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No. 188 (2008)

THE PERFORMANCE OF SOLAR WATER HEATERS IN NEW ZEALAND

A R Pollard and J Zhao

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Preface

This report examines the performance of solar water heaters and follows on from BRANZ *Study Report 184* which looked at the installation practices of these heaters. The summer time performance of a small number of heat pump hot water systems is also examined

Acknowledgements

This work was jointly funded by the Building Research Levy and the Energy Efficiency and Conservation Authority (EECA).

The Centre for Research, Evaluation and Social Assessment (CRESA) undertook the collection and reporting of the householder attitudes and experiences which is reproduced in Appendix A of this report.

The enthusiastic participation of the many users of the solar and heat pump water heating systems which were monitored is also gratefully acknowledged.

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THE PERFORMANCE OF SOLAR WATER HEATERS IN NEW ZEALAND

The Energy Efficiency and Conservation Authority (EECA) and Building Research commissioned BRANZ to undertake a research project to provide independent evidence of the energy performance, installation quality and durability of solar water heating systems in New Zealand.

This executive summary is the culmination of a three part research project begun in October 2006. The first stage of the project was to inspect solar water heating systems and assess their current condition including installation. The results from that stage have been documented in a separate report available from EECA and BRANZ.

The purpose of the second and third stages of this project were to measure the amount of energy that the units capture at each site over a one year period and to survey the attitudes of the householders who installed these solar water heaters. Results from stages 2 and 3 have been provided in the following executive summary.

It is important to note that the average solar water heating system installed today under the Government schemes is different in key ways from the systems monitored in this report, which were installed between June 2004 and October 2006.

For example, since 25 May 2007, EECA has made it a requirement for suppliers participating in the Government Solar Grants and Loans schemes that their systems must have their energy performance calculated and published on the EECA website www.energywise.govt.nz/solar.

The theoretical average annual solar contribution of these systems is 67% of a households hot water needs[1]. The improved performances are largely the result of improved control strategies and the use of element timers. The use of timers has increased by from 20% to 80%[2] since the requirement to performance model systems.

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[1] Household hot water needs" refers to the 39MJ peak load for a 4 or 5 occupant home as described in AS/NZS 4234 : 2008 (Draft) Heated Water Systems – Calculation of energy consumption.

[2] 20% systems audited by EECA in 06/07 year used timers to control the booster element in 07/08 year this increased to 80% of systems.

There has also been a significant focus on the quality of installations, where the performance of systems is heavily influenced. Training of installers has been a key focus with a Short Course Certificate in Solar Water Heating installation being developed and provided through three training providers.

The acceptable solution G12/AS2 was developed to create greater consistency in solar installation practices and to smooth the building consent process.

EECA also continues to audit solar water heating installations to provide valuable information on installation quality. Any issues that arise are then fed back into the training programmes and directly to the solar industry.

This report sets a benchmark for SWH performance in New Zealand prior to the rapid industry development of the last two years. In those two years, EECA and the Solar Industries Association have worked together to improve the quality and performance of SWH. The work that has been delivered during this time that should provide homeowners with greater confidence in the performance of solar water heating includes:

- G12/AS2 was published in December 2007. This document specifies the acceptable solar water heating design and construction Standards and the means of installation to comply with the New Zealand Building Code.
- EECA launched a new solar Grants and Loans scheme that required systems to be tested to acceptable design and construction standards, as well as performance standards. There are currently over 130 different packaged systems from 15 Solar Suppliers that have met these requirements and this is growing.
- A New Zealand test facility started testing solar water heaters to the Standards required by G12/AS2 (above) in 2007, giving easier access to testing for New Zealand solar suppliers.
- More than 300 installers have completed the Short Course Certificate in Solar Water Heating Installation training programme since the first course in March 2007.
- The number of solar suppliers that are accredited to the Solar Industry Association (SIA) has increased from 13 in August 2005 to 32 currently, with over 500 approved solar installers.

To assess the effects of these improvements EECA has offered funding via the Innovation Fund to two projects that will monitor the performance of a number of newly installed systems and we look forward to the results of these projects, which will be completed in a year’s time.

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1. EXECUTIVE SUMMARY

The performance of 39 solar water heating (SWH) and heat pump water heating (HPWH) systems were examined by measuring key performance parameters of the systems over the course of one year (or over the summer in the case of the HPWH systems).

Systems were selected in Auckland, Wellington, Christchurch and Dunedin, with four technologies examined: pumped evacuated tubes, thermosiphon flat plate, pumped flat plate and air-to-water heat pumps. The measurements, however, showed that the individual systems and their installation were more important than any effect due to the technology used or the region and climate for how much renewable energy the system can supply.

A range of performances was seen. On average, 38% of the annual household hot water heating needs (or 1260 kWh/year) was supplied from the sun for the monitored SWH systems. A set of higher performing systems (about 27% of systems) was identified which provided an average of 2060 kWh/year of energy from solar with an average fraction of the energy coming from solar of 43%. Another lower performing set of about 21% of systems was indentified with these systems contributing on average 550 kWh from solar or 26% of the total water heating needs for these households.

The summer performance of the heat pump systems was to provide approximately 1190 kWh/year more environmental heat than electrical input into the system. The households using HPWH systems were smaller hot water users so this energy was about 52% of these households' total hot water heating needs. The performance of the HPWH systems is dependent on external temperature, and the winter time (and therefore year round) performance of the heat pump hot water systems will be less than the summer time performance.

1.1 Surveyed responses

A survey of the householders experiences and attitudes was undertaken by CRESA in the 35 households with SWH. These households were predominantly 2 person households or households with 3 or 4 people. Only 30% of the households had 2 or more children. 43% of the households reported that their hot water use was average, with the remainder roughly evenly split between higher than average and lower than average. The household incomes were skewed towards higher income households with 60% of households having a household income over $70,000 per year.

The majority of the interviewees believed that New Zealand needed to change its way of life if New Zealanders were to enjoy a good quality life and environment into the future. The interviewees typically reported their attitude to environmental issues as 'middle of the road' with about three quarters of them highlighting environmental concerns as a contributing reason for getting SWH.

The most popular reason given by householders (over 90%) for installing SWH was to save money.

In addition to the cost, the systems selected by the householders were based on their impression that the system was well designed and reliable. The choice of supplier influenced the choice of system with suppliers selected from recommendations of friends and neighbours who already had a SWH system or who worked in an associated industry. Selection was influenced by the amount of electricity savings claimed that could be made with the system however many interviewees expressed frustration that independent information was hard to find. Over 40% of respondents were dissatisfied with the amount of information available on operating and maintaining SWH.

Overall just over half of the interviewees were satisfied with the installation process. The majority of householders were not well informed on the need for a building permit. While over 80% of householders received a manual, 21% found it too difficult to follow. Most were not told if the unit had a timer, shown the different parts of the system or how to operate and manage the controls.

The technical understanding of the householders varied from a high level to a very limited understanding. A small number of users were active managers of their systems while the majority were passive but were satisfied with the degree of control they had. Many interviewees were not aware that their SWH system would require any maintenance.

Approximately 57% of respondents reported that the savings on their power bills had met their expectations while 29% of respondents said that the power bill savings had not met their expectations. Overall 86% of interviewees would recommend SWH to family and friends.

1.2 Ensuring performance

The research has shown that there are opportunities to ensure the performance of SWH systems throughout the process of system design, specification, installation, handover and operation.

1.3 Design and installation

It is important to ensure that the SWH system supplier and the householders discuss and understand the design choices which impact on the overall performance of the SWH system. The following sub-sections highlight some of the issues seen in this research that could be addressed before or during the SWH system installation.

1.3.1 Inclination angles

Most of the SWH systems examined had their collectors installed at the same angle as the roof and little consideration appears to have been given to the inclination angle at which the solar collector was installed at. None of the 35 solar collectors examined were installed at inclination angles greater than or equal to the site latitude.

In summer when the sun is high in the sky, a low solar collector inclination angle will allow a good capture of heat to the collector. In winter, the sun is low in the sky and an angle greater than the latitude of the site will provide best capture of the solar radiation.

As the solar radiation is lower in winter, temperature differences are higher, and potentially there is a greater household demand for hot water. Year round performance of SWH may be improved by installing the solar collectors at a high inclination angle.

For the SWH systems for which it was possible to determine winter time performance, over half of these systems provided less than 10% of the winter time water heating needs. A general trend of increasing proportion of water heating needs met by solar was observed for systems with steeper collector inclination angles. However, there is a high degree of other variation in this data.

Recommendation: *That the inclination angle of the solar collectors be installed at an angle at least equal to the latitude of the site.*

1.3.2 Standing losses

Standing losses form a sizeable part of energy balance of each system. If the losses of the system are reduced, more of the renewable energy collected can go towards replacing the heat drawn-off from the system by the household’s occupants. Six of the 35 solar systems measured were retrofitted B-grade cylinders.

Recommendation: *That retrofitting SWH to existing B-grade cylinders is not allowed.*

Many of the systems with high standing losses were thermosiphon systems. These systems included large cylinders which, as a result of being installed outside, have a large temperature difference across them.

Recommendation: *That the high heat losses for thermosiphon systems be examined to see if changes, such as increased thermal insulation on cylinders, should be required.*

1.3.3 Connection of open systems

One of the open pumped flat plate systems experienced high heat losses at night due to back thermosiphon circulation at night. The likelihood of this back circulation could be reduced by using an appropriate piping arrangement.

Recommendation: *That open systems be required to incorporate piping arrangements to reduce the chances of back circulation of the system at night.*

1.3.4 Controlling of supplementary heating

In order to maximise the capture of solar gains, SWH systems must have capacity to store heat within the water. An important part of this is to prevent supplementary heating from operating before the solar has an opportunity to contribute heat to the system and a timer is a practical way to achieve this. Only seven of the 35 SWH systems made use of a timer.

Recommendation: *That timer controls are installed on the supplementary water heating for all SWH systems.*

1.3.5 Use of top elements in large cylinders

Three of the systems examined had large cylinders which had elements at both the top and bottom of the cylinder. The top elements in these systems were regularly used however the bottom element was only occasionally used in one of the systems. Two of these three systems were seen to be well performing. Using a top element allows the supplementary heating to heat only the top part of the cylinder while allowing the heat collected from the solar collector to be stored in the lower part of the cylinder.

Recommendation: *That greater use of cylinders with elements at the top of the cylinder is encouraged.*

1.3.6 Equipment to monitor performance

There are a number of components of SWH systems that may be useful for the occupants to monitor to help them assess if their system is performing adequately. For example, many pump controllers report the temperature of the collector and hot water cylinder. The cylinder temperature may be useful as a gauge of the current capacity of heat stored within the system.

Recommendation: *That system displays are installed in a prominent location within the living space of the house so they can be monitored by the occupants.*

1.3.7 Confirm system is operating correctly

The fault with the system that was back circulating at night may have been identified at the time of installation had a more thorough examination taken place once it was installed.

Recommendation: *That after an SWH systems is installed, a process is undertaken to ensure it is working to specifications.*

1.4 Handover and operation

Once the installation is complete, there is an important role for the installers to educate the householders about how the system works and how they need to operate and monitor it. During the operational phase, the system users need to monitor the performance and seek help when this is not up to standard. Some of the issues occurring during the operational phase are set out in the following sub-sections.

1.4.1 Controlling of supplementary heating

In addition to ensuring a timer is installed, it is also important that it is set correctly to minimise the amount of supplementary heating required.

Recommendation: *That sufficient guidance is provided to SWH system users' to allow them to operate the timers to minimise the time the supplementary water heating is use while still providing for their needs.*

1.4.2 Identified problems with systems

A number of the systems monitored were not performing satisfactorily. However, the system users had little information on how well their SWH systems were performing. Where information is available, guidance is required about what values are appropriate.

Recommendation: *Users need information on of how well their systems are performing to allow them to seek help if the performance is substandard.*

1.4.3 Alarms when systems are not working

Many occupants are not interesting in closely monitoring their SWH system. It is therefore beneficial if the system draws attention to itself if it not operating correctly.

Recommendation: *That SWH control systems emit an audible alarm if the system is not operational due to a fault in the system.*

1.4.4 Installers to troubleshoot performance issues

After the installation of the monitoring equipment, a number of sites were visited by the system installers to attend to maintenance issues. A number of these systems were not performing well, although the installers did not identify this.

Recommendation: *That SWH installers are better equipped to evaluate and diagnose performance issues with SWH systems.*

1.5 Other opportunities

Electricity supplier records currently provide data on the total electricity use in each household.

The analysis of electricity supplier records to examine the impact of the installation of a SWH system proved to be problematic as other changes of electricity usage within the household masked the effect of the SWH installation.

Water heating makes up a large proportion of the electricity usage in most homes and it would be beneficial if water heating energy use was separately metered. This would allow both the householders to monitor their water heating energy use but would also allow more information to be gathered collectively on how much electricity is being used for water heating.

Recommendation: *That analysis is undertaken on requiring that the water heating be separately metered.*

2. INTRODUCTION

This report continues an EECA / Building Research funded project looking at methods of improving the means of heating water within residential water heating systems, in particular, SWH and HPWH.

The HEEP project[3] undertaken by BRANZ (Isaacs et al 2006) reported that water heating accounts for 29% of residential energy use and is therefore deserving of greater examination.

The water heating energy use in a single household comprises the energy used to heat water for the hot water services required by the household ('used' energy), as well as the energy 'lost' from the hot water system including the 'standing losses' or the energy used to keep the water in the cylinder at a certain temperature.

Savings in water heating energy use can be made by improving:

1. Piping insulation
2. Cylinder insulation (including beyond Code requirements to AA or AAA levels)
3. Means of water distribution and plumbing layout
4. Means of heating water
5. Hot water conservation.

This project focuses on the means of heating water and, in particular, on SWH and air-to-water HPWH. There are other technologies that can be employed to provide water heating which have not been considered in this report. These technologies include the use of condensing gas systems, ground source heat pumps, combined heat and power (CHP) systems, or heat recovery systems.

While all (35) of the SWH systems examined for this report included supplementary electric heating within the storage cylinder, a small number of the systems (4) also included a 'wetback' input from a solid fuel burner.

Three areas were identified for examination in this project:

1. The installation practices of SWH systems
2. The attitudes of people towards SWH systems
3. How well SWH systems perform.

These three areas were examined using a common sample of SWH systems which included systems in Auckland, Wellington, Christchurch and Dunedin. Further details on this sample can be found in Section 3.1.

Four air-to-water HWPH systems were also monitored over the summer to provide some information on this type of water heating.

The installation practices for the SWH systems were examined by physical inspection of the systems and included examination of materials selection, weathering, structural suitability and performance design. This work was reported in BRANZ *Study Report 184* (Kane et al 2007).

The experiences and attitudes of the users of the SWH systems were examined by CRESA and involved face-to-face interviews with members from each of the households in the sample. The CRESA report can be found in Appendix A of this report.

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[3] The Household Energy End-use Project (HEEP) carried out by BRANZ measured energy use in approximately 400 homes throughout New Zealand.

The performance of the SWH systems, which is the focus of this report, was assessed by measurement of key system parameters of the sample of SWH systems over the course of one year.

2.1 Previous water heating performance studies

Following on from the oil shocks of the 1970s, interest in SWH in New Zealand was high. In the 1978 Budget, the Muldoon Government introduced an interest-free loan scheme for SWH's which required rules around how systems would be appraised to qualify for the scheme (Synergy Applied Research 1985). A component of this was detailed product testing by the then Department of Scientific and Industrial Research (DSIR) following specific testing procedures. (A range of results are provided in Synergy Applied Research 1985.)

It began to emerge that the performance of SWH's in actual operation (i.e. in-situ) was less than that determined by following the specific testing procedures. However, by the time Synergy Applied Research proposed an in-situ measurement programme in 1986 (Synergy Applied Research 1986), interest in SWH had waned, oil prices had dropped and government programmes were out of favour with the free market approach taking centre stage.

During this lull, progress continued on testing standards. An important component of this was the development and validation of computer simulation programmes such as TRNSYS (Solar Energy Laboratory 2007). These programmes could reliably predict the performance of SWH systems from component measurements, reducing the cost of testing and providing tools to improve system design. Extensive work has been undertaken at the University of New South Wales on adapting these programmes for Australian conditions (Morrison 2007) and EECA and the Standards Committee has recently undertaken work to adapt this modelling programme to New Zealand standards and conditions.

An early in-situ project involved the monitoring of 12 SWH systems in a solar village development in Sydney around 1984 (Morrison et al 1984), where it was found that energy savings of 50% or more were obtained in nine of the 12 systems.

A more recent study in Australia (Lloyd et al 2000), examined the performance of 33 water heating systems in remote indigenous communities around Australia and considered a range of technologies such as SWH and HPWH. The extremely varied water use within these communities caused the systems to have a wide range of performance.

With rising energy costs, increasing environmental awareness, climate change and Kyoto protocol commitments, there has been renewed interest in New Zealand in SWH over the last five years.

The University of Otago undertook a series of laboratory-based performance measurements on a number of current SWH (and HPWH) systems in 2005 (Thomas and Lloyd 2005). This work saw large differences in the performance of the different types of systems. At the same time, an analysis of some of the half dozen SWH systems that were part of the households in the HEEP sample raised some concerns about how these systems were being managed by householders (Pollard et al 2005).

An immediate predecessor to this project was the report by Stoecklein (2005), which looked to examine the cost-effectiveness of SWH systems, and highlighted the lack of verified field performance measures underpinning the financial analysis.

The performance of HPWH's received early attention by the University of Otago in 1984 (Carrington et al 1984). Six residential HPHW systems were examined and performance extrapolated to New Zealand conditions with expected savings of between 50-59%. The type of HPHW system differed from that examined in this project, in that the University of Otago monitored systems involved the evaporator and condenser in a separate outdoor unit remote from the hot water cylinder which was located within the house.

2.2 Report outline

This report will describe how the sample of SWH and HPWH systems was constructed, which measures to make to determine the performance of the systems and how those measurements were made. The solar radiation and outdoor temperatures for these regions over the monitored periods are summarised.

Section 5 provides the core of the performance analysis on the SWH and HPWH systems, with results from the measured data from each of the systems compared. Regional and technology differences are examined, as well as the use of timers, insulation levels, performance ranges, seasonal winter summer variations and the inclination angle of the solar collectors.

Section 6 and Appendix B of this report looks at the electricity supply records for each of the households, examining what impact the SWH system installation made on the total electricity usage of the household.

Section 7 provides a commentary on each particular individual system, highlighting some important performance issue, as well as operational issues including the extent to which the supplementary heating is controlled.

Appendix A provides a report on the work undertaken by CRESA for this project to examine the householders’ experiences and attitudes to SWH.

3. EXPERIMENTAL DESIGN

SWH performance is dependent on a number of factors which can be grouped into a number broad categories such as climate, system design and installation as well as user interactions.

In order to explore these influences on SWH performance, a number of different types of SWH's from a range of climates will be examined.

The climates examined were taken as the four major population centres: Auckland (including Manukau, North Shore and Waitakere), Wellington (including Lower Hutt, Porirua and Upper Hutt), Christchurch and Dunedin.

The technology classes chosen to be examined were: integrated flat plate thermosiphon systems, pumped flat plate systems, pumped evacuated tube systems and air-to-water heat pump systems. Examples of these types of systems are shown in Figure 1. The examples are from neutral sources and not from this study, in order to ensure the privacy of the participants in the study.

Also, in order to ensure that a particular technology or climate was not heavily biased by the specific characteristics of one individual household, the experimental design called for three systems of each climate/solar technology combination to be measured.

As it was expensive to monitor multiple HPWH's in all climates, it was decided to focus on a similar number of heat pump systems in a warm climate (Auckland) as well as a cooler climate (Dunedin)

The systems examined were those that were installed within the last three years so that recent rather than historic performance is reported.

3.1 Sample selection

Presently only about 2% of households in New Zealand have a SWH system[4]. Thus, selecting houses randomly was not practical as it would require a very large number of households to be contacted.

The sampling frame chosen for the SWH systems was the EECA SWH financing database. EECA has been running a scheme since 2005 whereby government funding is provided to assist with loan repayments for the purchase of new SWH systems. At August 2006, the database contained 1560 addresses of SWH purchases and this list was broken down for city and type of SWH.

Heat pump systems were not included in the financing scheme and no nationwide database of HPWH systems was identified. The distributors of two prominent brands of integrated HPWH systems were asked to provide contact details of recently installed systems in Auckland and Dunedin for BRANZ to approach and to take part in the study. Another distributor approached BRANZ and provided one site for monitoring. A household known to have a recently installed heat pump system was also asked to take part in the study.

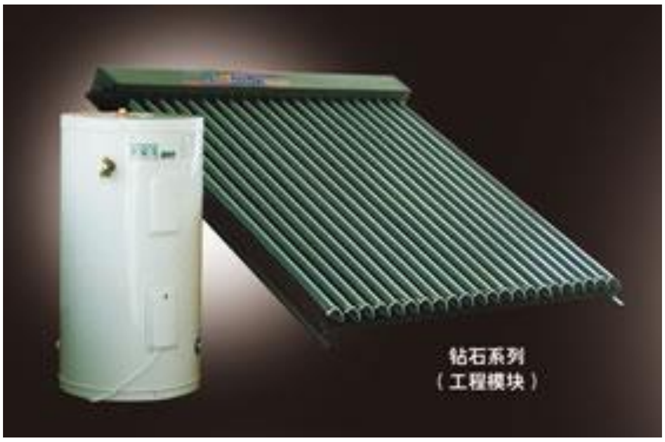
There were some variations in the selection process. The final number of each system used (city by technology) is shown Table 1.

[4] The January 2008 EECA solar water heating fact sheet (EECA 2008) states there are approximately 35,000 solar water heaters in New Zealand homes with the latest (March 2008) estimates from Statistics New Zealand of the total number of households in New Zealand (Statistics New Zealand 2008) being 1,598,000.

Table 1. Surveyed houses by each technology at each defined region

City/technology	Evacuated tube pumped	Flat pumped	Flat thermosiphon	Heat pump
Auckland	3	5	1	3
Wellington	3	3	3	-
Christchurch	3	3	3	-
Dunedin	4	1	3	1

A flat plate thermosiphon system



An evacuated tube system (collector installed on roof or exterior and cylinder is installed within building)

A flat plate collector (cylinder is within building)

An air-to-water heat pump system (fan and evaporator unit under black cover on top of hot water cylinder – system is typically installed outside)

Figure 1. Types of water heating systems examined

3.1.1 Selection process variations

The database recorded only the name of the supplier of the system, and as some suppliers provided more than one type of technology there were some mis-classifications of systems as part of the selection process. Two systems in Auckland (which were thought to be thermosiphon systems) turned out to be pumped flat plate systems on arrival at the house for installation of monitoring equipment. The thermosiphon system monitored in Auckland was not from the financing database, but was known to the researchers as being a thermosiphon rather than a pumped system. For the later installations in Christchurch and Dunedin, the reply forms were modified to confirm the type of systems more carefully.

Not all brands of SWH's appear in the financing scheme. As it was important to EECA to have a broad range of manufacturers represented, a local manufacturer whose products did not appear in the financing scheme database was asked to provide a list of 12 systems installed in the last two years in Christchurch. Three of these systems were selected in place of the flat plate systems for Christchurch.

As the sampling for Dunedin was underway, it was realised that there was under-representation of a particular brand of thermosiphon systems in the other centres. As a result, two of these systems were selected in Dunedin to make up for the deficiency.

Owing to the small number of systems in Dunedin, once the different technologies were considered, only one pumped flat plate systems could be selected. To provide a similar number of systems in Dunedin to the other centres, an additional evacuated tube system was included in this city.

The size of the HPWH market is smaller again than the SWH market.

A difficulty one of the heat pump distributors had was that the customers to whom they sold the units were plumbers and plumbing merchants and the address of where the system was installed was not known to them. A short-list of known addresses was sourced from sales records.

With delays occurring in selecting the heat pump systems, only the summer time performance was measured. These systems work best when the temperature difference between the ambient temperature and the hot water storage temperature is at its smallest, such as over this summer time period.

Four Auckland households with heat pump systems agreed to take part in the study. However the week before installation was to take place, one household withdrew as they had decided to sell their house.

The selection of systems in Dunedin was difficult due to the small population and only one system was monitored

As the sample was constructed in a considered manner, it cannot be taken as representative of SWH systems or heat pump systems in New Zealand. The sample, however, does includes a range of systems and provides some interesting insights into the performance of these types of systems in actual conditions.

3.2 Determination of solar performance

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) would be 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:

$$Q_{std\ loss} + Q_{draw\ off} = Q_{supp.\ heat} + Q_{solar} \tag{3.1}$$

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:

$$E_{hot\ water} = Q_{supp.\ heat} + Q_{solar} + E_{aux} \tag{3.2}$$

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 2.

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 3 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 measurements was collected.

Two of the thermosiphon systems were used as pre-heater systems for an existing hot water cylinder located within the house. For these systems the inlet temperature is the pipe feeding the collector, whereas the outlet temperature is the pipe from the cylinder within the house.

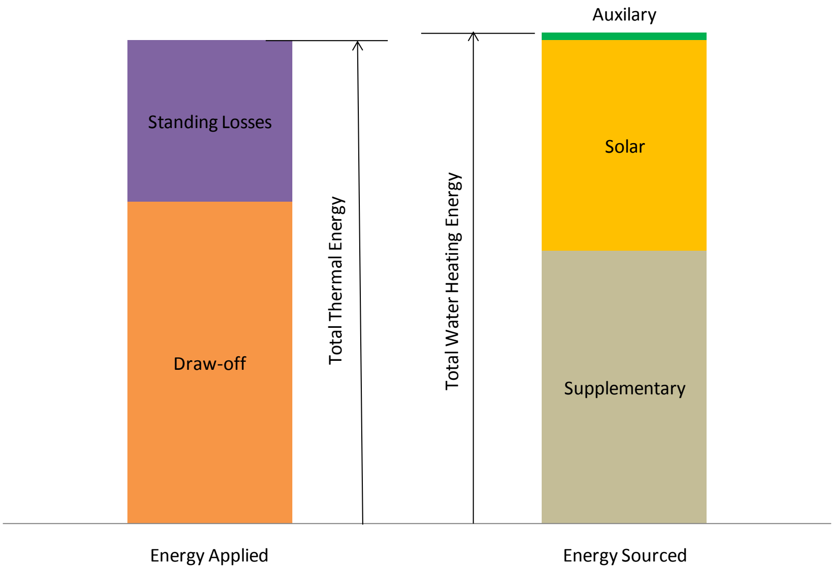


Figure 2. Example of a heat balance for one system

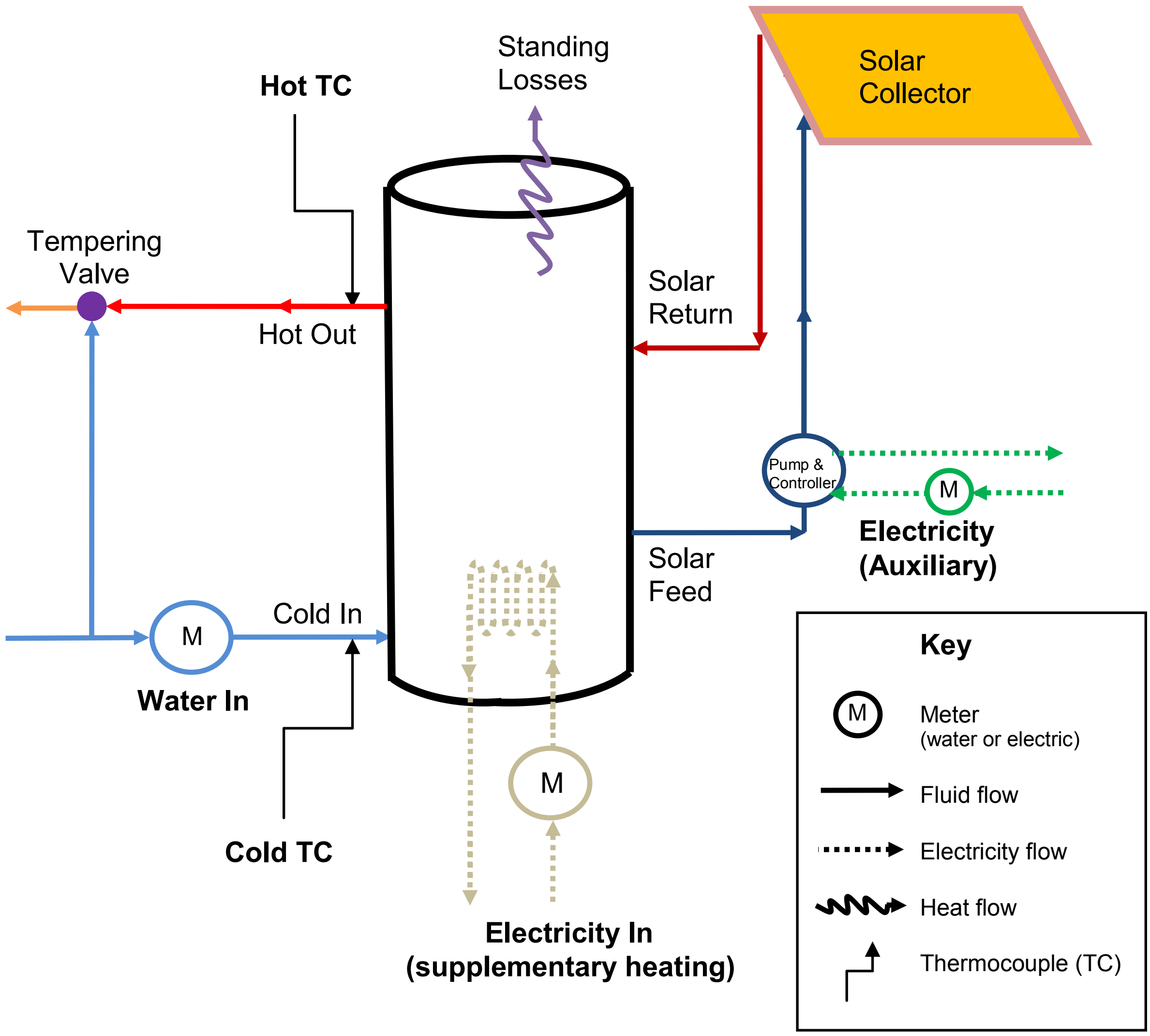


Figure 3. Typical monitoring arrangement

3.3 Measurements

The measurement system installed at each site was kept as simple as possible, for reasons of cost and reliability. The key factors mentioned in Section 3.2 *Determination of solar performance* were measured, as well as the total electricity usage for the house.

With a need to measure a number of systems in four centres, and with no need for user feedback or system control, a data logger based data collection system was chosen as the most practical way of collecting the data.

Modifications were made to the existing loggers used by BRANZ for the HEEP project (Isaacs et al 2006) so that they could be used for this project. The data collection and processing methods used were similar to that used in HEEP.

Generally, each system was instrumented at the same time that the inspection was undertaken. The data was collected by a local BRANZ representative visiting each of the installations each month. Data was sent back to BRANZ via email and was then subject to a process of conversion to useful units, consolidation, cleaning and checking, structuring and storage for later analysis.

A Siemens S2AS electricity tariff meter with a pulsed output (2% accuracy, 1 Wh per pulse) was installed to determine the amount of supplementary electrical heating used by the element inside each of the hot water cylinders. A second meter was installed to measure the total auxiliary energy use of any pumps and/or controllers, with a third meter providing a general measure of the total electricity usage of each household.

The pulsed output from each of the electricity meters was measured with a BRANZ pulse logger. The total household electricity and cylinder elements were frequently measured by electricity meters added to the household fuse board. The pump and controller (auxiliary energy), and sometimes the cylinder element, were measured near the cylinder with the meter in an electrical enclosure box.

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.

A pulsed output water meter (a Manuflo MES-MR meter with a high pulse rate of 34 pulses per litre) was installed in the cold water feed line which, subject to a small temperature correction, is the same as the flow out of the system.

Where a combined valve group-set was involved, or space was limited, the installation of the water meter proved difficult. As many systems have cold feeds for the tempering valve taken off the cold feed to the cylinder,[5] care is required to ensure that the meter is placed after this take-off as shown in Figure 3. Unfortunately for one household in the sample, the pipe work was particularly complicated (this household also had a wetback), and the meter was incorrectly placed so that it also measured the water flow to the solar collectors making the data collected from this household unusable.

The pulsed output from the water meter was also recorded by a BRANZ pulse logger, which was installed near the water meter in a place accessible to the download person. For a few of the roof-top thermosiphon systems which had tempering valves alongside the system, it was necessary to place the water meter on the roof and run cabling down alongside the pipe work back into the interior of the house.

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

[5] It may also be the case that there are other take-offs in the cold feed to the cylinder (after the pressure-reducing value) for pressure-balancing reasons, such as for the cold feed for showers.

thermocouples taped to an exposed section of copper pipe. The thermocouple locations were lagged with closed-cell foam and the thermocouples wired into a BRANZ microvolt logger. For some of the roof mounted thermosiphon systems, it was necessary to run the thermocouple wires up one of the feed pipes, via the flashing boot. The logger was then placed in a handy place within the house for the download person to access it.

The temperature measured by a thermocouple taped to the side of the copper pipe is slightly delayed by the time needed to heat the sides of the copper pipe. Both the pulse loggers and the microvolt loggers were set to record at six minute intervals, and it was found that it was necessary to advance the temperature measurements by one of these intervals to align the time of peak water flow and peak temperature.

3.4 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 provides good results when the system is not on a timer and the cylinder size is not large in comparison to the amount of heating going into the system. Sixteen of the 33 SWH systems were estimated in this way.

Another way to regard the heat losses of the system is to consider the varying daily energy requirements for the system over a number of days. Rearranging the heat balance Equation 3.1 for the standing losses gives:

$$Q_{std\ loss} = Q_{supp.heat} - Q_{draw\ off} + Q_{solar} \quad (3.3)$$

If the solar radiation was zero, then this equation would give the standing losses as the supplementary heating less the draw-off energy. Some information on the solar radiation at the sites was available from the NIWA Cliflo Climate Database (NIWA 2007) as will be discussed in Chapter 4. Graphs of the daily supplementary heating less the draw-off energy were examined against the daily global horizontal solar radiation as determined from the Cliflo database. A linear regression equation was fitted and the intercept, or the value of the supplementary heating less draw-off energy for no solar contribution, was used as an estimate for the system standing losses. For some of the systems where the supplementary heating is occurring overnight to balance the draw-offs and solar gains of the previous day, it was necessary to aggregate the data to consider two days together rather than single days. Overall, this method was used for nine of the 33 SWH systems

In the colder areas of Dunedin and Christchurch, for systems that had a high level of timer control on the supplementary heating, this technique encountered problems as the daily standing losses had an amount of scatter introduced by the variation in the outside temperatures. For five of the 33 SWH systems, the standing losses were estimated by examining the size and frequency of the typical standing loss heating event of the supplementary heating.

The standing losses for the two systems that rarely used supplementary heating were estimated by considering the average temperatures of the system (lower than for other systems) and the construction details of the cylinder. This technique was more inaccurate than the other standing loss estimates.

3.5 Heat pump systems

The integrated heat pump hot water systems examined in this project were air-to-water systems which extracted heat from the air surrounding the cylinder and deposited this into the water within the cylinder.

The heat balance for the heat pump systems differs from that used for the SWH systems in that the heat sourced is not from two separate sources (electricity and solar), but one source (heat pump heat output), which in turn is related to a measured variable (electrical energy input into heat pump) by a proportionality constant (the system performance factor, *SPF*). This can be expressed as:

$$SPF \cdot E_{hpwh} = Q_{hpwh} = Q_{draw\ off} + Q_{std\ loss} \tag{3.4}$$

Where E_{hpwh} is the total electrical input energy into the heat pump system

SPF is the system performance factor of the heat pump or the ratio of the heat output of the heat pump to the electrical input energy to the heat pump system

Q_{hpwh} is the heat output of the heat pump system

$Q_{draw\ off}$, $Q_{std\ loss}$ as previously defined.

Estimates of the performance of the heat pump systems were made by calculating the *SPF* of the system by taking a linear regression of the measured daily electrical input (E_{hpwh}) with the daily draw-off energy ($Q_{draw\ off}$) of the system. The standing losses of the systems were calculated either as the constant term of this regression equation or, where the system did not have sufficient low draw-off data to provide a good estimate, this value was estimated by comparison with the other heat pump systems.

In order to produce a measure comparable to the SWH systems, the heat pump output heating energy was separated into a component comparable to the supplementary heating component of the SWH systems. This was the electrical input energy into the heat pump as well as a renewable energy component, which is the amount of heat extracted from the environment by the heat pump less the energy used to extract it.

The efficiency of the heat pump system is dependent on outside temperature and as the data from these systems was only available over the summer period only summer time performance estimates could be made on them.

4. CLIMATE

The performance of a SWH system ultimately depends on the climate at the site, the amount of solar radiation it receives, the ambient temperatures and the extent of the wind flow over the collector.

Data on the solar radiation and outdoor temperatures for locations within each of the four monitored centres was obtained from the national climate database that is maintained by NIWA and accessed via an internet-based query tool, CliFlo (NIWA 2008).

Weather stations in each of the centres were identified which were centrally located to the monitored SWH systems and which had frequent readings of the global horizontal solar radiation and the outdoor temperature. The stations selected were Khyber Pass (Agent Number 22164) for Auckland, Kelburn (Agent Number 25354) for Wellington, Kyle Street (Agent Number 24120) for Christchurch and Musselburgh (Agent Number 150954) for Dunedin. Data was extracted for the period from January 2006 until February 2008.

Table 2 and Figure 4 provide monthly summaries of the global horizontal solar radiation from each of the stations. The year of monitoring is shown by the shading in Table 2. For the studied period, the solar radiation in Auckland, Wellington and Christchurch is similar (within 2% of one another), with the solar radiation for the Dunedin site being lower by about 8%. The seasonal variation is less for the Auckland site than the other centres.

Table 3 and Figure 5 provide similar monthly comparisons of the air temperature, with the Auckland site seen as warmer than the other locations. The temperature at the Wellington site is also warmer than Christchurch and Dunedin over the winter period.

The NIWA solar radiation data was primarily used for standing loss calculations as discussed in Section 3.4.

Table 2. Global horizontal solar radiation for the four centres

	Global horizontal solar radiation (kWh/m²)			
	Auckland	Wellington	Christchurch	Dunedin
Jan-06	169	193	187	185
Feb-06	145	154	150	137
Mar-06	128	112	108	101
Apr-06	87	78	84	65
May-06	63	48	46	39
Jun-06	59	41	39	35
Jul-06	67	46	44	38
Aug-06	79	68	72	61
Sep-06	106	99	104	97
Oct-06	122	121	156	126
Nov-06	149	153	171	152
Dec-06	180	198	174	167
Jan-07	169	178	161	150
Feb-07	152	168	139	136
Mar-07	124	140	129	113
Apr-07	95	85	83	61
May-07	69	58	56	44
Jun-07	50	40	42	31
Jul-07	51	44	40	40
Aug-07	74	75	72	58
Sep-07	97	98	99	90
Oct-07	135	150	152	128
Nov-07	143	185	188	156
Dec-07	150	186	182	178
Jan-08	189	206	188	201

	Auckland (36.9°S)	Wellington (41.3°S)	Christchurch (43.5°S)	Dunedin (45.9°S)
Total 2006	1353	1310	1334	1201
Total 2007	1310	1407	1342	1186
Study Period	1341	1358	1369	1236

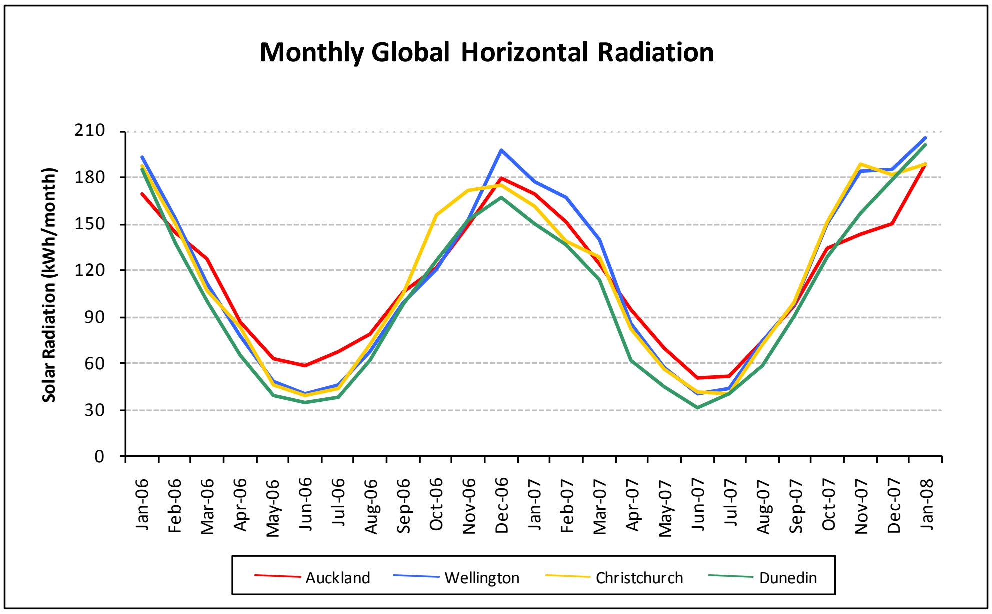


Figure 4. Monthly global horizontal solar radiation for the four centres

Table 3. Outdoor air temperature in the four centres examined

	Average air temperature (°C) Auckland	Wellington	Christchurch	Dunedin
Jan-06	19.6	16.7	16.7	14.9
Feb-06	19.8	16.8	16.8	14.8
Mar-06	18.2	13.7	12.9	11.4
Apr-06	17.5	14.8	13.9	12.5
May-06	14.3	11.4	9.6	9.4
Jun-06	10.6	8.4	5.3	6.1
Jul-06	10.7	9.2	6.4	7.0
Aug-06	11.1	8.8	7.6	7.4
Sep-06	13.1	10.8	11.3	10.8
Oct-06	13.2	10.4	12.4	10.7
Nov-06	15.2	12.4	13.4	11.6
Dec-06	15.1	12.4	13.1	11.8
Jan-07	18.4	15.1	15.6	13.8
Feb-07	19.0	16.0	16.2	14.4
Mar-07	18.6	16.1	15.9	14.6
Apr-07	15.6	12.3	11.9	10.8
May-07	15.0	12.7	12.1	11.2
Jun-07	11.9	8.7	6.4	5.8
Jul-07	11.7	8.3	6.5	6.4
Aug-07	12.5	8.9	7.8	7.9
Sep-07	13.4	9.9	9.9	9.6
Oct-07	14.3	10.8	11.6	10.2
Nov-07	15.6	12.4	13.6	11.9
Dec-07	18.4	14.8	16.6	13.7
Jan-08	20.7	17.5	18.3	16.0

	Auckland (36.9°S)	Wellington (41.3°S)	Christchurch (43.5°S)	Dunedin (45.9°S)
All of 2006	14.8	12.0	11.4	10.7
All of 2007	15.3	12.1	12.0	10.8
Study Period	15.0	11.8	12.2	11.0

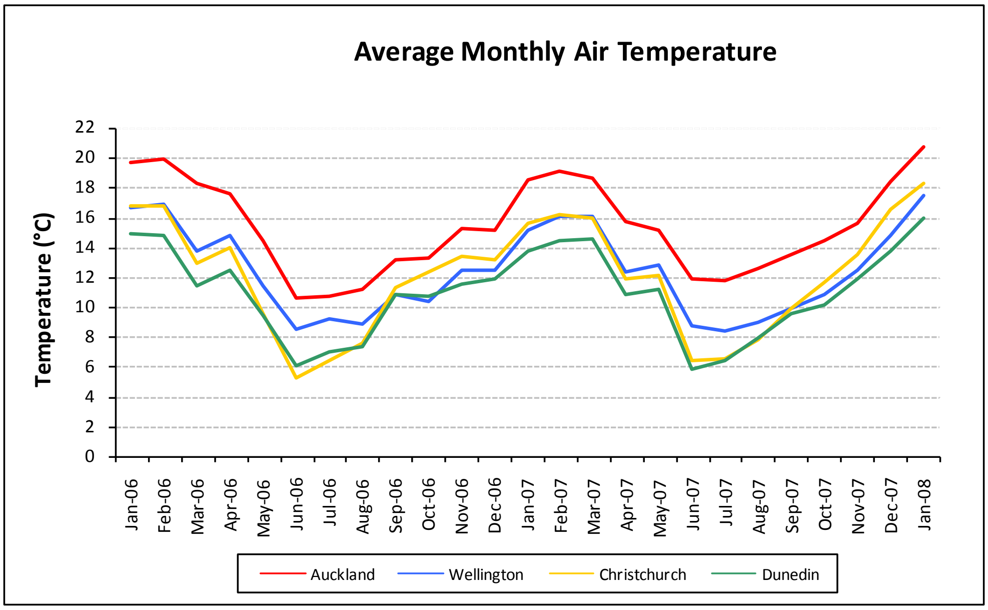


Figure 5. Monthly air temperatures for the four centres

5. MEASURED DATA

This section provides details and results of the measurements undertaken in each of the households. Section 5.1 provides a description of core channels examined for each household, as well as some examples of the exploratory data analysis graphs generated for each household. Section 5.2 makes comparisons between the systems of the various key measurements and calculated parameters. Finally, Section 1.1 provides a commentary for each of the individual systems on any interesting features.

5.1 HEEP EDA plots

With the extensive amount of data processed during HEEP it became necessary to develop particular exploratory data analysis (EDA) graphs to allow the data to be quickly examined. The processing structures for this project were similar and some HEEP data processing and analysis methods have been modified and used for this project. EDA graphs have been generated for each of the monitored systems.

Figure 6 provides example EDA graphs from one of the monitored systems and the following description is given here to provide an indication of what information can be gleaned from the monitoring data.

The channel label appears in the title of the graph: ***Total Electricity*** is the total electricity usage for the house; ***Supplementary Heating (Electricity)*** is the electricity usage of the element inside the hot water cylinder (supplementary heating); ***Solar Collector Pump (Electricity)*** is the electricity usage of the pump circulating fluid through the solar collector and of the pump controller; ***Water Flow into System*** is the cold water flow into the SWH system; ***Temperature Water Out*** is the temperature of the hot water outlet; and ***Temperature Water In*** is the temperature of the cold water inlet to the SWH system.

Underneath the channel label is summary information. This reports the number of days monitored, the number of days of NAs (missing values), then the percentage of valid data points with values in the ranges: equal to zero; greater than zero and less than 20; greater than 20; and finally the energy use (kWh) over a year (one average day x 365) is provided for electricity channels or the average temperature for temperature channels.

Each individual EDA graph (see Figure 6 contains three plots: a ***histogram,*** a ***time-series plot*** and a ***daily profile*** of the data recorded every six minutes.

The ***histogram*** shows how often the data was in a given range. The data range is given on the horizontal axis and the counts are on the vertical axis. For appliances that have too many values in the ‘zero’ bin, this bin is replaced by a number, otherwise the remaining bins would be too small to see clearly. The histogram of the total electricity usage is typically strongly skewed. The water pump only operates at a number of distinct levels.

The ***time-series plot*** has the date (start of month) on the horizontal axis (below the daily profile graph), and the data value on the vertical axis. As there is so much data, the lines sometimes overlap slightly, causing a solid block of black. This indicates rapid switching between high and low values. If a solid block has an apparent straight edge on the top or bottom, and this indicates that it is switching to a constant value. If the solid block has a ragged edge, it is switching to a changing value. Periods of missing values are indicated by a straight horizontal line near the top of the time-series plot. These may occur if there was a problem with the monitoring, a power cut, or the appliance was not monitored during a given period. In the example, some missing data occurred in January for the cold water flow into the cylinder as well as during March for

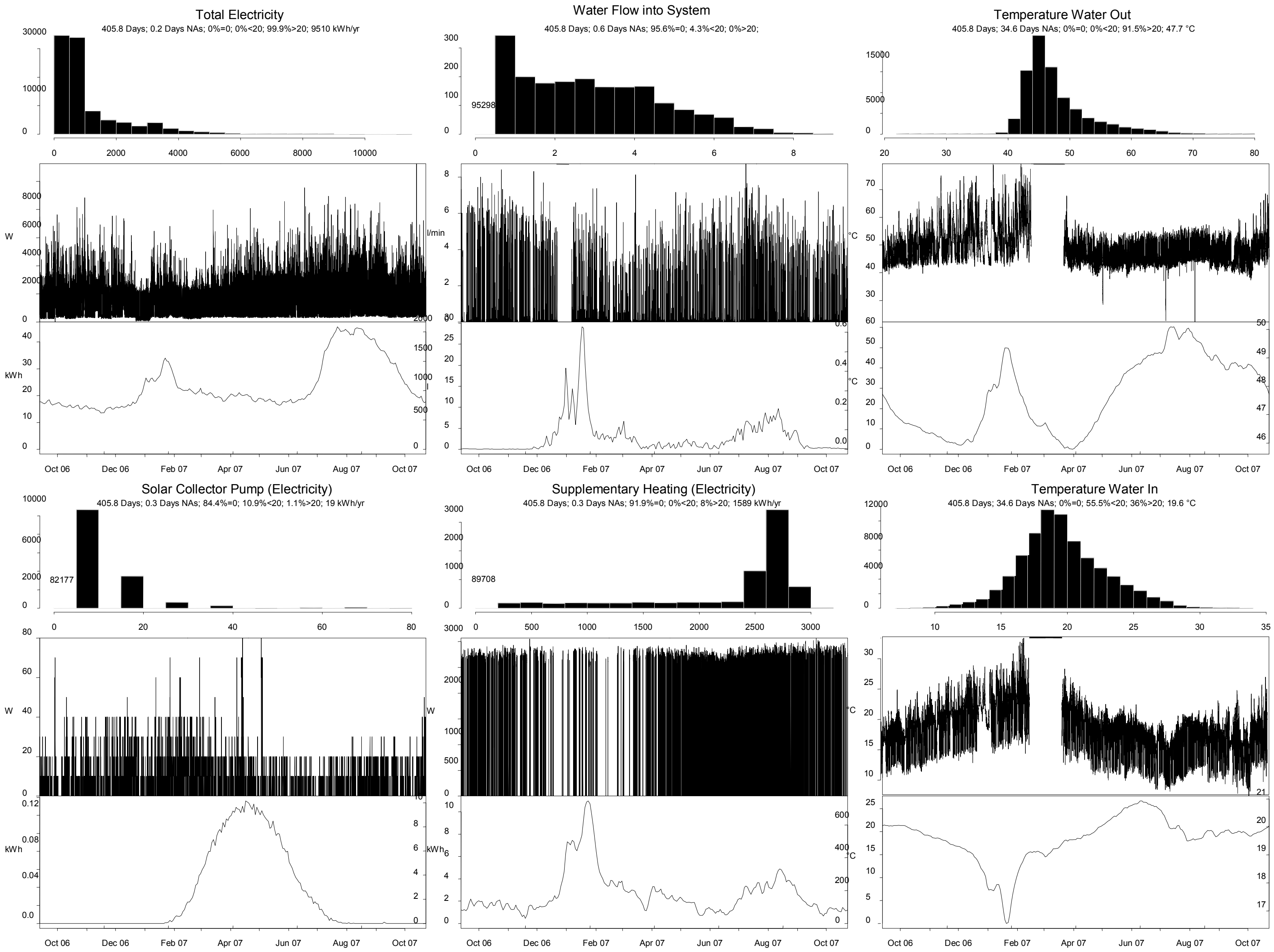


Figure 6. Example EDA plots for one system

the temperature data. The most characteristic feature in the example time-series plots in Figure 6 is that of the electrical element, where an increase in dark lines occurs in winter, matching the increase in electrical energy use for the heating element.

The third plot contains the average ***daily profile*** for the respective channel averaged over the complete set of data. This profile is given from midnight on the left to midnight on the right. In Figure 6, the operation of the circulation pump can clearly be seen as peaking during the middle of the day corresponding to when solar radiation is present. The daily profile for the water flow into the system shows typical strong morning usage as well as some evening usage. The corresponding heating element usage has a peak in the morning. The daily profile of the total electricity usage for the house shows a strong baseload energy with peak usage occurring in the evenings.

5.2 Comparing systems

Data was examined in detail for 33 of the 35 SWH systems monitored. In one of the other two cases the water meter was mis-positioned so did not record the correct water flow, with the remaining system having a high level of sensor and data logger problems causing an unacceptable level of invalid data. Of the four HPWH systems, three performed well. The other system provided accurate data, but the system itself was not performing well. Only the summer time performance of the heat pump systems was measured.

Comparing the systems soon reveals large differences in household hot water use. Figure 7 gives a histogram of the average daily hot water use from the 33 SWH systems in each of the households examined. The number of systems in each 'bin' is given on the scale on the left hand side of the graph, The curve in Figure 7, as well as the other histograms in this report, is a density curve which is a smoothed representation of the data and is independent of the choice of bins used to divide the data into bars the values of the density curve is given by the scale to the right of the graph. The highest system (System H01) used an average of 290 L of hot water per day – over eight times the average usage of the lowest system. This water use figure is for water removed from the cylinder (e.g. if the temperature of the water in the cylinder is at 60°C, then this 290 L of hot water would equate to usage of 520 L of warm water for, say, showering at a water temperature of 40°C).

The distribution of the average daily hot water use of the SWH systems is varied. with a high standard deviation of 70 L compared with the mean value of the average daily hot water use of 140 L.

The HEEP Year 9 report (Isaacs et al 2005) gives the mean total electricity usage for electricity storage hot water cylinders in the HEEP sample as 7.3 kWh per day, as well as the mean standing losses for the cylinders as 2.4 kWh per day. Neglecting the impacts of wetbacks, this would give an average delivered hot water energy of 4.9 kWh per day. Taking an average temperature difference of 45°C, this delivered energy would be equivalent to an average delivery of 94 L of hot water per day.

The temperatures in SWH systems are more varied than for standard electric storage systems. Lower storage temperatures would increase the amount of hot water drawn-off from the cylinder to satisfy a certain demand for warm water. However, approximately 70% of the SWH systems use more than this HEEP average.

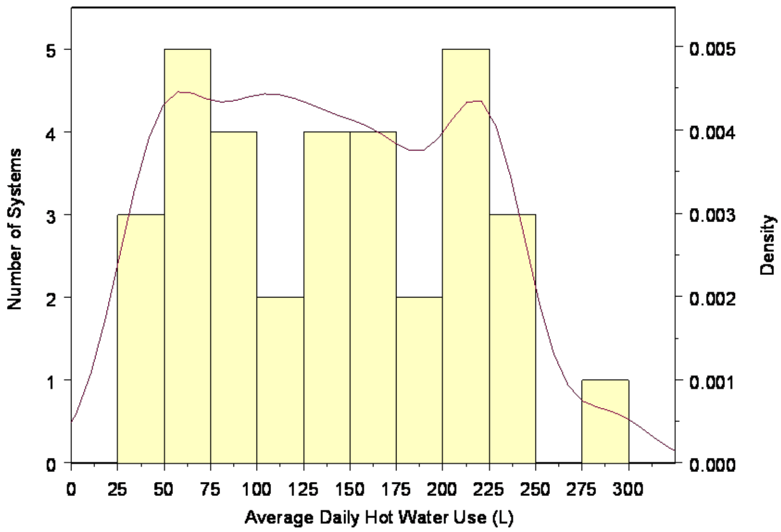


Figure 7. Histogram of the average daily hot water use from each of the monitored SWH systems

Figure 8 provides a comparison of two ‘consumptive’ measures for the households: the average daily hot water consumption from the SWH system is shown on the vertical axis with the horizontal axis showing the total household electricity consumption. The two measures show a poor association with a correlation of 0.54.

Like the average daily hot water use of the SWH systems, the total household electricity also has a large variation between the lowest and highest user, with the lowest user (H22) using less than 2000 kWh per year and the highest household (H32) more than 21000 kWh per year. This highest consuming household had a second all-electric hot water cylinder supplying the kitchen – an old D-grade 180 L cylinder which used 1940 kWh per year. The water flows were not measured for this cylinder and the measurements for this household (H32) only refer to the SWH system. Removing this household, the correlation between the average daily hot water use and the total household electricity use increases only marginally to 0.65 indicating that, in general, the total hot water use is poorly related to the total electricity consumption.

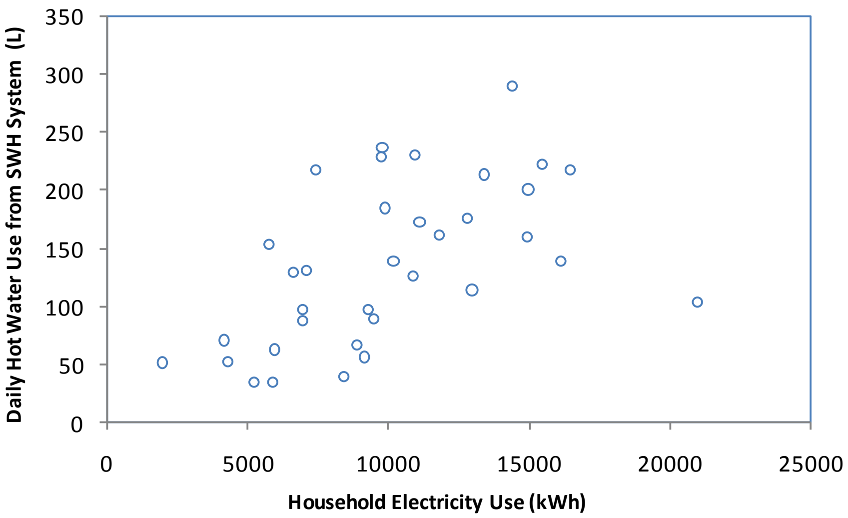


Figure 8. Total household energy use and average daily water use of the household SWH systems

Many of the households use water in the morning as can be seen by the daily profiles (see Section 5.1 for a explanation of these) for each of the hot water systems shown in Figure 9. Many of these households have a pronounced spike in the morning, perhaps resulting from regular hot water activities such as always showering at the same time. The size of the day-time and evening usage can be seen to be more varied between the households. Three of the four HPHW systems (H36, H37, H38 and H39), however, show greater usage in the evenings.

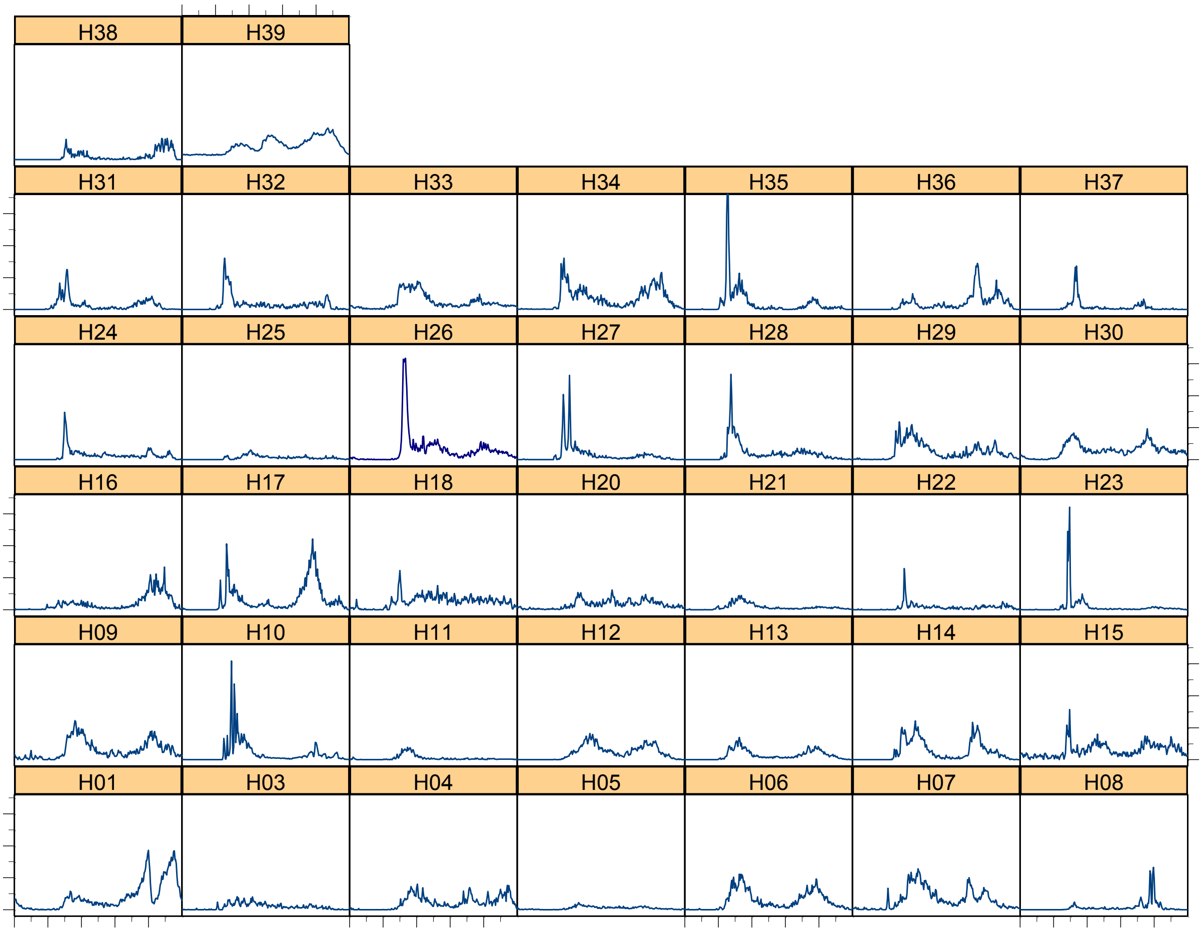


Figure 9. Daily profile plots for each of the monitored systems

The supplementary electric heating required by each system is an important direct measure of each system and determines a large proportion of the running costs of the SWH system. Figure 10 provides a histogram of the total annual supplementary water heating energy and shows a positively skewed distribution (increased number of higher values) with a mean supplementary energy use of 2400 kWh per year and a standard deviation of 1500 kWh per year. The system with the highest supplementary heating (H04) used over 7000 kWh per year,[6] whereas the system with the least (H08) used just 53 kWh of supplementary heating over the year.

The HEEP Year 9 report (Isaacs et al 2005) figure for supplementary heating of electric hot water cylinders of 7.3 kWh per day equates to an annual figure of approximately 2700 kWh per year. This figure is not directly comparable to the 2400 kWh for the SWH sample, as the hot water use within these two samples is different.

[6] This system had a 3300 W element so this equates to the element being on for 24% of the time.

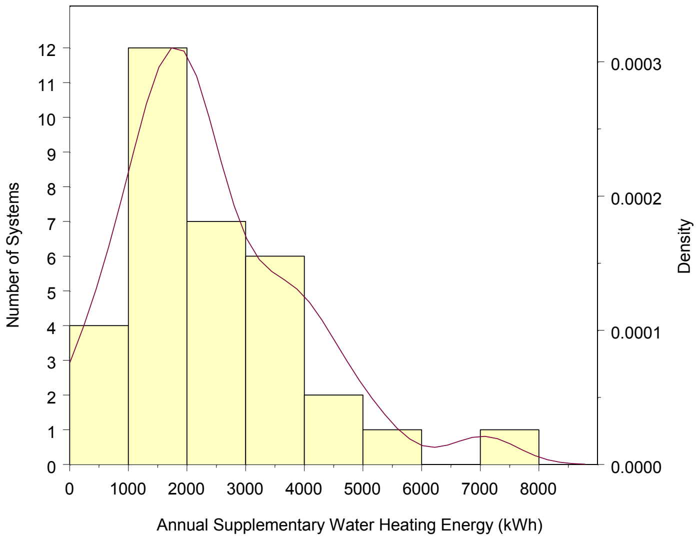


Figure 10. Histogram of the total annual supplementary water heating energy use

The supplementary water heating energy use is compared with the average hot water use for the SWH systems in Figure 11. While the supplementary water heating energy use can be seen to roughly increase with increasing water use, the system with the largest supplementary water heating is considerably higher than what might be expected for this system given the other data. The total household electricity use for this household was 11800 kWh, so that the supplementary heating was responsible for 60% of the total electricity usage for this house. The reason for this high usage is due to back circulation of the system at night which is discussed in Section 7.4.

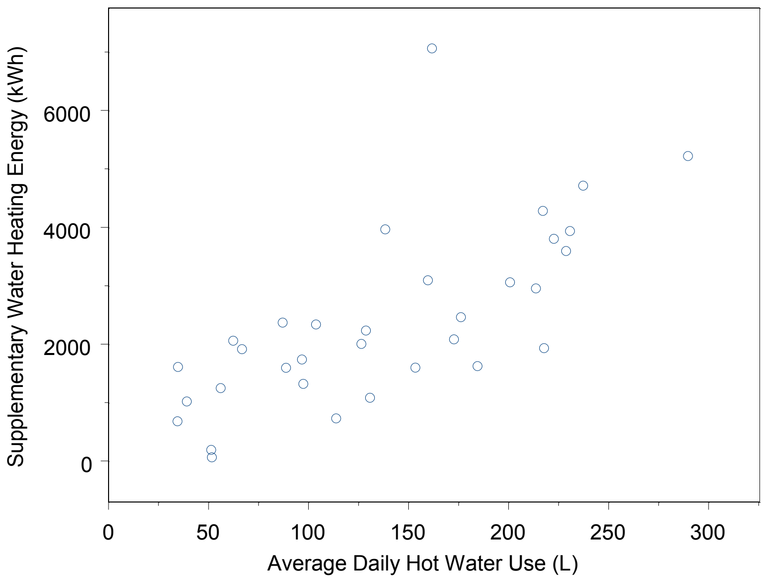


Figure 11. Average hot water use and the supplementary water heating energy use

5.2.1 Draw-off energy

The energy removed from the hot water cylinder can be estimated by measuring the volume of water drawn-off from the cylinder, the temperature of that water, as well as the temperature of the cold water that has replaced it. The heat capacity of the water can then be calculated and the quantity of heated water removed from the cylinder calculated.

Figure 12 provides a histogram of the amount of energy draw-off from each of the SWH systems. The system with the highest draw-off can be seen to be quite distinct from the remaining systems.

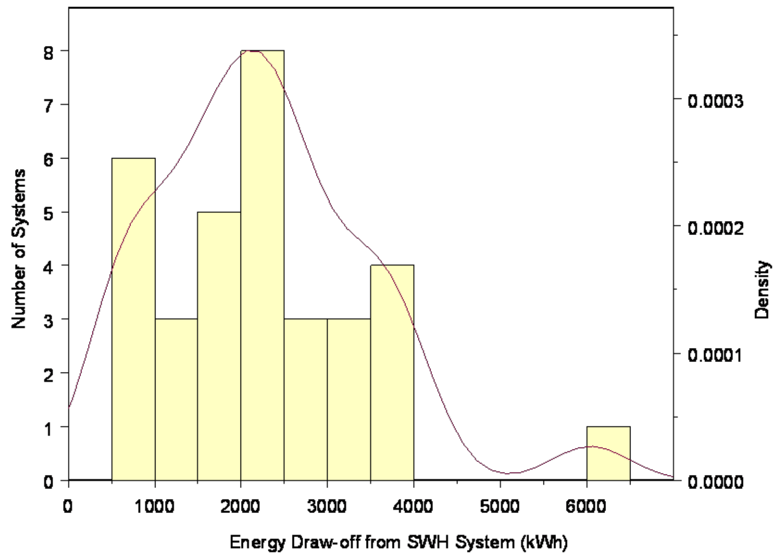


Figure 12. Histogram of the amount of energy draw-off from the SWH systems by the occupants

5.2.2 System standing losses

As mentioned in Section 3.4, calculating the system standing losses of SWH systems can be difficult. The system losses include all of the heat losses from the system other than the heat in the water drawn off from the cylinder. The graph in Figure 13 shows the estimated system losses for the measured systems as well as the volume of the cylinder. The volume for the heat pump systems is approximate only.

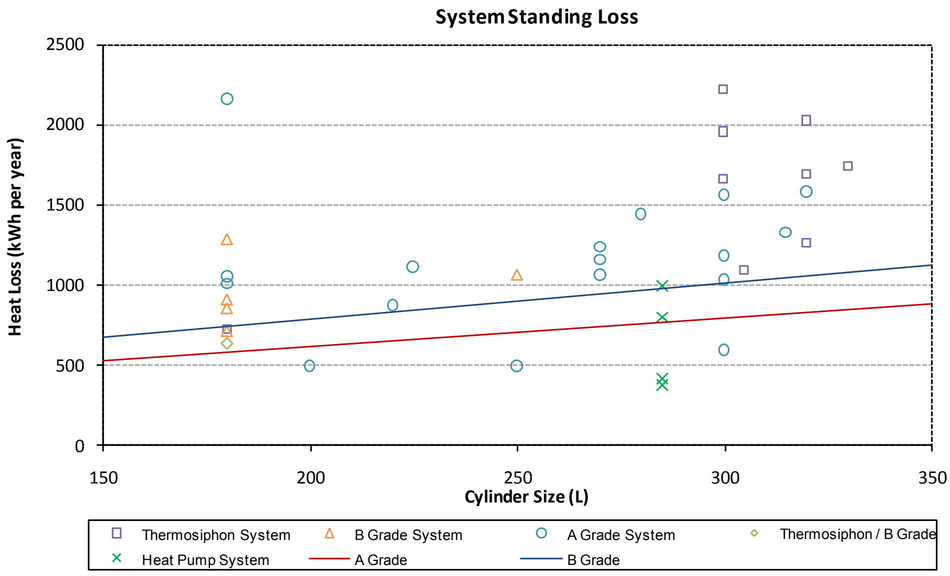


Figure 13. Estimated system standing losses and the volume of the hot water cylinder for which the energy balance was calculated (System H04, 6400 kWh for a 160 L cylinder, has not been plotted)

Overall, the system losses are high and there would be scope to improve the system performance with improved insulation levels.

Also shown on the graph are the levels for the A-grade and B-grade cylinder standing loss levels when the cylinders are tested to the relevant test standard. These test levels are not directly comparable to the system standing losses as the testing standards only involve the cylinder and do not include any draw-off of water from the system or any heat losses from associated pipe work. The test is also a static test undertaken at particular set temperatures (or temperature differences).

Of the 35 SWH systems, twelve (34%) made use of an existing hot water cylinder, 'retrofitting' the solar collector into the hot water system. Six of these retrofit cases had hot water cylinders insulated only to the B-grade level.

The thermosiphon systems are also shown in Figure 13 with a separate label. These systems generally have a larger-sized cylinder than other systems and tend to have higher systems losses as the cylinders are subject to a higher temperature difference with them being located outside the building envelope. Of the two thermosiphon systems used as pre-heaters, one was also connected to a B-grade cylinder, so this is indicated as a separate label.

From Figure 13 there are a number of particular systems that stand out from the others. The first one, H04, is the one system that has not been plotted as it is so far off the graph. The graph was not adjusted to include H04, as doing so reduces the ability to see the variation in the system losses for the other systems. System H04 had standing losses from the 160 L cylinder of approximately 6400 kWh. This is due to back circulation of the system at night which is discussed more fully in Section 7.4. Another small cylinder (this time 180 L), which has elevated standing losses of about 2200 kWh, is H05. This had problems with the circulation within the system and is discussed in Section 7.5.

Three of the systems – H08, H20 and H22 – appear to have small heat losses with their system losses appearing below the A-grade line. The temperature of the water stored within each of the cylinders of these systems is low. The supplementary heating is also seldom used for H08 and H22.

5.2.3 Overall energy balance and solar contribution

For SWH systems which have only electric supplementary heating, the renewable (solar) energy contribution 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:

$$Q_{renew} = Q_{solar} = E_{hot\ water} - Q_{supp.\ heat} \quad (5.1)$$

or

$$Q_{renew} = Q_{solar} = Q_{draw\ off} + E_{aux} + Q_{std\ loss} - Q_{supp.\ heat} \quad (5.2)$$

For the systems with wetbacks, the calculation is essentially the same however the renewable energy contribution is for both the solar energy and wetback contribution.

For the heat pump systems, the renewable energy contribution is the amount of heat provided by the heat pump less the electrical energy used to provide that heat.

$$Q_{renew} = Q_{hpwh} - E_{hpwh} \quad (5.3)$$

Table 4 gives the details of the energy balance calculation for each of the systems and also provides values for the coefficient of performance (COP) which is discussed in Section 5.2.3.1.

Section 7 provides notes on individual systems and it may be helpful to consider these alongside the data in Table 4.

Table 4. 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 (kWh)	System losses (kWh)	Auxiliary Energy (kWh)	Total energy (kWh)	Supplementary water heating (kWh)	Renewable energy Q_{renew} (kWh)	(% of total)	COP	Wetback
H01	6000	1600	88	7700	5200	2400	31%	1.1	no
H03*	1200	850	2	2000	1900	140	7%	0.6	no
H04	2400	6400	100	8900	7100	1800	20%	0.3	no
H05	580	2200	160	2900	1600	1100	39%	0.3	yes
H06§	3900	1200	39	5100	4700	340	7%	0.8	no
H07	3500	910	49	4500	3600	840	19%	1.0	no
H08	740	500	140	1400	53	1200	86%	3.9	no
H09	2500	1700	0	4300	1900	2400	55%	1.3	no
H10	1900	1100	19	3000	2000	940	32%	0.9	no
H11	670	710	57	1400	670	710	49%	0.9	no
H12	2800	1200	170	4200	1600	2400	58%	1.6	Yes
H13	1600	1100	61	2700	1300	1300	49%	1.2	no
H14	3300	1000	100	4500	2500	1900	43%	1.3	no
H15	3800	1400	48	5300	4300	1000	19%	0.9	no
H16	2100	2200	0	4300	4000	360	8%	0.5	no
H17	3100	2000	0	5100	3800	1300	26%	0.8	no
H18	2500	1700	0	4200	1600	2500	61%	1.5	no
H20	1500	600	50†	2100	720	1400	64%	1.9	no
H21	880	1100	50†	2100	1200	760	37%	0.7	no
H22	620	500	42	1200	180	940	81%	2.8	no
H23	1400	1300	75	2700	2100	590	22%	0.6	no
H24	1900	730	0	2700	2400	300	12%	0.8	no
H25	580	640	0	1200	1010	200	17%	0.6	no
H26	3900	1100	0	5000	2900	2100	41%	1.3	no
H27	2000	1000	46	3100	1700	1300	43%	1.1	yes
H28	1700	1200	50†	3000	1100	1900	62%	1.5	no
H29	2500	1100	11	3600	2100	1500	41%	1.2	no
H30	2700	1300	85	4200	3000	1000	25%	0.9	no
H31	1600	880	20	2500	1600	850	35%	1.0	no
H32	2100	1600	8	3700	2300	1300	36%	0.9	no
H33	2400	1700	0	4100	3100	970	24%	0.8	no
H34	3500	2000	0	5500	3900	1600	29%	0.9	no
H35	2200	1300	0	3500	2200	1300	37%	1.0	no
H36‡	1700	380	0	2100	1200	950	44%	1.5	no
H37‡	590	800	0	1400	3600	-2200**	-160%**	0.2	no
H38‡	1100	990	0	2100	910	1200	57%	1.2	no
H39‡	2300	400	0	2700	1200	1400	54%	1.9	no

* H03 had a fault with a sensor and was consequently not pumping fluid to the collector
§ H06 had a change of occupants so only winter time performance was available for this site
† The auxiliary energy for these systems was not available so a nominal figure of 50 kWh/yr has been used
‡ These heat pump systems were only measured over summer
** This heat pump system delivered less heat into the hot water than the amount of electricity the heat pump consumed.

Figure 14 provides a histogram of the annual solar energy contribution for those SWH systems that were exclusively solar systems (i.e. excluding the heat pump systems and the three systems with wetbacks). H03 and H06 were also excluded due to the H03 SWH system not operating correctly and H06 for only having summer time data. Overall, the average annual solar contribution of the monitored solar systems was 1260 kWh per year. Figure 15 gives a histogram of the fraction this solar energy contribution makes to the overall water heating needs for the same systems. This 'solar fraction' distribution is more stretched out than the solar contribution distribution. Overall, solar energy contributes on average 38% to the water heating needs for the SWH systems.

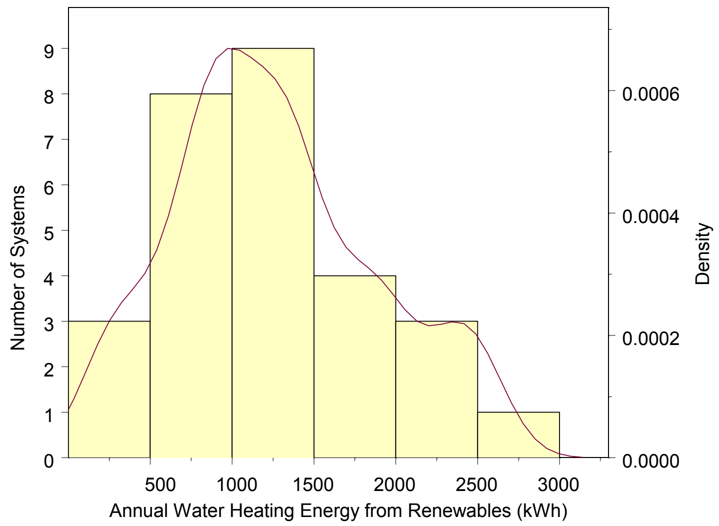


Figure 14. Annual contribution of solar energy to the solar only SWH systems

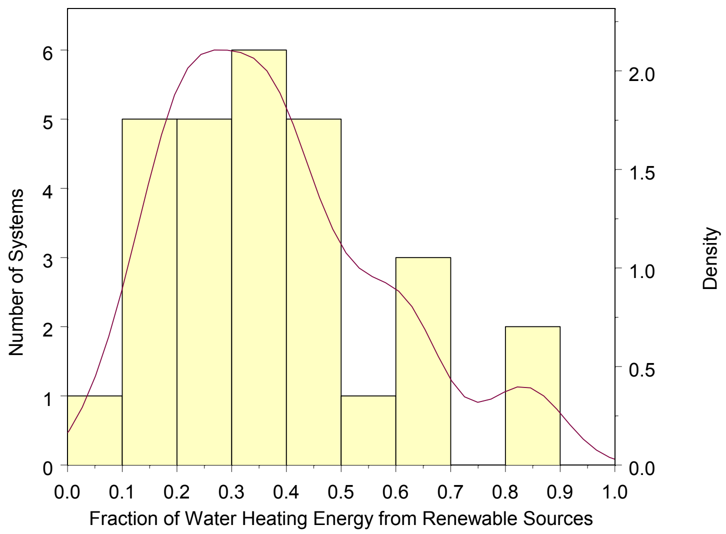


Figure 15. Fraction of the household's water heating energy sourced from solar energy for solar only SWH systems

The average of the three heat pump systems was similar to the solar-only average, with the heat pumps sourcing an additional 1190 kWh of energy from the environment per year (based on summer time performance) or an average of 52% of the total water heating needs for these households.

5.2.3.1 Coefficient of performance (COP)

There are a range of measures to summarise the performance of water heating systems (Lloyd and Kerr, 2008). The renewable energy and the renewable energy fraction discussed above require a estimate of the system losses. 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 (the supplementary heating for SWH systems or the compressor energy for HPWH systems as well as an associated energy used for pumps and controllers (the auxiliary energy);

$$COP = \frac{Q_{draw\,off}}{E_{ne}} \tag{5.4}$$

where $E_{ne} = E_{supp\ heat} + E_{aux}$ for a SWH system

or $E_{ne} = E_{hpwh} + E_{aux}$ for a HPWH system

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.

Figure 16 provides a histogram of the COP values from the solar only SWH systems excluding H03 and H06. The average COP in Figure 16 was 1.2 representing an approximate 74% improvement over an average electric cylinder.

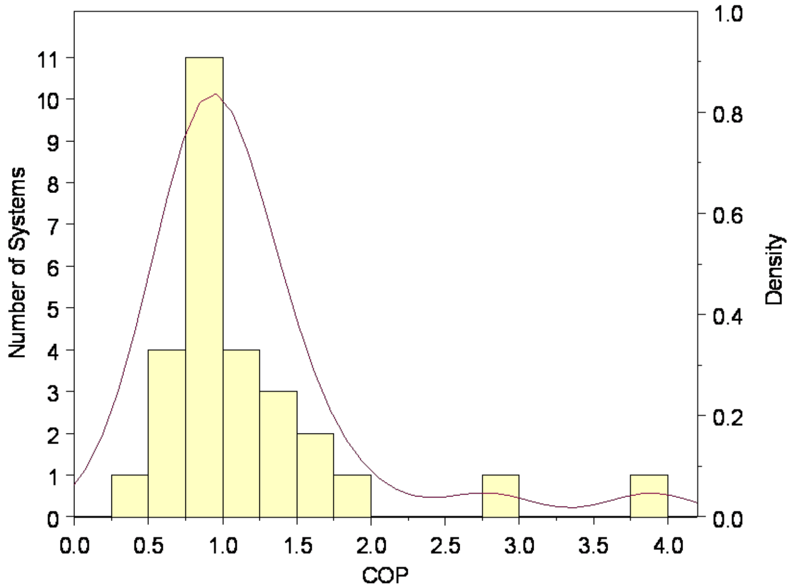


Figure 16. Coefficient of Performance (COP) value for each of the solar only SWH systems

5.2.4 Region and technology comparison

In order to examine if the hot water systems have any regional or technological patterns, a number of tests were undertaken on the renewable energy contribution of the systems. In this section the wetback systems (along with systems H03, H06 and H37) have been excluded.

Table 5 provides a breakdown of the average renewable energy contribution of each of the systems by region and technology with the number of systems given in brackets. Unfortunately, a number of the combinations of region and technology only produced one system.

Table 5. Regional and technology breakdown of renewable energy contribution (excluding solid fuel – the number in brackets is number of systems)

	Evacuated tube pumped		Flat plate pumped		Flat plate thermosiphon		Heat pump			
Auckland	2400	(1)	1340	(3)	2370	(1)	1060	(2)	1560	(7)
Wellington	1670	(2)	1070	(3)	1290	(3)	–		1300	(8)
Christchurch	830	(2)	1420	(3)	1400	(3)	–		1260	(8)
Dunedin	1030	(3)	590	(1)	860	(3)	1450	(1)	960	(8)
	1310	(8)	1210	(10)	1300	(10)	1190	(3)		

One-way ANOVA tests were undertaken for both the region and technology groups in turn. These ANOVA tests produced p-values[7] of 0.31 and 0.98 for the between-group variation when the groupings examined were the region and technology respectively. These high p-values highlight the fact that the between-system variation is large. and this suggests that the amount of renewable energy contributed by a water heating system is more dependent on having a system capable of delivering a high renewable energy contribution than where it is located or what type of system it is.

While the between-system variation on the one-way ANOVA tests are large and obscure any systematic variation with region or climate, it is possible to classify the systems into clusters based on their renewable energy contribution and to examine similarities of the clusters.

Rather than creating these clusters arbitrarily, such as breaking them into even thirds, a mathematical cluster analysis was undertaken and the grouping was taken to the point where three clusters were formed. The number of systems in each cluster, the average renewable energy contribution and the average renewable fraction for each of the clusters are shown in Table 6.

Table 6. Properties of each cluster

Cluster	Number of systems	Range of renewable contribution (kWh)	Mean of renewable contribution (kWh)	Range of renewable fraction (%)	Mean of renewable fraction (%)
High	8	1600 – 2540	2060	20% - 62%	43%
Medium	17	840 – 1480	1140	19% - 86%	43%
Low	6	320 – 760	550	8% - 49%	26%

Figure 17 and Figure 18 provide graphs of the composition of each of the clusters as they relate to region and technology respectively. The lowest performing cluster does not have any systems from Auckland or Wellington in it with Dunedin systems over-represented in this group. There is, however, a Dunedin system in the highest performing cluster.

[7] A p-value is the probability of obtaining the sample result at least as extreme as the observed result given that the null hypothesis is true.

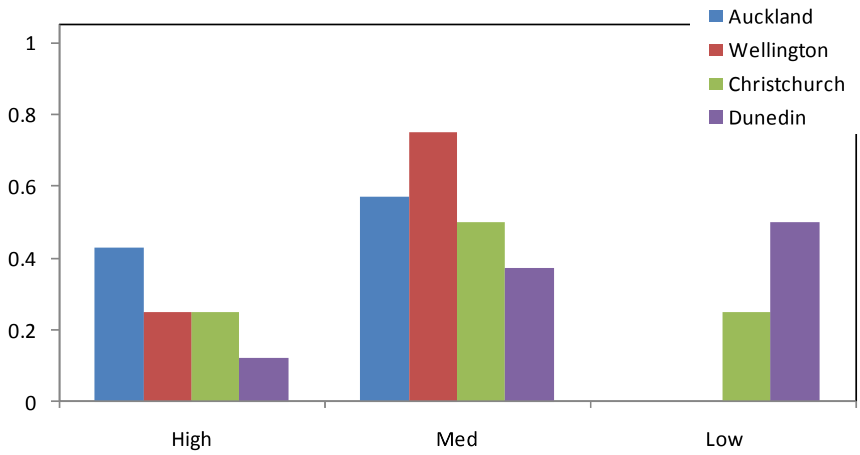


Figure 17. Proportion of each region fitting into each of the three performance classifications

Figure 18 provides the distribution of the technologies within the clusters. The evacuated tube, flat plate pumped and heat pump systems all show a central tendency, with these systems more likely to be found in the medium performance cluster than the other two clusters. The flat plate thermosiphon systems are fairly evenly spread across the performance clusters.

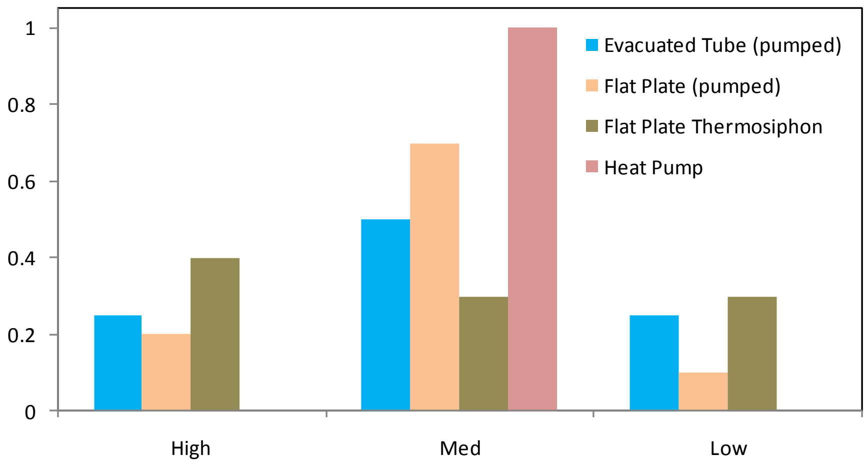


Figure 18. Proportion of each of the technologies fitting into each of the performance classifications

5.2.5 Control of systems

The collection of heat in a SWH system is dependent on multiple factors and many of these are fixed by the design of the system: the area of solar collectors, the size of the hot water cylinder, the collector inclination angle, as well as the direction the panels face. The amount of heat captured by a SWH system also depends on how the system is used and, in particular, when the supplementary heating is allowed to operate (Pollard et al 2005). In order to have a large solar contribution, the supplementary heating should not be allowed to operate in the mornings immediately after water has been drawn-off from the system, otherwise the cylinder will reheat and will have limited capacity for solar gains to be captured (Pollard et al 2005).

The easiest way to eliminate this morning use of supplementary heating is with the use of timers (Kerr 2006a and 2006b).

Only seven (20%) of the 35 SWH systems monitored had timer control on the supplementary heating. Another five systems had occupants who switched the supplementary heating off for an extended period of more than a couple of weeks. There were differences in the proportion of systems in each of the centres. The sample in Auckland had no systems that had timers, whereas four of the nine systems in Christchurch had timers.

Just having the system under timer control is not sufficient for the SWH system to be well-performing. Of the seven SWH systems with timers, three occurred in the highest performing cluster, three in the medium cluster, but one was in the lowest performing cluster.

Three of the systems (H20, H28 and H30) included large cylinders with top and bottom elements within them. The top element was used in all systems however the bottom element was not used in H20 and H28 and only used for three short periods of 5 days, 9 days and 2 days for H30. The performance of H20 and H28 was good with them both providing over 60% of the household's water heating needs. The performance of H30 was however only to provide 25% of the households water heating needs.

A two sample t-test was undertaken on the households with a timer on their SWH system and the households with a well-performing SWH system (and which did not include a wetback). While the solar energy contribution was higher in the seven systems with timer control (1520 kWh/year) than those without (1180 kWh/year), the variability within the data resulted in a high p-value of 0.21 indicating a low significance of the difference.

The timer should be set to minimise the time the supplementary heating needs to operate for while matching the needs of the occupants. For example, if the occupants primarily use hot water in the morning, then instead of having a timer that comes on at 10 pm and turns off at 7 am just before the first water use, it may be better to have the timer come on at 4 am, consequently reducing the system losses from 10 am to 4 am. Should there still be sufficient heat in the cylinder from the previous day,[8] then the heating would not be required at 4 am, but if the previous day had insufficient solar then supplementary heating, for say three hours, may be required to provide for hot water demand in the morning. Similarly, if there is a large amount of hot water required in the evening, the timer may require a period of heating time in the late afternoon.

5.2.6 Seasonality of the solar energy

The performance of SWH systems are dependent on the amount of solar radiation received by the system. As was seen in Section 4, the solar radiation in the monitored regions is quite seasonally dependent with between three times (Auckland) and four-and-a-half times (Dunedin) the global horizontal solar radiation in summer rather than in winter.

Table 7 gives estimates of winter time and summer time performance for a number of the monitored systems. Measured data for the draw-off energy and supplementary energy were used for the corresponding periods. The standing loss figures were seasonally adjusted by calculating the temperature difference between an assumed water storage temperature (60°C) and the ambient temperatures over the summer or winter period from the data from Section 4.

Estimates for a number of the systems could not be made for one or both of the seasons. Where this is the case a dash is indicated in Table 7.

[8] Hence the insulation levels of the hot water cylinder are important (see Section 5.2.2).

Table 7. Seasonal energy balance for each of the monitored systems
(except for panel direction, figures to two significant figures)

System	Winter renewable energy		Summer renewable energy		Panel inclination minus latitude	Panel direction	
	(kWh)	(% of total)	(kWh)	(% of total)	(degrees)	(degrees)	(offset from North)
H01	400	17%	700	51%	-13	38	38
H03	-	-	-	-	-17	295	65
H04	280	10%	710	35%	-16	328	32
H05	-	-	-	-	-4	1	1
H06	86	6%	-	-	-3	3	3
H07	78	6%	-	-	-15	41	41
H08	270	80%	340	90%	-2	351	9
H09	300	27%	870	79%	-17	311	49
H10	4	1%	370	60%	-19	5	5
H11	34	9%	320	94%	-12	337	23
H12	-	-	-	-	-19	359	1
H13	160	20%	500	81%	-14	342	18
H14	380	27%	520	59%	-19	359	1
H15	0	0%	580	47%	-19	312	48
H16	71	6%	200	21%	-29	342	18
H17	0	0%	630	56%	-29	337	23
H18	500	39%	860	82%	-14	352	8
H20	250	48%	490	98%	-6	295	65
H21	65	12%	410	84%	-19	35	35
H22	-	-	320	96%	-6	290	70
H23	0	0%	300	51%	-13	15	15
H24	29	4%	160	28%	-24	265	95
H25	5	2%	85	32%	-35	30	30
H26	360	25%	550	65%	-29	335	25
H27	-	-	-	-	-15	338	22
H28	260	30%	750	97%	-17	336	24
H29	-	-	-	-	-23	325	35
H30	47	4%	470	53%	-11	290	70
H31	0	0%	440	77%	-27	290	70
H32	0	0%	680	99%	-5	322	38
H33	0	0%	770	88%	-12	288	72
H34	0	0%	800	67%	-24	323	37
H35	110	11%	450	61%	-29	288	72
H36	-	-	240	44%	na	na	na
H37	-	-	-540	-160%	na	na	na
H38	-	-	300	57%	na	na	na
H39	-	-	360	54%	na	na	na

The solar altitude angle is the angle between the horizontal and a line to the sun. In summer the sun is high in the sky and the solar altitude angle is greater that the site latitude. In winter the sun is low in the sky and is below the site latitude. An existing 'rule-of-thumb' for the installation of SWH systems is to install the collectors at an angle equal to the latitude of the site. In practice, many SWH systems are installed with the solar collector parallel to the roof line of the building.

The solar energy fraction is compared with the angle[9] at which the solar collector is installed at for both winter and summer in Figure 19 and Figure 20 respectively. While both of these plots have much scatter, there is a general trend of increasing solar utilisation with increasing collector angle.

The summer time performance of the systems is quite varied. No system that was installed with a collector inclination angle lower than 20° less than the site latitude had a solar fraction of greater than 80%.

In winter over half of the systems did not achieve a solar fraction of more than 10%. The trend of increasing solar fraction with collector angle can also be seen in this graph. However, there is a system (H26) which achieves a 25% solar fraction despite being installed at an inclination angle 29° below the latitude of the site which masks the effect. This system had a well-specified timer control operating so that its winter time performance is much better than what it would have otherwise been. With the exception of H26, no other system with a collector installation angle lower than 20° less than the latitude had a solar fraction greater than 12%.

Winter time performance of SWH systems is important. Water heating energy may be higher in winter due to a greater heat loss from the cylinder due to lower ambient temperatures, more energy required to heat the colder water and possibly a greater use of hot water for winter comfort. In order to improve the winter time performance of the SWH system, the angle at which the SWH collector is installed at needs to be steep. The common practice of installing the collector at the roof angle may not be sufficient to ensure good winter time performance.

NIWA have also commented (Liley et al 2005) that solar collectors may work better if installed at an angle greater than the site latitude.

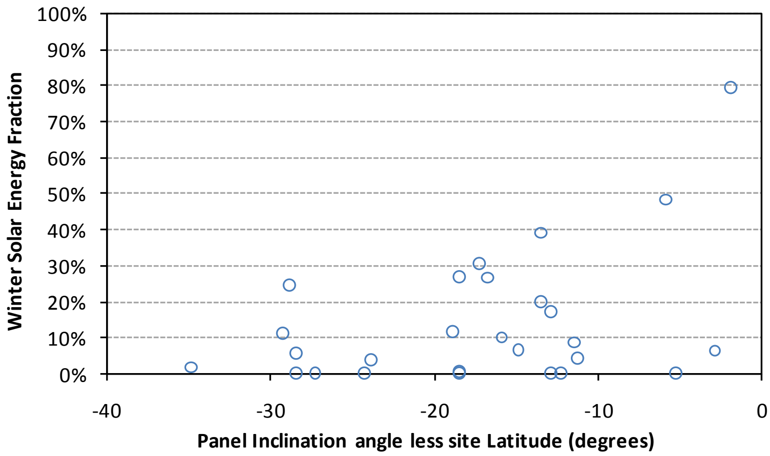


Figure 19. Winter time solar energy fraction by panel aspect

[9] The angle shown is the excess of the collector inclination angle to the latitude of the site. As all the collectors had an inclination angle less than the latitude angle, this number was always negative. The further to the right of the graph the system is, the steeper the collector.

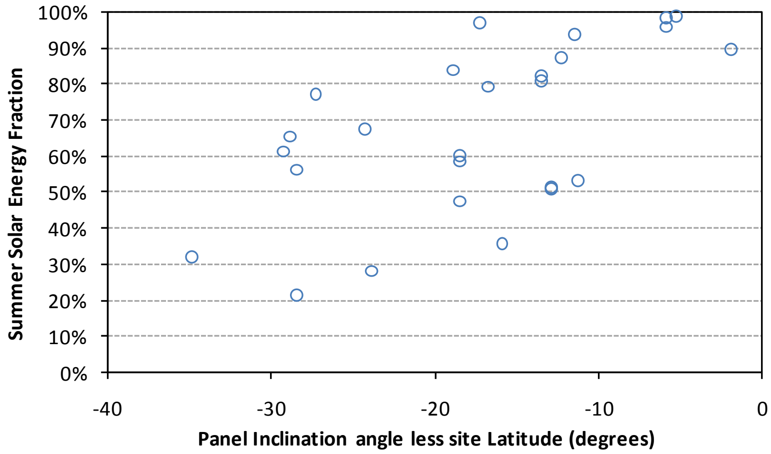


Figure 20. Summer time solar energy fraction by panel aspect

6. ELECTRICITY SUPPLIER RECORDS

Electricity supply records provide a ready source of data on household electricity usage. However it is not typical to meter water heating separately in New Zealand with most electricity usage data only recording the total electricity used for that particular site.

This section examines electricity supply records from the SWH sample houses to determine if useful information can generally be extracted from the electricity usage data before and after the installation of the SWH system.

6.1 Potential savings

As electricity supply records do not separately record hot water usage, it is difficult to determine targets for electricity savings for an individual house, instead less accurate information on the average proportion of water heating electricity usage to the total electricity usage needs to be used.

The HEEP Year 10 report (Isaacs et al 2006) states that average annual hot water electricity usage is 2440 kWh per year or 31% of the average 7800 kWh overall household electricity usage.

The SWH guidebook from EECA (2006) suggests that an effective and well-installed SWH system can reduce the electricity consumption for water heating from between 50% and 75% over the course of a year.

Combining these two estimates gives an expectation that an effective and well-installed SWH hot water system may reduce overall household consumption in an average household by between 15% and 23%. However, the level of savings achieved will depend on how much electricity the household actually uses for water heating and what other changes to the household electricity use have occurred within the household.

6.2 Electricity supplier records

The sample householders with SWH systems were asked to provide details of their electricity provider, their current supplier and any previous electricity suppliers they may have had in the last 5 years. Of these 35 households, two of them could not be linked back to an electricity supplier records. One had sold the house and no longer had any electricity records for the property; the other household did not wish to provide authorisation.

From the 33 remaining households, electricity use records were provided by Contact Energy, Genesis Energy, Mercury Energy, Energy Online, Empower, Meridian Energy and Trustpower.

Electricity usage records for 10 of the households had a period of less than one year of data before the date of the SWH installation. Reasons for this included that the house was a new construction and no previous household electricity usage had occurred, and that the SWH system was installed shortly after the purchase or rental of the house so that previous electricity usage was for a different set of occupants.

6.3 Estimate and actual electricity readings

The electricity supplier records frequently contained both estimated meter readings as well as actual meter readings. The estimated meter readings were removed from the analysis as their reliability could not be assessed. Meter readings were frequently carried out on a read one month and estimate the next month basis so that it was usual to have two months between actual meter readings.

Figure 21 shows a graph for each of the 33 households for which meter readings were obtained, as well as the date of when the SWH was installed (the red line) and the date of the first meter reading (the green dot). The exact date of the SWH system installation was not always known, with sometimes just the month identified. In such cases, the date was assumed to be the 15th of that month. One household had their SWH system installed in June 2004, 23 in 2005, and the remaining nine systems between January and September 2006.

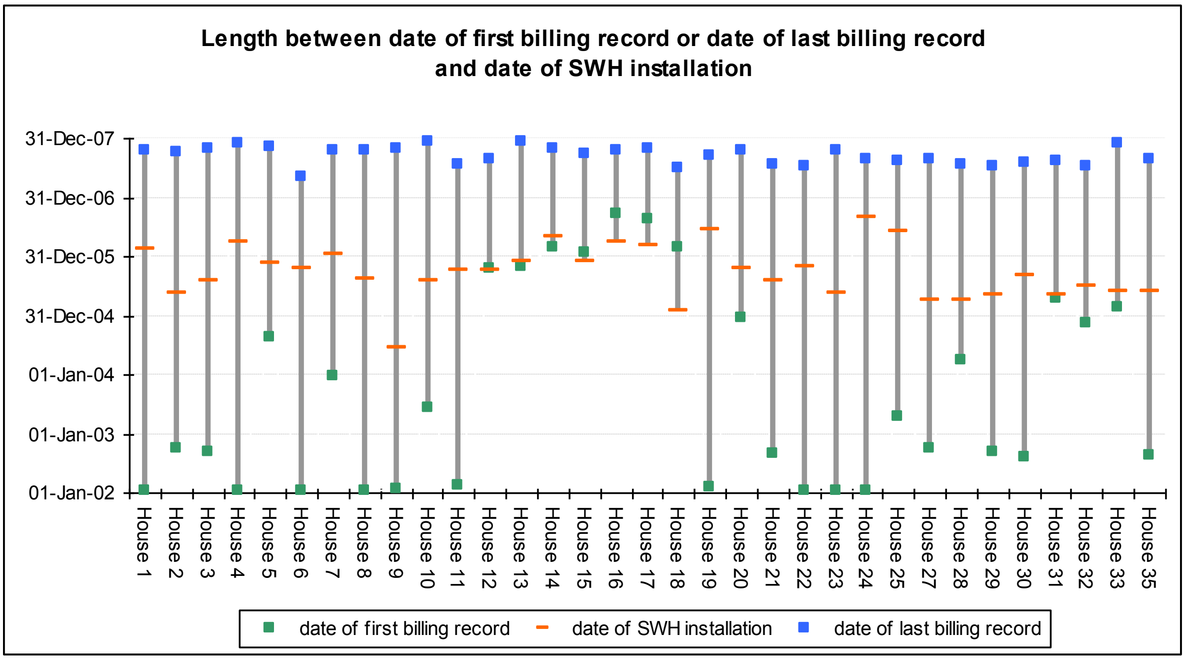


Figure 21. Length between date of first available billing record or date of last available billing record and date of SWH installation

6.4 Impact of SWH installation on household electricity use

As the savings a SWH system provides are seasonal, the SWH systems were compared by considering a period of one year before the installation of the system against one year after.

The installation of the SWH systems are frequently accompanied with other changes to the household such as energy efficiency upgrades and these will also have an impact on the total electricity usage of the household. As the one year period before and after the change is quite long, it is also likely that other unrelated changes that impact on the total electricity usage of each household may have also taken place.

Some of the reasons why the sampled households used more electricity after the installation were reported informally, such as one house was unoccupied four months prior to the SWH installation as part of a major renovation and another household reported that a new baby was born just after the SWH system had been installed.

It is unknown what extent these changes will impact on the total electricity usage of the household. Unless the changes other than the installation of the SWH system are small, recording the nature of the changes would only be useful where a comprehensive list of changes is considered and that a sufficiently large sample size is used.

The approach used for this report was to examine whether the other changes in total household use could be disregarded given the large proportion water heating makes to the total electricity usage and the large potential for SWH systems to reduce that electricity demand

Figure 22 and Table 8 provide comparisons of the absolute and relative changes in electricity use before and after the SWH installation. Overall, the average absolute change was a saving of 1220 kWh per year or an average of 12% savings in total electricity usage.

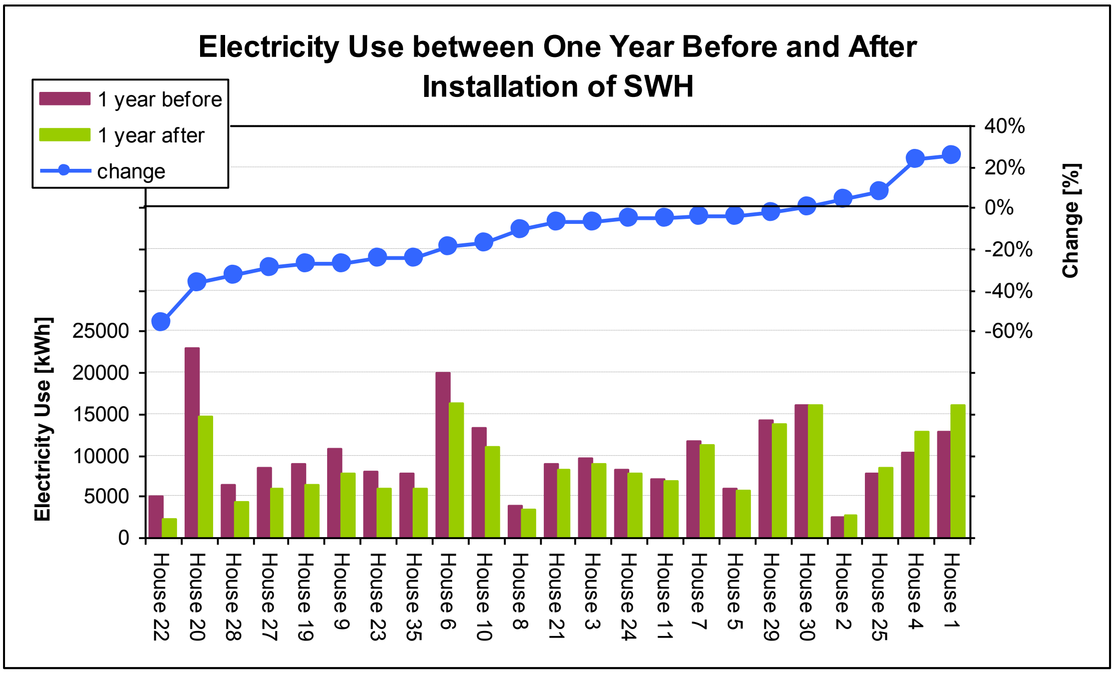


Figure 22. Electricity use between one year before and after SWH installation

Table 8. Electricity consumption comparison for one year before and after the installation (data to 3 significant figures)

Surveyed House	One year before (kWh)	One year after (kWh)	Change (kWh)	Change (percent)
H22	5060	2220	-2840	-56%
H20	23000	14700	-8280	-36%
H28	6450	4350	-2100	-33%
H27	8470	6000	-2460	-29%
H19	8910	6470	-2440	-27%
H09	10900	7940	-2930	-27%
H23	7970	6030	-1950	-24%
H35	7920	6020	-1910	-24%
H06	20100	16200	-3860	-19%
H10	13400	11100	-2280	-17%
H08	3860	3450	-409	-11%
H21	9000	8340	-662	-7%
H03	9630	8920	-703	-7%
H24	8350	7910	-439	-5%
H11	7250	6880	-369	-5%
H07	11800	11300	-515	-4%
H05	6020	5760	-260	-4%
H29	14200	13900	-310	-2%
H30	16100	16200	108	1%
H02	2620	2720	95	4%
H25	7900	8520	617	8%
H04	10400	12900	2430	23%
H01	12800	16000	3240	25%

Seventy-eight percent of the households had electricity savings after the SWH was installed, with 43% having a percentage saving higher than the 15% saving level discussed in Section 6.1. The largest relative savings in total household electricity was over 56%, with the largest absolute savings over 8280 kWh. At the other end of the scale, two systems had an increase of over 23% in their household electricity use or over 2420 kWh in absolute terms.

Graphs of each individual household's electricity usage, as well as their usage one year before and one year after the SWH installation, are provided in Appendix B.

If the change of electricity usage is largely as a result of the SWH installation, then it might be expected that the amount of solar energy captured (i.e. the renewable energy figure from Table 4) would be comparable to the change of electricity usage that was seen in Table 8.

Figure 23 plots the renewable energy captured for each of the systems against the change of electricity use before and after the SWH system installation. Also shown in Figure 23 is a red line, indicating a full utilisation of renewable energy. Systems that are above this line have savings in household electricity less than that provided by the SWH system, whereas systems that are below this curve achieved greater savings in electricity usage than might be expected from the renewable energy sourced by the SWH system alone.

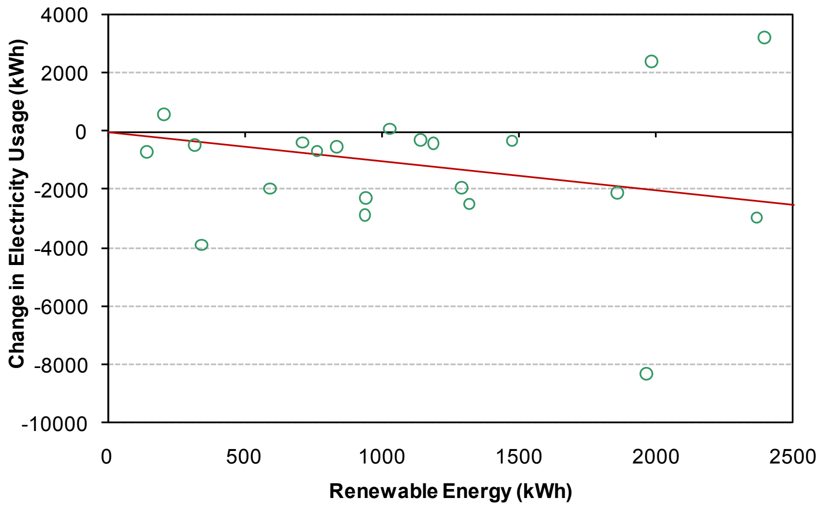


Figure 23. Amount of renewable energy and the change in household electricity use

The amount of scatter in Figure 23 is large, and it is likely that there are changes other than the SWH installation that are impacting on the amount of electricity used by the household.

Electricity supply records would have to be interpreted cautiously if used to examine the effectiveness of SWH systems. Much more detailed information on the nature of changes taking place in the household should be collected. The electricity supply records would be enriched considerably if the electricity supply companies were required to separately meter the SWH supplementary heating.

Electricity supplier record analysis has been undertaken by Guthrie et al (2005) in Victoria, Australia for 31 systems. Unlike New Zealand, hot water systems in Australia are directly metered with the systems being connected to off-peak electricity. Overall, savings in water heating energy use from the study by Guthrie et al (2005) averaged 54%.

7. INDIVIDUAL SYSTEMS CHARACTERISTICS

This section provides a brief commentary on the monitoring of individual systems, exploring any unusual characteristics of individual systems.

For each of the systems a table similar to Table 9 summarising the relevant data for each system is presented. The **New** field indicates if a new cylinder was installed as part of the installation of the SWH system so that a no indicates that the cylinder was not replaced. The **Time Control** and **Seasonal Operation** fields were determined by examining the data to see the use timers or seasonal switching off of the supplementary heating was evident.

Table 9 Example of the data presented for each system

House Identifier	H01			**Technology**	Pumped Evacuated Tube		
No. of Occupants	5			**Hot water use**	290 Litres per day		
Cylinder							
Size	300 Litres	**New**	yes	**Grade**	A	**Wetback**	no
Collector							
Area	1.5 m^2	**Direction**	38°	**Inclination angle less latitude**	-13°		
Control							
Time Control	no			**Seasonal Operation**	no		
Performance							
Renewable Energy	2400 kWh			**Renew. Fraction**	31%		
System Losses	1600 kWh			**COP**	1.1		

Table 10 provides a summary table of the technologies and operation for each the systems and should be read alongside the performance information shown in Table 4 as well as Table 7 which gives, along with the seasonal performance, the collector inclination angle and direction for each of the monitored systems.

Table 10. System characteristics for the monitored systems

System	Technology	Collector Area (m^2)	Cylinder Size (L)	Cylinder New?	Cylinder Grade	No. of occupants	Water Usage (L/Day)	Timer	User control
H01	Pumped Evacuated Tube	1.5	300	yes	A	5	290	no	no
H03	Pumped Evacuated Tube	1.5	180	no	B	2	67	no	no
H04	Pumped Flat Plate	1.8	160	no	A	3	162	no	no
H05	Pumped Flat Plate	1.9	180	no	A	2	35	no	yes
H06	Pumped Flat Plate	1.9	300	yes	A	5	238	no	no
H07	Pumped Flat Plate	2.9	180	yes	B	2	229	no	no
H08	Pumped Flat Plate	2.9	250	yes	A	3	52	no	yes
H09	Thermosiphon Flat Plate	3.8	330	yes	A	4	218	no	no
H10	Pumped Evacuated Tube	1.5	250	no	B	4	127	yes	no
H11	Pumped Evacuated Tube	1.0	180	no	B	1	35	no	yes
H12	Pumped Evacuated Tube	1.5	270	yes	A	4	154	no	no
H13	Pumped Flat Plate	3.2	270	no	A	2	98	yes	no
H14	Pumped Flat Plate	4.8	300	no	A	3	177	yes	no
H15	Pumped Flat Plate	3.2	280	no	A	4	217	no	no
H16	Thermosiphon Flat Plate	3.6	300	yes	A	4	139	no	no
H17	Thermosiphon Flat Plate	3.7	300	yes	A	6	223	no	no
H18	Thermosiphon Flat Plate	3.6	300	yes	A	3	185	yes	no
H20	Pumped Evacuated Tube	2.4	300	yes	A	5	114	no	no
H21	Pumped Evacuated Tube	1.6	200	yes	A	2	56	no	no
H22	Pumped Evacuated Tube	1.6	200	yes	A	2	52	no	yes
H23	Pumped Flat Plate	2.3	180	no	B	2	63	yes	no
H24	Thermosiphon Flat Plate	3.7	180	no	A	2	87	no	no
H25	Thermosiphon Flat Plate	1.8	180	no	B	2	39	no	no
H26	Thermosiphon Flat Plate	3.6	305	no	A	4	214	yes	no
H27	Pumped Evacuated Tube	2.4	180	yes	A	2	97	no	no
H28	Pumped Evacuated Tube	2.4	270	yes	A	4	131	no	no
H29	Pumped Evacuated Tube	1.5	180	yes	A	3	173	no	no
H30	Pumped Flat Plate	3.8	315	yes	A	6	201	no	no
H31	Pumped Flat Plate	3.8	220	yes	A	3	89	no	no
H32	Pumped Flat Plate	5.7	320	yes	A	5	104	no	yes
H33	Thermosiphon Flat Plate	3.7	320	yes	A	4	160	no	no
H34	Thermosiphon Flat Plate	3.7	320	yes	A	na	231	no	no
H35	Thermosiphon Flat Plate	3.7	320	yes	A	2	129	yes	no
H36	Air to Water Heat Pump	na	300*	yes	A	na	123	no	no
H37	Air to Water Heat Pump	na	300*	yes	A	na	44	no	no
H38	Air to Water Heat Pump	na	300*	yes	A	na	70	no	no
H39	Air to Water Heat Pump	na	300*	yes	A	na	151	yes	no

* The size for the air to water heat pump systems is approximate only

7.1 System H01

House Identifier	H01	**Technology**	Pumped Evacuated Tube
No. of Occupants	5	**Hot water use**	290 Litres per day

Cylinder

Size	300 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector

Area	1.5 m^2	**Direction**	38°	**Inclination angle less latitude**	-13°

Control

Time Control	no	**Seasonal Operation**	no

Performance

Renewable Energy	2400 kWh	**Renew. Fraction**	31%
System Losses	1600 kWh	**COP**	1.1

System H01 is a closed pump system and stands out from other systems due to the large amount of energy and water drawn-off from the system. Five occupants are usually present in the household. The cylinder is a large 300 L one with the temperature of the draw-off water kept regularly at 65°C.

Figure 24 provides a time-series graph of the quantity of water drawn-off from the cylinder and shows an increase in water draw-off from about March until winter. While some of this increase may have been seasonal (greater showering in winter), when the monitoring equipment was removed a leak was detected around the cylinder.

This system provided a good level of solar energy collection (2400 kWh). However, the solar fraction was lower than it otherwise would have been due to the increased draw-off energy increasing the total water heating energy.

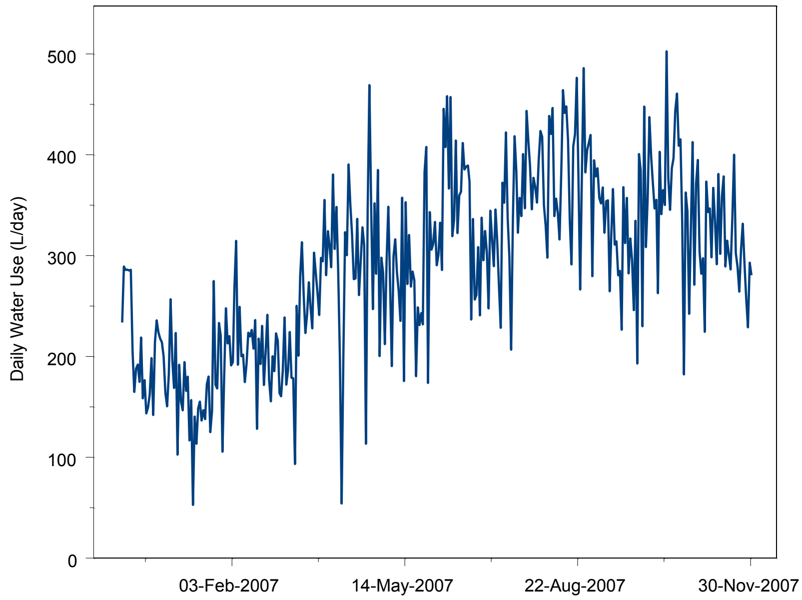


Figure 24. Quantity of the water drawn-off from the cylinder at H01

7.2 System H02

System H02 was not included in the monitoring results due to the water meter being mis-positioned at the time of installation so that it also registered water flowing to the collectors along with the water flow into the cylinder. This system also had a wetback connection resulting in a complicated plumbing arrangement leading into the cylinder.

7.3 System H03

House Identifier	H03			**Technology**	Pumped Evacuated Tube		
No. of Occupants	2			**Hot water use**	67 Litres per day		
Cylinder							
Size	180 Litres	**New**	no	**Grade**	B	**Wetback**	no
Collector							
Area	1.5 m^2	**Direction**	295°	**Inclination angle less latitude**	-17°		
Control							
Time Control	no			**Seasonal Operation**	no		
Performance							
Renewable Energy	140 kWh			**Renew. Fraction**	7%		
System Losses	854 kWh			**COP**	0.6		

System H03 did not operate correctly and was a particularly awkward system to monitor. This system was not included in the calculations of overall performance in this report.

The collector was directly connected to the existing cylinder in an open system arrangement so that water from the cylinder was directly circulated through the collector. The existing B-grade cylinder was located in the roof space of the house making the installation of thermocouple wiring and other monitoring equipment difficult. Cabling from the sensors was run through the roof space and down into loggers placed alongside the circulation pump controller in a hallway cupboard.

From an analysis of the monitored data, the circulation pump was constantly being recorded as zero. It was thought that there was a fault in the monitoring wiring connecting the circulation pump to the logger. However, after the roof space monitoring wiring was checked the zero data continued.

At the time of removal of the monitoring equipment it was discovered that the circulation pump controller was displaying 888.8°C for the collector temperature. This 888.8°C is the error code the circulation pump controller displays when it cannot determine the temperature from the sensor. There was a fault in the wiring, but it was not in the monitoring wiring but in the system wiring. As the controller could not determine the collector temperature, the circulation pump did not operate and therefore the zero values for the circulation pump was valid data. During the removal of the monitoring equipment, the sensor wiring was repaired.

It was unknown when this fault occurred. From an examination of the billing records (see Appendix B) there is no large change in overall electricity demand at any point, suggesting it could have been present soon after the installation.

An important point here is that the controller unit was in error, but that this was not effectively communicated to the occupants. The location of the controller inside a hallway cupboard did not encourage the occupants to monitor the unit. Had there been an audible alarm on the controller, which is difficult to ignore, then the fault with the system may have been identified earlier.

The collector for this system was an array of evacuated tubes which have a high stagnation temperature. Given that the water in the evacuated tubes was not being pumped to the cylinder (some natural flow may have occurred), the water in the collectors may have reached high temperatures when there were high levels of solar radiation. The inspection of the pipe insulation alongside the collector revealed perishing of the insulation.

7.4 System H04

House Identifier	H04			**Technology**	Pumped Flat Plate		
No. of Occupants	3			**Hot water use**	162 Litres per day		
Cylinder							
Size	160 Litres	**New**	no	**Grade**	A	**Wetback**	no
Collector							
Area	1.8 m^2	**Direction**	328°	**Inclination angle less latitude**	-16°		
Control							
Time Control	no			**Seasonal Operation**	no		
Performance							
Renewable Energy	1770 kWh			**Renew. Fraction**	20%		
System Losses	6427 kWh			**COP**	0.3		

System H04 appears as an outlier in a number of graphs, with the system harvesting a good amount of solar radiation but experiencing excessive heat losses. The system comprised of a solar collector retrofitted to a small 160 L externally mounted valve-vented cylinder. The height difference between the cylinder and the collector was large due to the single-storey house being on a sloping section requiring a sizable sub-space where the cylinder was located.

The reason for the excessive heat losses is that the system was undergoing back (thermosiphon) circulation at night.

Figure 26 is a schematic diagram of the day-time operation of the pumped solar system. Cold water from the bottom of the cylinder is pumped up to the collector where it is heated and then pumped back down to the top of the cylinder. The circulation pump operates when the temperature of the water in the collector is hot relative to the cylinder.

At night-time, or when there are not sufficient solar gains to heat the water in the collector, the circulation pump will not operate which it is assumed makes the collector loop redundant. Unfortunately for this system, thermosiphon processes occur at night creating back circulation flow through the collector loop (see Figure 27). Hot water from the top of the hot water cylinder travels upwards to the solar collector where it loses heat to the environment causing it to cool down and sink along the ‘feed’ to the solar collector. Then the water pushes past the circulation pump to return to the cylinder where it is heated, reinforcing the circulation.

The connection between the collector loop and the hot water cylinder is important (see p253, Morrison 2001). To reduce the tendency of the system to start back circulation, it is recommended to not return the water from the heat source (collector) directly to the top of the cylinder (p52, Williamson and Clark 2001).

A heat trap (an uninsulated dip in piping) may offer some protection against back circulation. Alternatively the cold 'feed' to the solar panel could be placed alongside the solar 'return' to act as a low-grade heat exchanger (see Figure 25). This arrangement has the advantage that the heat lost from the solar 'return' is captured by the cold 'feed' to the solar collector retaining the heat within the system (Cox-Smith 2008).

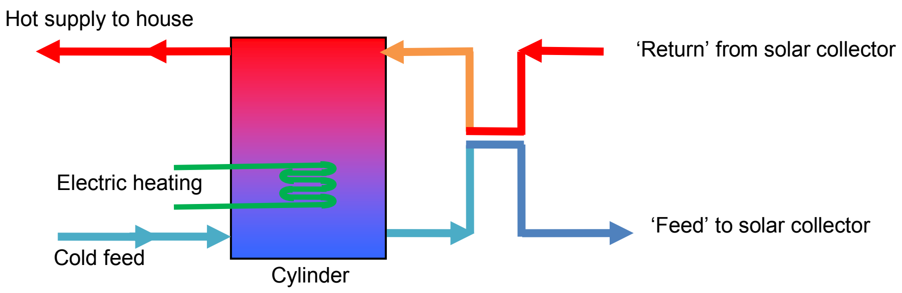


Figure 25. Pipe arrangement to avoid back circulation at night

A non-return valve may offer some protection against back circulation, but these devices are not generally manufactured to prevent backflow under static conditions. As there is no significant pressure on the valve mechanism, any poorly aligned mechanism or small amount of debris caught within the mechanism will allow reverse flow to occur (Clark 2007).

Figure 28 provides a graph of the temperatures of the system, as well as the operation of the supplementary heating and the circulation pump over the course of one day. The supplementary heating can be seen to be coming on frequently during the night, influencing the temperatures in the bottom of the cylinder as indicated by the varying cold inlet temperatures. Overnight the temperatures in the solar 'return' are in the low 40's. During the day this solar 'return' temperature rises when the circulation pump is in operation.

Figure 29 and Figure 30 provide graphs of the same measurements on the system on the day the system was modified to reduce back circulation and on a few days after that. The solar 'return' temperature can be seen to be a key parameter, and after the repair drops back down to approximately ambient temperatures outside of the time the circulation pump is operating. After the repair the supplementary heating is on much less frequently.

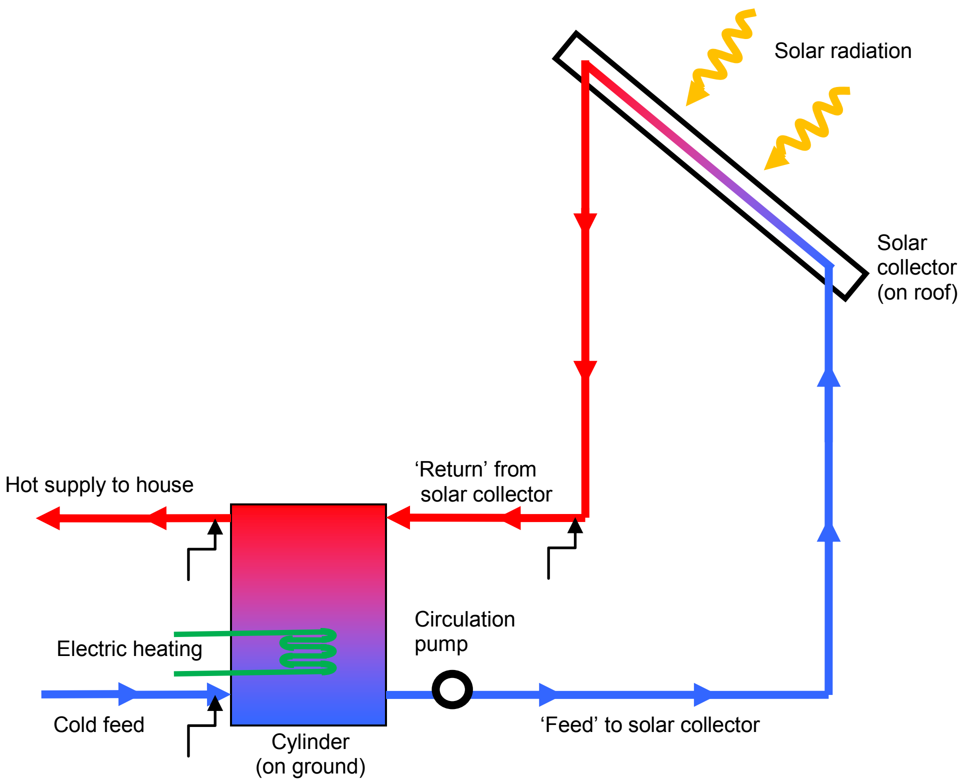


Figure 26. Normal day-time operation (pumped circulation)

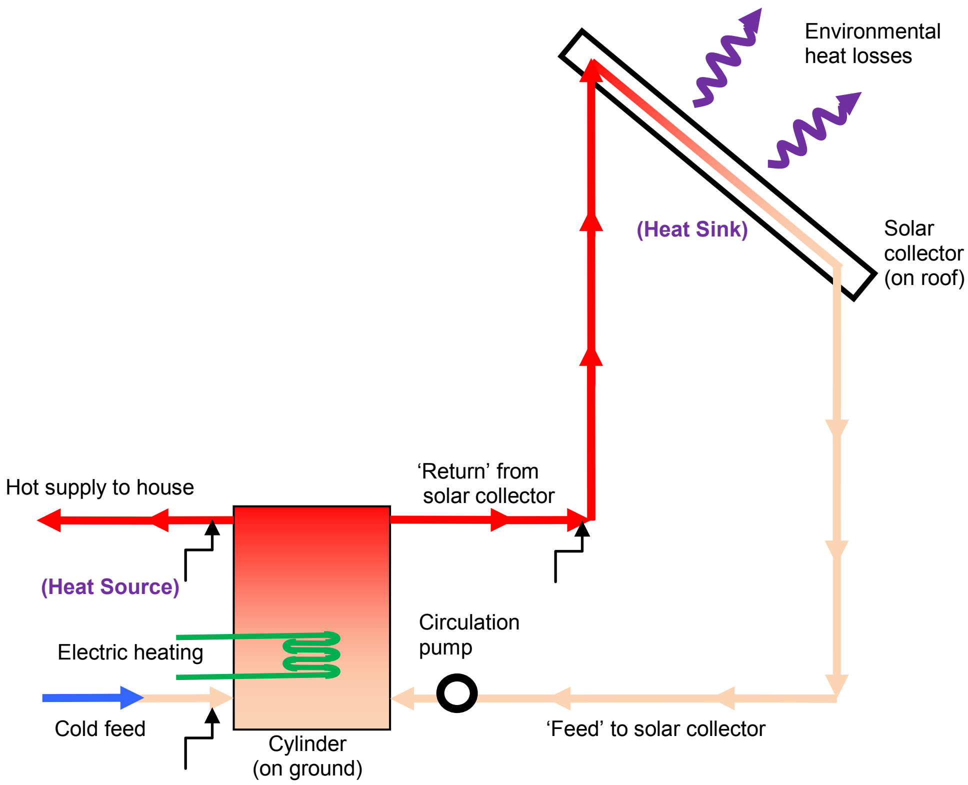


Figure 27. Night-time back circulation (thermosiphon circulation)

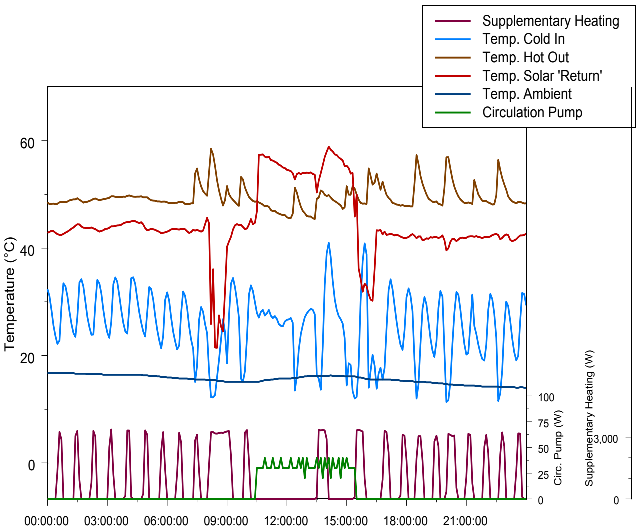


Figure 28. Operation of the system before repair

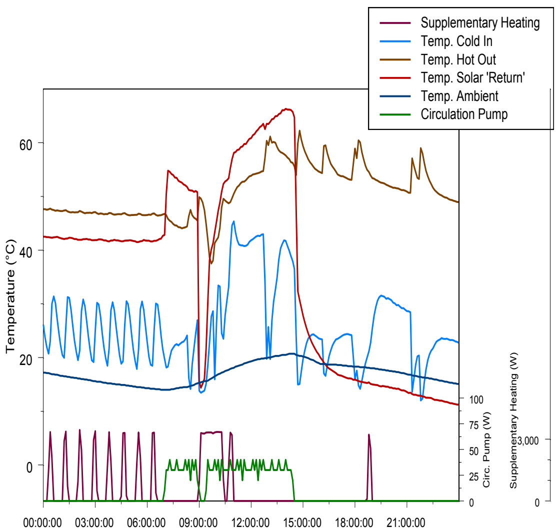


Figure 29. Operation on the day of repair

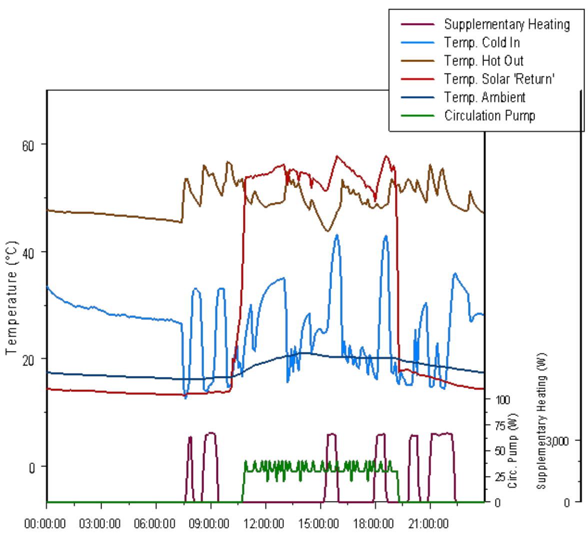


Figure 30. Operation of the system after repair

7.5 System H05

House Identifier	H05	**Technology**	Pumped Flat Plate
No. of Occupants	2	**Hot water use**	35 Litres per day

Cylinder

Size	180 Litres	**New**	no	**Grade**	A	**Wetback**	yes

Collector

Area	1.9 m^2	**Direction**	1°	**Inclination angle less latitude**	-4°

Control

Time Control	no	**Seasonal Operation**	yes

Performance

Renewable Energy	1140 kWh	**Renew. Fraction**	39%
System Losses	2166 kWh	**COP**	0.3

System H05 is a low-water-using household with an average water draw-off of 35 L per day. It has a 180 L cylinder and is a pumped system. In addition to the solar collectors, heat into the cylinder is provided by a wetback connection. The supplementary heating appears to be turned off for part of the summer. The heat losses for the system, given the small size of the cylinder, are high and it was necessary to use the zero solar contribution method to determine these losses.

In looking to examine a reason for the high heat losses of the system, the time when the pump was operated was examined. A graph of the use of the circulation pump by time of day (midnight at left and right of graph with midday in the middle) for each day of the monitored year is shown in Figure 31. Shading indicates that the pump was operating at that date and time with no shading indicating that the pump was not running. The pump seems to be operating excessively. The top quarter of the graph represents the summer months and it can be seen that there is frequent shading on the left hand side of the graph representing the early hours of the morning as well as shading on the right for the late evening. The pump therefore appears to be operating when the sun is not shining and presumably losing heat to the environment at that time. The pump can also be seen to be continually operating for approximately two weeks at the start of September.

As this extended pump operation is occurring over summer, it will not be forced circulation for frost protection (the system is in the Auckland region). The arrangement of the wetback is unknown and it may be that back circulation similar to System H04, is occurring with the wetback acting as a heat sink during the unused summer months. Other possible reasons for the faulty operation could be due to a faulty controller, temperature sensors or circulation pump.

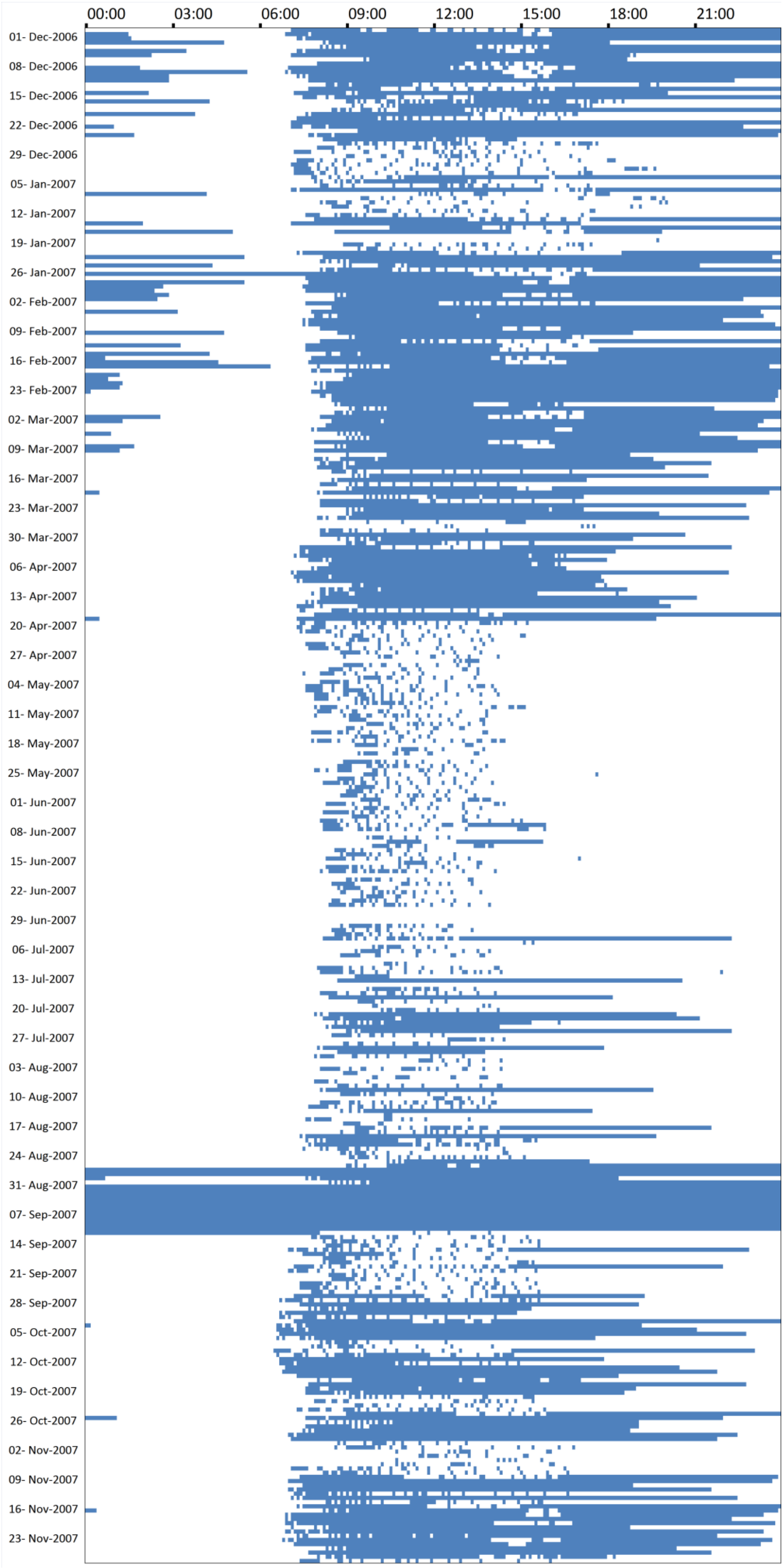


Figure 31. Operation of the pump by time of day (in blocks of six minutes) and day of year (blue indicates pump operating)

7.6 System H06

House Identifier	H06	**Technology**	Pumped Flat Plate
No. of Occupants	5	**Hot water use**	238 Litres per day

Cylinder							
Size	300 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector					
Area	1.9 m^2	**Direction**	3°	**Inclination angle less latitude**	-3°

Control			
Time Control	no	**Seasonal Operation**	no

Performance			
Renewable Energy	340 kWh	**Renew. Fraction**	7%
System Losses	1187 kWh	**COP**	0.8

System H06 had a change of occupants with the property being unoccupied and then rented out in May 2007. The data for the initial period of occupancy was too short to analyse so no summer time performance for the system could be established. The new tenants had a high water use (238 L per day) with the renewable energy sourced by the system being low.

7.7 System H07

House Identifier	H07	**Technology**	Pumped Flat Plate
No. of Occupants	2	**Hot water use**	229 Litres per day

Cylinder							
Size	180 Litres	**New**	yes	**Grade**	B	**Wetback**	no

Collector					
Area	2.9 m^2	**Direction**	41°	**Inclination angle less latitude**	-15°

Control			
Time Control	no	**Seasonal Operation**	no

Performance			
Renewable Energy	840 kWh	**Renew. Fraction**	19%
System Losses	909 kWh	**COP**	1.0

System H07 was a retrofitted system with the existing cylinder being a 180 L B-grade cylinder. The system had a high water use (229 L per day) and sourced a modest amount of energy from the sun.

7.8 System H08

House Identifier	H08	Technology	Pumped Flat Plate
No. of Occupants	3	Hot water use	52 Litres per day

Cylinder							
Size	250 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector					
Area	2.9 m^2	**Direction**	351°	**Inclination angle less latitude**	-2°

Control			
Time Control	no	**Seasonal Operation**	yes

Performance			
Renewable Energy	1190 kWh	**Renew. Fraction**	86%
System Losses	500 kWh	**COP**	3.9

This low usage household used on average 52 L of hot water per day and just 53 kWh of supplementary water heating over the year, with the occupants manually turning the cylinder off except for occasional times over the winter. This system was very dynamic with the system temperatures tending to follow ambient conditions. With the system only being rarely heated from the supplementary water heating, the methods of calculating the standing losses which assume static conditions did not work. The standing loss estimate of 500 kWh per year was established by estimating the heat losses from the hot water cylinder (by taking the measured temperatures, known geometry of the cylinder and the R-value of the insulation material) as 400 kWh per year and allowing an additional 100 kWh for piping and other component energy losses.

This resulted in the System H08 household having the highest percentage of renewable energy as a fraction of total water heating of 86%.

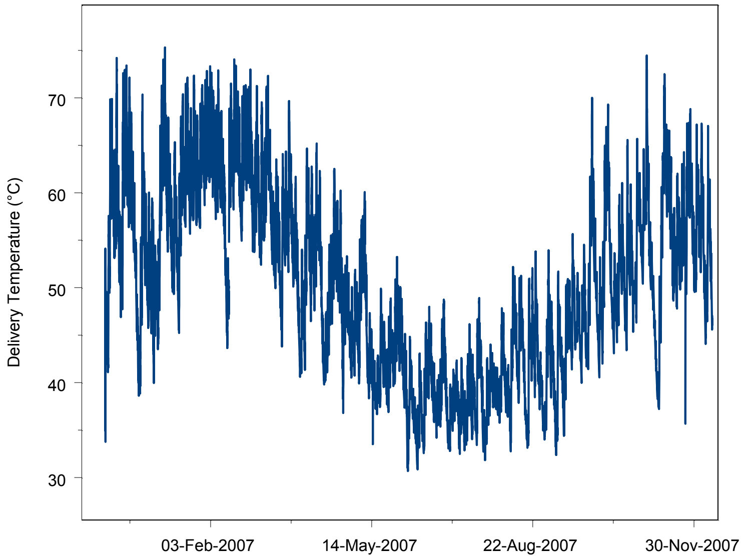


Figure 32. Time-series of the delivered cylinder temperatures for System H08

As supplementary heating was only rarely applied, the resulting system temperatures were low. Figure 32 provides a plot of the cylinder delivery temperatures. Only those temperatures when water was being drawn-off are shown on this diagram. It can be seen that from the start of May until the end of September the delivery temperatures did not reach the 60°C threshold regarded as appropriate for the control of Legionella.

7.9 System H09

House Identifier	H09	**Technology**	Thermosiphon Flat Plate
No. of Occupants	4	**Hot water use**	218 Litres per day

Cylinder

Size	330 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector

Area	3.8 m^2	**Direction**	311°	**Inclination angle less latitude**	-17°

Control

Time Control	no	**Seasonal Operation**	no

Performance

Renewable Energy	2370 kWh	**Renew. Fraction**	55%
System Losses	1746 kWh	**COP**	1.3

System H09 was a well-performing thermosiphon system with 2400 kWh of energy sourced from the sun. This system had an average hot water demand of 218 L per day and achieved a renewable energy fraction of 55%.

7.10 System H10

House Identifier	H10	**Technology**	Pumped Evacuated Tube
No. of Occupants	4	**Hot water use**	127 Litres per day

Cylinder

Size	250 Litres	**New**	no	**Grade**	B	**Wetback**	no

Collector

Area	1.5 m^2	**Direction**	5°	**Inclination angle less latitude**	-19°

Control

Time Control	yes	**Seasonal Operation**	no

Performance

Renewable Energy	940 kWh	**Renew. Fraction**	32%
System Losses	1065 kWh	**COP**	0.9

System H10 involved a retrofitted B-grade 250 L cylinder connected to a solar collector. The water draw-offs for H10 (see Figure 9) have pronounced morning spikes with little usage during the day or in the evening. The supplementary heating for H10 is controlled by a timer with heating occurring between 10 pm and 7 am.

The standing losses for the system were estimated from cylinder heating just before dawn.

The average profile of the supplementary heating can be seen in Figure 33. The element in the cylinder is approximately 3000 W, so it can be seen from the size of the peak at 10 pm that during the non-daylight savings time the element is coming on as soon as it is able about two-thirds of the time.

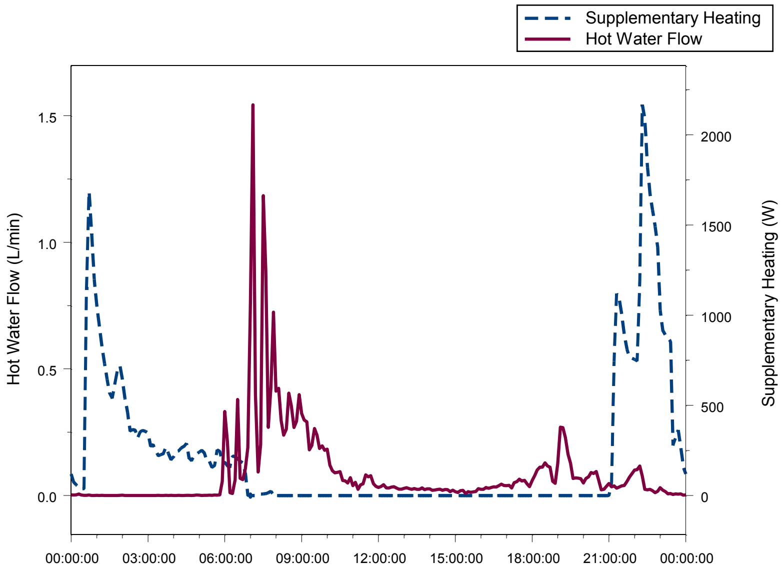


Figure 33. Average daily profile of hot water flow and supplementary heating for H10

The peak at 9pm is presumably due to summertime usage during daylight savings with the smaller peak indicating that the element is less likely to come on given the greater solar energy capture during the daylight savings period.

This system has very separate events: water draw-off in the morning, solar gains during the day and supplementary heating overnight.

As soon as a heat storage system heats up, heat losses will occur. To minimise the overnight supplementary heating, the solar heat gains made during the day need to be conserved as much as possible by providing a good level of insulation around the hot water cylinder.

Furthermore, the added heat input made at 10 pm drives further heat losses overnight. As hot water is not required until 7 am, it may be possible to set the timer to come on say three hours before. This will reduce the amount of overnight heat losses, but still provides time for the system to heat up if solar heat gains from the previous afternoon (and the insulation level of the cylinder) are not sufficient.

7.11 System H11

House Identifier	H11	**Technology**	Pumped Evacuated Tube
No. of Occupants	1	**Hot water use**	35 Litres per day

Cylinder

Size	180 Litres	**New**	no	**Grade**	B	**Wetback**	on

Collector

Area	1 m^2	**Direction**	337°	**Inclination angle less latitude**	-12°

Control

Time Control	no	**Seasonal Operation**	yes

Performance

Renewable Energy	710 kWh	**Renew. Fraction**	49%
System Losses	711 kWh	**COP**	0.9

The household using System H11 only required an average of 35 L of hot water per day. The system appears to have had the supplementary heating turned off during summer. The modest water needs were approximately evenly split by the solar contribution and the electrical supplementary heating component.

7.12 System H12

House Identifier	H12	**Technology**	Pumped Evacuated Tube
No. of Occupants	4	**Hot water use**	154 Litres per day

Cylinder

Size	270 Litres	**New**	yes	**Grade**	A	**Wetback**	yes

Collector

Area	1.5 m^2	**Direction**	359°	**Inclination angle less latitude**	-19°

Control

Use of Timer	no	**Seasonal Operation**	no

Performance

Renewable Energy	2400 kWh	**Renew. Fraction**	58%
System Losses	1165 kWh	**COP**	1.6

System H12 had a 270 L cylinder mounted horizontally on a mezzanine floor above a solid fuel burner which had a wetback connection into this cylinder. The solar and wetback together provided 58% of the household's water heating needs.

7.13 System H13

House Identifier	H13	**Technology**	Pumped Flat Plate
No. of Occupants	2	**Hot water use**	98 Litres per day

Cylinder

Size	270 Litres	**New**	no	**Grade**	A	**Wetback**	no

Collector

Area	3.2 m^2	**Direction**	342°	**Inclination angle less latitude**	-14°

Control

Time Control	yes	**Seasonal Operation**	no

Performance

Renewable Energy	1340 kWh	**Renew. Fraction**	49%
System Losses	1071 kWh	**COP**	1.2

System H13 was a well-performing system with modest needs. The supplementary heating was on a night-rate with 49% of the water heating needs provided by solar.

7.14 System H14

House Identifier	H14	**Technology**	Pumped Flat Plate
No. of Occupants	3	**Hot water use**	177 Litres per day

Cylinder

Size	300 Litres	**New**	no	**Grade**	A	**Wetback**	no

Collector

Area	4.8 m^2	**Direction**	359°	**Inclination angle less latitude**	-19°

Control

Time Control	yes	**Seasonal Operation**	no

Performance

Renewable Energy	1900 kWh	**Renew. Fraction**	43%
System Losses	1040 kWh	**COP**	1.3

System H14 provided for an average of 177 L of hot water draw-off each day with solar contributing 43% of the water heating energy. This system was also only able to use supplementary heating overnight.

7.15 System H15

House Identifier	H15			**Technology**	Pumped Flat Plate		
No. of Occupants	4			**Hot water use**	217 Litres per day		
Cylinder							
Size	280 Litres	**New**	no	**Grade**	A	**Wetback**	no
Collector							
Area	3.2 m^2	**Direction**	312°	**Inclination angle less latitude**	-19°		
Control							
Time Control	no			**Seasonal Operation**	no		
Performance							
Renewable Energy	1020 kWh			**Renew. Fraction**	19%		
System Losses	1446 kWh			**COP**	0.9		

Solar contributed 1020 kWh or 19% to the water heating of H15. The hot water use for H15 was high using an average of 217 L of water per day. A number of leaks were detected around the hot water cylinder and repairs made midway through the monitoring.

7.16 System H16

House Identifier	H16			**Technology**	Thermosiphon Flat Plate		
No. of Occupants	4			**Hot water use**	139 Litres per day		
Cylinder							
Size	300 Litres	**New**	yes	**Grade**	A	**Wetback**	no
Collector							
Area	3.6 m^2	**Direction**	342°	**Inclination angle less latitude**	-29°		
Control							
Time Control	no			**Seasonal Operation**	no		
Performance							
Renewable Energy	360 kWh			**Renew. Fraction**	8%		
System Losses	2218 kWh			**COP**	0.5		

System H16 was a poorly-performing thermosiphon system. The heat losses in the system were high and only 8% of the water heating energy came from solar. The water use for this household (shown in Figure 34) is different from many of the other systems in the study in that the hot water use largely occurs in the evenings.

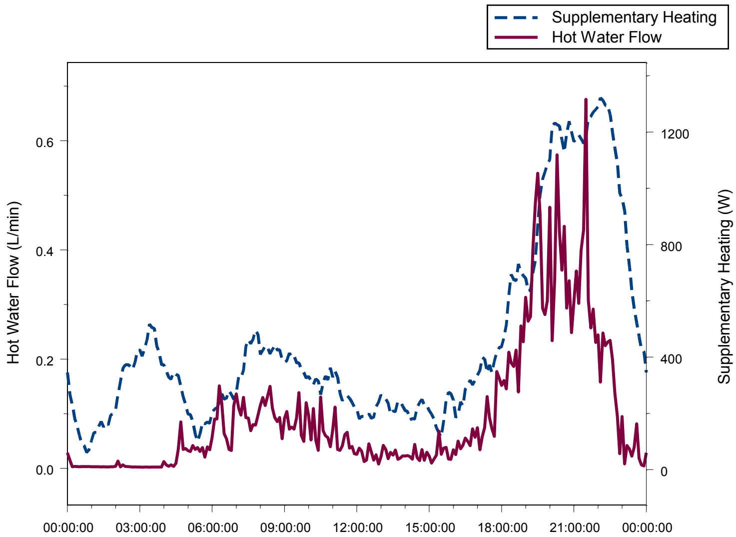


Figure 34. Average daily profile of hot water flow and supplementary heating for H16

The supplementary heating (also show in Figure 34) can also be seen to have a large evening peak slightly after the draw-off peak. This supplementary heating recovers the heat drawn-off by the occupants. By morning, the water temperature in the cylinder is at its temperature setpoint and the solar has little opportunity to contribute heat to the system.

Improvements could be made to the system by installing a timer to prevent the supplementary heating from operating late in the evening. Supplementary heating needs to operate three to four hours before the period of main hot water use in the mid to late afternoon and will contribute heat only when there hasn't been sufficient solar heating that day.

7.17 System H17

House Identifier	H17	**Technology**	Thermosiphon Flat Plate
No. of Occupants	6	**Hot water use**	223 Litres per day

Cylinder

Size	300 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector

Area	3.7 m^2	**Direction**	337°	**Inclination angle less latitude**	-29°

Control

Time Control	no	**Seasonal Operation**	no

Performance

Renewable Energy	1300 kWh	**Renew. Fraction**	26%
System Losses	1955 kWh	**COP**	0.8

The thermosiphon system H17 has an average hot water usage of 223 L per day, having peaks in the evening and the morning. The supplementary heating was uncontrolled and the solar contributes about 1300 kWh of energy (26%) to the water heating needs.

7.18 System H18

House Identifier	H18	Technology	Thermosiphon Flat Plate
No. of Occupants	3	Hot water use	185 Litres per day

Cylinder

Size	300 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector

Area	3.6 m^2	**Direction**	352°	**Inclination angle less latitude**	-14°

Control m

Time Control	yes	**Seasonal Operation**	no

Performance

Renewable Energy	2540 kWh	**Renew. Fraction**	61%
System Losses	1665 kWh	**COP**	1.5

The thermosiphon system H18 provides 2500 kWh of solar energy, contributing 61% of the household's water heating needs. The household's water use has a morning peak, but frequent usage during the day (see Figure 9). The supplementary heating is controlled by a timer which results in the average daily profile shown in Figure 35.

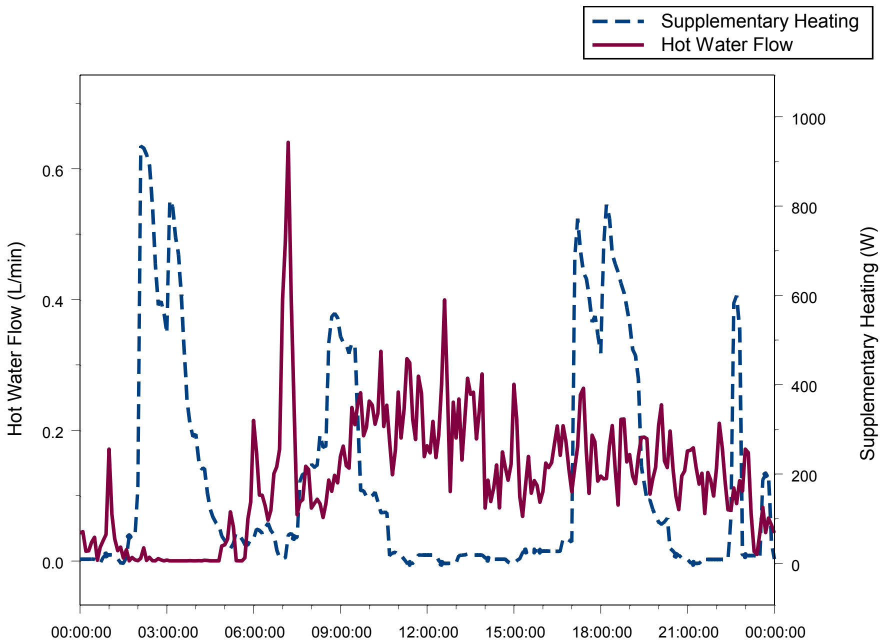


Figure 35. Average daily profile of hot water flow and supplementary heating for H18

7.19 System H19

The installation of the monitoring equipment at H19 did not proceed well and there were problems with the configuration at the start of the monitoring. These problems were further compounded with some of the data loggers failing to record a complete set of data. The data collected from H19 was unable to be analysed.

7.20 System H20

House Identifier	H20	**Technology**	Pumped Evacuated Tube
No. of Occupants	5	**Hot water use**	114 Litres per day

Cylinder							
Size	300 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector					
Area	2.4 m^2	**Direction**	295°	**Inclination angle less latitude**	-6°

Control			
Time Control	no	**Seasonal Operation**	no

Performance			
Renewable Energy	1370 kWh	**Renew. Fraction**	64%
System Losses	602 kWh	**COP**	1.9

System H20 comprised of a large 300 L cylinder with two heating elements, one in the top part and one in the bottom part of the cylinder. Only the top element was used. The temperature setpoint was low and consequently the heat losses from the system were low, estimated to 600 kWh per year. The average hot water use was 114 L with solar providing 72% of the water heating needs.

This house had large overall electricity savings after the SWH system was installed.

7.21 System H21

House Identifier	H21	**Technology**	Pumped Evacuated Tube
No. of Occupants	2	**Hot water use**	56 Litres per day

Cylinder							
Size	200 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector					
Area	1.6 m^2	**Direction**	35°	**Inclination angle less latitude**	-19°

Control			
Time Control	no	**Seasonal Operation**	no

Performance			
Renewable Energy	760 kWh	**Renew. Fraction**	37%
System Losses	1122 kWh	**COP**	0.7

The renewable energy proportion for H21 was 37%. The broad morning peak in water usage was matched with a peak in the supplementary heating and this system may benefit from a timer to exclude the supplementary heating from coming on in the mornings.

The pump controller for this unit was located in the living room (the cylinder was located in the garage below) so that it could be monitored by the occupants.

7.22 System H22

House Identifier	H22	**Technology**	Pumped Evacuated Tube
No. of Occupants	2	**Hot water use**	52 Litres per day

Cylinder							
Size	200 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector					
Area	1.6 m^2	**Direction**	290°	**Inclination angle less latitude**	-6°

Control			
Time Control	no	**Seasonal Operation**	yes

Performance			
Renewable Energy	940 kWh	**Renew. Fraction**	81%
System Losses	500 kWh	**COP**	2.8

The temperature setpoints for H22 were kept low (unfortunately there was a high amount of missing data) and the standing losses for the system (which included a 200 L cylinder) were estimated to be 500 kWh per year. The low water use (average 52 L per day) had a strong morning peak. The supplementary heating was rarely on (again data collection problems limited available data) using 180 kWh over the year. The renewable energy fraction was the second best for any system at 81%.

7.23 System H23

House Identifier	H23	**Technology**	Pumped Flat Plate
No. of Occupants	2	**Hot water use**	63 Litres per day

Cylinder							
Size	180 Litres	**New**	no	**Grade**	B	**Wetback**	no

Collector					
Area	2.3 m^2	**Direction**	15°	**Inclination angle less latitude**	-13°

Control			
Time Control	yes	**Seasonal Operation**	no

Performance			
Renewable Energy	590 kWh	**Renew. Fraction**	22%
System Losses	1288 kWh	**COP**	0.6

The water use at H23 had a strong morning peak however the overall usage had an average of only 63 L per day. The water temperatures for this system were set quite high (averaged over 65°C at delivery time), driving the heat losses from the system which included a 180 L B-grade cylinder. The cylinder was, however, surrounded with loose polyester blankets as a cylinder wrap. The cold feed to the cylinder was under the house and was very hot to touch, indicating a large amount of backflow from the hot water cylinder. The water meter measuring the flow into the system was placed in front of the header tank that fed the system. From the monitoring results it appears that the filling of the header tank may not have been fully responsive to the household's use of hot water. Small quantities of water that are drawn-off from the cylinder are replaced by water from the header tank. However, this tank may not fill from the cold supply due to the float valve in it not responding to the small change of level in the header tank.

The supplementary heating for H23 looks to be actively managed with the supplementary heating switched off during the day. The times when the supplementary system is switched back varies, but is frequently around 5 pm as can be seen in Figure 36. Overall solar provided 22% of H23's water heating needs.

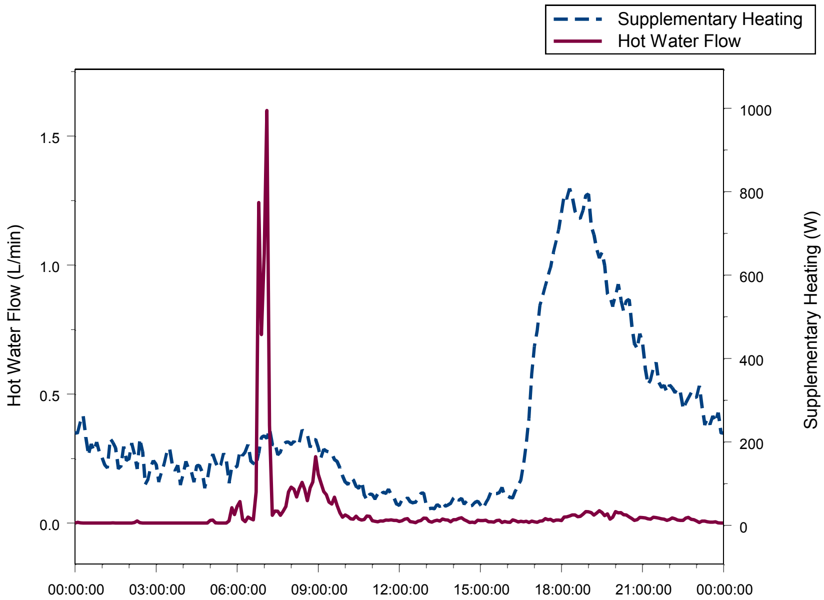


Figure 36. Average daily profile of hot water flow and supplementary heating for H23

7.24 System H24

House Identifier H24	**Technology** Thermosiphon Flat Plate
No. of Occupants 2	**Hot water use** 87 Litres per day

Cylinder							
Size	180 Litres	**New**	no	**Grade**	A	**Wetback**	no

Collector					
Area	3.7 m^2	**Direction**	265°	**Inclination angle less latitude**	-24°

Control			
Time Control	no	**Seasonal Operation**	no

Performance			
Renewable Energy	320 kWh	**Renew. Fraction**	12%
System Losses	731 kWh	**COP**	0.8

System H24 involved a 300 L thermosiphon cylinder pre-heating a 180 L cylinder. The water use had a strong morning peak and the uncontrolled supplementary heating follows a similar profile.

The cylinder delivery temperatures in this system were very high, reaching over 70°C on average.

H24 does not perform well and provides just 320 kWh of solar energy (or 12%) into the water heating needs.

7.25 System H25

House Identifier H25	**Technology** Thermosiphon Flat Plate
No. of Occupants 2	**Hot water use** 39 Litres per day

Cylinder							
Size	180 Litres	**New**	no	**Grade**	B	**Wetback**	no

Collector					
Area	1.8 m^2	**Direction**	30°	**Inclination angle less latitude**	-35°

Control			
Time Control	no	**Seasonal Operation**	no

Performance			
Renewable Energy	200 kWh	**Renew. Fraction**	17%
System Losses	638 kWh	**COP**	0.6

System H25 also involved a thermosiphon system (this time a smaller 180 L unit) as a pre-heater into a 180 L B-grade cylinder.

The collector was installed on a frame on a flat roof. There was a low vertical wall alongside the collector to the west that would shade part of the collector from midday onwards.

The hot connection to the tempering valve was fed from the outlet of this cylinder. However, the cold connection of the tempering valve was fed from the input into this cylinder which was the solar pre-heated water and therefore at an elevated temperature.

The water use for this household averaged a low 39 L per day. The supplementary heating did not show much reduction during summer, with an overall solar contribution of 17%.

7.26 System H26

House Identifier	H26	**Technology**	Thermosiphon Flat Plate
No. of Occupants	4	**Hot water use**	214 Litres per day

Cylinder

Size	305 Litres	**New**	no	**Grade**	A	**Wetback**	no

Collector

Area	3.6 m^2	**Direction**	335°	**Inclination angle less latitude**	-29°

Control

Time Control	yes	**Seasonal Operation**	no

Performance

Renewable Energy	2070 kWh	**Renew. Fraction**	41%
System Losses	1100 kWh	**COP**	1.3

System H26 was a 300 L thermosiphon system which provided a good level of service, capturing 2100 kWh of solar radiation and providing for 41% of the water heating needs which averaged out to 214 L per day. This water use had a strong peak in the morning. The supplementary heating was controlled by a timer which excluded heating during the day. A plot of the water draw-off and supplementary heating is shown in Figure 37.

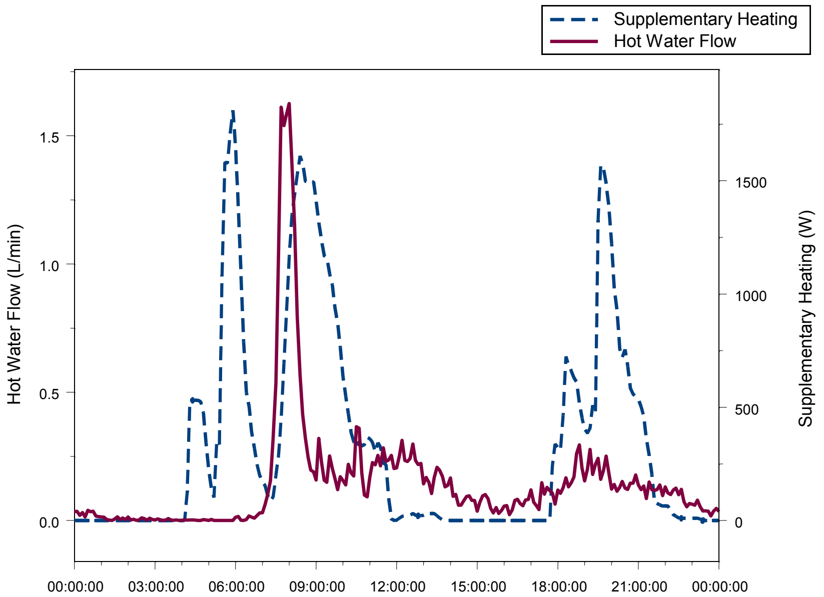


Figure 37. Average daily profile of hot water flow and supplementary heating for H26

7.27 System H27

House Identifier	H27	**Technology**	Pumped Evacuated Tube
No. of Occupants	2	**Hot water use**	97 Litres per day

Cylinder

Size	180 Litres	**New**	yes	**Grade**	A	**Wetback**	yes

Collector

Area	2.4 m^2	**Direction**	338°	**Inclination angle less latitude**	-15°

Control

Time Control	no	**Seasonal Operation**	no

Performance

Renewable Energy	1320 kWh	**Renew. Fraction**	43%
System Losses	1014 kWh	**COP**	1.1

System H27 featured a low pressure 180 L cylinder which had inputs for both solar collectors and a wetback. The mains pressure delivery of hot water in this system occurred via a coil within this cylinder. The renewable energy fraction for this system was 43%.

7.28 System H28

House Identifier	H28	**Technology**	Pumped Evacuated Tube
No. of Occupants	4	**Hot water use**	131 Litres per day

Cylinder

Size	270 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector

Area	2.4 m^2	**Direction**	336°	**Inclination angle less latitude**	-17°

Control

Time Control	no	**Seasonal Operation**	no

Performance

Renewable Energy	1860 kWh	**Renew. Fraction**	62%
System Losses	1242 kWh	**COP**	1.5

A 270 L cylinder with top and bottom elements was used in H28. Only the top element was used. The water draw-off again had a sharp morning peak. The system delivered good solar gains of 1900 kWh per year meeting 62% of the water heating needs.

7.29 System H29

House Identifier	H29	**Technology**	Pumped Evacuated Tube
No. of Occupants	3	**Hot water use**	173 Litres per day

Cylinder

Size	180 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector

Area	1.5 m^2	**Direction**	325°	**Inclination angle less latitude**	-23°

Control

Time Control	no	**Seasonal Operation**	no

Performance

Renewable Energy	1480 kWh	**Renew. Fraction**	41%
System Losses	1059 kWh	**COP**	1.2

System 29 achieved solar gains of 1500 kWh per year meeting 41% of the households water heating needs.

7.30 System H30

House Identifier	H30	**Technology**	Pumped Flat Plate
No. of Occupants	6	**Hot water use**	201 Litres per day

Cylinder

Size	315 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector

Area	3.8 m^2	**Direction**	290°	**Inclination angle less latitude**	-11°

Control

Time Control	no	**Seasonal Operation**	no

Performance

Renewable Energy	1030 kWh	**Renew. Fraction**	25%
System Losses	1333 kWh	**COP**	0.9

System H30 made use of a 300 L cylinder with two sets of elements, one at the top and one at the bottom of the cylinder. Of all the two element cylinders in the study this system was the only one to use the lower element and this was only for three short periods of 5 days, 9 days and 2 days.

The circulation pump controller for this system was the most difficult to access. As well as being in the subspace alongside the cylinder, it was located in a metal enclosure box with the circulation pump.

This system had a high water use of 201 L per day with the solar providing 25% of the water heating needs.

7.31 System H31

House Identifier	H31	**Technology**	Pumped Flat Plate
No. of Occupants	3	**Hot water use**	89 Litres per day

Cylinder

Size	220 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector

Area	3.8 m^2	**Direction**	290°	**Inclination angle less latitude**	-27°

Control

Time Control	no	**Seasonal Operation**	no

Performance

Renewable Energy	850 kWh	**Renew. Fraction**	35%
System Losses	882 kWh	**COP**	1.0

System H31 sourced 850 kWh of energy from the sun contributing 35% of the water heating needs.

7.32 System H32

House Identifier	H32	**Technology**	Pumped Flat Plate
No. of Occupants	5	**Hot water use**	104 Litres per day

Cylinder

Size	320 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector

Area	5.7 m^2	**Direction**	322°	**Inclination angle less latitude**	-5°

Control

Time Control	no	**Seasonal Operation**	yes

Performance

Renewable Energy	1320 kWh	**Renew. Fraction**	36%
System Losses	1590 kWh	**COP**	0.9

System H32 included a 320 L cylinder located in the roofspace. The supplementary heating was turned off over the summer from December to April and the system achieved a solar energy fraction of 36%.

7.33 System H33

House Identifier	H33	**Technology**	Thermosiphon Flat Plate
No. of Occupants	4	**Hot water use**	160 Litres per day

Cylinder							
Size	320 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector					
Area	3.7 m^2	**Direction**	288°	**Inclination angle less latitude**	-12°

Control			
Time Control	no	**Seasonal Operation**	no

Performance			
Renewable Energy	970 kWh	**Renew. Fraction**	24%
System Losses	1691 kWh	**COP**	0.8

System H33 was a 320 L thermosiphon system which had an overall energy solar fraction of 24%.

7.34 System H34

House Identifier	H34	**Technology**	Thermosiphon Flat Plate
No. of Occupants	0	**Hot water use**	231 Litres per day

Cylinder							
Size	320 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector					
Area	3.7 m^2	**Direction**	323°	**Inclination angle less latitude**	-24°

Control			
Time Control	no	**Seasonal Operation**	no

Performance			
Renewable Energy	1600 kWh	**Renew. Fraction**	29%
System Losses	2026 kWh	**COP**	0.9

The owners of System H34 sold their house during the year of monitoring. The data for H34 relates to the new owners. The average water use for H34 was 231 L per day. Solar contributed 1600 kWh per year or 29% of the total water heating needs for the house.

7.35 System H35

House Identifier	H35	**Technology**	Thermosiphon Flat Plate
No. of Occupants	2	**Hot water use**	129 Litres per day

Cylinder

Size	320 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Collector

Area	3.7 m^2	**Direction**	288°	**Inclination angle less latitude**	-29°

Control

Time Control	yes	**Seasonal Operation**	no

Performance

Renewable Energy	1290 kWh	**Renew. Fraction**	37%
System Losses	1265 kWh	**COP**	1.0

The 320 L thermosiphon system for the System H35 cylinder was operated on a night-rate schedule and sourced 37% of its water heating needs from solar.

7.36 Heat pump systems

Systems H36 to H39 were integrated air-to-water heat pump systems. The plumbing detail for the heat pump systems was quite straightforward, usually just involving a hot and cold connection into the house piping.

7.37 System H36

House Identifier	H36	**Technology**	Air to Water Heat Pump
No. of Occupants	na	**Hot water use**	123 Litres per day

Cylinder

Size	Approx. 300 Litres	**New**	yes	**Grade**	A	**Wetback**	no

Control

Time Control	no	**Seasonal Operation**	no

Performance

Renewable Energy	950 kWh	**Renew. Fraction**	44%
System Losses	378 kWh	**COP**	1.5

The monitoring equipment for System H36 was installed in September 2007. The household with System H46 used on average 123 L of hot water per day. The system performance factor over the summer was 1.8, giving a renewable energy fraction over the summer time period of 44%.

7.38 System H37

House Identifier	H37	**Technology**	Air to Water Heat Pump
No. of Occupants	na	**Hot water use**	44 Litres per day

Cylinder							
Size	Approx. 300 Litres	**New**	yes	**Grade**	A	**Wetback**	no
Control							
Time Control	no			**Seasonal Operation**	no		
Performance							
Renewable Energy	-2170 kWh			**Renew. Fraction**	-156%		
System Losses	800 kWh			**COP**	0.2		

Heat pump hot water system H37 had its monitoring equipment installed at the same time as H36. This system was placed in the roof space of the house. There is an amount of fan noise associated with heat pump hot water systems and the distributors specify them as outdoor units.

This heat pump system appears to have a fault with it with the draw-off from the cylinder being less than the electrical heating going into the heat pump. At the end of November the occupants were away for approximately two weeks with the heat pump left running. Over this period where no water draw-off occurred, the heat pump averaged over 250 W continuous power use – this equates to over 2100 kWh per year.

The householders for this system were only modest hot water users, over the summer period averaging 44 L per day.

7.39 System H38

House Identifier	H38	**Technology**	Air to Water Heat Pump
No. of Occupants	na	**Hot water use**	70 Litres per day

Cylinder							
Size	Approx. 300 Litres	**New**	yes	**Grade**	A	**Wetback**	no
Control							
Time Control	no			**Seasonal Operation**	no		
Performance							
Renewable Energy	1180 kWh			**Renew. Fraction**	57%		
System Losses	994 kWh			**COP**	1.2		

The heat pump System H38 was installed in December 2007. The occupants used an average of 70 L per day. The system performance factor for the system was 2.3, giving a renewable energy fraction for the system over the summer time period of 57%.

7.40 System H39

House Identifier H39	**Technology** Air to Water Heat Pump
No. of Occupants na	**Hot water use** 151 Litres per day
Cylinder **Size** Approx. 300 Litres **New** yes **Grade** A **Wetback** no	
Control **Time Control** yes **Seasonal Operation** no	
Performance **Renewable Energy** 1450 kWh **Renew. Fraction** 54% **System Losses** 400 kWh **COP** 1.9	

The monitoring equipment for the heat pump System H39 was installed in December 2007. The system users had installed a wooden box around the cylinder (clear of the fan) and included an amount of thermal insulation to reduce the heat losses from the system.

The pulse logger recording the total water use produced high readings. From an initial examination of the data in appears that the logger was placed too closely to the water meter so that the magnetic sensor in the water meter caused regular false readings to be recorded by the logger. Applying filtering for these small values provided an estimated daily hot water use of 151 L per day.

The system performance factor for H39 over the summer time was estimated at 2.2 with a renewable energy fraction of 54%.

8. DISCUSSION AND RECOMMENDATIONS

A range of performances was seen. On average, 38% of the annual household hot water heating needs (or 1260 kWh/year) was supplied from the sun for the monitored SWH systems. A set of higher performing systems (about 27% of systems) was identified which provided an average of 2060 kWh/year of energy from solar with an average fraction of the energy coming from solar of 43%. Another lower performing set of about 21% of systems was indentified with these systems contributing on average 550 kWh from solar or 26% of the total water heating needs for these households.

The highest two performing systems relative to their total water heating needs had occupants who turned off the supplementary heating regularly. While these systems gained a high proportion of their energy from the sun, the storage temperatures were frequently below the 60°C recommended for Legionella control.

The summer performance of the heat pump systems was to provide approximately 1190 kWh/year more environmental heat than electrical input into the system. The households using the heat pump systems were smaller hot water users, so this energy amount was about 52% of total hot water heating needs for these households. The performance of the heat pump hot water systems is dependent on external temperature and the winter time (and therefore year round) performance of the heat pump hot water systems will be less than the summer time performance.

The amount of hot water used in households with SWH systems varies. The households in this sample appear to use more hot water than an average New Zealand household. The hot water use of the four houses with heat pump hot water systems is similar to the average New Zealand hot water usage.

The sample was designed to examine the region and technology influences on the amount of energy of renewable energy the systems could supply. The analysis of this information revealed that it depends more on the individual system and its installation than any effect due to the region or the climate for how much renewable energy the system can supply. This perhaps reinforces the point that SWH systems are complex and their performance can be affected by many factors.

8.1 Surveyed responses

A survey of the householders experiences and attitudes was undertaken by CRESA in the 35 households with SWH. This report is provided in Appendix A. These households were predominantly 2 person households or households with 3 or 4 people. Only 30% of the households had 2 or more children. 43% of the households reported that their hot water use was average, with the remainder roughly evenly split between higher than average and lower than average. The household incomes were skewed towards higher income households with 60% of households having a household income over $70,000 per year.

The majority of the interviewees believed that New Zealand needed to change its way of life if New Zealanders were to enjoy a good quality life and environment into the future. The interviewees typically reported their attitude to environmental issues as 'middle of the road' with about three quarters of them highlighting environmental concerns as a contributing reason for getting SWH.

The most popular reason given by householders (over 90%) for installing SWH was to save money.

In addition to the cost, the systems selected by the householders were based on their impression that the system was well designed and reliable. The choice of supplier influenced the choice of system with suppliers selected from recommendations of friends and neighbours who already had a SWH system or who worked in an associated industry. Selection was influenced by the amount of electricity savings claimed that could be made with the system however many interviewees expressed frustration that independent information was hard to find. Over 40% of respondents were dissatisfied with the amount of information available on operating and maintaining SWH.

Overall just over half of the interviewees were satisfied with the installation process. The majority of householders were not well informed on the need for a building permit. While over 80% of householders received a manual, 21% found it too difficult to follow. Most were not told if the unit had a timer, shown the different parts of the system or how to operate and manage the controls.

The technical understanding of the householders varied from a high level to a very limited understanding. A small number of users were active managers of their systems while the majority were passive but were satisfied with the degree of control they had. Many interviewees were not aware that their SWH system would require any maintenance.

Approximately 57% of respondents reported that the savings on their power bills had met their expectations while 29% of respondents said that the power bill savings had not met their expectations. Overall 86% of interviewees would recommend SWH to family and friends.

8.2 Ensuring performance

The research has shown that there are opportunities to ensure the performance of SWH systems throughout the process of system design, specification, installation, handover and operation.

When the system is installed, it is important to ensure that it is connected correctly, of appropriate capacity and size, has solar collectors well-positioned, that heat losses are kept to a minimum, that controls and display outputs are available for the users to monitor and that it is operating correctly.

When the system is turned over to the householders, the installers need to provide them with sufficient information on how it works, how to use it, what performance they could expect from it, how to determine performance and how to identify when the system is not performing.

The operational stage of the SWH system is when its performance pays back in terms of cost savings. The householders need to be able to identify when the performance of their system is not up to scratch and seek help to address this.

8.3 Design and Installation

At the time the system is designed and specified it is important to ensure that the supplier and homeowner discuss and understand the design choices that were made than impact on the performance of the system as many aspects of the ongoing performance of the system are set these choices. The following sub-sections highlight some of the issues, not in any particular order, seen in this research that could be addressed before or during the SWH system installation.

8.3.1 Inclination angles

Most of the SWH systems examined had their collectors installed at the same angle as the roof, and little consideration appears to have been given to the inclination angle which the solar collector was installed at. None of the 35 solar collectors examined were installed at inclination angles greater than or equal to the site latitude.

In summer, when the sun is high in the sky, a low solar collector inclination angle will allow a good capture of heat to the collector. In winter, the sun is low in the sky and an angle greater than the latitude of the site will provide best capture of the solar radiation.

As the solar radiation is lower in winter, temperature differences are higher. Potentially there is a greater household demand for hot water, and year round performance of SWH may be improved by installing the solar collectors at a high inclination angle.

For the SWH systems for which it was possible to determine winter time performance, over half of these systems provided less than 10% of the winter time water heating needs. A general trend of increasing proportion of water heating needs met by solar was observed for systems with steeper collector inclination angles. However, there is a high degree of other variation in this data.

For the summer time performance of the SWH systems, a similar trend of increasing solar fraction for increased inclination angle was observed, although the solar fraction values were higher. None of the systems with an inclination angle of less than 20° had a solar fraction of greater than 80%.

Recommendation: *That solar collectors be installed at an inclination angle at least equal to the latitude of the site.*

8.3.2 Standing losses

Standing losses form a sizeable part of the energy balance of each system. If the losses of the system are reduced, more of the renewable energy collected can go towards replacing the heat drawn-off from the system by the household's occupants. Six of the 35 SWH systems measured were retrofitted to B-grade cylinders.

Recommendation: *That retrofitting SWH to existing B-grade cylinders is not allowed.*

Many of the systems with high standing losses were thermosiphon systems. These systems included large cylinders which, as a result of being installed outside, have a large temperature difference across them.

Recommendation: *That the high heat losses for thermosiphon systems be examined to see if changes, such as increased thermal insulation on cylinders, should be required.*

8.3.3 Connection of open systems

System H04 had unnecessarily large standing losses of over 6400 kWh per year due to the pumped system having a thermosiphon back circulation at night. The likelihood of this back circulation could be reduced by using an appropriate piping arrangement.

Recommendation: *That open systems be required to incorporate piping arrangements to reduce the chances of back circulation of the system at night.*

8.3.4 Controlling supplementary heating

In order for SWH systems to maximise the capture of solar gains, the systems must have capacity to store heat within the hot water. An important part of this is to prevent supplementary heating from operating before the solar has an opportunity to contribute heat to the system.

Recommendation: *That timer controls are installed on the supplementary water heating for all SWH systems.*

8.3.5 Use of top elements in large cylinders

Three of the systems examined had large cylinders which had elements at both the top and bottom of the cylinder. The top elements in these systems were regularly used however the bottom element was only occasionally used in one of the systems. Two of these three systems were seen to be well performing. Using a top element allows the supplementary heating to heat only the top part of the cylinder while allowing the heat collected from the solar collector to be stored in the lower part of the cylinder.

Recommendation: *That greater use of cylinders with elements at the top of the cylinder is encouraged.*

8.3.6 Equipment to monitor performance

There are a number of components of SWH systems that may be useful for occupants to monitor. For example, many pump controllers report the temperature of the collector and hot water cylinder. The cylinder temperature may be useful as a gauge to the current capacity of heat stored within the system.

Recommendation: *That system displays are installed in a prominent location within the living space of the house so that they can be monitored by the occupants.*

8.3.7 Confirm system is operating correctly

The back circulation at System H04 would have been present from the time of installation of the system. A more comprehensive examination of the system at the time of installation, perhaps including some basic monitoring such as recording of the system temperatures, would have identified these issues.

Recommendation: *That after an SWH system is installed, a process is undertaken to ensure that it is working to specifications.*

8.4 Handover

There is an important education role for the installers to tell the householders what sort of performance they can expect from their system, how it works and how they need to operate it. They also need to be shown the controls and displays of the system and how to identify when it is not performing well.

8.5 Operation

SWH systems users are either active managers of their systems, monitoring them and setting controls, or are passive managers allowing the system to look after itself (Scotts and Saville Smith 2007). Both of these types of users need feedback. The active managers would like as much feedback as possible, but the passive managers still need some feedback about when the system is not performing well. The following sections provide some important issues to consider while the SWH system is being used.

8.5.1 Controlling supplementary heating

In addition to the installation of a timer, in order to ensure that the supplementary heating is only used for a minimum amount of time it should be operating using an appropriate schedule that matches the user's needs. For example, if the occupants primarily use hot water in the morning, then instead of having a timer that comes on at 10 pm and turns off at 7 am just before the first water use, the system may be better optimised by having the timer come on at 4 am and consequently reducing the system losses from 10 am to 4 am.

Recommendation: *That sufficient guidance is provided to SWH system users' to allow them to operate the timers to minimise the time the supplementary water heating is use while still providing for their needs.*

8.5.2 Information on system performance

A number of the systems monitored were not performing satisfactorily. In general, the system users had little information on how well their SWH systems were performing. Where information was available (such as an electricity meter on the supplementary heating), there was no guidance about what values are appropriate.

Recommendation: *Users need information on how well their systems are performing to allow them to seek help if the performance is sub-standard.*

Ideally this could be a smart system with a real-time feedback of system performance which allows past readings to be reviewed.

A number of SWH system controllers are now available that also control (in addition to the circulation pump) the supplementary heating element. Further information is required on these systems about the extent to which they minimise the use of the supplementary heating element.

Further development of controllers to better minimise the supplementary water heating use by incorporating features, such as weather prediction, would also be helpful and this could be incorporated into a smart system controller.

Recommendation: *That means of integrating greater prediction abilities into SWH system controllers be developed.*

8.5.3 Alarms when systems are not working

Many occupants are not interested in closely monitoring their SWH system. However, there may still be a need for them to attend to the system when a fault is present which causes it to be completely ineffective. It is therefore beneficial if the system draws attention to itself when in such a state. It is common these days for control systems to have audible alarms, such as the door-open alarms on new fridges. The system at H03 had a broken sensor wire, so did not operate the circulation pump, and therefore the entire SWH system was not operational. This fault was present for a long time as the controller displaying the fault was in a hallway cupboard and not inspected by the occupants.

Recommendation: *That SWH control systems emit an audible alarm if they are not operational due to a fault in the system.*

8.5.4 Installers to troubleshoot performance issues

After the installation of the monitoring equipment, a number of sites were visited by the system installers to attend to service or maintenance issues. A number of these systems were not performing well, although the visiting installers did not identify this.

Recommendation: *That SWH installers be better equipped to evaluate and diagnose performance issues with SWH systems.*

8.6 Other opportunities

Electricity supplier records currently provide data on the total electricity use in each household.

The analysis of electricity supplier records to examine the impact of the installation of a SWH system proved to be problematic as other changes of electricity usage within the household masked the effect of the SWH installation.

Water heating makes up a large proportion of the electricity usage in most homes and it would be beneficial if water heating energy use was separately metered. This would allow both the householders to monitor their water heating energy use but would also allow more information to be gathered collectively on how much electricity is being used for water heating.

Recommendation: *That analysis is undertaken on requiring that the water heating be separately metered.*

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APPENDIX A CRESA HOUSEHOLDER REPORT

The following pages contain the report commissioned from the Centre for Research, Evaluation and Social Assessment (CRESA) on the experiences and attitudes of the householders of the 35 households with SWH taking part in this study.

Page numbering has been modified in this CRESA report so that it is consistent with the rest of this Study Report.

HOUSEHOLDER EXPERIENCES AND ATTITUDES WITH SOLAR HOT WATER HEATING

Prepared for BRANZ
by
Centre for Research, Evaluation and Social Assessment (CRESA)

Margie Scotts and Kay Saville Smith

September 2007

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1. INTRODUCTION

1.1 BRANZ Ltd has asked CRESA to report on some aspects of research it is providing to Building Research Ltd and EECA on the actual performance of solar hot water (SHW) units installed in New Zealand and the attitude of the owner/users to the systems. This report is entirely concerned with the experiences of users, the factors that influenced their take-up of SHW, their perceptions about the performance of their systems, their management and satisfaction with their SHW.

1.2 This report is structured as follows:

- Section 2 covers research focus and method;
- Section 3 describes the households participating in the study;
- Section 4 describes the characteristics of water systems in the dwellings;
- Section 5 explores the households' attitudes to the environment;
- Section 6 asks why households got SHW;
- Section 7 describes the factors that influenced selection;
- Section 8 presents data related to SHW installation;
- Section 9 looks at household SHW management and maintenance practices;
- Section 10 looks at householders perception of SHW performance.

2. RESEARCH FOCUS AND METHOD

2.1 The research reported here has involved 35 SHW owner/user households in Auckland, Wellington, Christchurch and Dunedin. The majority of participant households have received an interest free loan from EECA to help buy the SHW units, and all units were been installed within the last three years. Data was collected largely through in-depth, face-to-face interviews, although phone interviews were conducted with four participants who were not available for face-to-face interviewing.

2.2 Each interview was based on a mix of closed and open-ended questions. Interviews took between sixty and ninety minutes. The interviewing was semi-structured conversational interviewing supported by the interview schedule attached in Appendix A. Selected data from the BRANZ[10] physical survey and monitoring of the SHW of these households was incorporated with quantitative data from close-ended questions from the interviews and inputted and analysed in SPSS. Data from open-ended questions was content analysed.

3. HOUSEHOLD PROFILE

3.1 The 35 participant households are located in four cities – Auckland, Wellington, Christchurch and Dunedin. In Auckland, Wellington and Christchurch, 9 households participated in the interviews. In Dunedin, 8 households participated. Thirty of the 35 households were reported as Pakeha/NZ European. There was one Maori household and one Chinese

[10] BRANZ data includes type and size of SHW system, supplementary energy source and controls, extent of plumbing work carried out at time of installation, and householders main reason for purchasing SHW.

household. The remaining three households were South African, Australian and German.

3.2 The households were predominantly 2 person households or households with 3 or 4 people in them. There was only one 1-person household and very large households made up a small minority of households (Table3.1).

Table 3.1: Household Size

Household Size	Households	% Households
1 person	1	2.9
2 people	14	40.0
3-4 people	16	43.7
5 -6 people	4	11.4
Total	***35***	***100***

3.3 Because water and energy use are associated with the numbers of people in a house at any one moment, the interviews explored the extent to which households had regular visitors staying in the dwelling. As Table 3.2 shows, just over half the households were only occasionally hosting visitors. About a third, however, had visitors every few weeks and a small number of households report having overnight visitors most weeks.

Table 3.2: Frequency of Households Hosting Overnight Visitors

Household Size	Households	% Households
Seldom	16	45.7
Every Few Weeks	11	31.4
Most Weeks	4	11.4
Total	***35***	***100***

3.4 Most households had no children under the age of 17 years. Table 3.3 sets out the numbers of households with children under the age of 17 years.

Table 3.3: Households with Children Under 17 Years

Number of Children	Households	% Households
No children	20	57.1
1 child	5	14.3
2 children	7	20.0
3 or more children	3	8.6
Total	***35***	***100***

3.5 Energy and water use has, to a lesser extent, been found to be associated with the number of people using the house during the day. This can, of course, vary between week days and weekends. Eight households were reported as having no one at home during the day on week days. Sixteen of the households were reported as having 2 or more people at home on the week days. All the households had people home on weekends.

3.6 The largest single group of interviewees described their household water use as average. Similar substantial proportions of households were typified as having high hot water use or low hot water use.

Table 3.4: Household Hot Water Use

	Households	% Households
High or very high	9	25.7
Average	15	42.9
Low or very low	10	28.6
Don't know	1	2.9
Total	***35***	***100***

3.7 There is a definite skew towards high income households in the set of participant interviewees. As Table 3.5 shows, over half of the households were reported by interviewees as having incomes in excess of $70,000 annually.

3.8

Table 3.5: Household Income Distribution

Annual Household Income	Households	% Households
$30,000 or less	2	5.7
$30,001-$50,000	9	25.7
$50,001-$70,000	3	8.6
$70,001 or more	21	60.0
Total	***35***	***100***

4. THE CHARACTERISTICS OF THE DWELLING WATER SYSTEMS

4.1 The interviews explored with householders the nature of their hot water systems and the extent to which those systems were changed by the installation of SHW.

4.2 Like most houses in New Zealand, over half the houses in this survey were reported to have a mains pressure hot water system. About a quarter were reported to have a low pressure system. Electricity is the primary source of energy for hot water heating, although several householders reported using wetbacks. All the interviewees had installed SHW in the last three years.

4.3 Apart from the usual kitchen and laundry use of hot water, the use of hot water for washing is mainly by way of showers. All but one of the houses has a shower and more than half have two showers. Most of the dwellings also have a bath but just over a third of the interviewees with baths reported that it was seldom or never used. The most common reason given why the bath was not used was that the householders had a preference for showers. In only one case was it reported that the bath was not used because there was insufficient hot water.

4.4 Typically houses had only one hot water cylinder. Only 26 of the 35 interviewees were willing to estimate or knew the capacity of their hot water cylinders. Sizes of those cylinders are set out in Table 4.1.

Table 4.1. Capacity of Dwelling Hot Water Cylinders

Litre Capacity	Cylinders
160 –280	13
300 - 330	13

4.5 Just over a third of interviewees reported that their SHW was installed using the existing cylinder. Sixty percent of the hot water cylinders are relatively new and were installed at the same time as the SHW system.

4.6 New cylinders were installed for a variety of reasons. Those included:

- the old cylinder leaked or was old;
- the SHW system had a built-in cylinder; or
- the SHW system purchased required a different pressure cylinder to the one currently installed in the house.

A number of householders saw the installation of SHW as an opportunity to upsize the dwelling hot water storage capacity.

4.7 A small proportion of interviewees reported that 50 percent or more of the existing plumbing in their house was replaced when the SHW system was installed. In most cases, however, the plumbing system remained largely unchanged.

5. ATTITUDES TO THE ENVIRONMENT

5.1 The take-up of SHW is often seen as representing quite a sophisticated understanding and/or committed view on environmental issues. Consequently, this aspect of interviewees world view was explored with them. There was some diversity among interviewees. The majority of interviewees reported that they believed that New Zealand needed to change its way of life if New Zealanders were to enjoy a good quality life and environment into the future. All but three of the interviewees expressed concern about the environment in general. Some householders also reported they take environmental action at a household level for example by recycling, composting, installing insulation, heat pumps or SHW. Nevertheless, interviewees typified their household members as generally fairly middle of the road on environmental issues. Typical comments included “not fanatical”, “not green with a capital G” and not “out protesting”.

6. WHY GET SOLAR HOT WATER HEATING

6.1 Despite an awareness and concern with environmental issues, the reason cited by householders as to why they installed SHW was to save money immediately (Table 6.1).

Table 6. 1: Reasons for Getting SHW

Reason	Household	% Households (n=35)
To save money	32	91.4
Environmental concerns	26	74.3
Future cost of energy	15	42.8
Future security of supply	9	25.7

*Multiple response

6.2 Almost three-quarters of householders, however, did cite environmental concerns. Immediate concerns rather than future concerns was a marked feature of the householders thinking. Only minorities of the householders were reported as installing SHW because of concerns around the future cost of energy or the future security of supply.

6.3 Other reasons for getting SHW reported by householders included: interest in alternative energy, wanting to get rid of existing gas installations, and greater independence from power supply companies. For the landlord of the only tenanted property in the study, a benefit was their current tenants thought a house with SHW was a more desirable rental proposition because of the opportunity to save money.

6.4 The stimulus to actually install SHW was very much associated with the availability of interest free loans. For many this was the tipping point for installing SHW at the time they did. For a smaller group the immediate prompt was the opportunity to install SHW with less upheaval to the household because a new home was being built or major renovations were already being undertaken.

7. SELECTING A SHW SYSTEM

7.1 The SHW systems purchased by the 35 households was fairly equally divided between flat thermo-siphon, flat pumped and evacuated tube technology. The set of households had the following:

- 10 flat plate thermo-siphon systems;
- 12 flat plate pumped systems; and
- 13 evacuated tube systems.

Ten different manufacturers of SHW units were represented in the study, although one brand dominated. There were eight Linuo systems. The second most common manufacturers were Edwards, Solahart and Apricus, being used in five households respectively.

7.2 Regardless of the price they paid the majority of householders chose a system because they believed it was well designed and reliable. The informal measures of reliability cited by interviewees included:

- BRANZ appraisals and Consumer Institute reporting;
- Brands with a history of use in Australia;
- The country where the system was designed or manufactured (Germany, Christchurch and China were considered reliable);
- Reports found on the internet that rate evacuated tube systems as the most efficient solar collectors.

7.3 The other major factors in governing choice were price, availability, perceptions of the likely energy savings and amount of water the SHW would heat, and the supplier. How householders responded to those issues, however, could vary or involve a multiplicity of considerations. Thus, with regard to price, some systems were chosen because they were the cheapest available. Some were chosen because the cost was fully covered by the interest free loan. Others were chosen because the difference between the price of the preferred system and the value of the interest free loan was affordable for the household.

7.4 Many interviewees reported that their selection was influenced by the amount of saving they could make on power bills. This was based on estimates provided by suppliers of how much water the system they were considering would heat by solar energy. Those estimates varied and were often vague, for example "a great deal" and "all in summer, less in winter". The most common estimate was 70 percent of water able to be heated by solar energy.

7.5 The choice of a supplier influenced the choice of system. Interviewees mainly chose a supplier because the interest free loan was available through them. Friends and neighbours who already had SHW or who worked in associated industries also played a role in influencing system and supplier choice. For a smaller number of householders the aesthetic of the solar unit was very important and influenced the type of system bought.

7.6 To make their selection decisions, interviewees reported seeking information through a variety of sources. The internet was the most common source of information and was also seen by the interviewees as the most useful. Other householders shopped around locally, responded to radio and newspaper advertisements, visited supplier show rooms and Home Shows. In only one instance was an architect or builder reported as a source of information about SHW (Table 7.1).

Table 7.1: Source of Information

Information Source	Households	% Households (n=35)
Internet	15	44.1
Neighbour	5	14.7
Installer	5	14.7
Manufacturer	5	14.7
EECA	1	2.9
Friends/family	2	5.7
Radio/Print Media	8	22.8
Home Show or Exhibition centre	4	11.4
Environmental Group	3	8.5

*Multiple response

7.7 The time people took to search for information varied. Several householders had very limited time to find information because their existing hot water cylinder was no longer working. Three households made only one phone call, and one responded to a cold call from a single supplier. Seven households took the advice of either a neighbour who already had a SHW system, or a family member or a friend.

7.8 There was also variation in the extent to which interviewees were satisfied with the information they sought. A significant minority found both the range and sources of information less than satisfactory, particularly in the area of operating and maintaining SHW and performance of SHW systems in New Zealand conditions.

Table 7.2: Household Satisfaction with Information

Type of information	Households Satisfied		Neither		Households Dissatisfied	
	Households	*%*	*Households*	*%*	*Households*	*%*
Benefits & limitations of SHW	22	62.8	2	5.7	11	31.4
Different kinds of system	21	60.0	3	8.6	11	31.4
Best system for my household	24	68.6	2	5.7	9	25.7
Costs of SHW	26	74.3	1	2.9	8	22.8
How to operate & maintain SHW systems	18	51.4	2	5.7	15	42.9

7.9 Regardless of whether they were satisfied or not, many interviewees expressed some frustration that independent information was hard to find. Typical comments included:
"There was plenty of information out there. You have to go looking, you have to know what to ask, but when you go looking there's plenty available".

"We could only find commercially driven information. There was no real substance to the marketing information I was given".

"*… with hindsight there's a lot we weren't told, and some of what we were told wasn't right. We couldn't find good independent information to compare with what the salesperson was telling us".*

8. INSTALLATION

8.1 The majority of the SHW systems were installed as a one-off job. Only a minority of installations were in the context of major renovation or new-build (Table 8.1).

Table 8.1. Installation of SHW

Type of installation	Households	% Households
New build home	4	1.4
Part of major renovation	6	17.1
Main job done at the time	25	71.4
Total	***35***	***99.9****

*due to rounding

8.2 The majority of interviewees relied on their installer or supplier to arrange all aspects of the installation including dealing with building permits. The majority of householders were not well informed about the need for a building permit for a SHW installation. More than half did not know a permit was needed. Most assumed the installer was responsible for getting the permit or making it known if one was required.

8.3 Similarly, the majority of interviewees depended on the SHW system to be largely self-managing and set at appropriate settings. Thus, while 80 percent of the interviewees reported they were supplied with an owner's manual or other written instructions about their SHW system, 21 percent found the manual too difficult to follow. Moreover, less than half the households (40 percent) reported they received a written guarantee for the SHW system's principal components such as collector panels and water cylinder, or for the installation and associated plumbing or wiring.

8.4 In the majority of installations it was the installer who programmed the SHW controls. Only eight householders were asked if the settings were correct for the particular household. The majority of householders were not shown the different parts of the SHW system or how to operate and manage the controls. Most were not told whether the system had a timer or not.

8.5 Just over half of the interviewees were satisfied with the installation process (Table 8.2).

Table 8.2: Satisfaction with Installation

Satisfaction Level	Households	% Households (n=35)
Very satisfied	10	28.6
Satisfied	9	25.7
Neither satisfied nor dissatisfied	1	2.9
Somewhat dissatisfied	10	28.6
Very dissatisfied	5	14.3
Total	***35***	***100***

8.6 Problems ranged from what the householders perceived as minor to very serious. Fourteen householders provided detail of the problems associated with their installation. Three households reported catastrophic cylinder failures that resulted in a collapsed ceiling, water pouring down an internal wall and a flood that saturated carpets.

8.7 The problems were most often plumbing related, followed by installation of the solar collectors. The most common reported problems were

- Leaks in cylinders, valves and pipes;
- Faulty valves, pumps, resistors and solenoids;
- Holes drilled through the roof in wrong places;
- Pump capacity too small;
- Panels not ideally aspected to the sun;
- Wrong cylinder installed;
- Restricted water circulation.

8.8 The majority of householders had not needed any back up service. Where they had required back up or remedying of installation problems, there were an equal number of householders who were happy with the service as were dissatisfied. Where there was dissatisfaction it was often about getting panel suppliers, plumbers or electricians to come and sort out problems.

8.9 Installation problems were more frequently reported in Auckland and Wellington than in Christchurch. Very few installation problems were reported in Dunedin and all were very minor. In Wellington the same installer was mentioned in relation to three of the installations which were reported as having problems.

9. HOUSEHOLD MANAGEMENT & MAINTENANCE OF SHW

9.1 A small group of householders have a high level of technical understanding and expertise. At the other end of the continuum are a group with very limited understanding. Most interviewees reported that at least one person in the household had some or a reasonable understanding of the system. With prompting most interviewees could identify whether they had an evacuated tube system or flat panel system.

9.2 Households tend to manage their SHW in one of two ways. A small number are very active managers. The majority are relatively passive and want to be so. They are satisfied with the degree of control that they have. Only a third of householders were dissatisfied with their knowledge and control.

9.3 The range of activities associated with active management include:

- Use of temperature gauges and manual switches for the supplementary energy supply;
- Regular checking of water temperature and adjustment of the supplementary energy supply;
- Occasionally checking panels and fittings, insulation and pipes for wear and dirt build up;
- Not turning on the supplementary energy source until evening and after the sun has done its work over the day.

9.4 Passive managers have fewer controls installed and/or do not adjust the controls they do have. For them, the supplementary energy source comes on automatically or is turned on continuously. The most passive of managers do not turn the supplementary energy off over summer. Table 9.1 sets out the number of interviewees reporting various management actions in their households.

Table 9.1: Household Management of SHW

Management Activity	Households	% Households (n=35)
Check water temperature	14	40.0
Adjust supplementary energy after monitoring temperature	10	28.6
Check thermostat setting	10	28.6
Adjust settings for household changes	4	11.4
Set or adjust timer(*note: not all systems are fitted with timers*)	3	8.6
Programme system to suit lifestyle	2	5.7

*Multiple ResponseR

9.5 Many interviewees were not aware their SHW system would require any maintenance. The most commonly reported maintenance activity was checking on the roof or in ceiling for signs of wear and tear, rust or leaks. Only five householders reported they check or clean their collector panels Table 9.2).

Table 9.2: Maintenance Activities

Maintenance Activity	Households	% Households (n=35)
Check in ceiling for signs of leaks or wear in pipes, valves, fittings	16	45.7
Check on roof for leaks, signs of wear or rust in panels, frame, fittings and roofing	15	42.9
Check lagging of pipes in roof and ceiling for deterioration	9	25.7
Check quality of contractors work	6	17.1
Check panel for build up of dirt	5	14.3
Clean collector panels	5	14.3
Clean roof under collector frame	1	2.9

*Multiple Response

10. HOUSEHOLDER PERCEPTIONS OF SHW PERFORMANCE

10.1 The performance of the SHW systems is being monitored by BRANZ and will be subject to separate reporting. This section is concerned with householders' views of SWH performance. It presents data relating to:

- The extent to which the SHW has met their expectations and provided benefits;
- The extent to which they are satisfied with the particular system they chose;
- The extent to which they would advise others to take up SHW.

10.2 It has previously been reported that the benefits most frequently sought by householders are:

- Savings on electricity and gas bills;
- Support for environmental values;
- Increased value of home.

10.3 Table 10.1: shows the extent to which householders expectations around power savings, independence from power cuts, support for environmental values and increased value of the home have been met.

Table 10.1: SHW Meeting Householders Expectations

Expectation	Households Met		Households Not Met		Don't know		Total
	Households	*%*	*Households*	*%*	*Households*	*%*	
Savings on bills	20	57.1	10	28.5	5	14.2	35
Independence from power cuts	7	77.7	0	0	2	22.2	9
Support for environmental values	26	89.6	1	3.4	2	6.8	29
Increased value of home	4	21.0	3	15.7	12	63.1	19

10.4 Table 10.2 set out the levels of satisfaction that interviewees have in relation to the costs associated with SHW.

Table10.2: Satisfaction with Cost

Costs	Households	% Households
As expected	23	65.7
Higher than expected	8	22.9
Lower than expected	2	5.7
Don't know	2	5.7
Total	***35***	***100***

10.5 The majority of interviewees report that their hot water supply is always adequate, although a third of report that occasionally there is less hot water than required (Table 10.3).

Table 10.3: Household Supply of Hot Water

Hot water supply	Households	% Households
Supply always adequate	19	54.3
Sometimes less than needed	13	37.1
Often less than needed	2	5.7
Total	***35***	***100***

10.6 Having less hot water than needed on some occasions does not seem to compromise the enthusiasm of householders for either SHW in general or their system in particular. Only 4 (11.4 percent) of householders reported being unhappy with their choice of systems and over two thirds (68.6 percent) reported that they would get the same system again. Some interviewees noted that a selection in the future would depend on the extent of technological improvements.

10.7 Seven householders reported their satisfaction with the brand of SHW they purchased changed as a result of recent media coverage. This has worked in several different ways. Some householders now believe there are more efficient types of SHW available. Others feel happy they have new models. Others reported they now feel less confident that New Zealand conditions are suited to SHW.

10.8 Some 85.7 percent of interviewees would recommend to family and friends that they install a SHW system. The main advice these owners/users would give to other households considering getting SHW is to thoroughly research what is best for the particular household and to get independent advice. The suggestions included:

- Take time to check out a variety of different types of SHW, suppliers and installers;
- Ensure the supplier knows the product;
- Get independent advice about the right system;
- If savings are important work out what the real cost savings will be before you decide to invest;
- Make sure your house and where the panels are installed on it is an efficient site for solar collection.

10.9 The relationship between householders' perceptions of their SHW's performance and their satisfaction with it is complex. BRANZ Ltd has characterised the performance of the SHW system in each dwelling as High, Medium or Low Effectiveness. Analysis shows that low performance in terms of the BRANZ measure[11] is not always associated with problems of unmet expectations or dissatisfaction. Similarly, high performance does not always mean that satisfaction is achieved or expectations met. The following findings clearly indicate the decoupling of performance in terms of the BRANZ SHW Effectiveness Score:

- Of the 20 households reported as having expectations of bill savings met, 14 were in the High or Medium Effectiveness category but 6 were in the Low Effectiveness category.
- Of the 26 households reported as having expectations regarding environmental values met, 18 were in the High or Medium Effectiveness category but 8 households' SHW was rated as Low Effectiveness.
- 9 households were reported as receiving a hot water supply that was as they expected or better but had SHW which was in the Low Effectiveness category.
- 7 households with SHW of High or Medium Effectiveness received less hot water than they had expected.
- Of the 19 households receiving an always adequate supply of hot water, 9 households had SHW working at Low Effectiveness. However, 2 of the 8 households with SHW in the High Effectiveness category had less hot water than needed.
- Of the 11 households with SHW in the Low Effectiveness category over half wee achieving power savings greater than they expected. However, dissatisfaction about power savings tend to be clustered among those with SHW of Medium or Low Effectiveness.
- Among those that are not likely to recommend SHW to family or friends those with SHW in the Low or High Effectiveness categories were over-represented, while those with SHW performing in the Medium category are under-represented.

10.10 It is interesting to note that householders with SHW performing in the High Effectiveness category are over-represented among those dissatisfied with the installation process, as they were in relation to the back-up service. Those with SHW performing with Low Effectiveness are also over-represented among those dissatisfied with installation and back-up service but to a lesser extent.

10.11 Overall, householders think SHW is well worth having. They judged their satisfaction with SHW by power savings, having enough hot water to meet the household needs, and reducing their environmental impact. Most householders are happy they installed SHW. They think on the whole they are making some savings on their power costs. They feel they are making a positive difference to the environment. They would recommend to friends and family they install a SHW system.

10.12 Some householders would do things differently next time. The two most common things they would do differently are more research and choosing a different installer. They would perhaps buy the same type of system, but a bigger one. Others would find a more sophisticated system or search out the latest models and technology. Some would consider a wider variety of

[11] The BRANZ measure is based on the amount of power used to boost the hot water. A High Effectiveness score equates with a low quantity of the water being heated by supplementary heating and Low Effectiveness with more. BRANZ based the effectiveness rating on 4 months data collected between February and June 2007.

systems before making a choice than they did last time, or get energy specialists to design a system for their house. Some people would not retrofit a SHW system again and many others would ask more questions of suppliers, plumbers and builders.

OWNER/USER EXPERIENCES OF SOLAR HOT WATER SYSTEMS SURVEY

A. Identification

CRESA UI________________**BRANZ UI**___________________

1. Name ____

2. Address ____

____

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B. Your solar hot water system

3. Was the solar hot water system installed as part of

- □ 1. A new build home
- □ 2. A major renovation, or
- □ 3. The main job done at the time
- □ 4. House had SHW when I moved in

4. What kind of system do you have?

- □ 1. Flat thermo
- □ 2. Flat pumped
- □ 3. Evac thermo
- □ 4. Evac pumped
- □ 5. Other. Please specify _________________________
- □ 6. Don't know

5. How many hot water cylinders are there in the house? ________

6. How many others are solar heated?_______________________

7. What made you decide to install solar hot water?

- □ 1. To save money
- □ 2. Environmental concerns
- □ 3. Concern about future security of energy supplies
- □ 4. Concern about future cost of energy
- □ 5. Other. Specify

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8. What kind of issues did you consider when deciding whether or not to install SHW?

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9. What benefits did you expect from installing solar hot water?

	Y/N	Met?
1. Savings on electricity or gas bills	□1 Yes □2 No	□1 Yes □2 No
2. Independence from power cuts	□1 Yes □2 No	□1 Yes □2 No
3. Support for environmental values	□1 Yes □2 No	□1 Yes □2 No
4. Increased value of home	□1 Yes □2 No	□1 Yes □2 No
5. Other. Please specify	□1 Yes □2 No	□1 Yes □2 No

Comments ____

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10. What is the most important benefit for you?

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D. Hot water use

11. Has there been any change in household hot water use since you got SHW? (Such as, more people using hot water; installation of a shower, bath or spa; installation of a dishwasher?)

□ 1. Yes □ 2. No - go to Q 13

12. If yes, does the household use

□ 1. More hot water than it used to
□ 2. Less hot water than it used to

Comments ____

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13. How many showers are there in the house? ____________

14. How may tubs and basins with hot water supply __________

15. How many baths are there in the house? ________

16. If there is a bath, is it used? □ 1. Yes □ 2. No

17. If the bath isn't used, why not?
- □ 1. Water isn't often hot enough
- □ 2. Don't usually use baths anyway
- □ 3. Added cost of heating water
- □ 4. Other *e.g. limited water supply, cost*. Please specify

18. Compared with other households, is your hot water use
- □ 1. Very high
- □ 2. High
- □ 3. About average
- □ 4. Low
- □ 5. Very low
- □ 6. Don't know

Comments ____

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____

19. Is your water supply
- □ 1. Metered

- □ 2. Metered and charged
- □ 3. Unmetered
- □ 4. Independent of town supply

20. How many litres of water do you use? _______Period_______

Comments ____

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E. Satisfaction with information about SHW

21. How satisfied are you with the information you were able to find

	Very satisfied	Satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Very dissatisfied
a. About benefits & limitations of SHW	□1	□2	□3	□4	□5
b. Different kinds of system	□1	□2	□3	□4	□5
c. The best system for you	□1	□2	□3	□4	□5
d. Costs	□1	□2	□3	□4	□5
e. How to operate & maintain	□1	□2	□3	□4	□5

Comments ____

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22. What were the most useful sources of information?

- □ 1. Internet
- □ 2. Neighbour
- □ 3. Installer
- □ 4. Manufacturer
- □ 5. EECA
- □ 6. Friends/family
- □ Other. Please specify

Comments ____

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F. Satisfaction with Installation

23. How satisfied were you with the installation process?
- ☐ 1.Very satisfied
- ☐ 2. Satisfied
- ☐ 3. Neither satisfied nor dissatisfied
- ☐ 4. Somewhat dissatisfied
- ☐ 5. Very dissatisfied

Comments ______________________________________

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____

24. Did you know when you installed the SHW it needed a permit?
- ☐ 1. No
- ☐ 2. Yes, and I got one at the time
- ☐ 3. Yes, but I didn't apply for one
- ☐ 4. Don't remember

25. If you knew a building permit was needed, who provided that information? ______________________________

26. If you didn't know, have you since applied for a building permit?
☐ 1. Yes ☐ 2. No

27. If yes, what has the process been like – any problems?

____

____

28. How satisfied are you with the back up service from the installer/manufacturer?
- ☐ 1. Very satisfied
- ☐ 2. Satisfied
- ☐ 3. Neither satisfied nor dissatisfied
- ☐ 4. Somewhat dissatisfied
- ☐ 5. Very dissatisfied

Comments______________________________________

29. Were you given an owners manual or other information by the installer/supplier about your SHW operation and maintenance? (*probe range of information supplied)*

□ 1. Yes □ 2. No. *Go to Question 31*

30. If yes, how easy are the instructions to understand and use?

- □ 1. Very easy
- □ 2. Easy
- □ 3. Neither easy nor hard
- □ 4. Somewhat difficult
- □ 5. Very difficult

31. Did the installer

- □ 1. Programme the SHW system for you
- □ 2. Confirm with you the programming was correct
- □ 3. Check you knew how to manage the system controls
- □ 4. Tell you if there was a timer
- □ 5. Set the timer for you
- □ 6. Show you the different parts of the control system (*e.g timer, switches, isolating switch, thermostat, valves)*
- □. 7. Provide any written supplier or installer guarantees

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G. Satisfaction with performance of SHW

32. What did you expect overall, from a SHW system?

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33. What was it about your particular system that made you buy it?

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Temperature

34. Where is your hot water temperature gauge?

□ 1. Inside house
□ 2. Outside
□ 3. N/A. No gauge
□ 4. Other. Specify ____________________

35. Is the temperature gauge easy to access and read?

□ 1. Yes □ 2. No.

Comments ____________________

____

36. If you have a timer, where is it?____________________

37. Were you told how much of your water was likely to heated by solar energy for your location and system?
□ 1. Yes
□ 2. No
□ 3. Don't remember

38. How does the actual supply of hot water compare to what you expected it would be?
□ 1. A lot better than I expected
□ 2. Somewhat better than I expected
□ 3. About what I expected
□ 4. Somewhat worse than I expected
□ 5. A lot worse than I expected

Comments ____________________

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Certainty

40. Do you find you?
□ 1. Always have adequate hot water
□ 2. Sometimes there is less hot water than needed
□ 3. Often there is less hot water than needed

41. If there times when you don't have enough hot water, in what kind of situation does that happen? Please describe

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42. Has your SHW system been affected by power cuts? What happens?

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Cost of SHW

43. What other costs did you have, apart from the main collector and cylinder unit?

- □ 1. Installation
- □ 2. Essential fittings not supplied as a standard part of the package
- □ 3. Additional plumbing
- □ 4. Additional wiring
- □ 5. Ongoing maintenance
- □ 6. Repairs
- □ 7. Repeat visits by installer
- □ 8. Building consent
- □ 9. Other. Please specify

____

44. How do these costs compare with what you expected?

- □ 1. As expected
- □ 2. Higher than expected
- □ 3. Lower than expected

Comment ____

____

____

45. How satisfied are you with the ongoing cost of maintaining your SHW system?

- □ 1.Very satisfied
- □ 2. Satisfied
- □ 3. Neither satisfied nor dissatisfied
- □ 4. Somewhat dissatisfied
- □ 5. Very dissatisfied
- □ 6. N/A

Comment____

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46. How much per electricity or gas bill do you think you save by having solar hot water? *(prompt for a proportion and a $ amount)*

$ _______________ % ________

47. How do your actual power bills seem to compare with what you thought you would save?

- □ 1. As expected
- □ 2. Higher than expected
- □ 3. Lower than expected

Comments____

____

48. How satisfied are you with the power cost savings?

- ☐ 1.Very satisfied
- ☐ 2. Satisfied
- ☐ 3. Neither satisfied nor dissatisfied
- ☐ 4. Somewhat dissatisfied
- ☐ 5. Very dissatisfied

Comments ____

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49. Have there been any unexpected benefits or costs? Describe.

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Performance

50. How long do you expect your SHW system to last ?___________

51. How happy now are you overall, with the choice of system that you made?

- ☐ 1. Very happy
- ☐ 2. Happy
- ☐ 3. Unhappy

Comments ____

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52. Overall, how well do you think you understand your solar hot water system and how to look after it?

- ☐ 1. Understand my SHW system well and can look after it
- ☐ 2. Have a reasonable understanding and knowledge
- ☐ 3. Have some understanding, but don't really know how to look after it
- ☐ 4. Don't really understand it very well at all

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53. What isn't performing the way you would like to?

____

54. Do you know why performance isn't as good as you'd like it to be?

□ 1. No □ 2. Yes. Please explain

55. What could you do to improve the system's performance?

56. Has your satisfaction with your system changed as the result of anything you have heard or read in the media?

□ I. No □ 2. Yes. Please explain

57. If you had to make the decision again about installing a SHW, would you choose the same system?

□ 1. No □ 2. Yes. Please explain

58. If you didn't get this system is there another system you would want? Is there anything you would do differently next time?

59. Would you recommend to family and friends that they install SHW?

□ I. Yes □ 2. No

60. If yes, what advice would you give to people considering it?

Management of SHW system

61. Do you ever do any of the following?

- □ 1. Set or adjust the timer (if fitted)
- □ 2. Programme the system to suit your lifestyle
- □ 3. Adjust the settings for lifestyle for household changes
- □ 4. Check the thermostat setting
- □ 5. Check the water temperature
- □ 6.. Check on roof for leaks, signs of wear or rust in pipes, panels, frame, fittings and roofing
- □ 7. Check in ceiling cavity for signs of leaks or wear in pipes, valves and other fittings
- □ 8. Check lagging on roof and in ceiling for signs of deterioration
- □ 9. Check collector panels for build up of dirt or debris
- □ 10. Clean collector panels
- □ 11. Clean roof under collector frame
- □ 12. Check quality of repairs or maintenance done by installer or other contractors
- □ 13. Other. Specify

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62. How often do you monitor the hot water temperature?

- □ 1. Daily, in the morning
- □ 2. Daily, at night
- □ 3. Several times a week
- □ 4. Once or twice a month
- □ 5. Seasonally
- □ 6. Never
- □ 7. N/A (*e.g. no temp gauge*)

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63. Do you regularly adjust the supplementary energy input after

monitoring the water temperature?
- □ 1. Yes
- □ 2. No
- □ 3. N/A

64. Are you happy with the amount of control you have over water temperature and supplementary heating?

Attitudes to Environment Issues

65. Have you heard of the term sustainable development?
- □ 1 Yes
- □ 2. No

66. Do you agree or disagree that most people in New Zealand today need to change their way of life so future generations can continue to enjoy a good quality of life and environment?
- □ 1. Strongly agree
- □ 2. Agree
- □ 3. Neither agree nor disagree
- □ 4. Strongly disagree
- □ 5. Don't know

67. How concerned are you about the environment in general?
- □ 1. Very concerned
- □ 2. Fairly concerned
- □ 3. Not very concerned
- □ 4. Not at all concerned
- □ 5. Don't know

Household Characteristics

68. How many people usually live here? ____________________

69. How often would more people stay in the household? (*people who regularly come and go e.g. children, extended family members)*

- ◻ 1. Seldom
- ◻ 2. Every few weeks
- ◻ 3. Most weeks
- ◻ 4. Every weekend

70. On average, how many extra people regularly stay?

____

71. How many children under 17 usually live here? ____________

72. How many people are usually home during the day on

(a) weekdays _____________

(b) weekends _____________

73. What ethnic group do you belong to?

- ◻ 1. New Zealand European/Pakeha
- ◻ 2. Māori
- ◻ 3. Samoan
- ◻ 4. Cook Island Māori
- ◻ 5. Tongan
- ◻ 6. Niuean
- ◻ 7. Chinese
- ◻ 8. Indian
- ◻ 9. Asian
- ◻ 10. Other. Please specify______________________

74. Total household (that is, you and other people in the house) income before tax?

- ◻ 1. 10,000 or less
- ◻ 2. 10,001 – 20,000
- ◻ 3. 20,001 - 30,000
- ◻ 4. 30,001 – 40,000
- ◻ 5. 40,001 – 50,000
- ◻ 6. 50,001 – 70,000
- ◻ 7. 70,001 – 100,000
- ◻ 8. Over 100,000

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APPENDIX B ELECTRICITY SUPPLIER GRAPHS

Figure 38, which is continued over the following pages, gives a graphical representation of the total household electricity consumption records from the electricity supply companies for each of the 33 households for which consumption information was obtained.

Each row of Figure 38 gives the data from each individual household with the graph on the left showing the full record of consumption provided and the graph on the right consumption one year before and one year after the SWH installation. Five years of consumption data was requested for each household. However, some periods of data could not be provided for such reasons as the house had not yet been built or the occupancy of the house had changed.

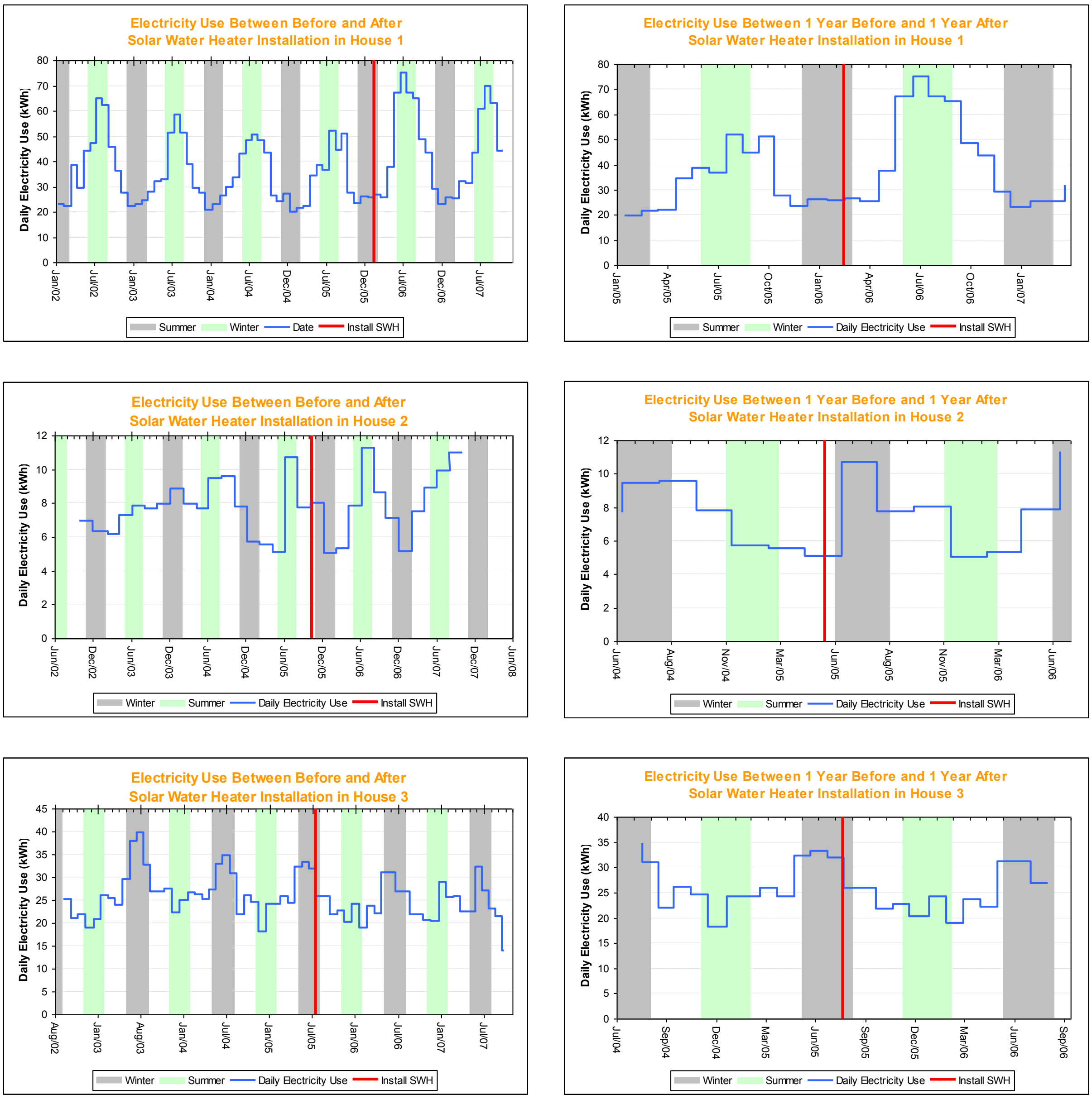


Figure 38. Electricity use over available data (left) and one year before and after installation of SWH (right) – each row is an individual house

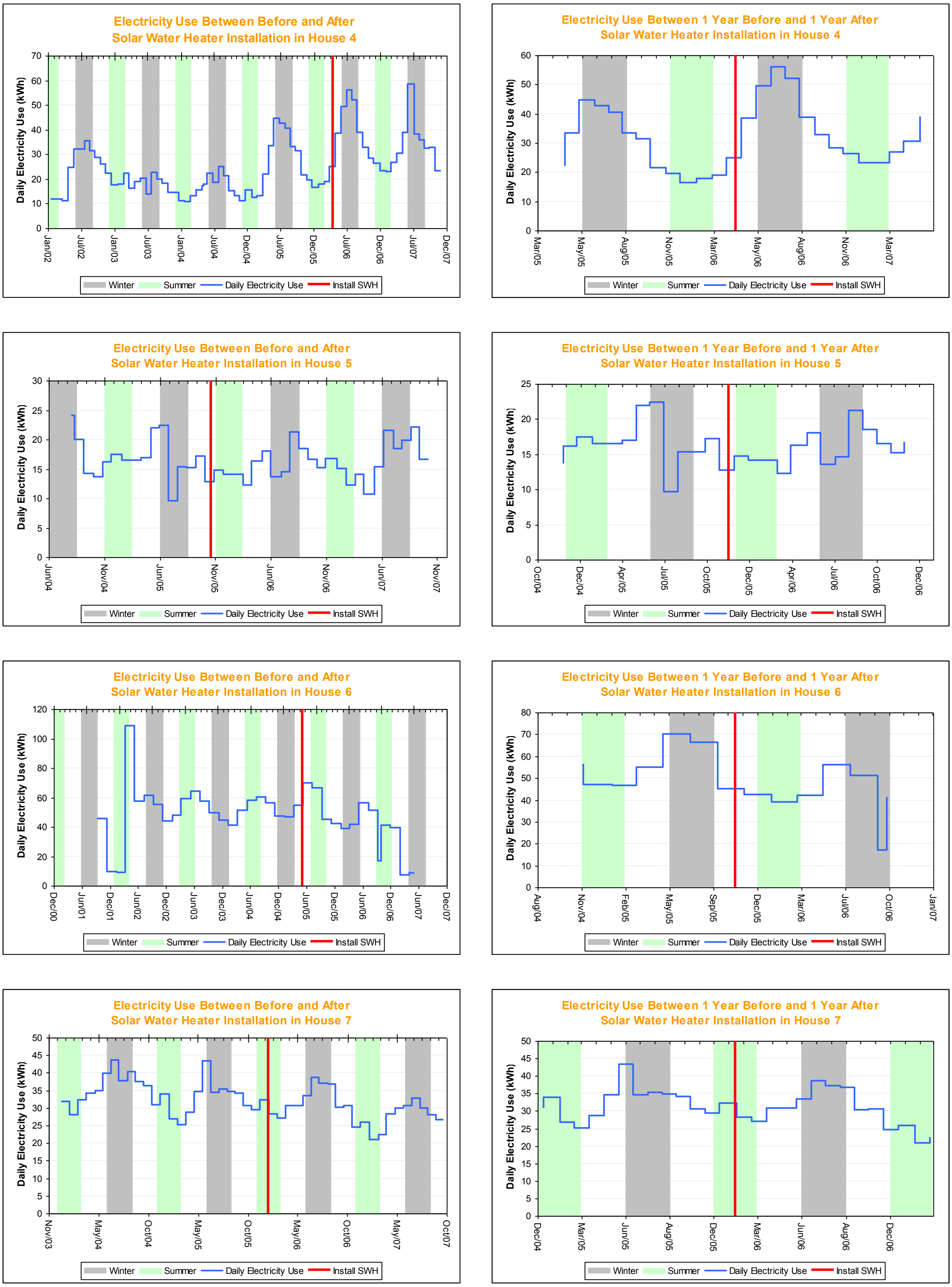


Figure 38 (cont.) Electricity use over available data (left) and one year before and after installation of SWH (right) – each row is an individual house

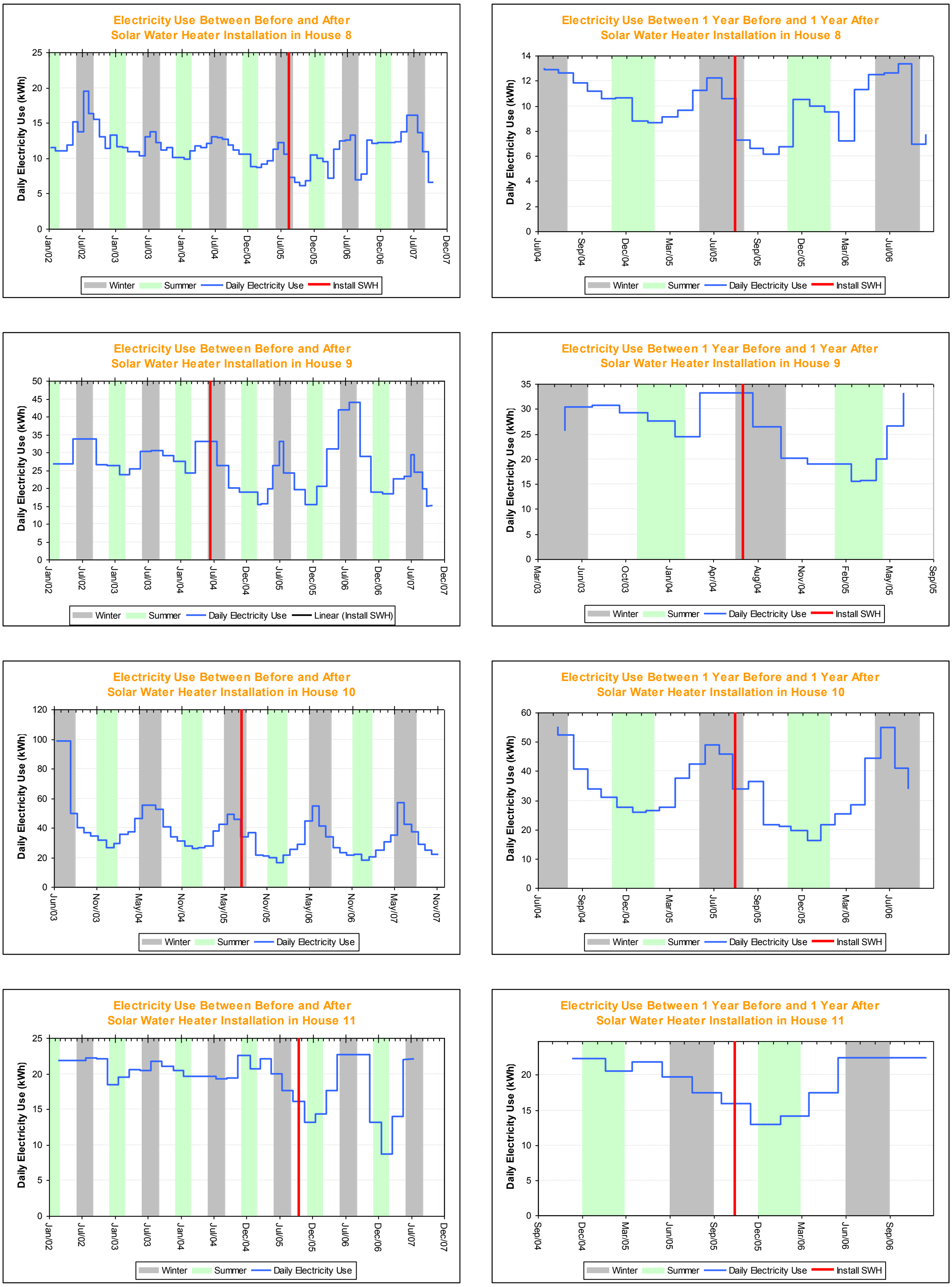
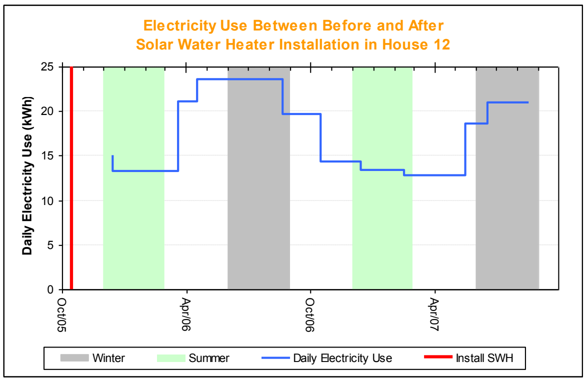
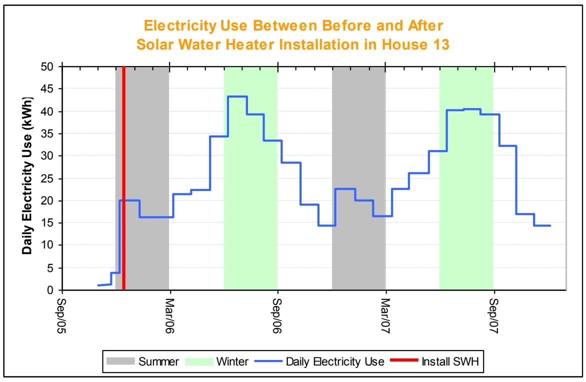
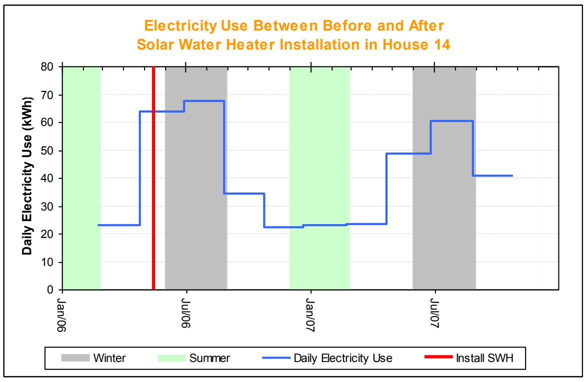


Figure 38 (cont.) Electricity use over available data (left) and one year before and after installation of SWH (right) – each row is an individual house







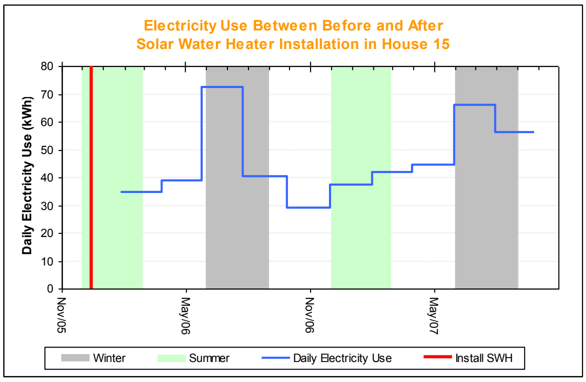
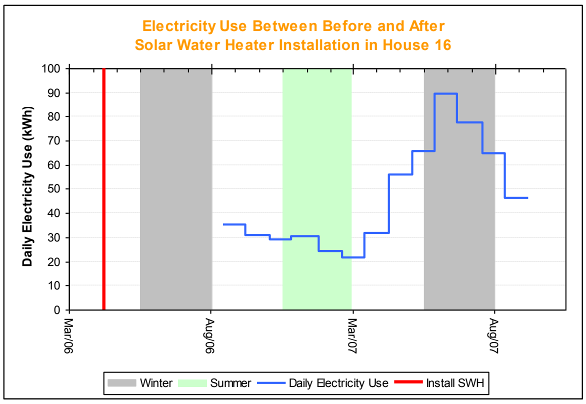
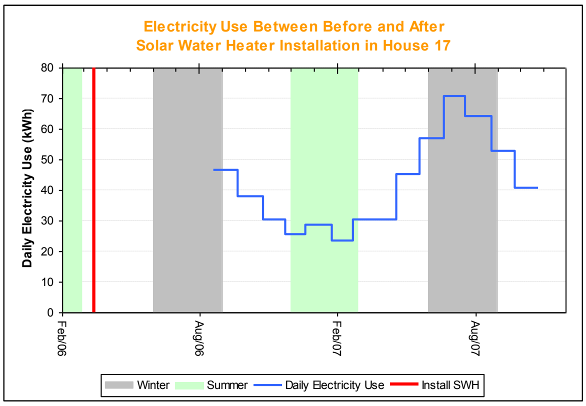
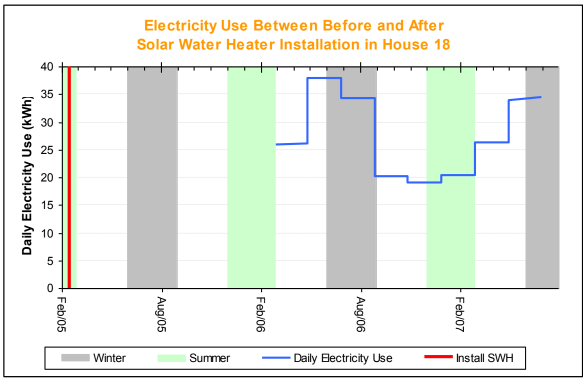
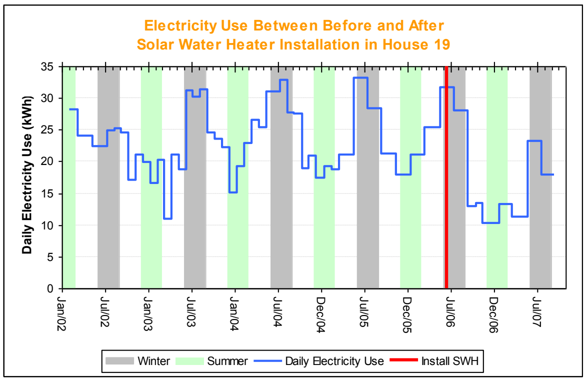


Figure 38 (cont.) Electricity use over available data (left) and one year before and after installation of SWH (right) – each row is an individual house









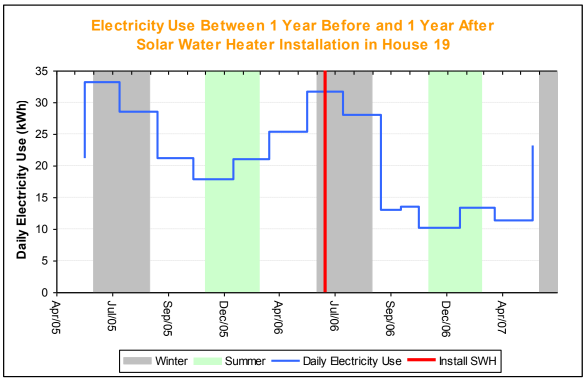
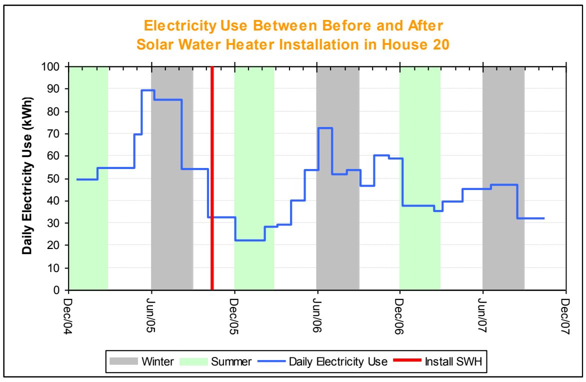
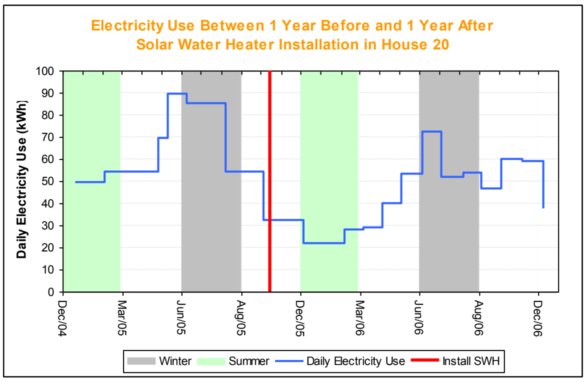
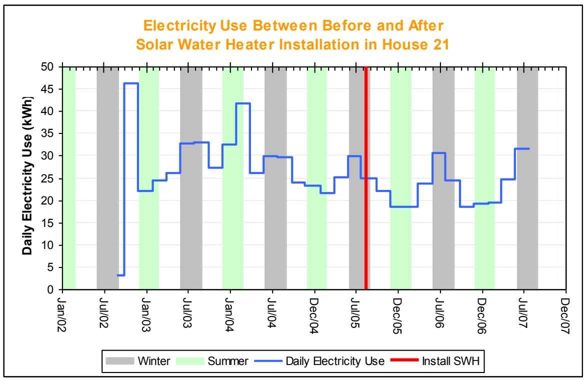
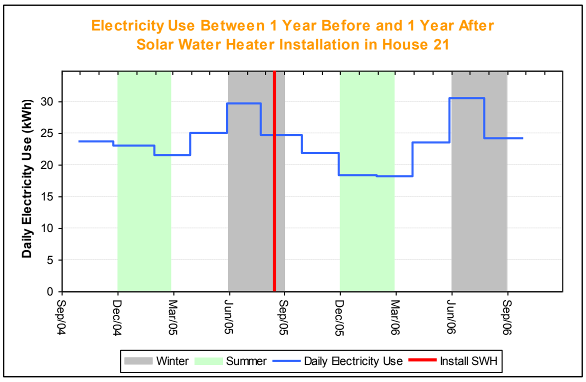


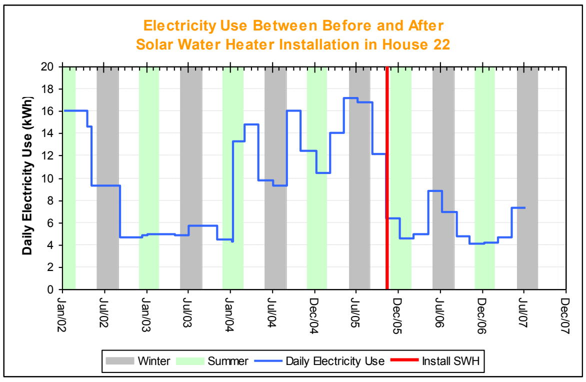
Figure 38 (cont.) Electricity use over available data (left) and one year before and after installation of SWH (right) – each row is an individual house

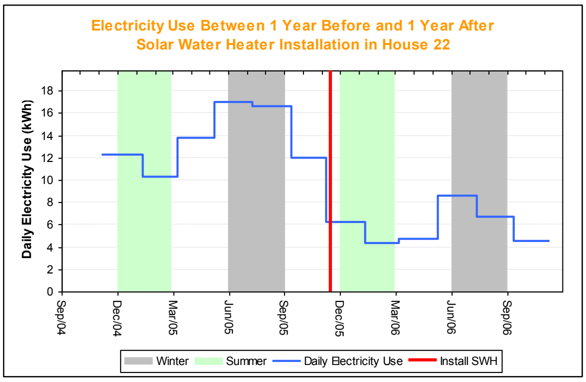


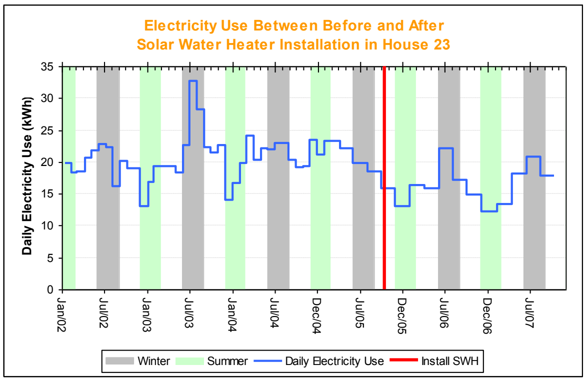












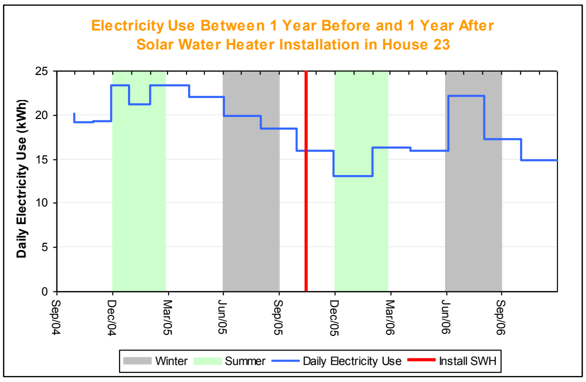
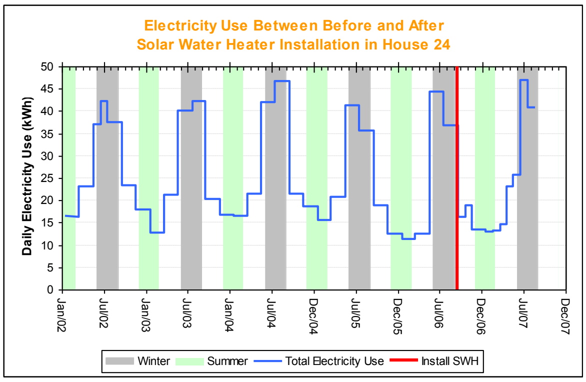
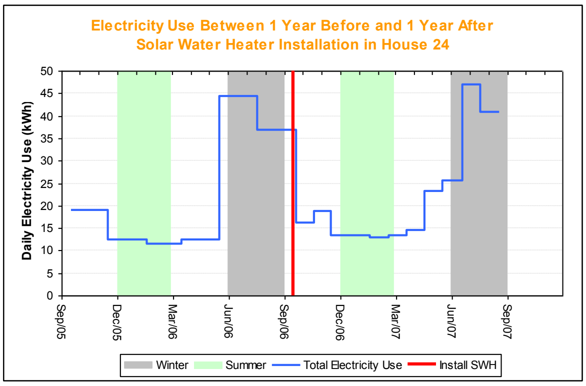
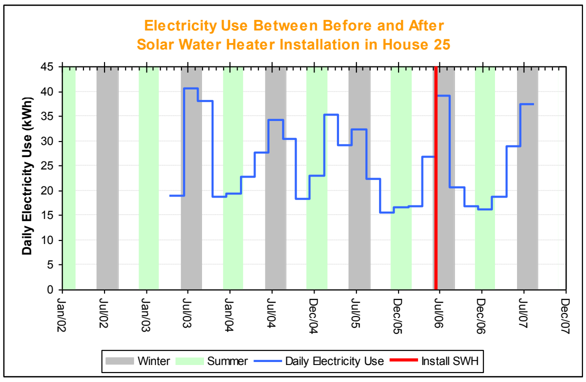
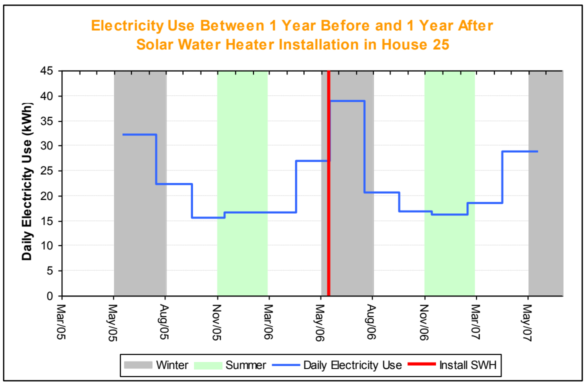


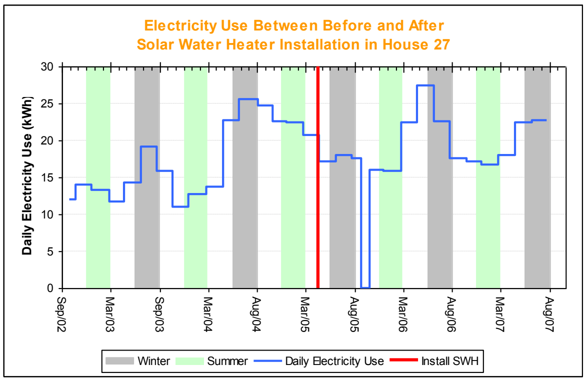
Figure 38 (cont.) Electricity use over available data (left) and one year before and after installation of SWH (right) – each row is an individual house

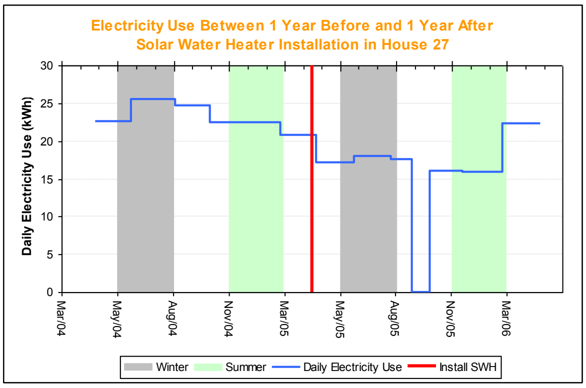


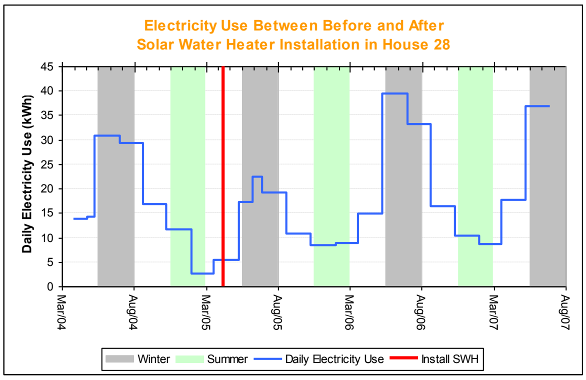












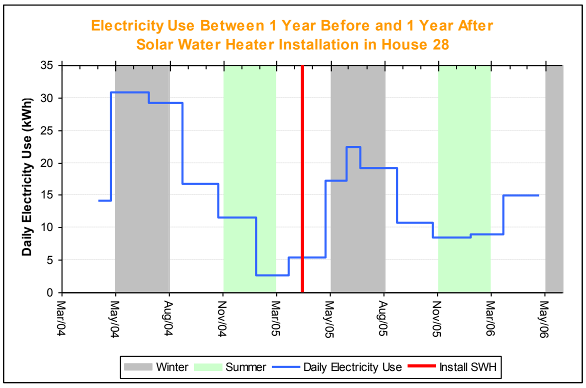
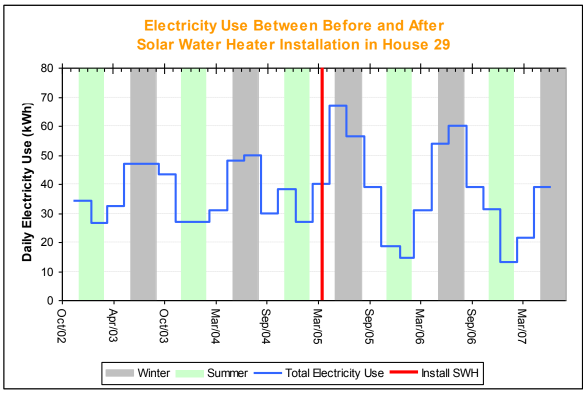
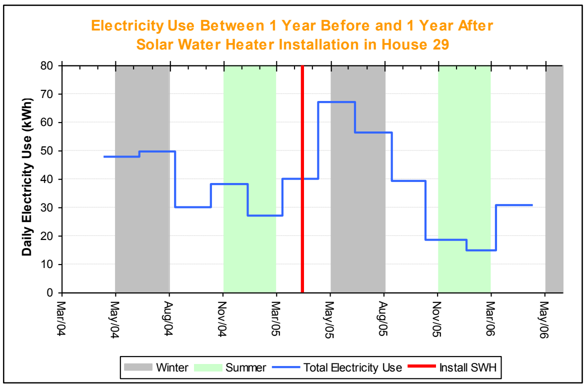
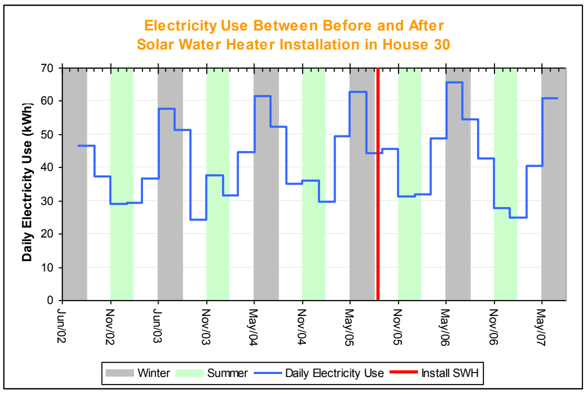
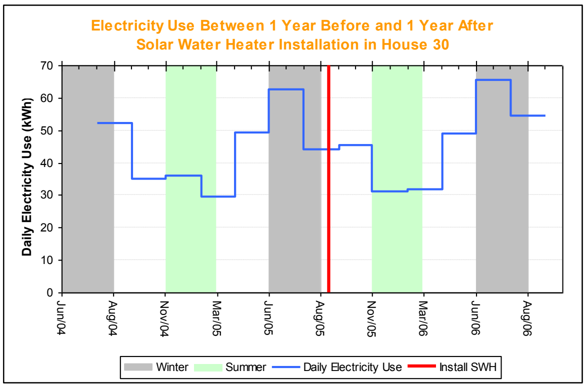


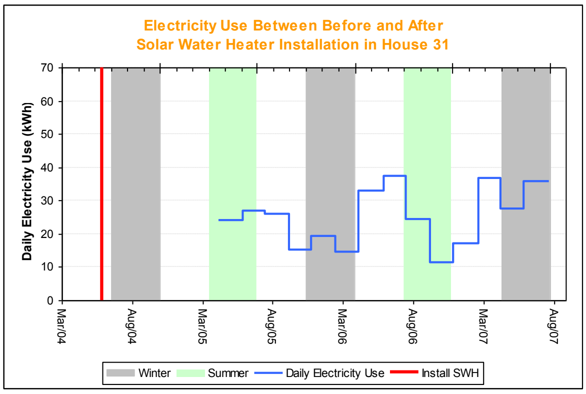
Figure 38 (cont.) Electricity use over available data (left) and one year before and after installation of SWH (right) – each row is an individual house











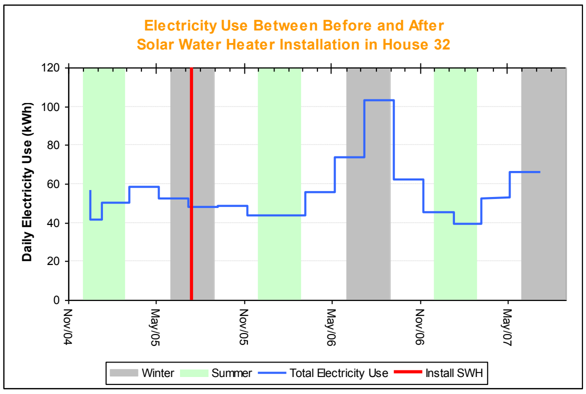
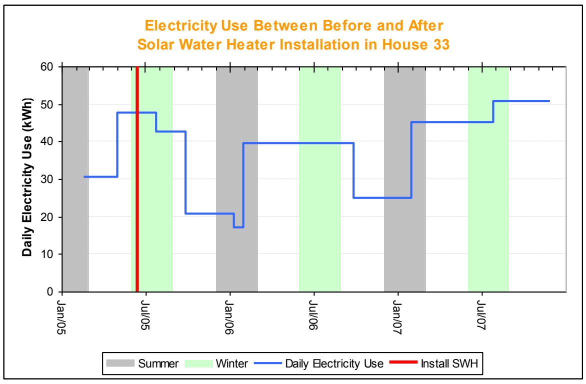
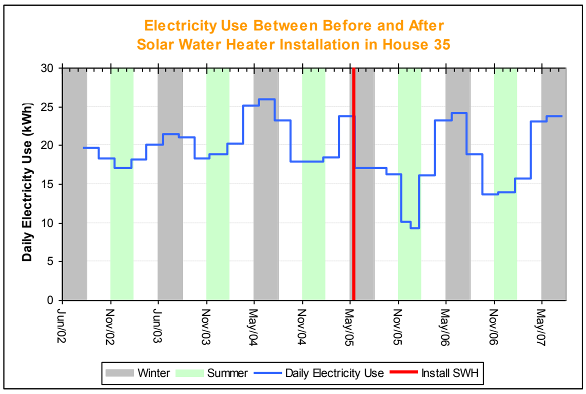


Figure 38 (cont.) Electricity use over available data (left) and one year before and after installation of SWH (right) – each row is an individual house





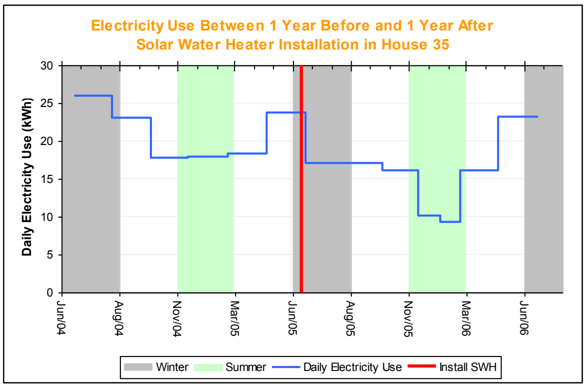


Figure 38 (cont.) Electricity use over available data (left) and one year before and after installation of SWH (right) – each row is an individual house