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Clawback of heating services in Beacon research homes

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About This Report

Title

Clawback of heating services in Beacon research homes

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Abstract

Increased energy efficiency of hot water and space heating should reduce the cost of providing these services. However, the phenomenon of 'clawback' – where occupants use the improved heating system to increase comfort, can alter the effect of energy efficiency upgrades. In this work, the data from the Papakowhai Renovation Project, and the Waitakere NOW Home® are used to assess the clawback from the water heating and space heating services in ten New Zealand homes.

Reference

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1. Executive Summary

Increased energy efficiency of the hot water and space heating services in domestic buildings in New Zealand should reduce the cost of providing these services.

However, the phenomenon of 'clawback' – where occupants use the improved heating system to increase comfort, can alter the effect of energy efficiency upgrades.

In this work, the data from two experimental projects, the Papakowhai Renovation Project, and the Waitakere NOW Home® are used to assess the clawback from the water heating and space heating services in ten New Zealand homes.

The Papakowhai Renovation Project involved the application of interventions to the space heating, thermal envelope, and water heating services of nine homes in the Papakowhai suburb of Porirua (Wellington), including:

- the replacement of three storage electric hot water systems with solar hot water systems
- the replacement of three aging woodburners with a pellet burner, a new woodburner and a heat pump, and a wetback woodburner.
- The installation and modification of heat transfer systems
- Insulation of walls, floors, windows and ceilings through a variety of means
- The installation of hot water cylinder insulation wraps
- The installation of two gas-fired instant hot water systems

The Waitakere NOW Home® included the assessment of the changes to the hot water service demand in a new home designed with highly sustainable features in the New Lynn suburb of Waitakere (Auckland) over two years of occupancy.

The analysis of the data shows that in the Papakowhai homes (nine homes) that:

- Space heating services in the winter period are strongly influenced by household composition.
- Occupants of homes which are heated in winter to lower temperature levels are more likely to clawback increased service levels, as comfort.
- Extensive upgrades to the thermal envelope are more likely to result in large improvements in indoor temperatures and reductions in space heating energy use, irrespective of whether clawback occurs.
- Annual variations in hot water use overwhelm the anticipated energy efficiency improvements rendered by the installation of hot water cylinder wraps.

- SWH systems had similar or reduced water heating demand after their installation, and could therefore be considered as effective energy efficiency intervention with little or no clawback.

The analysis of data from the Waitakere NOW Home® (one home) shows that:

- Clawback of water heating service occurred over the two years of monitored data, resulting in a 25% increase in demand.

While recognising that clawback is a difficult parameter to assess, this work has revealed varying degrees of clawback of hot water and space heating services in ten New Zealand homes.

The conclusions show that the full value of potential reductions in space and water heating energy use due to improved energy efficiency were not delivered from the homes assessed due to householders clawing back savings as improved comfort and levels of service.

It is important to consider the role of clawback in large scale energy savings programmes and whether these programmes will deliver the savings expected.

It is postulated that it will only be once the New Zealand housing stock has been improved to provide high levels of comfort and service, that energy efficiency upgrade programmes deliver the reduced demand that they promise.

2. Introduction

This work presents an assessment of one of the unintended consequences of performing sustainability interventions in space and water heating services in domestic buildings – the takeback, or 'clawback' of an increased level of comfort or service.

The clawback of the space heating and water heating service is analysed from two separate Beacon Pathway research projects, the Papakowhai Renovation Project (Burgess, et. al., 2008) and the Waitakere NOW Home® (Pollard et. al., 2008).

Beacon's Papakowhai Renovation Project examined the impact of a number of sustainability upgrades in a set of nine existing 1970's houses in the Porirua suburb of Papakowhai. A range of measures were employed in these houses, ranging from simple roof insulation top ups to full retrofitting of roof, floor and wall insulation, the installation of double glazing and the upgrading of heating systems. The Papakowhai Renovations houses were closely monitored with energy use and indoor temperatures measured and provide a useful dataset to examine the impacts of thermal envelope and heating system improvements (Burgess, et al., 2008).

The Waitakere NOW Home® was a new-build project in New Lynn, Waitakere, which looked to maximise the sustainability features achievable within a typical new home budget. The house was extensively monitored which included tracking the occupant use of efficient water heating services for a period of two years following construction in 2005.

After presenting the phenomenon of 'clawback', this report discusses the water heating service in the Waitakere NOW Home®. It also discusses the space and water heating service in the Papakowhai Renovation Project in separate sections, each ending with a discussion of the clawback inherent in that project, and for that service.

The report is completed with a conclusions section, where the three pieces of work are drawn together so that an overview of clawback can be presented.

3. Clawback

Residential energy use occurs as a by-product of providing household energy services such as space heating, water heating, refrigeration and lighting. To fully understand residential energy use requires knowledge of how these services are provided and the occupant demand for these services.

People's use of household energy services is inherently variable and difficult to predict. A decision to use a household service may not be thoroughly rationalised and may be influenced by any number of personal or social factors. Factors may include financial and domestic circumstances and attitudes towards comfort.

Programmes looking to reduce residential energy use need to be aware of the interaction between efficiency improvements and occupants behaviour towards household energy services. Energy savings from applying an energy efficiency intervention may not be fully realised as the occupants choose to have a greater utility from that energy service. For example, space heating savings from increasing the thermal envelope insulation levels of a house may not be fully realised as the occupants may choose to heat more and operate their house at a higher space temperature. Another example would be efficiency interventions to a water heating service, such as the installation of a solar water heating (SWH) system that may result in increased use of heated water.

The terminology of such effects is applied differently for each discipline and is not consistent within the literature.

Economic approaches focus on the efficiency interventions making the price of the energy service cheaper (Greening, et al., 2000). The direct 'rebound' effect is then the proportion of the effective savings offset by the cost of the greater usage of that energy service. An indirect rebound effect can also be defined where savings from one energy efficiency intervention results in increased spending on other energy services. An example of this may occur where a heat pump is installed to replace a lower efficiency space heater. Direct monetary savings may be made with reduced winter time space heating energy use if heating patterns are similar. However if the heat pump is used to provide summer time cooling when previously no mechanical cooling was used, overall energy use may not have reduced as much as expected and indirect rebound may occur.

Building evaluation work frequently uses 'takeback' as an analogous term to the direct rebound effect. Takeback refers specifically to trading off energy savings with increased provision of services doing away with price as an intermediary.

It would be convenient to consider takeback as a step process; after an intervention the occupants immediately establish a new level of demand for that household energy service. Occupant behaviour however is more complicated than this and takes some time to adjust. While the immediate response after an intervention may be expected to achieve a high proportion of the expected energy savings, new levels of energy service demand may evolve from a range of feedbacks many of which are infrequent, such as monthly or bi-monthly energy bills.

Direct measurements of the use of household services and their resultant energy use have a high degree of variability, changing greatly from day to day. It is not clear for how long, or for what time after an energy intervention that takeback should be assessed. To emphasise this vagueness and the slow process of the eroding of expected energy savings, an alternate term of 'clawback' could be used in preference to the exactness and immediacy suggested by the term 'takeback'. The term 'clawback' will be used for the rest of this report.

Clawback may or may not occur after an energy efficiency intervention for a number of reasons such as;

- Whether the system is capable of delivering to a level of service that the occupants desire and are able to afford. Efficiency improvements frequently also increase the capacity of systems. For example, a new hot water cylinder may provide a larger volume of heated water that would provide more heated water service before 'running out of hot water'. Upgraded thermal envelope insulation may make it easier for an existing space heating system to provide comfortable conditions, that the heating is used more frequently.
- The system being used more extensively within the house. For example, where previously occupants may have only heated the family room in the evenings, after an intervention occupants may heat more of the bedrooms and other rooms of the house as well.
- The characteristics of service delivered. Where there is a subjective assessment of the acceptability of the service provided, there may be variations after an intervention. For example, space heating is applied to counter the occupants not feeling sufficiently warm. The acceptability of a heating system which has a high radiant component, which provides a feeling of being heated more readily may have a different use than a convective-type heating system which provides a more consistent temperature and is less noticeable to the occupants.
- The amount of active engagement the occupants have with the mechanisms of providing the energy service.

A traditional water heating system comprising of an electric hot water storage cylinder has little input from the occupants in providing the service; with the water being kept at a set temperature with the use of a thermostat rather than having the occupants turn the heating element on and off to heat more water. Efficiency improvements for a water heating system generally don't change how much the occupants are involved.

Space heating systems in New Zealand have traditionally had a high degree of user engagement. It is frequently left up to the occupants to turn on or off heaters within the appropriate rooms as required. Many traditional heating types, such as woodburners, have limited thermostatic control and may be prone to either under or over-heating.

Moves to less user involved heating systems may impact on how much comfort people expect the systems to deliver. The greater use of timers, ducted systems, room thermostats, heat pump systems which also deliver cooling (French, 2008) will all impact of how people respond to the service levels their heating systems are delivering.

4. Warm environments

Providing suitable domestic indoor environments in the temperate New Zealand climate requires indoor environments that include the following characteristics:

- are sufficiently warm
- are sufficiently free from overheating
- are sufficiently dry (not excessively damp)
- sufficiently control pollutants

From the list above, this report will only consider if indoor conditions are sufficiently warm, where the level of warmth varies, and is at the discretion of the occupant. Within an existing household, space heating is the typical means to achieve sufficiently warm environments. Space heating is the largest energy use of the services provided inside New Zealand households, accounting for, on average, 32% (Isaacs et al. 2006) of household energy use. The thermal performance of a house is a complementary aspect to space heating in order to achieve sufficiently warm environments. A well insulated house with good orientation and high levels of solar gains through the north facing windows will use less applied heating than a poorly orientated, poorly insulated house to achieve sufficiently warm indoor environments.

4.1 Measured data

The data available from the two separate projects, (Waitakere NOW Home®, and the Papakowhai Renovation Project) has been used in this work.

As the insulation levels of the thermal envelope in the Waitakere NOW Home® were sufficiently high that the occupants seldom needed to use additional heating to maintain comfortable living temperatures, heating behaviour information in the Waitakere NOW Home® was limited, and so clawback has not been assessed for this service. Clawback has been assessed for the water heating service at Waitakere, see section 5.1.

Both the water heating service and the space heating service is analysed in the Papakowhai Renovation Project, with the heater and thermal envelope changes made within the houses, described in the next two subsections, and the water heating service discussed in 5.2 and 5.3.

4.1.1 Heater changes

Of the nine houses in the Papakowhai Renovation Project, six had woodburners while only three relied entirely on reticulated energy for applied space heating. Some appliances were due for replacement, and so in line with the efficiency improvement, air pollution reduction, and indoor environmental quality improvement ideals of the Papakowhai Renovation Project, some of the high-intervention houses had their main heater replaced. The changes are noted in Table 1.

The most extensive changes to the space heating in one house occurred in P03, where the dilapidated woodburner and a room heat pump were replaced with a new woodburner and a ducted central heat pump system.

House	Heaters/ heat transfer before renovations	Changes
P01	Woodburner, oil column heaters	Pellet burner replaced woodburner. Heat transfer system installed
P02	Woodburner, oil column heaters	Unchanged
P03	Heat pump, dilapidated woodburner, fan heater	New woodburner replaced old woodburner. Central heat pump system replaced lounge heat pump.
P05	Open gas fire, electric convection heater	Heat transfer system installed
P06	Woodburner, LPG cabinet heater, oil column heaters	Unchanged
P07	Woodburner, heat transfer system	Heat transfer system thermostat moved, ducting extended
P08	Electric underfloor heating, nightstore heaters	Unchanged
P09	Halogen radiant heater, fan heater	Heat pump replaced halogen radiant plug-in heater
P10	Dilapidated woodburner, electric column heaters	New woodburner (with wetback) replaced old woodburner

Table 1: Space heater changes in the Papakowhai Renovation Project.

4.1.2 Thermal envelope changes

The changes to the thermal envelope for each of the Papakowhai houses are listed in Table 2. The largest changes were full envelope insulation (double glazed windows plus roof, wall, and floor insulation wherever possible) in P03 and P10, while the least changes were to P06, which received ceiling insulation only.

	Changes			
House	**Roof**	**Walls**	**Floor**	**Windows**
P01	Ceiling lowered, battened, R5 fibreglass insulation installed	Remained uninsulated	R2 insulation, polythene ground cover	Existing single-glazed timber frames retained
P02	Old insulation rearranged, new layer put over	Remained uninsulated. Bedroom extension insulated	R2 insulation, polythene ground cover	Existing single-glazed aluminium and timber frames retained
P03	Ceiling lowered, battened, R5 fibreglass insulation installed	Old thin fibreglass segment insulation replaced with R2.4	R2 insulation and polythene ground cover installed; concrete slab and midfloor over garage remained uninsulated	Worn out single-glazed aluminium frames replaced with new aluminium frames with double-glazed panes
P05	Existing insulation rearranged, topped up	Original fibreglass segment insulation remained	R2 insulation, polythene ground cover; concrete slab remained uninsulated	Existing single-glazed timber frames retained
P06	Existing insulation rearranged, topped up	Remained uninsulated	Existing insulation under lounge remained, rest remained uninsulated	Existing single-glazed aluminium and timber frames retained
P07	Existing insulation rearranged, topped up	Living areas remained R2.2, bedrooms insulated to R2.4	R2 insulation, polythene ground cover; concrete slab, midfloor above garage remained uninsulated	Existing single-glazed aluminium frames retained
P08	Existing insulation rearranged, topped up	Walls backing onto sub-floor insulated, lined walls remained uninsulated	R2 insulation, polythene ground cover where possible; concrete slab remained uninsulated	Existing modern aluminium frames retrofitted with double-glazed panes
P09	R2.6 installed over existing original fibreglass	Original fibreglass segment insulation remained	R2 insulation, polythene ground cover where possible; concrete slab remained uninsulated, garage ceiling stripped, insulated and re-lined.	Original single-glazed aluminium frames retained
P10	Double layers of R2.6 installed throughout	Walls stripped, insulated with R2.4, relined	R2 insulation, polythene ground cover installed; concrete slab uninsulated, but later battened and raised to create an airgap	Worn out single-glazed aluminium frames replaced with new aluminium frames with double-glazed panes

Table 2: Insulation changes in the Papakowhai Renovation Project

4.2 Performance

Providing a suitably warm indoor environment generally requires the use of space heaters. Measuring the total heating energy use is not straightforward as the energy use of each individual heater needs to be measured. For houses with many portable electric heaters, measuring the energy use of each heater becomes more arduous and expensive, and so this was not undertaken in the Papakowhai Renovation Project.

The Papakowhai Renovation project recorded (Burgess, et al. 2009) the energy use of the solid fuel burners present (using the HEEP methodologies; see Isaacs, et al. 2005) both portable and fixed gas heating, as well as measuring the electricity use of some of the larger electrical heaters that were on dedicated electrical circuits. Small portable electric heaters were not monitored. The Papakowhai Renovation Project also recorded the overall total reticulated energy (electricity and gas) usage for each house, as well as the living room and bedroom temperatures. Hot water energy use was also separately monitored.

Table 3 is taken from Burgess, et al (2009) and indicates the change in winter season energy use and indoor temperatures after the interventions in the nine houses participating in the Papakowhai Renovations project. The data reported here has been adjusted to account for variation in the external temperature.

The method of adjustment for this data was to plot short term averages of the variable under consideration for each year against short term averages of the external temperature. The average long term winter external temperature for Wellington for this period (9.5°C) was then used to determine adjusted values for each year for the variable being considered. It should be noted that the Space heating energy column in Table 3 refers to the solid fuel burner usage, gas heater usage and the usage of separately monitored electric heaters and is not necessarily equal to the total space heating energy use. The total energy column presents data that was measured from the existing house electricity meter readings, and the reticulated hot water energy data does not include the contribution from solar or wetback energy.

Summary of winter season changes in energy and temperatures							
	Energy					**Temperatures**	
House	Energy intervention cost (excl GST)	Total reticulated energy	Space heating energy	Total energy	Total reticulated hot water energy	Average 24 hr family room temps	Average 24 hr bedroom 1 temps
'High' package homes							
P03	$74,350	Less	Less	Less	Less	Higher	Higher
P10	$71,990	Less	More	More	Less	Higher	Higher
P08	$22,980	Less	Less	Less	Less	Lower	Unchanged
'Standard' package homes							
P01	$19,270	Less	Unchanged	Unchanged	Less	Higher	Higher
P05	$7,415	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged	Higher
P09	$6,995	Less	Unchanged	Less	Less	Higher	Higher
P07	$5,335	Less	Unchanged	Unchanged	Less	Higher	Higher
'Basic' package home							
P02	$875	Less	Unchanged	Less	Less	Higher	Higher
'Contrast' home							
P06	$1,380	Less	Unchanged	Less	Less	Lower	Lower

Table 3: Statistically significant changes in energy and temperatures

Only in P06 and P08 were the indoor temperatures lower after the intervention. The fall in P06's temperatures can be explained by the presence of five adult members of the household in the first year, reducing to three in the middle year, and two in the final year. There was also absence of the homeowners over extended periods, leaving one occupant or nobody living in the house. The reason for the fall in the temperatures of P08 were likewise due to occupancy changes with one occupant leaving home, another spending weekends away and a reasonably long period were the occupants were away from the house after the renovations had taken place.

The temperatures were higher in the remaining houses after the energy interventions, except for P05 where the temperature in the living room was unchanged. The bedroom temperatures in P05 did show a small (but statistically significant) increase, but all of the energy measures (total energy, reticulated (electricity and gas) energy, space heating energy and hot water energy) in this house were unchanged after the intervention.

After the interventions within the houses, the space heating energy use was unchanged except for in the high intervention houses (P03, P08 and P10), each of which also had pre-intervention temperatures higher than average. The space heating energy use was reduced in two of the high intervention houses while the third high intervention house had an increase in heating energy use. The changes (or lack of them) in space heating energy use are strongly connected with the provision of heating service, which will be examined in more detail in the next section.

Total energy includes space heating energy, non-space heating reticulated energy and hot water energy. Total energy increased for P10, which had increased its space heating, and was unchanged for P05, P01 and P07. P01 and P07 are interesting as they were amongst the three households with the lowest family room temperatures at the start of the project. Total energy decreased for the high intervention houses P03 and P08 as well as for P02, P06 and P09.

Reticulated energy includes portable electric heaters where these were present, but also many other appliances whose use may change over time. Other than P05, the reticulated (electricity and gas) energy use in each of the houses was reduced, perhaps reflecting in part the other energy efficiency measures (CFL lighting, solar water heating) that were implemented in these houses.

4.3 Observed heating and temperature changes

While there is information to be gained from examining the energy/heating and indoor temperature changes separately, a fuller picture of the building performance and occupant behaviour is achieved by considering the space heating and indoor temperatures together as multivariate data.

The temperatures within a house will increase, not only from space heater use occurring within the house, but also from the heat given off from other energy uses such as cooking, lighting and other appliances. All energy transformations ultimately end up as heat, however not all of these contribute to increasing the temperatures within a building – for example a large proportion of the energy going into heating water ends up down the drain. The total space heating energy will be estimated as the total energy less the energy going into water heating.

The interaction between heating and temperatures can be examined by plotting them on a graph with total heating energy on one axis and the indoor temperatures on the other axis.

Figure 1 shows some examples. Consider first a house which before an energy intervention used 4000 kWh of heating and had an indoor temperature of 16.5°C. This could be identified as point X in Figure 1. After the energy intervention, the house could be located at any number of points. Figure 1 presents three alternates, A, B and C.

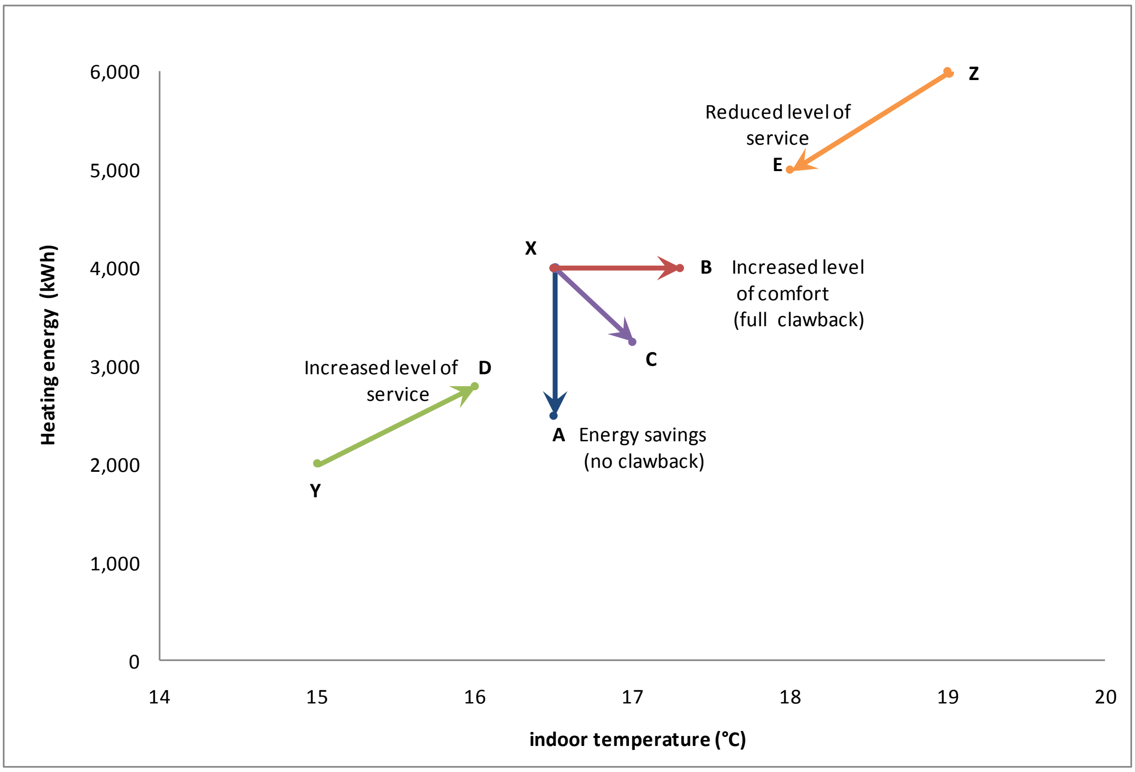

Figure 1 Example changes from hypothetical energy interventions

The first alternative would be to end up at point A. This is where the potential resulting from the energy intervention is fully realised as energy savings, the upgraded house is heated less to achieve the same temperature levels as before, and consequently the heating energy used is lower. This outcome results in no clawback of the energy intervention as an improved level of comfort.

The second alternative, B, would be to continue to use the same amount of heating as before which, with the improved building performance, will result in higher indoor air temperatures. This outcome is full clawback of the energy intervention as an improved level of comfort.

The third alternative, C, is the partial clawback case where both the heating energy is reduced and indoor temperatures are increased but both below the possible levels achievable in either direction, if the effort is directed only towards one outcome.

These simple examples assume that the effect of the external conditions before and after the intervention have be normalised out since warmer or cooler weather after the intervention will require less or more heating energy to achieve a fixed temperature level.

The other variable to consider is the occupant demand for the level of heating service. For example the house at point Y in Figure 1, has a low amount of heating (2000 kWh) but also reaches a low indoor temperature of 15°C. Should the occupants choose to heat the house more after the intervention, then it may be the case that the house would end up at a point D, where more heating energy is used but a higher indoor temperature is achieved.

The converse situation is also possible when a house at say point Z, may look to reduce their level of heating service which lowers their heating energy used as well as lowering the indoor temperature, ending up at point E.

Movement to the top and left in Figure 1 would reflect increasing heating energy use and lower temperatures. This unusual situation may reflect a lessening of the building performance.

The total heating energy use and mean indoor temperature over the winter season (May to September) for the Papakowhai houses is displayed in Figure 2. This data has been taken from Table 6 in Burgess, et al. (2009) which was adjusted to reduce the impacts of the varying climatic severity of each year.

The average indoor temperature was constructed from weighting the family room temperature and the bedroom temperature to better represent the temperature throughout the house. The heavy line for each house indicates the changes in total heating energy and average indoor temperature between the first year (before intervention) and the third year after the intervention. The two step dotted line shows the changes for the intermediate year. This intermediate year was part way through the intervention and was more complete for some than for others so cannot be treated consistently. Except for P08, the intermediate year does not deviate greatly from the transition between year one and three, shown by the solid line. In P08 there were major changes to the structure of the household affecting the occupancy of the house as mentioned previously.

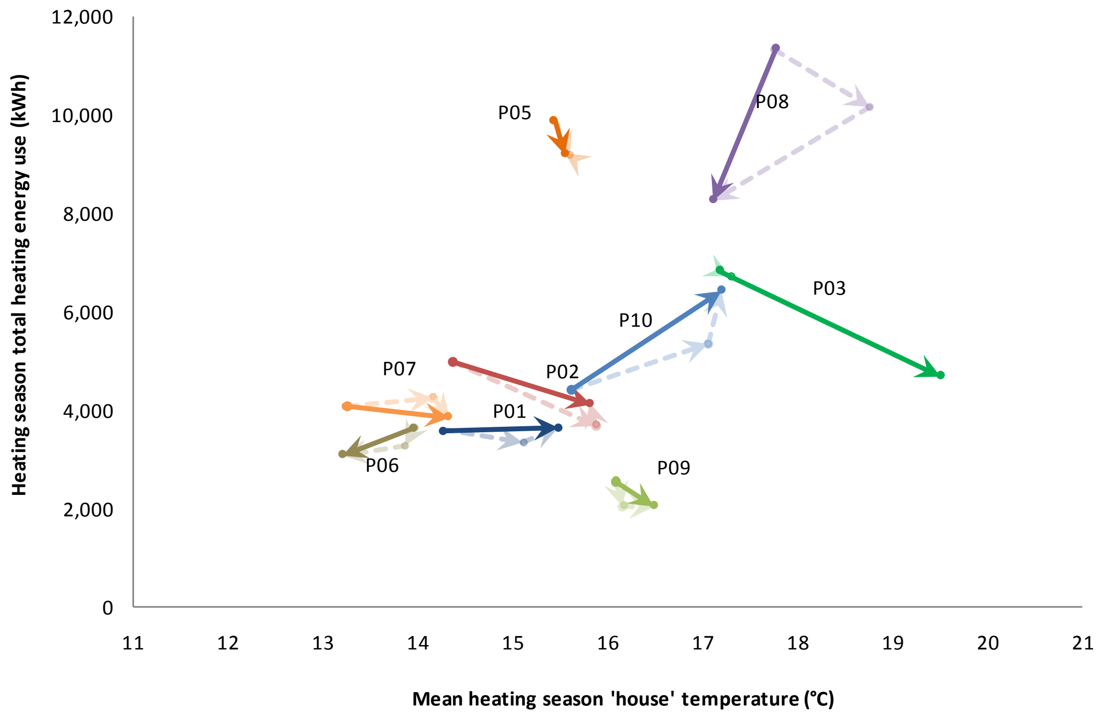

Figure 2 The heating season total space heating energy use and the mean heating season indoor temperature before and after the interventions

There are many interesting features in Figure 2 which is dominated by the large movements seen in houses P02, P03, P08 and P10. Except for P02, these are all the high intervention houses, indicating the greater potential for more extensive interventions to make a bigger impact.

The large increase in temperature for P02 with a small reduction in heating energy usage is surprising, given that this house was only subject to a basic upgrade involving ceiling and floor insulation. Changing heating habits and reduced moisture levels could be contributing factors in the improved temperatures seen in the house.

The three high intervention houses have overall changes in different directions. P03 shows the typical increasing temperatures and decreasing energy use reflecting an effective upgrade. These changes have been observed despite the fact that P03 had a central heat pump system replace the family room heat pump so that a greater area of the house would have been heated than prior to the intervention.

The shift in P08's total heating energy use and indoor temperatures were from a high base with the occupants tending to heat a lot using electrical heating methods compared to the other homes. The overall shift involved a decrease of total heating energy use as well as a decrease of indoor temperature. This shift is characteristic of a decrease of service which is matched by the observed reduction in the occupancy of the house in the second year, as mentioned previously. During the first year, noticeably increasing temperatures and decreasing energy, characteristic of an effective energy efficiency upgrade, were observed.

The movement in the P10's total heating energy use and indoor temperatures was in a direction of increasing level of heating service with increased temperatures and increased heating energy use. The pre-renovation woodburner in P10 was in a dilapidated state, and the occupants were reluctant to use it, suggesting that the household was under serviced by the space heating system. The renovation package included a new woodburner chosen because of its high efficiency, low emissions, and that it had a wetback system that could complement the solar water heating system. This woodburner was one of the lower output burners available, and was too big for the space unless the wetback was put on. This particular woodburner, was unusual in the respect that is had a high ratio of heat-to-water at 50%, so approximately half of its maximum heat output would go into water, while the other half would heat the air. Other woodburners were generally 20% or lower, leaving the heat-to-air ratio too high to optimally operate the woodburner – it would have to be run at a low level to avoid overheating which may result in incomplete combustion and air quality problems.

In addition to P02 and P03, increasing space temperatures with reduced heating energy use is seen in houses P01, P07 and, to a smaller degree, P09.

The calibration of the energy use of the solid fuel burners varies in the level of accuracy from house to house. For P01 the analysis was based on a challenging calibration for the original solid fuel burner and so the space heating estimates for P01 may be more uncertain than for other houses.

The changes in both P01 and P07 are shown in Figure 2 as reasonably flat (horizontal) indicating that clawback of energy efficiency improvements as increased comfort may be taking place. Both of these households had indoor temperatures that were amongst the coolest in the project.

A pellet burner was installed into P01 during the renovations to replace an old woodburner. The occupants found it to be effective and easy to use, and as a result they began to use it more intensively than their old woodburner. This increased use was ultimately tempered by the higher operating costs of the burner.

The occupants of P07 had described their house as being like a 'fridge' (Easton, 2009) before the interventions, with family room temperatures being the lowest of the nine Papakowhai houses. Not surprisingly the data after the interventions showed increased average indoor temperatures suggesting that potential energy savings have been taken up as improved comfort.

The household with the lowest overall total heating energy in the project was the sole occupant of P09. This house had temperatures in the middle of the range seen before the interventions. The effect of the insulation upgrades and the installation of a heat pump to replace an electric plug in heater was a small increase in the average indoor temperatures, while making a sizable reduction in the total space heating energy use for the small amount of initial usage.

P06 experienced a decrease in heating service with reductions in both family room temperature and total space heating energy. As previously discussed, this reflects the reduced occupancy of the house at the end of the study as compared with the start.

The largely unchanged results in P05 could be due to consistency of habits. The top up of ceiling insulation, however, would be expected to produce higher family room temperatures. This additional heat may have been used to heat the house more extensively. A heat transfer system was installed but failed to operate as hoped due to the room not being heated to a high enough level to trigger the thermostat-controlled switch (further investigation confirmed it was installed and operating correctly).

4.4 Evening periods

Considering the space heating service in the evening periods in isolation is difficult. The indoor temperature in a building is an integrated response to space heating and other factors (weather, solar gains, occupancy, internal gains, humidity levels, degree of ventilation, etc.) so that the temperatures during the evening depend in part on what was happening before the evening period started. The method of temperature correction can also not be applied for measurements from part of the day.

HEEP (Isaacs, et. al., 2006) has shown that people mainly heat their family rooms in the winter evenings, so examining the family room temperatures in the evening periods may provide an indication of the average temperature that people heat to.

Figure 3 provides a plot of the uncorrected evening only winter family room temperatures and the winter total space heating energy use. Many of the features in Figure 3 are similar to the average household temperature – total space heating energy use graph shown in Figure 2. Some of differences are the unusual results for P10, the small overall movement in P07 and the larger movement of P05. These differences may be due to heating outside of the evening period and the use of heating in other parts of the home.

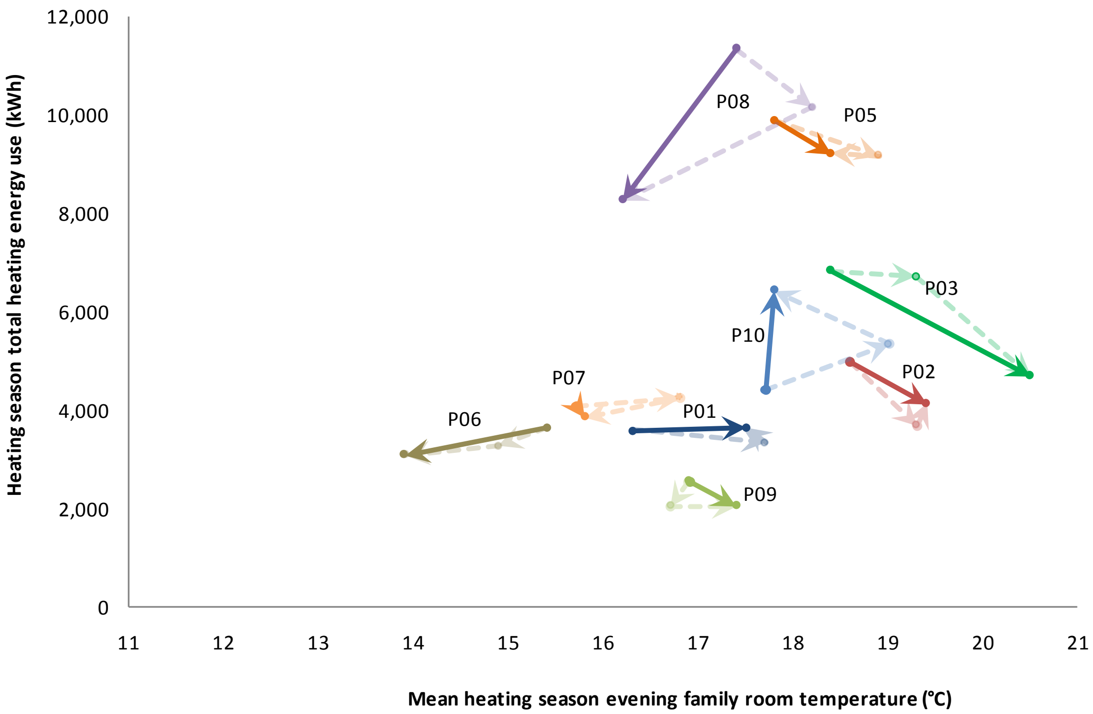

Figure 3 The heating season total space heating energy use and the heating season average evening family room temperatures (uncorrected) before and after the interventions

4.5 Space heating system replacements

The success of a space heating appliance in maintaining adequate indoor space air temperatures - provided that it is of sufficient capacity - is dependent upon the user. All of the houses in the Papakowhai study were considered to have adequately sized heaters after the retrofit, however the way heating appliances were used, varied. Family room and bedroom temperatures were frequently kept at low temperatures. Although the existing woodburners in P02, P06 and P07 were capable of reasonable outputs, they were not utilised to their full capacity. Upon talking to the occupants, there were three main reasons for under utilizing heating systems;

1. Budget constraints. The cost of operating a heating system to a comfortable level can be high. Where fuel for heating has to be purchased separately, this may bring the amount of heating under greater focus and control. P01 did not utilise the pellet burner to the extent they would have liked to as they needed to purchase pellets for the pellet burner where they had previously been receiving free wood for their old woodburner.
2. Preserving fuel. Some occupants preferred to preserve their fuel for a variety of reasons, from perceived environmental pollution from burning the wood, through to the 'keep for best' (when guests came over) or 'keep for a rainy day' (when it gets very cold) mentalities.
3. 'Comfort' at cooler temperatures. Some occupants preferred living in a cool house. In the comfort surveys it became apparent that what occupants called

neither cold nor warm 'neutral' did not necessarily mean they were content with the temperature (Smith, 2008). Many responses where occupants had said they were neutral also included a report that they would have preferred the room temperature to be a little higher. The Papakowhai Renovation Project illustrated quite well that the 'put on another jersey' mentality is alive and well in many New Zealand homes.

As a side note, it was interesting to observe the use of the woodburners in many of the houses. Often, woodburners were used on a low or medium burn rate, when the highest efficiency and lowest particulate emissions generally occur at high burn rates. It appeared that many of the existing woodburners were oversized and/or underutilised, and that people may be installing larger woodburners than are required as they perceive it will be better. In reality, a woodburner that is sized for the particular circumstance it is put in will be far more efficient and less polluting. Even today, when looking at woodburners, most retailers have vague guides as to how much space the woodburner can heat. This information appears to be generic around the country, while in reality a woodburner in Auckland could afford to have a far lower output than one in Invercargill, for example.

4.6 Discussion

The amount of clawback of space heating present within the Papakowhai Renovation Project houses is difficult to quantify. The monitoring in the third year, well after the interventions have taken place, ensures that experiences with the change in the performance of the building have settled in. This longer term picture is also subject to households which have a structural change of occupants joining or leaving the household. These changes in the composition of the household are a major factor on the space heating service levels within the household. Studies looking at clawback should pay careful attention to any changes of composition of the household taking place during the period being assessed.

The households with the highest level of increased insulation also tended to be amongst the warmer houses to begin with. These households had the largest changes in energy use and indoor temperatures but these changes were not always in the expected direction. Increased service levels were seen in one of the houses, while another had reduced service levels due to a reduction in occupancy. The extent of the intervention does not seem to be a factor in whether clawback of space heating services takes place.

Those households tending to exhibit clawback which can be seen as predominantly horizontal movement in Figure 2 (higher indoor temperatures with little change in the space heating energy use), were all amongst the cooler houses before the interventions took place. This is not an unexpected result.

5. Water heating

The energy used for water heating ($E_{hot\ water}$) can be sourced from an energy network (E_{ne}) such as electricity or gas (ie reticulated energy) or from local renewable sources (E_{renew}) such as solar or wood (using a wetback) as shown below

$$E_{hot\ water} = E_{ne} + E_{renew} \quad (5.1)$$

The network energy (E_{ne}) may also include a small component of auxiliary energy for any control systems or pumps used within the water heating system.

The resultant amount of water heating ($Q_{hot\ water}$) can be broken into two components; heat that is provided to users of the system in the form of heated water drawn-off from the system ($Q_{draw\ off}$) and the heat lost from the system to the environment surrounding it ($Q_{std\ loss}$), so that;

$$Q_{hot\ water} = Q_{draw\ off} + Q_{std\ loss} \quad (5.2)$$

Using this equation, water heating can be viewed as being composed of a component, $Q_{draw\ off}$, dependent primarily on the occupants and a component, $Q_{std\ loss}$, that is primarily dependent of the physical characteristics of the water heating system (Pollard, et al., 2001).

Where there are multiple water heating energy sources of varying efficiencies, the connection between the purchased network energy (E_{ne}) and the useful output is more involved so that it is helpful to consider an alternate relationship;

$$E_{ne} = \frac{Q_{draw\ off}}{COP} \quad (5.3)$$

which relates the observed network (reticulated) energy for water heating to a primarily occupant factor, $Q_{draw\ off}$, and to a primarily physical scaling factor, *COP* or coefficient of performance, which measures the efficiency of a water heating system from a physical point of view and incorporates both standing heat losses and the advantages of heat sourced from efficient sources (Lloyd and Kerr, 2008).

An instantaneous electric water heater would have a *COP* of 1 as 100% of the electrical energy input is converted to heated water for the users. Electric storage cylinders have standing losses that reduce their *COP*. A well performing electric storage cylinder may have a *COP* of 0.8, an average system just under 0.7, and systems subject to high heat losses, around 0.5. A solar water heating (SWH) system or heat pump water heating system may have a *COP* much greater than 1 but system performances may vary (Pollard and Zhao, 2008).

5.1 Waitakere NOW Home® hot water use long term

The Waitakere NOW Home® measured in detail the operation of a SWH system over a two year period. Over this period there were no interventions, or major changes to the technical aspects of the hot water system, so that changes in water heating energy or water use are likely due mainly to the occupants changing use, (the $Q_{draw\ off}$).

The second year of monitoring for the Waitakere NOW Home® (Pollard, et al, 2008) showed that there was an increase of 690 kWh (or 44%) in supplementary electric water heating from 1580 kWh in the first year to 2270 kWh in the second year.

In looking to attribute this increased energy use to changes in the use of hot water, weekly averages for each of the monitored hot water uses were examined and are shown in Figure 4. This figure shows hot water usage of water at the 60°C delivery temperature from the hot water system. As heated water services, such as showers, need water at around 40°C, cold water is mixed with this quantity of hot water to provide the larger observable volume of warm water used by the occupants. The ensuite shower can be seen to be both the major hot water use as well as the hot water use that has the greatest increase of usage.

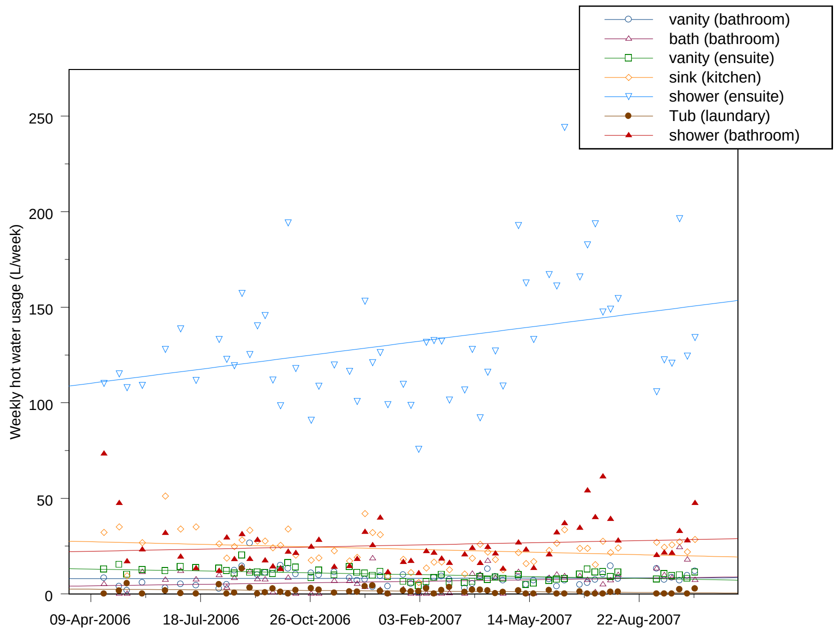

Figure 4 Weekly hot water usage in the Waitakere NOW Home®

The next figure, Figure 5 shows the daily water use of the ensuite shower. Also shown on this graph are two trend lines; one constructed from a 21 day moving average (shown in green) shows an increased use during the last winter, and a high degree of variability for the rest of the data. The increased variability at the left of the graph is due to the increased amount of missing data before May 2006. The other trend line (shown in purple) is a simple linear trend, and while the data shows a very high degree of variability about this line (the R^2 is less than 0.03) there is increased usage apparent over time.

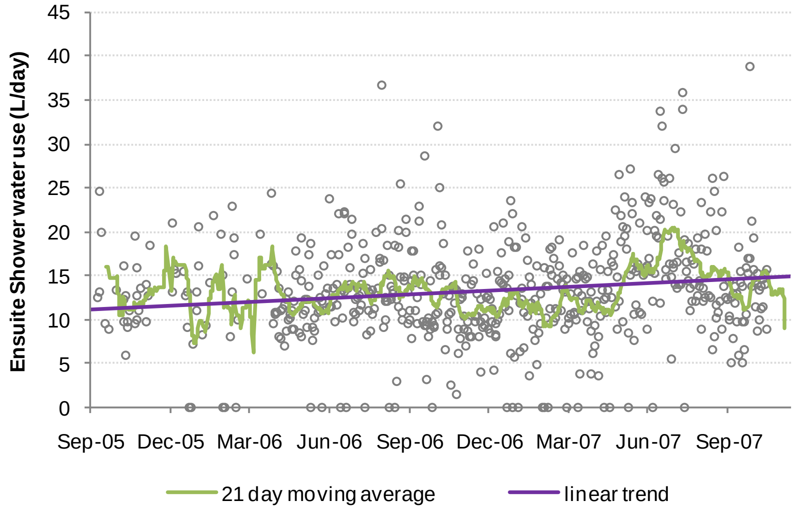

Figure 5 Daily Ensuite shower hot water usage in the Waitakere NOW Home®

The high variability in daily ensuite shower use makes analysis over short periods of time difficult and dependent on how the time periods are selected. Over the two year period the average use of hot water for the ensuite shower per day has increased by approximately 25% from around 12 Litres per day to 15 Litres per day at the end of the monitoring period. This increase service uptake reflects a socially-driven clawback of the hot water service.

5.2 Papakowhai Renovation Project

The nine houses participating in Beacon's Papakowhai Renovation Project had a range of interventions to improve their water heating service.

Two of the houses, P03 and P10 had inadequate hot water service at the start of the project. Both sets of occupants were families, had three school-age children, had 135 litre hot water cylinders and the initial surveys established that both ran out of hot water on a regular basis. P03 and P10 both received SWH systems with large 300 litre cylinders. Although P08 had adequate hot water provision at the start of the project, the house had good solar access and so a SWH system was installed here also.

The other household that received a replacement of their hot water system was P05, where a wrapped 'D' grade electric storage cylinder was replaced with two instant gas water heaters.

The remaining five households received an intervention to their water heating systems of added insulation wraps to the cylinders, (which did not necessarily result in improved efficiency).

Table 4 provides some of the characteristics of the hot water systems in the nine Papakowhai renovation households.

Table 4 Characteristics of the Papakowhai hot water systems

House	Household size	Water heating energy type	Cylinder capacity (L)	Cylinder capacity (L/person)	Initial cylinder insulation grade	Thermostat setting (°C)	Intervention
P01	4	elec.	180	45	B	70°C	Wrap cylinder
P02	2	elec.	180	90	D	na†	Wrap cylinder
P03	5	elec/SWH,elec	135/300	27/60	B	65°C‡	Install 300 L SWH system
P05	2	elec./gas	180	90	D*	na†	Install two instant gas systems
P06	5/2	elec.	180	36/90	B	65°C	Wrap cylinder
P07	2	elec.	180	90	B	na†	Wrap cylinder
P08	3/2	elec/SWH,elec	180/280	60/140	B	65°C‡	Install 280 L SWH system
P09	1	elec.	180	180	B	60°C	Wrap cylinder
P10	5	elec/SWH,sf,elec	135/300	27/60	B	70°C‡	Install 300 L SWH/wetback

Cylinder capacities that had a change of value between the first and second years are shown with both values with the pre-renovation year shown first. The systems replaced with a SWH system are shown in green, while the blue indicates the system replaced with instant gas systems.
*had a cylinder wrap present before the intervention.
† not available.
‡ The thermostat setting for the SWH systems was of the cylinder before replacement. After the SWH system was installed the cylinder element was subject to control by the solar controller.

Table 4 includes the thermostat settings for those systems for which inspection was possible. Only one of the six known systems (P09) had a temperature setpoint of 60°C with the remaining five systems having temperatures 5°C or 10°C hotter than required for Legionella control. These increased temperatures add support to the argument that the capacity of the hot water systems is less than desired, and that people are turning up their thermostats to gain additional capacity, although it is recognised that the inherent inaccuracy of the thermostats will also be a factor.

5.3 Changes in efficiency and service level

The *COP* and hot water used ($Q_{draw\ off}$) were determined for each of the Papakowhai Renovation Project households. For the three SWH systems, the energy content of the drawn-off water ($Q_{draw\ off}$) was measured directly as was the electrical energy for water heating (E_{ne}) allowing the *COP* to be calculated.

For the electric storage hot water cylinders, the electrical energy for water heating (E_{ne}) was measured. This measured data was analysed using a variety of methods (Camilleri, 2009; Isaacs, et al., 2005) to provide an estimate of the *COP* which therefore allowed the hot water used ($Q_{draw\ off}$) to be calculated.

In P05, the two instant gas systems have no or minimal standing losses, and small flue-gas energy losses, so a *COP* of 0.9 was used as an estimated overall combustion efficiency of the gas burners which included both a standard combustion and a condensing combustion unit. (They were reported by the supplier to have efficiencies of 85 and 95%). The gas energy content (E_{ng}) was measured using the standard HEEP method (Pollard, 1999) and the hot water used ($Q_{draw\ off}$) calculated.

Table 5 gives a listing of the *COP*'s and the hot water used ($Q_{draw\ off}$) for each of the Papakowhai Renovation project water heating systems before and after the interventions.

Table 5 Hot water system COP and the energy content of the hot water used for the Papakowhai Renovation Project households before and after retrofit

House	Before			After			Change	
	$Q_{drawoff}$ (kWh)	$Q_{drawoff}$ (kWh/person) †	*COP*	$Q_{drawoff}$ (kWh)	$Q_{drawoff}$ (kWh/person) †	*COP*	$Q_{drawoff}$ household	*COP*
P01	5200	1300	0.8	5100	1300	0.8	-3%	2%
P02	1900	950	0.5	1100	550	0.5	-42%	-2%
P03	2900	590	0.7	3000	590	3.2	1%	332%
P05	1400	700	0.6	1900	950	0.9*	32%	42%
P06	1900	370	0.7	1300	650	0.7	-30%	1%†
P07	1300	650	0.6	860	430	0.5	-34%	-6%
P08	2400	800	0.7	1900	960	3.1	-21%	310%
P09	1000	1000	0.5	930	930	0.5	-8%	8%
P10	2800	560	0.8	2400	470	2.6	-16%	277%

The systems replaced with solar water heating (SWH) systems are shown in green, while the blue indicates the system replaced with instant gas systems.

* Estimated

† As the occupancy of the house is not always stable, calculations involving the number of persons per house are indicative only.

All three of the household which received SWH systems had a large increase in *COP* from values between 0.6 and 0.9 to values between 2.5 and 3.3.

The other system with a large increase in system efficiency was P05 where the old electric hot water cylinders were replaced with two instant gas burners.

The other five systems had cylinder wraps added to them. None of the cylinder wraps changed the *COP* of the system by more than 10%. The lower usage of hot water in P07 and P02 is suspected to have caused the decrease in the *COP* after the wrap was installed.

The change in hot water use ($Q_{drawoff}$), shown in Table 5, shows a high degree of variation. The hot water use per person is more consistent but is indicative only as the number of people present in the house is not reliably known, especially when there are changes to the household composition from people moving out or joining the household.

The largest reduction in hot water use ($Q_{drawoff}$) occurred in P02 where 42% less energy was removed from the cylinder in the second year. P07, another two person household, also had a large decrease in the hot water used reducing by 34% in the second year.

The 30% reduction in hot water use ($Q_{drawoff}$) for P06 was also accompanied by a reduction in the household size from five to two, so that the water use per person may not have reduced.

The household which had the highest hot water use ($Q_{drawoff}$), P01, had little change reducing by only 3% in the second year. The single person household, P09, reduced the energy content of hot water draw-off by a slightly larger 8%.

Two of the three SWH systems (P10 and P08) had good reductions in the hot water use ($Q_{drawoff}$) of 16% and 21%, while the remaining SWH system (P03) had usage that was largely unchanged.

The occupants of P10 expressed a high degree of satisfaction with their new water heating system (Easton, 2009) and they had increased service from the system. This appears to be in contrast to the 16% reduction in the hot water use ($Q_{drawoff}$) observed. The hot water use ($Q_{drawoff}$) is measured from the cylinder and water cooling off in pipework would be included in this usage but may not be perceived by the occupants. The SWH systems used in P10, P03 and P08, included much larger sized cylinders which could be operated at lower temperatures which in turn would affect the change due to the losses in the pipework.

The hot water system to have the largest increase in hot water use ($Q_{drawoff}$) in the second year was P05, which had had their low pressure electric storage cylinder replaced with two mains pressure instant gas water heaters. As part of this change, flow restrictors and a low flow shower head were installed. Easton (2009) notes that the occupants were not satisfied with the performance of the shower after the intervention.

It is unclear why this household has increased its water use so markedly. While it could suggest that a high clawback is taking place, there are a number of other technical reasons to consider, including:

- The increased pressurisation would lead to some increased usage but the low flow shower head and flow restrictors should limit this increase.
- The *COP* of the system was assumed – if the COP had actually been lower, then the actual water use would be less.

5.4 Discussion

Only the household that had the instant gas systems installed and the households with the three SWH systems installed resulted in a large improvement in the efficiency of their water heating service. The other households which had cylinder wraps installed, resulted in only small changes of efficiency.

The hot water energy use of the household that had the instant gas systems installed (P05) did not significantly change after the energy efficiency upgrade (Table 3) so therefore water use would have had a large increase . This could be regarded as a case of high clawback but there are a number of technical issues (including the possible removal of some flow restriction due to unacceptable garden hose water pressure) that cast doubt on how the water heating system was operating and whether significant clawback was taking place.

For the remaining households, the changes in hot water use showed similar or less use after the intervention. Other than P05, no systems had a large increase in hot water use so that it seems that clawback for water heating services (except perhaps where other technical changes were made, such as changing from low pressure to high pressure) is only small.

The hot water use between the years for each of the Papakowhai households seems highly varied. The data from the Waitakere NOW Home® also shows large changes in hot water use despite no change to the structure of the household or the performance of the hot water system.

The households that had SWH systems fitted, had similar or reduced hot water use ($Q_{drawoff}$), after the installation, resulting in no clawback or fully realised energy savings for the water heating system improvements. One of these households had lower occupancy and lower demand for water heating service.

6. Conclusions

When energy efficiency improvements are made to a household energy service, the energy savings may be realised as energy savings or clawed back by the occupants as an increased level of service over time. This clawback process of taking a higher level of service, evolves slowly so needs to be examined over a long period. The extent to which clawback takes place, also varies considerably depending on whether space heating services or hot water services are being considered.

1. Clawback can be seen in the Waitakere NOW Home® water heating service, due to a slow increase in the occupant demand.

2. Clawback of space heating service in the Papakowhai Renovation Project revealed the following:
    a. Space heating services are strongly influenced by the changing household compositions and these need to be understood first.
    b. Those households which have lower temperatures are more likely to experience clawback with their occupants choosing to have warmer houses than those houses which have a higher indoor space temperature.
    c. Extensive upgrades to thermal envelope insulation levels are more likely to see large scale changes to the space heating energy use and indoor temperatures, however this is independent of whether their occupants choose to take a higher level of comfort or not.

3. Clawback of water heating service in the Papakowhai Renovation Project revealed the following:
    a. Year to year variations in hot water use are large in comparison to the small energy efficiency improvements from the installation of hot water cylinder wraps.
    b. Only major replacements of hot water systems produce noticeable changes in water heating energy use
    c. Significant clawback occurred in the replacement of an old low pressure electric storage cylinder with two mains pressure instant gas water heating systems, since this intervention resulted in no change of water heating energy use.
    d. The three SWH systems had similar or reduced water heating demand after their installation, and could therefore be considered as effective energy efficiency intervention with little or no clawback.

6.1 Concluding Discussion

The full value of potential reductions in space and water heating energy use due to improved energy efficiency were not delivered from the homes assessed due to householders clawing back savings as improved comfort and levels of service.

It is important to consider the role of clawback in large scale energy savings programmes and whether these programmes will deliver the savings expected.

It is postulated that it will only be once the New Zealand housing stock has been improved to provide high levels of comfort and service, that energy efficiency upgrade programmes deliver the reduced demand that they promise.

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