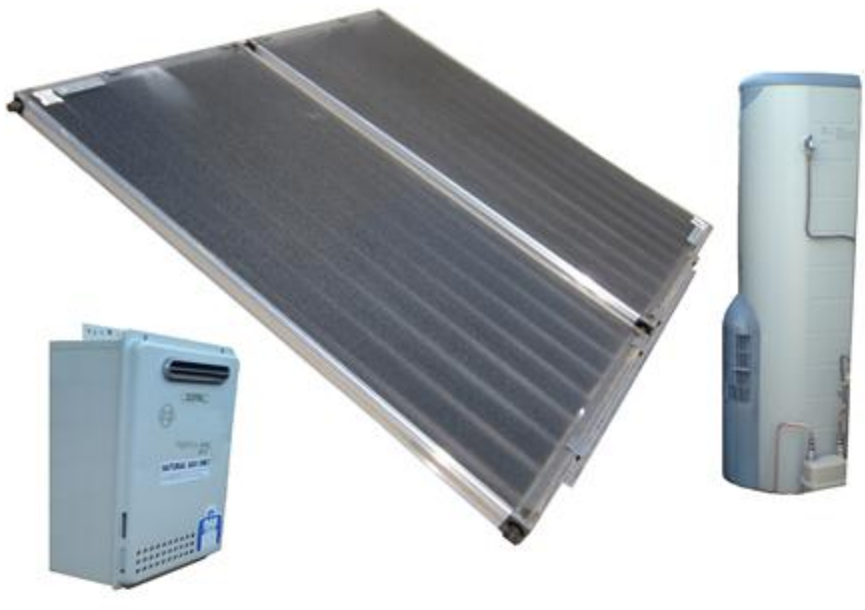
UniSA | Barbara Hardy Institute

Department for Manufacturing, Innovation, Trade, Resources and Energy

Residential Water Heater Baseline Data Study- Final Report



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Executive Summary

This report investigates the energy usage of prevalent hot water system types installed within South Australia through an in situ monitoring program. Data collected throughout this study was used to develop the methodology for a Microsoft Excel based tool to be used by the Department of Manufacturing, innovation, Trade, Resources and Energy (DMITRE) to estimate the energy usage, greenhouse emissions and expected lifetime costs of water heaters installed in South Australian dwellings.

The monitoring program was conducted by the Sustainable Energy Centre (SEC) at the University of South Australia, between the 1st of December 2012 and the 31st of November 2013 within the Adelaide metropolitan area. The purchased energy, water temperatures and ambient air temperature associated with 12 water heaters, representing 6 different types of water heater were recorded at a rate of one reading a minute.

The study into the collected monitoring data was used to:

- Provide 'real world' monitored data for hot water systems in South Australian Dwellings;
- Review and compare to the assumptions made by existing purchased energy calculations used within the industry including those described in AS4552-2005 and AS/NZS4234:2008;
- Develop a lifecycle energy, cost and greenhouse gas emissions estimation tool.

The restriction of the monitoring program to 12 water heater resulted in the selection of the water heaters based on their type as well as the residents of the dwellings. Care was taken to ensure that a spread of system types as well as dwelling sizes, locations and socioeconomic groups were monitored. This enabled a comparison between a wide range of factors.

Through analysing the detailed monitoring data of the 12 water heaters within this study and comparing these results with data collected from 27 solar hot water systems in the Lochiel Park Green Village for which UniSA has historical data, it was possible to evaluate actual performance of hot water heaters within S.A.. The SEC was able to compare the assumptions that are used by current calculation methods such as the TRNSYS modelling of solar and heat pump water heaters with 'real life' data. The study highlights that there is a great variation in the amount of hot water required by South Australian dwellings. The hot water requirement or 'heat load' is the largest contributing factor to the overall cost of hot water production. The size of the heat load will affect the size of the water heater required, the efficiency of the heater once installed and the amount of purchased energy required. Through consultation with residents, it has been established that residents typically know very little about their hot water heaters and their hot water usage.

Keeping in mind the limited number of systems monitored, the results of the study demonstrate the soundness of current evaluation methodologies and assumptions (the trend patterns). One major outcome of the study demonstrates the significance and impact of the heat load profile. Most of the systems monitored consumed a hot water heat load that is classified as a small load in AS4234:2008 and typically around one third the size of the load used to calculate the energy usage of gas water heater. This will impact on the calculated efficiency and purchased energy of each water heater. The magnitude of this variation is obvious when comparing extreme cases observed between the two 5 star, gas storage water heaters in this study. One system operated at an average heat load that was just 11% of the Australian Standard heat load size and as a result the overall efficiency was just 20%. This compares to the other gas storage system that operated with a heat load equivalent to the Australian Standard heat load and achieved an overall system efficiency greater than 60%. The poor efficiency witnessed has been attributed to the relatively high heat loss associated with the storage tank of the gas system.

The system efficiency of the conventional systems varied between 20% for an underutilised gas storage water heater to 76% for an electric storage water heater. All heat pump and solar water heaters operated with a system purchased energy efficiency greater than 100% with the heat pumps operating consistently throughout the year at an efficiency of approximately 200%. All solar hot water heaters monitored performed exceptionally well in the months between October and April, providing the majority of their required hot water demand through the solar collector loop alone. During the months between May and September, all monitored solar systems relied increasingly on their boosters (electrical element or gas booster) to supplement their energy requirements. Overall, the solar water heaters were able to work with a system purchased energy efficiency of 160-170%. The gas boosted solar hot water heaters were able to meet their hot water load requirements with the lowest greenhouse gas emissions at 40 g CO_2-e/MJ of heat load. This signifies a great improvement on the worst performing system, an electric storage hot water heater producing 501 g CO_2-e/MJ of heat load.

The Gas boosted solar hot water heaters had the lowest running purchased energy costs at 0.25 c/L of inside hot water. There was a large variation between the energy costs associated with the electric boosted solar hot water systems. This variation has been attributed to the different combination of components and the manner In which the residents used their water heaters. The continuous flow gas hot water heaters proved to be cost effective with a purchased energy cost of 0.45 c/L of hot water. The conventional storage systems in this study had the lowest performance with the storage systems that were underutilised exhibiting high running purchased energy costs. The worst performing electric storage and gas storage water heaters cost 2.0 c/L and 2.85 c/L respectively. Interestingly, a well utilised electric, storage water heater located indoors and connected to an off-peak electricity tariff was able to produce hot water at 0.67 c/L. This illustrates the importance of system sizing and the benefit of the off-peak electricity tariff.

The development of the energy and cost estimation tool has demonstrated the correct selection of a water heater can have a significant impact on the capital cost, operational costs and greenhouse gas emissions associated with domestic hot water usage. Household specific hot water requirements and access to a gas connection will determine which system will be most appropriate. The high initial outlay associated with heat pumps and solar hot water systems is a deterrent for many when selecting a hot water heater however, it has been observed that these systems do significantly reduce purchased energy requirements and greenhouse gas emissions. The correct sizing of any system type is be imperative in ensuring that system will work at its peak efficiency.

The tool has been designed to remain as flexible as possible. It is designed to be used by individuals with an understanding of the relevant hot water heaters. It is recommended that if this tool is to be used by consumers, many of the options should be limited or additional information should be provided. It is important that the values used in the tool are constantly updated. Utility costs, system purchase costs, installation costs as well as greenhouse gas emissions and system efficiencies are likely to evolve over time and these changes will need to be adapted into this tool.

1 Introduction

The Sustainable Energy Centre (SEC), a division of Barbara Hardy Institute (BHI) at the University of South Australia (UniSA), was appointed by the Department for Manufacturing, Innovation, Trade, Resources and Energy (DMITRE) to conduct a study to gather observed data and to use monitoring data as the basis for developing a methodology for estimating the life cycle costs and the relevant greenhouse emissions associated with the range of residential water heaters in use within South Australia.

Currently, very little evidence-based information exists to estimate costs and energy use of various types of water heaters available in South Australia. Some published operating costs and greenhouse emissions data is available for solar water heaters based on modelling conducted using the TRNSYS computer modelling package, in accordance with AS/NZS4234:2008. This standard uses a number of assumptions to predict the hot water requirements of an 'average household' for small, medium and large residential hot water consumption. By monitoring, in detail, the water usage and energy usage patterns of the most prevalent types of water heaters installed in South Australian dwellings, this study aims to generate domestic water heater baseline data. It is proposed that this data will be used to facilitate the estimation of life cycle costs, energy consumption and greenhouse emissions of domestic water heaters in the range of South Australian climate zones. Furthermore, this information will be utilised in the development and refinement of a predictive tool for estimating the expected energy, cost and greenhouse gas emissions associated with various types of domestic water heaters. The report describes the findings from the 12 months of monitored data, provides additional information gathered by the SEC from monitoring of hot water systems located within the Lochiel Park green village and describes the process of developing an energy cost and CO_2 prediction tool.

2 Project and Monitoring Overview

2.1 Project Outline

The project team has installed monitoring equipment on water heaters at 12 metropolitan Adelaide households to record water and energy usage of 6 different types of water heaters, as summarised in Table 2-1. The data collected by the monitoring systems will provide the Department for Manufacturing, Innovation, Trade, Resources and Energy (DMITRE) with: i) *real world* hot water usage data for one BCA climate zone; and ii) estimated hot water usage data for three BCA climate zones, within South Australia.

Table 2-1: Summary of hot water heater types and quantity monitored.

Main / Auxiliary Energy Source	Type	Minimum Requirements	Number of water heaters
Electric	Heat Pump		2
	Solar		2
	Storage		2
Gas	Continuous Flow	Current 5 ★ rating	2
	Solar		2
	Storage	Current 5 ★ rating	2

In addition to the data collected from these households, long term data (up to 3 years) collected at the Lochiel Park Green Village (of up to 27 households) has been analysed to provide additional '*real life*' hot water consumption and energy usage data.

The Project was divided into two stages to enable the SEC to provide initial data to DMITRE. An initial one-month data set was collected for most of the above-mentioned water heaters. The data from this period was provided to DMITRE in March of 2013 to demonstrate the effectiveness of the monitoring equipment and preliminary findings. These findings were extrapolated using a combination of historical data from Lochiel Park monitored water heaters and typical monthly climatic trends taken from AS/NZS4234:2008 to allow the SEC to predict the water load requirements for each type of water heater, per year. This data was then used to predict associated annual energy consumption, cost and greenhouse gas emissions for each water heater type.

Data relating to the typical capital cost of each water heater type was collected and this enabled the SEC to generate an initial estimate for associated lifetime cost.

The SEC continued to monitor the 12 domestic water heaters for a period of 12 months.

Data collected through this extended monitoring period, along with data collected from the Lochiel Park Green Village was used in the development typical baseline water heater load requirements based on household occupancy, demographic and water usage for various water heater types.

2.2 Monitoring Overview

This section describes the monitoring equipment used throughout this study and includes details of the meters, sensors and data logging equipment.

2.2.1 Meter Types and Resolution

A summary of the meter and sensor details, including the manufacturer, model number, supplier, and sensor resolution is listed below in Table 2-2.

Table 2-2: Meter and sensor information.

	Meter	Sensor	Sensor Resolution	Supplier
Water	Actaris, TD8	Actaris, Cyble™	1 L	Itron (Actaris)
Gas	Landis + Gyr, Model 750	Elster, IN-Z61	10 L	Landis + Gyr
Electricity	Lanx Australis LXEM150	-	1 Wh	Schnap
Temperature	-	Carel NTC015WP00	Infinite	Outpost Central

The temperature sensors, listed above in Table 2-2, are NTC type thermistors and have the capacity to measure temperatures over a range of -50°C to +105°C, which exceeds the project requirements. The accuracy of these sensors is stated to be at least ±1% and is likely to be better over the range of temperatures predominately encountered in the project. The temperature sensors are connected to the datalogger, which actually measures and records their instantaneous resistance at one-minute intervals and uploads these data to a centralised server, via standard mobile communication infrastructure. The values of resistance collected by the datalogger are converted to temperature within the database on the server, based on the known relationship between temperature and resistance for a specific sensor.

The gas meter, listed in Table 2-2 above, is a standard billing type gas meter used by Australian gas utilities in the domestic residential environment. These meters are a positive displacement diaphragm gas meter with a stand-alone twin chamber measuring unit and have a 2L cyclic volume to reduce speed and therefore maintain long-term measurement stability to an accuracy of approximately ±1%. Data is collected from the gas meter using a sensor module that was attached by UniSA, which creates one pulse for every 10L of gas consumed by the water heater. Each pulse is recorded by the datalogger and uploaded to a database in the manner described previously. The meters also have an accumulating analogue display to facilitate calibration and data-checking, which was used by the UniSA team in the commissioning phase to ensure that the water heater was operating correctly.

The electricity meter, listed above in Table 2-2, is a Class 1 device and, as such, has specifications that are equivalent to a standard billing type electricity meter, with an accuracy of 1% or better. UniSA have previously used and tested these meters and found them to be an accurate device with far greater flexibility, due to their highly compact construction. These meters measure real power and generate a pulse for every Wh (1000 pulses/kWh) of energy consumed by the water heater. Each pulse is recorded by the datalogger and uploaded to a database in the manner described previously. The meters also have an accumulating digital display to facilitate calibration and data-checking, which was used by the UniSA team in the commissioning phase to ensure that the water heater was operating correctly.

The water meter, listed in Table 2-2 above, is a standard billing type water meter used by Australian water utilities in the domestic residential environment. These meters utilise piston type technology in combination with an extra dry register (no gears in contact with water), have a 1L cyclic volume and are designed to maintain long-term measurement stability to an accuracy of approximately ±1%. Data is collected from the water meter using a sensor module that was attached by UniSA, which creates one pulse for every 1L of water passing through the water heater. Each pulse is recorded by the datalogger and uploaded to a database in the manner described previously. The meters also have an accumulating analogue display to facilitate calibration and data-checking, which was used by the UniSA team in the commissioning phase to ensure that the water heater was operating correctly.

2.2.2 Data Loggers

The data loggers used for this study were supplied by a New Zealand company, Outpost Central. These were selected as they operate from long lasting batteries and are able to transmit data to a web-based server via either a 2G or 3G cellular network, using an integrated Telstra SIM card. This allowed data to be collected from each household, without the need for mains electrical power usage or an existing Internet connection. In addition, the loggers and all sensor connections were contained within a weatherproof enclosure with an ingress protection (IP) rating of 65.

The data loggers are customisable and are able to accept up to two digital inputs, using high-speed counters, and up to two analogue input channels. In addition, the logging and data upload frequency can be adjusted to suit any application; however, this can significantly reduce the logger's battery life. The expected life of the battery varies according to the logger's configuration, as shown in Table 2-3 below. The battery life experienced during this study was much shorter. All data loggers required changing after 6 months, as their battery voltage dropped to a level where the loggers could no longer communicate with the Outpost server.

Table 2-3 Battery life expectancy of the Outpost Central data loggers, for two configurations.

Case	Logging Frequency	Data Upload Frequency	Number of Channels Logged	Battery Life Expectancy
Default	15 minutes	24 hours	1	5 years
Expected for this study	1 minute	12 hours	4	2 years
Achieved during this study	1 minute	12 hours	4	6 months

2.3 Monitored Water Heater Details

Table 2-4 below summarises the specifications of the 12 monitored water heaters. This table and Figure 2-1 show there is a good geographical spread of the water heaters, around the Metropolitan Adelaide region. Sections 2.3.1 and 2.3.2 (Figs 2-2 to 2-7) show photographs of the six monitored electric and six monitored gas type water heaters, respectively.

Table 2-4: Details of the 12 water heaters monitored.

Reference	Type	Suburb	Manufacturer	Tank Vol.	Thermostatic Mixing Valve?	Residents
ELE_HPU_ROST	Electric heat pump	Rostrevor	Quantum	250 L	No	4
ELE_HPU_YATA	Electric heat pump	Yatala Vale	Quantum Replaced in May 2013 with new Quantum	340 L 340 L	No	3
ELE_SOL_LPON	Electric-boosted, evac. tube solar	Campbelltown	Everlast / Hills	264 L	Yes – solar	2
ELE_SOL_MAWS	Electric-boosted, flat-plate solar	Mawson Lakes	Rheem	340 L	Yes-Solar	3
ELE_STO_NADL	Electric storage	North Adelaide	Hardie Dux	250 L	Yes	4
ELE_STO_NETH	Electric storage	Netherby	Dux	259 L	No	1
GAS_INS_DOVE	Gas instantaneous	Dover Gardens	Bosch	N/A	Not applicable	2
GAS_INS_WOOD	Gas instantaneous	Woodville North	Rinnai	N/A	Not applicable	3
GAS_SOL_LPSS	Gas-boosted, flat-plate solar	Campbelltown	Rinnai	215 L	Yes – solar	4
GAS_SOL_LPST	Gas-boosted, flat-plate solar	Campbelltown	Rinnai	215 L	Yes – solar	4
GAS_STO_ABER	Gas storage	Aberfoyle Park	Rheem	160 L	No	3
GAS_STO_CUMB	Gas storage	Cumberland Park	Rheem	130 L	No	2

Note: All water heaters are installed outdoors, except for the Electric Storage unit at North Adelaide (ELE_STO_NADL)

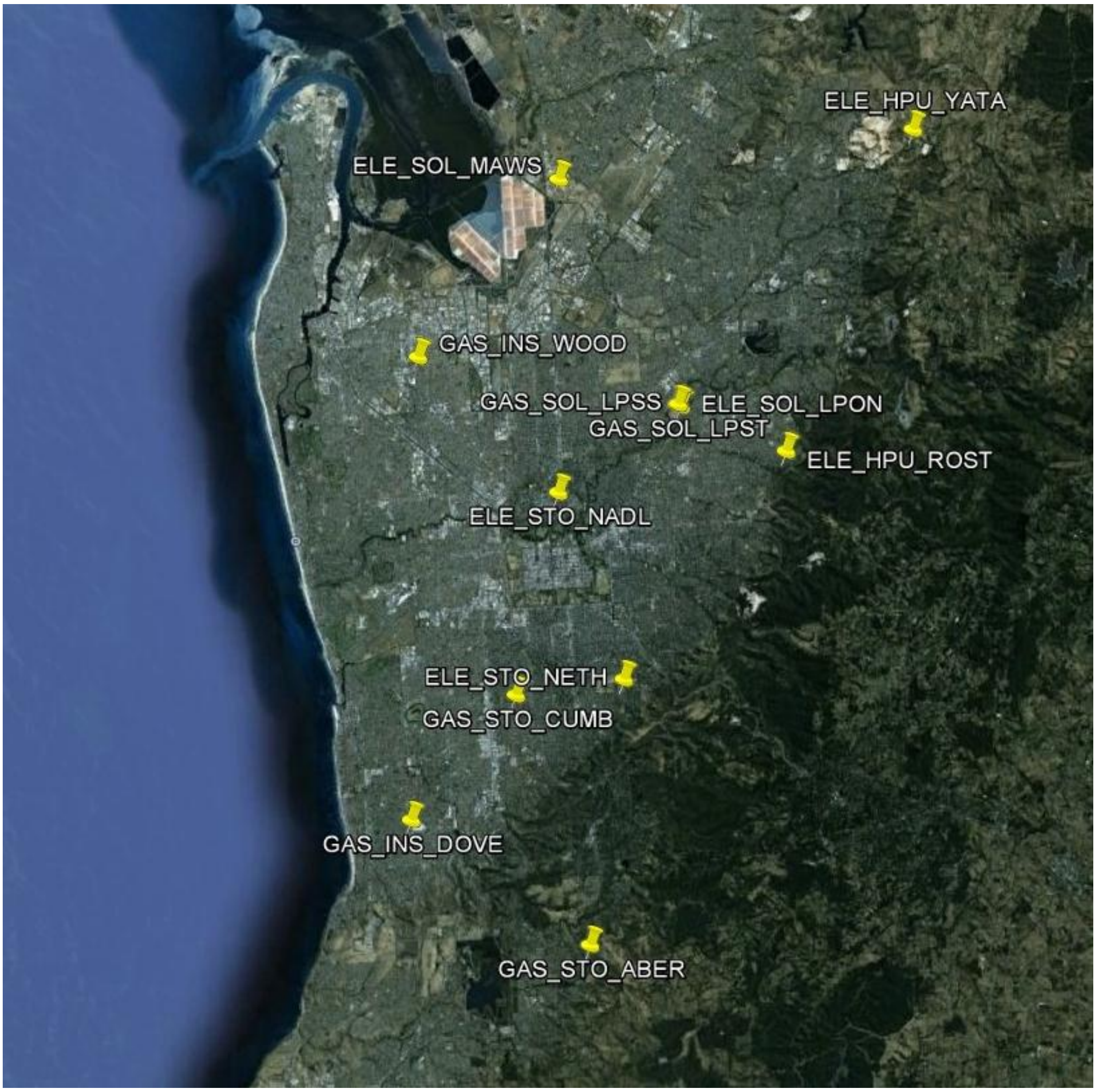


Figure 2-1 Location of water heaters monitored

2.3.1 Electric Water Heaters

(a) Rostrevor (b) Yatala Vale

Figure 2-2: Photographs of the Electric heat pump water heaters and the associated monitoring equipment, installed in (a) Rostrevor, and (b) Yatala Vale.

(a) Campbelltown (b) Mawson Lakes

Figure 2-3: Photographs of the Electric-boosted solar water heaters and some of the required monitoring equipment, installed in (a) Campbelltown, and (b) Mawson Lakes.

(a) Netherby (b) North Adelaide

Figure 2-4: Photographs of the Electric storage water heaters and the associated monitoring equipment, installed in (a) Netherby, and (b) North Adelaide.

As previously noted in Table 2-4, the electric storage water heater shown in Figure 2-3b is installed inside the buildings occupied space, within a closet-like enclosure. All other water heaters are external to their respective dwellings.

2.3.2 Gas Water Heaters

(a) Dover Gardens (b) Woodville North

Figure 2-5: Photographs of the continuous flow gas water heaters and the associated monitoring equipment, installed in (a) Dover Gardens, and (b) Woodville North.

(a) (b)

Figure 2-6: Photographs of the two gas-boosted solar water heaters and some of the required monitoring equipment, all of which is installed in Campbelltown.

(a) Aberfoyle Park (b) Cumberland Park

Figure 2-7: Photographs of the 5 star gas storage water heaters and the associated monitoring equipment, installed in (a) Aberfoyle Park, and (b) Cumberland Park.

All Gas water heaters are installed outside of their respective dwellings.

3 Project Methodology

3.1 Monitoring

Running performance data has been collected from the 12 water heaters using data loggers recording energy usage, cold water inlet temperature, hot water outlet temperature and water flow rate (volume) every minute. The water flow and differential temperature of the water between the inlet and outlet of the water heaters was used to calculate the theoretically required heat energy to heat water flowing through the various heater types. This was compared to the actual electrical and gas usage measured with the watt meters and gas meters to determine the overall efficiency of each system.

There are many factors that affect the performance of hot water heaters that vary throughout the year. Monitored data in conjunction with participant questionnaires were used to investigate the factors that impact on the daily performance of a water heater throughout the 12 month monitoring period including:

- Standing heat loss of storage water heaters
- Daily total energy consumption of water heater
- Daily water load patterns
- Inlet (T_{in}) and outlet (T_{out}) temperatures
- Ambient air conditions
- Heating component efficiencies

In many cases these factors are specific to the water heater type. Monitored data needs to provide enough detail to show average daily energy and water usage and how these are affected by the aforementioned factors to enable the researchers to be able to predict the energy and water requirements of hot water systems used in households not monitored within this study.

3.2 Monitored Data Analysis

The water heating load, as referenced throughout this report, is the quantity of heat energy required to heat the volume of water consumed within a house for various domestic purposes, e.g. bathing, dish washing etc. This is calculated for each of the households based on the individually measured hot water usage volume, inlet and outlet water temperatures and a series of assumptions. The calculation and the assumptions are listed below:

- The heat load, Q, (expressed in MJ) is calculated based on the equation below:

$$Q = mc_p\Delta T$$

  where, the mass, m, is determined by the volume of hot water consumed, V, and the water density, ρ, i.e. $m=\rho V$. The difference in water temperature, ΔT, is equal to the difference in water outlet and inlet temperatures, i.e. $T_{out} - T_{in}$.

- The water inlet temperature, Tin, in most cases has been monitored via the data logger. This is not the case for the Gas boosted solar water heaters in Lochiel Park where the temperature sensors connected to the logger have been placed between the storage tank and the gas booster to enable the SEC team to determine the split of energy input into the water from the solar boosted storage tank and the gas booster. In this case, due to the close proximity of all Lochiel Park households, the cold water inlet temperature recorded at the Lochiel Park based electric boosted solar water heater has been designated as the equivalent cold water inlet temperature for both gas boosted water heaters at Lochiel Park.
- The average ambient air temperature, T_a, has been obtained from the Bureau of Meteorology (BoM) for Adelaide (Kent Town weather station),
- The water outlet temperature, T_{out}, is straightforward in most cases and has been directly monitored at the immediate water heater outlet, via the data loggers. This is, however, not the case for the solar water heaters and one electric storage water heater, where a thermo-mixing valve (see Section 4.3) has been incorporated into the water heater. In these cases, spot checks of the water temperature, after the thermo-mixing valve have been used to determine the overall hot water outlet temperature, given that the water temperature at the immediate storage tank outlet has been monitored with the data logger. Preliminary studies (see Figure 4-2) have shown that although temperatures of the hot water leaving a storage tank can vary considerably, those leaving a thermo-mixing valve do not, hence the need to only perform spot checks on these devices. (It should be noted that for the purposes of this study, the water flow is measured on the cold inlet, before the T-piece between the hot water tank and the thermo mixing valve, therefore the heat load for these water heaters is calculated based on the water flow and overall temperature differential of the water).
- The water density, ρ, used in the calculation is that at a temperature equal to T_{in}.
- The specific heat capacity, C_p, used in the calculation is that at the mean temperature of the water heater, i.e. $0.5*(T_{out}-T_{in})$

3.3 Monitored Data Extrapolation

For the purposes of the estimation tool, all data collected has been extrapolated, based on various information and assumptions. As there were only two water heaters of each of the most common water heater types, data extrapolation for a range of heat loads and climate zones were required. These extrapolations were made using trends found in this study, trends provided in AS/NZS4234:2008 and a number of previous UniSA water heater monitoring studies, including the Lochiel Park ongoing study.

4 Water Usage Data Analysis

4.1 Cold Water Inlet Temperatures

Inlet water temperatures varied throughout the course of the monitoring period, as well as between locations across Adelaide. AS/NZS 4234:2008 (Table A6) provides monthly cold water temperatures for each climate zone of Australia, Table 4-1 shows these temperatures for Zone 3. (Adelaide) Table 4-1 also shows the average monthly cold water temperature recorded during draw-off events in this study and Figure 4-1 illustrates the range of temperatures recorded as part of this study in comparison to the standard temperatures.

Comparison between the two sets of mains inlet water temperatures in Figure 4-1 it is evident that the temperatures found as part of the DMITRE study are higher than as stated in AS/NZS 4234:2008 with the exception of two months in Netherby and three months at Yatala Vale. The differences between AS/NZS 4234:2008 and this study are approximately 2°C each month with the exception of October and November where the cold inlet temperatures are very similar.

Table 4-1: AS/NZS 4234:2008 Monthly Cold Water Temperatures for Zone 3

Month	AS/NZS 4234:2008 Zone 3	DMITRE Recorded Cold Water
January	23	26.0281
February	23	25.8365
March	21	25.1387
April	18	20.3872
May	15	17.4826
June	12	15.0964
July	11	13.7830
August	12	14.4138
September	15	17.2494
October	19	19.1700
November	21	20.8965
December	22	24.3399

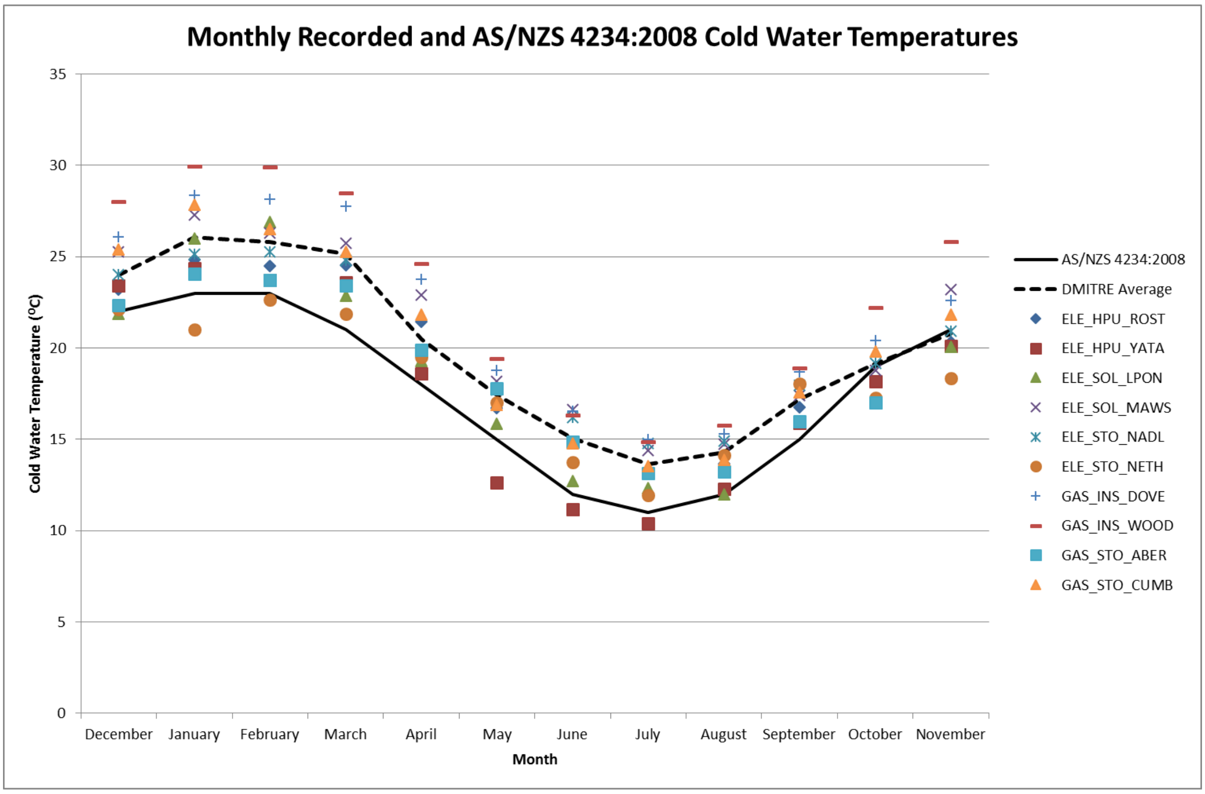


Figure 4-1: Monthly recorded and AS/NZS 4234:2008 cold water temperatures

4.2 Outlet Temperatures

Measurement of the water heater outlet temperature is required to calculate the heat energy added to the water by the water heater. The 12 monitored water heaters in this study produce hot water at different temperatures. The Continuous flow gas heaters in this study have temperature controllers that can be set by the householder. The typical hot water temperature from these water heaters is 40-45^{O}C. Eight of the ten storage water heaters monitored in this study heat at least 45% of the water within the tank to a minimum of 60^{O}C each day, partly to inhibit the growth of Legionella bacteria, in accordance with Australian Standards. This has been evident in the results with all tanks consistently showing outlet water temperatures above 60^{O}C. The monitored instantaneous gas boosted solar water heaters utilise a different Legionella control strategy. In these water heaters, the temperature of water exiting the storage tank is used to determine the requirement of the gas booster. If the outlet temperature of the tank falls below 55^{O}C the instantaneous gas booster is activated to boost the water temperature to 70^{O}C. This boosting was also evident in the data, however the 70^{O}C required was not recorded by the monitoring equipment which was located external to the water outlet pipe of the gas booster.

4.3 Thermo Mixing Valve Water Heaters

Current regulations stipulate that all new installations of water heaters need to have protection against scalding. Storage water heaters can protect against scalding with the addition of a thermo mixing valve. This valve mixes hot water, from the outlet of the storage tank, with cold water to provide tempered hot water at times when the water contained in the storage tank exceeds a nominal temperature of 50^{O}C. It should however be noted that a thermo mixing valve, which is located next to the water heater, can sometimes be manually set to provide hot water outlet temperatures between 35^{O}C and 50^{O}C. The SEC researchers have measured water temperatures after the mixing valve at all relevant monitored water heaters. A small case study was conducted at one of the electric storage water heaters that was fitted with a thermo mixing valve, logging the temperature of water after the thermo mixing valve. This study showed that the thermo mixing valve was well equipped to be able to steadily regulate the hot water temperature. The hot water temperature in this case was constant throughout the year.

This consistency of the temperature after the thermo maxing valve enables the hot water temperature to be assumed to be constant for all water heaters with thermo mixing valves, provided that the water heater is energised and stored water is therefore above this temperature. This proved useful for this study as the hot water temperature sensors for all thermo mixing valve equipped water heaters could therefore be positioned on the pipe work between the water heater and the thermo mixing valve, providing greater detail on the operating temperature of the water heater (this is especially of great interest in relation to heat pump and solar water heaters).

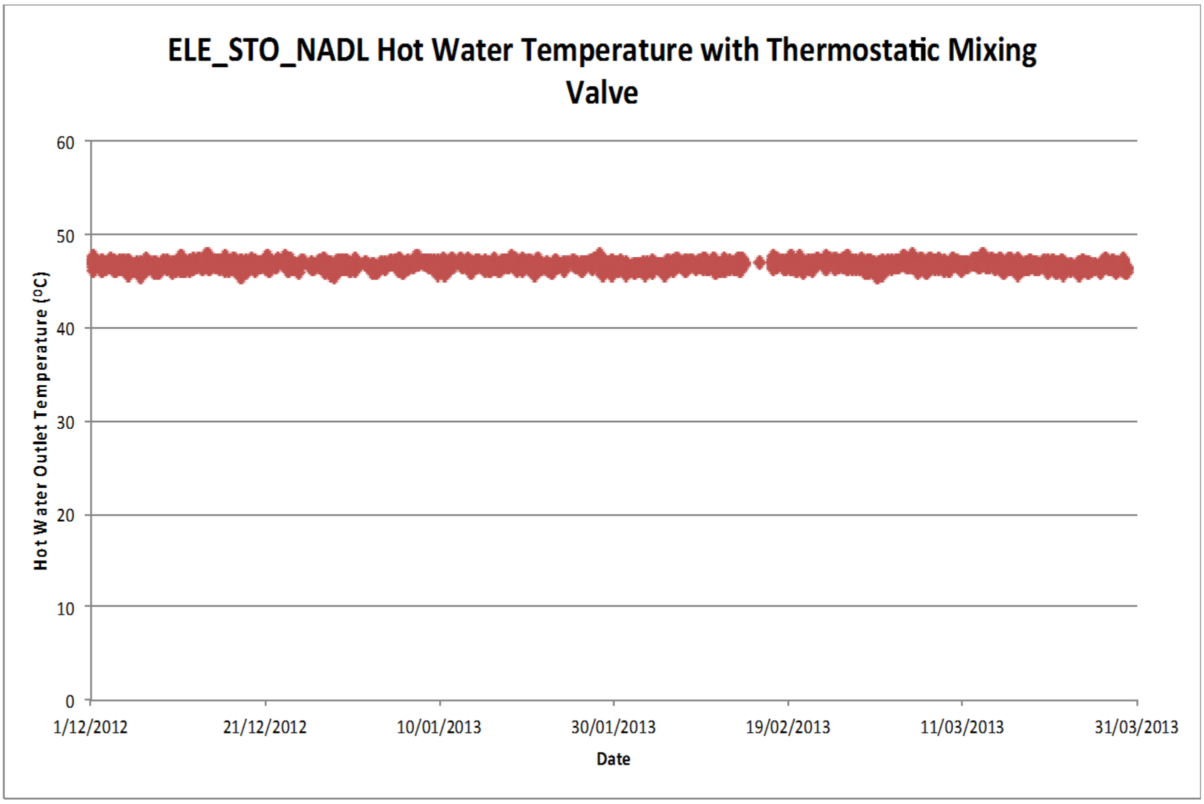


Figure 4-2: Hot water outlet temperatures at ELE_STO_NADL from only the thirds and subsequent minutes of hot water draw-off

4.4 Water Usage Trend Data

The total annual water consumption of each system in this study demonstrates variation between systems by up to 77,000 litres. Figure 4-3 displays that the highest consumption, exceeding 86,000 litres was recorded at GAS_SOL_LPST, one of two systems with four occupants. The other household with four occupants, namely ELE_STO_NADL, demonstrates approximately average total water consumption of 54,455 litres. Two storage hot water systems, one electric and one gas recorded the lowest annual consumptions, leading to the lowest system efficiencies overall, (this will be discussed in a later section). Note that Figure 4-3 displays corrected data where any full months of missing consumption have been estimated using linear interpolation of the preceding and following two months. This data correction was utilised on four occasions, in December for ELE_STO_NETH and GAS_STO_ABER, January for GAS_SOL_LPST and April for ELE_STO_NADL.

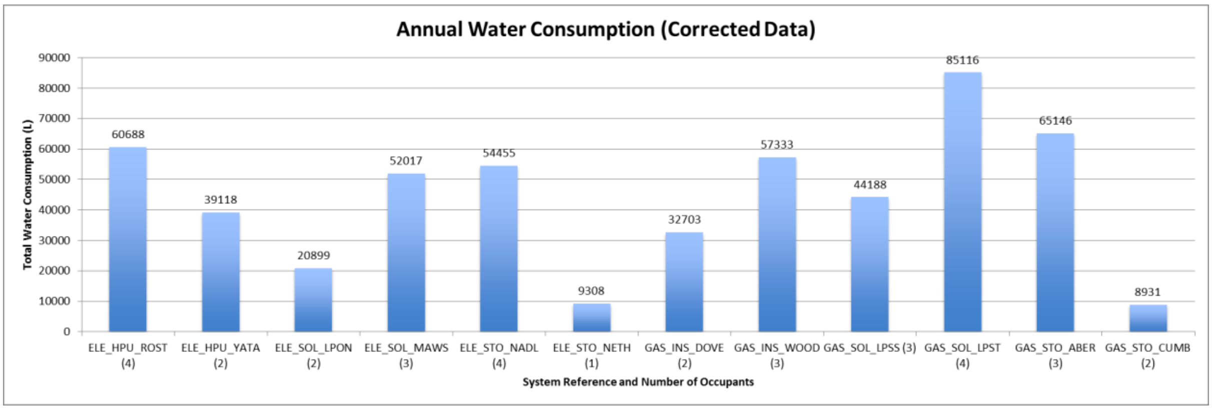


Figure 4-3: Total annual water consumption for each system, with data labels indicating total consumption (corrected data)

Analysis of the total hot water consumptions in each household has revealed an average of 39 litres per person per day throughout the twelve months of this study. This figure is slightly lower than the quoted figure (40 litres/pp per day) from the December 2012 interim report, due to decreases in both the ELE_STO_NETH and GAS_STO_CUMB consumptions because of changes in occupancy. Figure 4-4 shows the average daily consumption per occupant, revealing that the households with higher than average water consumption tend to have higher monthly variation in accordance with the cooler weather, while, households with the lowest consumption tend to be constant throughout the year. It is not apparent that occupants situated in Lochiel Park use any more or less water than occupants in other areas (refer to Figure 4-4). A comparison between hot water usage and system type reveals that three out of the four lowest users of hot water utilise a conventional storage hot water system and as a result their overall system efficiencies were the poorest. Owners of solar and heat pump systems did not necessarily consume less water per capita, nor did instantaneous users; an unexpected observation due to perceived environmentally friendliness and awareness associated with the purchased of these systems, particularly solar boosted hot water systems. One common misconception was noted as a result of the questionnaires where both the occupants of GAS_STO_ABER and ELE_STO_NETH replied with owning "solar gas" hot water systems, neither of which have solar collectors and ELE_STO_NETH does not utilise gas energy. The most likely explanation for this misconception is confusion of the respondents between solar photovoltaic systems and solar thermal hot water systems.

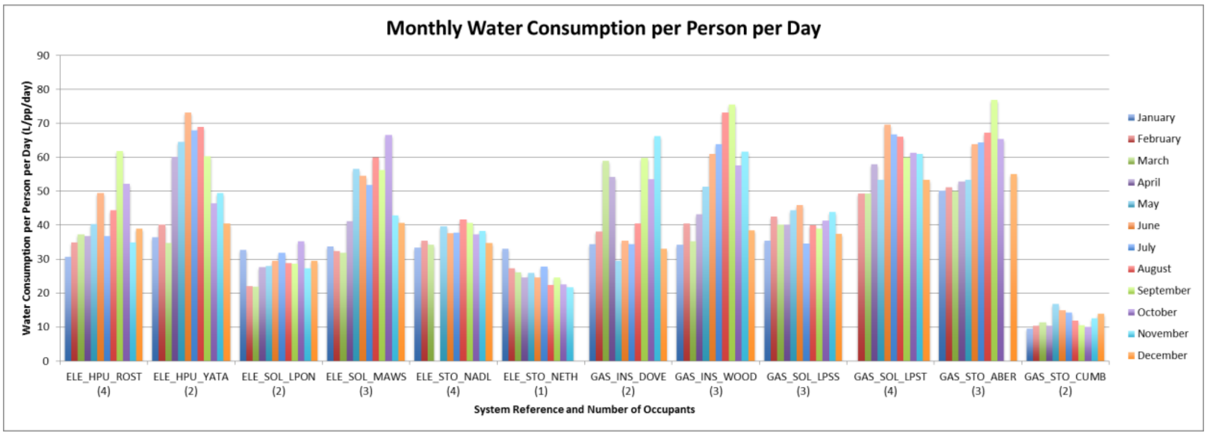


Figure 4-4: Household monthly water consumption per person per day

Figure 4-4 demonstrates that in general, the higher the number of occupants in a household, the higher the average daily water consumption per person. This trend is illustrated in Figure 4-5, where the 3 and 4 occupant households generally required more hot water in comparison with the small households. Such a pattern can be attributable to larger homes, requiring more cleaning and increased dishwashing and clothes washing activities per person, possibly due to the presence of children. The four households with 2 occupants each show the greatest variation in water consumption per person, ranging from 12 L/pp day to 54 L/pp day (refer to Figure 4-5). The lowest per capita consumption was recorded at GAS_STO_CUMB, where the occupants required an average of only 12 L/pp day throughout the monitoring period.

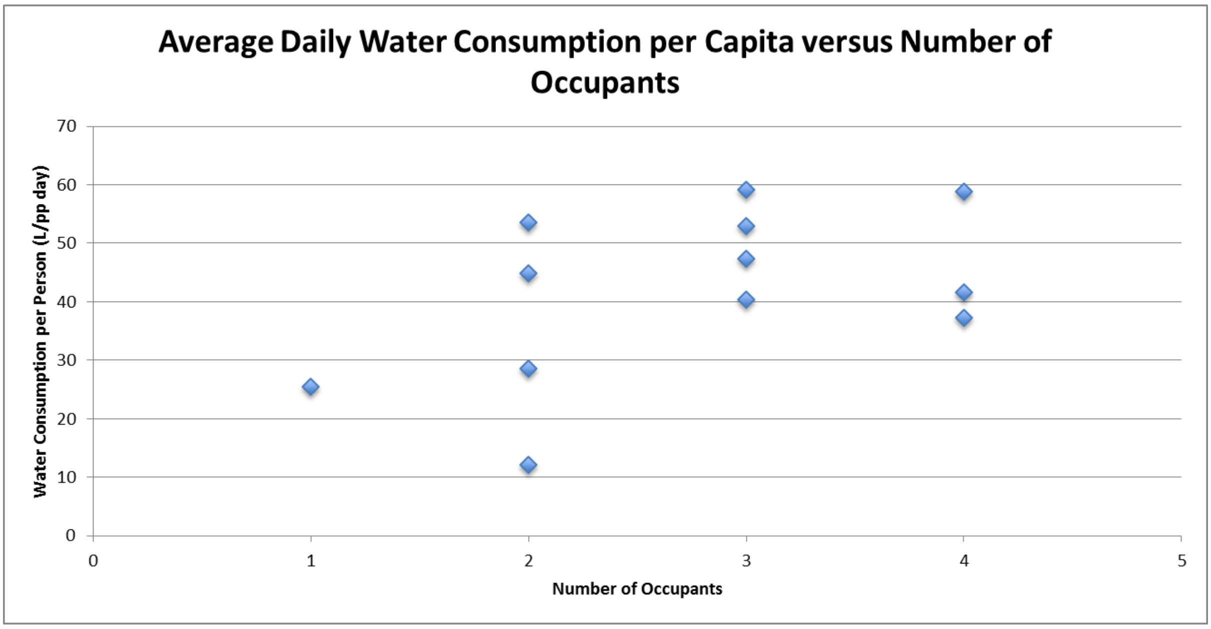


Figure 4-5: Average daily water consumption per capita versus the number of occupants in each household

While an average daily water usage was determined for each system, it is important to note that the maximum daily water usage of each system was typically twice the volume of the stated average daily water usage. Figure 4-6 shows the distribution of daily hot water usage for the ELE_HPU_ROST water heater. This distribution is representative of the distributions of daily hot water usage found throughout this study. The average daily water usage at ELE_HPU_ROST was calculated at 164 L/day.

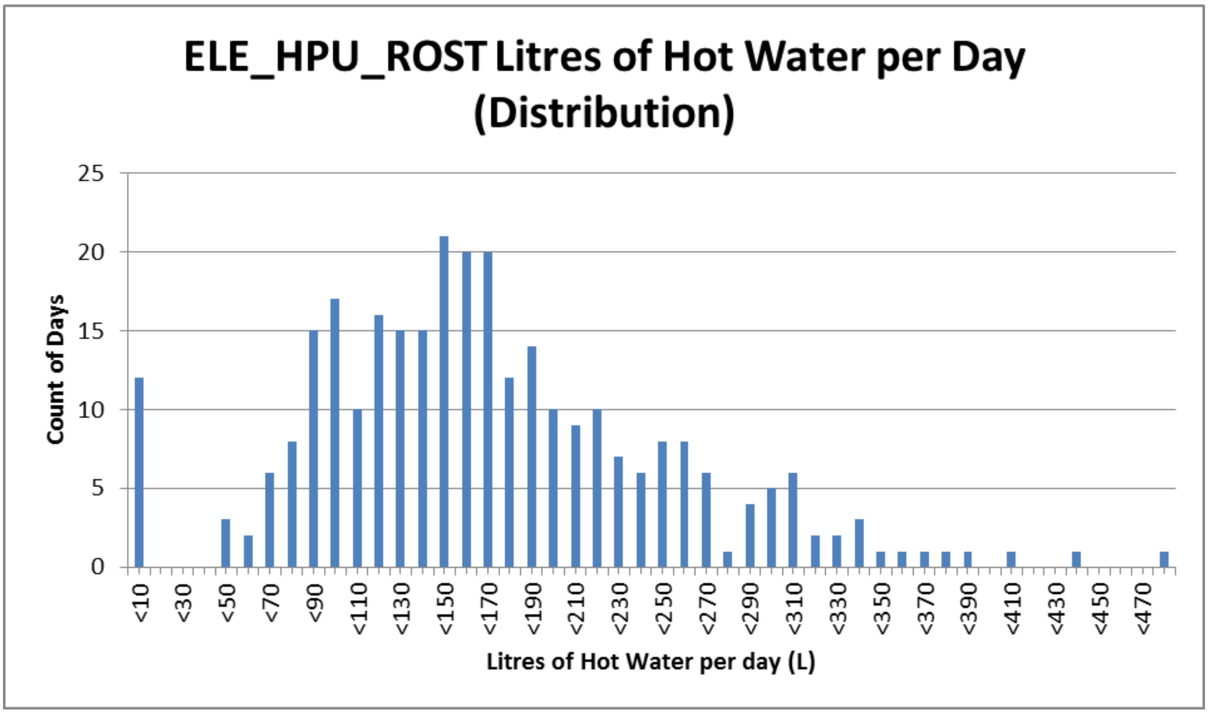


Figure 4-6 Distribution of daily hot water consumption at ELE_HPU_ROST

In sight of the development of baseline estimates, the daily water consumption per capita has been sub-divided into three categories; namely, small medium and large. These categories and the systems in each are defined as follows, but do not yet consider system load, which will be subsequently discussed.

- Small: 0-30 L/pp day, (ELE_SOL_LPON, ELE_STO_NETH, GAS_STO_CUMB)
- Medium 30-50 L/pp day, (ELE_HPU_ROST, ELE_SOL_MAWS, ELE_STO_NADL, GAS_INS_DOVE, GAS_SOL_LPSS)
- Large: Greater than 50 L/pp day, (ELE_HPU_YATA, GAS_INS_WOOD, GAS_SOL_LPST, GAS_STO_ABER)

Using these categories, the monthly usage profiles for each, in comparison to the average of this study are demonstrated in Figure 4-7. The usage profiles developed illustrated an observation made previously, where the large usage category has higher month-to-month variation with a steady rise and fall, in comparison to the low usage category. Additionally, the medium category is noted to have a noticeable dip in July in comparison to the study average, this is due to four out of the five systems in the medium category recording lower consumption in July in contrast to June and August. While household vacancies have been accounted for, periods of below average water consumption were noticed in four households, possibly in correlation to the July school holidays.

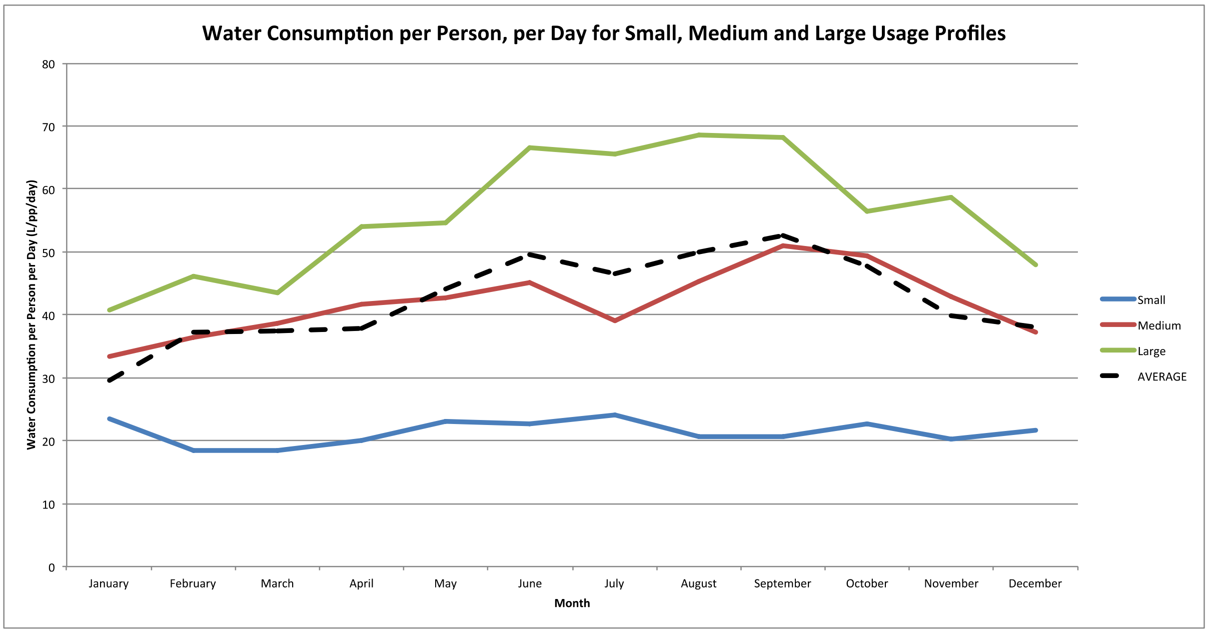


Figure 4-7: Water consumption per person per day for small, medium and large usage profiles in this study

4.5 Seasonal Usage Profiles

AS/NZS 4234:2008 provides standard operating conditions for domestic water heating in Australia by providing the thermal energy loads based upon peak daily loads of large, medium and small systems, daily and seasonal load profile multipliers. In order to compare these load profiles with the results of this study, the system loads must be considered accordingly. Irrespective of the thermal energy load categories provided in AS/NZS 4234:2008, small, medium and large heat load utilisation categories have been devised for the systems in this study, as shown in Table 4-2. These categories bare some similarities to the ones considered previously for hot water consumption, but are based on total system load, not consumption per person and hence vary slightly in the classifications for each system. Furthermore, these categories have been devised based upon system heat loads per day (refer to Table 4-2). Table 4-2 demonstrates that the systems in this study could clearly be divided into the three categories shown with only the ELE_SOL_MAWS system close to a defined boundary, potentially able to be categorised as medium or large depending on the category definitions. The decision was made to make the medium category from 10MJ/day to 25 MJ/day rather than 20 MJ/day in sight of the high variation of system heat loads that would arise in the large categorisation if ELE_SOL_MAWS were placed in that category.

The AS/NZS 4234:2008 system heat loads are defined by climate zone and based upon peak daily thermal energy loads with loads of 57MJ/day, 38MJ/day and 22.5MJ/day for large, medium and small system peak loads respectively in climate zone 3 where all of the systems in this study are located. In the consideration of the AS/NZS 4234:2008 energy loads, the system categorisations in Table 4-2 would vary in two instances, ELE_STO_NADL would be placed in the small category and ELE_HPU_YATA in the large.

Table 4-2: System heat load usage categories and classification

Category	System Heat Load (MJ/day)	System References	Number of Occupants	System Average Daily Heat Load (MJ/day)
Small	0-10	ELE_SOL_LPON	2	5.58
		ELE_STO_NETH	1	4.54
		GAS_INS_DOVE	2	7.22
		GAS_STO_CUMB	2	4.11
Medium	10-25	ELE_HPU_YATA	2	18.64
		ELE_SOL_MAWS	3	23.57
		ELE_STO_NADL	4	16.64
		GAS_INS_WOOD	3	15.10
		GAS_SOL_LPSS	3	15.46
Large	>25	ELE_HPU_ROST	4	26.67
		GAS_SOL_LPST	4	32.03
		GAS_STO_ABER	3	37.62

The impact of cold water inlet temperature on the system heat load is emphasised when the GAS_SOL_LPST and GAS_STO_ABER system heat loads and water consumption are compared (refer to Figure 4-3 and Table 4-2). Where the GAS_SOL_LPST system demonstrated the highest annual water consumption, exceeding that of GAS_STO_ABER by more than 18,000 litres, the average daily system heat load at GAS_STO_ABER exceeds GAS_SOL_LPST by more than 5MJ/day. This is attributable to the cooler water inlet temperatures and the fact that GAS_SOL_LPST has a thermostatic mixing valve, regulating the outlet water temperature to a lower value than at GAS_STO_ABER.

The variation in heat load on a monthly basis is higher than that of water consumption due to changing inlet water temperatures and ambient air temperatures contributing to increased thermal losses to the environment in the cooler months of the year. The categorisations in Table 4-2 allow for average small, medium and large daily heat loads to be calculated and compared to AS/NZS 4234:2008, as shown in Figure 4-8. Similarly to the water consumption trends, the small usage category displays lowered monthly variation when compared to the medium and large categories as well as compared to the study-wide calculated average. The comparison to AS/NZS 4234:2008 is also shown on Figure 4-8, illustrating that the study-wide average is below that of the AS/NZS 4234:2008 small category in all months of the year. Furthermore, the DMITRE medium category is similar to the AS/NZS 4234:2008 small category from April through to November, the summer months show that lowered system loads were experienced here than as estimated in AS/NZS 4234:2008. A similar trend in seen in the DMITRE large category, where the summer months show a decrease well below the AS/NZS 4234:2008 medium line. This observation highlights that the TRNSYS modelling used in AS/NZS 4234:2008 underestimates the variation in system load between winter and summer months as compared to the usage recorded here.

Figure 4-8 provides an indication that AS/NZS 4234:2008 overestimates the system thermal energy loads significantly in comparison to the systems monitored as part of this study. It is possible that in the time since the AS/NZS 4234:2008 model was developed, human patterns have begun to change due to increased environmental awareness, drought and water restrictions or changes in locational habits such as the occupants in this study that did not regularly shower at home or that this study failed to find a residence with a large load size (household with 5 or more residence).

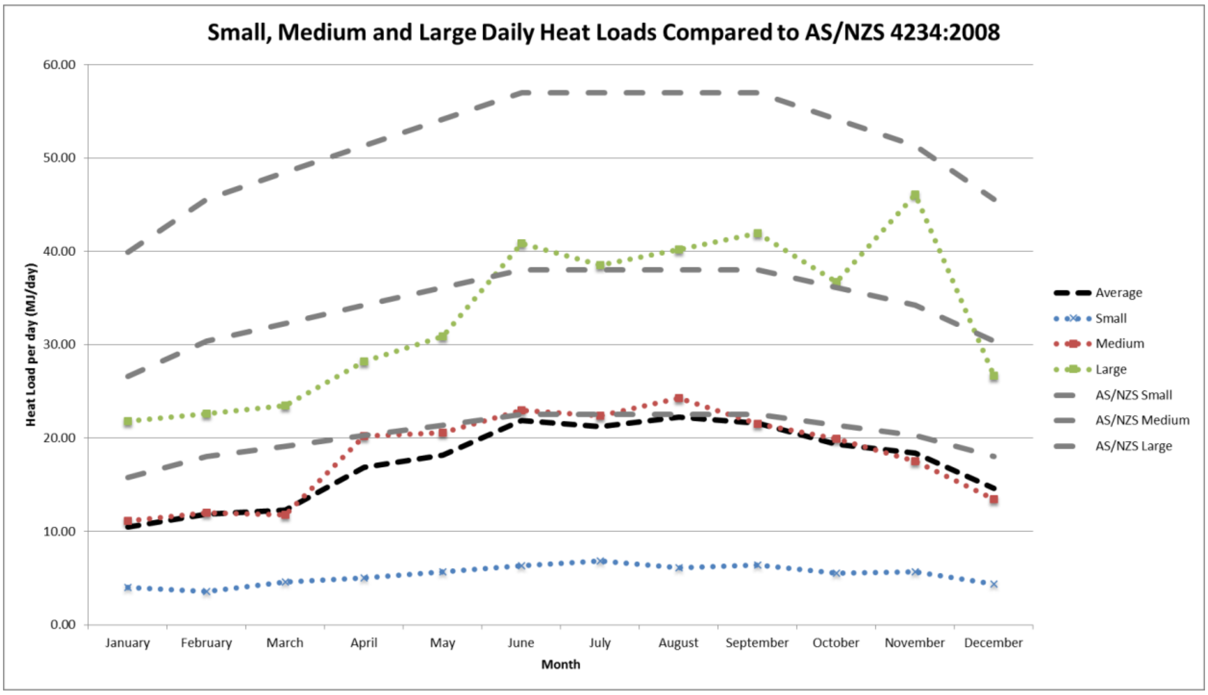


Figure 4-8: Small, medium and large daily system heat loads compared to AS/NZS 4234:2008 on a monthly basis

The seasonal load profiles provided in AS/NZS 4234:2008 have been demonstrated in Figure 4-8 to overestimate the system heat loads and underestimate the seasonal variation in comparison to the systems recorded in this study. Such differences could possibly be attributable to factors such as the local climate in Adelaide from December 2012 - November 2013 may have been warmer than average or the systems in this study may not be representative of the general population. It is also possible that the system heat load variation in Adelaide is different to the average for all climate zones and areas in Australia, as the AS/NZS 4234:2008 applies to all four climate zones, not only zone 3.

Table 4-3 illustrates the seasonal load profiles of both AS/NZS 4234:2008 and as found in this study for each month, illustrating the previous observations in the differences in the overall variations. The DMITRE load profile shows that the minimum overall load was found in February when temperatures are generally the warmest in Adelaide, however AS/NZS 4234:2008 assumes a minimum in January (refer to Table 4-3). Where this study estimates that the load varies by up to 51% between February and the peak months of July and August, AS/NZS 4234:2008 estimates only a 30% variation between January and June through September when the load peaks.

Table 4-3: Comparison between AS/NZS 4234:2008 and DMITRE seasonal load profiles

Month	AS/NZS 4234:2008 Seasonal Load Profile	DMITRE Average Seasonal Load Profile
January	0.70	0.54
February	0.80	0.49
March	0.85	0.59
April	0.90	0.69
May	0.95	0.87
June	1.0	0.97
July	1.0	1.00
August	1.0	1.00
September	1.0	0.93
October	0.95	0.85
November	0.90	0.74
December	0.80	0.62

4.6 Daily Usage Profiles

In addition to the seasonal load profile provided in AS/NZS 4234:2008, a daily load profile for Australia is provided whereby eight load events are defined, each for a period of 0.1h (or 6 minutes). In contrast, this study has found that the load events on each system vary greatly, however with the overall average illustrating a primary morning peak, a secondary afternoon peak and some load factor throughout all except four hours of the day. The methodology used by the UniSA team is slightly different to that employed in AS/NZS 4234:2008, with each hour considered from the 0 to 59th minute beginning at midnight, the resulting load profiles for each system and the overall average are shown in Figure 4-9. Figure 4-9 illustrates that a primary morning peak was experienced at eleven out of the twelve households, with GAS_STO_CUMB being the exception.

The primary morning peak was generally found either between 5:00am and 7:59am or 6:00am and 9:59am, depending on the habits of the household (refer to Figure 4-9). An additional peak in the afternoon to evening was observed in most households with those of ELE_STO_NADL, GAS_INS_WOOD and GAS_SOL_LPST being most pronounced. Each of these three households had either 3 or 4 occupants and the pronounced peak was most likely due to bathing of children at this time. On average the secondary peak occurred between 4:00pm and 8:59pm and contributed approximately 5% per hour of the total daily system heat load. An average daily usage profile of all the systems in this study has been developed and is shown in Figure 4-9 and Table 4-4, illustrating that the peak consumption of 13% occurs between 7:00am and 7:59am and 10% between 8:00am and 8:59am. No usage is recorded between 1:00am and 4:59am and a small secondary peak occurs between 5:00pm and 7:59pm. The calculated daily load profile for this study is compared to the AS/NZS 4234:2008 daily load profile in Table 4-4, highlighting some modest differences.

The primary morning peaks of the two profiles are similar, occurring in the hours of 7am and 8am, however the AS/NZS 4234:2008 estimates a higher portion of the daily load is consumed at this time. Furthermore the AS/NZS 4234:2008 load profile assumes load at 11am and 1pm, then from 3pm through 6:59pm, however the DMITRE study has found system loads far more evenly spread throughout the course of the day. This study found that 9% of the load is consumed between 9:00am and 9:59am and then between 3% and 6% is consumed each hour from 10:00am through until 11:00pm when it drops to only 2%. Furthermore this study recorded 1% of the daily load between midnight and 00:59am where the AS/NZS 4234:2008 predicts no load will be seen at this time. A fundamental difference between the two profiles is in the secondary peak which occurs later in the DMITRE study as compared to AS/NZS 4234:2008. The comparison between the two daily load profiles reveals that a more even distribution throughout the day was recorded throughout this study in comparison with AS/NZS 4234:2008.

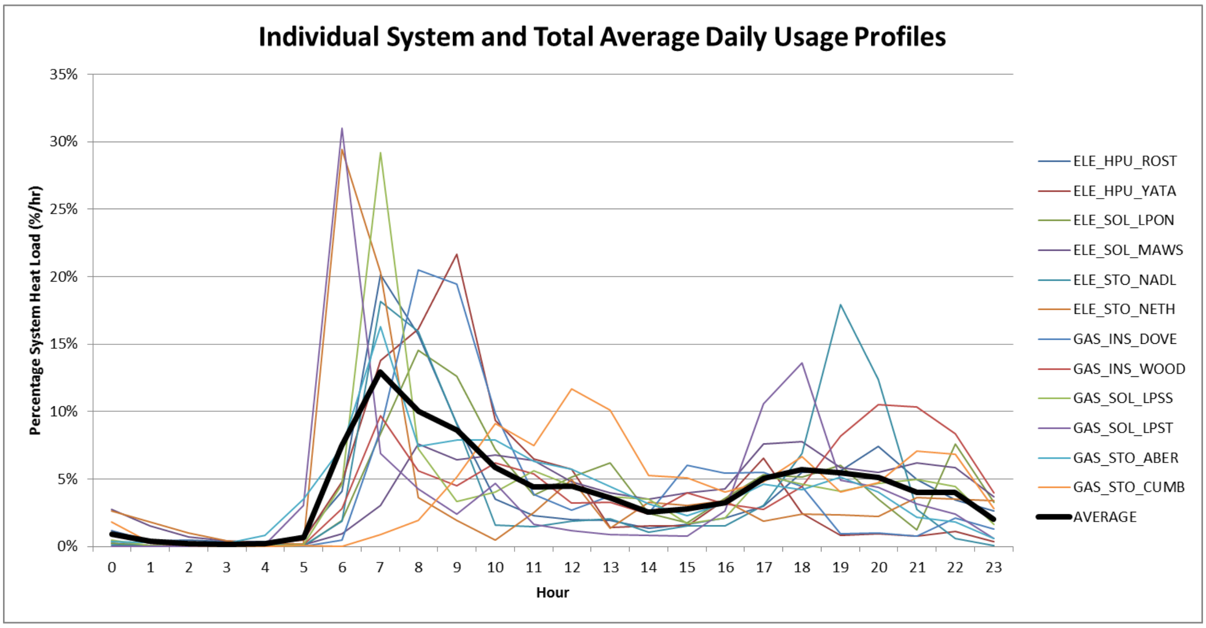


Figure 4-9: Individual system and overall average daily load profiles

Table 4-4: Daily load profiles for AS/NZS 4234:2008 and the DMITRE study

Hour Beginning	AS/NZS 4234:2008 Daily Load Profile	DMITRE Study Daily Load Profile
0:00	0%	1%
1:00	0%	0%
2:00	0%	0%
3:00	0%	0%
4:00	0%	0%
5:00	0%	1%
6:00	0%	7%
7:00	15%	13%
8:00	15%	10%
9:00	0%	9%
10:00	0%	6%
11:00	10%	4%
12:00	0%	4%
13:00	10%	4%
14:00	0%	3%
15:00	13%	3%
16:00	13%	3%
17:00	13%	5%
18:00	13%	6%
19:00	0%	5%
20:00	0%	5%
21:00	0%	4%
22:00	0%	4%
23:00	0%	2%

5 Trends and Analysis (Water Heater Type)

5.1 Electric Storage Water Heater Data Analysis

ELE_STO_NADL

The 250-litre electric storage system with a thermostatic mixing valve situated at North Adelaide was the only indoor system monitored in this study. As a result of the system being situated indoors, the tank heat losses are expected to be lower than for the systems situated outdoors due to higher ambient temperatures creating lowered temperature differences between the tank and ambient air during colder months. The residence of the house hold were a 4 person family including two children.

ELE_STO_NETH

This conventional electric storage hot water system situated at Netherby utilises a 259L storage tank, and unlike the other electric storage system in this study, is situated outdoors. Consequently, it is expected that the efficiency of the system will be lower than that of ELE_STO_NADL, due to increased heat losses. The system is connected to an off-peak tariff and hence, utilises overnight boosting of the water temperatures in the storage tank. The resident of this house was a single professional female.

Thermal Efficiency

The two conventional electric storage water heaters monitored in this study were connected to the electrical 'off peak tariff', allowing the electrical element to be energised only during the off peak period, with associated cost savings.

The thermal performance of the electrical storage systems were analysed, with consideration of associated heat losses and the internal tank energy throughout the year. Electric storage hot water systems are considered to be conventional water heater. Unlike solar hot water and heat pump water heaters where some, if not most of the heat energy added to the water comes from the environment, conventional water heaters gain all of their heat energy through the use of purchased energy. As such, conventional water heaters can never run at a thermal efficiency above 100%. As electrical elements immersed in water can be considered to have approximately 100% efficiency, the largest factor on the efficiency of electric storage hot water heaters is the standing heat loss of the tank. The daily efficiency of these water heaters can be described by the following equation,

Thermal Efficiency = (*Heat Load + Standing Heat Losses)/ Energy Purchased*

Standing Heat Loss

The purchased energy requirement of an electric storage hot water system is influence by the heat load and the standing heat losses. The standing heat losses are determined by the tank size and construction, water temperature and ambient environmental conditions. Both of the electric storage systems in this study were in the 250-260L capacity range. It is expected that the heat loss value of the tanks were similar, however as the ELE_STO_NADEL tank was located inside the residence, the heat loss observed for this tank throughout the year was marginally lower. The average yearly heat loss for ELE_STO_NADL and ELE_STO_NETH were 5.3MJ/day (1.47KWh/day) and 6.65MJ/day (1.85kWh/day) respectively. There was a seasonal variation in this value however the seasonal variation was relatively small, varying by approximately 1MJ/day throughout the year. The energy associated with the heat loss of the tank is significant and the proportion of the tank heat loss energy of electric storage systems can be seen in Figure 5-1 and Figure 5-2 .

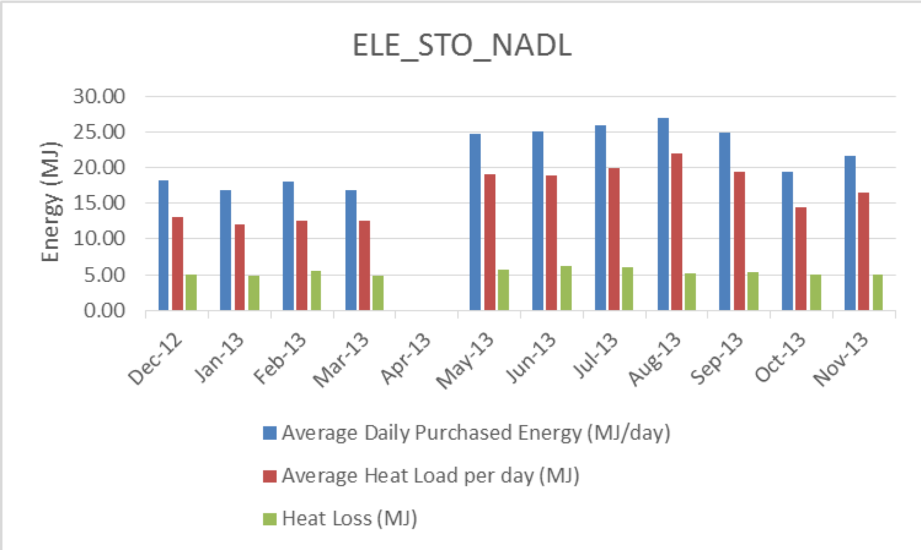


Figure 5-1 Energy break down of ELE_STO_NADL

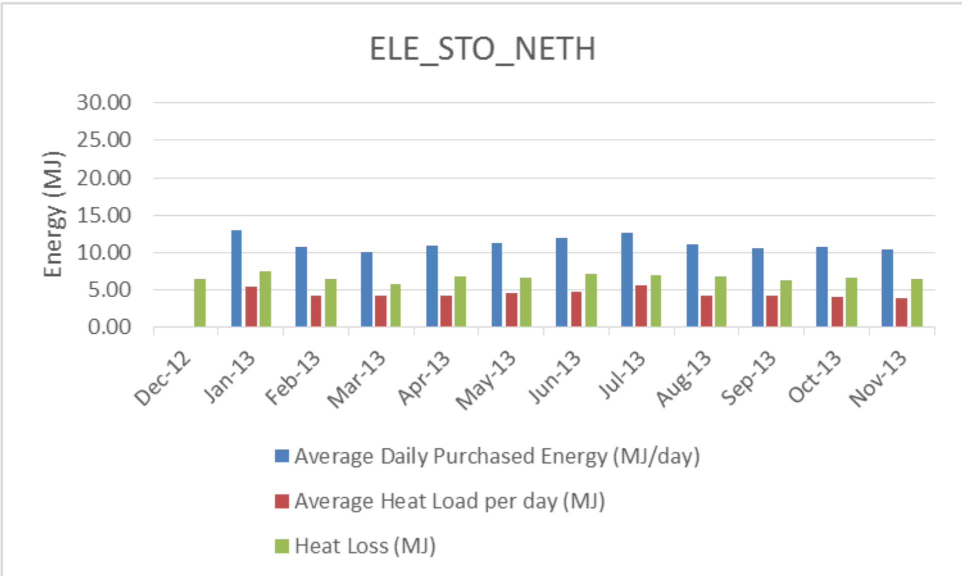


Figure 5-2 Energy break down of ELE_STO_NETH

Where electric storage hot water systems are underutilised relative to their capacity (such as in ELE_STO_NETH), the energy required to counter heat loss can be greater than the energy required to heat the consumed hot water. The most economical method of running an electric storage system is by sizing the unit to match the needs of the household, thus minimising the effect of the standing heat losses. Figure 5-3 illustrates the potential increase in efficiency achievable when system size and system usage is well matched. It is important that any storage tank be sized to have sufficient additional capacity such that on days of higher than typical use there is enough hot water within the tank to meet the heat load. If this capacity is not present the residents will be left without hot water until the next boosting period. The exact daily capacity a specific storage tank is dependent on many factors including electricity tariff connection, resident hot water usage pattern, standing heat losses and booster set temperature and will vary from household to household.

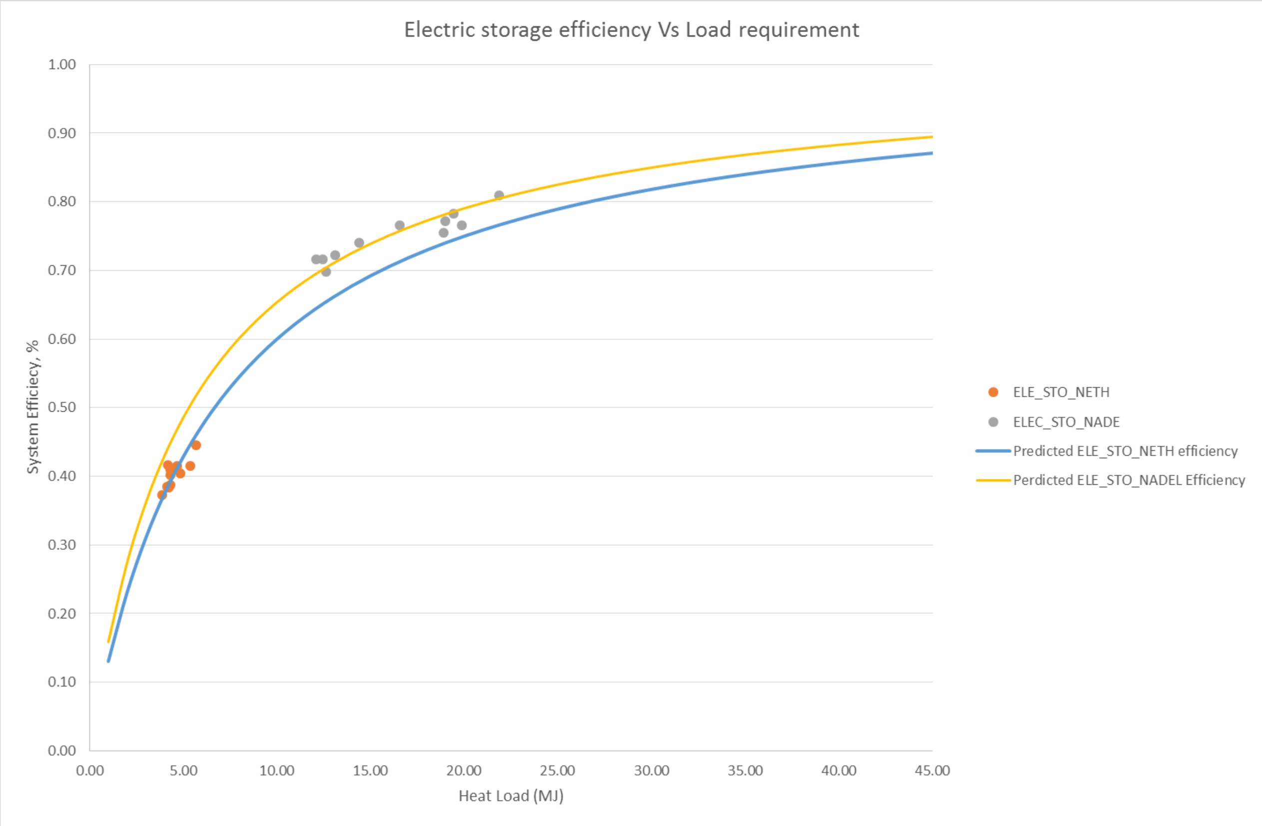


Figure 5-3 Monitored monthly efficiencies of ELE_STO_NADL and ELE_STO_NETH and predicted yearly overall efficiency based on average daily heat load requirement.

5.2 Gas Storage Water Heater November Data Analysis

GAS_STO_ABER

The gas storage system at Aberfoyle Park utilises a 160L storage tank and generally the water consumption on a daily basis exceeds the tank capacity. Unlike the electric storage systems, there are no off-peak gas tariffs available in South Australia and hence the gas hot water systems do no utilise overnight boosting but heat the water based on a thermostat setting as required. There were three occupants residing at the household labelled GAS_STO_ABER, a married couple and their 23 year old dependent son who studies at university. The water usage of this house was the second highest found in this study.

GAS_STO_CUMB

The two current occupants who utilise the gas storage system at Cumberland Park first occupied the household on the 21st December 2012, consequently for the purposes of baseline water consumption data, only data collected on or after this date can be analysed. The hot water system labelled GAS_STO_CUMB utilises a 130 litre storage tank, there were two adult occupants in the house and the hot water usage was the lowest observed in the study.

Thermal Efficiency

The thermal efficiency of the gas storage water heaters is lower than that of the electrical storage units as there is a significant loss of energy due to various factors including the transfer of heat energy from the vessel containing the gas burner as well as a significant quantity of energy being exhausted through the flue gases and combustion losses. The thermal efficiency of gas storage systems can be described in this manner.

Thermal Efficiency = ((Gas burner efficiency; heat transfer ability)**Heat Load) + maintenance rate)/ Energy used*

There are three major contributing factors to the performance of gas storage systems:

- The heat load
- The gas burner efficiency and the ability of the gas burner to impart its heat energy into the water
- The maintenance rate

The two conventional gas storage systems in this study possessed tank sizes of 130 litres at GAS_STO_CUMB and 160 litres at GAS_STO_ABER, the system at GAS_STO_CUMB was only utilised for an average of 24 litres or 4.10MJ per day and the system at GAS_STO_ABER averaged 177 litres per day or 37.41MJ. Using the standardised energy comparison for a water delivery of50°C, the GAS_STO_ABER system utilised approximately one third of the purchased energy per litre compared to the GAS_STO_CUMB system, as demonstrated in Figure 5-4. Due to the higher heat load on the GAS_STO_ABER system, the annual gas consumption was estimated as 23,218MJ in contrast to the GAS_STO_CUMB gas consumption of 7,692MJ. AS/NZS 4552.2:2010 stipulates that the maximum allowable energy consumption of a gas fired water heater is 22,831 MJ/year for delivery water heated with the specified 37.67MJ/day load. Results from GAS_STO_ABER indicate that the system heat load very close to that specified in AS/NZS 4552.2:2010. The conditions required for the AS/NZS 4552 yearly consumption calculations are simplified in comparison to the amount of data collected during this study. It is possible to compare the yearly gas consumption at GAS_STO_ABER with AS/NZS 4552. With an average daily heat load equivalent to AS/NZS 4552 requirements, the system required 11.5% more purchased energy for the year than 5 star systems are required to use in the standard. The system at GAS_STO_CUMB is not compared to this as the system load delivery averaged only 4.10MJ and it was not possible to extrapolate energy usage to 37.67MJ/day.

As a result of the inefficiencies demonstrated by the underutilisation of the GAS_STO_CUMB system, the cost per litre (based on standardised data) was estimated at 4.74 cents/L if the daily gas supply charge is included and 2.16 cents/L if the daily gas supply charge is excluded. Similarly for GAS_STO_ABER, the estimated cost of hot water is 1.01 cents/L if the daily gas supply charge is included and 0.74 cents/L if the daily gas supply charge is excluded. The inclusion of the daily supply charge has a bigger impact on the cost of the GAS_STO_CUMB system due to the low daily utilisation, however the system is still more expensive per Litre to run than the GAS_STO_ABER system.

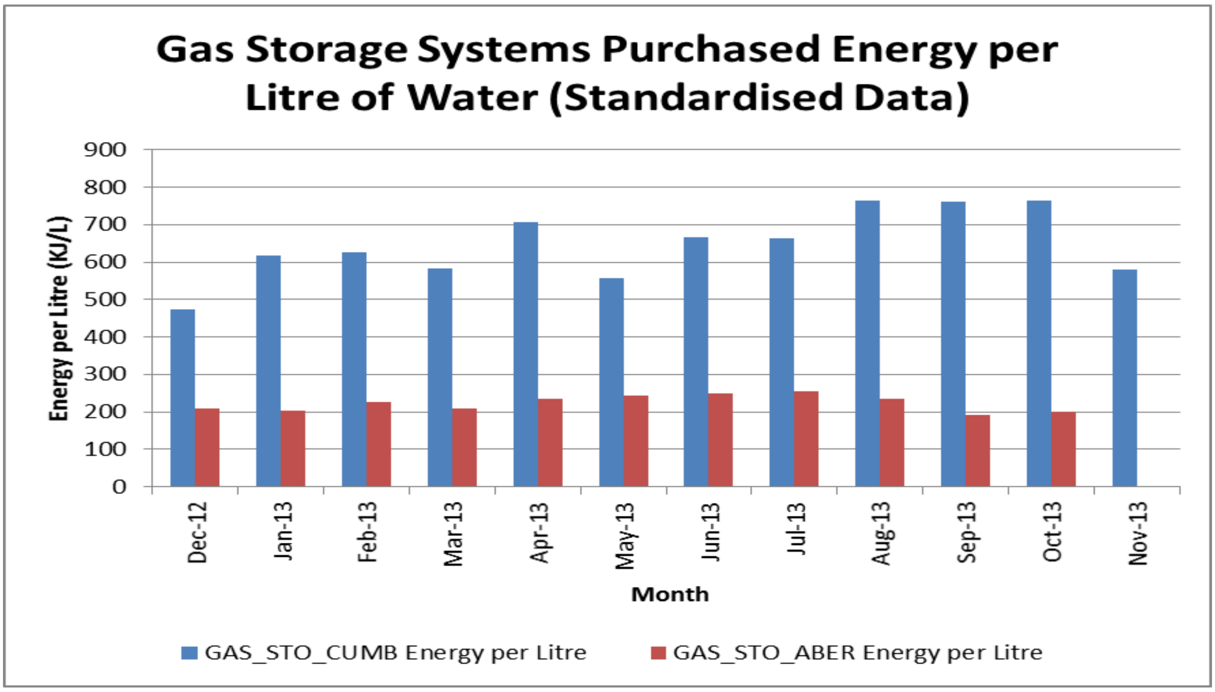


Figure 5-4: Monthly purchased energy per litre of water based upon standardised 50^{O}C water outlet temperature at GAS_STO_ABER and GAS_STO_CUMB

As previously discussed, under-utilisation of the storage hot water systems, in particular at GAS_STO_CUMB results in low efficiencies and relatively high costs per litre. The daily purchased energy with heat load of each system is demonstrated in Figure 5-5, where both systems indicate a strong linear trend. Such a trend indicates that the system efficiency would increase to a maximum value of approximately 80%, this would correlate with the expected burner efficiency. This value would likely be reached as the maintenance rate factor becomes significantly small compared to the required heat load. The calculated overall system efficiencies of the GAS_STO_ABER and GAS_STO_CUMB systems are 60% and 20% respectively, indicating that both systems would need to be utilised more in order to perform at their maximum efficiencies. Figure

5-6 illustrates the effect of the low utilisation of hot water on the overall efficiency of both systems.

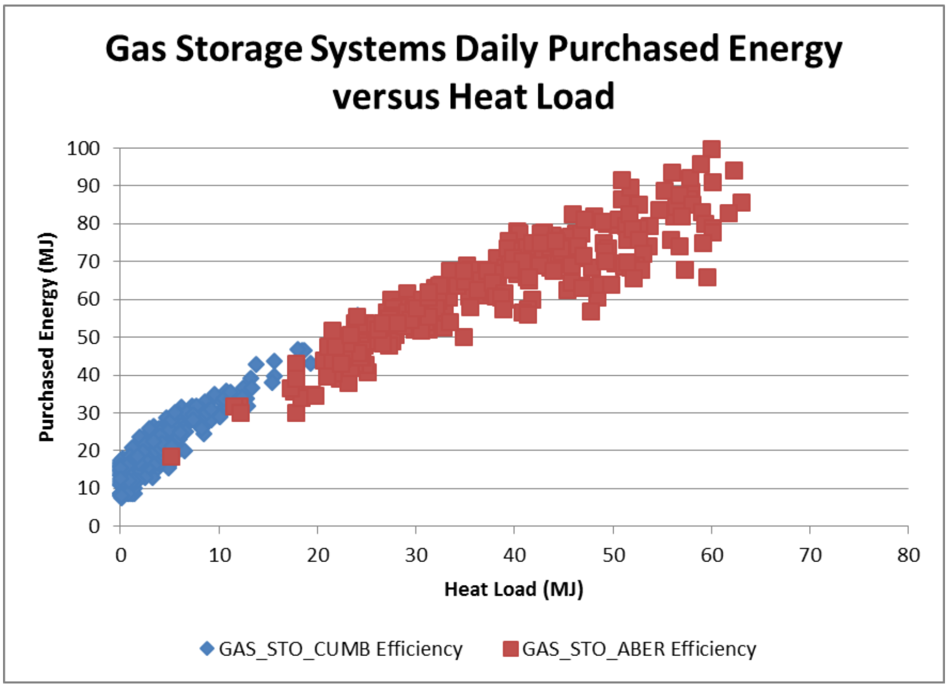


Figure 5-5: Daily purchased energy versus heat load at both GAS_STO_ABER and GAS_STO_CUMB

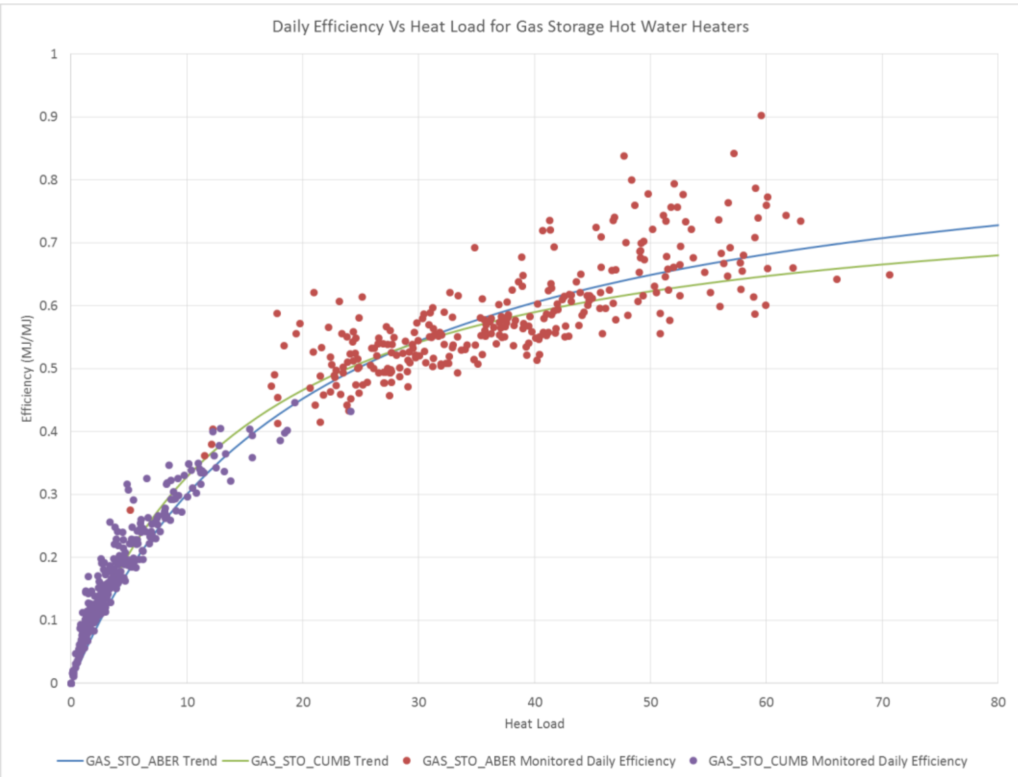


Figure 5-6 Daily Efficiency versus Heat Load at both GAS_STO_ABER and GAS_STO_CUMB

5.3 Continuous Flow Gas Water Heater Analysis

GAS_INS_DOV

The continuous flow gas hot water system at Dover Gardens was awarded 5.5 stars for energy efficiency and capable of producing hot water at 21 L/min at a 25°C temperature rise. The two occupants were over 65 year of age and retired. The required heat load was the third smallest in this study with an average heat load requirement of 7.22MJ/Day.

GAS_INS_WOOD

The continuous flow gas hot water system at Woodville was awarded 5 stars for energy efficiency and capable of producing hot water at 24 L/min at a 25°C temperature rise. There were three occupants within the residence, two adults and a child. With an average daily heat load of 15.1 MJ/Day, the hot water energy usage was in the medium range of this study.

Seasonal Variation in Heat Load

Both of the gas, continuous flow water heaters in this study limited the output temperature of the heater (GAS_INST_DOVE average hot water temperature = 42°C, GAS_INST_WOOD average hot water temperature = 44.4°C). As a result of the seasonal variation in inlet water temperature (January inlet water temperature =26°C, June Water temperature = 13.6°C), the required heat load varied greatly throughout the year. Figure 5-7 shows the variation in required heat load per litre of water as a result of the large difference in required temperature rise.

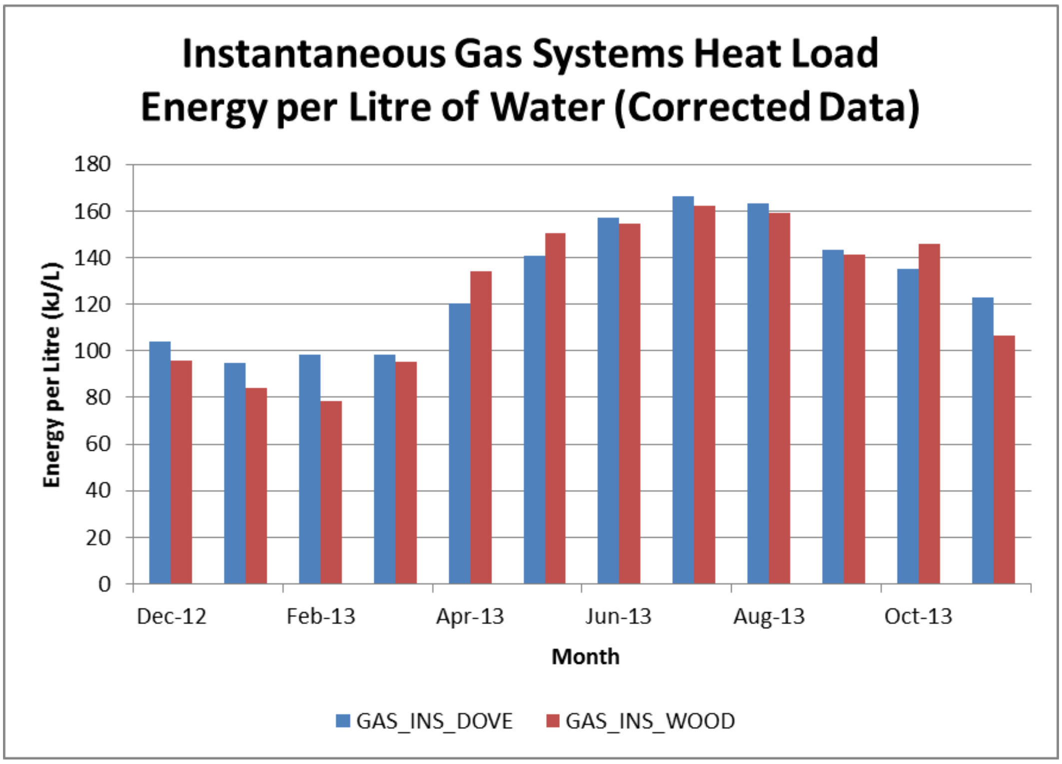


Figure 5-7 Continuous flow water heater purchased energy per L (monthly variation)

Thermal Efficiency

Typical domestic electric storage water heaters generally use 5.4-9.0 MJ (1.5-2.5kWh) of electricity per day to maintain the water inside a storage tank at the desired temperature. The daily energy required to maintain the same volume of water at the same temperature in a gas storage water heater is greater than this, approximately 20 MJ/day (5.5 KWh/day) in this study. Continuous flow gas water heaters do not store hot water, thus avoiding the standing heat losses which are inherent in all storage water heaters. With the exception of a relatively small amount of energy usage by an electrical controller and/or pilot, the energy used for water heating in a continuous flow unit is linearly proportional to the heat load (determined by the quantity and temperature of hot water required) and the number of instances the heater starts up.

Thermal Efficiency = (standby power + number of start-ups*start-ups efficiency + Gas burner efficiency**Heat Load)/ Energy used*

Standby Power and Booster Running Power Consumption

Typical gas, continuous flow water heaters use a small amount of electricity for their electrically controller continuously throughout the day while in standby mode. During times of operation a fan inside the gas booster and the electronic controller requires additional energy. Typical energy requirements during these functions are Standby: 1-5Wh Booster Operation: 40-60Wh. These values were evident at GAS_INS_DOVE where the daily electrical energy requirements consistently averaged 200 Wh/ Day. The GAS_INS_WOOD residence however did not appear to have any standby power. There was little to no standby evident in the monitored data. All electrical energy usage at GAS_INS_WOOD (average of 14Wh/ day) has therefore been attributed to the gas booster fan.

Burner Efficiency and Start-Up Gas Losses

Unlike storage hot water heaters, in most cases there is a lag between the start of water flow through a continuous flow water heater and the production of adequately hot water i.e. above 45^{o}C outlet temperature. Due to the 1 minute resolution and the external location of the temperature sensors, gas burner start-up losses could not be accurately measured within this study, instead, the water temperature during the first minutes of flow for every water usage event in the monitored data have been adjusted to represent real life temperatures.

The burner efficiency and the start-up gas losses could not be disaggregated. By comparing the purchased energy and the heat load at GAS_INST_WOOD and GAS_INST_DOVE it was possible to determine a trend which represents the burner efficiency and start-up gas losses assuming that the number of start-ups is proportional to the amount of heat load. From Figure 5-8 it is possible to establish that this trend is linear and that this trend can then be converted to show the efficiency of the two systems with respect to their heat load (Figure 5-9).

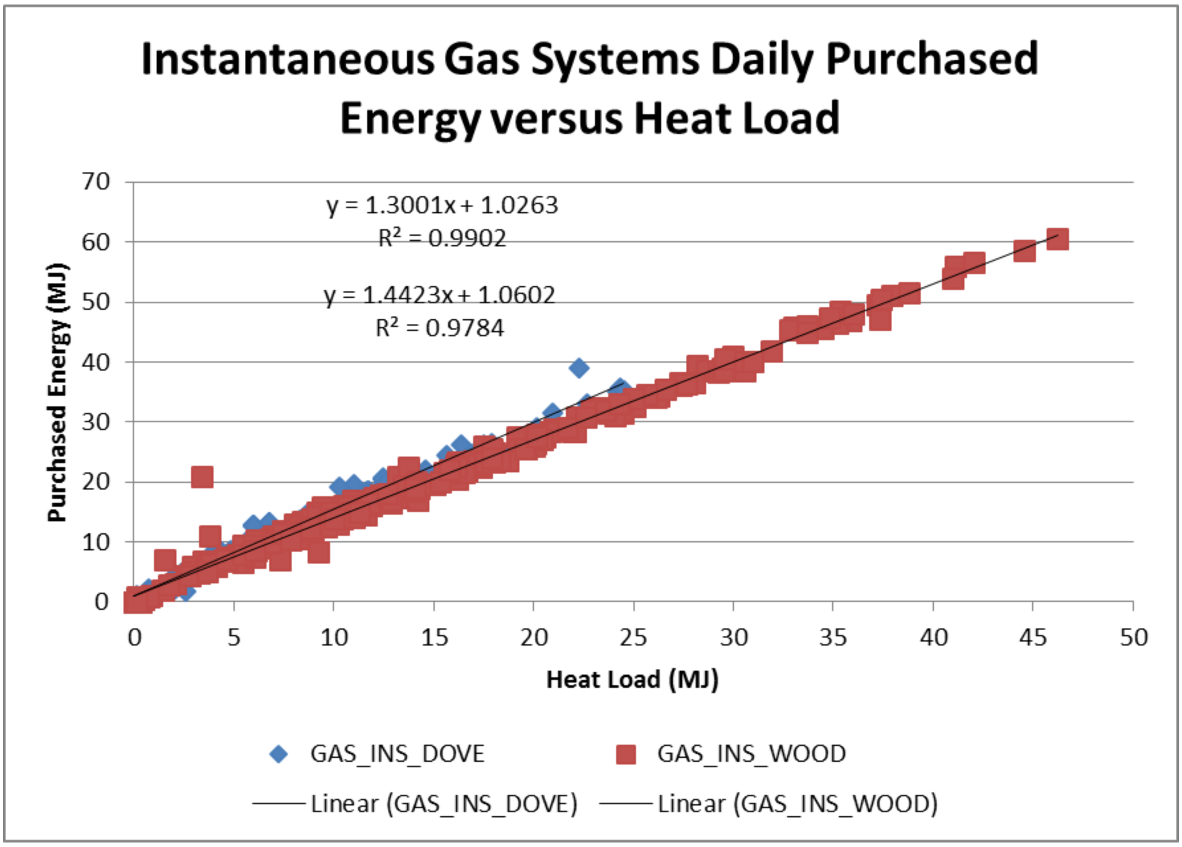


Figure 5-8 Gas continuous flow water heater purchased energy VS heat load

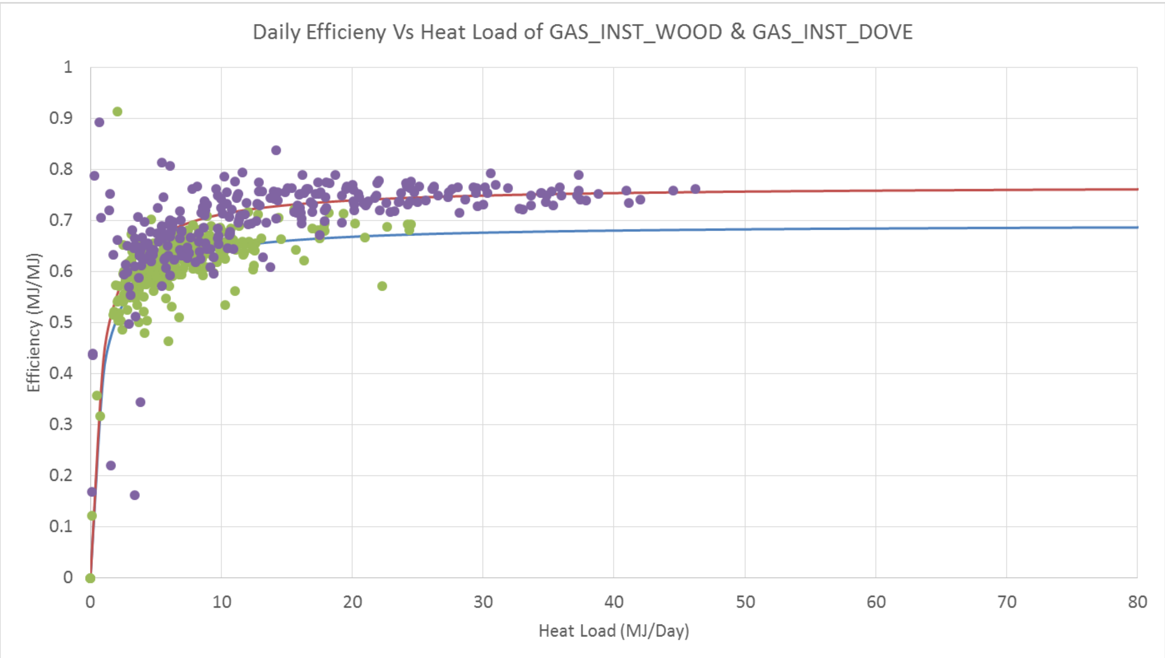


Figure 5-9 Gas continuous flow water heater efficiency Vs average daily load

5.4 Heat Pump Water Heater Analysis

ELE_HPU_YATA

The heat pump system located at Yatala Vale comprises of a 340 litre storage tank and a heat pump heat exchanger which was replaced in May 2013; as a result, the data analysis at the site has been adjusted accordingly. Observation of the hourly data recorded at ELE_HPU_YATA revealed that the original heat pump did not utilise off-peak boosting tariffs, however the replacement pump did, as a result the costing for the system will be separated depending on which heat pump was in place at the time. The ELE_HPU_YATA consisted of couple without dependent children, occupying a single-family sized home. The average heat load associated with ELE_HPU_YATA was 18.64 MJ/Day. This value falls in the middle of the medium water usage range found in this study.

ELE_HPU_ROS

The heat pump hot water system at Rostrevor utilises a 250 litre storage tank and is not connected to an off-peak electricity metering tariff. Consequently, the system heats the water stored in the tank as required. The residence of ELE_HPU_ROS consist of a family of 4 people, including two children. ELE_HPU_ROS utilised the third highest heat load within this study with an average heat load of 26.67Mj/day.

Refrigeration Cycle COP

An electric heat pump water heater uses a similar principle to a refrigerator in that it utilises an air-sourced heat pump to absorb heat from the air and transfer this heat into the hot water tank in order to heat water. The effectiveness of the refrigeration system to withdraw heat from the air and deposit that heat into the water is affected by the following factors.

- Ambient air temperature and humidity
- Tank water temperature
- Inlet water temperature
- Refrigerant
- Refrigerant system design (evaporator, condenser, compressor)

The operation of the refrigeration circuit is complex and it was not feasible to monitor in detail the numerous variables that affect the operation of the heat pump during this study. A parametric analysis of aforementioned factors was conducted, however, without detailed monitored information no conclusive trends were discovered.

Energy Usage and Efficiency

$$\textit{Energy used} = \text{COP}*(\textit{Heat Load} + \textit{standing heat losses})$$

Daily variances between the overall efficiency of the heat pump water heater performance were larger than seasonal trends. This indicates that environmental factors such as air temperature and humidity and tank water temperature (partly dependant on the daily heat load) which affected the operation of the heat pump refrigerant system had the greatest effect on the thermal performance of the system. It was possible to develop an understanding of the usual operating window within which each heat pump operated, i.e. the typical thermal efficiency window that the heat pump system operated at during expected operation throughout the year. Figure 5-10 Illustrates that the three heat pump water heaters monitored in this study had differing typical operating rangers. The ELE_HPU_ROS water heater typically operated with a system efficiency of between 150%-250% with outliers occurring during times of lower/higher than average heat loads. Throughout the year the ELE_HPU_ROS system operated with an average thermal performance efficiency of 197%. The original ELE_HPU_YATA heater operated with a typical operating system efficiency between 50% and 150% while the replacement ELE_HPU_YATA heater operated within a window of efficiency between 150% and 350%. During their respective times of operation during the monitored period, the original and replacement heat pumps at ELE_HPU_YATA operated with a total average system efficiency of 105% and 249% respectively.

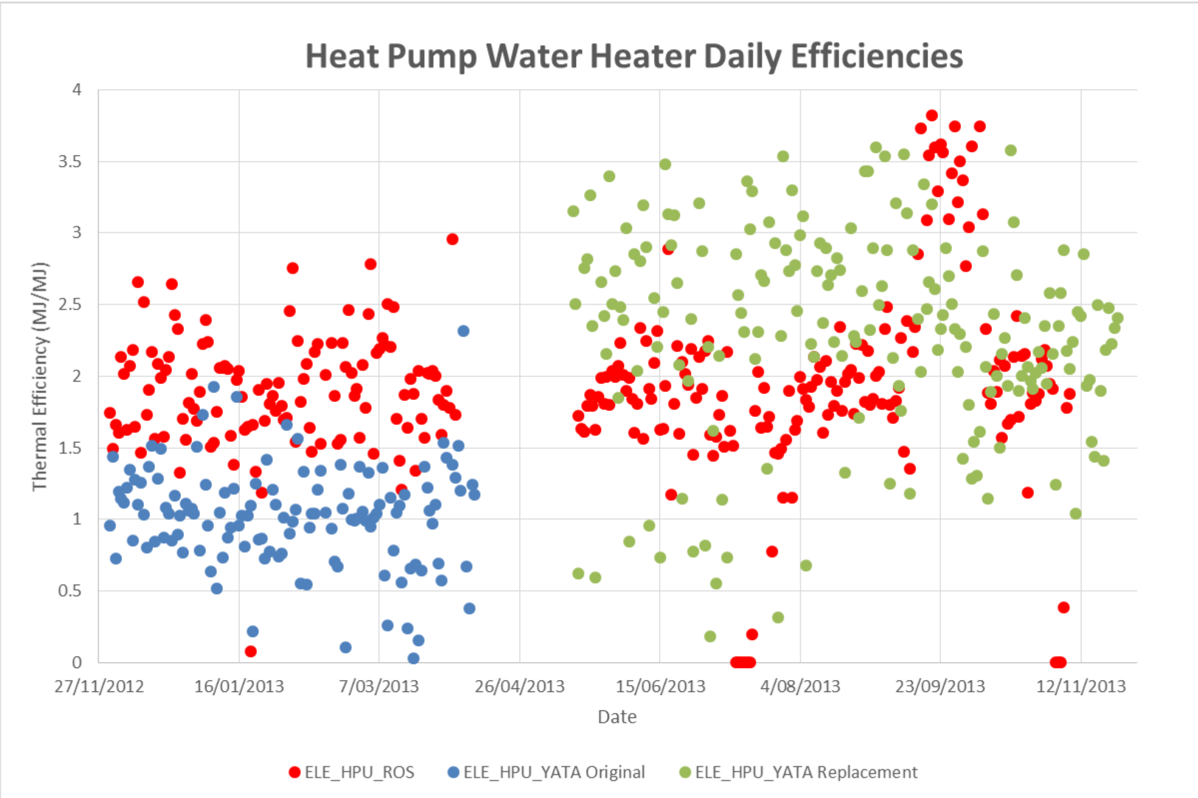


Figure 5-10 Heat Pump Daily Efficiency

Standing Heat Loss

Figure 5-11 demonstrates that, as is the case with the conventional water heaters, standing heat losses associated with storage tanks have a large effect on the performance of a water heater. For all three heat pumps, where the heat load is less than 10MJ/Day, the system thermal efficiency of the heat pump is less than 1 and that there is an upward trend for all systems associated with the efficiency in relation to the heat load. Because there is such a variation between the daily system efficiencies due to the aforementioned factors that affect the COP during daily operation it is not feasible to predict, with any certainty an average, typical curve for the daily performance of heat pumps or the standing heat losses. Currently heat pump water heaters do not need to comply with the minimum energy efficiency for standing heat loss limits associated with electric element storage hot water heaters. Typically, tanks used for heat pump water heaters are derived from conventional electric water heaters and therefore it can be expected that the heat loss associated with a heat pump water heater will closely match that expected of a similar sized conventional electric water heater. It is important to note that the purchased energy required to offset the standing heat losses associated with the storage tank are smaller than those of conventional systems as the heat pump operates at a COP greater than an electric element or gas burner.

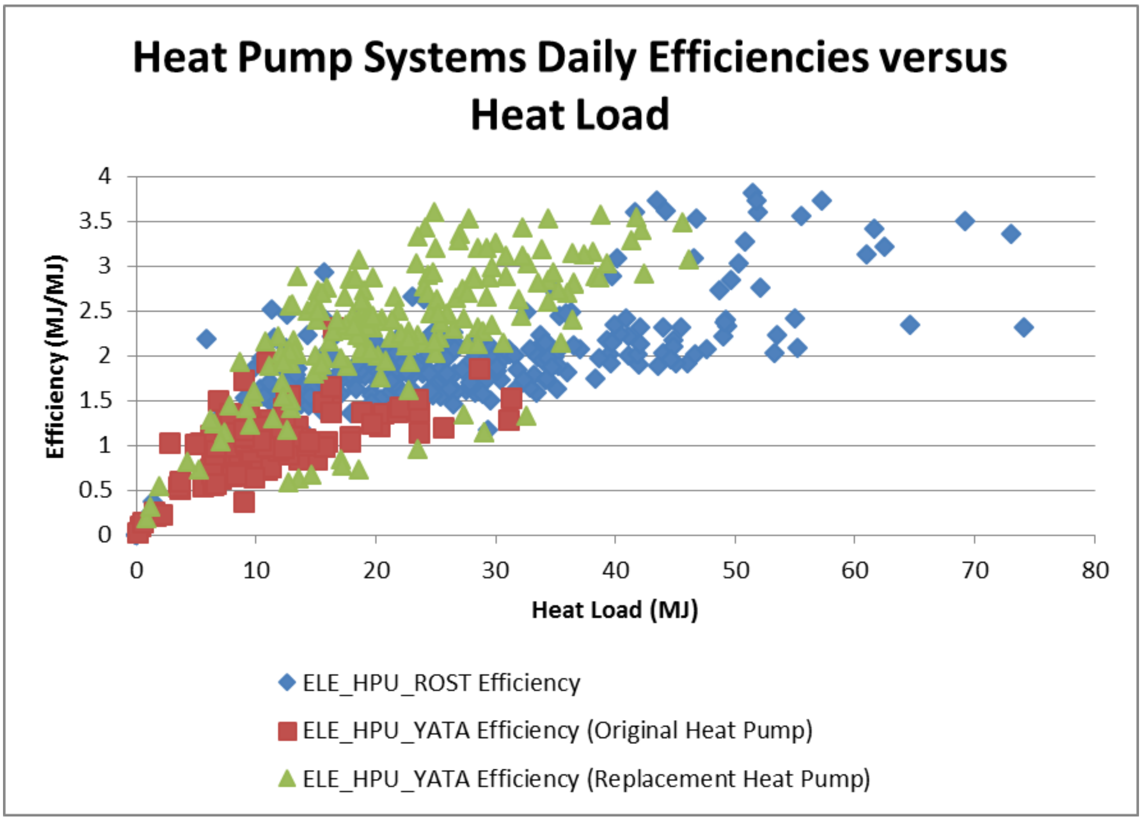


Figure 5-11 Heat pump Daily efficiency Vs Heat Load

5.5 Electric Boosted Solar Water Heater Data Analysis

ELE_SOL_LPON

The electric boosted solar system at Lochiel Park is the only evacuated tube, solar hot water system in this study. The system utilises a 250 litre water storage tank and it has been noted that the owners turn off the tank electric boosting element in the warmer months of the year. The data analysis of the electricity consumption of the boosting element will demonstrate the periods of the year for which the element was powered off and enable an analysis of the proficiency of the system to provide heated water at these times. There were two retired occupant at the residence and the average daily heat load was 5.58 MJ/Day, the third lowest found in this study.

ELE_SOL_MAWS

Unlike the other electric-boosted solar hot water system in this study, the system at ELE_SOL_MAWS utilises two flat plate collectors and 340 litre storage tank. It was not apparent at any time throughout the monitoring period that the boosting element was switched off. There were three occupant at the residence and the average daily heat load was 23.57 MJ/Day.

Electric Boosted Solar Hot Water Performance

The operation of solar hot water heaters can usually be disaggregated into two components.

The Solar loop- consisting of a storage tank, solar collector, the connection between the tank and in many cases a pump to circulate water through the collector and tank.

Electric booster element- For electrically boosted systems this is an electrical element immersed within the tank or for gas systems this can either be a gas burner integrated into the tank or a gas booster attached to the outlet of the storage tank.

For both, the electrically boosted and the gas boosted solar hot water heaters monitored within this study, the solar loop portion of the water heater was able to supply a majority of the hot water load during the period between November and March. Depending on the specific residential water usage and the water heater specification the length of this period varied by approximately 1 month. Figure 5-12 and Figure 5-13 clearly show that during this period the hot water outlet temperature is in excess of 60°C and often above 70°C (red line) while there is little to no electrical element usage (green bar). During the colder months of the year where there is also less solar irradiance, the water heaters show a higher dependency on the electrical booster. Figure 5-13 Shows that the outlet temperature during this period is consistently approximately 60°C (the set temperature of the electrical element). The residence at ELE_SOL_LPON often turned their electrical element off. This is evident in Figure 5-12 where the winter time outlet often fell below the 60°C electrical element set temperature and the number of days during this period where the element was not used.

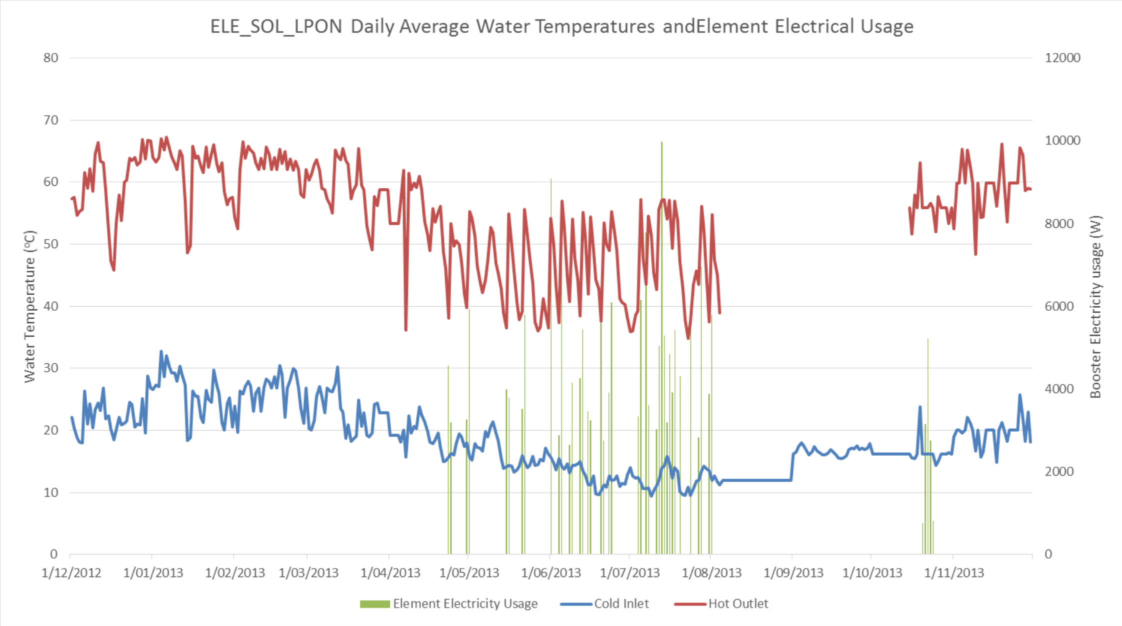


Figure 5-12 ELE_SOL_LPON Water Temperatures and Electrical Usage

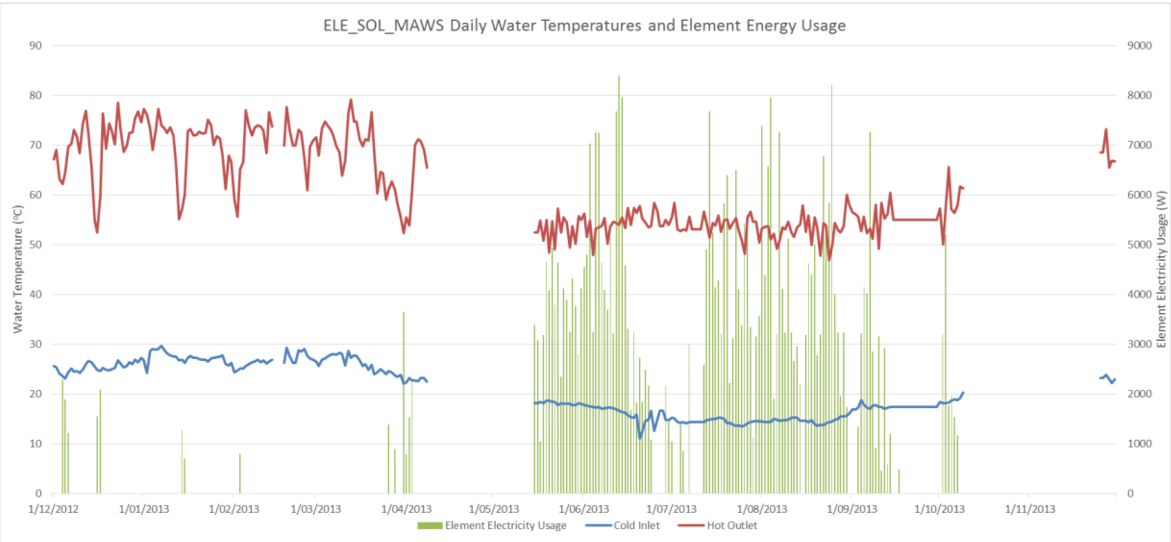


Figure 5-13 ELE_SOL_MAWS Water Temperatures and Electricity Usage

The purchased energy requirement of an electric boosted solar water heater can be described as:

Energy used = Heat Load + standing heat losses + solar pump energy - energy added by solar collector

Solar Loop

There are two typical types of electric boosted solar hot water heaters, thermosiphon and pumped. Thermosiphon type solar water heaters utilise the natural convection flow to pass water between the storage tank and the solar collector while pumped systems use an electric pump to flow water around the tank and collector. Both of the electric element boosted solar water heaters in this study were the pumped circulation type. The solar pumps only operate when solar irradiance is great enough that there is a temperature difference across the solar collector. Figure 5-14 shows the average daily energy usage of the solar loop pump for each month. It can be seen that during the colder months, the pump is activated for a shorter period during each day. The energy collected during the pump operation times is also less than that witnessed during summer months.

The efficiency and correct combination of the solar loop components will determine the overall efficiency of a solar hot water heater. The importance in ensuring that the solar collector area and tank size is appropriately sized for its application was evident during this study. Both of the electric hot water heaters within this study were able to supply a majority of their heat load during the warmer months through the solar loop alone. Between October and May, the ELE_SOL_MAW purchased energy requirement was 5% of the used heat load. During November to April, the ELE_SOL_LPON purchased energy requirement was 20% of the used heat load. Typically, the electrical requirement of a solar pump is negligible compared to the heat load, however, the higher percentage of purchased energy used at the ELE_SOL_LPON residence was a result of the heat load being considerably small enough to affect this system efficiency.

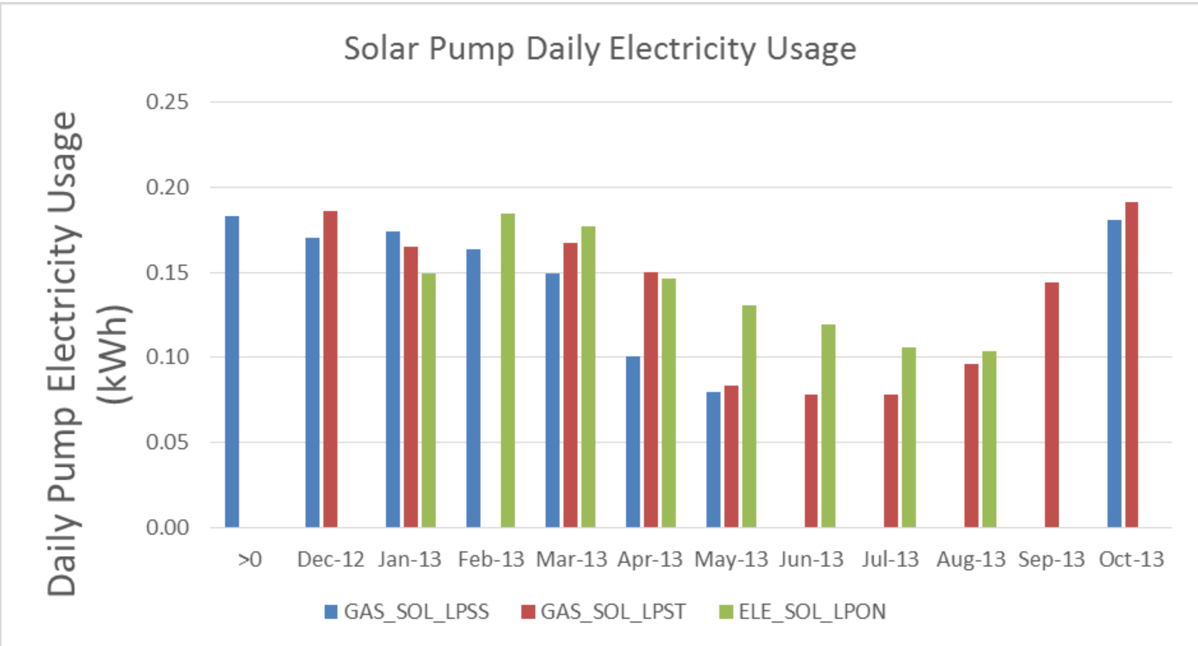


Figure 5-14 Daily Solar Pump Electrical Usage

Standing Heat Loss

This study considered the hot water systems as black boxes, looking at input and outputs only. As a result, it is not possible to disaggregate the energy input into the storage tank via the solar loop and the heat losses associated with the storage tank. It can, with some confidence be assumed that the tank heat loss value will be similar to that of a conventional storage electric hot water system of the same size and that this value will closely match the maximum allowable tank heat loss values specified in AS/NZS4692.2. Yearly total standing heat losses will be higher for electric boosted solar water heaters compared to conventional electric water heaters as the stored water temperature exceeds the element set temperature during months of sufficient solar irradiance. The energy lost as a result of this higher standing heat loss is supplied by the solar collector and therefore in not evident in the purchased energy required during these periods. During the months where the solar irradiance is insufficient to supply all of the required heat load, the electrical element typically controls the storage tank temperature and therefore standing heat losses during this time can be expected to match that of a similar sized conventional electric/ storage hot water heater.

Electric Element

The efficiency of the electrical element in an electrically boosted solar hot water heater can be assumed to be 100%. In this study, the solar loop was able to produce a sufficient amount of hot water to ensure that the electrical element was rarely used during the period between October and May. During the period between June and September, both of the solar/electric water heaters relied on the electrical element to boost water temperatures to the thermostat setting of 60°C. Figure 5-15 and Figure 5-16 show the split between the energy split between the electrical element and the solar loop for ELE_SOL_LPON and ELE_SOL_MAWS.

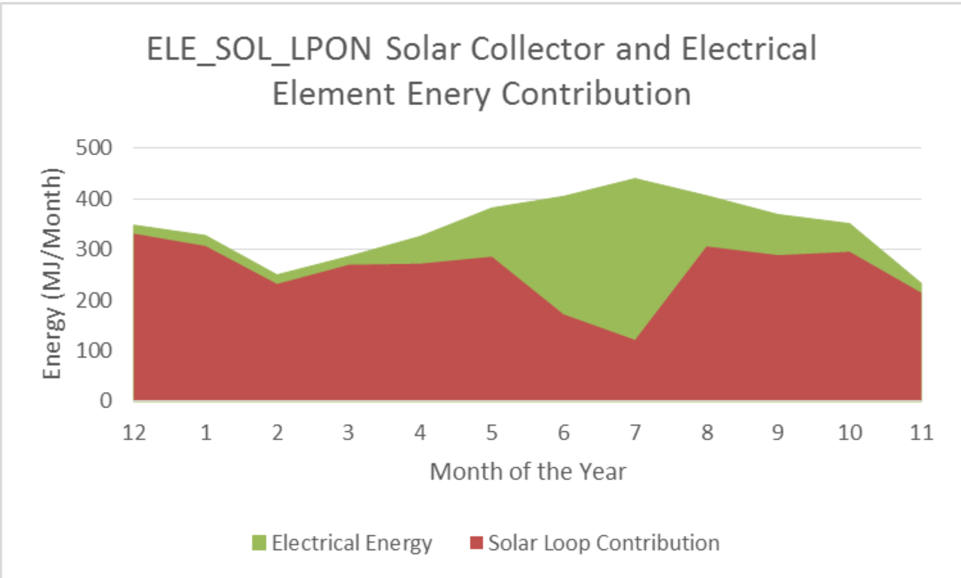


Figure 5-15 ELE_SOL_LPON solar and electrical element energy contributions

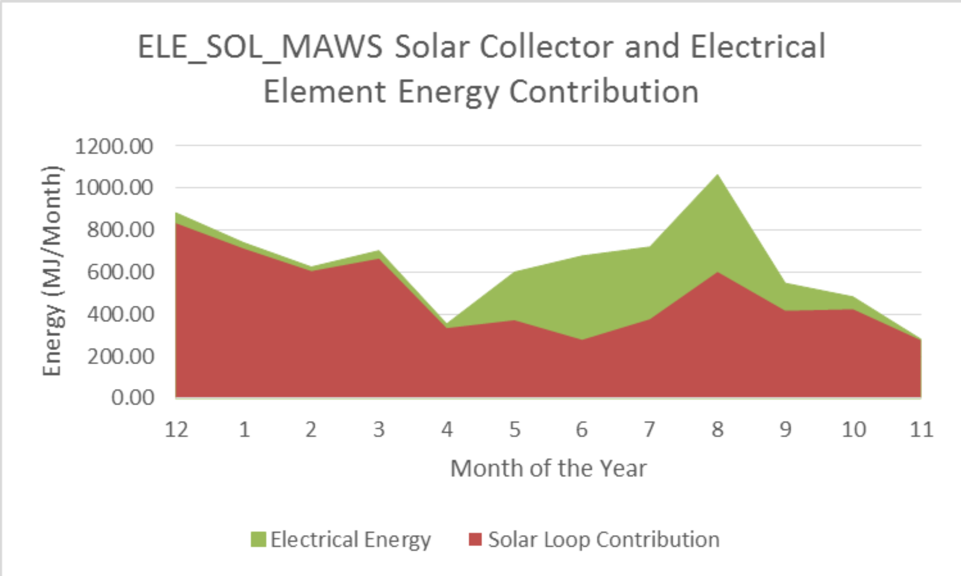


Figure 5-16 ELE_SOL_MAWS solar and electrical element energy contributions

5.6 Gas Boosted Solar Water Heater Data Analysis

GAS_SOL_LPSS

Both of the gas solar hot water systems in this study are located in Lochiel Park and utilise two flat plate collectors and a 215 litre storage tank with continuous flow gas boosters. The residents at GAS_SOL_LPST were a mother and her two teen aged daughters. The consumption of hot water at GAS_SOL_LPSS averaged 121 litres per day.

GAS_SOL_LPST

The second gas boosted solar hot water system in this study situated at Lochiel Park is an identical system to the previous system. The residents at GAS_SOL_LPSS were a family with two young children. On average, 222 litres of hot water was consumed at GAS_SOL_LPST throughout the 12 month monitoring period.

The thermal efficiency of a gas boosted solar water heater is dependent on the following variables:

- Heat Load
- Standing heat losses
- Solar pump energy
- Gas booster efficiency
- Solar collector loop efficiency

Standing Heat Loss

The standing heat losses associated with continuous flow gas boosted hot water heaters varies from other storage systems. During days where there is sufficient solar irradiance to supply the heat load, the internal tank water temperature will be greater than 55°C and during summer months this value is typically closer to 70°C or higher. During days where the heat load exceeds the energy input into the tank via the solar collector loop the tank temperature will fall below 55°C. Typically, all other storage systems will maintain the water temperature within the tank at 60°C during these periods to ensure adequate hot water supply and to protect against the growth of legionella within the tank. The continuous flow gas booster allows the tank temperature to fall below this temperature by boosting the water temperature after it exits the storage tank. The gas booster has sufficient capacity to boost the water to the required temperature to supply water to an acceptable temperature as well as to protect against Legionella (increase water temperature above 70°C for a minimum of 1 second). This study showed that in the colder months of the year (June-September), the tank water temperature was consistently below 30°C. The reduced tank water temperature during these months will significantly reduce the tank heat loss during this time. Figure 5-17 illustrates that as expected heat loss associated with the storage tank at GAS_SOL_LPST.

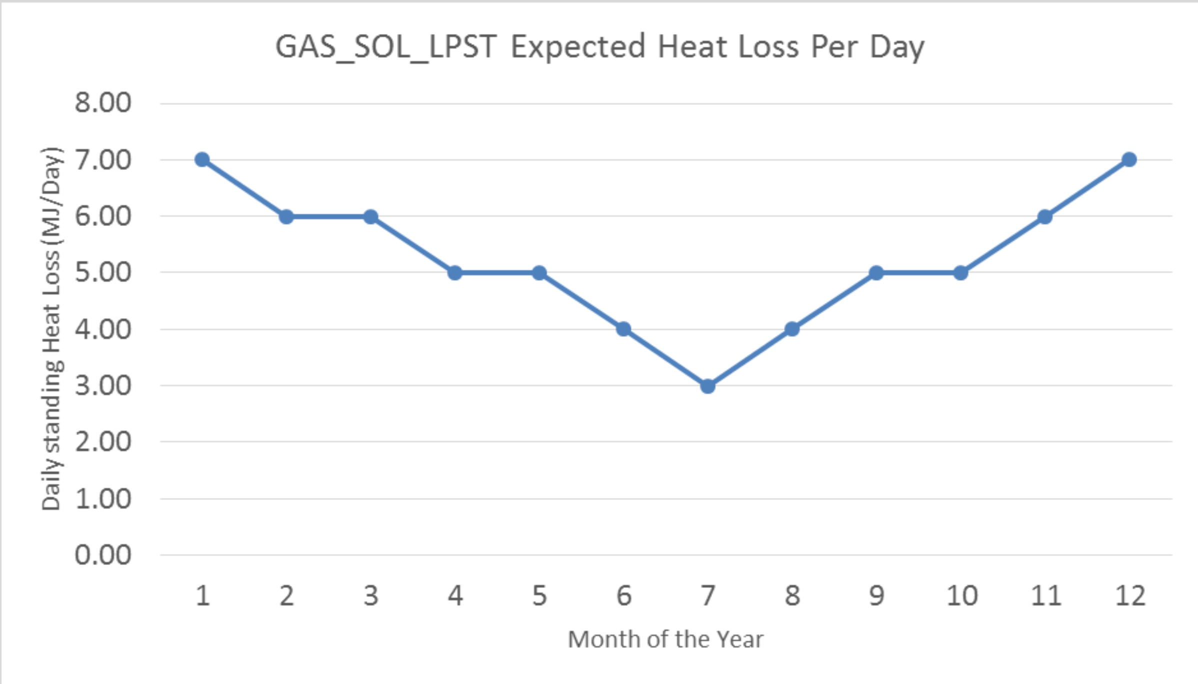


Figure 5-17 Predicted tank heat loss based on tank water temperature, air temperature and tank MEPS value

Gas Boosting

The efficiency of the gas burner was not measured during this study, however, it can be expected to be 75-82% where the gas burner usage is greater than 10MJ/day.

Heat Load and Solar Loop Efficiency

The two gas boosted solar hot water heater monitored in this study are the same model and the households are located within 50M of each other. It can be expected that the system performance of both of these systems are almost identical. The average daily required heat load at GAS_SOL_LPST is almost twice that of GAS_SOL_LPSS allowing a comparison of system performance based on the heat load required from a specific system.

Figure 5-18 and Figure 5-19 Show that the annual performance of gas boosted solar hot water heaters can be separated into two periods: sufficient solar gain and insufficient solar gain. During the period between October and May, a large proportion of the required heat load was supplied through energy produced through the solar collector loop. The internal tank temperature during this period for both systems continuously exceeded 60ºC and the gas booster usage only occurred on days of higher than usual heat load or periods where there were short term drops in solar irradiance (due to one or more successive cloudy days).

During the months between April and September the solar irradiance collected by the solar collector is insufficient to provide the required energy to the storage tank to supply water at the required hot water temperature. The value of the heat load supplied by the solar collector decreases from the summer high of >90% to <20% during the coldest winter months. This results in an increase in the dependency on the gas booster. The overall coefficient of performance of both gas boosted solar hot water heaters dropped just below 1 during this period. This COP is approximately 25% higher than expected from the gas continuous flow hot water heaters which are used to supply the boosting during this period. It can therefore be determined that in the coldest month, the solar collector contributed to this 25% reduction in purchased energy requirement.

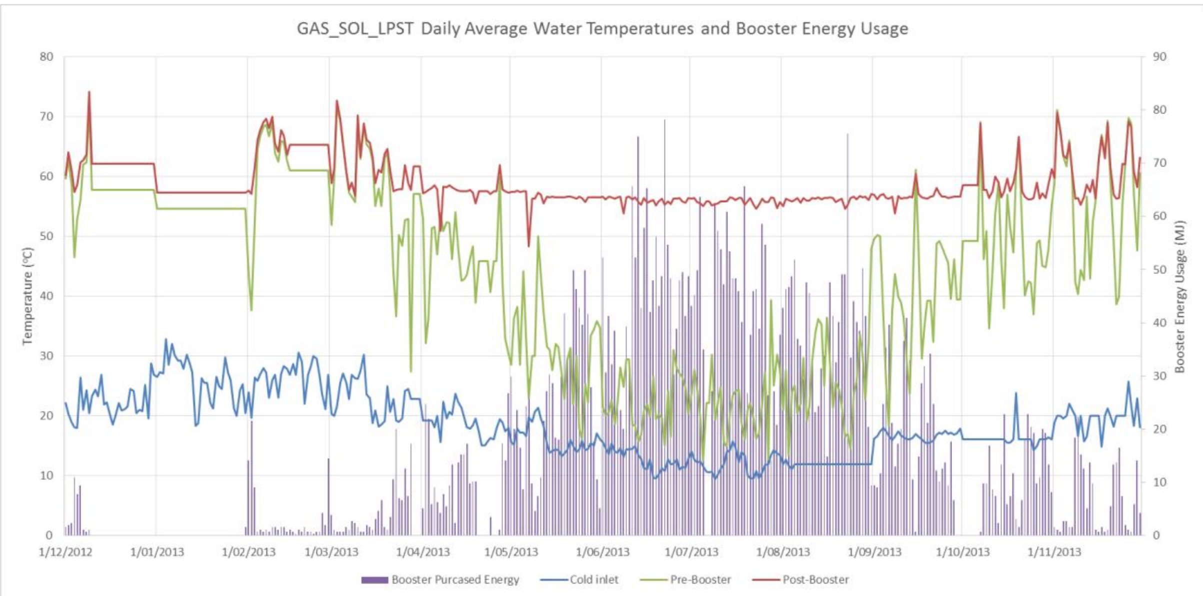


Figure 5-18 GAS_SOL_LPST Average daily water temperatures and booster energy usage

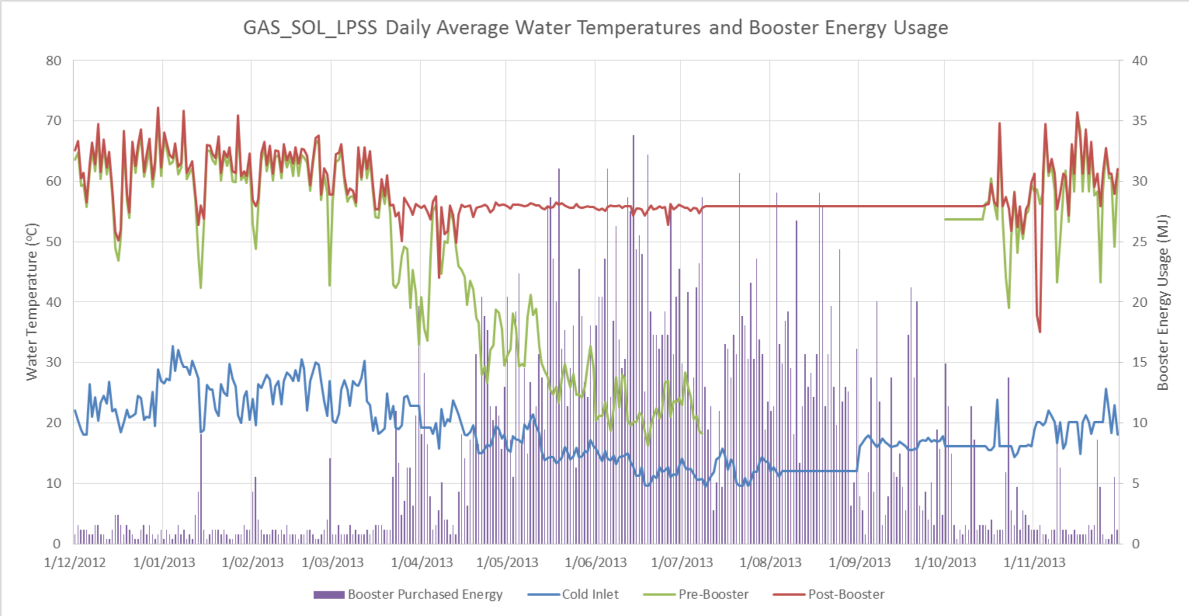


Figure 5-19 GAS_SOL_LPSS Average daily water temperatures and booster energy usage

The gas boosted solar hot water heaters have more separate components with varying efficiencies than any other water heaters monitored in this study. Figure 5-20 shows how the varying efficiencies, loads and losses vary throughout the year. In this figure, the heat load (dark blue increases during the colder months as a result of decreased inlet temperature and an increase in the water consumed by the residence. The heat loss (orange) varies between a predicted high of 217MJ/month during the summer months to a predicted low of 93 MJ/month in the colder months. If the heat loss associated with the tank is added to the Heat load, the combined, required energy can be established (red). The required combined energy is supplied through the solar collector loop (green) and the gas booster (purple). The purchased energy (light blue) will be greater than the required energy from the booster once the predicted gas burner efficiency of the gas booster of between 70% and 80%, is considered.

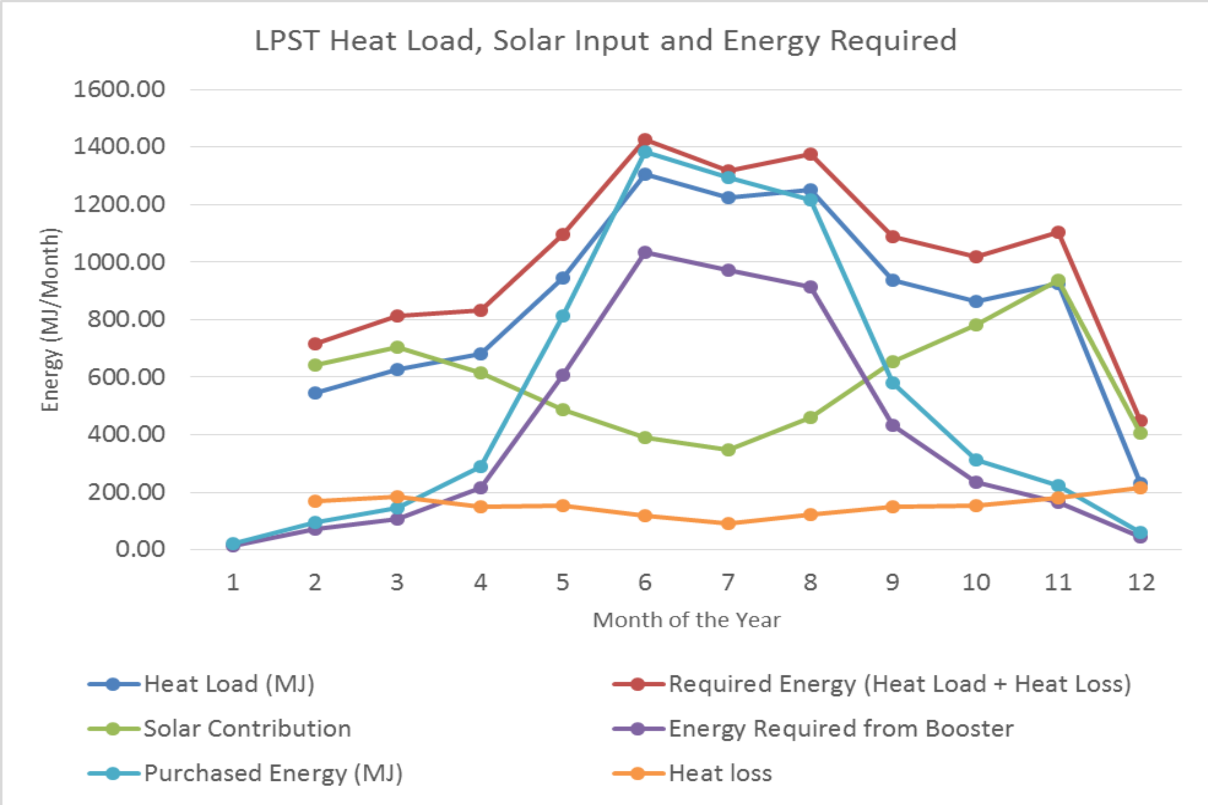


Figure 5-20 Energy breakdown of GAS_SOL_LPST

Figure 5-21 shows that the gas boosted solar hot water systems proved highly efficient during the summer months and were able to provide feasible gains in efficiency over the colder, lower solar irradiance months.

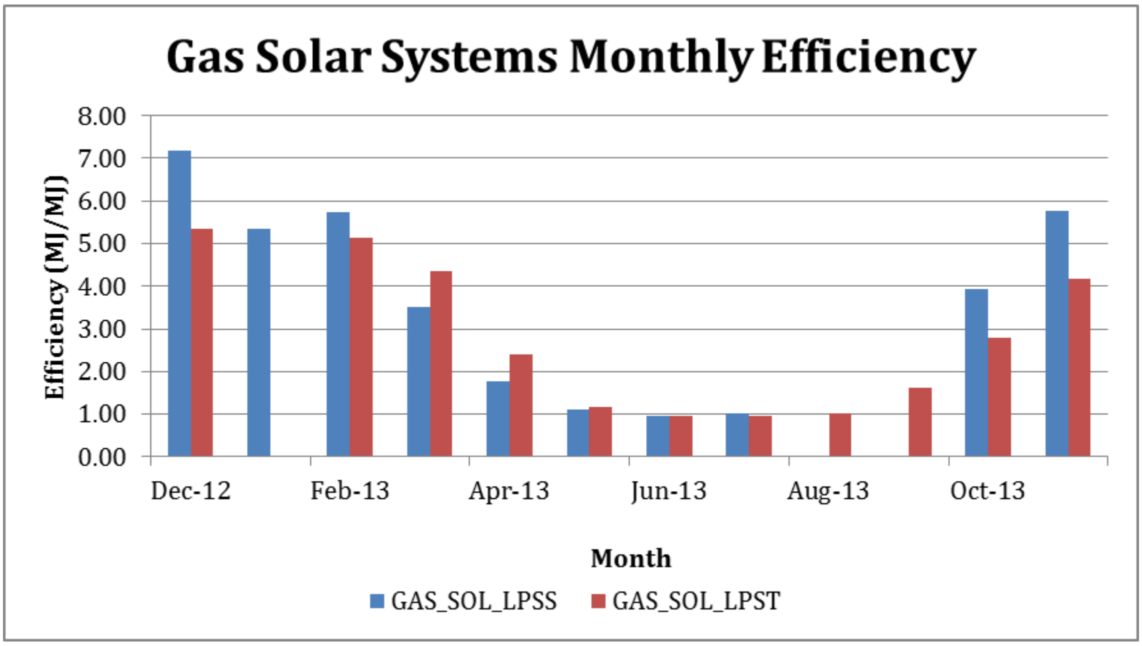


Figure 5-21 Gas boosted solar hot water heater efficiencies

6 Comparison of Systems

Seasonal and yearly energy and CO_2 emissions play a large role in the decision of the selection of a hot water system at the time on installation. Initial costs of water heaters range from $800 for conventional systems to $7000 for a highly efficient solar system. By comparing the energy usage trends across the monitored range of hot water heaters, it is possible to calculate the lifetime costs associated with each type of water heater to determine their viability in a specific household.

6.1 Comparison of Conventional Hot Water Heaters

6.1.1 Conventional Electric Storage Systems

The two electric storage systems in this study possessed similar tank capacities of 250 litres as ELE_STO_NADL and 259 litres at ELE_STO_NETH, however the system utilisations varied significantly. The average daily water consumption at ELE_STO_NADL was 146 litres (37 litres per person per day) as opposed to the 25 litres per day average recorded for the soul occupant at ELE_STO_NETH; as a result the calculated daily average heat loads were 16.3MJ and 4.48MJ respectively. Due to the utilisation of the ELE_STO_NADL tank of approximately 58% of the storage tank per day, the resulting overall annual efficiency was 76%. At ELE_STO_NETH only 10% of the tank was utilised per day resulting in an overall efficiency of 44%; this indicates both systems have the potential to perform at higher efficiencies. In order for to perform a standardised system comparison, Figure 6-1 estimates the energy required per litre of delivered water for each of the electric storage systems if the water had been delivered at 50°C. The data shows that the system at ELE_STO_NETH consumed approximately twice the purchased energy per litre of hot water, with water consumption approximately one sixth as high as at ELE_STO_NADL (see Figure 6-1). Such inefficiencies highlight the requirement for sizing of a hot water system to the user, the two similar systems analysed here are shown to perform better for four people than for one. As neither system is fully utilised on a daily basis it is expected that the purchased energy per litre of hot water would reduce further if the system was used with higher loads than the ones seen here. The standardised costing of each of the two electric storage systems resulted in an average cost of 0.89 cents/L at ELE_STO_NADL and 1.91 cents/L at ELE_STO_NETH, this difference is a direct consequence of the difference in loads on the systems.

Comparison of the daily purchased energy of the two systems against the heat loads in Figure 6-2 demonstrates similar relationships, which are expected to be linear as this indicates that the efficiencies are asymptotic to a maximum efficiency. The two data sets show similar trends with ELE_STO_NADL displaying a slightly higher slope if the trend was linear which would indicate slightly higher efficiencies (refer to Figure 6-2). A higher overall efficiency at ELE_STO_NADL is expected as the hot water tank is located indoors and hence the tank losses are lower.

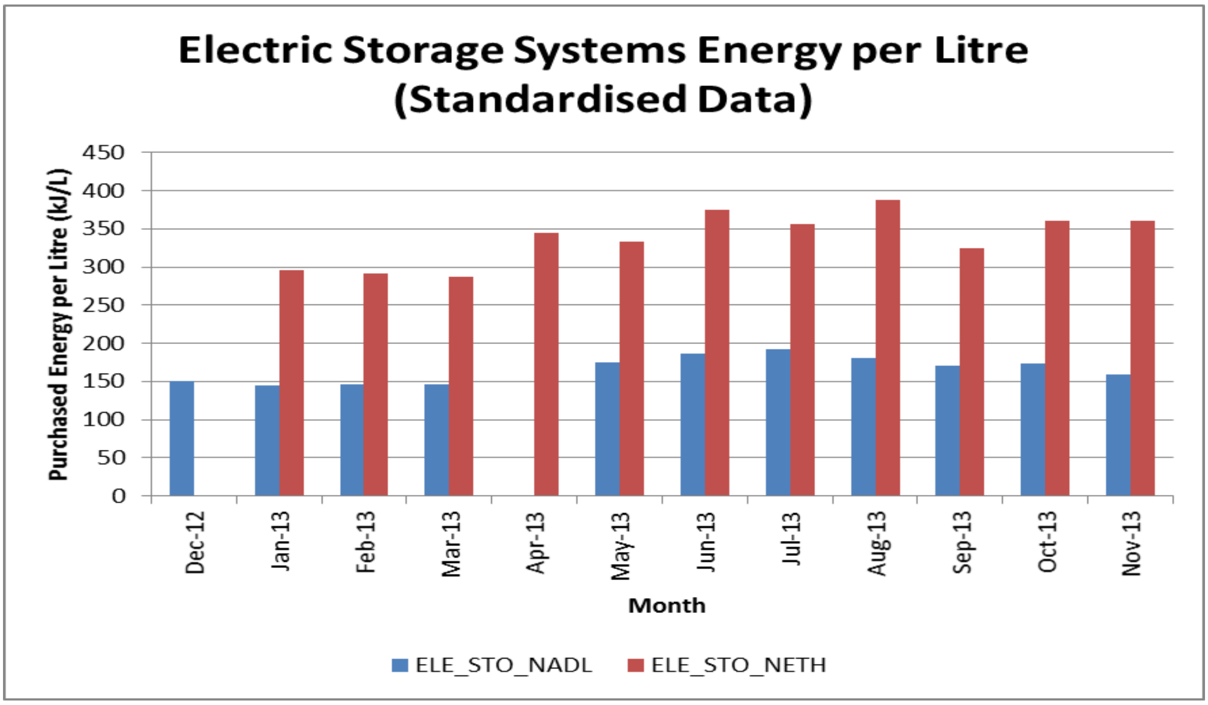


Figure 6-1: Monthly purchased energy per litre of water based upon standardised 50^{O}C water outlet temperature at ELE_STO_NADL and ELE_STO_NETH

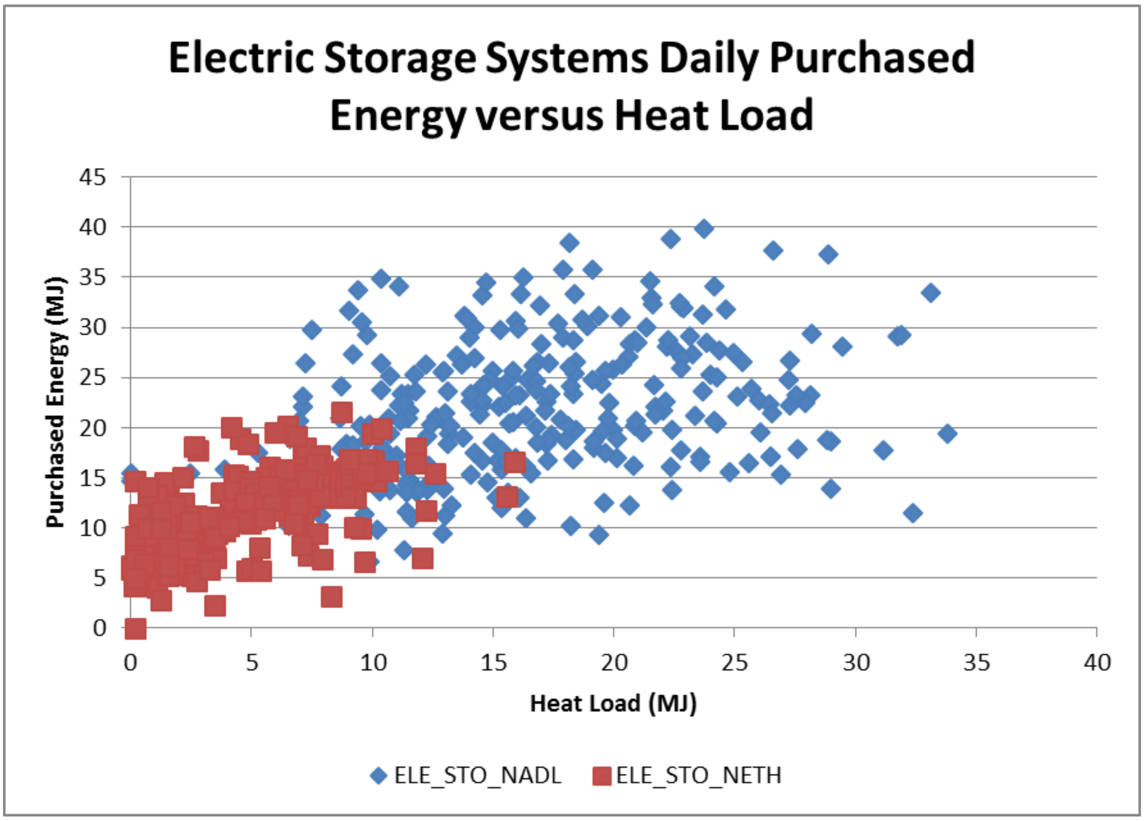


Figure 6-2: Daily purchased energy versus heat load at both ELE_STO_NADL and ELE_STO_NETH

Both of the electric storage hot water heaters were connected to an off-peak electricity tariff. The daily water usage at ELE_STO_NETH never reached the volume of stored water in the tank so the hot water required was always able to be supplied by the tank. The ELE_STO_NADL water heater on average utilised 146L of hot water per day. The ELE_STO_NADL tank capacity is 250L and the average daily water usage is easily met by the storage capacity of the tank. The histogram displayed in Figure 6-3 shows that daily water usage regularly exceeded the average daily water usage. There is a significant reduction in the number of days where the daily water consumption exceeds 230L/day. This value correlates with the storage tank hot water capacity. An investigation into the hot water temperatures on the 12 days where the daily water usage exceeded 230 L/day revealed that the water temperature dropped below 45ºC i.e. the water heater was no longer supplying adequately hot water. This illustrates the consideration required when sizing an electric water heater. Low daily water utilisation in comparison to the storage tank capacity will result in a low efficiency. High water usage will result in the water heater not being capable of supplying the required daily hot water load. System specific configurations such as element size and electricity tariff connection as well as water usage patterns will alter the hot water heaters daily hot water delivery capacity and efficiency and need to be considered during storage tank sizing.

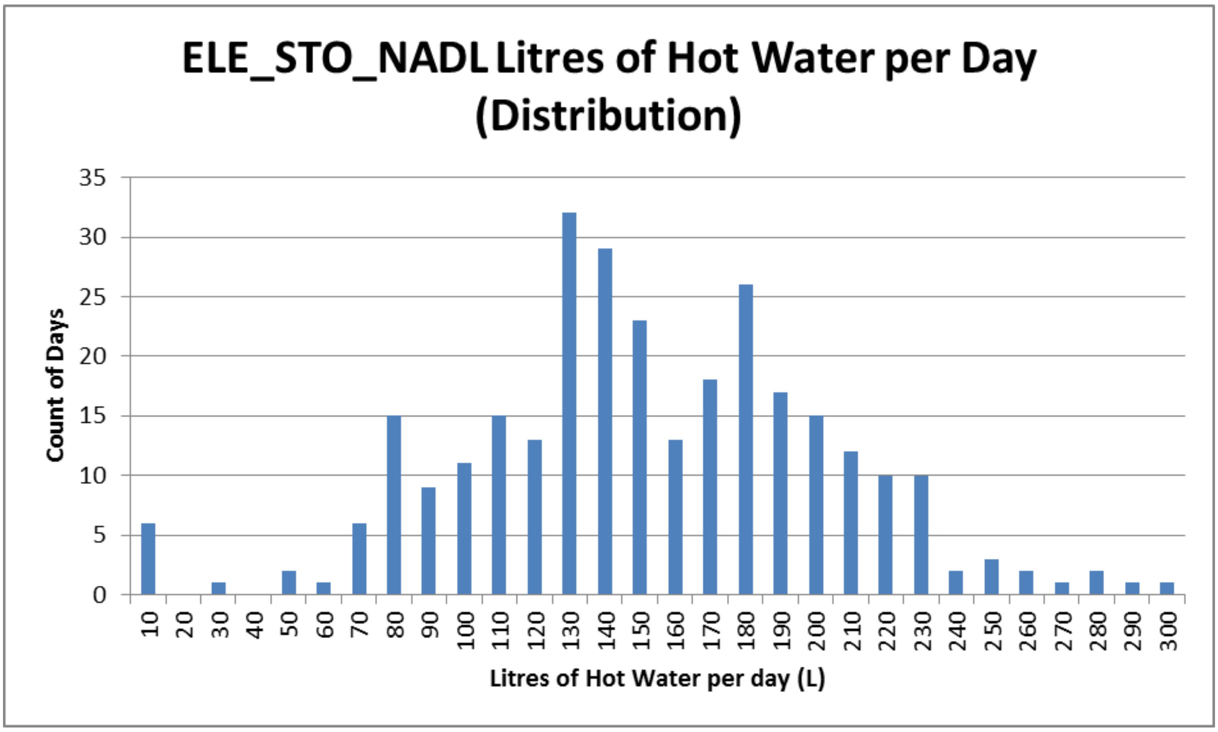


Figure 6-3 Histogram of hot water usage per day at ELE_STO_NADL

6.1.2 Conventional Gas Storage Systems

The two conventional gas storage systems in this study possessed tank sizes of 130 litres at GAS_STO_CUMB and 160 litres at GAS_STO_ABER, the system at GAS_STO_CUMB was only utilised for an average of 24 litres or 4.10MJ per day and the system at GAS_STO_ABER averaged 177 litres per day or 37.41MJ. Using the standardised energy comparison for a water delivery of 50°C, the GAS_STO_ABER system utilised approximately one third of the purchased energy per litre of the GAS_STO_CUMB system, as demonstrated in Figure 6-4.

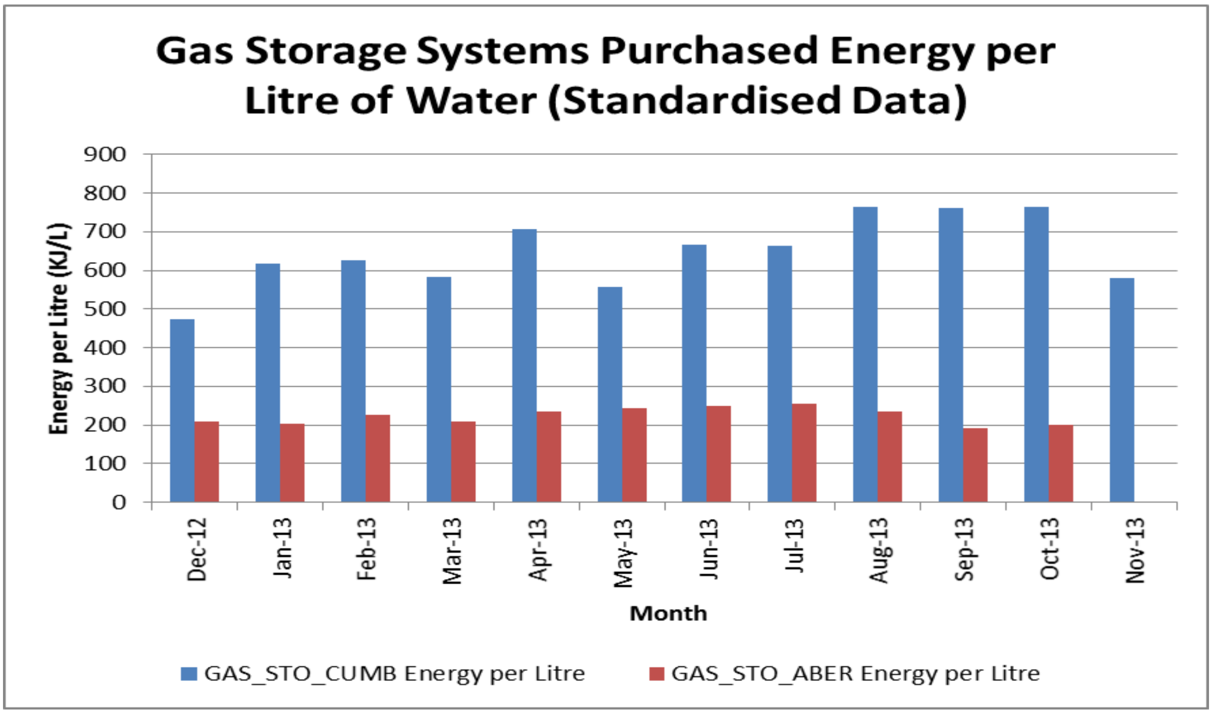


Figure 6-4 Monthly purchased energy per litre of water based upon standardised 50oC water outlet temperature at GAS_STO_ABER and GAS_STO_CUMB

Both systems indicate a strong linear trend between heat load and purchased energy. Such a trend indicates that the system efficiency would increase to a maximum value of approximately 80% in this case. The calculated overall system efficiencies of the GAS_STO_ABER and GAS_STO_CUMB systems are 60% and 20% respectively, indicating that the efficiency of both systems would increase if they had higher hot water utilisation.

As a result of the inefficiencies demonstrated by the underutilisation of the GAS_STO_CUMB system, the cost per litre (based on standardised data) was estimated at 4.74 cents/L if the daily gas supply charge is included and 2.16 cents/L if the daily gas supply charge is excluded. Similarly for GAS_STO_ABER, the estimated cost of hot water is 1.01 cents/L if the daily gas supply charge is included and 0.74 cents/L if the daily gas supply charge is excluded. The yearly cost of purchased energy for the GAS_STO_CUMB and GAS_STO_ABER water heater assuming the inclusion of the gas connection fee (if the water heater is the only gas appliance and the connection fee is 100% attributed to hot water heater) was $532 and $956. This cost difference is relatively small considering that GAS_STO_CUMB consumed 10,180 L of hot water at 50°C compared to GAS_STO_ABER which consumed 85,670 L at 50°C. This illustrates that lower hot water usage will result in lower purchased energy costs, however, due to the increased system efficiency when gas storage systems are utilised at their designed capacity and the significance of the cost of the daily gas connection fee, the cost penalty for high water utilisation is relatively small.

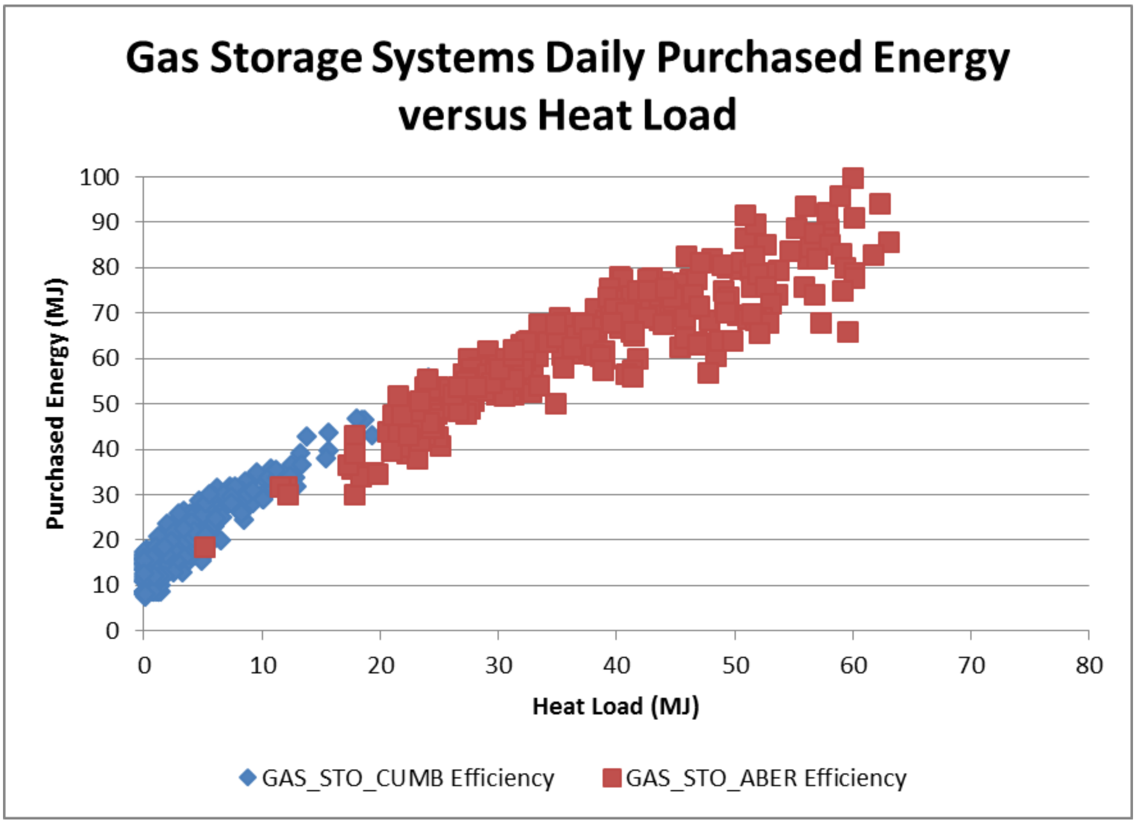


Figure 6-5: Daily purchased energy versus heat load at both GAS_STO_ABER and GAS_STO_CUMB

6.1.3 Continuous Flow Gas Systems

Due to the nature of an instantaneous gas hot water heater, varied water consumption and system heat loads do not impact overall system efficiency in the same manner as for systems with a water storage tank. As such, the performances of the two instantaneous gas water heaters in this study are extremely similar, despite different system heat loads. The average daily heat loads at GAS_INS_DOVE and GAS_INS_WOOD were 7.22MJ/day and 15.1MJ/day with an average of 10 and 18 hot water events per day respectively. Figure 6-6 demonstrates similar performance between the two systems throughout the year with a steady rise in the purchased energy required per litre as inlet cold water temperatures dropped. It is to be noted that the booster fan at GAS_INS_WOOD ran only as water was required by the system, averaging 15Wh per day whereas the GAS_INS_DOVE fan/ indoor control panel ran at a continuous rate of approximately 8W, consuming 199Wh per day on average, accounting for slightly lower efficiencies at GAS_INS_DOVE.

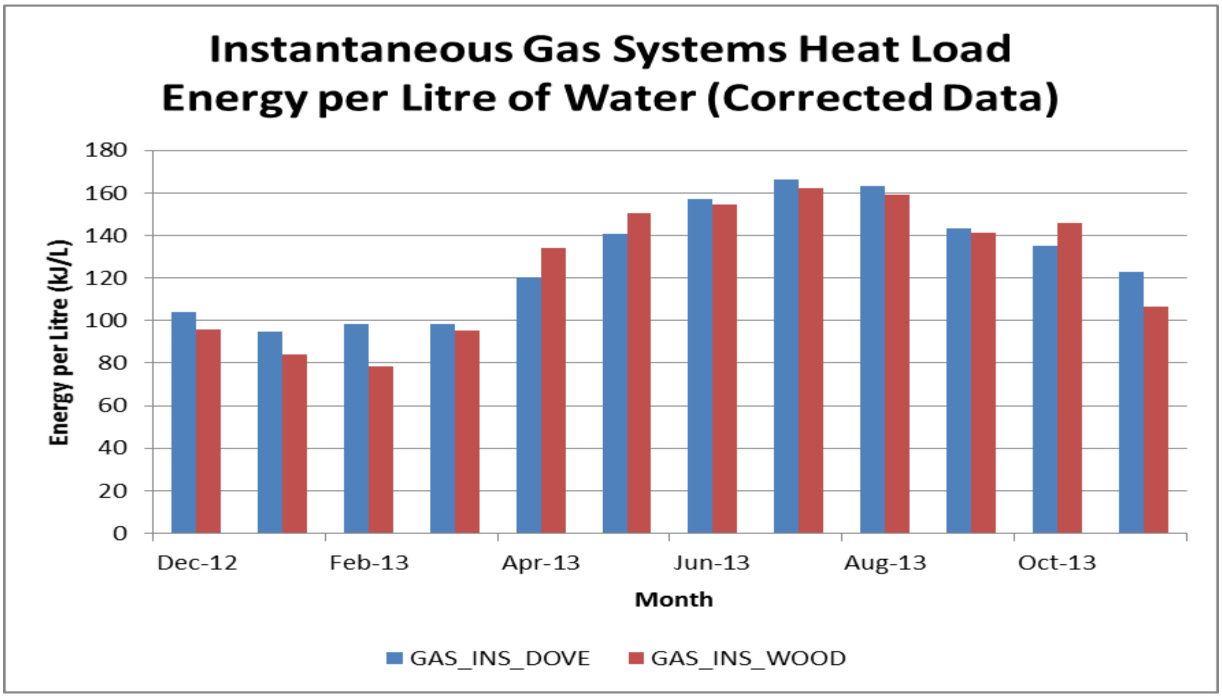


Figure 6-6: Instantaneous gas systems monthly purchased energy per litre of water (Corrected data)

The yearlong efficiencies of the two systems illustrate that in general, GAS_INS_WOOD performed better attributable to system design and the very low heat load often found at GAS_INS_DOVE.

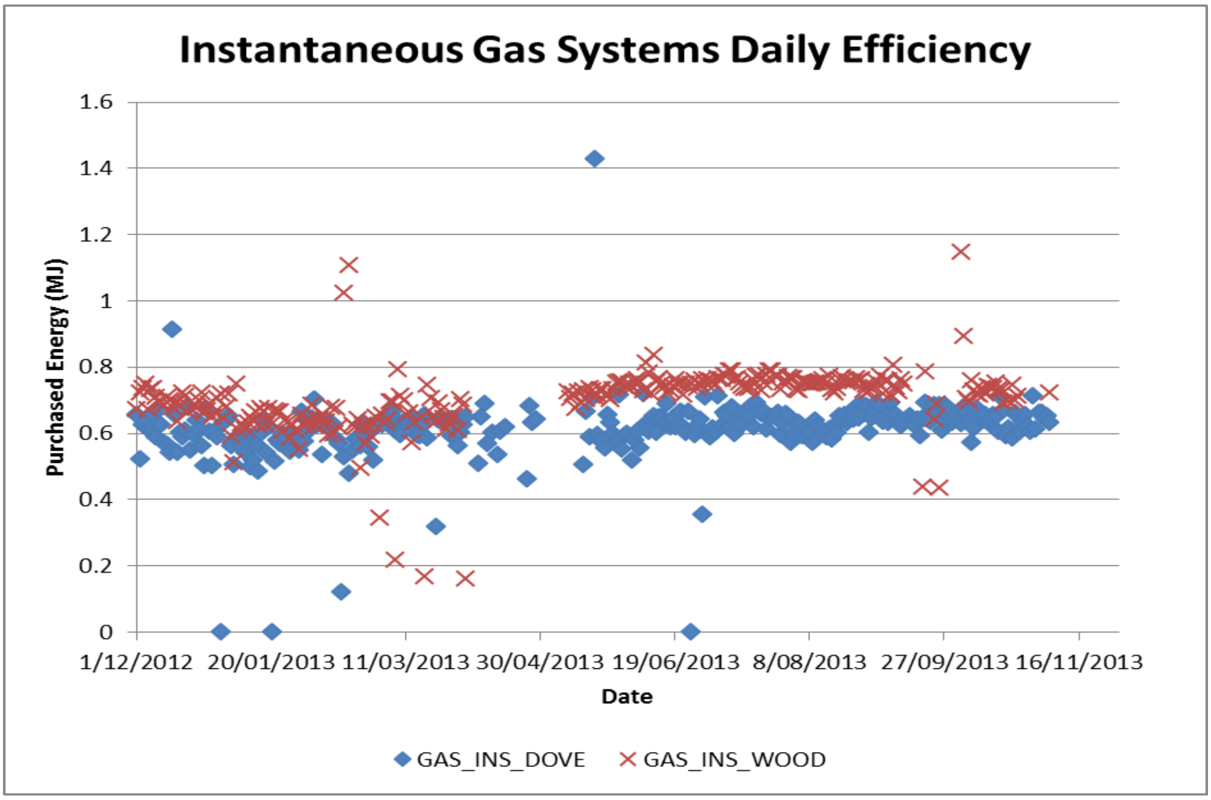


Figure 6-7: Daily efficiencies of GAS_INS_DOVE and GAS_INS_WOOD

A number of uncharacteristically low temperature recordings during draw-off found in the data after residents' complaints at both GAS_INS_DOVE and GAS_INS_WOOD can be justified through the examination of the water flow rate. It was determined that the burner would occasionally switch off if the water flow rate fell below a minimum value. It was also proposed that if the water outlet temperature exceeded a temperature too far above the set temperature the burner would switch off for a short time during the event in order to cool the outlet water temperature. Analysis has revealed that high occurrence of low temperature recordings occurred at low water flow rates as demonstrated in Figure 6-8. The average water temperatures at GAS_INS_DOVE and GAS_INS_WOOD were 42.25℃ and 44.56℃ respectively, and it was chosen that a low temperature would be one where the hot water outlet temperature was below one standard deviation from the mean. These thresholds were 38.69℃ and 40.95℃ for GAS_INS_DOVE and GAS_INS_WOOD respectively, as a result Figure 6-8 shows high occurrence of temperatures below this for flow rates less than 5L/minute.

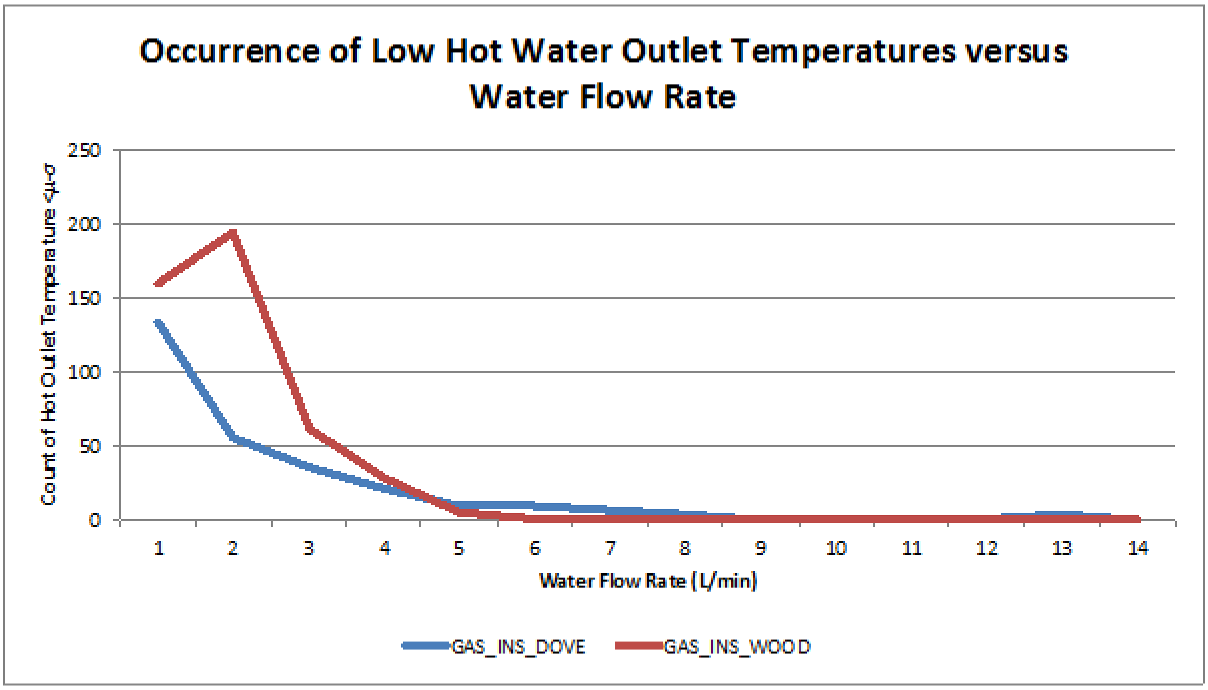


Figure 6-8: Occurrence of hot water outlet temperatures lower than one standard deviation from the mean versus water flow rate for both instantaneous gas units

Neither of the instantaneous gas systems delivered system loads comparable to the test load of 37.67MJ/day as stipulated in AS/NZS 4552.2:2010, however due to the direct relationship between gas consumption and heat load, the annual gas consumption was estimated and both systems satisfied the maximum allowable gas consumption of 22,831MJ/yr. It was estimated that the GAS_INS_DOVE system would consume approximately 19,921MJ/yr and the GAS_INS_WOOD system would consume 18,211MJ/yr.

6.1.4 Comparison of Conventional Systems

Due to their relatively simple design and construction, conventional water heaters such as electric and gas storage systems and continuous flow gas hot water heaters are relatively inexpensive. For this reason they are found in many smaller dwellings and lower social economic residence. This was evident in this study. It was also evident that 4 of the 6 conventional systems had a daily heat load of less than 10MJ/Day (Small load). For this reason, it is important to understand how these systems operate at low to medium heat loads and the effect on purchased energy and CO_2 emissions.

The electric element in an electric storage hot water heater can be assumed to be 100% efficient. Due to heat losses associated with the storage tank the highest system efficiency found in this study was 80%. With a higher heat load, it can be expected that the efficiency could exceed 90%. ELE_STO_NETH illustrated that when the heat load decreased, this efficiency will decrease to 44%. Peak electricity prices will make electric storage water heaters the most expensive water heaters to run. Off-peak electricity tariffs effectively reduce the running costs of electric storage water heaters to a cost comparable to other conventional systems, however they are the most expensive systems to run and the most CO_2 intensive water heaters available. Both of the electric water heaters in this study were on the off-peak electricity tariff.

The storage gas water heaters were able to meet all hot water requirements and the residence had no complaints about the water heaters.

The continuous flow, gas water heaters were able to meet all hot water requirements. The residents did complain that where the water flow rate was too small, the systems did not provide hot water.

Figure 6-9 describes the change in system efficiency versus daily heat load for all of the conventional water heaters monitored in this study. It is interesting to note that the continuous flow gas hot water systems have a superior efficiency at low heat loads and that they also reach their maximum efficiency at a lower heat load. Electric storage water heaters have a higher efficiency when utilised effectively, however, due to the higher cost of electricity and higher unit CO_2 emissions, electric storage hot water heaters have higher running costs and CO_2 emissions. Both of the gas storage systems seemed to underperform in this study. The efficiency of the gas storage systems should have been similar to the continuous flow water heater at the AS4552 test point.

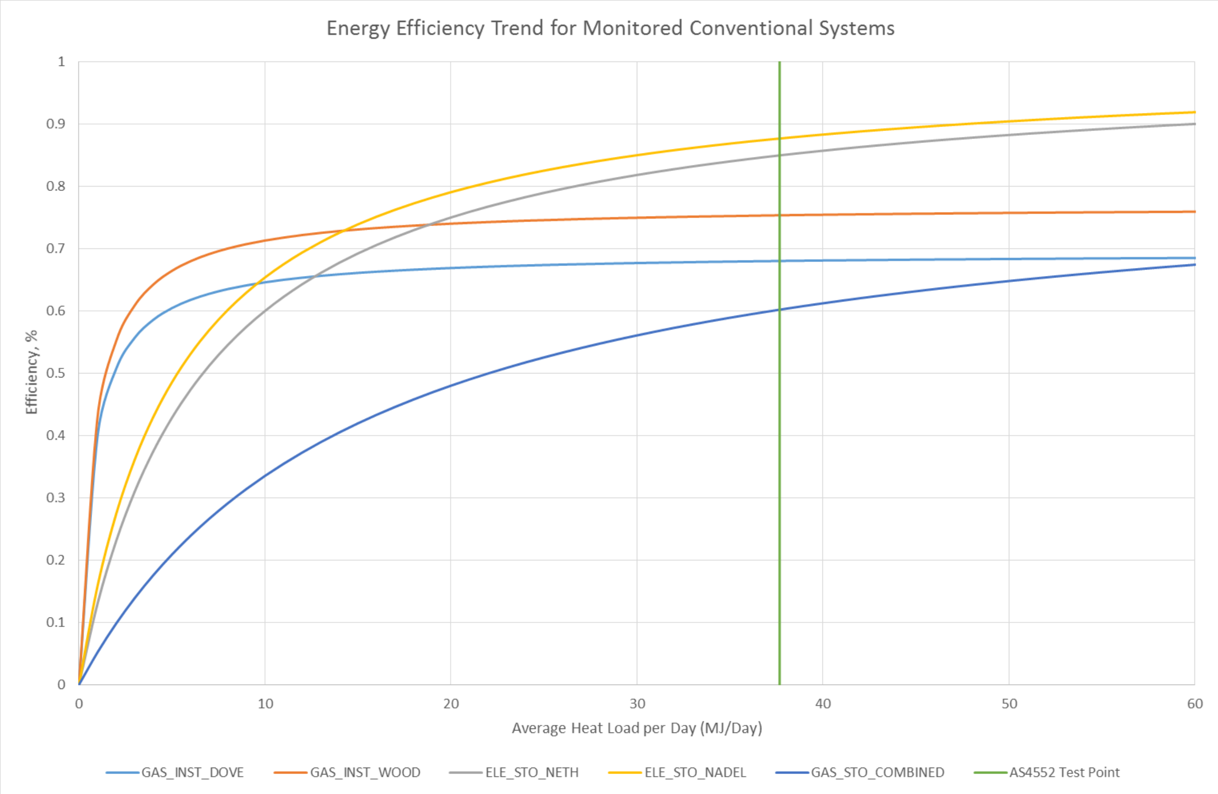


Figure 6-9 Efficiency trends for monitored Conventional systems based on average daily heat load

6.1.5 Comparison of Solar and Heat Pump Water Heaters

The daily average water consumptions, heat loads and tank sizes of the four solar hot water systems in this study are summarised in Table 6-1, demonstrating that the GAS_SOL_LPST system had the highest average utilisation and ELE_SOL_LPON the least. As a result it is expected that the efficiencies of the four systems would not only show high variation due to differing available solar radiation throughout the year, but due to differing system utilisations and configurations. Figure 6-10 illustrates the average purchased energy consumed by each system per litre of water required throughout the monitoring period. The data has been standardised based upon an outlet temperature of 50°C. The ELE_SOL_MAWS flat plate solar collector was the most efficient system of the four solar hot water systems. This can be attributed to two major factors; the first, due to higher system utilisation than at ELE_SOL_LPON, as such the purchased energy per litre was lower and the second was due to the use of electricity as a supplementary energy source rather than gas, as losses associated with the gas burner were not experienced at ELE_SOL_MAWS.

Table 6-1: Summary of water consumption, heat load and tank capacities for all solar hot water systems

System	Average Water Consumption (L)	Average Heat Load (MJ)	Hot Water Tank Capacity (L)	Percentage Daily Tank Utilisation (%)
ELE_SOL_LPON	56	5.50	250	21.6
ELE_SOL_MAWS	125	19.54	340	36.8
GAS_SOL_LPSS	121	15.47	215	56.3
GAS_SOL_LPST	222	30.51	215	103.3

A comparison of the average cost per litre of hot water delivered for each of the solar hot water systems demonstrated an unexpectedly high cost of the ELE_SOL_LPON system, shown in Figure 6-11. The costs are based upon the standardised data at a 50℃ outlet water temperature and exclude gas and electricity supply costs. In June and July, the system efficiencies of ELE_SOL_LPON were 97% and 80% respectively, indicating that the majority of the supplied energy was purchased electricity. Due to low tank utilisation of approximately 60 litres per day in conjunction with increased thermal losses and insufficient solar gains at this time, the system was inefficient and performed similarly to a conventional storage electric system.

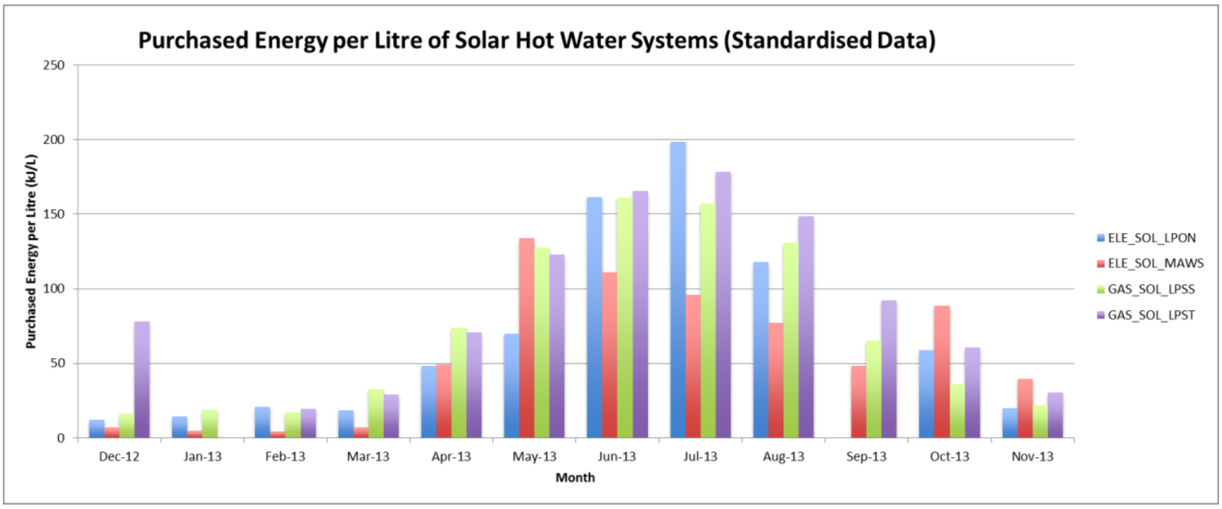


Figure 6-10: Purchased energy per litre of water for solar hot water systems, based upon standardised data

Figure 6-11 illustrates similar costs per litre for the gas-boosted solar hot water systems and ELE_SOL_LPON in December through to May, October and November.

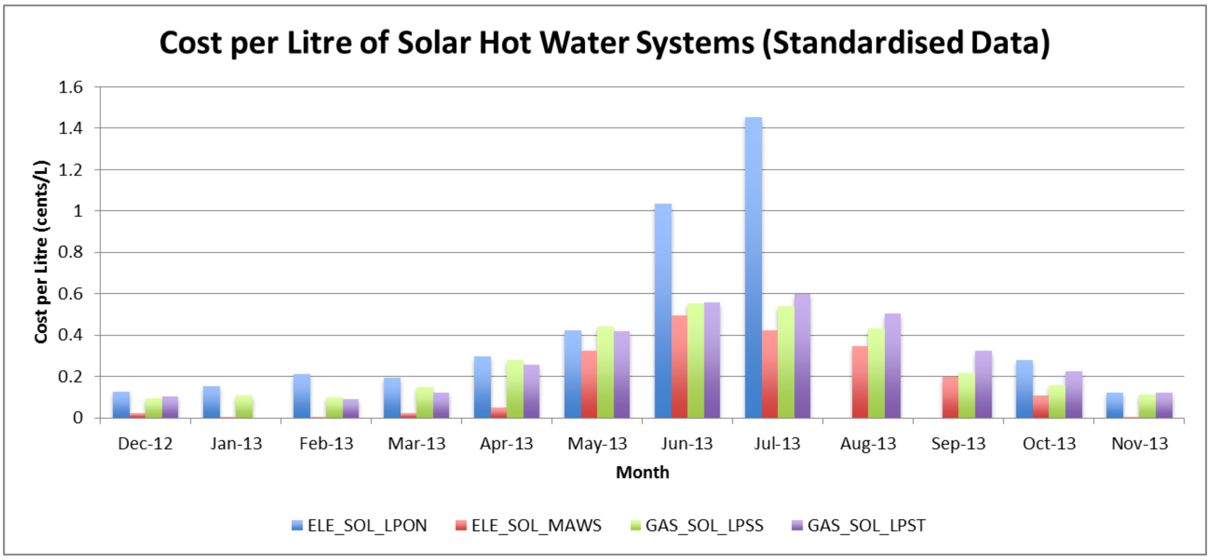


Figure 6-11: Cost per litre of water for all solar hot water systems, based upon standardised data

The performance of the two gas-boosted solar hot water systems was demonstrated to be similar throughout the monitoring period with the efficiency of the GAS_SOL_LPSS system in December, February, October and November exceeding that of the GAS_SOL_LPST system, as shown in Figure 6-12. The system load at GAS_SOL_LPSS was generally half that of GAS_SOL_LPST and so it was expected that the monthly efficiency in the summer months would be higher as the available solar energy could provide the additional heat load. In March through May, while both systems were utilising their gas boosters regularly, the GAS_SOL_LPST system efficiency was higher, presumably due to lowered losses as a direct result of better utilisation. It was noted that the flat plate collectors at GAS_SOL_LPSS face west, while the collectors at GAS_SOL_LPST face north, however due to different system load deliveries the efficiency differences cannot be directly attributed to different amounts of useful solar radiation gained.

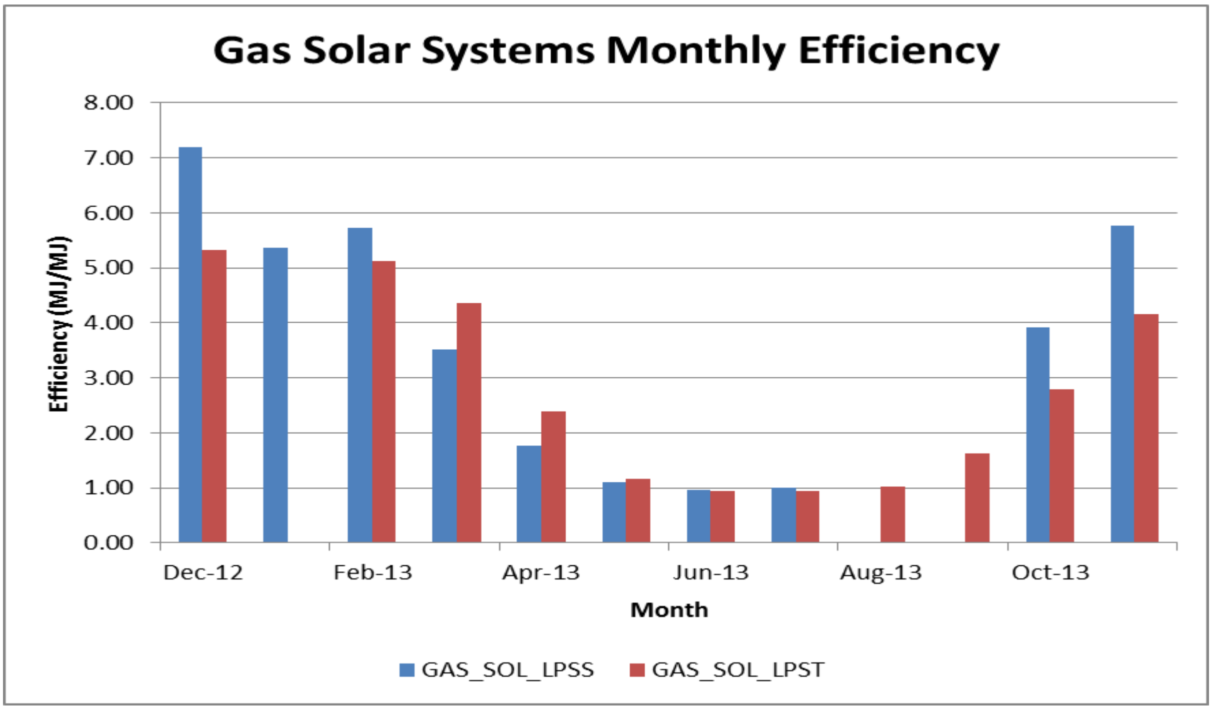


Figure 6-12: Monthly efficiency of GAS_SOL_LPSS and GAS_SOL_LPST

All solar systems showed a high degree of energy requirement variation with the change of season. All systems were able to provide the bulk of the heat load requirement utilising solar energy alone with little or no auxiliary heating required in summer months. The auxiliary energy requirement rose for all systems and during the coldest winter months, all systems relied on auxiliary heating as the predominant heat source.

The energy saving of both the heat pump and solar hot water heaters over all conventional hot water systems was evident throughout this study. Throughout the 12 month study the heat pump water heater's monthly average energy requirement per litre of hot water varied from 60-80 KJ/L. There was a seasonal trend with energy requirements raising slightly during the colder months. Figure 6-13 illustrates that this seasonal trend is much smaller than those related to solar systems. The warmer months operation costs are higher while the colder months operation costs are lower than that of the solar systems.

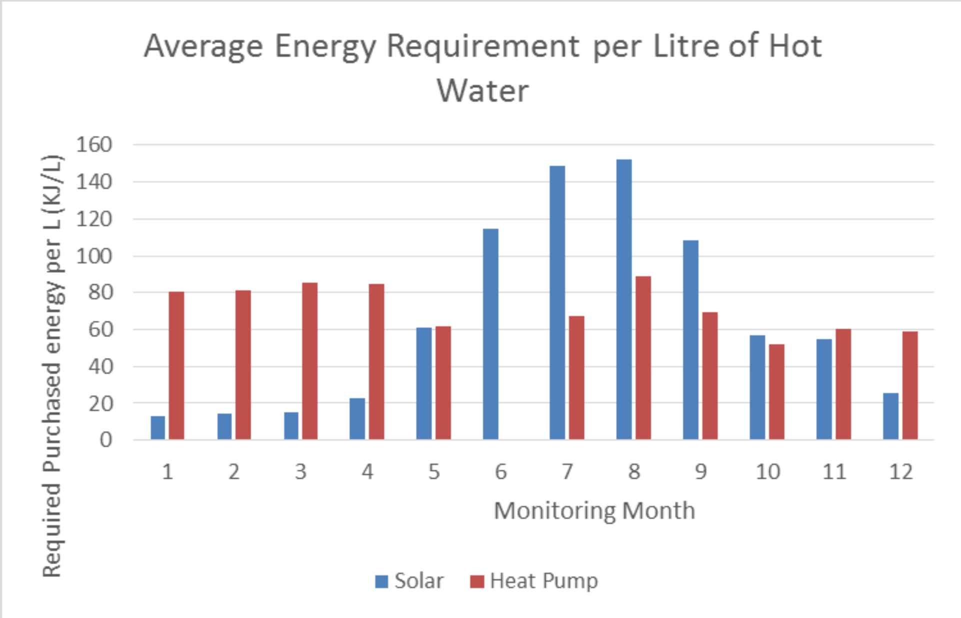


Figure 6-13 Average energy required per Litre of water for all solar and heat pump water heaters monitored in this study

6.2 System Efficiency, Cost and Greenhouse Gas Emissions

In order to conduct a comparison between each of the hot water systems the cost and purchased energy and Co_2 emissions per litre of delivered water has been standardised for a delivered water temperature of 50°C. The 50°C temperature was chosen as it represents a typical hot water temperature used in domestic situations for bathing and cleaning. The calculation requires a calculation of a volume ($V_{standardised}$) such that the calculated system heat load is equal to a heat load, $(Heat\ Load)_{standardised}$, had it been provided at a hot water outlet temperature of 50°C. The calculation assumes that the factor ρc_p in the calculated heat load (Equation 4) is the same as for the standardised calculation at the given outlet temperature (Equation 5).

$$(Heat\ Load)_{calculated} = (\rho c_p) V_{actual} (T_{out} - T_{in}) \tag{4}$$

$$(Heat\ Load)_{standardised} = (\rho c_p) V_{standardised} (50 - T_{in}) \tag{5}$$

From the calculated standard volume, the cost and purchased energy per litre for each system could be estimated and compared

Based upon the standardised methodology, the monthly purchased energy per litre of water delivered for each system is illustrated in Figure 6-14, emphasising the inefficiencies of the ELE_STO_NETH and GAS_STO_CUMB systems due to their low utilisation. The other two storage systems (ELE_STO_NADL and GAS_STO_ABER) had good utilisation, resulting in better efficiencies, however they are still outperformed by the solar, heat pump and instantaneous units. Each solar hot water system shows increased purchased energy consumption throughout the middle of the year when insufficient solar radiation was present to heat the water, with the highest peak in consumption per litre at ELE_SOL_LPON due to low system utilisation (refer to Figure 6-14). Both heat pump systems demonstrate good yearlong efficiency, with an obvious decrease in purchased energy at ELE_HPU_YATA when the heat pump was replaced in May.

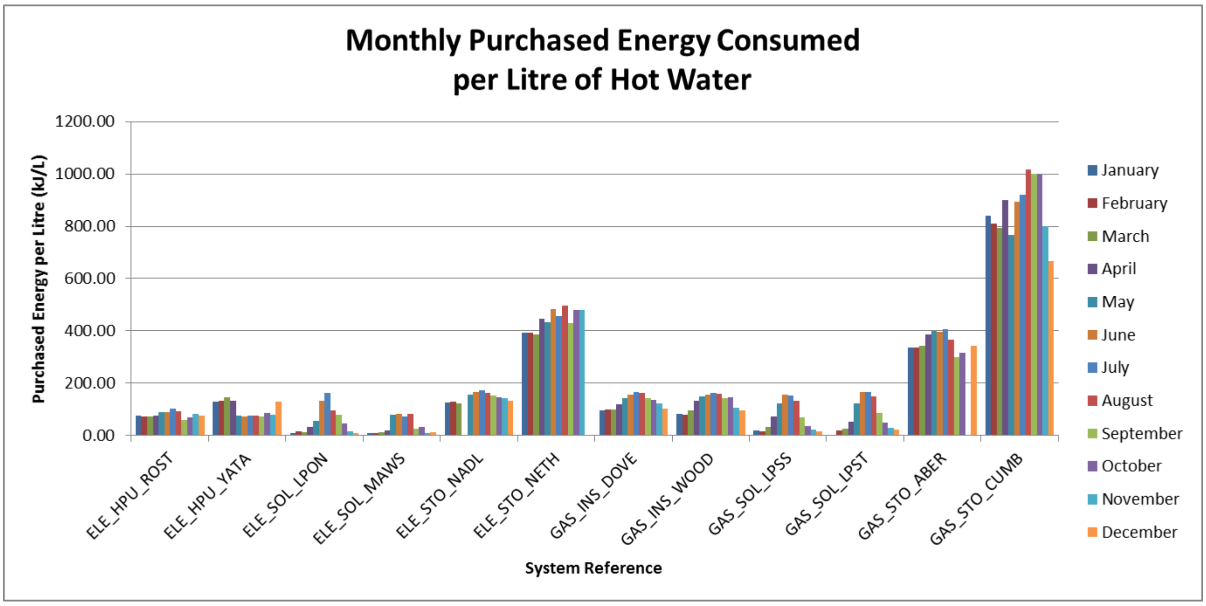


Figure 6-14: Monthly purchased energy per litre for each system, using standardised data

The overall system efficiencies, average cost per litre of hot water delivered and specific greenhouse gas emissions are shown in Table 6-2.

. Where the average cost per litre excludes gas and electricity daily supply charges and is based upon an outlet temperature of 50°C. The specific greenhouse gas emissions have been calculated in accordance with AS/NZS 4234:2008 as grams of equivalent carbon dioxide per mega-joule of heat load, using emission factors from the *Department of Climate Change and Energy Efficiency,* National Greenhouse Accounts (NGA) Factors, 2013. The accounts factors utilised are applicable to South Australia in 2013 (DCCEE 2013):

- 0.73 kg CO_2-e/kWh for electricity
- 2.42 kg CO_2-e/m^3 for gas

Table 6-2: System overall efficiency, cost per litre (excluding supply charges) and specific greenhouse gas emissions

System Reference	Overall Efficiency (MJ/MJ)	Average Cost per Litre (cents/L)	Specific Greenhouse Gas Emissions (g CO_2-e/MJ) Heat Load
ELE_HPU_ROST	2.03	0.77	100
ELE_HPU_YATA*	1.06 / 2.31	0.43	106
ELE_SOL_LPON	1.69	0.64	114
ELE_SOL_MAWS	3.91	0.19	55
ELE_STO_NADL	0.76	0.67	265
ELE_STO_NETH	0.40	2.01	501
GAS_INS_DOVE	0.63	0.42	111
GAS_INS_WOOD	0.73	0.44	85
GAS_SOL_LPSS	1.79	0.24	40
GAS_SOL_LPST	1.69	0.27	44
GAS_STO_ABER	0.60	1.18	103
GAS_STO_CUMB	0.20	2.85	315
* Heat pump efficiency displayed as original/replacement heat pump			

The overall system efficiencies demonstrate that the system with highest overall efficiency was the electric-boosted (flat-plate) solar system at Mawson Lakes, as a result the cost per litre for this system was calculated as 0.19 cents/L (refer to Table 6-2

). Unlike any of the other conventional storage systems, the ELE_STO_NADL system outperformed both instantaneous gas units as a result of high tank utilisation and decreased losses due to the water storage tank being situated indoors. It has been demonstrated that while the instantaneous gas units generally outperform the storage units, the efficiency is limited by that of the gas burner and hence the systems should be preferred for users of minimal hot water.

The storage hot water system efficiencies demonstrate that the utilisation of the tank volume and system sizing is a major contributing factor to cost, greenhouse gas emissions and efficiency. Both the ELE_STO_NETH and GAS_STO_CUMB systems were under-utilised for their sizes and hence the resulting cost per litre and greenhouse gas emissions were the highest in this study. While the cost per litre of the system of GAS_STO_CUMB (2.16 cents/L) is higher than that at ELE_STO_NETH (2.01 cents/L), the system at ELE_STO_NETH was calculated as the highest emitter of greenhouse gases at 501 g CO_2-e/MJ (refer to). It can be determined from that three of the four highest greenhouse gas emitters are storage hot water systems, with the GAS_STO_ABER system the exception due to high utilisation and consumption of gas rather than electricity.

Comparison of the four solar boosted systems illustrates that the under-utilised ELE_SOL_LPON system demonstrated similar performance to both the gas-boosted solar systems in terms of efficiency, due to the inherent losses associated with a gas burner. The gas-boosted solar hot water systems however, were cheaper per litre to run and released lower greenhouse gas emission due to the low cost and cleanliness of gas compared to electricity. The heat pump systems outperform all of the conventional storage and instantaneous gas units in terms of efficiency, with the replacement system at ELE_HPU_YATA performing at a higher efficiency than the gas-boosted solar units. However, due to the utilisation of electricity, the greenhouse gas emissions of the heat pumps systems are higher than the gas-boosted solar units and similar to the instantaneous gas units.

Table 6-2 demonstrates that the gas-boosted solar hot water systems are cheaper to run and their greenhouse gas emissions are lower compared to the electric-boosted solar units. The system at ELE_SOL_MAWS demonstrates lower costs but higher emissions, due to the dependence on grid electricity in comparison with the gas-boosted solar systems.

The consumption of hot water is the dominant factor in the calculated running cost of the hot water systems; as a result of this, the overall system running costs do not necessarily reflect the efficiencies of each system. Figure 6-15 shows the monthly gas and electricity costs of each system. The GAS_SOL_LPST and GAS_STO_ABER systems had the highest system heat loads, and as a result GAS_STO_ABER is the most expensive system in this study to run costing between $50 and $80 per month. In general the solar hot water systems and instantaneous gas systems were the cheapest on a monthly and annual basis, however the storage systems with low utilisation were also relatively cheap to run (refer to Figure 6-15). ELE_SOL_LPON was calculated as the cheapest system in this study, costing less than $105 for the year, as the electrical element was switched off for approximately 4 months.

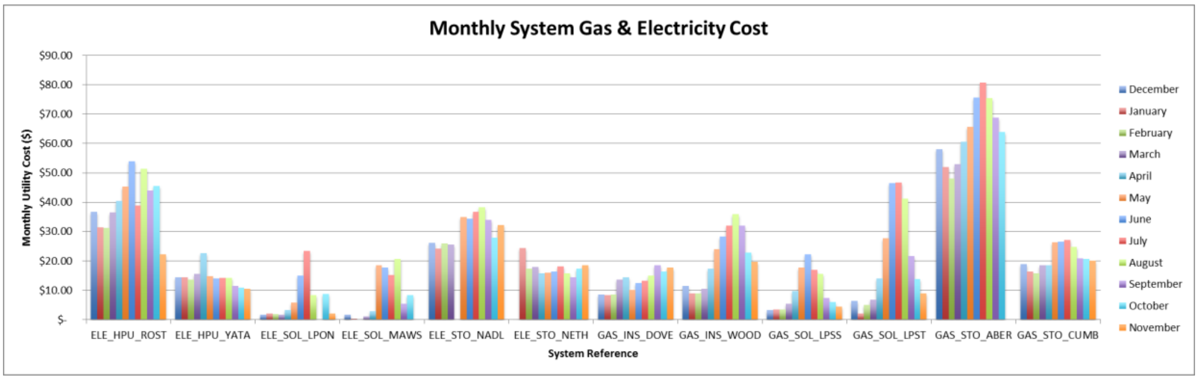


Figure 6-15: Total calculated monthly system costs (excluding daily supply charges)

7 Estimation Tool

This section describes the draft tool layout, the features of the tool, the user (customer) inputs, and the methodologies used to extrapolate water heater energy usage data, costs and emissions.

7.1 Tool Layout

The tool, estimates the end use energy requirement of many common types of water heater. This energy is based on baseline annual water heating usage and load pattern observed during this study, within the Lochiel Park Green Village during a 12-month monitoring period and utilised in AS/NZS 4234:2008 which is further discussed in section 7.4.2.

The tool is spreadsheet based and has been developed using Microsoft Excel 2007. The tool layout is shown in.

7.1.1 Data Entry

Data is entered using a series of dynamic dropdown lists over 4 worksheets. Sheet 1, "Inputs (customer)" is used to establish details about the residence. Data relating to the water usage of the customer, location, utility connections and utility costs are input into this page. The following two worksheets, "Electric Systems" and "Gas Systems" are used to establish hot water system details. This tool provides a comparison for 6 types of hot water system. In order to determine the viability of each water heater type for a specific conditions of use, the user must input details relating to the specific water heaters they wish to compare. The details that are required to be input on these pages have been deemed to be the most significant system factors required for the determination of energy requirements for each water heater type.

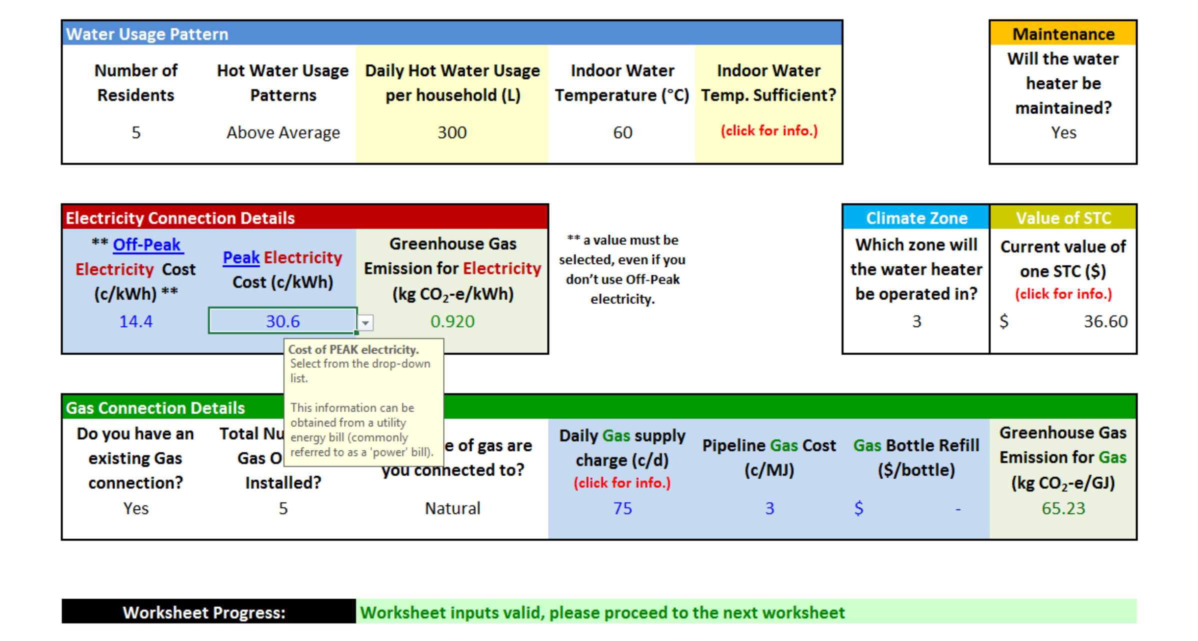


Figure 7-1 Estimation Tool "Customer (Inputs)" page

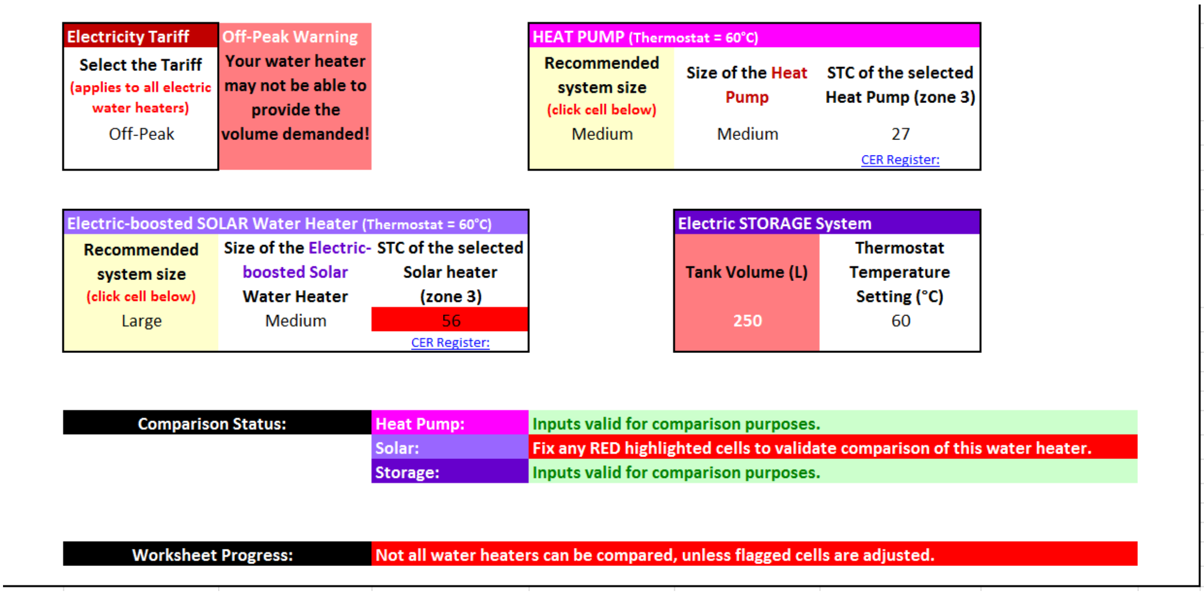
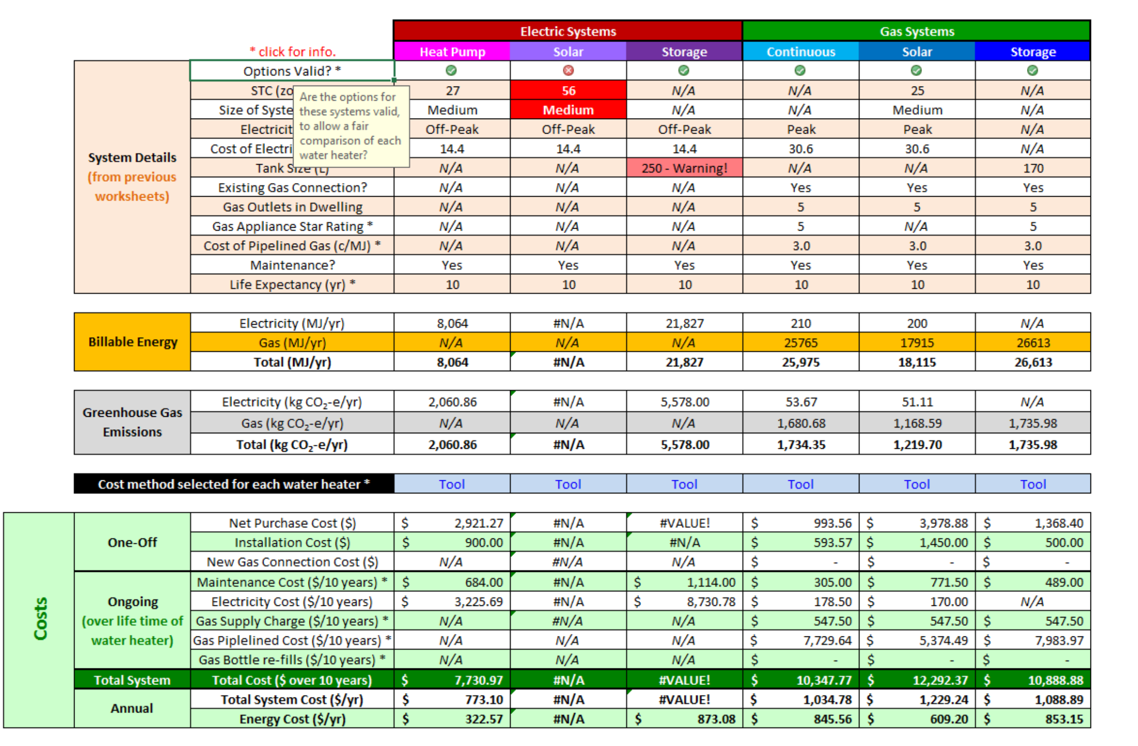


Figure 7-2 Estimation Tool “Electrical Systems” page

The “Costs” worksheet provides a summary of the system details and the predicted costs relating to system purchase costs, installation costs, utility connection costs and maintenance costs. If the user accepts these costs they can proceed to the output worksheets. If the user wants to change any of these costs they can do so in the “CUSTOM Inputs” section by replacing all associated costs.

There are two output pages “Comparison” and “Graphical SUMMARY”. The “Comparison” page provides a comparison of system details, predicted energy requirements, Greenhouse emissions and capital and operating expenses while the “Graphical SUMMARY” page provides a visual comparison of these values.



	* click for info.	Electric Systems – Heat Pump	Electric Systems – Solar	Electric Systems – Storage	Gas Systems – Continuous	Gas Systems – Solar	Gas Systems – Storage
System Details (from previous worksheets)	Options Valid? *	✓	✗	✓	✓	✓	✓
	STC (zo…	27	56	N/A	N/A	25	N/A
	Size of Syste…	Medium	Medium	N/A	N/A	Medium	N/A
	Electricit…	Off-Peak	Off-Peak	Off-Peak	Peak	Peak	N/A
	Cost of Electri…	14.4	14.4	14.4	30.6	30.6	N/A
	Tank Size (L)	N/A	N/A	250 - Warning!	N/A	N/A	170
	Existing Gas Connection?	N/A	N/A	N/A	Yes	Yes	Yes
	Gas Outlets in Dwelling	N/A	N/A	N/A	5	5	5
	Gas Appliance Star Rating *	N/A	N/A	N/A	5	N/A	5
	Cost of Pipelined Gas (c/MJ) *	N/A	N/A	N/A	3.0	3.0	3.0
	Maintenance?	Yes	Yes	Yes	Yes	Yes	Yes
	Life Expectancy (yr) *	10	10	10	10	10	10
Billable Energy	Electricity (MJ/yr)	8,064	#N/A	21,827	210	200	N/A
	Gas (MJ/yr)	N/A	N/A	N/A	25765	17915	26613
	Total (MJ/yr)	8,064	#N/A	21,827	25,975	18,115	26,613
Greenhouse Gas Emissions	Electricity (kg CO_2-e/yr)	2,060.86	#N/A	5,578.00	53.67	51.11	N/A
	Gas (kg CO_2-e/yr)	N/A	N/A	N/A	1,680.68	1,168.59	1,735.98
	Total (kg CO_2-e/yr)	2,060.86	#N/A	5,578.00	1,734.35	1,219.70	1,735.98
Cost method selected for each water heater *		Tool	Tool	Tool	Tool	Tool	Tool
Costs – One-Off	Net Purchase Cost ($)	$ 2,921.27	#N/A	#VALUE!	$ 993.56	$ 3,978.88	$ 1,368.40
	Installation Cost ($)	$ 900.00	#N/A	#N/A	$ 593.57	$ 1,450.00	$ 500.00
	New Gas Connection Cost ($)	N/A	#N/A	N/A	$ -	$ -	$ -
Costs – Ongoing (over life time of water heater)	Maintenance Cost ($/10 years) *	$ 684.00	#N/A	$ 1,114.00	$ 305.00	$ 771.50	$ 489.00
	Electricity Cost ($/10 years)	$ 3,225.69	#N/A	$ 8,730.78	$ 178.50	$ 170.00	N/A
	Gas Supply Charge ($/10 years) *	N/A	#N/A	N/A	$ 547.50	$ 547.50	$ 547.50
	Gas Piplelined Cost ($/10 years) *	N/A	N/A	N/A	$ 7,729.64	$ 5,374.49	$ 7,983.97
	Gas Bottle re-fills ($/10 years) *	N/A	N/A	N/A	$ -	$ -	$ -
Costs – Total System	Total Cost ($ over 10 years)	$ 7,730.97	#N/A	#VALUE!	$ 10,347.77	$ 12,292.37	$ 10,888.88
Costs – Annual	Total System Cost ($/yr)	$ 773.10	#N/A	#VALUE!	$ 1,034.78	$ 1,229.24	$ 1,088.89
	Energy Cost ($/yr)	$ 322.57	#N/A	$ 873.08	$ 845.56	$ 609.20	$ 853.15

Are the options for these systems valid, to allow a fair comparison of each water heater?

Figure 7-3 Estimation Tool “Comparison” page

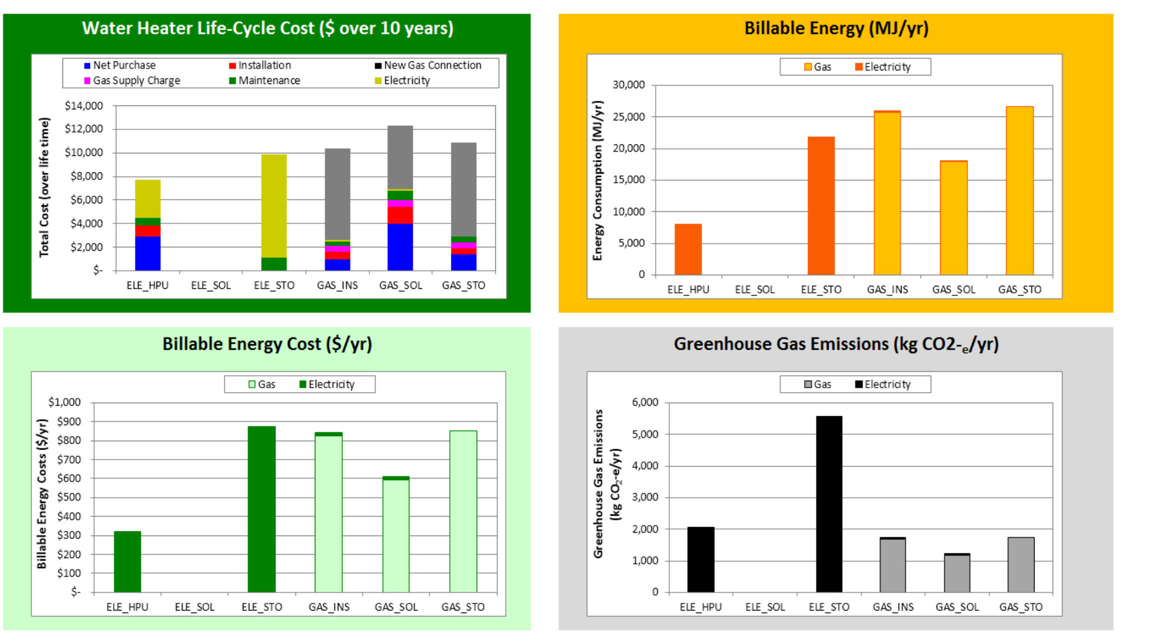


Figure 7-4 Estimation Tool “Graphical SUMMARY” page

Please note that although dropdown lists update dynamically, selected input parameters do not if a preceding input parameter is changed. For example, if a medium load size is selected for a heat pump or solar water heater and the STC available to that water heater is outside of the acceptable range, the STC value will not change to one that is acceptable. If this occurs,

In the event that an input parameter becomes invalid, due to a change in a preceding input parameter, the cell will be flagged (e.g. the cell may be highlighted red) to indicate that a new valid input value must be selected. At the bottom of all input worksheets there are status indicators. If these are green, all inputs are valid. If these cells are red, the user will need to find the highlighted cell and input a valid entry from the drop down list. At the top of the comparison page there is an additional check which will allow the user to see if all options are valid. Failure to update a flagged cell will invalidate all subsequent calculations.

This tool can be used to investigate the performance of any single water heater type or a number at once. If the user wishes to only consider one heater type, they need only input data relating to that heater type, I.e. Customer inputs and the selected water heater details from the "Electricity Systems" or "Gas Systems" page.

The UniSA team has endeavoured to provide a tool with as much flexibility as possible. For a simplified use, it is also possible that DMITRE will want to preselect values for many of the details such as electricity and gas costs and associated emissions, STC values and even system specific details allowing a quicker comparison of a specific water heater to "standard water heater". It is important to note that for a fair comparison, each water heater type should be the optimum size and specification for the intended operation.

7.1.2 Guidance Messages / Additional Information

The above figures also show examples of additional explanatory information that is shown to the user via small pop-up messages. These are displayed to assist the user enter the data, guide the customer, or prompt the user for customer clarification. Similarly, some cells contain the text "**(click for more info.)**", which also display additional information, when selected. In addition, some cells contain the text "**(if applicable)**", which indicate that this value is only applicable to one type of water heater types, e.g. star ratings and temperature controllers only apply to continuous flow gas water heaters.

7.2 Customer Inputs – Water Usage

7.2.1 Hot Water Load Inputs

The top row shown in Figure 7-1 has a number of parameters that require input to determine the customer hot water load. These inputs relate to the number of residents in the house, their perceived water usage pattern, and thermostat settings. The perceived determination of hot water usage is possibly the most difficult input in this tool as many people find it is hard to understand personal water usage. The values used in this tool have been established based on a study of 27 households in Lochiel Park and data collected from this study and are based on an average usage of water per person. The simplest method to decide on a category for this option to look at the average length of shower, if the residence usually have hot baths and the frequency of the use of hot water for dish and clothes washing. An example of a small load would be a person that has short showers, 5 minutes or less and cold washes clothes. Medium load hot water users may shower for approximately 10 minutes a day assuming they have a low flow shower head and large user will often run a bath, use hot water for clothes washing and have extended showers.

7.2.2 STC of Heat Pumps and Solar Water Heaters

The user is able to select an STC value for a water heater if a solar water heater or heat pump is selected. This list of available STCs is determined on the current CER register of heat pumps and solar water heaters, for climate zone 3 and 4, i.e. Within South Australia. The drop down list shows only a limited range of STCs, based on the size of the water heater, which is predetermined by the hot water pattern inputs.

7.2.3 Continuous Gas Burner Options

The user must select the star rating and indicate whether or not an indoor temperature controller is installed. Note that continuous gas water heaters range from 5 to 7 stars, and that information regarding temperature controllers is required, as these parameters influence the overall gas and electrical energy consumption, respectively.

7.2.4 Indoor Hot Water Temperature Information

The typical temperature of the water used within the house is an important factor in determining the heat load of the system. This temperature can be estimated by determining the largest use of hot water. Bathing usually requires hot water of approximately 45^{o}C while dish washing and clothes washing may require higher temperatures. A questing regarding indoor water temperature is included in the tool to inform customers how to increase the indoor water temperature if a thermostatic mixing valve (safety device) is installed. This is deemed necessary, as previous UniSA studies indicate that residents are generally unaware of the techniques required to increase the indoor hot water temperature, if such a safety device is installed. In the past, residents have been noted to increase the tanks thermostat setting, which increases the tank heat loss and overall fuel consumption, where applicable.

7.3 Customer Inputs – Gas Connection, Cost and Greenhouse Gas Factors

The second row of the tool requires many inputs to be selected by the user; these are mainly based on a gas connection, billing costs, and greenhouse gas emission factors. Note that if an electric water heater is selected, the user must select 'N/A' from the drop down lists for the various gas inputs, and that all costs quoted include GST.

7.3.1 Gas Connection

If a gas water heater is selected the tool requires several gas-based inputs to be selected. These are used to determine if the water heater is the only gas appliance and whether or not a gas connection currently exists. These inputs determine whether or not to pass on the connection and or daily supply charges directly to the water heater.

The user must select which type of gas they are connected to (or considering connection to). The options include natural gas and both bottled and pipelined LPG; some developments, such as Mt Barker have distributed LPG pipelines and billing meters. As such, the user is able to select either bottled or pipeline LPG. The successive required inputs regarding costs automatically adjust to reflect the choice of gas connection. Note that regardless of the type of connection, the 'Typical Gas supply charge' value is required. In contrast, inputs such as 'Typical Bottle' and 'Typical Pipeline' costs are specific to certain gas connections. As such, a value of '0' should be selected if this cost is not applicable to the gas connection type selected.

7.3.2 Utility Billing Costs

The user is required to enter both the gas and electricity typical supply charges and tariffs such that the tool can estimate the running costs of the water heater selected. These must be selected from drop down lists, and can be estimated by the customer based on their current bills. If billing information cannot be found, the user may choose to select an average rate, as indicated by the pop up message, which shows typical billing rates for January 2013.

7.3.3 Electricity Tariff

The user must select the electricity tariff if the customer has selected (or is considering) an electric storage water heater. If an off-peak tariff is selected, this will cause the water heater to heat only between 11pm and 5am. Electricity tariff is cheaper during this time and this is reflected in the successive drop down (electricity tariff) list.

7.3.4 Greenhouse Gas Emission Factors

The user is required to input the current greenhouse gas emission factors / coefficients, for both electricity and gas. The gas drop down list will automatically select the factors based on the type of gas selected, i.e. natural or LPG. The current values will be displayed in the respective pop-up messages. Note both the electricity emission factor is specified in kg CO_2-e/kWh, whilst that for gas is expressed in kg CO_2-e/GJ. The tool also assumes that all electricity is purchased from the retailer and as such does not include the impact of any solar PV systems connected at the property, if any. The emission factors for LPG are constant for the previous four years, whilst those for natural gas and electricity slightly decrease each year. If an electric water heater is selected, the gas emission must be set to '0'.

7.4 Calculated Energy and Running Costs

7.4.1 Hot Water Usage

The tool first calculates the average daily hot water consumption, based on some of the customer inputs from the first row. Data from previous hot water monitoring projects, such Lochiel Park, and preliminary data from this study indicate that the average household uses 40L of hot water per resident per day. Having said this, the user is able to adjust the amount of water used by the house by selecting whether the householders use an average amount of hot water, below average or above average. Note that the below average corresponds to 50% less than the average daily usage (27L), whilst above average corresponds to 50% above the average usage (60L); these values are shown in the relevant pop-up message.

7.4.2 Hot Water Energy Load Baseline

This tool uses a measured baseline hot water energy load from this study and a separate 12-month monitoring period at Lochiel Park, between April 2010 and March 2011. This was preferred to using the former ORER methodology as stated in AS4234:2008, as it was found in a previous UniSA study that the methodology used is dissimilar to actual measured hot water usage patterns.

This energy load is independent of the type of water heater used as it only reflects the energy needed to heat the water used, i.e. it does not include maintenance rates for gas storage water heaters, nor does it contain tank heat loss data for water heaters utilising a storage tank.

7.4.3 Water Heating Load Energy

Figure 7-5, shows the variation of the water heater load energy usage per month, for Lochiel Park houses. The figure clearly shows energy variation based on seasonal variability, and that given any month's hot water usage data, it is reasonable to extrapolate, with a relatively high level of confidence, the hot water energy load over a 12-month period. Although this value is based on a thermostat setting of 60°C, the tool takes this into consideration by scaling the annual energy value based on the variable thermostat setting, i.e. the tool subsequently calculates the monthly energy load using the new hot water temperature. Note that changing the thermostat setting also affects the tank heat loss or maintenance rate, depending on the water heater. These are discussed below.

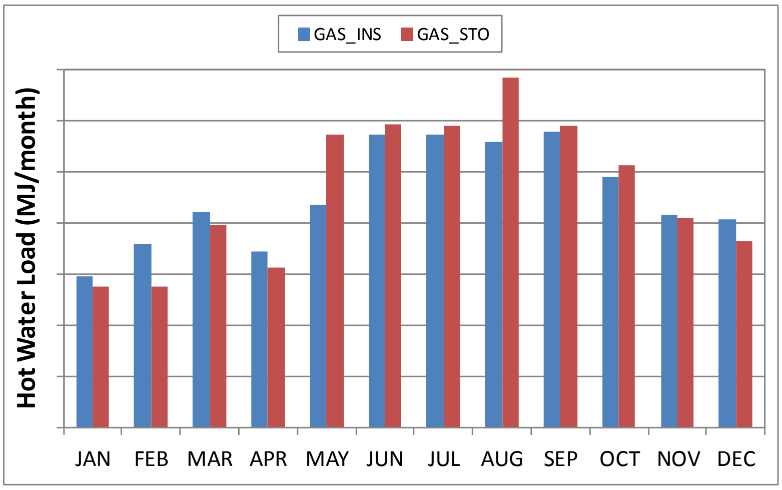


Figure 7-5: Monthly variation of hot water load for Lochiel Park residents over a 12-month period.

7.4.4 Tank Heat Loss

The standard heat loss coefficient of a storage tank is calculated for a difference between tank internal hot water and ambient air conditions of 55K. This parameter varies with the ability of the tank to deliver its rated output, as defined in ASZS4692.2:2005. Although the tank heat loss varies with manufacturer and claimed tank volume, we are able to determine a relationship between claimed tank volume and rated hot water delivery and hence heat loss, based on industry experience in relation to such storage tanks. In fact, the majority of tank manufacturers only just meet the minimum energy performance standards (MEPS), and as such, the MEPS of a storage tank is used for the heat loss coefficient, as shown in Figure 7-6. Note this applies only to electric storage or solar water heaters, and that the Y-axis label and trend line equations are deliberately not shown, as this is based on confidential data.

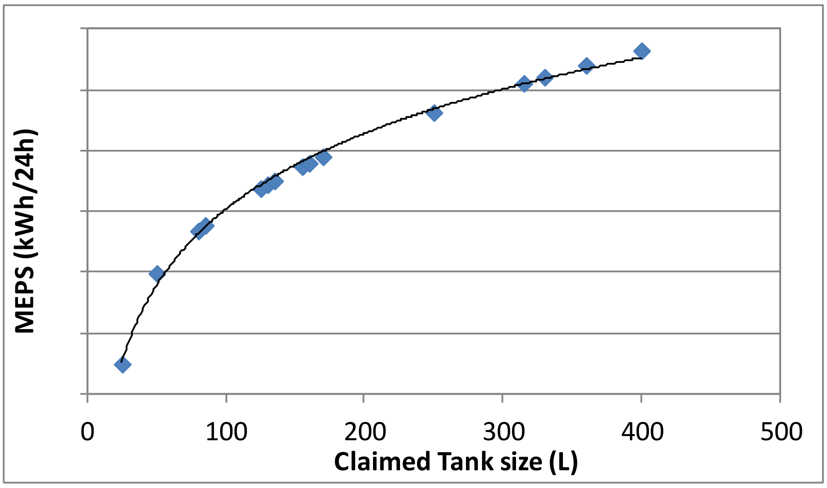


Figure 7-6: Predicted tank heat loss, based on manufacturer claimed tank volume and MEPS.

The tool extrapolates the tank heat loss energy to that for a 12-month period, based on 12 months of measured ambient air temperatures, obtained from the Bureau of Meteorology, and the thermostat setting input.

7.4.5 Maintenance Rate

The maintenance rate is defined as the energy required to maintain the tank at the thermostat setting (AS4552:2005), and only applies to a gas storage water heater. This parameter is effectively the gas boosted storage water heater equivalent to the value of standing heat loss, a value which is only legally required in Australia for a non-gas based storage tank (including the non-internally boosted storage tank used in continuous gas boosted solar water heaters).

The maximum allowable maintenance rate is shown in Figure 7-7, again with the Y-axis labels deliberately obscured. These values are based on the tank volume and the water heater gas consumption, in accordance with the methodology outlined in AS4552:2005. Note that the slight variation shown is due to the different gas consumptions of the manufacturers' various products.

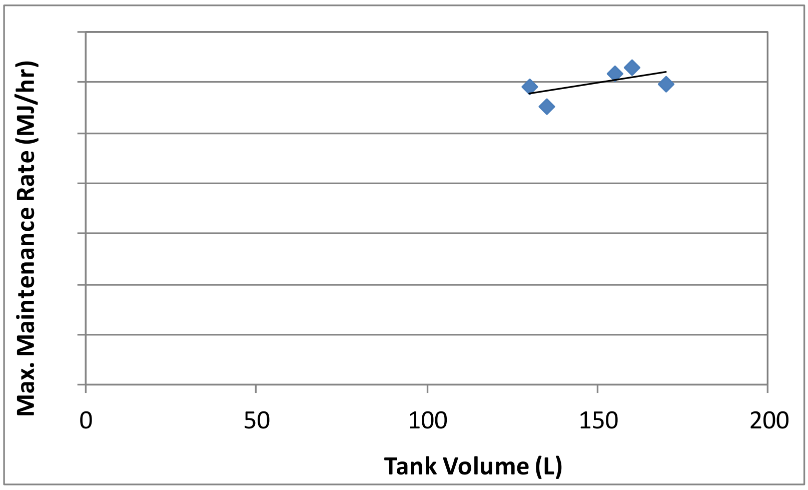


Figure 7-7: Calculated maximum maintenance rate of gas storage water heaters.

7.4.6 Billable Energies and Costs

The billable electrical energy is dependent on the type of water heater selected and is summarised below in Table 7-1. Note that those calculated using STCs are complex and are not disclosed here.

Table 7-1: Summary of billable electrical energy usage methodologies for various water heaters.

Fuel Type	Sub Type	Electrical Energy Calculation
Electric	Heat Pump	Based on STC
	Solar	Based on STC
	Storage	Hot water load + heat loss
Gas	Continuous	Burner fan + temperature controller
	Solar	Burner fan + solar circulation pump
	Storage	N/A

Similarly, the billable gas energy is dependent on the type of gas heater. Table 7-2 below summarises the methodologies used to calculate the gas energy. Note that the burner (thermal) efficiencies vary with type of water heater (e.g. storage vs. continuous) and the star rating, if applicable. This is summarised in Figure 7-8, which is based on modelling deduced from manufacturers' datasheets and AS4552:2005.

Table 7-2: Summary of billable gas energy usage methodologies for various gas water heaters.

Sub Type	Gas Energy Calculation
Continuous	Hot water load / burner (thermal) efficiency + startup losses
Solar	Based on STC
Storage	Hot Water load / thermal efficiency + maintenance rate

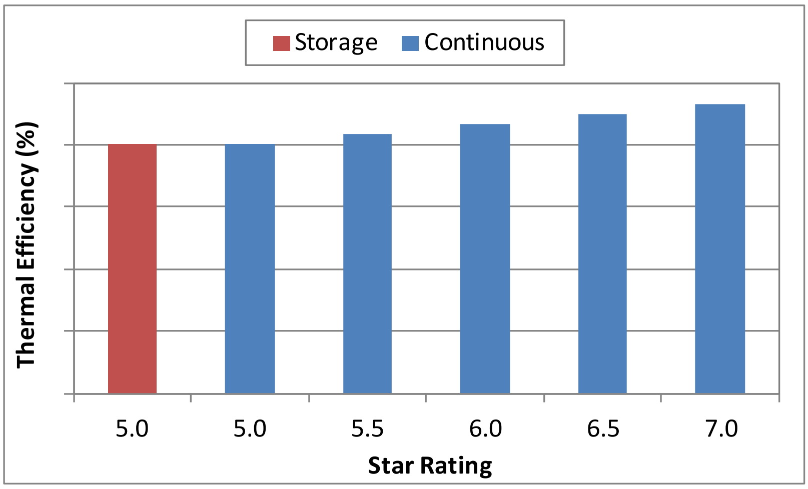


Figure 7-8: Comparison of storage and continuous gas water heater thermal (burner) efficiencies.

The calculation of the required purchased energy for all systems is based on the required heat load and system specific efficiencies. Each water heater type has its own calculation worksheet where, based on the input values, a heat load is calculated and system efficiencies based on system specific details and heat load is calculated. The heat load for each system is calculated based on:

- The Number of Residence
- Water Usage
- Inside water temperature
- Water inlet and outlet temperature

These values are input into the “Inputs (customer)” sheet and that information is used by each of the system specific calculation worksheets. Figure 7-9 illustrates the inputs required for each system to calculate the heat load.

Required Inputs					
	Heat Load Calculation				
		Daily hot water usage	40	Average water usage	
		number of people	water usage	water usage PP/Day system	zone
		5	Average	200	3
			inside water temperatu	Zone 3 inlet temp	Zone 4 inl
			60	17.4	14.3
		Required water usage			
		35.6136	per day		
		12998.964	per year		
	tank size	zone	stc	stc calculated load size	
	250	3	30	Medium	
		stc need to be calculated on these values			

Figure 7-9 System specific calculation of heat load

The system efficiency for each water heater type is calculated for varying heat loads based on the factors that affect the performance of each heater type.

Electric Storage Water Heater Calculations

The calculations for the required purchased energy for electric storage water heaters is based on the heat load and the storage tank heat loss. The heat loss of the tank is calculated using the tank volume, expected heat loss derived from MEPS values taken from AS/NZS4692.2 and a yearly average ambient air temperature.

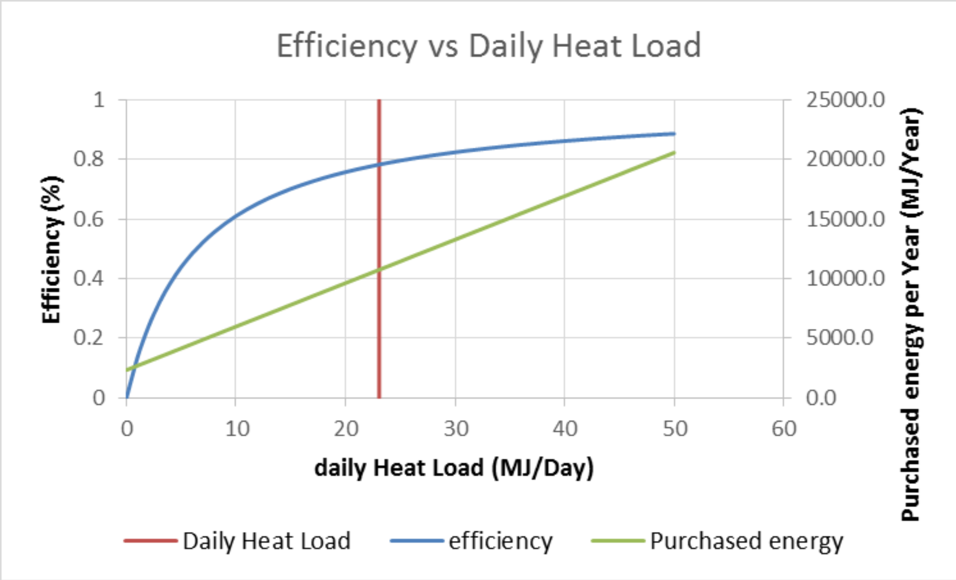


Figure 7-10 Efficiency and energy usage trend used for the calculation of Purchased energy for electric storage water heaters

Heat Pump Water Heater Calculations

There is a large variation in the performance of heat pump and solar hot water heaters across the market place. The method with the highest accuracy of calculating the purchased energy of a specific heat pump or solar hot water heater is to use the STC value calculated for that system. As STC calculations are only conducted at one heat load, the UniSA researchers have developed methodologies to scale purchased energy with respect to heat load. For heat pumps, it was found that the purchased energy usage was linearly proportional to the heat load. With an offset evident which accounted for the heat loss of the tank. This offset is calculated using the expected heat loss of the tank and the average COP of the heat pump. The proportionality of the purchased energy and heat load has been calculated at the STC calculation load. Purchased energy estimation for heat loads between 0 MJ/day heat load and the STC calculation point have been produced.

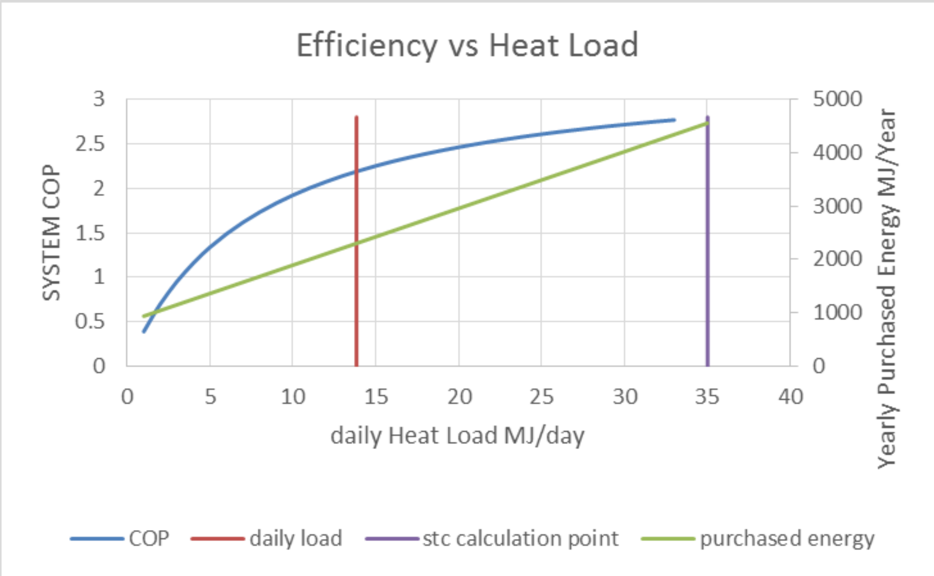


Figure 7-11 Efficiency and energy usage trend used for the calculation of Purchased energy for heat pump water heaters

Electric and Gas Solar Water Heater Calculations

The calculation methodology for the purchased energy for the solar hot water heaters was based on the same principles as the heat pump methodology. Data collected from this study and from Lochiel Park and from TRNSYS modelling shows that the relationship between heat load and purchased energy is not linear. Researchers have used all the available data to produce a trend line that approximates the change in purchased energy with heat load for typical solar water heaters and have applied this trend to determine the purchased energy of each water heater based on a known purchased energy/ heat load point at the STC calculation point.

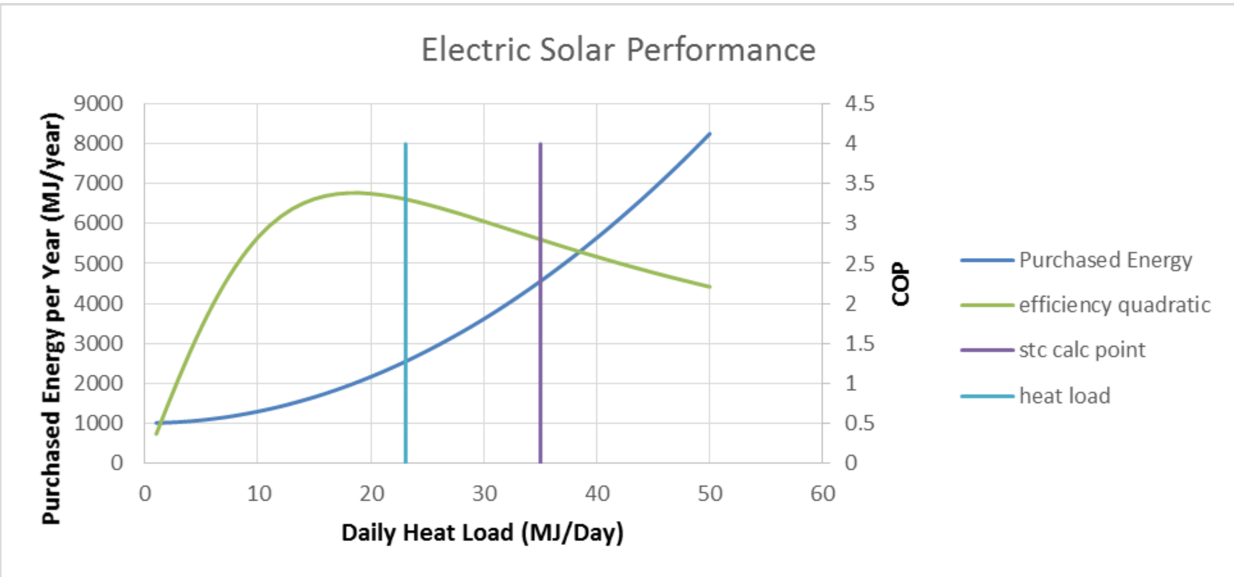


Figure 7-12 Efficiency and energy usage trend used for the calculation of Purchased energy for solar water heaters

Continuous Flow Gas Water Heater Calculations

Data collected from this study showed that the relationship between the heat load and purchased energy of a continuous flow water heater is linear. This is a small offset evident, believed to be associated with the control of the water heater. The star rating of continuous flow water heaters as determined in AS4552-2005 provides a heat load/ purchased energy point at a heat load of 37,500MJ/year. Data from this study showed that these values are reliable and hence the purchased energy for heat loads between 0 MJ/year and 37,500MJ/year can be determined.

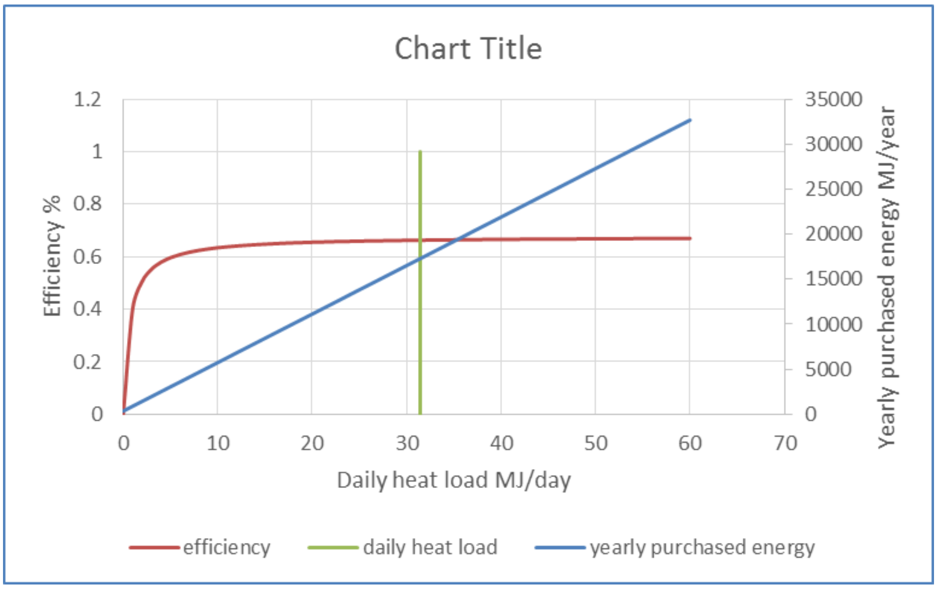


Figure 7-13 Efficiency and energy usage trend used for the calculation of Purchased energy for continuous flow, gas water heaters

Gas Storage Water Heater Calculations

The calculation methodology for the purchased energy requirement of gas storage water heaters is similar to continuous flow gas water heater and electric storage water heaters. The proportionality of the purchased energy and heat load is derived once again from the star rating as calculated by requirement in AS4552-2005. The storage tank losses and gas burner efficiency lead to a base energy usage at a 0MJ/year heat load which is known as the maintenance rate of the system. Purchased energy between 0MJ/year and 37,500MJ/year have ben interpolated between a maintenance rate energy requirement and the star rating calculation point energy requirement. The energy requirement for the gas storage water heater heaters monitored in this study was consistently 11% higher that the trend expected in the tool. As the sample size is small, researchers have used the test method values for energy usage and not values found in this study.

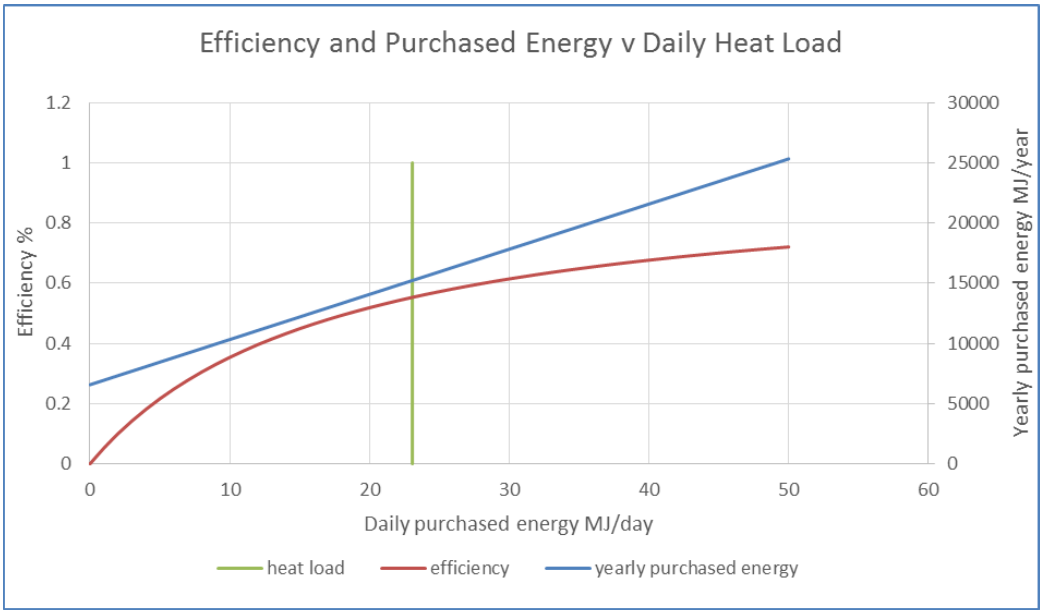


Figure 7-14 Efficiency and energy usage trend used for the calculation of Purchased energy for gas storage water heaters

7.4.7 Annual Running Costs

The tool calculates the annual running costs based on the relevant tariffs inputted, and the previously calculated billable energy values. Note that tool assumes constant billing tariffs to simplify the calculations, however, in reality tariffs will be regularly adjusted and this will alter the outcome.

7.5 Predicted Costs and Greenhouse Gas Emissions

The fourth row shows the projected total annual cost of a particular water heater, as well as the annual greenhouse gas emissions. The cost includes the purchase, installation, maintenance and running costs, some of which are discussed below in sections 7.5.1 to 7.5.4. The greenhouse gas emissions are discussed in section 7.5.6.

7.5.1 Purchase Costs

A substantial search was undertaken to collect the purchase costs of several water heater varieties. The tool predicts the cost of a water heater based on its type, STC value, tank volume or star rating, as summarised by Figure 7-15 and

Table 7-3. The figure again deliberately conceals the Y-axis labels.

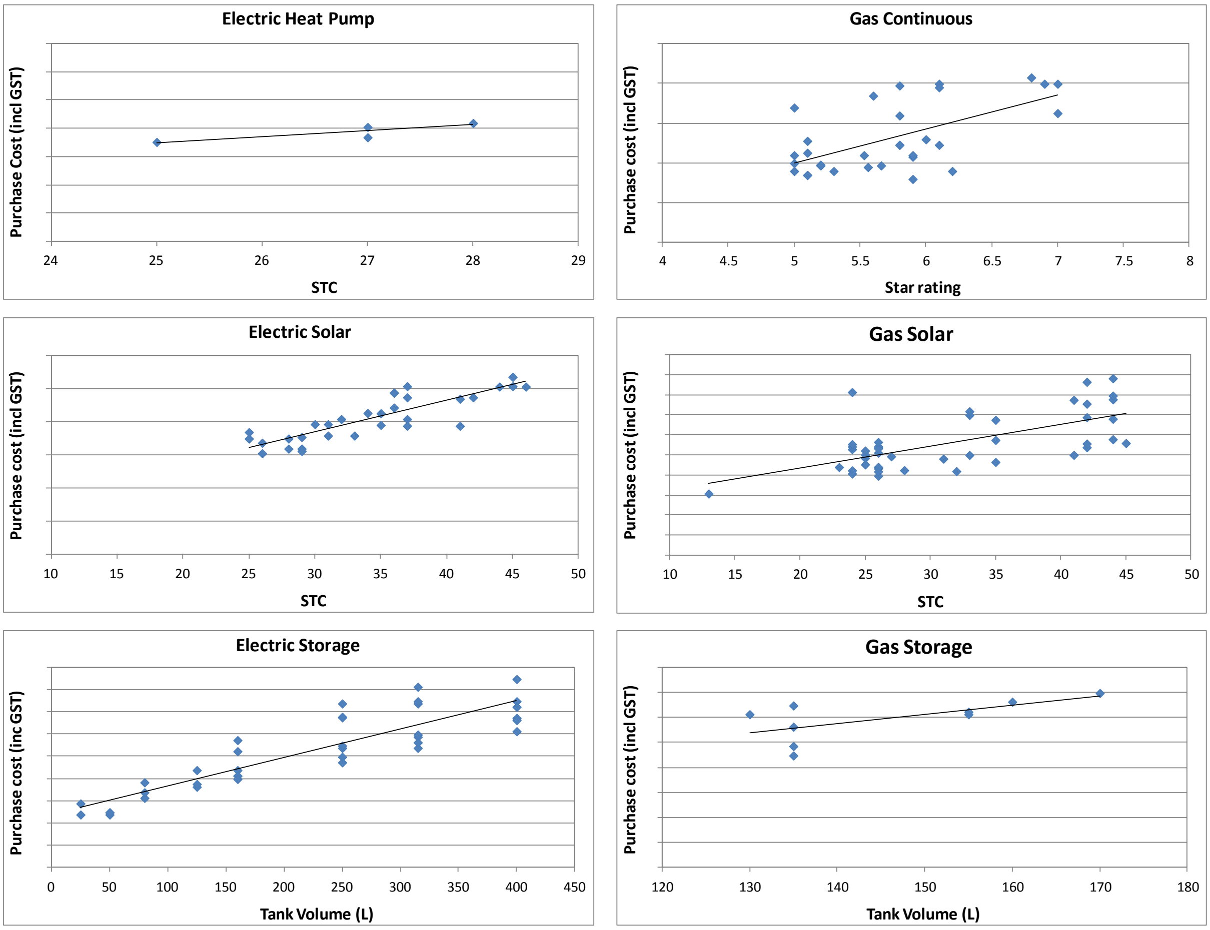


Figure 7-15: Purchase cost comparison and trends of various water heaters.

Water heaters based on STCs, i.e. heat pumps or solar water heaters, estimate the purchase cost based on the system size (small, medium or large) based on the inputted hot water usage pattern.

Table 7-3: Summary of purchase cost estimation.

Fuel Type	Sub Type	Purchase Cost Estimated, based on:
Electric	Heat Pump	STC
	Solar	STC
	Storage	Tank volume
Gas	Continuous	Gas burner star rating
	Solar	STC
	Storage	Tank volume

7.5.2 Installation Costs

The tool predicts various plumber and electrician requirements and hence the installation cost, based on the water heater selected. A summary of the assumptions used to generate the electrician's costs is listed below in Table 7-4. These are added to the predicted plumber's costs, and form the basis for the installation costs shown in Figure 7-16. Note that the costs are deliberately obscured; however, show a relative installation cost for each water heater type, i.e. the installation cost of solar boosted water heaters is significantly higher than all other types of water heaters.

Table 7-4: Summary of Electrician works to completed for various water heater installation.

Fuel Type	Sub Type	Electrician's role:
Electric	Heat Pump	Install power circuit to water heater and associated circuit breaker
	Solar	Install power circuit to water heater and associated circuit breaker, and one general power outlet
	Storage	Install power circuit to water heater and associated circuit breaker
Gas	Continuous	Install one general power outlet
	Solar	Install one general power outlet
	Storage	N/A

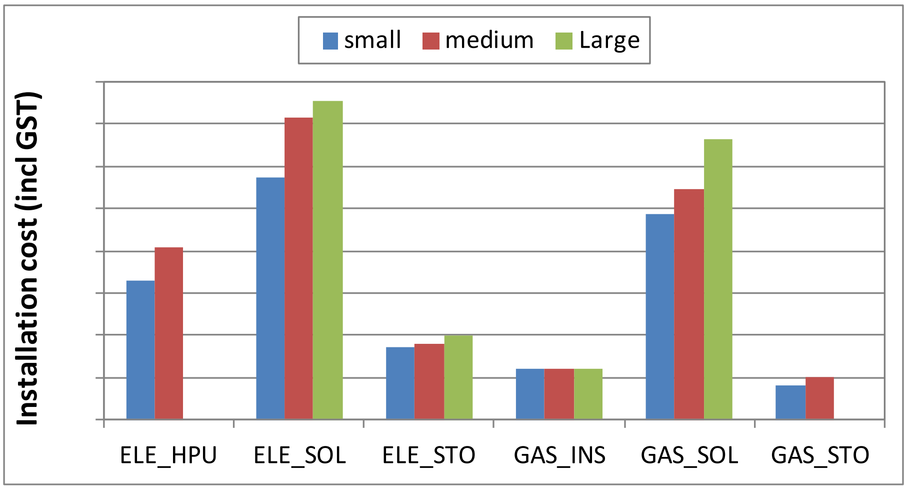


Figure 7-16: Installation cost comparison of various water heaters.

7.5.3 New Gas Connection Costs

The tool estimates the costs of installing a new gas connection, which is based on plumber's costs associated with installing pipework from the meter onwards, and the gas retailer's cost of extending the gas pipe work to the boundary of a house. The latter is only applicable for natural gas and LPG pipeline installations. Note that the plumbers' cost increases with the number of gas appliances / outlets to be installed at the house, due to increased labour and parts costs.

7.5.4 Maintenance Costs

The tool assumes that a water heater will operate for six years without regular maintenance, whilst it is expected that regular maintenance will increase the life expectancy to 10 years. Each water heater requires unique maintenance, as summarised by Table 7-5, which recommends how often certain components should be replaced. These relative maintenance costs are compared for various water heater types in Figure 7-17.

Table 7-5: Frequency of maintenance / replacement of water heater components, in years.

Fuel Type	Sub Type	Anode	Element	PTR Valve	Thermocouple	Circulation Pump
Electric	Heat Pump	3.5	4.5	5	N/A	N/A
	Solar	3.5	4.5	5	N/A	5
	Storage	3.5	N/A	5	N/A	N/A
Gas	Continuous	N/A	N/A	N/A	4	N/A
	Solar	N/A	N/A	5	4	5
	Storage	N/A	N/A	5	4	N/A

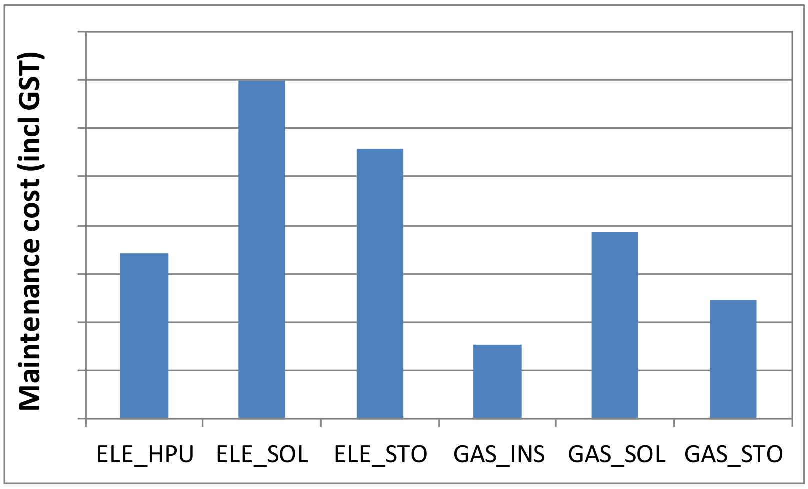


Figure 7-17: Maintenance cost comparison of various water heaters, over a 10 year period.

7.5.5 Total Costs

The total annual cost is calculated based on the purchase, installation, maintenance and running costs, for the expected life of the water heater. This value also includes any costs associated with installing a new gas connection, and daily pipe or bottle rental charges, if a gas water heater is selected and is the only gas appliance connected to the house.

7.5.6 Annual Greenhouse Gas Emissions

The tool calculates the annual greenhouse gas emissions in equivalent kilograms of Carbon Dioxide (kg CO_2-e), based on the greenhouse gas emission factors inputs selected.

8 Conclusion

This study has shown that there are many variables that affect the long term viability of different types of hot water heaters. These factors include:

- Number of residence
- Water temperature
- Personal water usage habits
- Heat loss
- Gas star rating
- STC rating for solar and heat pumps
- Number of gas appliances within a household
- Electricity tariff
- Government rebates and incentives
- Water heater location
- Purchase costs
- Installations costs
- Maintenance costs

This study focused on monitoring a very small number of water heaters across the most prevalent water heater types. In most cases, the monitored data was able to provide clear evidence of the efficiency and performance of each water heater type. This data was then consolidated and with the addition of the associated costs for each water heater type an evaluation tool was created to compare lifetime cost of domestic water heating in South Australia.

What the monitored data and tool prove is that it is imperative to consider the manner in which any hot water heater will be utilised once installed within a household. Conventional storage systems can provide an economical method of producing hot water but they need to be sized appropriately with the resident's needs. Continuous flow, gas water heaters have proven to be efficient and highly economical, especially at low heat loads while it has also been proven that solar and heat pump water heaters perform with high efficiency significantly reducing running costs and CO_2 emissions.

Due to the large range of hot water heaters available within each water heater category, the tool and this report are only able to provide a general prediction of the performance and cost of a water heater based on its water heater category. Quality of construction, specific design details (e.g. trade-off between maintenance rate and gas burner efficiency or thermosiphon solar water heater vs pumped closed loop solar water haters), accuracy of STC calculation modelling or star rating calculations are all factors that are specific to every water heater available within the South Australia market and need to be taken into consideration when selecting a water heater.

9 Appendix

Monitored Hot Water System Purchased Energy

Purchased Energy (MJ) - Corrected Data						
	ELE_HPU_ROST	ELE_HPU_YATA	ELE_SOL_LPON	ELE_SOL_MAWS	ELE_STO_NADL	ELE_STO_NETH
January	285.37	293.15	20.60	27.85	523.18	400.98
February	281.75	296.38	17.84	21.00	506.17	300.78
March	327.05	312.69	16.33	37.77	521.50	311.82
April	336.78	480.78	53.76	75.79	642.61	330.04
May	451.87	296.29	96.25	416.54	763.72	349.58
June	537.52	316.12	232.77	398.65	751.37	358.19
July	466.34	319.46	318.81	343.60	803.90	394.64
August	512.24	318.88	171.11	462.55	837.64	344.05
September	437.74	256.20	136.21	130.72	744.65	316.70
October	454.23	244.25	101.31	201.77	670.83	333.66
November	342.09	237.42	25.15	36.11	647.71	312.44
December	**365.77**	**323.58**	**16.68**	**49.31**	**563.75**	**N/A**
Yearly Total (MJ/Year)	**4798.74**	**3695.19**	**1206.82**	**2201.67**	**7977.04**	**4094.03**

Purchased Energy (MJ) - Corrected Data						
	GAS_INS_DOVE	GAS_INS_WOOD	GAS_SOL_LPSS	GAS_SOL_LPST	GAS_STO_ABER	GAS_STO_CUMB
January	201.60	266.94	59.66	127.41	1565.32	495.97
February	210.17	266.57	59.38	106.73	1448.04	473.17
March	359.08	311.74	116.90	159.41	1600.30	560.42
April	391.80	521.53	257.68	380.26	1829.02	558.29
May	257.77	718.68	509.11	812.44	1983.51	797.23
June	333.83	847.86	648.48	1381.23	2280.97	802.51
July	355.19	960.94	492.34	1382.70	2438.57	817.83
August	408.99	1081.18	489.42	1217.53	2277.04	749.45
September	514.10	959.34	240.38	619.03	2076.22	631.55
October	449.31	683.48	134.00	372.01	1929.79	624.08
November	488.56	590.56	83.51	222.09	1840.30	604.43
December	**213.04**	**343.75**	**54.67**	**150.21**	**1750.82**	**572.60**
Yearly Total (MJ/Year)	**4183.46**	**7552.59**	**3145.54**	**6931.06**	**23019.89**	**7687.53**

Monitored Hot Water System Heat Load

Heat Load (MJ) - Corrected Data						
	ELE_HPU_ROST	ELE_HPU_YATA	ELE_SOL_LPON	ELE_SOL_MAWS	ELE_STO_NADL	ELE_STO_NETH
January	521.59	298.35	141.89	554.91	374.92	166.71
February	593.41	310.11	82.08	492.09	353.34	121.04
March	646.40	299.84	115.26	516.84	386.29	129.87
April	652.00	553.39	168.10	654.98	N/A	126.65
May	837.94	775.04	196.34	755.84	589.23	144.95
June	1036.76	870.69	225.13	742.82	567.13	144.90
July	801.63	843.66	254.38	783.15	615.94	175.83
August	987.95	845.55	220.48	878.32	678.32	133.44
September	1243.14	664.65	189.21	788.05	582.48	129.39
October	1056.49	511.36	165.38	1022.38	532.05	128.62
November	643.27	492.84	122.15	731.36	496.39	116.47
December	716.43	347.70	162.36	696.62	407.09	N/A
Daily (MJ/Day)	**26.68**	**18.67**	**5.60**	**23.61**	**16.67**	**4.54**
Year (MJ/Year)	**9737.03**	**6813.16**	**2042.76**	**8617.36**	**6090.75**	**1655.87**

Heat Load (MJ) - Corrected Data						
	GAS_INS_DOVE	GAS_INS_WOOD	GAS_SOL_LPSS	GAS_SOL_LPST	GAS_STO_ABER	GAS_STO_CUMB
January	117.04	171.39	319.64	N/A	829.98	73.98
February	125.23	181.33	340.49	547.06	759.44	74.01
March	224.12	215.77	411.35	694.19	843.40	100.83
April	216.81	365.77	454.95	910.61	976.19	92.85
May	165.14	506.54	566.27	942.93	1090.26	197.25
June	213.44	636.67	626.08	1304.72	1337.85	177.58
July	233.26	731.65	498.91	1309.02	1471.15	187.87
August	260.35	813.88	551.14	1250.32	1496.89	147.81
September	339.14	716.29	475.86	1003.22	1526.16	112.51
October	289.70	499.64	525.63	1035.24	1323.95	103.12
November	320.25	430.41	482.18	924.34	N/A	122.65
December	131.26	239.74	392.79	800.99	964.87	115.44
Daily (MJ/Day)	**7.22**	**15.09**	**15.47**	**32.10**	**37.67**	**4.13**
Year (MJ/Year)	**2635.74**	**5509.07**	**5645.28**	**11697.42**	**13767.42**	**1505.90**

Monitored Hot Water System Water Consumption

	Total Water Consumption (L) - Corrected Data					
	ELE_HPU_ROST	ELE_HPU_YATA	ELE_SOL_LPON	ELE_SOL_MAWS	ELE_STO_NADL	ELE_STO_NETH
January	3808	2262	2024	3138	4151	1023
February	3911	2252	1231	2719	3973	767
March	4620	2152	1353	2968	4240	809
April	4410	3610	1657	3713	N/A	738
May	5008	3999	1738	5268	4909	806
June	5940	4386	1775	4916	4511	740
July	4557	4207	1972	4827	4686	863
August	5510	4275	1782	5583	5174	694
September	7423	3616	1717	5057	4880	736
October	6464	2878	2181	6193	4627	697
November	4200	2965	1640	3855	4590	651
December	4837	2516	1830	3780	4306	N/A
Daily Average (L/Day)	**166**	**107**	**57**	**143**	**150**	**26**
Yearly total (L)	**60,687.53**	**39,118.23**	**20,899.47**	**52,016.93**	**54,691.98**	**9,314.90**

	Total Water Consumption (L) - Corrected Data					
	GAS_INS_DOVE	GAS_INS_WOOD	GAS_SOL_LPSS	GAS_SOL_LPST	GAS_STO_ABER	GAS_STO_CUMB
January	2132	3185	3294	N/A	4661	590
February	2131	3400	3574	5521	4304	584
March	3655	3271	3736	6109	4654	705
April	3253	3891	3609	7193	4757	619
May	1829	4771	4121	6607	4964	1039
June	2125	5482	4136	8344	5750	898
July	2136	5932	3216	8283	5989	890
August	2506	6798	3713	8185	6245	737
September	3587	6790	3512	7186	6921	631
October	3322	4684	3841	7361	6079	624
November	3978	5549	3952	7312	N/A	755
December	2049	3579	3484	6624	5125	860
Daily Average (L/Day)	**90**	**157**	**121**	**236**	**177**	**24**
Yearly total (L)	**32,702.60**	**57,332.95**	**44,188.00**	**86,031.83**	**64,773.37**	**8,931.15**

Monitored Hot Water System Performance, Cost and Co_2

	ELE_HPU_ROST	ELE_HPU_YATA	ELE_SOL_LPON	ELE_SOL_MAWS	ELE_STO_NADL	ELE_STO_NETH
Average Daily Water Cons. (L/Day)	166.3	107.2	57.3	142.5	149.8	25.5
heat load (MJ/Day)	26.7	18.7	5.6	23.6	16.7	4.5
heat load (MJ/Year)	9737.0	6813.2	2042.8	8617.4	6090.8	1655.9
Purchased Energy (MJ/Year)	4798.7	3695.2	1206.8	2201.7	7977.0	4094.0
efficiency (%)	2.03	1.84	1.69	3.91	0.76	0.40
cost ($)	467.2	168.8	132.9	100.6	364.4	187.0
c/L	0.77	0.43	0.64	0.19	0.67	2.01
g CO_2 / MJ	99.9	110.0	119.8	51.8	265.6	501.4

	GAS_INS_DOVE	GAS_INS_WOOD	GAS_SOL_LPSS	GAS_SOL_LPST	GAS_STO_ABER	GAS_STO_CUMB
Average Daily Water Cons. (L/Day)	89.6	157.1	121.1	235.7	177.5	24.5
heat load (MJ/Day)	7.2	15.1	15.5	32.1	37.7	4.1
heat load (MJ/Year)	2635.7	5509.1	5645.3	11697.4	13767.4	1505.9
Purchased Energy (MJ/Year)	4183.5	7552.6	3145.5	6931.1	23019.9	7687.5
efficiency (%)	0.63	0.73	1.79	1.69	0.60	0.20
cost ($)	138.6	250.3	104.2	229.7	762.9	254.8
c/L	0.42	0.44	0.24	0.27	1.18	2.85
g co2 / mj	111.0	84.4	40.0	44.0	103.0	314.5