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Practical Means of Assessing Solar Water Heater Performance and Operation

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Preface

This work follows on from a project looking at solar water heaters in New Zealand which was reported in *BRANZ Study Reports 184,* 'An Inspection of Solar Water Heater Installations' and *188* 'The Performance of Solar Water Heaters in New Zealand'. Material in *BRANZ Study Report 237* 'The Energy Performance of Heat Pump Water Heaters' may also be of interest.

This report is intended to be viewed in colour, especially the graphs in Appendix A and Figures 14-17. To minimise environmental impacts, please limit printing this report.

Acknowledgments

This work was funded by the Building Research Levy.

In God we trust, all others must bring data
W. Edwards Deming

Practical Means of Assessing Solar Water Heater Performance and Operation

BRANZ Study Report SR 239

A.R. Pollard

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Abstract

Solar water heating (SWH) systems can save large amounts of energy. These systems are, however, not simple so it is important to ensure that they are delivering the level of performance required.

Verifying that a SWH system is achieving a level of performance can be done cost-effectively to a basic level of accuracy. This study report describes practical means of establishing the overall SWH system performance.

A variety of other information can also be collected about the operation of a SWH system. This information can be helpful to the occupants interested in understanding their system and looking to improve how it performs. Operational information is also important to solar professionals looking to address any performance issues with the system.

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1. INTRODUCTION

Water heating accounts for around 29% of New Zealand's residential energy use, with electricity accounting for a large proportion of this (Isaacs et al, 2010).

Solar water heating (SWH) systems use solar collectors to gather thermal energy from solar radiation. This solar thermal energy can displace a large fraction of the energy which would otherwise need to be provided by energy sources, such as electricity or gas, in order to meet water heating needs.

The success of SWH as an energy-saving technology depends on getting sufficient, well-performing SWH systems installed.

Currently the proportion of New Zealand households with SWH systems is low. Previous work (Pollard and Zhao, 2008) found that the overall energy performance of 35 SWH systems installed between June 2004 and September 2006 was varied and included many poorly-performing systems.

The situation since then has changed. Testing and performance standards have been updated. The results of these performance standards for many systems have been listed on the EECA website (www.eeca.govt.nz). Top-performing SWH systems can now receive the internationally recognised ENERGY STAR® label for energy efficiency. Building code compliance has been clarified with the Department of Building and Housing, as they have published an Acceptable Solution (G12/AS2) for SWH systems as well as providing guidance for when this Acceptable Solution cannot be used. Industry training has been improved and is standardised throughout the country.

While all of these changes have improved the likelihood that a SWH system installed today will be well-performing, it is important to ensure that the actual system installed actually performs well and that its components are operating correctly.

This study report is focussed on what information is required to understand the performance and operation of SWH systems and provides some practical advice on how this information could be collected. Performance information needs to be put into context, so this report includes a section of what performance information needs to be made available to the users of a system at the time of handover.

1.1 OPERATION AND PERFORMANCE

SWH is not just a matter of placing a solar collector on a roof. A SWH system is made up of a number of distinct components such as solar collectors, hot water cylinders, supplementary heating, pumps and controls. These components are assembled together on-site to provide a complete water heating system.

There are two important approaches when considering a SWH system:

- **System operation** which examines the system in detail, and ensures that all the components are installed properly and are appropriate and operate correctly with the other components of the system, or
- **System performance** which considers the overall system of how much hot water it delivers and how much energy it requires.

Either of these two approaches may be a preferred way of thinking about SWH systems by different groups of people. Many purchasers of SWH systems are not interested in understanding the operation of all of the separate components of a SWH system and may think of it in broader overall performance terms such as how much energy or money the system will save. Suppliers, on the other hand, need to configure a SWH system for a particular situation and may represent systems as comprising of many different components and options.

It is important for users of a SWH system to know how well it is performing. Measurements can verify (or refute) that a SWH system is achieving the energy savings expected and provide justification for the purchase of the system.

As a SWH system can be made of many components, understanding how a system is operating can require an extensive array of measurements to be made including temperature, flow rates, supplementary heating and pump use. Understanding what values of these measurements are acceptable for each of the individual components requires detailed specific knowledge. However experience in reviewing these measurements can allow a user to develop a better understanding of how the system works and opportunities for improvements. When a SWH system is not performing well, detailed information can help identify the problem.

2. SWH SYSTEM PERFORMANCE

The overall SWH system performance can be examined by considering the overall heat flows into and out of the system as shown schematically in Figure 1. Heat flows are invisible and can be difficult for users to appreciate. The primary output is the heated water used in the household. The heating for this water is sourced from solar energy, and when this is not sufficient some form of supplementary heating such as a standard electric heating element. An often neglected heat flow is the standing losses which is the heat lost from the system when parts of it are hotter than the surrounding environment.

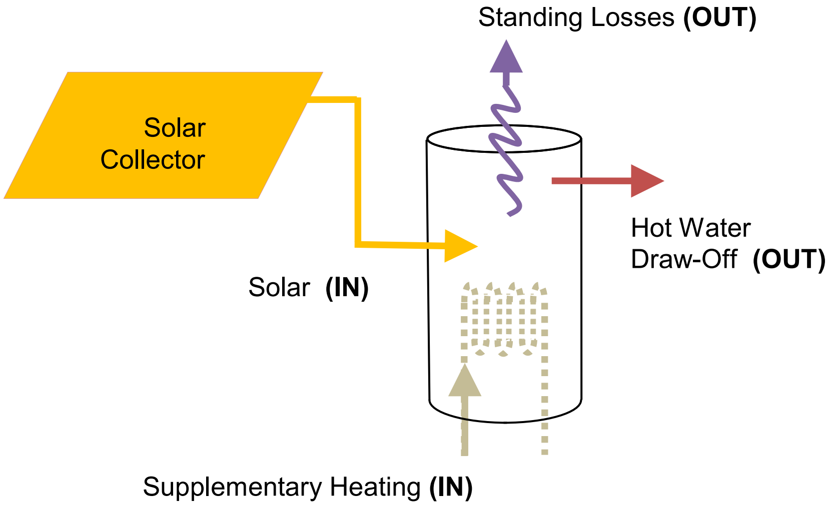

Figure 1. Thermal energy balance of a SWH system

Figure 2 shows a hypothetical example of an energy balance for a typical SWH system. The total thermal energy of the system is provided by the solar collector and supplementary heating shown on the left in Figure 2, and this balances the thermal energy supplied to the household as hot water (shown as the ‘draw-off’) and the standing losses. Some additional auxiliary energy may also be required to operate controls and pumps within the SWH system.

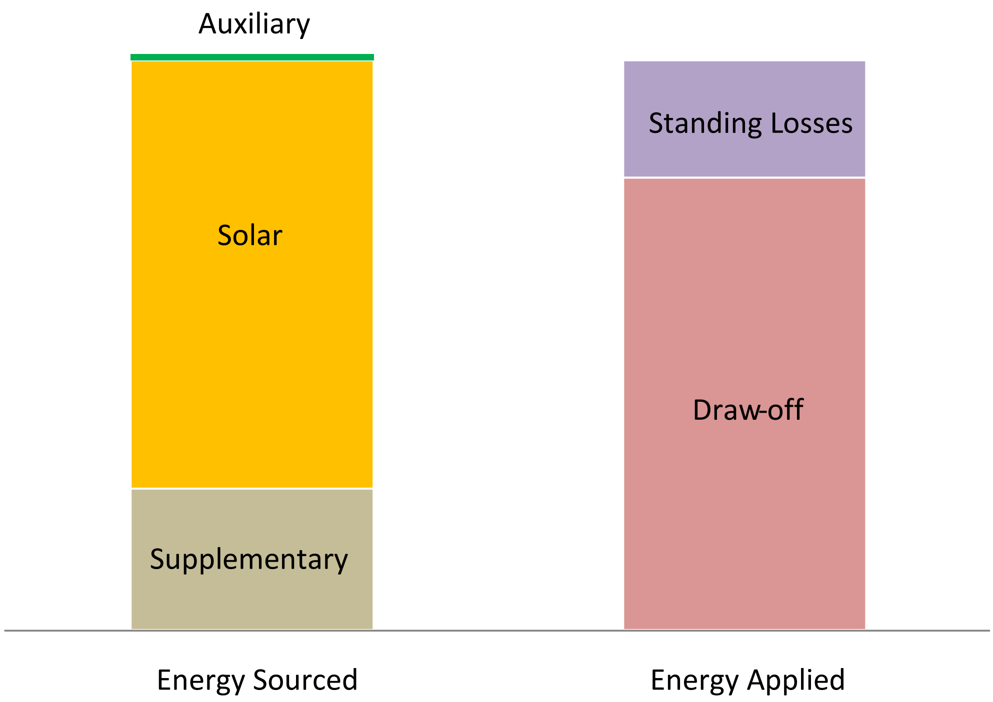

Figure 2. Example of an energy balance

A well-performing SWH system will have a large proportion of the sourced energy coming from the solar collectors keeping the supplementary heating small. A well-performing SWH system will only have a small proportion of the total thermal energy being lost as standing losses with most of thermal energy going into the draw-off water.

There are a number of alternate performance measures that can be defined and many of these can be done in subtly different ways (Lloyd and Kerr, 2008). One convenient performance measure, known as the coefficient of performance (COP), is a dimensionless ratio constructed from dividing the energy content of the amount of hot water supplied by the system ($Q_{draw\text{-}off}$) by the non-environmental energy (E_{ne}), which is equal to the supplementary heating and auxiliary energy used to operate the system.

$$\mathrm{COP} = \frac{Q_{draw\ off}}{E_{ne}} \qquad (2.1)$$

Rather than considering the energy balance of Figure 1 and Figure 2, the COP approach considers the SWH system as a 'blackbox' input-output system such as that shown in Figure 3. The inputs and outputs of the blackbox are the observables of the system and can be quantified as an energy value. The observables that the occupants are aware of are the amount of hot water a SWH produces and the required input of supplementary heating (and some auxiliary energy for any pumps and controls). What is excluded from the COP is the amount of solar energy captured, which depends on the solar collector and the difficult to measure standing losses of the system.

Figure 3. The SWH system 'blackbox'

An advantage of the COP is that the parameters can be readily measured and it does not require an estimate of the standing losses for the system to be made. This improves the accuracy of the estimate, but requires more thought when interpreting its values. An instantaneous electric water heater would have a COP of 1 as 100% of the electrical energy input is converted to heated water for the users. An average storage hot water cylinder, however, has standing losses of around 33% of the total water heating energy (Isaacs et al, 2010). These standing losses lead to a COP for an average electric storage cylinder 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.

2.1 Measuring SWH system performance

Measuring the inputs and outputs (Figure 3) for a SWH system in order to determine the COP of the SWH system can be achieved following the monitoring procedures outlined in Pollard and Zhao (2008). These procedures require an amount of equipment and level of sophistication beyond the scope of most SWH applications, so simplification of both the input and output sides needs to be considered.

EECA, in looking to review the energy performance of heat pump water heating (HPWH) systems in 2010, used a simplified approach in order to measure a large sample of systems. A smaller audit sub-sample was also measured to allow the differences in the measurement methods to be examined (Pollard, 2010).

The inputs and outputs are defined in terms of energy, which can be expressed as power multiplied by time. Both the inputs and outputs need to be measured over the time interval. Integrating sensors which accumulate energy over time are frequently used. Many integrating sensors feature a pulsed output where each incremental unit of energy use is accompanied with an output pulse. For detailed analysis, energy data is collected at regular short intervals to allow for individual events to be examined while allowing data to be aggregated together for analysis at longer intervals.

The means of collecting data at short regular intervals is to use some data acquisition systems or data loggers (Pollard, 2007) such as the use of pulse (data) loggers. Data acquisition or data logger systems can be expensive, but provide the most flexibility for data analysis and reporting. Where integrating sensors are used it is possible to analyse some historical information by taking manual readings at the required preset intervals (daily, weekly or monthly readings).

The means of measuring the input electrical energy and the output hot water draw-off energy will be separately discussed in the following sections 2.1.1 and 2.1.2.

2.1.1 Electrical energy

In many cases the supplementary water heating energy (and any auxiliary energy) is not quantified separately, as only the total electricity use from the monthly electricity bill is available. In this case, the system looks to the users more like Figure 4, where changes in the SWH system performance may not be apparent when there are also changes in other electricity use. It is important that the SWH system be separately monitored from the other electrical services within the house.

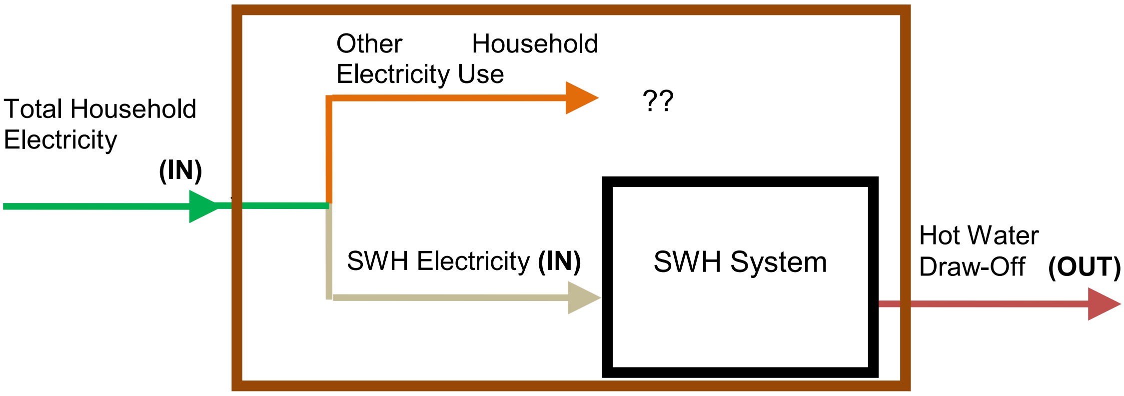

Figure 4. The 'brownbox' with supplementary heating and auxiliary energy as part of the total electricity use

Integrating meters for electricity are readily available. Pollard and Zhao (2008) made use of standard electricity meters such as the meter shown in Figure 5. These meters were generally installed on the external meter board such as shown in Figure 7. For its recent HPWH project, EECA has made use of smaller DIN rail-mounted electricity meters (Thompson, 2009) such as the one shown in Figure 6. These meters cost less than $40 (in quantity) and can be mounted alongside other items on modern fuse-boards such as the one shown in Figure 8.

An alternative to an integrating meter is to use an integrating home energy monitoring system. These systems use current transformers (CTs) placed around the cable feeding the circuit of interest. In this case the CT would be placed around the hot water circuit, but for most home energy monitoring systems the CT is placed on the main feed cable for the house. It is important to ensure that the home energy monitoring system records an integrated record of energy use as many only display the current power rate. Home energy monitoring systems tend to be a more expensive option than a single low-cost integrating meter. However they allow the electricity use of the SWH system to be reviewed in a convenient manner. The unattributed website (Anon, 2010) provides an overview of home energy monitoring systems available in New Zealand.

Figure 5. A Siemens S2AS electricity meter with a BRANZ pulse logger

Figure 6. A DDS1Y DIN rail electricity meter alongside a BRANZ pulse logger

Figure 7. The hot water and total household electrical energy use being monitored by Siemens S2AS meters

Figure 8. A DDS1Y DIN rail electricity meter (blue display) measuring a heat pump water heater installed on a typical modern fuse-board

2.1.2 Hot water draw-off energy

Providing for an integrated measure of the hot water draw-off energy is more complicated. The thermal energy content of the water drawn-off from the cylinder is proportional to the product of the quantity of water drawn-off and the temperature difference between the outgoing and incoming water to the cylinder. Mathematically this can be expressed as:

$$Q_{draw\text{-}off} = \rho \quad V \quad c(T_h - T_c) \tag{2.2}$$

Where

- ρ Is the density of the water drawn-off
- V Is the volume of the water drawn-off
- c Is the specific heat capacity of water
- T_h Is the temperature of the water drawn-off
- T_c Is the temperature of the incoming cold water

These terms need to be multiplied on instantaneous measures of flow rate and temperature difference and then integrated. While these flow rate sensors and multipliers are available, they are expensive with many costing thousands of dollars.

In the monitoring undertaken by Pollard and Zhao (2008), volumetric water meters with a pulsed output were used. These water meters were not suitable for use with hot water, so the meter is placed directly before the cold inlet to the hot water cylinder. It is important to make sure that no other take-offs, such as a cold water connections to tempering values, are between the meter and the cylinder. The pulsed data from these meters needs to be collected at short time intervals; in Pollard and Zhao (2008) a six minute interval was used. This is so that the multiplication with a measured temperature difference can be better resolved and a more accurate approximation to the thermal energy content made. The temperature of the draw-off water (hot) and the incoming water (cold) was measured by connecting a thermocouple to the outside of the copper pipe approximately 300 mm from the outlet. There is a delay for the pipe to warm up as water passes through it, so the temperature measurements were delayed one logger time step (six minutes) to more accurately reflect the temperature of the water at that time.

In simplifying this monitoring, the temperature difference could be assumed to be fixed and a totalised water volume obtained from the basic $100 water meter.

Figure 9 shows the correlation between the average daily hot water use and the draw-off energy for the 33 SWH systems from Pollard and Zhao (2008) indicating that the water volume can provide a reasonable basis as an estimation of the hot water draw-off energy. The average temperature difference for the 33 systems was 36°C. Using this temperature difference, along with the measured average daily hot water use in Equation 2.2, allows an estimation of the draw-off energy to be calculated. This calculated draw-off energy is compared with the measured draw-off energy in Figure 10 with the one-to-one line shown in purple providing a good fit to the data.

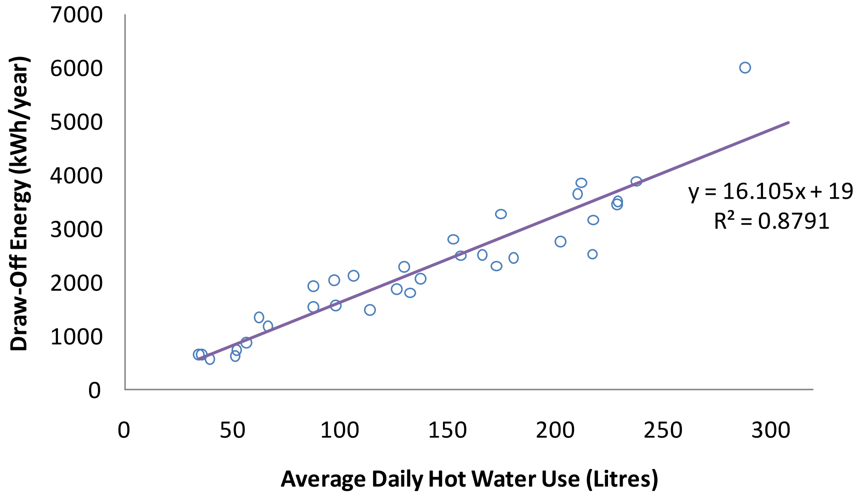

Figure 9. Correlation of the draw-off energy from the average daily hot water use

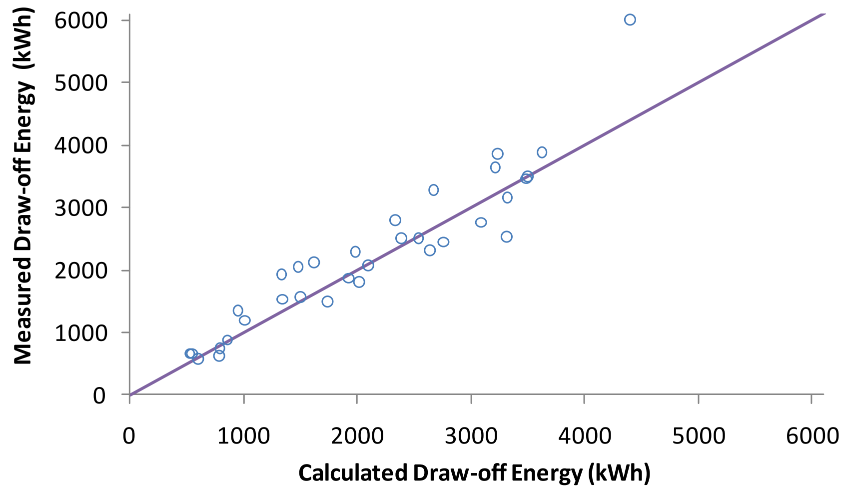

Figure 10. Comparison of the measured and calculated hot water draw-off energy

Using the volume as an approximation for the hot water draw-off energy was used by EECA in its monitoring of HPWH systems and is discussed in Pollard (2010).

Where the cost of a meter and its installation is too high, an estimation of the thermal energy content of the hot water used could be made from assuming a fraction of the total household water use that is heated (if the house is metered) or from totalling up individual water use durations, temperatures and water flow rates. Heinrich and Roberti (2010) reported on the make-up of water use in Auckland. However hot water was not specifically separated out. Where warm (mixed) water flow rates are considered, water temperatures need to be considered. For example, a 10 litre per minute shower at 40°C may draw-off hot water from the cylinder (60°C) at 5.5 litres per minute. This technique is subject to the quality of the data used and improved estimation tools in this area would be of benefit.

3. COMPONENTS OF A SWH SYSTEM

Historically, interest in SWH systems has tended to focus on solar collectors as these are specific to this technology and are critical to the performance of the systems. There are, however, a variety of other components within a SWH system whose operation can be examined and many that are important to the overall system performance.

There are many possible different designs of SWH systems and not all options and configurations can be covered in an introduction to these systems. This section introduces the typical components areas seen in most SWH systems which can be considered as comprising of a number of 'C's'.

3.1 Collectors

The solar collector is the first stage of getting solar energy into the hot water in the SWH system. All other design choices will reduce the amount of heat getting into the water.

A solar collector needs an efficient collector surface that is well insulated from the external environment. Ideally collectors should be installed free from shading by nearby objects, facing north and at an appropriate angle. Using the latitude of the site (37°C for Auckland, 41°C for Wellington or 43.5°C for Christchurch) will provide the collector with good year-round sun. Installing a collector at a steeper angle may provide more effective collection of solar radiation during the winter.

The size of the collector needs to be matched to the angle of the collector, the available heat storage within the system and the anticipated demand for hot water.

It is important to ensure that the solar collector is adequately protected from frosts and over-heating.

3.2 Cylinders

Cylinders can be made out of a variety of materials although some types, such as enamel lined steel cylinders, may require more tightly controlled temperature management than cylinders constructed from other materials.

The size of the cylinder needs to be matched to the size of the collector area.

The hot water cylinder provides two functions: one is storage of solar heated water, and the other is to provide supplementary heating for water when there has not been sufficient sun. A general means of achieving these two tasks within the one cylinder is to make the cylinder larger and to maintain a temperature gradient within it. The bottom of the cylinder is cooler, and provides water to the solar collectors, which are then returned as heated water mid-way within the cylinder. Supplementary heating can be provided by placing a heating element in the top section of the cylinder so that only the water in this top part is heated allowing room for the storage of the solar heated water below it.

The cylinder generally requires supplementary heating and how this is controlled is discussed in section 3.4

The heat losses from the hot water cylinder also need to be minimised by ensuring that the cylinder and all its associated pipework are well insulated.

3.3 Circulation pump

Many systems have the solar collector and cylinder separate and make use of a pump to transfer heat from the solar collector to the cylinder. This pump operation is managed by a controller which measures the collector and cylinder water temperatures. The controller can generally be set to prevent overheated water from being transferred to the cylinder which may potentially damage the cylinder.

3.4 Controls

The supplementary heating in the cylinder is subject to thermostat control but also needs additional control to prevent unnecessary heating when solar is – or soon will be – available. One means of achieving this control is the use of timers on the supplementary heating element. The timer would exclude heating except for a few hours before anticipated water demand (to ensure that water is available when there is not much solar). Many people have morning showers and it is important to prevent the supplementary heating from immediately heating the water before the sun has had a chance to heat the solar collectors. The use of timers is very important and Kerr (2008) has shown that performance can be improved by over 50% with their use.

Some regular heating may be required to provide Legionella control. The non-mandatory Acceptable Solution for SWH systems (G12 AS2 – DBH, 2007) provides for three Legionella control strategies (see G12 AS2 for details):

a) continuously heated to 60°C where the heating element is located in the bottom 55% of the cylinder
b) water above the element is heated to 60°C once a day where the element is in the bottom 20% of the cylinder
c) all of the stored water is heated to 60°C once a week for not less than one hour (the temperature measured is in the bottom 20% of the cylinder).

3.5 Connections

There are a variety of means of configuring systems. A solar heated cylinder may act as a preheater to another cylinder or an instant gas system. Wetback systems may be connected to the system to provide more heating in the winter season when solar input is reduced.

There are many important considerations to be made in connecting all of the separate elements together. SWH systems may require many special plumbing fittings that are capable of operating under more demanding conditions than is the case for regular domestic plumbing. Additional solar fittings, such as frost protection or overheating, may also be required.

Again, it is important to ensure that all parts of the system are well insulated.

3.6 Consumer displays

Getting all the other ‘C’s’ right will achieve a well-performing system but how is the user to know this?

The occupants’ attitude to a SWH system can be influenced by the type and quality of information provided. A well-performing system which does not provide any information may leave the occupants wondering what the system is actually doing and how much energy it is saving compared with a standard means of heating water.

Some householders like to know all about their system. With improved technology people are increasingly expecting systems, including household energy services, to be able to provide more and more information about what the system is doing. This allows them to better appreciate their system and to develop detailed knowledge (Bellinger et al, 2010) on how to use their systems efficiently. For example, familiarity of the display of cylinder temperature may allow occupants to know how much hot water the system has stored and to allow them to manually switch off the supplementary heating and still be confident that the system will be able to meet their upcoming hot water use.

The key measure of a SWH system is its energy performance. It is important that SWH owners are satisfied that their SWH systems are performing well and meet their expectations. Verifying system performance (discussed in section 2.1) should be made easily accessible to householders. At a minimum, a low-cost electricity meter, such as those described in section 2.1, and accompanying guidance should be included.

4. PERFORMANCE INFORMATION AT TIME OF PURCHASE

As the function of a SWH system is to save energy for water heating it is important to ensure the solar professionals are informing purchasers of systems what percentage of water heating costs will be saved with the installation of the SWH system. Scotts and Saville-Smith (2007) found that many estimates of the savings that a newly-installed SWH system would achieve were vague, offering the occupants little opportunity to confirm the system is performing as well as it could.

Many home owners are not interested in understanding ongoing performance issues of their SWH system and leave it to the solar professionals who specified and installed the system to ensure that performance is designed for and achieved (Scotts and Saville-Smith, 2007). Scotts and Saville-Smith (2007) also reported that a majority of householders were not shown the different parts of the SWH system or how to operate and manage the controls.

Computer simulation programs such as TRNSYS (Solar Energy Laboratory, 2007) allow the overall SWH system performance to be reliably estimated provided sufficiently accurate data is available on all of the individual components and that all of these components are operating as expected. These computer simulations are complex, calculating the operation of the system at sub-hour intervals over a typical year. Figure 11 shows an example layout for a SWH system in the TRNSYS program.

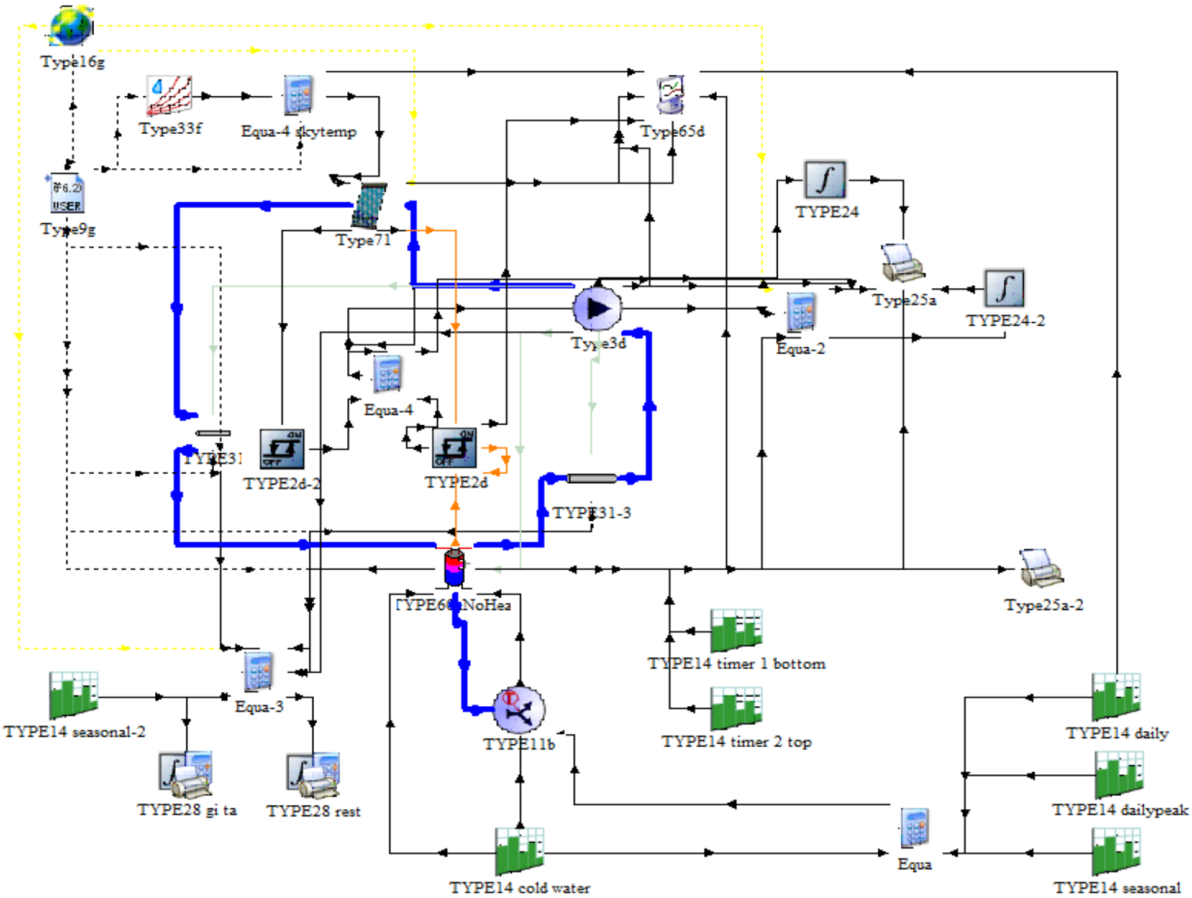

Figure 11. TRNSYS representation of a SWH system (from Kerr, 2008)

These computer simulations are dependent on the particular components used (model of SWH system), hot water usage patterns and climate the system is in. If standardised patterns of hot water use are used for particular locations then computer simulations can provide comparative information on the expected performance of different models of SWH systems.

The standard AS/NZS4324:2008 gives guidance on the use of TRNSYS for estimating the performance of SWH systems. AS/NZS4234:2008 provides standardised inputs to allow for different models of SWH systems to be compared in a systematic manner.

The EECA website (2009) lists the results of TRNSYS simulations following AS/NZS4234:2008 for many different models of SWH systems. A particular model of a SWH system must comprise the collection of components stated, as substituting components may change the overall performance of the system.

4.1 Overall expected performance

It is important for the solar professional to work through the impact of model selection and design choices on the performance of the system with their clients with quantifiable implications provided e.g. *"Yes, the solar collector can be installed flat on the roof for your particular site but instead of achieving x level of performance you will achieve y"*. An overall estimate of expected system performance should be made based on the final agreed design and configuration.

The most accurate way to determine the overall expected performance is to run a computer simulation for the particular model of SWH system with all of the particular design variations present. The high cost of producing these simulations however may be a limiting factor.

Some simplified tools are available to estimate overall expected performance. RETScreen® (Natural Resources Canada, 2010) is a clean energy project analysis framework that includes a SWH module. This module uses monthly climate information and system details to provide a financial analysis for SWH. The RETScreen® SWH module deals with the solar collector well, but lacks flexibility around heat losses and supplementary heating control.

Rather than using simplifying tools an alternate approach is to use the results of the computer simulations for base case systems and to apply correction factors to estimate the overall expected performance for the particular system. Such a process may make greater use of tables such as that shown in Figure 12, taken from the solar water heating guidance document from the Department of Building and Housing (DBH, 2009). This table shows the decrease in SWH system performance resulting from changes to the slope and orientation of a particular flat plate solar collector.

Tables like these are frequently constructed from multiple runs of computer simulation programs. Care must be taken when applying these tabulated factors beyond the range that was provided as input to the computer simulation. For example, Figure 12 refers to AS/NZS4234:2008 Climate Zone 5 which covers most of the country except for Otago, Southland and the West Coast. In these more southern locations, the winter sun angle is lower so that steeper collector angles may be more effective and performance drop-offs may differ from those given in Figure 12.

Orientation (degrees)		**Inclination angle (degrees)** 0	10	20	30	40	50	60	70	80
	240	0.86	0.81	0.76	0.69	0.62				
West	270	0.86	0.86	0.84	0.81	0.78	0.72	0.66	0.59	0.50
	300	0.86	0.89	0.91	0.91	0.90	0.86	0.80	0.72	0.63
	330	0.86	0.92	0.96	0.97	0.97	0.93	0.88	0.79	0.68
North	0	0.86	0.93	0.98	1.00	1.00	0.96	0.90	0.81	0.69
	30	0.86	0.92	0.96	0.98	0.98	0.95	0.89	0.81	0.70
	60	0.86	0.90	0.92	0.92	0.91	0.88	0.82	0.75	0.67
East	90	0.86	0.86	0.85	0.83	0.80	0.75	0.69	0.62	0.55
	120	0.86	0.82	0.77	0.71	0.65				

Figure 12. The effect of slope and orientation of a flat plate collector on the performance of a SWH system – taken from DBH (2009)

Modelled using a 3.3 m^2 flat plate collector, AS/NZS4234 2008 Zone 5.

There are other areas where quantifying the performance reduction would be helpful. For example, Kerr (2008) provides results from computer simulation of the over 50% improvement in system performance from the installation of a timer into a standard retrofitted SWH system.

It is important that expected performance is precise enough that it can be verified using the methods described in section 2.1. An important difference between expected performance and measured performance comes from how particular occupants use hot water.

5. SWH SYSTEM OPERATION

While many users of SWH systems are only interested in if their system is performing well, many users are interested in how their system operates, what amount of solar energy is collected or how much energy is stored in the cylinder. Information on how their SWH system is operating may allow occupants to better appreciate their SWH system. Detailed operating information may also allow interested occupants who are keen to maximise the performance of their system to know how best to control their system including when they use hot water.

If a system is not performing well, visual inspections by solar professionals may not be enough to diagnose the problem. Information on how the system is operating, such as the temperatures throughout the system and whether pumps or supplementary heating are operating, may assist in identifying problems with the system.

There are many parameters that could be measured for each of the many components of a SWH system. In order to get an overview of how a system is operating only a basic level of detail would be required. If information is required on a particular performance issue only detailed information may be required from specific components of the SWH system. As SWH systems involve time-dependent processes, such as when the sun is out or how much energy is stored in the hot water cylinder, it is useful to be able to record this information over a period of time. The ability to review past operation may allow the user to become familiar with what the typical values are for the system and to operate it more effectively.

Figure 13 shows a screenshot of a commercially available system monitoring tool from Splash Monitoring (Energy Conscious Design, 2010). This screenshot shows an instantaneous overview of how a particular system is operating. From the view graph button at the bottom of the page, historical information for a range of components can be displayed. The data required for this display is obtained from a variety of sensors throughout the SWH system. The sensor data is then fed into a processing unit that is connected to the internet which allows the system operation data to be transferred to a server and viewed anywhere as a webpage.

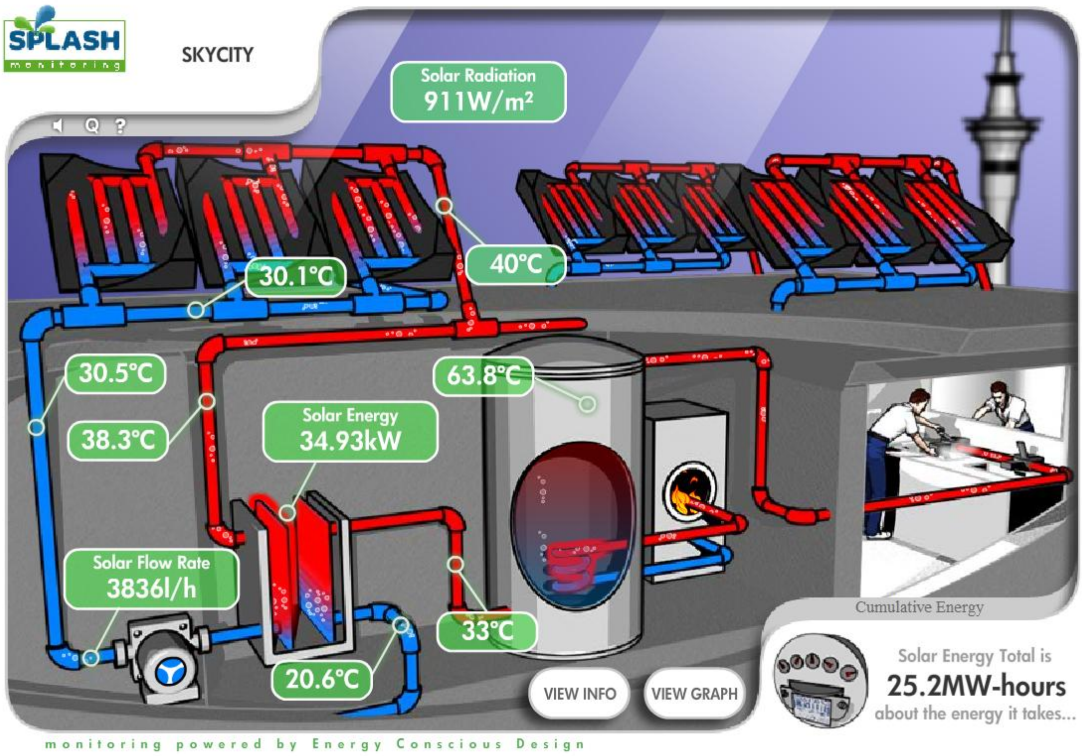

Figure 13. An example of a display of instantaneous system operation information (from Energy Conscious Design, 2010)

The supplementary heating is a key element in the overall performance of a SWH system. While a small electricity meter can be readily added to record (as was suggested in section 2.1) this meter (being located either at the meter board or near the hot water cylinder) may not be in a convenient location for the occupants to readily review. Home display units for electrical energy are becoming more popular in New Zealand and these could be used to display the electrical supplementary heating. The unattributed website (Anon, 2010) provides an overview of options available in New Zealand.

SWH systems that have a pump usually include a controller to monitor the temperature of the water in the collector and the cylinder and to operate the pump to transfer this heated water when appropriate. Many of these controllers will display these temperatures and other settings on the controller display. If these controller displays are intended to be used by the occupants, they need to be installed in a location within the house where the occupants can readily review the information. The SWH systems examined in Pollard and Zhao (2008) included many controller displays located in difficult (cupboard in hallway) or inaccessible (roof-space or sub-space) locations.

Most controllers only display the current information and it is not possible to review historical data. Diagnosing a SWH system that is not operating correctly may require understanding of how components are operating at different times. For example, one of the systems in Pollard and Zhao (2008) had a reverse circulation through the solar collector at night. This was not directly measured as part of the overall performance monitoring of the system (which would include temperature measurements on the inlet and outlet of the hot water cylinder), but was clearly revealed from measured values of the temperature in the solar collector loop. As this reverse thermosiphoning occurred at night, reviewing this parameter during the day may not have highlighted the issue.

In addition to any system operation reporting tool, data can be collected over time from sensors attached to components of interest using data loggers which come in a variety of types and costs. They are a valuable diagnostic tool, but require data processing and analysis. The data from loggers is historical so records of other factors influencing system operation (e.g. the number of people using the system) could provide useful information for the analysis.

The same component in different SWH systems may operate quite differently, either by design or due to the different operating conditions for the systems. As an example of this and to explore the variations possible, the operation of the circulation pumps for all of the relevant systems from Pollard and Zhao (2008) will be examined.

A difficulty in examining the operation of the circulation pumps is how to compare different systems. An average time-of-day profile can relate how average usage of the circulation pump changes depending on time-of-day, but this type of information does not show the full picture. The average time-of-day profile does not show the seasonal changes throughout the year or the occasional one-off events.

One way to show the differences in the operation of the circulation pumps is to display each individual data point appropriately arranged so that patterns can be explored. Figure 14 shows one such representation for system H01. The energy use of the circulation pump is shown as a six minute block of colour with white equalling zero energy use, blue energy use of up to 50 W and orange/red energy use of over 50 W. The graph shows every six minute block of time during the day on the horizontal axis (midnight at left and right of graph and midday in the middle) and for each day of the year on the vertical axis starting from 1 January at the top of the graph down to the 31 December at the bottom.

The year of monitoring for each system began at a date part-way through the year shown by a grey horizontal line in each of the graphs. The data below this line occurs before the data above the line. For system H01 (Figure 14) the data collection began in late November 2006 so the first data is the prevalently orange and red data at the bottom of the graph. The data is continued at the top of the graph working down, back to the grey line. An interesting observation in this graph is the sudden change in colour from orange to blue in February 2007 which followed a visit by a service person who adjusted the setting of the three-speed motor from its high position to a low position.

Graphs for each of the available systems from Pollard and Zhao (2008) are given in Appendix A and show many differing characteristics. However some interesting examples are shown on the next page.

The amount of time the pumps operate varies. H30 (Figure 15) has rows of data that have very few interruptions of colour once the pump has started in the morning until it stops later in the day, indicating that the pump is operating for much of the day. H29 (Figure 16) is a contrasting example of a system which has many white spaces during each row indicating that the pump is turning on and off frequently throughout the day.

Many of the systems had pumps that operated overnight. Many of these instances were occasional and intermittent and were probably due to pumped circulation frost protection. However system H05 (Figure 17) is an example of a system which had extended usage into the evenings and early mornings. There was also a period of about three weeks where the pump operated continuously. This type of pump operation is unusual and is lowering the performance of the SWH system. Having identified this unusual operation, the next stage should be for a solar professional to identify and correct problems with the system. Ongoing monitoring of the circulation pump and wider system operation would allow verification that repair has resolved the problem.

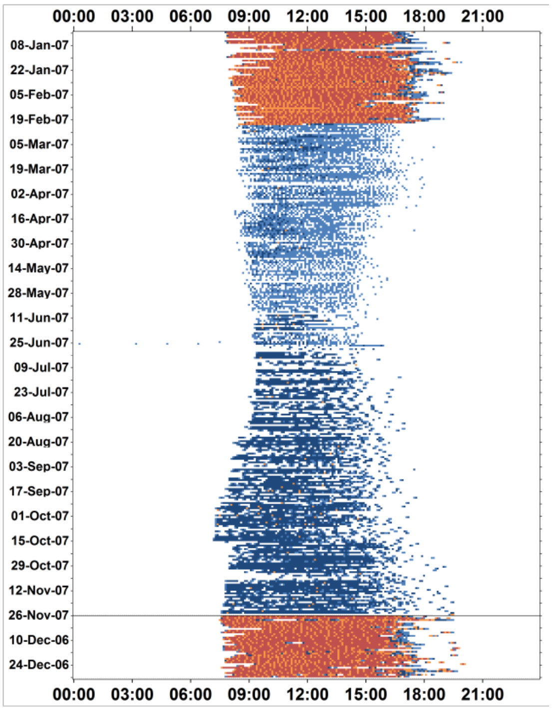

Figure 14. H01 pump operation (W)

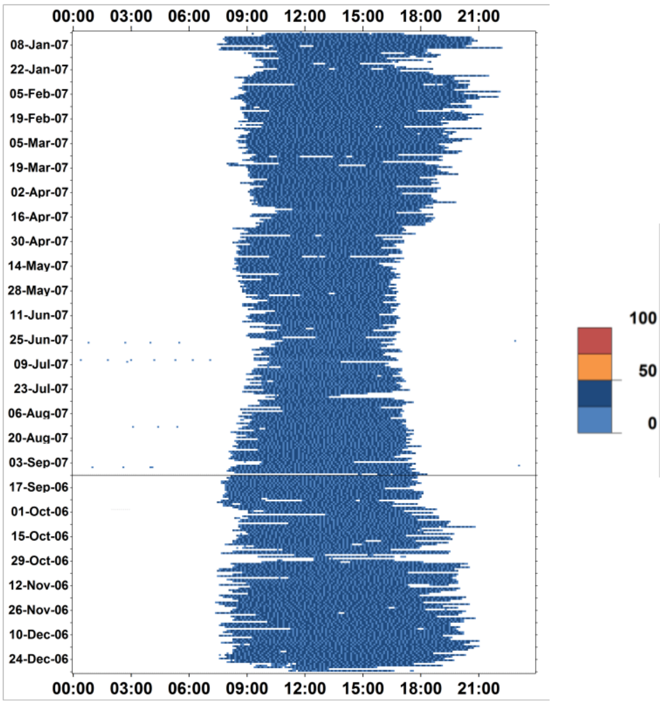

Figure 15. H30 pump operation (W)

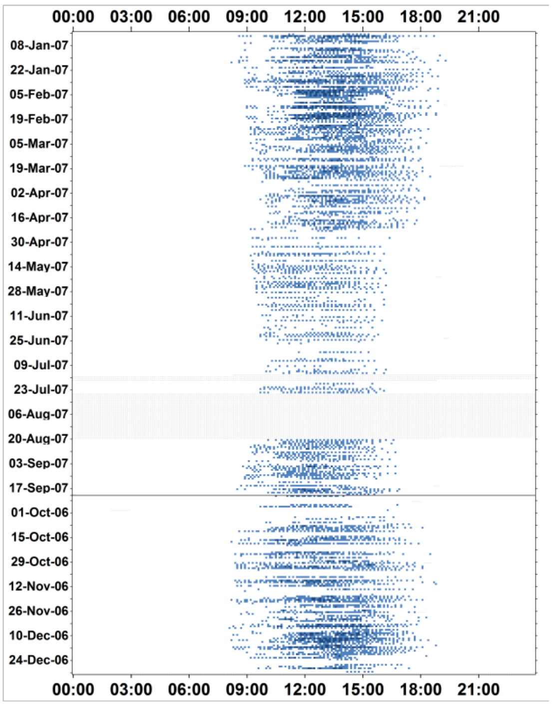

Figure 16. H29 pump operation (W)

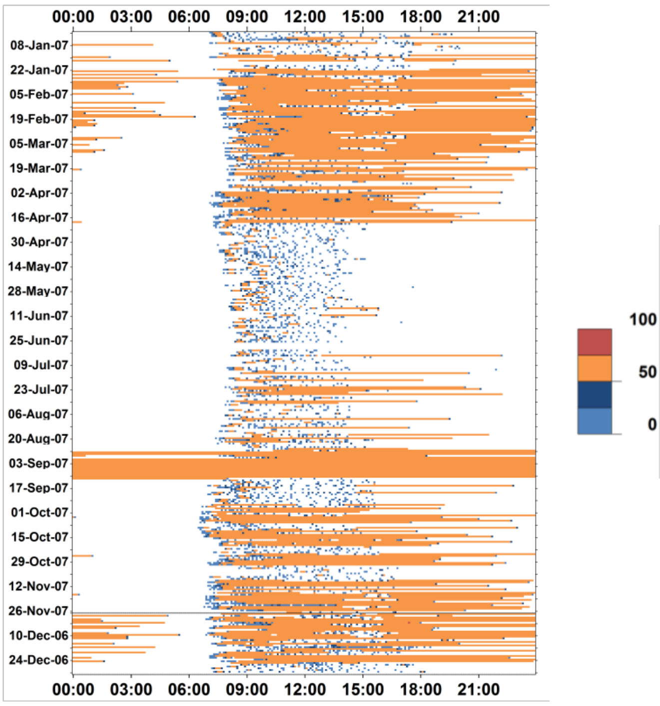

Figure 17. H05 pump operation (W)

6. CONCLUSIONS

Information from a SWH system can be useful to the household occupants in two ways. One is to determine the energy performance of the SWH system which is a key parameter of a SWH system. The other use of information is to give them an insight into the operation of the system, to appreciate what the system is doing and to allow interested occupants to improve the performance of their system.

The COP, or the ratio of the hot water draw-off energy to the supplementary heating energy, is a convenient performance measure for SWH systems and can be calculated to varying levels of accuracy. At a basic level the supplementary heating energy should be measured. This can be achieved with a low-cost (around $40) electricity meter. The hot water draw-off energy delivered by the SWH system can be estimated using a number of assumptions. A standard water meter (around $100) recording the amount of water put through the SWH system can improve this estimate.

The primary function of a SWH system is to save energy. SWH systems are sold with some indication as to what level of performance the system will achieve. Ideally this indicated level of performance should be specific and customised for each particular installation to allow the occupants to verify the system is achieving this by measuring its performance and seeking help if it is not performing as expected.

Many users of a SWH system are interested in how the system works and how they can optimise its performance. Historically, SWH systems have not provided much information to the users about how the system has been operating. Any improvements to the information made available will have a positive impact.

Information about how the system is operating would also be useful to a solar professional looking to resolve any performance issues with the system.

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APPENDIX A CIRCULATION PUMP OPERATION

The graphs in this appendix (Figure 18 to Figure 36) provide plots of the operation for each of the circulation pumps for valid systems from the Pollard and Zhao (2008) study. The interpretation and some interesting characteristics of these systems are discussed in section 5.

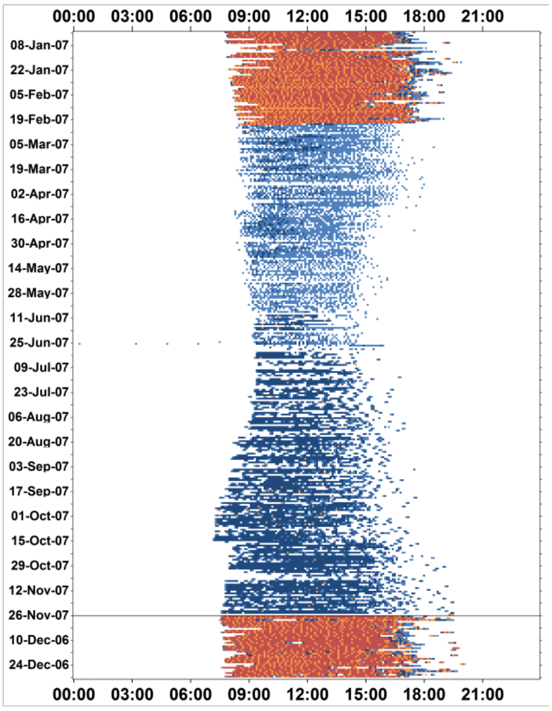


Figure 18. H01 pump operation (W)

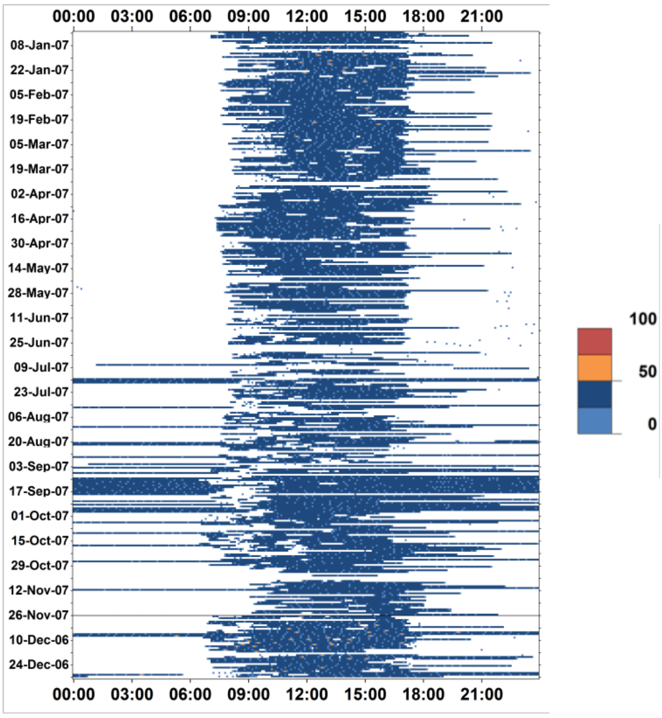


Figure 19. H04 pump operation (W)

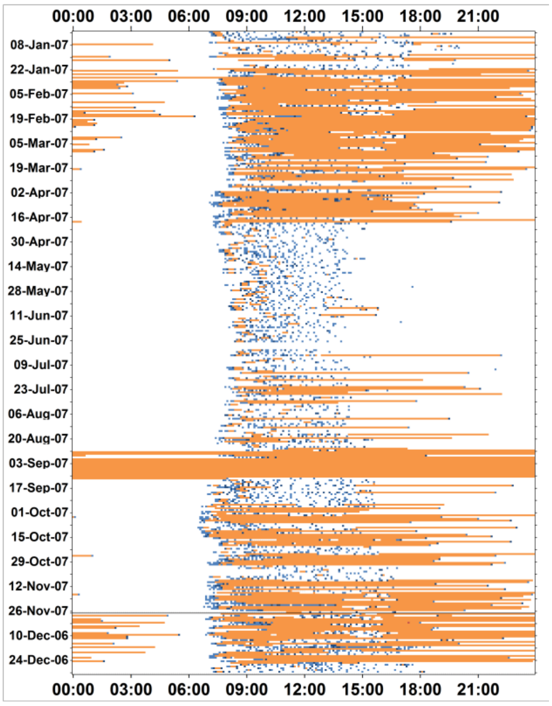
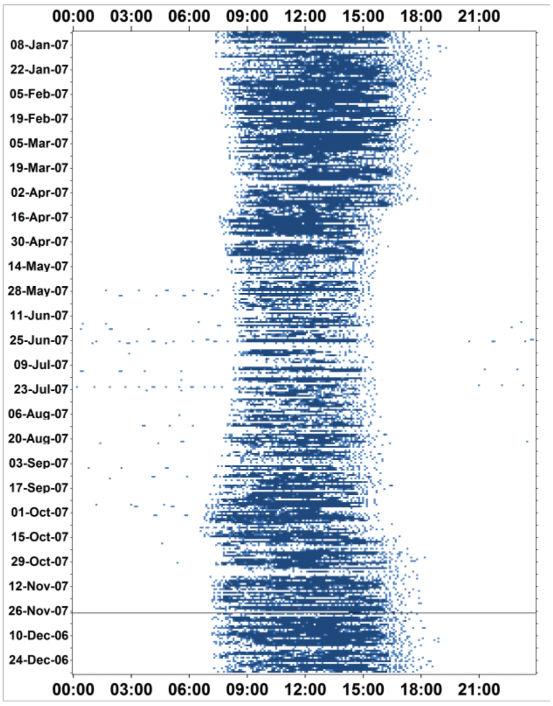


Figure 20. H05 pump operation (W)



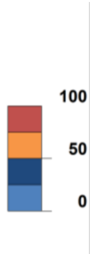


Figure 21. H06 pump operation (W)

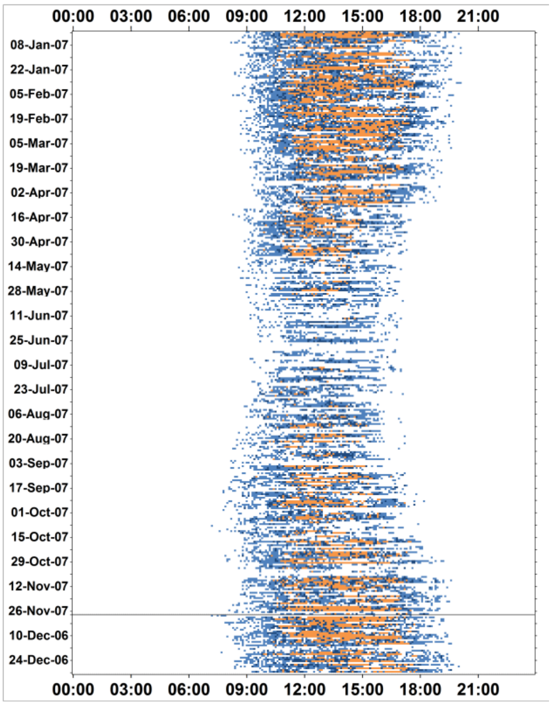
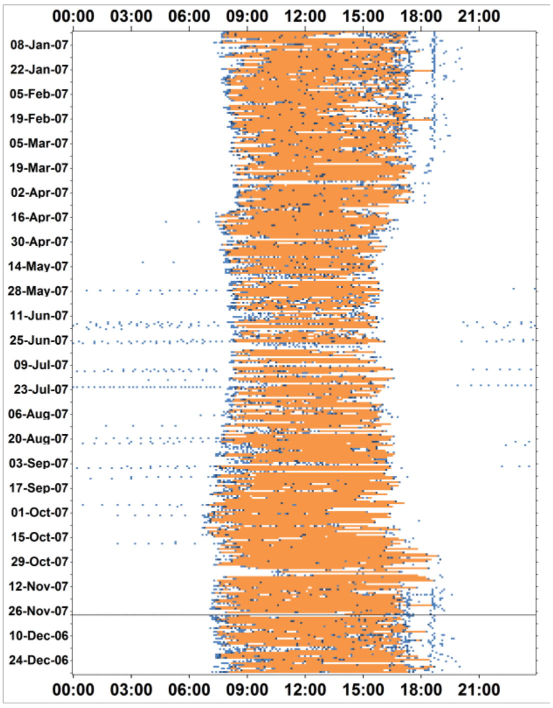


Figure 22. H07 pump operation (W)



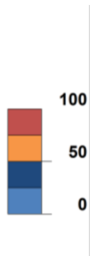


Figure 23. H08 pump operation (W)

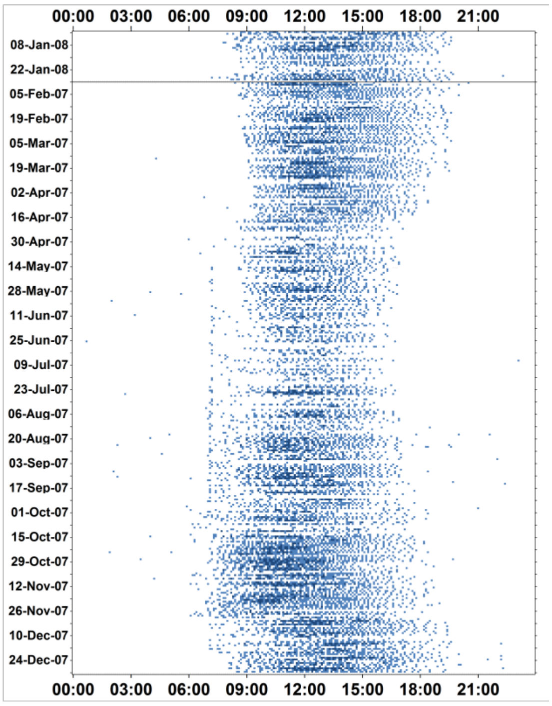


Figure 24. H10 pump operation (W)

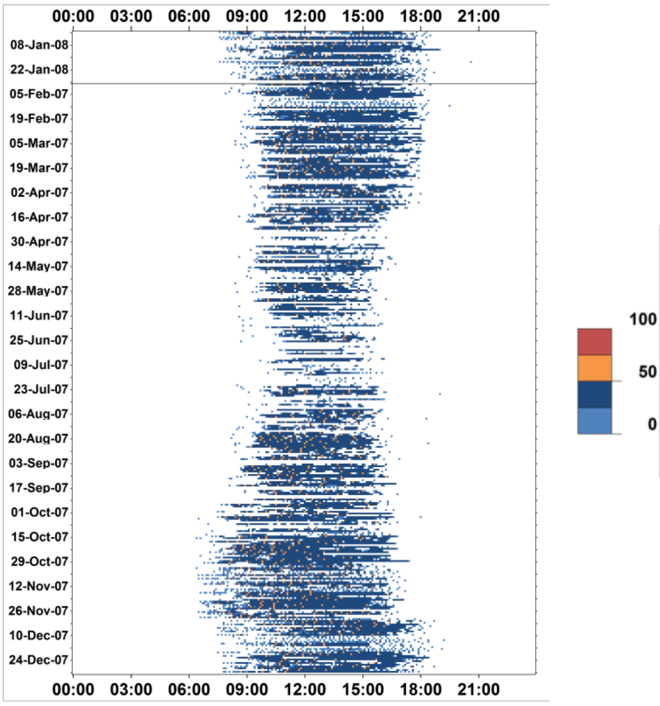


Figure 25. H11 pump operation (W)

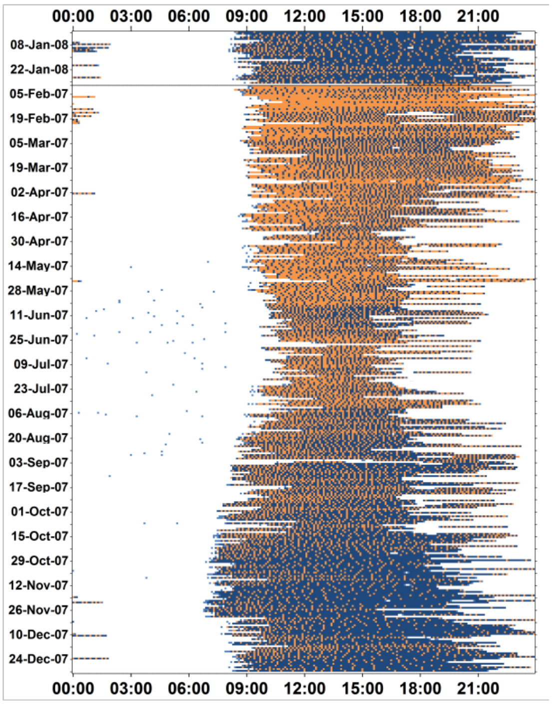


Figure 26. H12 pump operation (W)

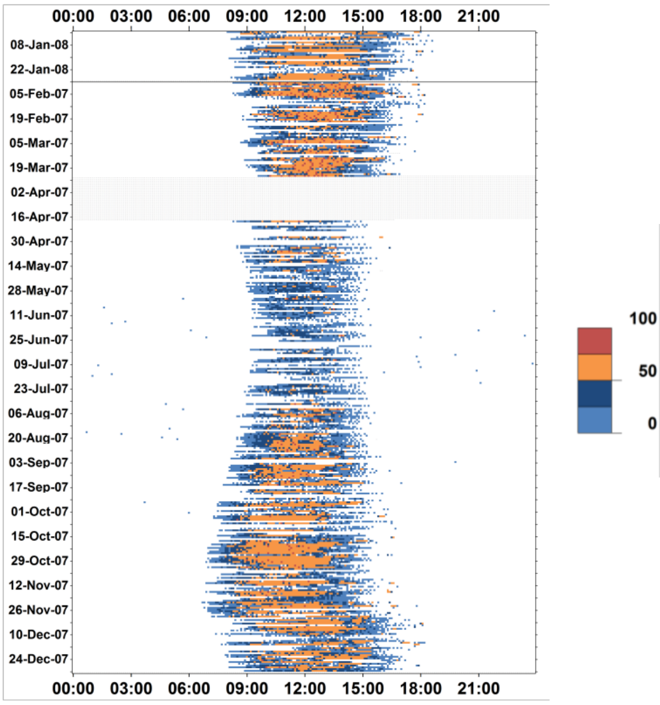


Figure 27. H13 pump operation (W)

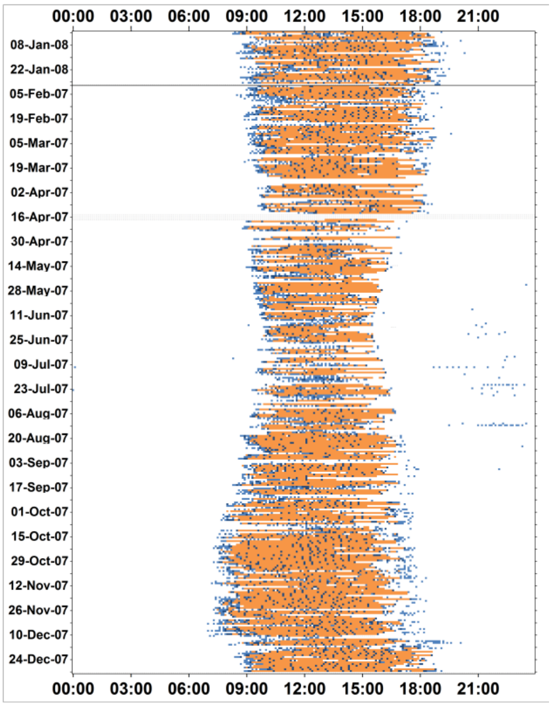


Figure 28. H14 pump operation (W)

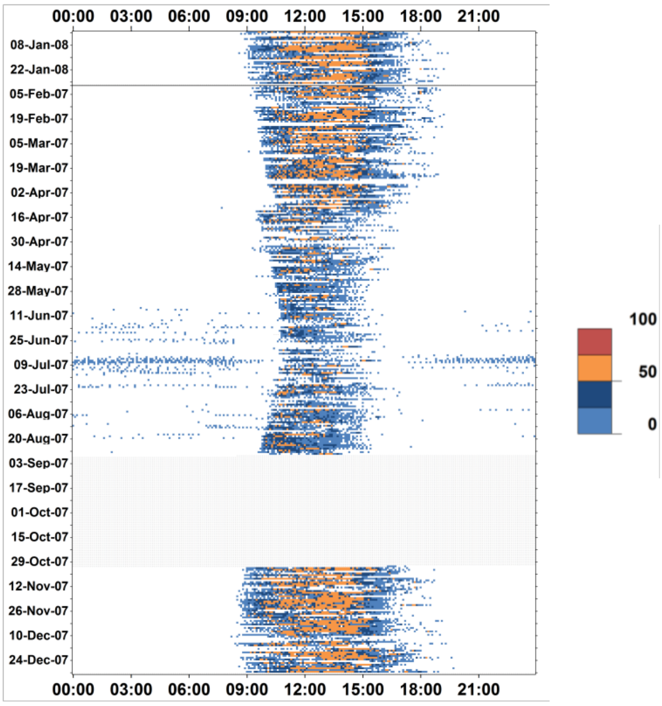


Figure 29. H15 pump operation (W)

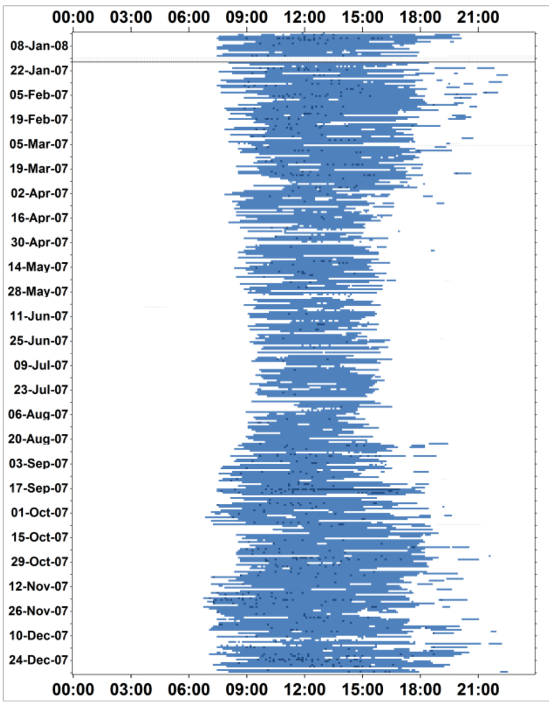


Figure 30. H22 pump operation (W)

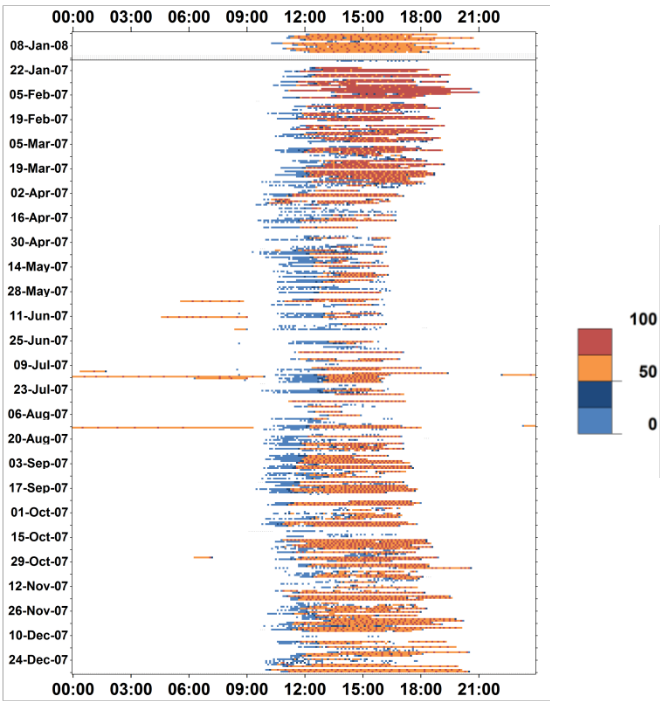


Figure 31. H23 pump operation (W)

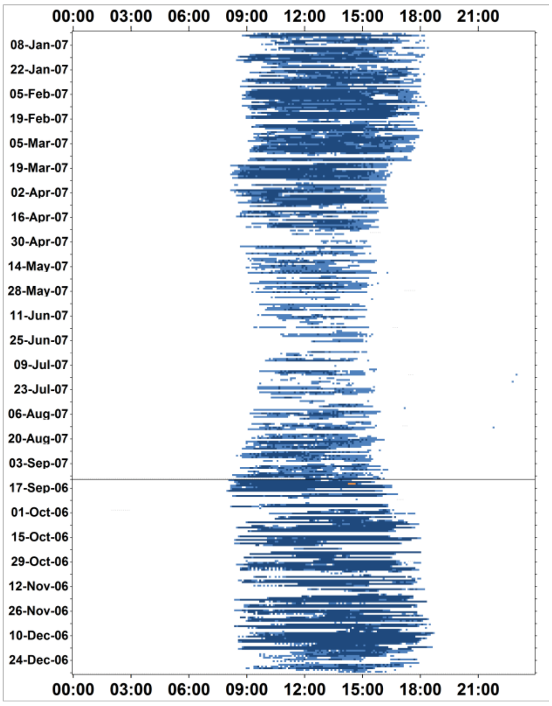


Figure 32. H27 pump operation (W)

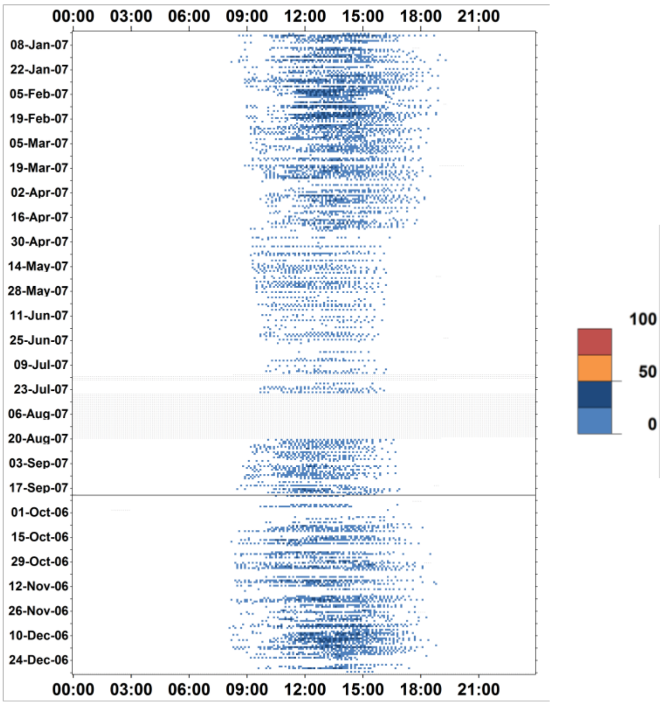


Figure 33. H29 pump operation (W)

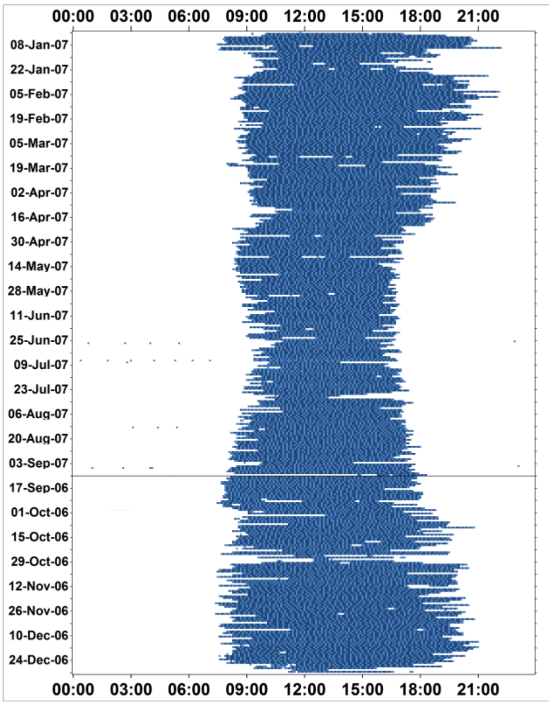


Figure 34. H30 pump operation (W)

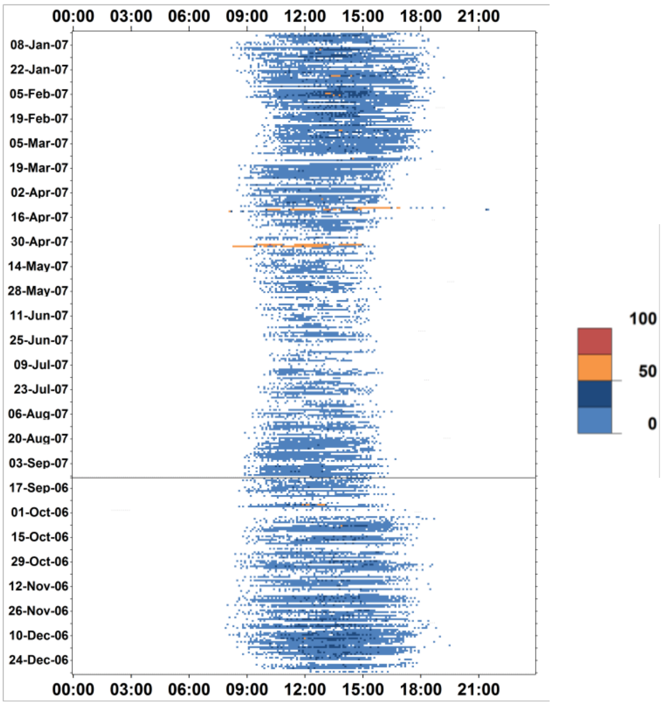


Figure 35. H31 pump operation (W)

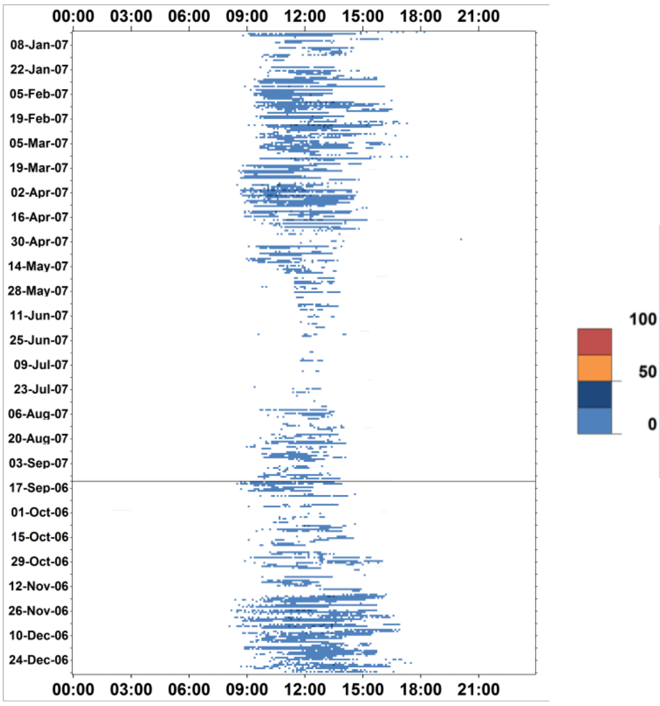


Figure 36. H32 pump operation (W)