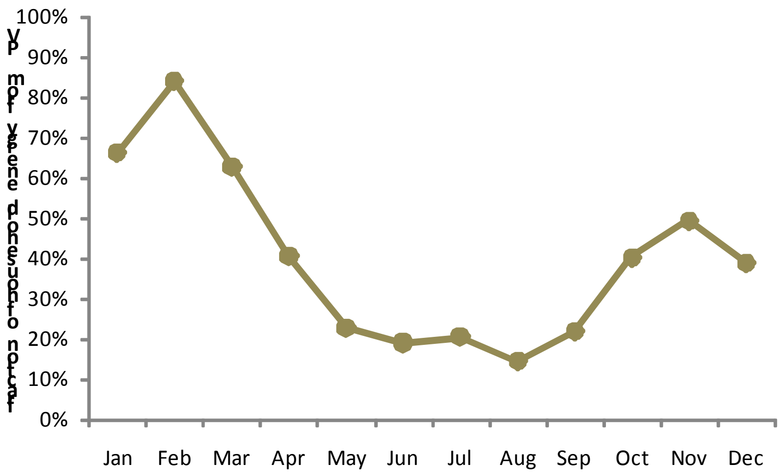

Figure 14: Contribution of electricity from PV system to total household energy use

5.2.1.1 Matching generation and consumption

Figure 15 shows the average time of day profile for electricity generated by the PV system (shown in green) against the daily pattern of household energy consumption (shown in brown). The output of the PV system peaks in middle of the day whereas household energy use peaks in the mornings and evenings.

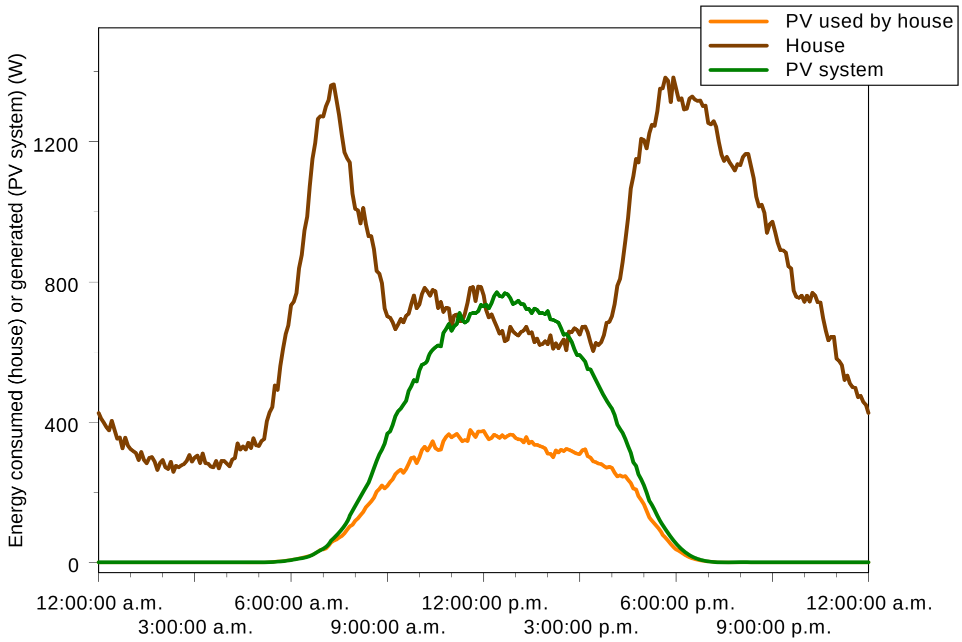

Figure 15: Average daily profiles of PV system output (green), household energy use (brown) and the amount of energy produced by the PV system that is immediately used within the house (orange)

Care must be taken when comparing the average output of the PV system and the average total household demand. The energy balance of a PV system occurs in real time and comparing averages can provide misleading information on how much storage is required or how much electricity will be exported to the grid.

From examining the energy balance of the five minute data it was possible to estimate the average amount of the output of the PV system that was able to offset the energy use within the household This is shown by the orange line in Figure 15 and can be seen to be much lower than the output of the PV system.

5.2.2 Expected PV performance

RETScreen[9] is an international tool for evaluating energy efficiency projects and includes a process to evaluate PV systems.

The RETScreen evaluation of the NZHF HomeSmart Home PV system estimated an annual energy output of 2,140 kWh (refer to Appendix A). The actual metered output of the PV system was 2,000 kWh (approximately 6.5% lower).

The amount of solar radiation used to calculate the average year data in the RETScreen evaluation was 1,530 kWh. This was slightly higher than the actual global horizontal solar radiation for 2010 which measured 1,460 kWh (a 4.5% difference). Figure 16 shows the difference between these radiation amounts by month. The difference may be due to deviations between the inclination and direction of the PV systems from that which was modelled.

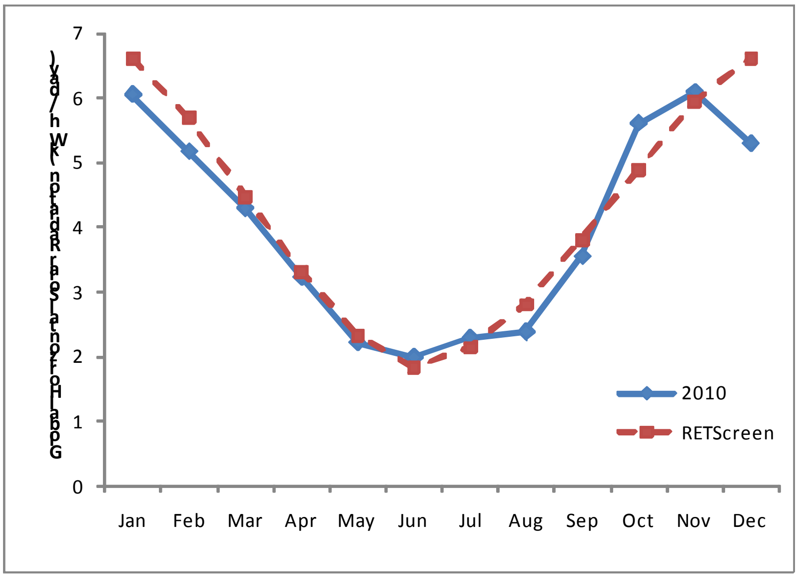

Figure 16: Estimated and actual global solar radiation for 2010

A comparison of the daily energy generated from the PV system and the daily horizontal radiation is shown in Figure 17. A correlation is evident with the energy generated aligned to the amount of horizontal radiation. This indicates the PV system is performing well. The solar radiation data was measured approximately 5km away from the site and was accessed through the NIWA Cliflo database[10].

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[9] *Natural Resources Canada (2011)*

[10] *NIWA (2011b)*

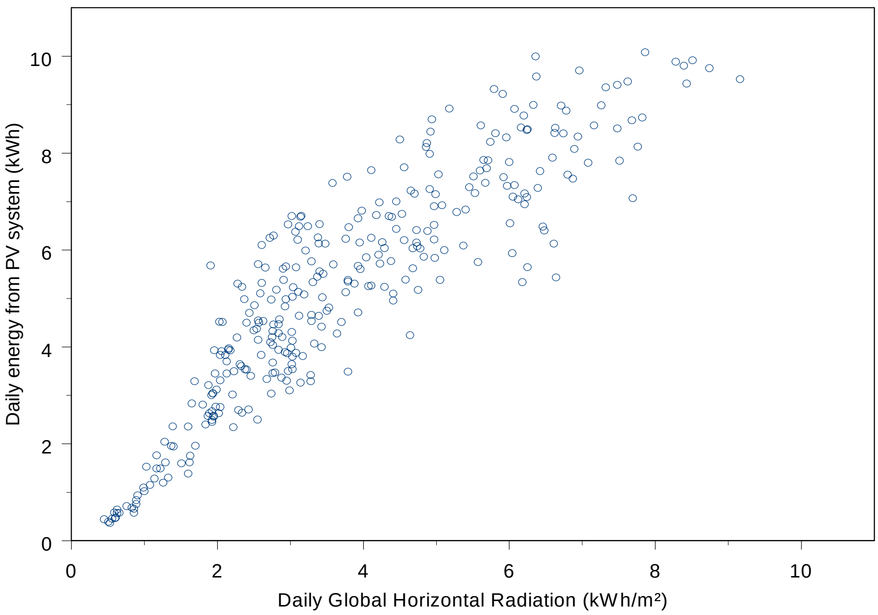

Figure 17: Output from PV system compared to global horizontal radiation

5.3 Grey water use

The low electricity use of the grey water system was just within the detection range of the electricity meter resulting in an irregular discrete pulse signal. Retrieval of useful water use information from this low signal required signal processing to reveal the details. A second order low-pass filtering was applied to the original signal to produce a filtered signal. In figure 16 a typical day-night cycle of this filtered signal is shown in blue to allow description of the signal's characteristics.

The elevated base level of the signal in this figure corresponds to the stand-by power consumption of the transformer, that feeds the two 12 Volt pumps. The blue line in Figure 18 also shows that superimposed on the continuous stand-by power of the transformer there are irregular pulses. These pulses correspond to pump activity triggered by toilet flush events. Obviously, the continuous stand-by energy use of the grey water was far more prominent than the incidental energy used for pumping water to the toilets. Further signal processing resulted in the green line in Figure 18 that singles out the electricity use of toilet flushing events. Analysis of the data found that a single flush of 4.5 litres corresponded to 0.33 Wh of power use.

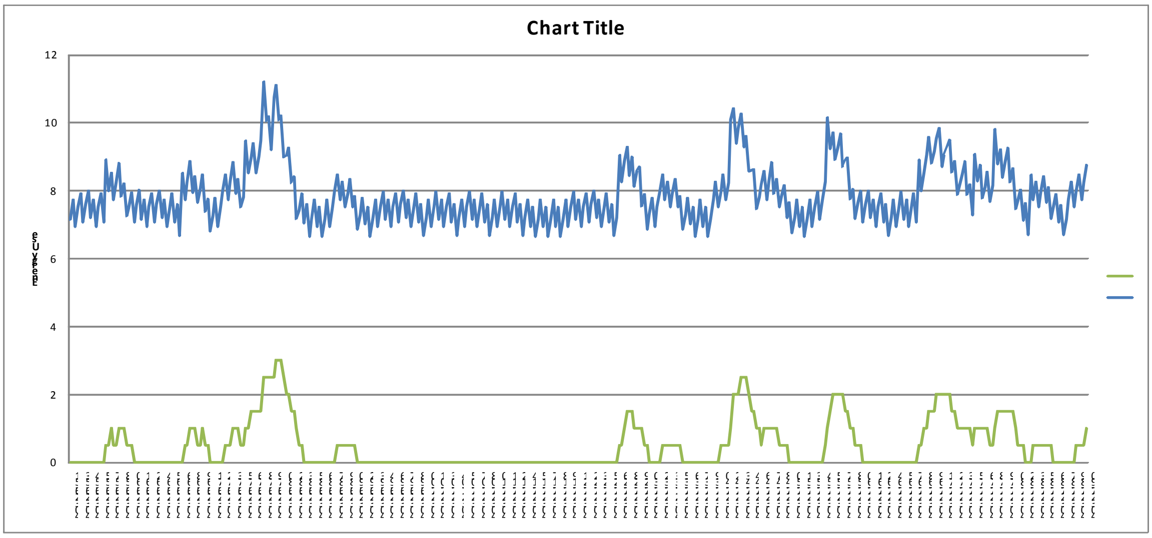

Figure 18: Pump energy signal (blue) after filtering, toilet flush events (green) seperated from the stand-by power usage

During the monitoring period, there were four intervals when the grey water system was turned off - a total of 22 days over the analysed period of 257 days. Therefore operational data was collected on 243 days. Most of these intervals coincided with school holiday periods suggesting the resident family switched off the system when they left the house for longer periods.

Figure 19 presents the average daily energy-use profile over the monitoring period associated with the grey water system. This profile gives information about the probability of somebody in the household using the toilet at a particular time during the day. This particular shape of the profile with elevated use in the morning and evening aligns with the sort of behaviour that is expected for the day-night rhythm in a typical family household.

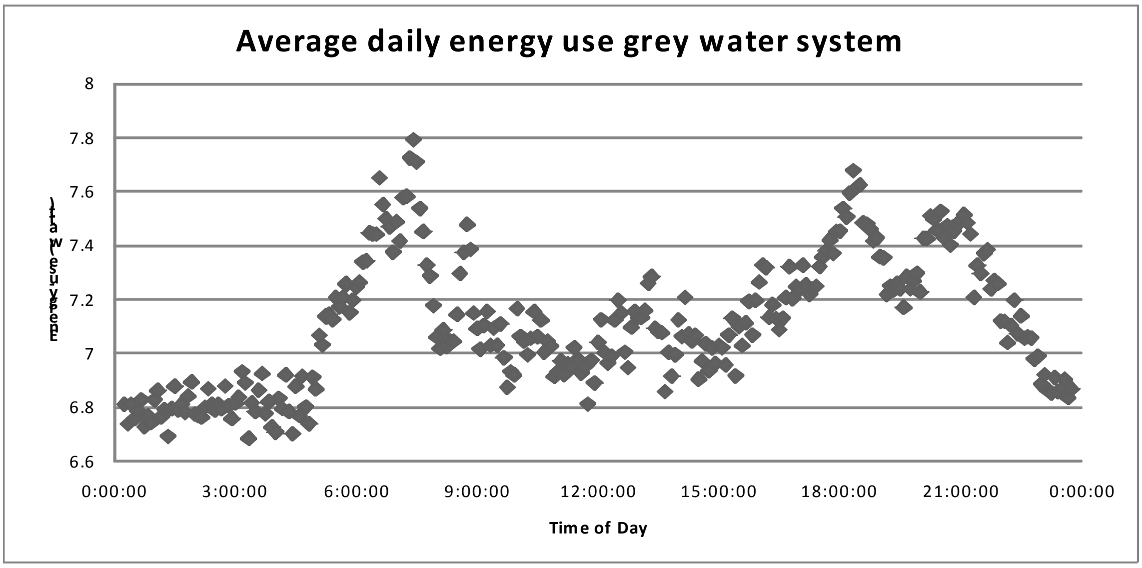

Figure 19: Average daily energy use profile for a grey water system

A general overview of energy use required in utilising the grey water system is provided in Table 2. When the grey system is switched-on its transformer uses 7.4 W continuously. The standby power consumption accumulates to a daily total of 0.18 kWh. The actual pumping of the grey water uses daily 0.008 kWh of electricity. On average this is equal to 25.4 full toilet flushes per day using the calibration factor of 0.33 Wh per 4.5 litre flush. This average number corresponds well to the number range (for similar households) identified in both the Water Energy End-use Project[11] and Auckland Water Use Study[12]. The total annual energy consumption of the grey system including both energy use of the transformer and pump was 68.1 kWh.

Table 2: Data Overview

Parameter	Result
Average power consumption of transformer on standby	7.4 W
Daily energy consumption of transformer on standby	0.18 kWh
Annual energy consumption of transformer on standby	65 kWh
Daily energy consumption of pump in operation	0.008 kWh
Annual energy consumption of pump in operation	3.1 kWh
Total annual energy consumption of transformer and pump	68.1 kWh
Energy consumption of a single flush (4.5 litres)	0.333 Wh
Average number of toilet flushes per day	25

5.3.2 Reticulated water use

The HSS® provides a performance benchmark of 125 litres of water/person/day as a sustainable amount. To verify if the NZHF HomeSmart Home meets this benchmark, readings from the water meter were analysed. Table 3 shows the recorded readings for water consumption taken by Watercare Services Limited[13]. An initial reading was taken by BRANZ during the installation of the monitoring equipment prior to occupancy of the NZHF HomeSmart Home.

Table 3: Water meter readings

Label	data source	reading date	meter reading
R2	*Branz*	4/12/2009	55
R3	*Watercare*	10/03/2010	130
R4	*Watercare*	13/09/2010	223
R5	*Watercare*	16/03/2011	328

[11] Heinrich (2007)
[12] Heinrich & Roberti (2010)
[13] http://www.watercare.co.nz

Based on these water meter readings, average daily usage and annual projected use can be calculated (Table 4).

Table 4: Analysis of water usage

Label	Stop date	Start date	Period length (days)	Usage (m^3)	Average Daily Usage (lpd)	Average Daily Usage (lpd/person)	Projected Annual Usage (m^3)
Period 1: R3-R2	10/03/2010	4/12/2009	96	75	781	156	285
Period 2: R4-R3	13/09/2010	10/03/2010	187	93	497	99	182
Period 3: R5-R4	16/03/2011	13/09/2010	184	105	571	114	208
Total Period: R5-R2	**16/03/2011**	**4/12/2009**	**467**	**273**	**585**	**117**	**213**
Water savings by grey water system					***115***	***23***	***42***
Water saving as percentage of current water usage							***20%***
Estimated Usage without Grey Water					***700***	***140***	***255***

The average daily usage across the total time period was 585 litres per day. Period 1 shows a much higher average daily usage of 781 litres per day. This may be a result of the household trying to establish a lawn during a dry summer period and using reticulated water for irrigation when the rain tank was empty.

The lowest daily usage was during Period 2 which corresponds to the winter months.

Based on the average number of toilet flushes (25.4) and the known capacity of each flush (4.5 litres), the grey water system saved approximately 115 litres per day of reticulated water. This equates to a saving of 42 m^3 of water annually. As a result household usage of reticulated water is reduced from 255 m^3 to 213 m^3 per annum (approximately 20%). The grey water system also reduced the waste water stream from the household by the same volume.

With the benefit of the grey water system, the average daily usage per person is calculated to be 117 litres per person per day. Approximately 23 litres of reticulated water per person per day was 'saved' by the use of grey water for flushing the toilets.

6 Discussion

6.1 HSS® benchmarks

The research results show that the NZHF HomeSmart Home met all the HSS® benchmarks that were monitored (Table 5).

Table 5: NZHF HomeSmart Home assessed against relevant HSS® benchmarks

Criteria	Benchmark	NZHF HomeSmart Home
Energy use (Climate Zone 1) – New home	5800 kWh/yr	3890 kWh/yr
Reticulated water use	125 litres / person / day	117 litres / person / day
Living room average temperature	>18°C - 5-11pm in Winter▫	19.0°C
Bedroom average temperatures	>16°C - 11pm-7am in Winter▫	18.0°C
Living room average RH	40-70% - 5-11pm in Winter▫	62%
Bedroom average RH	40-70% - 11pm-7am in Winter▫	62%

Winter has been taken as May to September

The total energy use for the NZHF HomeSmart Home was 5,890 kWh. The PV system produced a total of 2,000 kWh so the overall net balance of the NZHF HomeSmart Home was 3,890 kWh.

For reticulated water use, the daily water usage per person was 117 litres per day. This is less than the HSS® benchmark of 125 litres and was achieved with the benefit of the grey water system. Without the grey water system, the reticulated water usage per person would have been 140 litres per day.

6.2 PV system

The PV system produced 2,000 kW of electricity during 2010, which is in line with what was expected from the system design, and solar radiation in Auckland. This was equivalent to one-third of the total electricity needs of the household. Large scale deployment of such systems could provide for a significant proportion of residential energy use.

The PV system cost approximately $20,000. The retail value of the electricity it produced was around $530 (using a cost of 26.6 ¢/kWh[14]). Half of the electricity produced by the PV system was exported back into the electricity grid for which the household received no financial

[14] *MED (2011)*

benefit[15]. The financial return to the occupants from having the PV system would be around $265.

Having the costs and benefits of PV systems falling on different groups creates a distorted market. While the financial costs of the installing a PV system is fully met by the system purchasers (generally the household occupants), having a proportion of the PV system output fed back into the grid at no cost means that the benefits from the system are shared with electricity companies. Having the occupants receive some financial return for the exported electricity would address this imbalance. Many countries make use of rates much higher than the retail price (feed-in tariffs) to encourage these systems to be installed.

To reduce the amount of electricity that is exported, it is important to align energy services to times of the day that the PV system is producing energy. End-use monitoring would assist in better understanding the opportunities for matching household demand and PV generation. For example, some of the overnight energy use may be due to water heating. An alternate arrangement would be to limit the operation of the heat pump water heating system to during the day, when the PV system is operating.

The household has an important role in considering a shift in energy demand to times when solar radiation is higher. In the future electric vehicles could play an important role in utilising PV generated energy.

6.3 Grey water system and water efficiency

The grey water system reduced reticulated water use in the NZHF HomeSmart Home by approximately 20%. Would a larger saving have been possible?

For this house, water use in the bathroom and laundry is approximately 66% of the metered total water use based on the end-use distribution in the Auckland Water Use study[16]. Considering these two sources the annual grey water flow is estimated 140 m^3 per annum. This means that the system utilized about 30% of the available grey water volume. 70% of the recycled water goes unused into the drain. The grey water system is currently underutilised. Therefore it seems that the particular combination of a grey water system with low-flow toilets is over-engineered with unnecessary doubling up of water efficiencies. The potential to further reduce reticulated water consumption could be realised by the using the grey water for irrigating of lawn areas during the summer months, particularly once the rainwater tank is empty.

15 Note the occupants later installed a smart meter and were able to receive credits on their power bills

16 Heinrich et al. (2010)

6.3.1 Grey water system cost benefit analysis

Use of the grey water system delivers annually a financial benefit to the household. This can be identified from the balance between the extra cost of the energy used for pumping grey water and the reduced cost due to saving in reticulated water use.

Based on the current general water supply fees and waste water charges in Auckland[17], an effective price of \$4.34 per m^3 can be calculated for water use savings. Use of the grey water system saved the NZHF HomeSmart Home $42m^3$ of water, which corresponds to an annual saving of approximately \$182 for the household.

Running the grey water system requires 68 kWh of energy. Based on the unit rate of \$0.25 per kWh, the cost to be offset is about \$17. Additional expenditure associated with the grey water system includes chemical treatment of the water. Recommended in the owner's manual of the system is the use of two standard calcium hypo chlorite tablets per week with an estimated cost of around \$45 per year. Possible further additional costs for repairs and maintenance have been disregarded.

On balance the grey water system produces an overall annual financial benefit to the household of \$120.

The grey water system cost approximately \$3,745[18] excluding installation. Based on these calculated savings the simple payback period on this system is at least 32 years.

It is important that the system is operated and maintained properly to achieve optimal benefits and minimal health risks. An inventory of these risks can be found in the Beacon report WA7060/6 *Barriers to Water Demand Management: health, infrastructure and maintenance*[19]

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17 WaterCare Services Ltd., valid 1 July ,2011 until 30 June 2012 (Water supply rate of \$1.30/m³; waste water price structure of \$43.28 fixed charge and 75% of volumetric charge of \$4.06 per m³)

18 www.wastewater-recycling.co.nz (supplier of the grey water system)

19 Kettle (2010)

7 Conclusion

The introduction of a PV system and grey water system helped reduce the resource use of the NZHF HomeSmart Home. Only with the contribution from these components was the NZHF HomeSmart Home able to meet the HSS® benchmarks for energy and water use.

The NZHF HomeSmart Home's PV system performed as expected. The 10.4 m^2 PV array provided 2,000 kWh, which corresponds to one third of the households electricity needs. The PV system costing $20,000 was expensive compared to the energy savings it delivered. Half of the output of the PV system was exported to the electricity network for no return making the system difficult to justify in financial terms.

The grey water system was well supported by the occupants who undertook the required maintenance on the system. The system performed well and reduced the households demand on the reticulated water supply by approximately 42 m^3 or 20%. With the current low cost of water, the financial benefit from the grey water system is presently small.

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9 Appendix: Indoor Environment

This appendix has further information on the indoor environment in the house. The following tables and figures are presented:

f) Figure 22: Histogram of relative humidity in the living room for 2010

Figure 23: Histogram of relative humidity in the bedroom for 2010

Table 6: Average daily temperatures and relative humidity by month

Table 6: Average daily temperatures and relative humidity by month

	Temperature (°C)		Relative Humidity (%)	
	Living room	**Bedroom**	**Living room**	**Bedroom**
Jan	22.7	22.9	59	60
Feb	23.4	23.7	65	64
Mar	21.4	22.5	60	57
Apr	20.6	21.5	61	58
May	18.4	20.1	67	60
Jun	17.2	18.6	67	61
Jul	17.1	18.5	63	57
Aug	17.9	19.2	68	60
Sep	18.3	19.7	65	58
Oct	19.0	20.0	55	54
Nov	20.7	21.0	56	55
Dec	22.1	22.5	61	61

Table 7: Average daily minimum temperature and relative humidity by month

	Temperature (°C)		Relative Humidity (%)	
	Living room	**Bedroom**	**Living room**	**Bedroom**
Jan	19.9	20.1	46	52
Feb	21.2	21.3	55	56
Mar	19.2	19.7	50	49
Apr	18.1	18.6	50	51
May	16.6	17.6	57	54
Jun	15.4	16.4	57	56
Jul	14.5	15.9	52	52
Aug	16.4	17.4	59	57
Sep	16.4	17.1	54	52
Oct	16.4	17.3	43	48
Nov	17.7	18.1	44	49
Dec	19.6	19.9	51	55

Table 8: Average daily maximum temperatures and relative humidity by month

	Temperature (°C)		Relative Humidity (%)	
	Living room	**Bedroom**	**Living room**	**Bedroom**
Jan	26.5	24.7	69	69
Feb	25.9	26.1	73	72
Mar	24.4	25.2	68	65
Apr	23.9	23.8	69	65
May	20.4	21.9	72	66
Jun	20.0	20.4	73	67
Jul	20.9	20.5	68	63
Aug	19.7	20.6	74	64
Sep	21.1	21.6	71	65
Oct	23.3	21.6	65	61
Nov	25.0	22.9	67	64
Dec	25.5	24.2	70	68

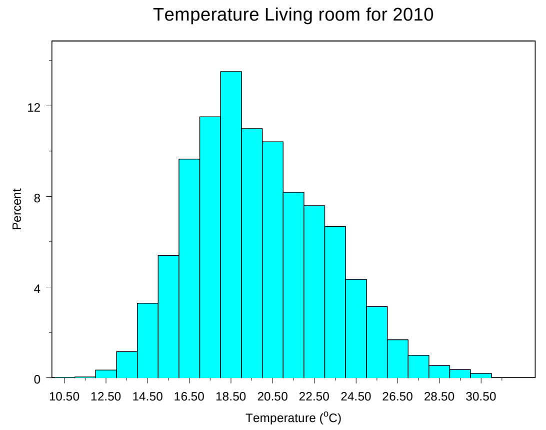

Figure 20: Histogram of living room temperatures for 2010

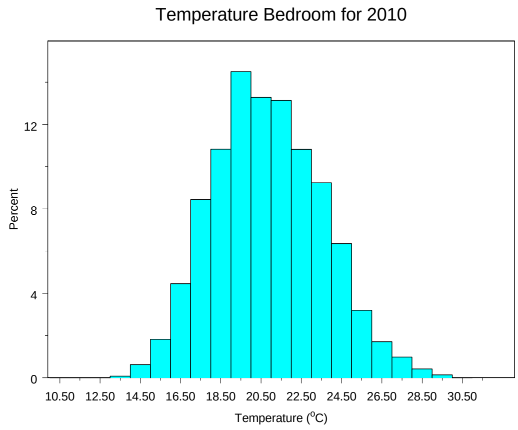

Figure 21: Histogram of bedroom temperature for 2010

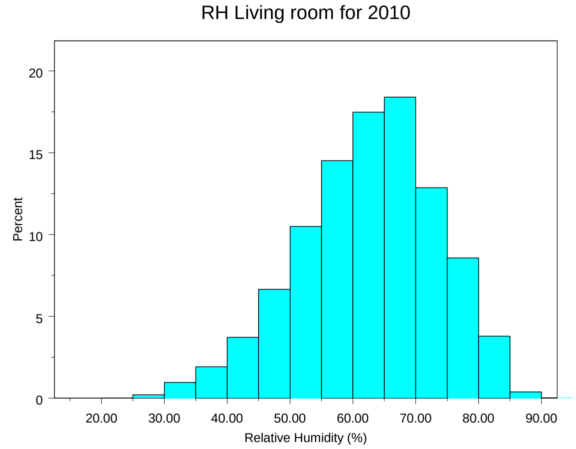

Figure 22: Histogram of relative humidity in the living room for 2010

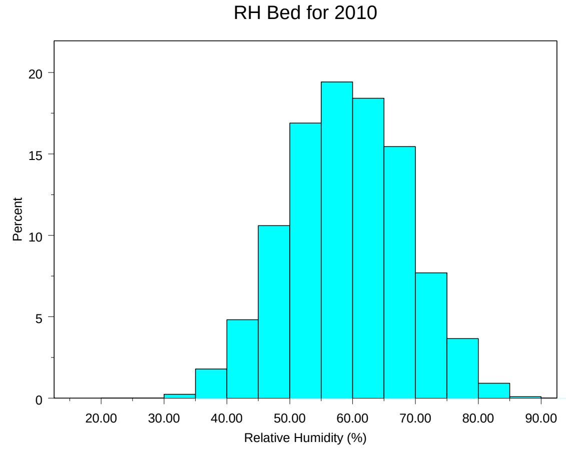

Figure 23: Histogram of relative humidity in the bedroom for 2010