HR2420/8

Solar Water Heating in the Waitakere and Rotorua NOW Homes® and in three Papakowhai Renovation homes

Final

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About This Report

Title

Solar Water Heating in the Waitakere and Rotorua NOW Homes® and in three Papakowhai Renovation homes

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Abstract

This report describes and examines the performance of the solar water heating (SWH) systems used in the Waitakere NOW Home®, the Rotorua NOW Home® and three of the Papakowhai Renovation houses. A variety of systems were used in these houses and performance varied from 75% of the water heating being provided by solar in one of the Papakowhai Renovation houses to 36% of the water heating needs being met by solar in the Rotorua NOW Home®. Reasons for the performance levels are suggested.

Reference

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

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1 Executive Summary

This report examines the performance of the solar water heating (SWH) systems used within the Waitakere and Rotorua NOW Homes® and the three Papakowhai Renovation Project houses that were extensively monitored.

It has been seen (Pollard and Zhao, 2008) that the performance of SWH systems in New Zealand is dependent on individual system characteristics rather than what system was used or in which climate the system was located. These Beacon systems should, therefore, be considered as case studies rather than representative of technology used.

The performance of a SWH system is dependent on all of the component factors being right and this research along with other work (Pollard and Zhao, 2008) has shown that it is important to ensure that:

1) Immediate reheating of cylinders is prevented with the use of timers.
2) Information on how the system is operating is available to the occupants such as display units or controls
3) The angle of the collector is near the site latitude angle to ensure good year round performance
4) Sufficient collector area and storage volume is provided
5) Heat losses of cylinders are minimised and pipes well insulated

The Papakowhai Renovation Project systems performed well with between 70-75% of total energy use being renewable over the monitored period. They featured well-sized collectors, installed at the latitude angle, and connected to well-insulated cylinders within the house. These systems featured a controller that controlled the heating element inside the cylinder. The addition of a timing component would have further improved the performance of these SWH systems.

The Waitakere NOW Home® system performed moderately well at 45% of total energy use from solar. Despite being the only system to feature a display unit in a prominent living space, the occupants were ‘passive’ (see Scotts and Saville Smith, 2007 for an analysis of passive use of SWH systems) users and left the system to operate against its default configuration. This default configuration did not, however, include any timer control to exclude morning reheating. The collector panel angle of 20° was low and biases the performance of the system towards the summer.

The Rotorua NOW Home® system did not perform well with only 36% of the energy use coming for solar. The collector area was small and was installed at a less-than-optimal angle. The system lacked timer control. The Rotorua NOW Home® also included additional pressure restriction systems resulting in shower flow rates that were very low (less that 2 L per minute) which may have interfered in how the occupants used hot water.

2 Acknowledgement

The solar water heating systems used in the Rotorua NOW Home® and the Papakowhai Renovations Project homes were provided by industry partners. We would like to thank the Excel Group (now known as Leap Ltd) for their donation to the Rotorua NOW Home® project and Azzuro Solar Ltd for their donation to the Papakowhai Renovation Project.

We would also like to acknowledge EECA in funding the purchase of the SWH system in the Waitakere NOW Home®.

3 Introduction

This report examines the solar water heating (SWH) systems used within the Waitakere and Rotorua NOW Homes® and three Papakowhai Renovations Project homes, and synthesises the information learnt from monitoring the five systems.

All of these SWH systems were 'new' systems, rather than 'retrofitted' systems, in that a specifically-designed hot water cylinder was used as part of the system rather than using multi-way valves to allow the solar collectors to be connected to an existing cylinder. How the heat is transferred from the solar collector to the hot water cylinder is an important factor in the efficiency of the system and the specially-designed new systems are generally more efficient than a retrofitted system.

The time of the specification and design of the Waitakere NOW Home® in 2005 coincided with a large increase in the number of SWH installations (see Figure 1). With the upsurge in installations of SWH, there has been an increased interest in how well SWH systems are performing in practice. BRANZ (Pollard and Zhao, 2008) was commissioned by Building Research and EECA to undertake one year of performance monitoring of 35 installed SWH systems in Auckland, Wellington, Christchurch and Dunedin (2005/2006), and found that performance of SWH systems was related to individual system characteristics (how well the system was designed and installed) rather than any systematic technology used or climate factors.

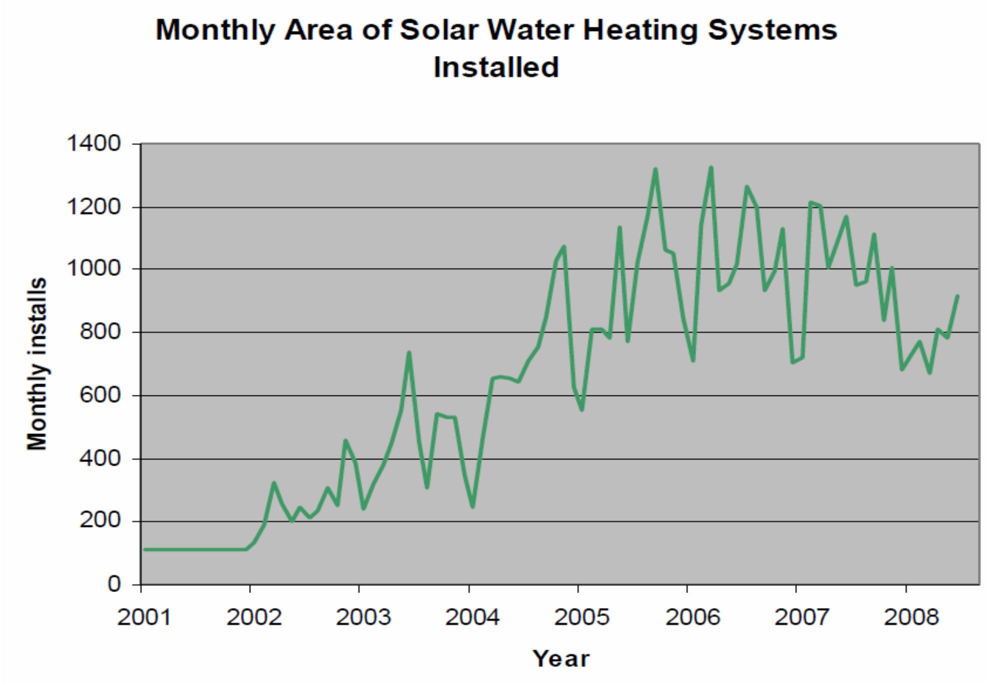

Figure 1: Area of solar collectors installed in New Zealand

(Source: Solar Industries Association, 2009).

4 Description of systems

4.1 Waitakere NOW Home®

At the time of the specifying the hot water system for the Waitakere NOW Home®, a common perception about SWH was that it required the installation of a hot water cylinder on the roof. An alternative option that provided an aesthetically unobtrusive example of SWH, a Solahart Streamline pumped flat plate collector and cylinder, was specified and installed in the Waitakere NOW Home®. These are shown in Figure 2 and Figure 3.

Figure 2: The flat plate solar collectors on the Waitakere NOW Home®

Figure 3: The hot water cylinder on a shelf above the monitoring equipment

Two all-copper, black chrome collectors with a total area of 3.7 m^2 were installed parallel with the 20° concrete tile roof. This was some 17° shallower than the desired angle – the site latitude - which was 37° (Auckland). Having the panel at a shallower angle means that the winter sun is not maximised as it glances the collector and the amount of solar energy collected in winter is reduced.

The element in the hot water cylinder was not subject to timer control and was only subject to thermostatic control. A panel (shown in Figure 4) was present in the main living area, which provided a temperature readout of the cylinder temperature, an on-off switch for the heating element, as well as a one-time operation heating override for the element.

Figure 4: Temperature display viewable from kitchen and living room

4.2 Rotorua NOW Home®

The Rotorua NOW Home® included a Solar Genius low pressure, thermosiphon, flat plate collector SWH system.

The storage tank and collector is made from one moulding of polyethylene. The 2.6 m^2 collector covers one fully-flooded cavity with no channels or pipes and is covered by an acrylic sheet. Polyurethane is used to insulate the collector and the 300L storage tank.

The installation at the Rotorua NOW Home® is shown in Figure 5. The frame on which the SWH system sits resulted in a collector angle of 30°, somewhat of a shallow angle considered that Rotorua is at latitude of 38°. The maximum angle at which the Solar Genius can be installed at is 40°.

The Solar Genius is a low pressure system. The pressurisation of hot water is achieved by the height of the storage tank above the water delivery point. However, additional water restriction devices were used in the Rotorua NOW Home® resulting in substandard shower flow rates of less than 2L/min.

The control scheme for the SWH system was a basic thermostat inside the storage tank set to 60°C. No system display was used.

Figure 5: The flat plate thermosiphon SWH system in the Rotorua NOW Home®

4.3 Papakowhai Renovation Project

The Papakowhai Renovation project installed a range of sustainable upgrade options to improve the environmental performance in nine houses in Papakowhai, a suburb of Porirua. All three houses selected for a 'High' intervention package included a SWH system. These systems were pumped evacuated tube systems and are shown in Figure 6 through to Figure 10.

Figure 6:The evacuated tube collectors at House 3

Figure 7: The hot water storage cylinder at House 3

Figure 8: The evacuated tube collectors at House 8

Figure 9: The SolaStat Plus controller unit at House 8

Figure 10: The evacuated tube collectors at House 10

The collectors featured a sizable collector area by connecting two twelve-tube panels together to provide a total 24 evacuated tubes. A feature of the Azzuro panel is that the back of the panel features a trough-like reflective backing that provides a small increase in the incident radiation onto the evacuated tubes. The Azzuro evacuated tubes have a fluid filled u-pipe within each tube.

The collector panels were installed on flat sections of the roof and were mounted in a frame to achieve a collector angle of 41° to match the latitude of the site. The majority of the roof at House 10 was low pitch (see behind the collector in Figure 10). The solar collector was installed in a flat section between the two main parts of the roof. As there were roofing elements in front of the collector, some shading of the collector occurs in winter when the sun angle is low.

The hot water cylinder in each of the houses was replaced with a solar-designed hot water cylinder (see Figure 7) so that these systems could be considered as a ‘new’ system rather than as a ‘retrofitted’ system. The solar designed tanks were stainless steel Superheat models made by Multimachinery Limited. An advantage of stainless steel hot water cylinders is that they are able to withstand higher temperatures than the 70°C limit found on many enamel-lined steel cylinders. However, standing losses are greater with increased temperature difference so that the average cylinder temperature should be kept low by using a larger than typical cylinder. Large 300 L cylinders were used for the Papakowhai installations. The cylinders were located in the roof-space for House 3, in a hallway cupboard in House 8 and in the basement in House 10.

The Papakowhai systems included a SolaStat Plus controller which was positioned alongside the cylinder. The SolaStat Plus controller features a differential temperature control so that fluid is pumped from the solar collector when the collector temperature is a set temperature warmer than the water in the cylinder. The SolaStat Plus controller also controls when electrical supplementary heating is able to take place within the cylinder. The operating characteristics of the controller are discussed further in section 5.

5 Operation

Work undertaken by CRESA (Scotts and Saville-Smith, 2007) as part of an examination of the performance of SWH systems in New Zealand (Pollard and Zhao, 2008), revealed than many operators of SWH systems are ‘passive’ users and don’t actively engage in monitoring the performance of their SWH system. These people rely on the SWH system delivering an adequate level of performance in its default configuration. There was, however, a minority of occupants that were regularly monitoring their systems and actively turning the heating element inside their SWH cylinders on and off.

The operation of a SWH system, and whether this is active or passive, has an impact on the overall performance of the system. How much occupants interact with the controls of a SWH system is likely to depend on how well-informed they are, how automated the system is and how easy and accessible the displays and controls of the system are.

Only the system in the Waitakere NOW Home® featured a display of the current cylinder temperature as well as on-off controls for the water heating element that were accessible from a living space; however, from an examination of the heating element operation (Figure 11), it can be derived that the cylinder was largely left on all of the time.

Figure 11 shows the supplementary electric heating comes on shortly after the hot water has been used in the morning. The supplementary heating in the evening, while a smaller demand, requires little supplementary heating making use of the solar energy collected during the day.

The data from the Waitakere NOW Home® was analysed for the year between 1 September 2006 and 30 August 2007.

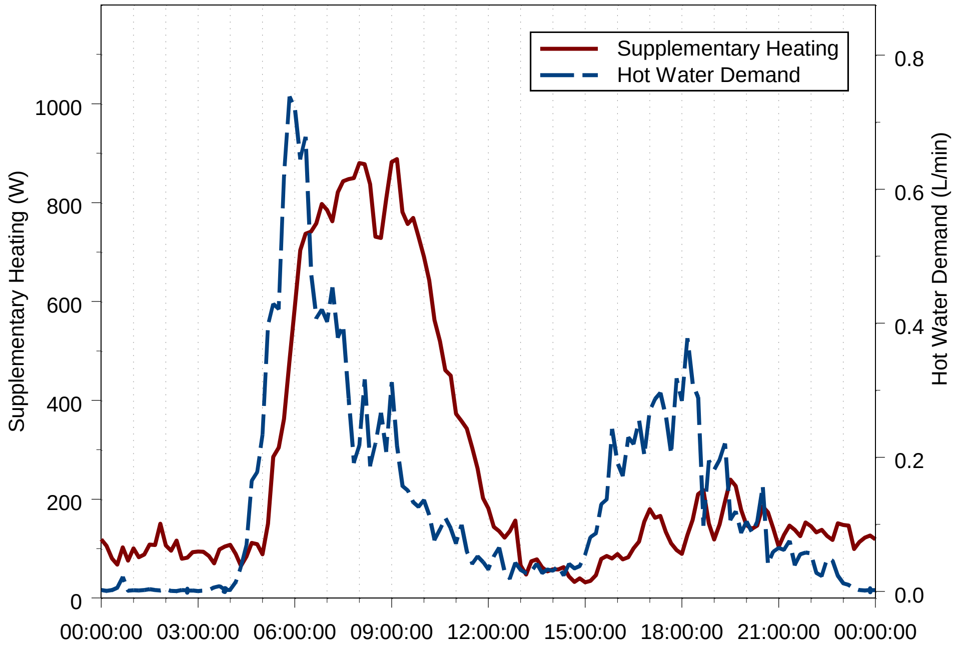

Figure 11: The time of day profile of the supplementary heating (electric boost) and hot water flow for the Waitakere NOW Home® SWH system

The Rotorua NOW Home® system did not include any feedback or control systems within the living space of the house. Turning the cylinder element off would be possible from the fuse board or meter board but this could not be expected of homeowners or occupiers. There was no evidence (Figure 12) that the occupants turned off the cylinder.

Figure 12 shows the supplementary heating and water flows for the Rotorua NOW Home®. The hot water use profile (dotted blue line) shows a large evening peak as well as a similar sized morning peak. The supplementary heating response to this water use (red line) follows the water use demand closely. Unlike the Waitakere NOW Home®, the size of the evening supplementary heating is large suggesting a limited collection or storage of solar energy during the day. The Rotorua NOW Home® data was collected[1] and analysed along with meter readings from 1 September 2007 to 30 August 2008.

1 Data was not available for a period of data over the summer.

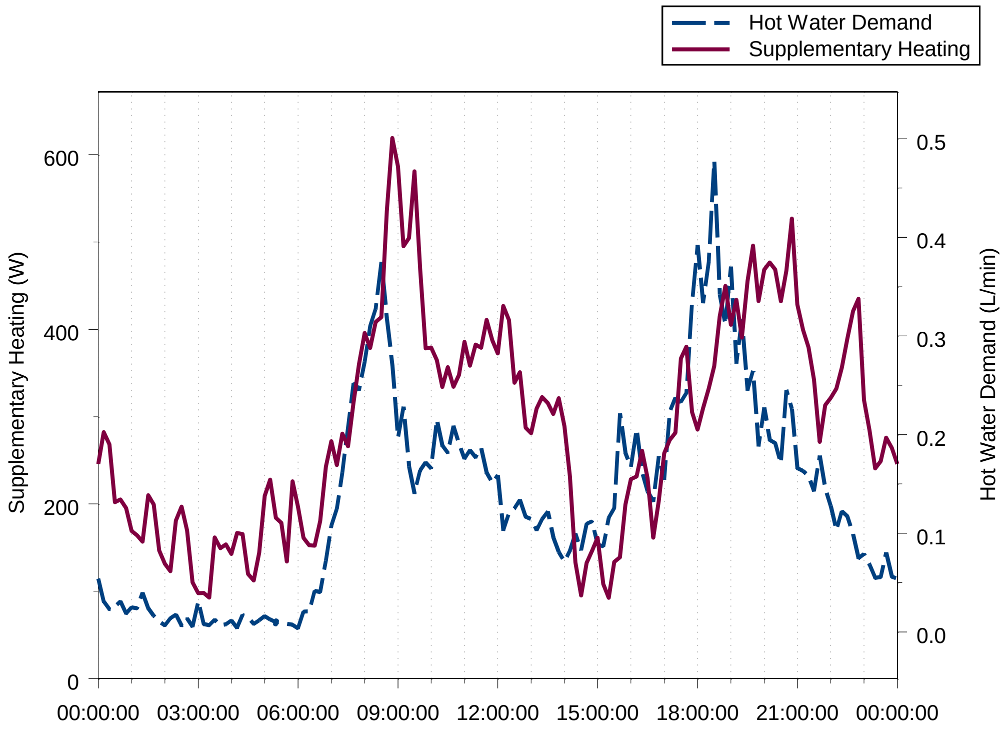

Figure 12: The time of day profile of the supplementary heating and hot water flow for the Rotorua NOW Home® SWH system

The Papakowhai systems provided a controller that displayed a range of system temperatures such as the collector and cylinder temperatures; however, these controllers were positioned alongside the cylinder making them not able to be seen directly from any living space within the house. Turning on and off the element of the cylinder would also require accessing the cylinder.

The SolaStat Plus controller used in the Papakowhai homes controls when the element inside the SWH cylinder can operate. Figure 13 is taken from the SolaStat Plus manual (SolaStat, 2009) and shows the algorithm used to decide whether to operate the heating element.

Figure 14, Figure 15 and Figure 16 shows the operation of the heating element and hot water drawn off from the three Papakowhai SWH systems. While the control algorithm inside the SolaStat Plus controller limits the amount of supplementary heating provided while the circulation pump is operating (and therefore when solar energy is available), there is no timer function to prevent the heating element from operating in the early morning before solar is available but when many people use hot water for showering. The addition of a timing component would improve the performance of the SWH systems.

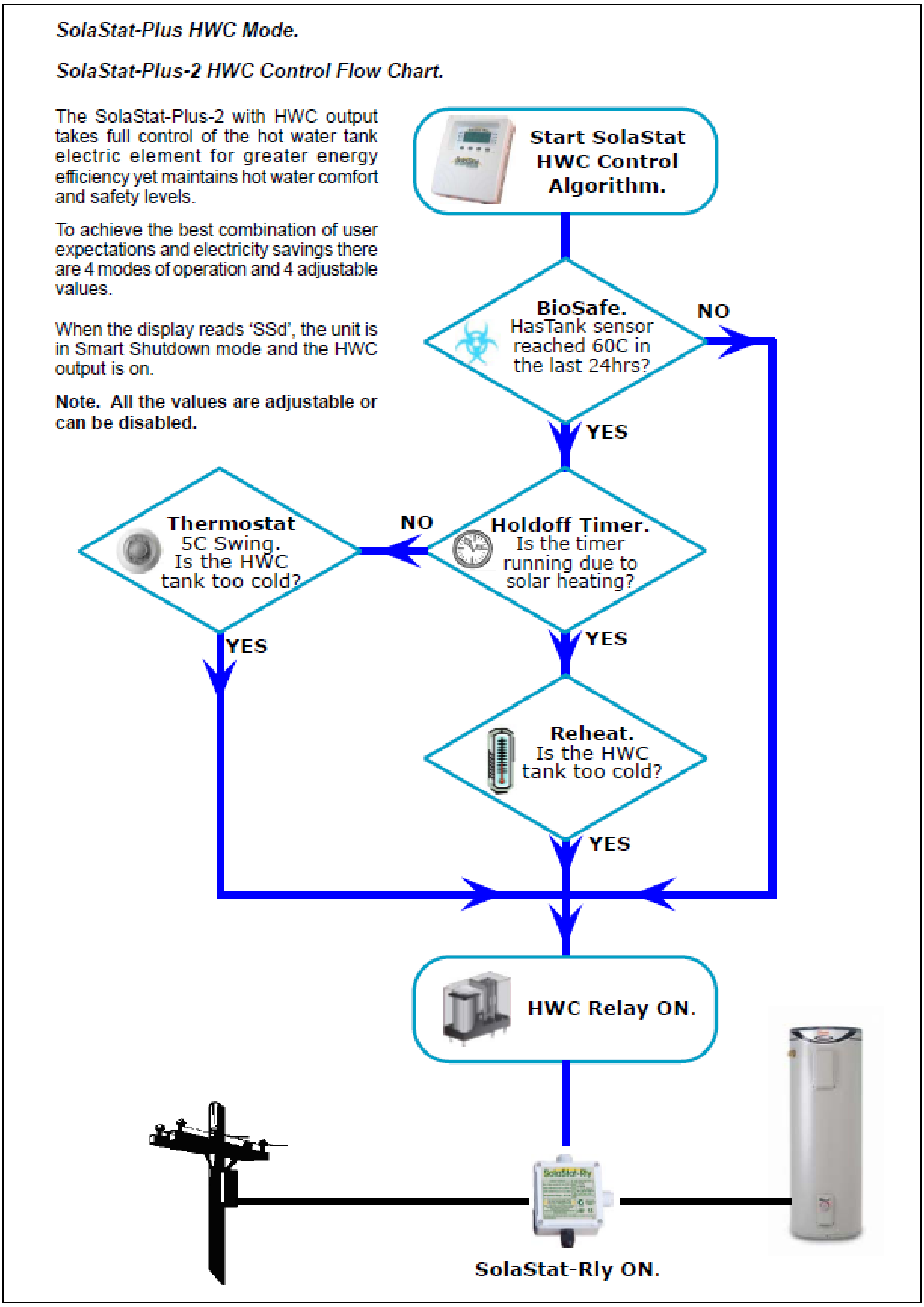

Figure 13: Process to determine if electric heating element should operate

(Source: SolaStat 2009).

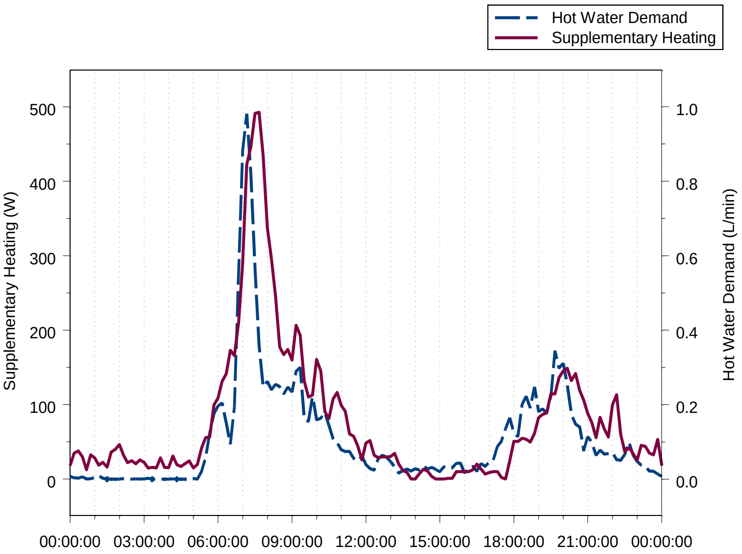

Figure 14: The time of day profile of the supplementary heating and hot water flow for House 3

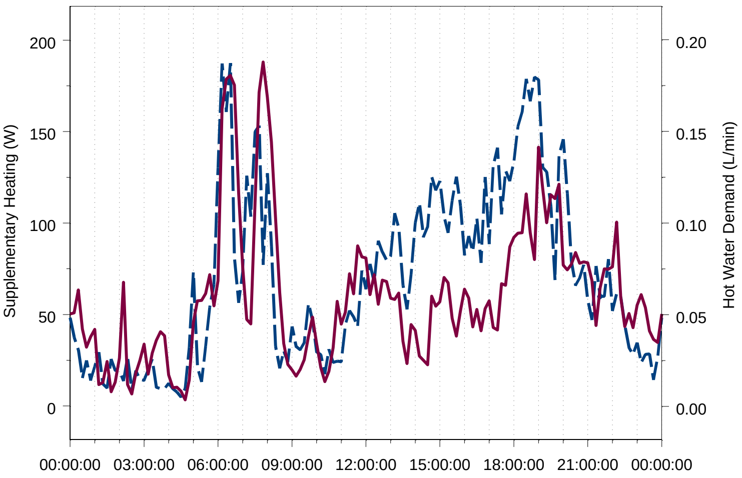

Figure 15: The time of day profile of the supplementary heating and hot water flow for House 8

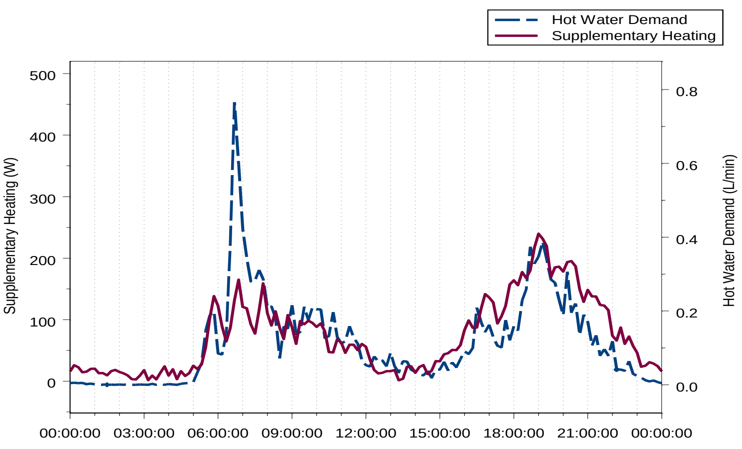

Figure 16: The time of day profile of the supplementary heating and hot water flow for House 10

The supplementary heating and water flow graph for House 3 (Figure 14) shows a well-defined water use peak in the mornings indicating regular patterns of water use. The supplementary heating follows the same water draw-off patterns.

The water use for House 8 (Figure 15) is much more irregular (dotted blue line) with usage occurring throughout the day causing a ‘spiky’ profile. The supplementary heating (solid red line) largely follows the water draw-off patterns but appears reduced during the afternoon period coincided with the period of maximum solar collection.

The water draw-off pattern for House 10 (Figure 16) is remarkably similar to the pattern for House 3 (Figure 14). The supplementary heating response (solid red line) however is quite different, being much reduced in the morning while having a larger-than-expected evening heating requirement. This system was a combined wetback and solar system so the reduced morning supplementary heating peak could be explained by retained heat within the cylinder from the operation of the solid fuel burner, while the higher than expected evening peak (for which the solar is expected to offset) could be due to the lower effectiveness of the solar system due to the shading of the panel mentioned in section 4.3.

6 SWH Performance

The monitoring of solar hot water systems was developed by BRANZ as part of a jointly funded Building Research/EECA project that was begun in 2006 and reported in Pollard and Zhao (2008). An overview of the details of the analysis to determine the energy balance, COP and performance of the monitored system have been included in Appendix A.

Table 1 summarises the energy balance for each of the Beacon research houses. This data is also displayed in a graphical form in Figure 17.

Table 1: Annual energy balance for each of the monitored systems
(all figures to two significant figures and figures may not add due to rounding errors)

System	Draw-off energy	System losses	Auxil-iary energy	Total energy	Supple-mentary water heating	Renewable energy Q_{renew}		COP	Daily hot water use	Wetback
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(% of total)		(L/day)	
NH1*	3330	820	70	4200	2300	1900	45%	1.4	200	no
NH2†	2700	1400	-	4200	2700	1500	36%	1.0	190	no
House 3	3000	470	38	3500	900	2500	73%	3.2	170	no
House 8	1900	500	91	2500	530	1900	75%	3.1	100	no
House 10	2400	380	250‡	3000	650	2100	70%	2.6	170	yes

* NH1 Waitakere NOW Home®
† NH2 Rotorua NOW Home®
‡ The auxiliary energy for P10 included the pump for both the SWH system and the wetback.

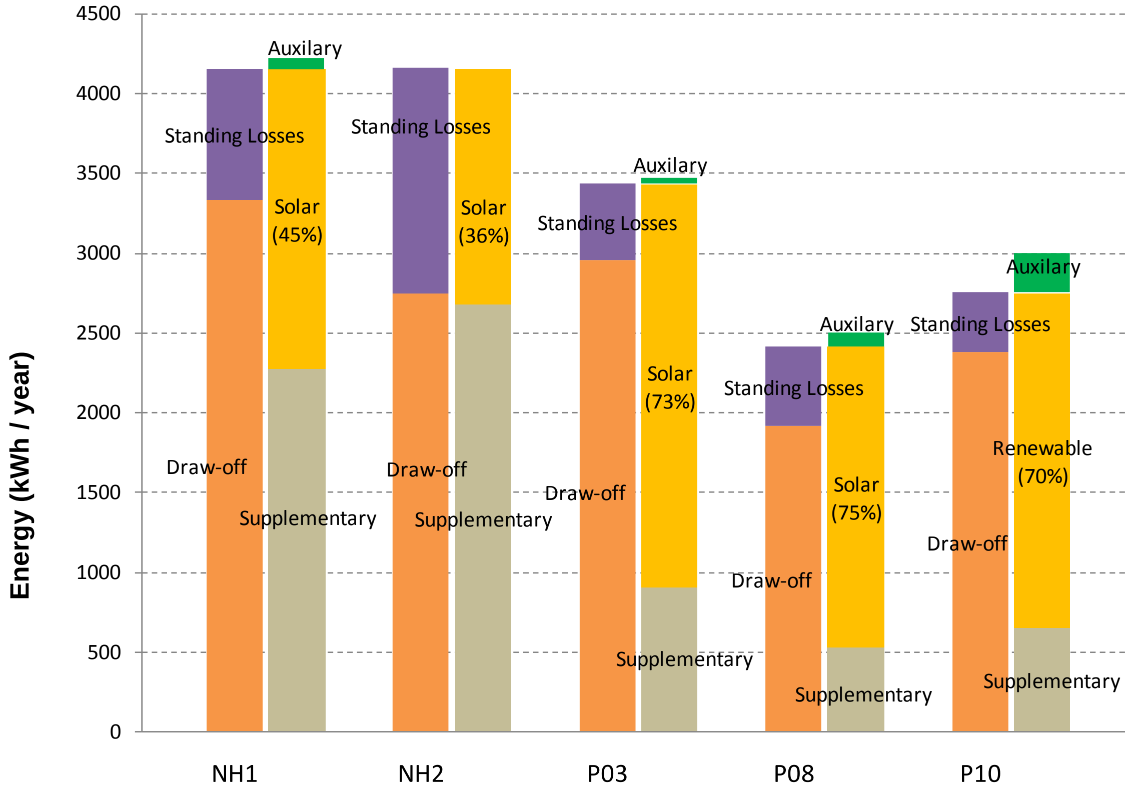

Figure 17: Energy sources for the SWH systems in the Beacon research houses

As can be seen from Figure 17, the systems in the Papakowhai Renovation houses performed better than the systems in both the NOW Homes®, however the quantity of hot water used in the two NOW Homes® is much higher than for the Papakowhai Renovation houses. The absolute quantity of solar energy gained by the Waitakere NOW Home® (1900 kWh) is equal to the solar energy gained by the system with the highest renewable energy fraction, House 8.

The performance of each system is discussed in detail in the next section.

7 Discussion

The Waitakere NOW Home® SWH system is moderately efficient. The system provides for about 45% of the water heating needs of the household having a COP of 1.4.

A key inefficiency present in many SWH systems, that is seen in the Waitakere NOW Home® system, is that there is no timer on the supplementary heating element. As was seen in Figure 11, when water is drawn off in the mornings (when no or low solar radiation is present) the supplementary heating operates at the same time, heating the quantity of used water up before there is there is sufficient solar radiation. A timer is capable of being set to prevent the supplementary heating from operating in the morning so this immediate heating of the morning draw-off of water is prevented. Kerr (2008) undertook computer simulations of systems and found a performance improvement (from a retrofit base case) of over 50% is achievable when a timer was used.

The supplementary heating energy consumption of the Waitakere NOW Home® SWH system was high in winter. The two collector panels were at the same angle as the roof at only 20°. This low angle improved the summer time performance of the solar collector but reduced its winter time performance. Mounting the collector panels in a frame at a steeper angle would improve the winter time performance but would make the panels more noticeable and would affect the aesthetics of the home. As the Waitakere NOW Home® was a new home, it would have been possible to incorporate a steeper roof angle into the roof design. Extra roof area at a good solar angle may also make mounting any solar PV panels in the future easier. An alternative solution would be to add an additional collector panel (at the roof angle) which may increase the amount of winter solar energy that may be collected; however, the amount of solar energy collected in summer may not be able to be stored within the system which would require either more storage (a larger cylinder) or a way of dealing with the excess heat.

The proportion of the energy obtained from the sun by the Rotorua NOW Home® SWH system was less than that for the Waitakere NOW Home®. Overall 36% of the water heating energy was met by the solar. The COP, like many of the systems in the Pollard and Zhao (2008) report, was approximately 1.0. Typically the reason for the low COP is the supplementary heating is uncontrolled and that the large water draw-offs occurred before solar energy was available so the system only has the potential to have solar energy recover the standing losses of the system and not the large quantity of drawn off water.

There is a large proportion of the daily hot water use occurring in the evenings in the Rotorua NOW Home® as can be seen in Figure 12. Solar energy collected during the day can offset the need for supplementary heating in the evening. For the Waitakere NOW Home® it can be seen (Figure 11) that. while the evening hot water use peak is smaller in proportion to the morning hot water use peak, the evening supplementary heating is considerably smaller than the morning supplementary heating. For the Rotorua NOW Home®, the evening supplementary heating is only slightly reduced as compared with the morning peak. This suggests the Rotorua NOW Home® SWH system is lacking in ability to capture effectively and/or store solar energy during the day.

Factors that may be influencing the performance of the Rotorua NOW Home® SWH system may be:

- The smaller collector area of only 2.6 m^2 (the Waitakere NOW Home® had a 3.7 m^2 collector area).
- The lower efficiency of the collector surface.
- The high heat losses from the cylinder.

Higher heat losses result from roof-mounted thermosiphon systems as the cylinder is exposed to colder ambient temperatures being outside the thermal envelope of the house. The insulation levels of the cylinders used in thermosiphon systems may also be lower than indoor cylinders used in pumped systems (such as in the Waitakere NOW Home® and the Papakowhai systems). Thermosiphon systems are commonly made for the Australian market where the insulation requirements for hot water cylinders is not as strict as the New Zealand market and where, typically, their ambient outside air temperatures are warmer than New Zealand.

The two solar-only Papakowhai systems, House 3 and House 8, perform to a similar high level with both systems providing over 73% of water heating needs from solar, having a COP of 3.2 and 3.1. Both of these systems featured un-obscured collectors of a good size and angle (at the latitude angle of 41°). These systems feature a controller which also controls the element; however, there is no time-based control in the controller and undesirable immediate heating of morning water use was observed in both houses.

The third Papakowhai system, House 10, featured a wetback in addition to its solar collectors which had a similar configuration similar to House 3 and House 8; however, the collectors were subject to some winter shading due to the roof line of the house.

The methodology for determining solar contribution cannot distinguish between different means of heat inputs into the cylinder so only a combined renewable (solar and wetback) energy input figure could be calculated. Overall 70% of the water heating energy was provided by renewable means. The COP was also slightly lower as compared with House 3 and House 8 with a value of 2.6.

Figure 17 shows that the auxiliary energy for House 10 is much higher than for the other systems. This is due to the pump for the wetback being included in this figure.

(Burgess, et al 2008) provides an estimate of 2000 kWh for the seasonal (May-September 2008) wetback water heating contribution for House 10 using the wetback calculation methods developed in HEEP (Isaacs, et al 2005). If this wetback figure is taken from the combined renewable energy figure of 2100 kWh from Table 1 then the solar contribution would be very small.

While subject to more shading, the design of the solar system for House 10 is not remarkably different from House 3 or House 8 so that the difference in solar performance would be surprising.

Examining the flow and supplementary heating graph for House 10 (Figure 16), shows that the size of the morning supplementary heating peak is reduced in comparison to House 3 and House 8 (Figure 14 and Figure 15) presumably being offset by energy input from the solid fuel burner.

It needs to be remembered that both the wetback and renewable energy contribution calculations use different assumptions and base data. These factors are subject to varying degrees of uncertainty. It is not recommended that they be compared directly with one another and that further work be undertaken to better understand the two methods.

There is the possibility there is a degree of undesirable interaction between the solar and the wetback systems that result in lower overall combined performance.

However, despite the difficulty in understanding the breakdown of solar and solid fuel contribution, the overall performance of the hot water system at House 10 is good.

8 Conclusions

Through the SWH monitoring of each of the Beacon Pathway projects, the learnings were used in the next project. The monitoring has corroborated other research (Pollard and Zhao, 2008) in this area with the following key findings:

1) **Timers and Controls**

One of the most important factors in the performance of SWH systems is how well the supplementary heating is controlled. Systems that are allowed to immediately heat water with supplementary electric heating after early morning water draw-offs, lose the ability to store solar energy during the sunny parts of the day.

Timers that are set to exclude electric supplementary heating in the mornings are a simple and practical way to achieve this.

Providing information back to the occupants about how their system is operating is helpful. Only the Waitakere NOW Home® system featured a display unit viewable from the living room.

2) **Collector Angle**

Solar energy is a strongly seasonal energy source. Water heating energy requirements are higher in winter than they are in summer and ensuring that the winter time performance of systems is good will produce benefits. Collectors than are installed at low angles (much less than the latitude of the location) improve the performance of the system in summer at the cost of reduced performance in winter.

The SWH systems in the Waitakere NOW Home® and to a lesser extent the Rotorua NOW Home® were installed at shallow angles which affected their winter time performance. The Papakowhai Renovation Project systems were installed at the latitude angle to provide good year round performance.

Systems also need to be able to be installed at appropriate angles. The Solar Genius system used in the Rotorua NOW Home® has a limit to its collector angle of 40° making it difficult to achieve appropriate collector angles in more southern locations.

3) **Sizing of System Components**

Connected with having a good angle for the solar collector is to ensure that the collector area is sufficiently large for the demand required. The Rotorua NOW Home® system had only a small collector area for the size of the household using it while the Waitakere NOW Home® may have also benefited from more solar collection in winter.

There also needs to be a good balance between collector area and the size of the hot water cylinder so that the solar energy collected during the day can be stored for later use when hot water is required.

4) Reducing Heat Losses

It is important to ensure that heat losses from the systems are kept to a minimum as these need to be balanced up by solar energy or supplementary heating. It is important to ensure that insulation levels on cylinders are appropriate for New Zealand conditions and that pipe run lengths are kept short and well insulated.

The Rotorua NOW Home® system was located outside and had higher heat losses than the other systems examined.

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10 Appendix A: Measuring Performance

The BRANZ solar performance report (Pollard and Zhao, 2008) provides a discussion of how to measure the performance of solar water heating systems and this section is largely taken from that report.

Many different measurements can be made on each of the components of a SWH system and it is important to cover the full range of influences on performance such as system design and installation, climate and user behaviour. In order that comparisons can be made for each different type of system, the broadest system measure (i.e. all of the collectors, pumps, pipes, cylinders, means of heating and controllers) is the most useful.

There are a range of international standards dealing with testing of SWH components and systems. ISO 9459-3 (1997) is a test standard relating to this type of system monitoring and is useful to consider when looking to develop a measurement approach.

A system measurement usually involves calculating the heat balance of a hot water cylinder. On one side of the equation is the heat *gained* by the hot water cylinder from the radiation collected by the solar collector, plus any supplementary heating such as the electric element inside the cylinder, as well as the heating contribution from any solid fuel wetback systems. On the other side of the equation is the heat *removed* from the hot water cylinder by the occupants drawing off hot water, as well as heat lost by conduction throughout the system (the standing losses). This can be written as:

$$Q_{std\ loss} + Q_{draw\ off} = Q_{supp.heat} + Q_{solar} \qquad (10.1)$$

Where
$Q_{std\ loss}$ is the standing heat loss from the system
$Q_{draw\ off}$ is the heat drawn-off from the system as hot water used by the household
$Q_{supp.heat}$ is the amount of supplementary heating going into the hot water cylinder
Q_{solar} is the balancing term, which is the amount of solar heat captured by the system.

In addition to this balanced thermal energy, the total water heating energy use also includes any auxiliary energy use by the system such as for circulation pumps or system controllers, which can be written as:

$$E_{hot\ water} = Q_{supp.heat} + Q_{solar} + E_{aux} \qquad (9.2)$$

Where
$E_{hot\ water}$ is the total energy used for water heating
$Q_{supp.heat}$, Q_{solar} are as defined above
E_{aux} is the energy use of any auxiliary equipment such as circulation pumps, pump controllers, element controllers.

A graphical example of a heat balance for a system is shown in Figure 18

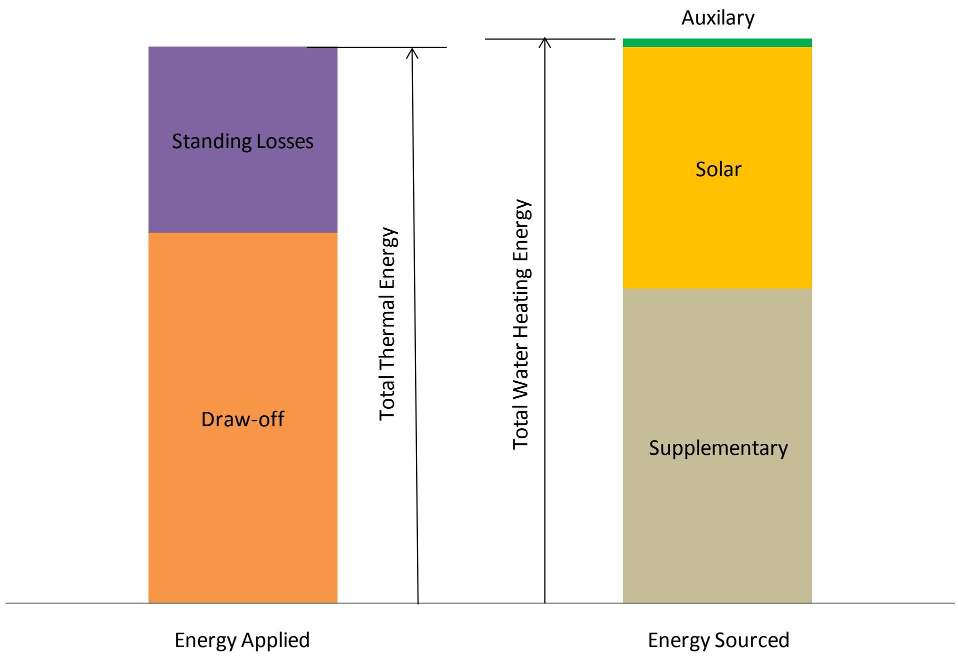

Figure 18: Example of a heat balance for one system

In order to calculate the energy balance, measurements are required of the electrical energy used by the heating element as well as any pumps or controllers, the water flow into the system and the inlet and outlet temperatures. The standing losses also need to be estimated. Figure 19 provides a layout diagram of a typical monitoring arrangement.

The heat balance of the hot water cylinder is dependent on both the amount of heat removed from the cylinder from the water used by the occupants, as well as the heat collected from the sun within the solar collector. Both of these heat processes are likely to vary throughout the year so a full year of measurement collection is useful.

The Rotorua NOW Home® involved a thermosiphon connection between the solar collector and the cylinder (the system was an integrated unit) and therefore did not require a circulation pump.

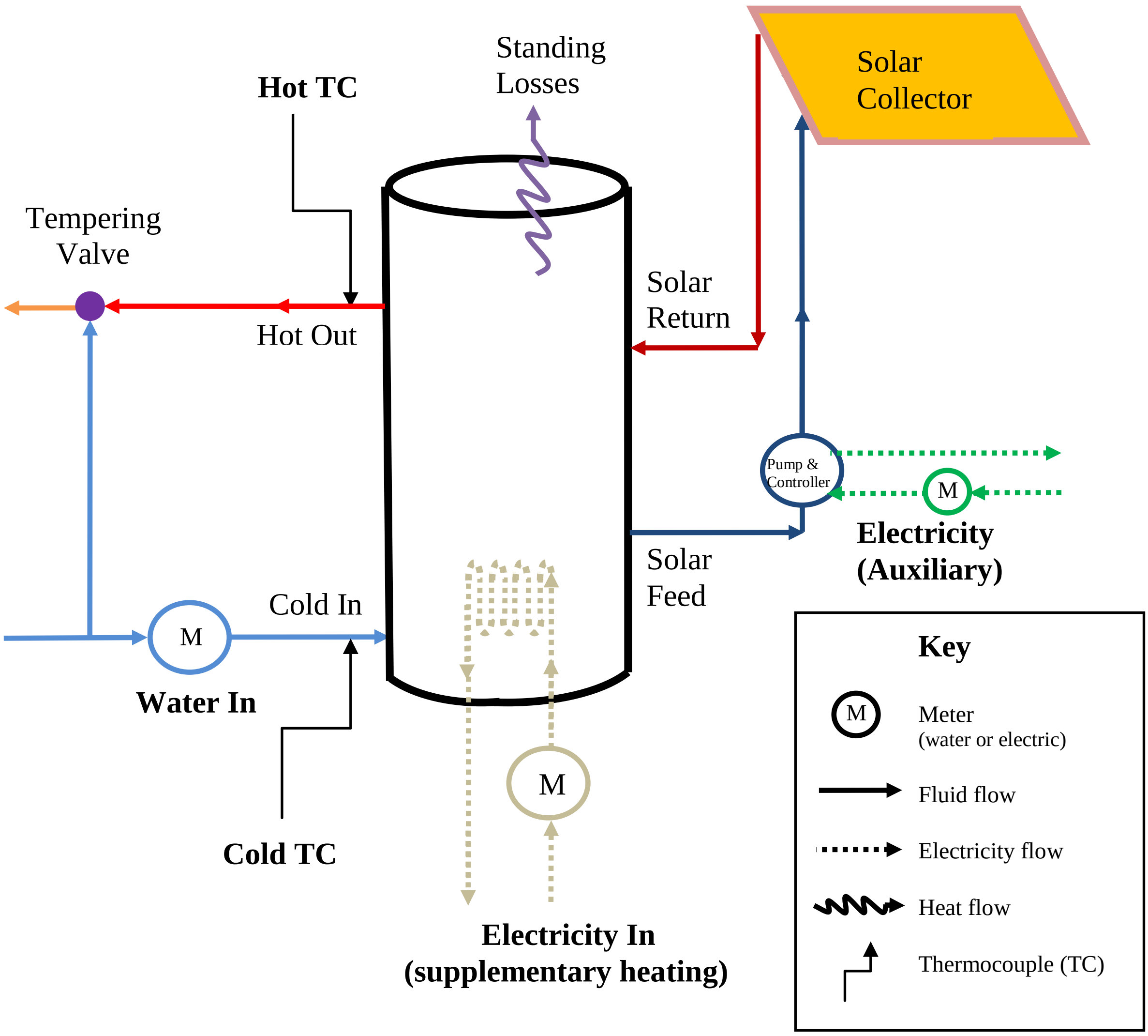

Figure 19: Typical monitoring arrangement

10.1 Equipment used

The data collection methodology for the Beacon research houses differed in application but essentially the same SWH system parameters were measured.

A Siemens S2AS electricity tariff meter with a pulsed output (2% accuracy, 1 Wh per pulse) was used to determine the amount of supplementary electrical heating used by the element inside each of the hot water cylinders. For the Waitakere NOW Home® and the Papakowhai Renovation houses a second meter was installed to measure the total auxiliary energy use of any pumps and/or controllers (the Rotorua NOW Home® did not have any auxiliary energy requirements).

The amount of energy drawn-off by the occupants was calculated from the water flow out of the system and temperatures of the outlet and inlet water temperatures.

For the Waitakere NOW Home® and the Papakowhai Renovation houses the water flow into the hot water cylinders was measured with a Kent PSM-T water meter. These low cost meters provided 2 pulses per litre.

The Rotorua NOW Home® used a higher quality Manuflo MES-MR water meter which had a pulse rate of 34 pulses per litre. These Manuflo meters were used in the Rotorua NOW Home® to allow for disaggregation of the water end-uses to be undertaken.

The water temperatures measured were the inlet and outlet temperatures of the hot water system which usually corresponded to the inlet and outlet water temperatures to the hot water cylinder. The water temperatures were measured by T-type thermocouples taped to an exposed section of copper pipe. The thermocouple locations were lagged with closed-cell foam.

10.2 System standing losses

Heat is lost throughout the system due to conduction, convection and radiation processes which are in turn driven by the temperatures throughout the system and in the surrounding environment.

The hot water cylinder, as the heat store of the system, is an important component of the standing losses. Larger cylinders present a greater surface area across which conduction losses will occur. The extent of these heat losses will depend on the temperature difference and the level of insulation.

When tested in a laboratory, a hot water system can be exposed to consistent temperatures and specific water draw-off patterns. Under such regular conditions the heat losses of the system can also be consistent and determined by calculation.

When a hot water system is used by householders in a real situation the system is much more unpredictable – supplementary heating is controlled, temperatures will vary and draw-off patterns with be uneven and irregular. The actual heat losses will be varied and any determination of these losses in such situations will only approximate those of the system.

A primary technique used for this report follows the method used in HEEP (Isaacs, et al 2003) which was to take a period overnight when there had been no water draw-offs for a period of time, so that the supplementary heating required was consistent and matching the amount of heat being lost by the system. This method requires that the supplementary heating is available overnight and that the heat storage capacity of the system has been met – the supplementary system is then just topping up the energy being lost by the system. This method provided suitable to provide estimates of the system standing losses for the Waitakere NOW Home® and the Papakowhai Renovation houses.

10.3 Summarising performance

The renewable energy contribution for SWH systems can be calculated as the total thermal water heating energy (which require the draw-off energy and system losses to be calculated) less the supplementary heating energy:

$$Q_{renew} = \mathbf{Q}_{solar} = \mathbf{E}_{hot\ water} - \mathbf{Q}_{supp.heat} \qquad (10.3)$$

or

$$Q_{renew} = \mathbf{Q}_{solar} = Q_{draw\ off} + \mathbf{E}_{aux} + \mathbf{Q}_{std\ loss} - \mathbf{Q}_{supp.heat} \qquad (10.4)$$

When the only other energy source is electric supplementary heating, the renewable energy contribution is equivalent to the solar energy contribution. For systems, such as P10, which included a wetback, the calculation gives the combined solar and wetback contribution which is best identified as the renewable energy contribution.

There are a number of ways to summarise the performance of water heating systems (Lloyd and Kerr, 2008). The renewable energy and the renewable energy fraction which is the fraction of the total water heating need met by renewable energy are intuitive measures. These calculations involve an estimate of the system losses and a higher value for renewable energy or the renewable energy fraction results if a higher value for the system losses is used. An alternate measure of system performance which does not involve the system losses is the Coefficient of Performance (COP) which is the ratio of the heat provided by the system (the draw-off energy) to the non-environmental energy or the supplementary heating and auxiliary energy use for SWH systems;

$$\mathrm{COP} = \frac{Q_{draw\ off}}{E_{ne}} \qquad (9.5)$$

Where $E_{ne} = E_{supp\ heat} + E_{aux}$

In comparing COP values it is important to consider what values are achieved by reference systems. For electric storage cylinders the standing losses can be a sizable proportion of the heat loss of the system. Results from the HEEP project (Isaacs, 2005) indicate that average standing losses are of the order of 33% of total water heating energy leading to COP for an average electric storage cylinders of 0.67. A system with a COP of 1.34 would therefore require half as much water heating energy as a standard electric storage cylinder for a given amount of hot water.

11 Appendix B: Seasonal Performance

Solar water heating is a seasonal energy supply. Figure 20 provides a graph of the supplementary water heating from the Waitakere NOW Home® and the Papakowhai Renovation houses averaged over two weekly periods, shown by time of year[2].

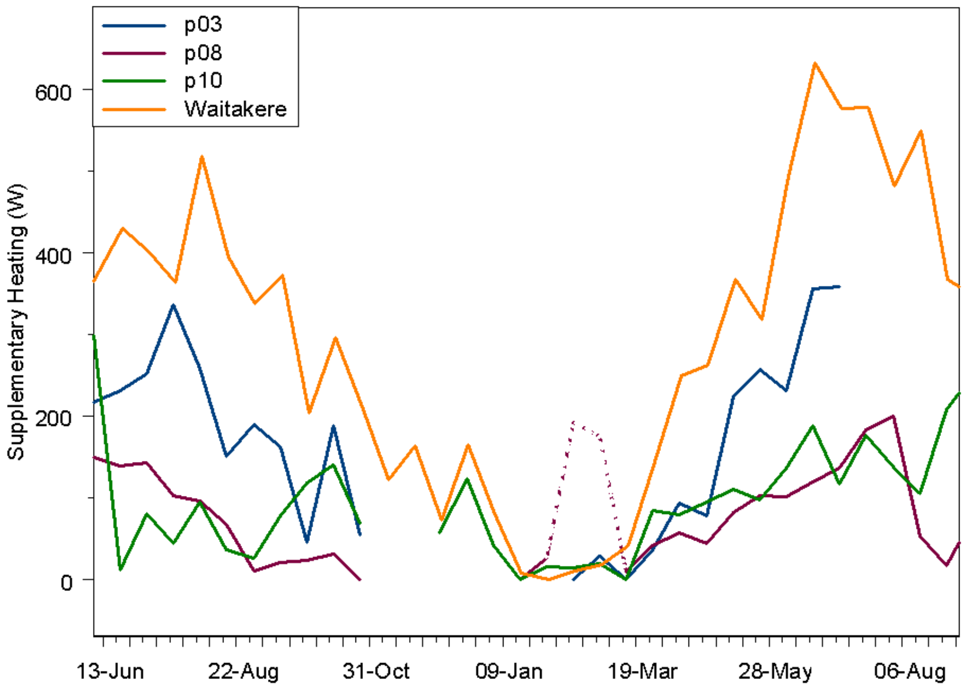

Figure 20: Supplementary heating energy use averaged over fortnightly time periods

During the summer, little electrical supplementary heating was required by the systems. The peak in the supplementary heating for House 8 (shown by dotted lines) was due to a fault in the system causing it to run abnormally. The Waitakere NOW Home® system has the narrowest summer period rising more steeply than the Papakowhai systems. This could be in part due to the shallow angle of the collector reducing its effectiveness in the cooler seasons. Another interesting feature seen in this graph is the reduced supplementary heating needs in P10 over winter (particularly the data to the left of the graph) presumably due to the operation of the solid fuel burner's wetback.

2 The data from the Waitakere NOW Home® was for 2006/2007 whereas the data for P03 and P10 covered 2007/2008. The data from the Rotorua NOW Home® could not be presented in this form.