10 Household Living Labs Study

Results Summary

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Executive Summary

Houses designed to be energy and water efficient often do not perform as intended. One of the reasons for this is occupant behaviour. Rebound effects and lack of awareness mean that behaviour and practices need to be addressed as part of the strategies to reduce emissions in the residential sector. While the design is important to minimise resource consumption in the house, the way houses are used can have an equal effect on performance. However, energy and water use in households are still poorly understood and so are the effects of behaviour change strategies.

To address these questions, ten detached suburban family homes located in the City of Fremantle (Western Australia) were monitored (grid energy, water, rainwater, temperature and PV) over a two-year period, subject to an educational intervention strategy at the start of Year Two. While these houses have a mix of occupancies and designs, they all present energy or water efficient features.

As a result of this intervention program, houses managed to save between 4 and 15% of grid electricity, between 11 and 27% of gas and between 11 and 30% of total water use between the two years. However, some houses also increased their energy and water use in the same period. While these households made an effort to modify habits, technical problems occurred, hindering the efforts. Issues were due to poor maintenance of the solar panels and rainwater tanks as well as water leaks and the interruption of solar generation after heavy rainfall events.

This research confirmed that energy efficient or ‘waterwise’ houses do not always perform optimally. Modifying the way houses are operated daily can make a great impact on performance and bills. Real-life monitoring systems can help detect failures and inform households to ensure that resources are not wasted. It is important that real-life monitoring is engaging, user-friendly and meets household needs so they are frequently used.

Six academic journal publications are being prepared as part of this study, in which results will be discussed in further detail.

Above: The research team and occupants of one of the participating family homes.

Project Background

Since 2012 all new houses built in Australia need to meet a minimum of 6 Stars under the current NatHERs (Nationwide Housing Energy Rating Scheme) regulation. NatHERS rates houses on a scale of 0 to 10 per the energy required for ambient heating and cooling. In theory, 10-Star houses, such as Josh's House (www.joshshouse.com.au), should be able to maintain a comfortable temperature year-round without the need for air conditioning or heating systems.

While houses are adopting more efficient technologies, they do not always achieve their full potential. One of the reasons for it is that occupants are often not aware how to make the most of their homes and ensure that they operate to capacity. 'Rebound effects' also mean that energy and water use can increase after occupants upgrade their house to include efficient features because they assume that the technology will solve the problem. Research has shown that changing occupant behaviour alone can lead to savings up to 20% in energy and water (Lopes *et al.*, 2012; Kurz *et al*., 2005). Studies have also suggested that occupant behaviour can have as much impact on the performance of houses as the building envelope (Gram-Hanssen, 2012; Lopes *et al.*, 2012). However, households' practices and behaviours are variable and still poorly understood. For instance, identical houses can differ up to 37% in energy use (Gill *et al.,* 2010). In spite of the abundant existing literature (Abrahamse *et al.*, 2005), the effectiveness of behaviour change methods is still unclear. Some claim that technology and feedback systems are the answer, while others argue that social interventions are more lasting.

The 10 Household Living Labs project aims to answer these questions. We are interested to know whether energy and water wise homes can reduce their resource consumption even further and identify the most effective methods to do so.

Above: Josh's House – a 10 star rated home in Hilton, Western Australia.

Methodology

Ten single detached family homes located in the City of Fremantle, Western Australia, were chosen to be part of this project. While they have a different mix of occupants, they all have energy or water efficient aspects, such as solar panels, solar hot water or rainwater tanks. Some of the houses also present elements of climate sensible design, such as north orientation, natural ventilation, thermal mass and insulation.

The ten houses had their electricity, water, gas and internal temperature monitored for two years, between January 2015 and December 2016. Solar electricity generation and rainwater use were also measured in the houses possessing solar panels and rainwater tanks. The monitoring equipment consisted of multiple sensors that were coupled to existing meters and transmitted electric pulses to a data logger (Figure 1). The data logger collected the data at 15 minute intervals and transmitted it to the researchers remotely through a 2G wireless internet connection.

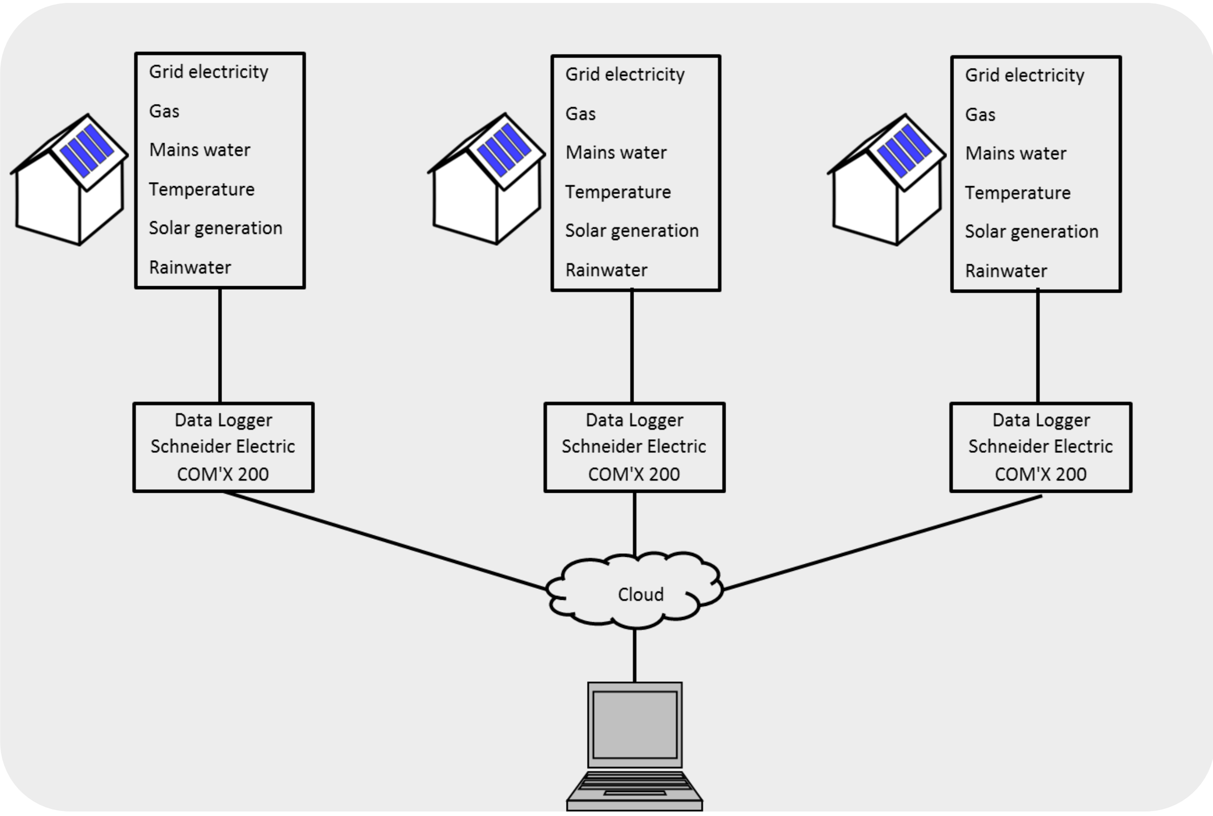
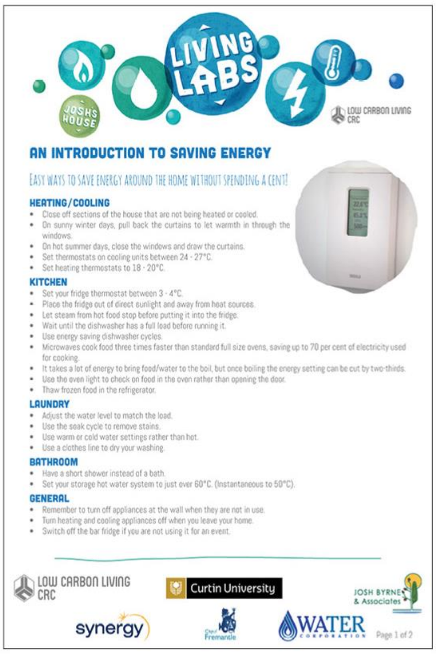


Figure 1 Data collection schematic.

The first year of monitoring was used to establish a baseline and determine the houses normal energy and water use. During the second year, a behaviour change program was put in place, providing each household with a series of tailored tools designed to increase their awareness and facilitate a reduction of water and energy while enabling occupants to maintain a high-quality lifestyle. This behaviour change program was based on a review of 34 papers that targeted energy and water reduction in residential homes. Methodologies use well-known socio-psychology theories (Ajzen, 1991; Festinger, 1957; Cialdini *et al.*, 1991) to base their approaches. However, these can vary significantly in different researches, favouring either a technology-based approach to modifying behaviour or tackling it from a social perspective through direct personal contact. Technology-based approaches are mainly focused on delivering real-time feedback through dashboards with the objective of increasing occupant awareness and providing households with a better understanding of the impact of their actions around the home (Fischer, 2008; Yew *et al.*, 2012). Social-based approaches to behaviour change focus on providing tailored advice and ensuring that social norms are also delivered (McKenzie-Mohr, 2011). In spite of the different approaches to promoting behaviour change, it has been suggested that a combination of strategies work better and have more lasting effects (Buchanan *et al.*, 2015; Delmas *et al.*, 2013). In this project, we combined several techniques, including an online dashboard with near real-time data monitoring and two home audits, where tailored information and household needs were discussed in detail.

The following tools were implemented:

- Energy and water reduction factsheets, which can be accessed at: http://joshshouse.com.au/resources/living-labs-lifestyle-factsheets/
- Summer and winter house audits, during which tailored tips were given on water and energy reduction throughout the house including the garden.
- Thermography, which was used to show occupants where they might be gaining or losing heat.
- Goal setting.
- Near real-time data on an online dashboard, including comparison with other participants.
- Monthly data summary reports including prompts and tracking against goals.



LIVING LABS
JOSH'S HOUSE
LOW CARBON LIVING CRC

AN INTRODUCTION TO SAVING ENERGY

EASY WAYS TO SAVE ENERGY AROUND THE HOME WITHOUT SPENDING A CENT!

HEATING/COOLING
- Close off sections of the house that are not being heated or cooled.
- On sunny winter days, pull back the curtains to let warmth in through the windows.
- On hot summer days, close the windows and draw the curtains.
- Set thermostats on cooling units between 24 - 27°C.
- Set heating thermostats to 18 - 20°C.

KITCHEN
- Set your fridge thermostat between 3 - 4°C.
- Place the fridge out of direct sunlight and away from heat sources.
- Let steam from hot food stop before putting it into the fridge.
- Wait until the dishwasher has a full load before running it.
- Use energy saving dishwasher cycles.
- Microwaves cook food three times faster than standard full size ovens, saving up to 70 per cent of electricity used for cooking.
- It takes a lot of energy to bring food/water to the boil, but once boiling the energy setting can be cut by two-thirds.
- Use the oven light to check on food in the oven rather than opening the door.
- Thaw frozen food in the refrigerator.

LAUNDRY
- Adjust the water level to match the load.
- Use the soak cycle to remove stains.
- Use warm or cold water settings rather than hot.
- Use a clothes line to dry your washing.

BATHROOM
- Have a short shower instead of a bath.
- Set your storage hot water system to just over 60°C. (Instantaneous to 50°C).

GENERAL
- Remember to turn off appliances at the wall when they are not in use.
- Turn heating and cooling appliances off when you leave your home.
- Switch off the bar fridge if you are not using it for an event.

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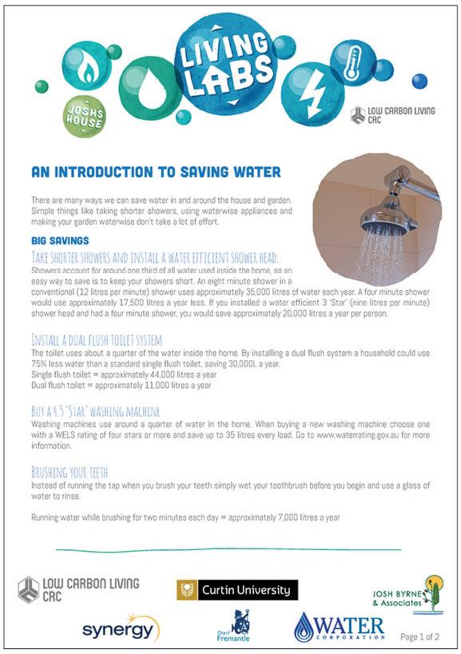

LIVING LABS
JOSH'S HOUSE
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AN INTRODUCTION TO SAVING WATER

There are many ways we can save water in and around the house and garden. Simple things like taking shorter showers, using waterwise appliances and making your garden waterwise don't take a lot of effort.

BIG SAVINGS

TAKE SHORTER SHOWERS AND INSTALL A WATER EFFICIENT SHOWER HEAD.
Showers account for around one third of all water used inside the home, so an easy way to save is to keep your showers short. An eight minute shower in a conventional (12 litres per minute) shower uses approximately 35,000 litres of water each year. A four minute shower would use approximately 17,500 litres a year less. If you installed a water efficient 3 'Star' (nine litres per minute) shower head and had a four minute shower, you would save approximately 20,000 litres a year per person.

INSTALL A DUAL FLUSH TOILET SYSTEM
The toilet uses about a quarter of the water inside the home. By installing a dual flush system a household could use 75% less water than a standard single flush toilet, saving 30,000L a year.
Single flush toilet = approximately 44,000 litres a year
Dual flush toilet = approximately 11,000 litres a year

BUY A 4.5 'STAR' WASHING MACHINE
Washing machines use around a quarter of water in the home. When buying a new washing machine choose one with a WELS rating of four stars or more and save up to 35 litres every load. Go to www.waterrating.gov.au for more information.

BRUSHING YOUR TEETH
Instead of running the tap when you brush your teeth simply wet your toothbrush before you begin and use a glass of water to rinse.

Running water while brushing for two minutes each day = approximately 7,000 litres a year

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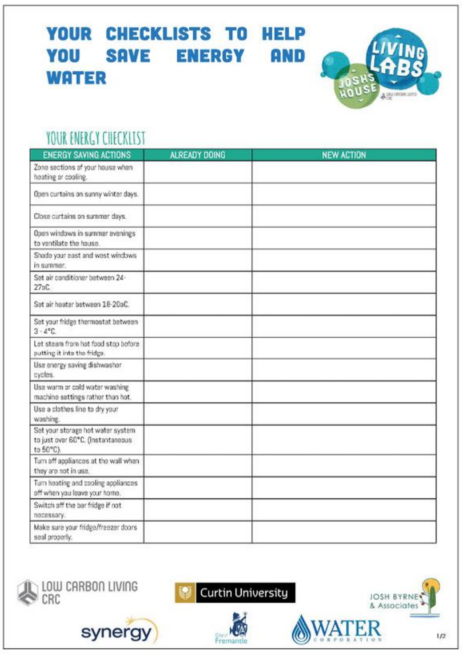

YOUR CHECKLISTS TO HELP YOU SAVE ENERGY AND WATER

LIVING LABS
JOSHS HOUSE

YOUR ENERGY CHECKLIST

ENERGY SAVING ACTIONS	ALREADY DOING	NEW ACTION
Zone sections of your house when heating or cooling.		
Open curtains on sunny winter days.		
Close curtains on summer days.		
Open windows in summer evenings to ventilate the house.		
Shade your east and west windows in summer.		
Set air conditioner between 24-27oC.		
Set air heater between 18-20oC.		
Set your fridge thermostat between 3 - 4°C.		
Let steam from hot food stop before putting it into the fridge.		
Use energy saving dishwasher cycles.		
Use warm or cold water washing machine settings rather than hot.		
Use a clothes line to dry your washing.		
Set your storage hot water system to just over 60°C. (Instantaneous to 50°C).		
Turn off appliances at the wall when they are not in use.		
Turn heating and cooling appliances off when you leave your home.		
Switch off the bar fridge if not necessary.		
Make sure your fridge/freezer doors seal properly.		

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Above: Examples of the Fact Sheets and Checklist provided to the participating households.

Results

Energy

Comparing one year to another can be challenging due to different conditions in weather, which end up affecting the internal household temperature and therefore the need for heating and cooling. One way to adjust for this is to perform a weather normalisation of energy consumption. In other words, it consists of comparing the number of degree days above or below the thermal comfort limits (18 and 28ºC respectively) and assuming that the need for heating and cooling is proportional to the number of degrees above and below these limits (for more information see BizEE, 2016).

Winter in Year 2 (2016) was much longer than the previous year, lasting from May to early November. Overall, 2016 had 21% lower temperatures and 26% higher temperatures compared to 2015 (Year 1) (Figure 2). Accordingly, 2016 energy data was compared against an adjusted baseline which took weather variations into account.

Above: Temperature monitoring.

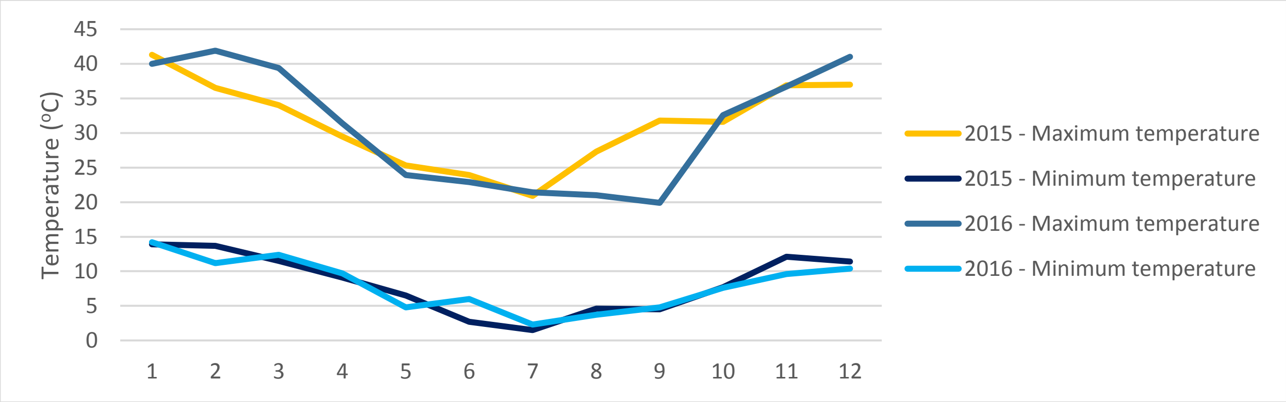

Figure 2: Maximum and minimum external temperatures in 2015 and 2016.

Electricity

Nearly all households managed to reduce grid electricity in 2016 (Figure 2), saving between 4 and 15% (Table 1). This translated in $400 collective savings in electricity bills and around 1,600 kg of avoided CO_2 emissions. Two of the participants, however, increased their grid electricity use by 11 and 23%. These increases were partly due to the reduced performance of their solar panels in 2016. This will be explained in more detail over the page.

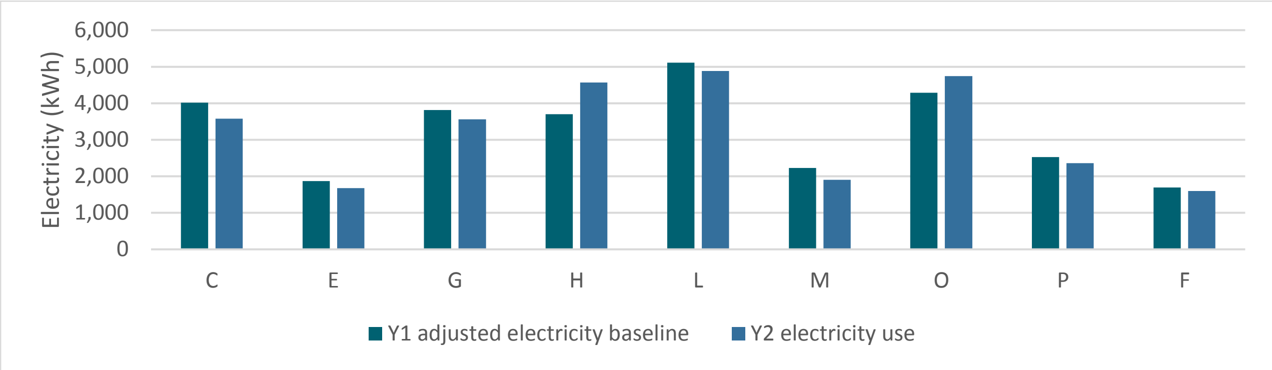

Figure 3: Electricity use.

Table 1: Electricity variations and goals.

	C	E	G	H	L	M	O	P	F
Y1 adjusted electricity baseline (kWh)	4013	1866	3810	3698	5110	2229	4290	2527	1692
Y2 electricity use (kWh)	3581	1672	3557	4565	4881	1901	4744	2361	1593
Variation	-11%	-10%	-7%	23%	-4%	-15%	11%	-7%	-6%
Goal	-10%	0%	0%	-40% sb[1]	-10%	-10%	0%	-10%	0%

[1]40% reduction in standby power

Gas

Five out of the six houses that use gas for ambient or water heating managed to reduce their consumption (Figure 3), saving between 11 and 27% (Table 2). This corresponded to $190 savings in collective bills and 285 kg of avoided CO_2 emissions over the year.

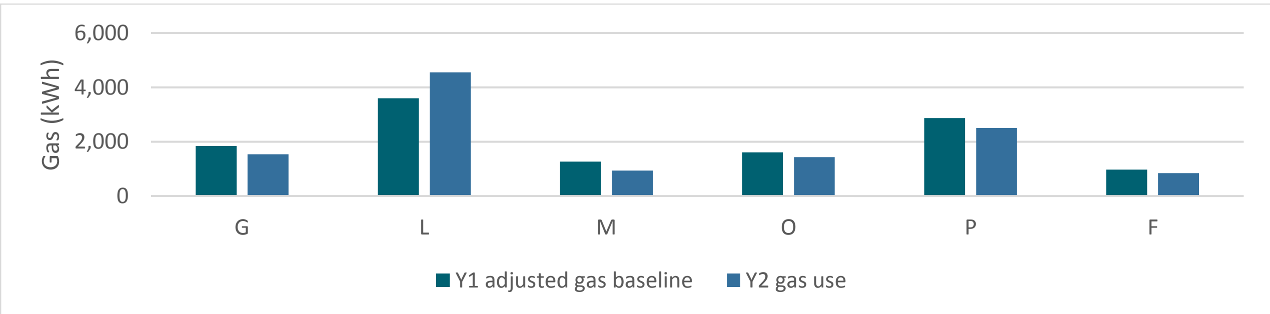

Figure 4: Gas use.

Table 2: Gas variations and goals.

	G	L	M	O	P	F
Y1 adjusted gas baseline (Kwh)	1843	3602	1273	1604	2868	978
Y2 gas use (Kwh)	1544	4550	935	1434	2501	847
Variation	-16%	26%	-27%	-11%	-13%	-13%
Goal	0%	-10%	-10%	0%	-10%	0%

Solar power generation

Another consequence of the long 2016 winter was the reduction of solar radiation. There was on average 2% less solar radiation in 2016 compared to the previous year (Figure 4). The decrease in sunlight, although small, affected the production of solar power, which could have meant that houses required more grid electricity in Year 2.

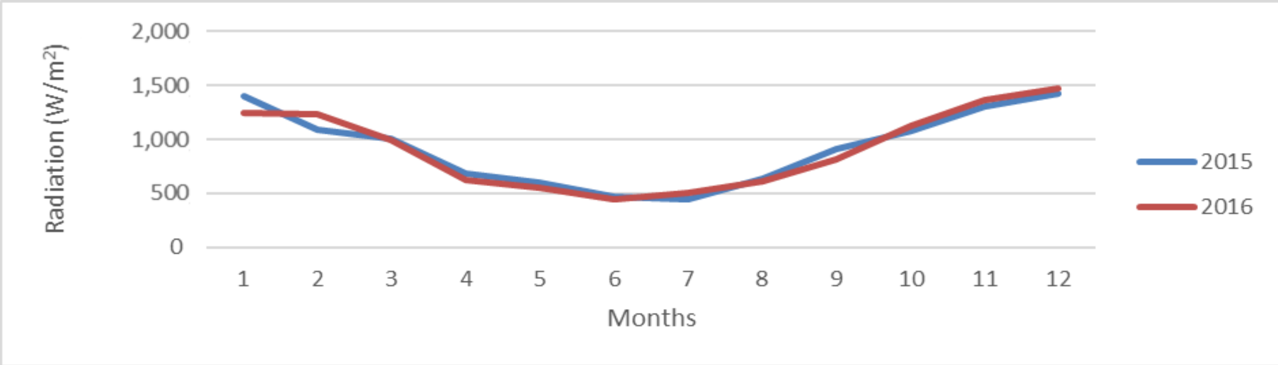

Figure 5: Solar radiation in 2015 and 2016.

However, when taking the 2% decrease in solar radiation into account, while some houses maintained approximately the same electricity production rates, one of them (House C) produced larger amounts of renewable electricity while four others produced considerably less (Houses G, O, H and F) (Figure 5).

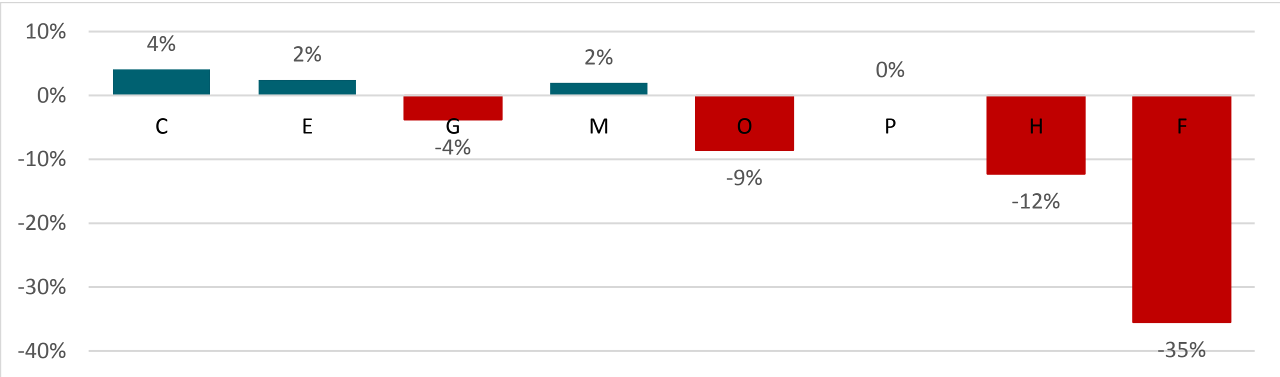

Figure 6: Variation in solar electricity production between 2015 and 2016.

Interviews with households as well as the observation of the data revealed that other factors impacted on the reduction or increase of solar electricity generation in these five homes. The occupants of House C, for instance, hosed the solar panels, removing some of the dust that had accumulated on their surfaces over the years. House O, on the other hand, was exposed to increased dust due to a construction that was happening next doors. Both Houses H and F experienced failures with their system. The solar system of House H tripped each time heavy rain occurred, and the solar system of House F short-circuited and the fault was not detected by the owners until the end of the project.

These results show how important it is to clean solar panels so they continue to function optimally. Additionally, monitoring solar generation through a dashboard enables faults to be detected promptly by households.

Above: Solar panels being installed.

Water

In 2016 there was a 12% increase in rainfall during the summer period compared to 2015 (Figure 6), which means that water used for irrigation (usually 40% of the total water used in the home) was probably also reduced by the same amount. Throughout the year, the rainfall increase was 28%, also contributing to an increase of rainwater yield for those who possess a rainwater tank used for internal purposes.

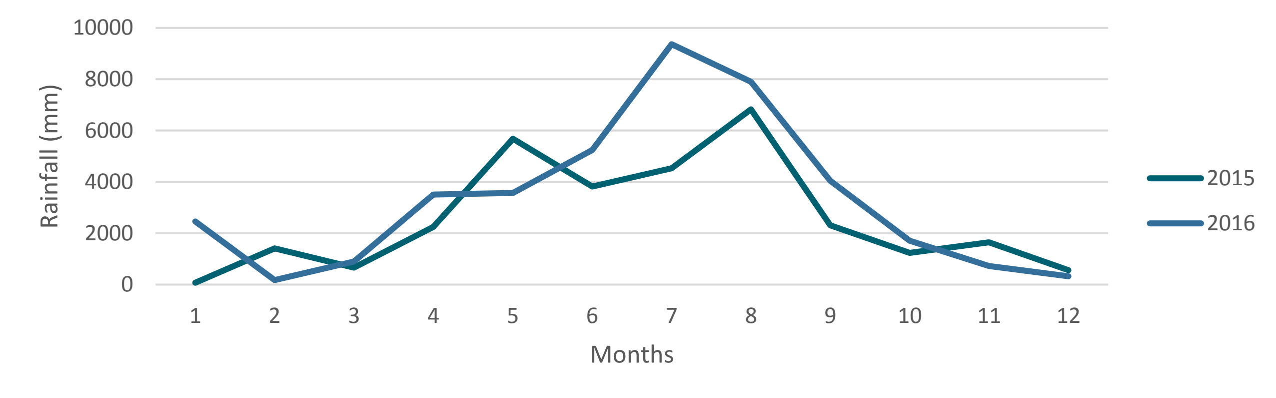

Figure 7: Rainfall in 2015 and 2016.

Taking these factors into consideration, five participants succeeded in reducing their total water use between 11 and 30%, while others increased it between 1 and 19%.

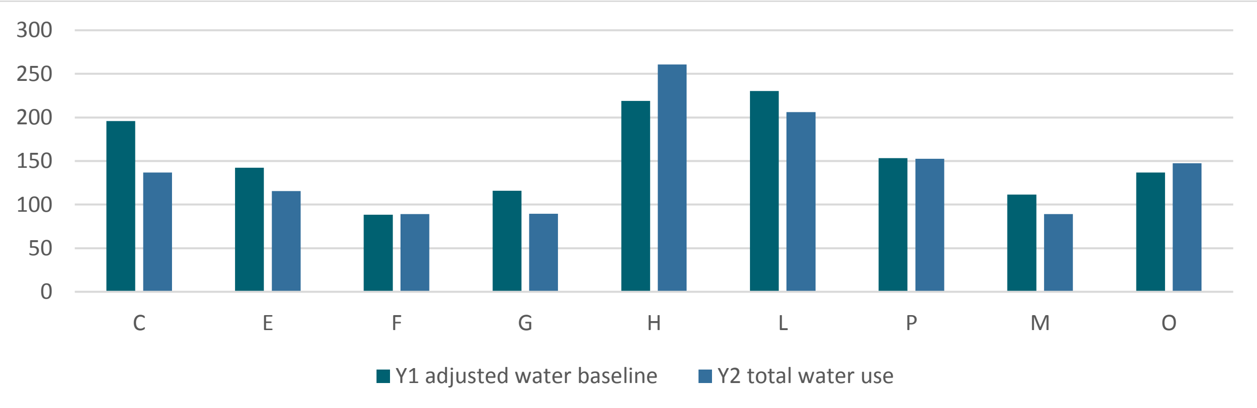

Figure 8: Water use.

Table 3: Water variations and goals.

	C	E	F	G	H	L	P	M	O
Y1 adjusted water baseline (kL)	196	142	88	116	219	230	153	112	137
Y2 water use (kL)	137	115	89	90	261	206	153	89	147
Variation	-30%	-19%	1%	-23%	19%	-11%	0%	-20%	8%
Goal	-10%	0%	-5%	0%	-30%	7.5	10	10	0

House H was the house that increased water use the most in 2016. Data revealed that this household experienced an underground rainwater leak, which was detected through the dashboard. Similarly, Houses F and G also experienced issues related to their rainwater tanks. In their cases, however, the problems were related to the maintenance of the filters, which had not been cleaned as required.

Positive Changes

Half the households achieved the goals that they set at the start of the behaviour change program. Some believed that they could not make any further changes to their lifestyle and decided to maintain the same levels of use from 2015. However, some still managed to make a difference simply by becoming more conscious of their resource consumption. Table 4 summarises all the actions taken by participant households to be able to reduce energy and water use. It should be noted that in some cases the changes were circumstantial rather than the result of a direct action.

Table 4: Actions to reduce energy and water use in the house.

House	Energy	Water
C	Filled insulation gaps in the ceiling Switched off standby power Installed more shading devices Became more conscious of using the heater	Switched irrigation to watering days Turned off irrigation on established plants Installed flow restrictor on all the taps
E	Hung cotton sheets outside East windows	Decided to plant native trees in the garden Reduced the use of the washing machine
G	Reduced the heater temperature and increased the air conditioner temperature Used appliances during the day	Fixed drip irrigation
L	Installed extra shade cloths in summer Changed some light bulbs to LED Filled the kettle with less water Switched off some standby power Installed an extra roof vent	Reduced irrigation as some plants became established
M	Programmed dishwasher to go during daylight hours Switched off standby power Installed a shade cloth on Western window Oldest son moved out of the house	Started having shorter showers
P	Used appliances during the day	Became more aware of long showers Stopped irrigating dead tree
F	Turned off standby	Had shorter showers
H	Installed a standby switch to turn it off automatically	Installed an extra 3000L rainwater tank
O	Switched pool filter timer to work later during the day when the sun is higher Set dishwasher on a timer Closed blinds during summer days	Installed drip irrigation in the garden Kept pool cover over the pool at all times Refilled the pool with rain

Lessons Learnt

While all households did not manage to reduce energy or water to the same extent, interviews revealed that they all became more aware of their behaviours daily and appreciated having tailored information to suit their individual needs. Participants enjoyed the audits the most as they had the opportunity to visually detect where they were gaining heat in summer, for example, making energy loss more tangible. The online dashboard, on the other hand, was not taken full advantage of, reasons being a lack of time and slowness of the server.

Whereas some did not think they could make many modifications to their lifestyle, most households made simple changes like programming appliances to run during the day (to utilise solar power) or installing new shading devices. The result of these changes impacted significantly on house comfort. Some households also transferred lessons learnt and their motivation to change to other parts of their lives; for instance, waste reduction or sustainable food consumption.

This research confirmed that energy efficient or water wise houses do not always perform optimally. Modifying the way houses are operated daily can make a great impact. But it was also interesting to notice that most houses also faced technology issues that were often not detected by the occupants. Energy and water efficient technologies need maintenance to continue to fully operate as designed, and maintenance is dependent on occupants being fully aware of these requirements. Real-life monitoring systems can help detect failures and inform households to ensure that neither renewable energy nor rainwater is wasted. However, it is also important to make the data more engaging and accessible to increase the likelihood of it being utilised.

Above: Project communication collateral.

Publications Arising from this Study

A series of scientific papers are being published with the results of this two-year monitoring project. These are currently in preparation or under review. Below is a list of expected publications.

Title	Synopsis	Reference
Unravelling everyday heating practices in residential homes	This paper discusses the differences in heating practices between and within different houses	Eon C., Morrison M. G., Byrne J. (2017). Unravelling everyday heating practices in residential homes. *Energy Procedia*. Awaiting publication
The influence of design and everyday practices on individual heating and cooling behaviour in residential homes	This paper discusses influences that design, lifestyle, occupancy and behaviours exert in the heating and cooling practices in the home	Eon C., Morrison M. G., Byrne J. (2017). The influence of design and everyday practices on individual heating and cooling behaviour in residential homes. *Energy Efficiency*. In review
Understanding water use practices in residential homes	This paper discussed irrigation and shower practices in homes and how they compare to demand management strategies	Eon C., Byrne J., Morrison M. G. (2017).Understanding water use practices in residential homes. *Urban Water Journal*. In preparation
Homes as a system of practice	This paper explores the home as a system, where practices are influenced by interlocked by other practices, occupancy and technologies	Eon C., Breadsell J., Morrison M. G. (2017). Homes as a system of practice. *Environmental Science and Technology*. In preparation.
The effect of a behaviour intervention program on heating and cooling practices	This paper explores the results from the behaviour change program in regards to energy use	Eon C., Morrison M. G., Byrne J. (2017). The effect of a behaviour intervention program on heating and cooling practices. *Energy and Buildings*. In preparation
Verification of an Emerging LCA Design Tool through Real Life Performance Monitoring	This paper presents the results from an LCA of these ten homes, comparing predicted and expected energy use as well as embodied energy	Eon C., Murphy L., Byrne J., Anda M. (2017). Verification of an Emerging LCA Design Tool through Real Life Performance Monitoring. Renewables: Wind, Water, and Solar. In review

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