ENERGY IMPLICATIONS OF HOUSEHOLD RAINWATER SYSTEMS

M Retamal, A Turner, S White

Abstract

The energy intensities of a range of household rainwater systems were monitored in Sydney and Newcastle as part of a study carried out by the Institute for Sustainable Futures (ISF) in collaboration with the Australian Commonwealth Scientific Investigation and Research Organisation (CSIRO). The study found that the energy intensity of these rainwater systems varied depending on system configuration, rainwater end uses and the water efficiency of the household. Preliminary results indicate that the energy intensity varies between 0.9 and 4.9 kWh/kL with a 'typical' household rainwater system using approximately 1.5 kWh to deliver each kilolitre of rainwater.

Introduction

Recent droughts in Australia have driven the water industry to find new and diverse ways of providing water services. This has ranged from large scale desalination plants and major inter-basin water transfers through to lot-scale distributed systems such as rainwater tanks and greywater reuse systems. Whilst this diversity has major benefits it may also have significant consequences if the impacts of these new systems are not addressed.

Recent research has shown that the energy intensity of centralised water supply systems in Australia's major cities prior to the recent droughts ranged from 0.1 to 0.85 kWh/kL (Kenway *et al.* 2008). However, in cities such as Sydney, Adelaide and Perth where major augmentation works have been undertaken in response to drought, the range of energy intensities is currently between 1.0 and 1.8 kWh/kL (Kenway *et al.* 2008). As more major augmentation works are completed, these figures are likely to increase as urban water systems become more energy intensive.

In addition to major augmentation works at the centralised scale, there has been a major increase in distributed systems, such as estate-scale water recycling systems and household rainwater tanks. A plethora of local, state and federal regulations and incentives has resulted in a large increase in the number of rainwater tanks installed across the country, which will continue to grow. However, despite the widespread use of rainwater tanks as an alternative water supply, to date, very little evaluation of these systems has been undertaken, both in terms of water savings and energy consumption.

Results from a preliminary monitoring study.

Limited available studies investigating water savings associated with rainwater tanks indicate a saving of approximately 20 kL/household/a in South East Queensland (Snelling *et al.* 2006; Turner *et al.* 2007), significantly lower than the theoretical potential savings of 70 kL/household/a in that area (Coombes *et al.* 2003). Another study by Lee *et al* (2008) found that savings in the ACT were as low as 12 kL/household/a. In both studies these results reflect programs dominated by rainwater tanks used for outdoor purposes only. It must be noted that water savings are very dependent on factors such as the roof catchment area, tank size, end uses to which the tank is connected and the climate of the region in question.

While further verification of the actual water savings achieved by these systems is required, energy consumption is now also emerging as an unknown and a potential issue for concern. One of the few available studies into the energy intensity of rainwater systems was carried out by Beal *et al.* (2008). This study examined the energy intensity of a cluster scale rainwater system (Silva Park) in South East Queensland and found that the pumping system and UV treatment had a combined energy intensity of approximately 5 kWh/kL, which is similar to that of desalination treatment.

While there is growing awareness of the need to mitigate and adapt to climate change impacts, there is evidence that the move towards both large and small scale diversification of water supply is actually increasing energy intensity. Evaluation of the energy consumed by new water supply systems is needed to ensure that the energy intensity of our water supply is not increased unnecessarily. Water supply systems can be modified to improve energy efficiency, particularly if problems are identified early.

The high energy intensities found at Silva Park by Beal *et al.* (2008) and the lack of data regarding the energy consumption of new urban water systems warranted further research.

Consequently, a research collaboration was established between ISF and CSIRO with the aim of researching the water-energy nexus and investigating the energy implications of emerging urban water systems. As part of this broad research project, ISF undertook a preliminary monitoring study in 2008/09 to investigate the energy intensity of a range of household rainwater systems in Sydney and Newcastle. The full results of this preliminary monitoring study and water-energy nexus research can be found in Retamal *et al.* (2009a); Retamal *et al* (2009b). This paper concentrates on the findings of the preliminary monitoring study of rainwater systems.

Rainwater Systems

Due to the diverse characteristics of households and their rainwater systems, such systems can be quite different and difficult to compare. Firstly, rainwater system configurations differ with different pump types, pump controllers, mains water back up systems and pressure aids such as pressure vessels. Secondly, the end uses for which rainwater systems are used vary, and these end uses require different flow rates, depending on whether rainwater is being used for cistern refilling or running a shower and/or irrigation system. Thirdly, the water efficiency of the appliances being used in each house and the water using behaviour of the householders is unique to each household. All of these factors affect how much energy and water is consumed by a rainwater system.

Monitoring Approach

In order to gain an understanding of the potential range of energy intensities associated with household rainwater systems, it was decided to monitor a spectrum of different systems. The features of each household monitored are described in Table 1. The table shows that the monitored households represent a range of different system configurations, with rainwater used for either toilet, laundry and outdoor or for all household end uses. The household sizes ranged from 1 to 5 people with the exception of one small suburban office. The approach was to monitor each system under normal operating conditions and then to replace specific components, such as pressure vessels, to test how this might affect the energy intensity of the system in question.

Table 1. Features of monitored households and their rainwater systems

Site	Pump type	Other features	End uses	No. people
Balmain	Fixed speed	Automatic switch to mains supply	Toilet, laundry, outdoor	4
Newtown	Fixed speed (Venturi)	Manual switch (test with and without pressure vessel)	All	5
Newcastle house #1	Variable speed trickle top up	Small pressure vessel,	All	2 to 3
Newcastle house #2	Fixed speed	Trickle top up	All	4
Padstow	Fixed speed	Automatic switch to mains supply	Toilet, laundry, outdoor	5
Redfern	Fixed speed (Submersible)	Automatic switch to mains supply	Toilets	10 workers
Enmore	Fixed speed	Automatic switch to mains supply (test with and without pressure vessel)	Toilet, laundry, outdoor	1
Concord	Variable speed	Small pressure vessel, automatic switch to mains supply	All	2

Two examples of the household systems that were monitored are shown in Figures 1 and 2. Figure 1 illustrates what appears to be the most common rainwater system configuration, that is, a fixed speed pump with an automated switch to the mains supply when the water level in the tank falls to a certain level defined by a float sensor. The rainwater is used for the toilet, laundry and garden. Figure 2 displays a less common rainwater system which makes use of a variable speed pump (connected to a small pressure vessel) and a mains trickle top-up system. This system also uses a number of filters as the rainwater is being used for all household end uses.

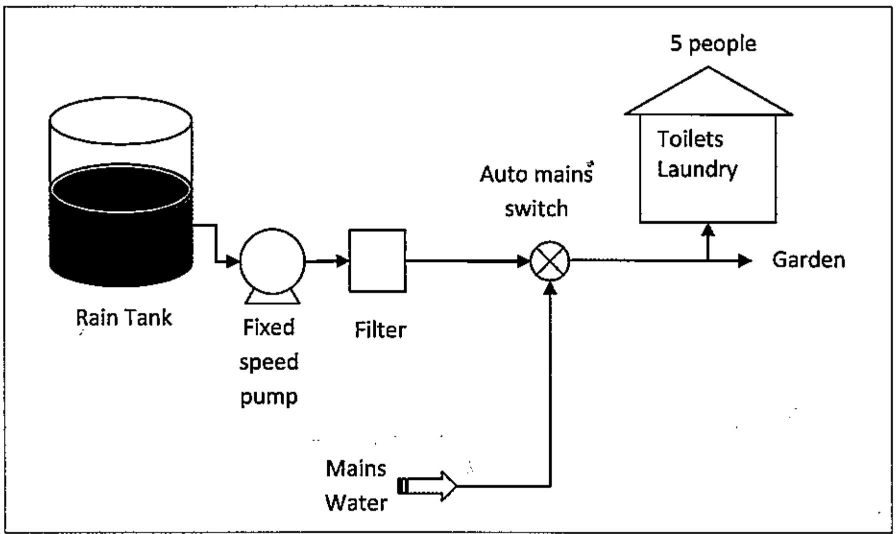

Figure 1. Schematic of a typical household rainwater system using a fixed speed pump with a mains switching valve to supply rainwater to toilets, laundry and garden.

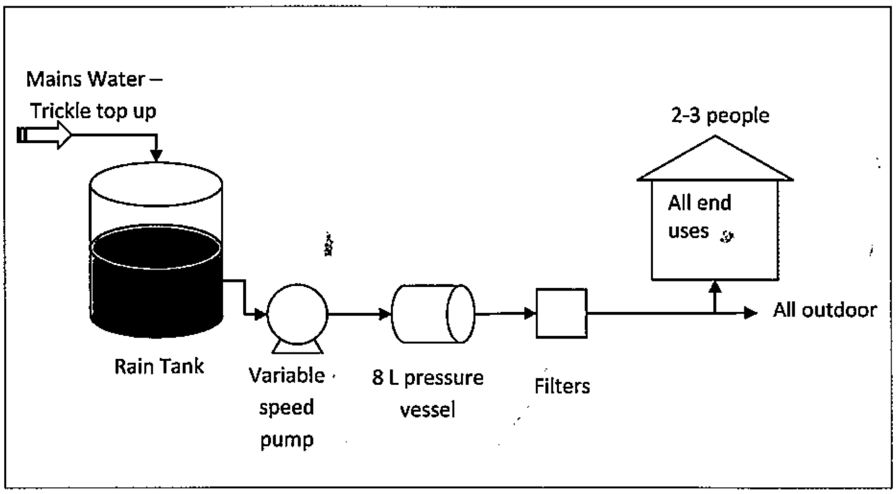

Figure 2. Schematic of a household rainwater system using a variable speed pump, small pressure vessel and trickle top-up to supply rainwater to all household end uses.

At each site, water and energy consumption of the rainwater systems were monitored and simultaneously recorded by a data logger. Rainwater consumption was measured by the use of a Manu-Flo MES-MR flowmeter with a pulse output of 61.5 pulses per litre. The pulse lead from the flowmeter was connected to the combined data logger and energy metering unit developed by Testing Certification Australia (TCA). The data was sampled and recorded at one minute intervals. An antenna attached to the data logger was then used to transmit data via GPRS (General Packet Radio Service) so that it could be downloaded remotely. An example of the metering set-up is shown in Figure 3. Each site was monitored for a minimum period of two weeks and the energy intensity was calculated over the entire monitoring period.

Results

As mentioned previously, the monitored households represented a spectrum of different configurations, household sizes and end uses. The monitoring results for this range of systems varied widely, with energy intensities ranging from 0.9 to 4.9 kWh/kL. These results have been grouped and analysed according to system configuration and rainwater end use in order to characterise some of the factors influencing energy intensity.

Results for households with similar system configurations

Systems using a fixed speed pump and automatic mains switching system

The fixed speed pump and automatic switch to mains appeared to be the most common household rainwater system configuration, following discussions with rainwater system installers (Hockings, B. & Caley, J. 2008). The results from four test sites using this configuration are shown in Figure 4, including daily rainwater consumption, daily energy consumption and energy intensity. Their energy intensities varied from 0.9 kWh/kL at Padstow to 2.3 kWh/kL at Enmore. However, this variance may be largely due to differences in water use, as Padstow represents a 5 person suburban household with inefficient water fixtures and Enmore represents a 1 person inner city household with highly efficient water fittings and appliances. The Padstow household uses more water outdoors which tends to have a higher flow rate compared to other end uses, such as a toilet cistern. As most rainwater pumps are designed to optimally run at high flow rates (i.e 20-30 L/min); a situation where rainwater is predominantly used outdoors would allow the pump to operate more efficiently and result in a lower energy intensity. Rainwater pumps tend to have a relatively flat power curve with regards to flow rate, which means that low flow end uses will use a similar amount of energy to high flow end uses, regardless of the volume of water being delivered.

With a large proportion of outdoor watering the Padstow household will have a low water intensity. In contrast, the household at Enmore uses rainwater primarily for a highly efficient toilet and washing machine, which have low flow rates, thus increasing the energy intensity.

These results show that the types of end uses and the efficiency of water using appliances all factor in the energy intensity of a rainwater system. As can be seen from the graph in Figure 4, energy intensity must be considered in conjunction with total water and energy use as low energy intensity may be due to higher water consumption. The average energy intensity for this configuration from the households considered is approximately 1.5 kWh/kL.

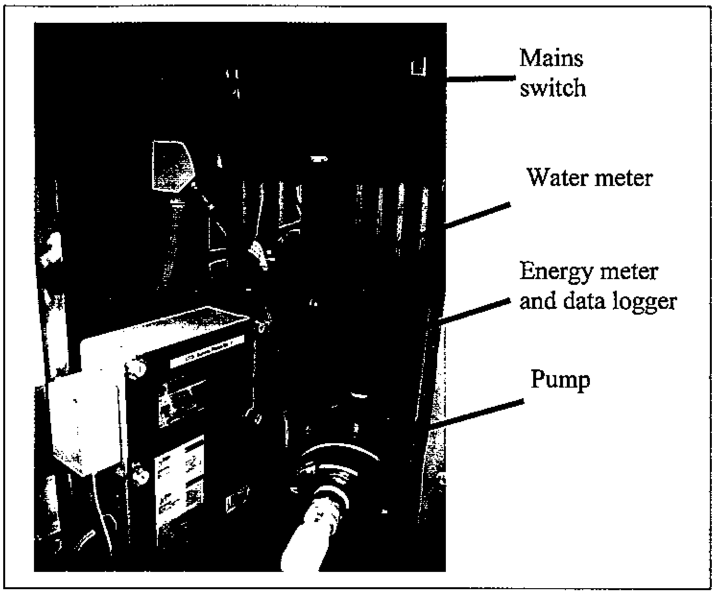

Figure 3. Example metering set up including water meter connected to a combined energy meter and data logger

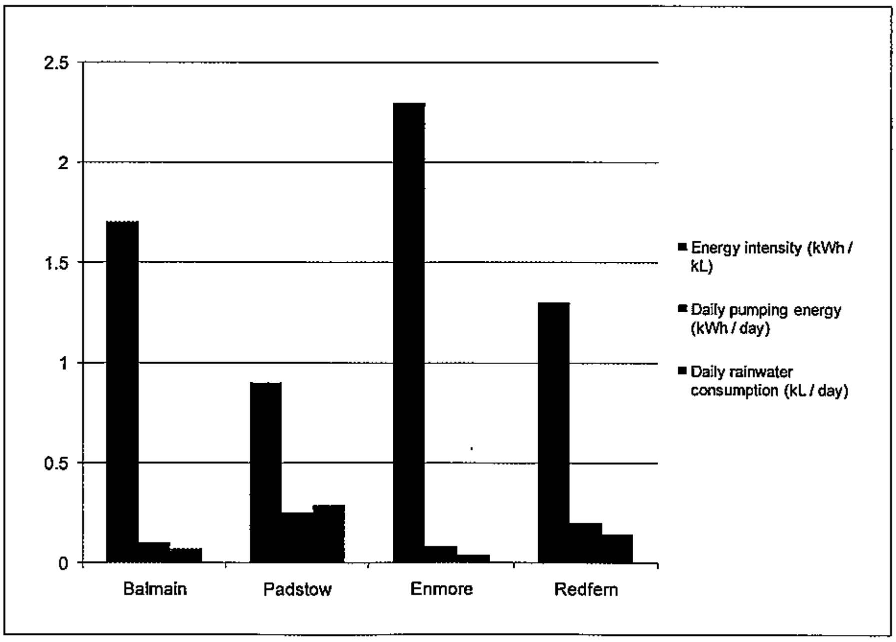

Figure 4. Energy intensity and daily energy and rainwater use for three households and one office using fixed speed pumps and automatic mains switches (for non-potable end uses only).

Systems using variable speed pumps

Two households with very similar configurations were tested in Newcastle and suburban Sydney. Both households used variable speed pumps fitted with a small 8 L pressure vessel to supply rainwater to all household end uses. These systems had energy intensities of 3.0 and 2.9 kWh/kL respectively, as shown in Figure 5.

Theoretically, a variable speed pump should be able to overcome the differences in flow rates required for the spectrum of household end uses (i.e. low flow required for toilet flushing and high flow required for outdoor irrigation) to reduce energy consumption. As, unlike fixed speed pumps, the power used by variable speed pumps varies according to flow rate. However, these tests indicate that the variable speed pumps currently available for household use may not be operating optimally, with energy intensities that are 100% higher than that of the most common system configuration using a fixed speed pump.

The two householders with variable speed pumps advised that their pumps required significant calibration and several visits from the pump manufacturer before they operated satisfactorily. At Newcastle 1, the system initially had an energy intensity of 3.8 kWh/kL as it had been cycling on and off when rainwater was not in use. This was thought to be due to the pump pressure controller being set

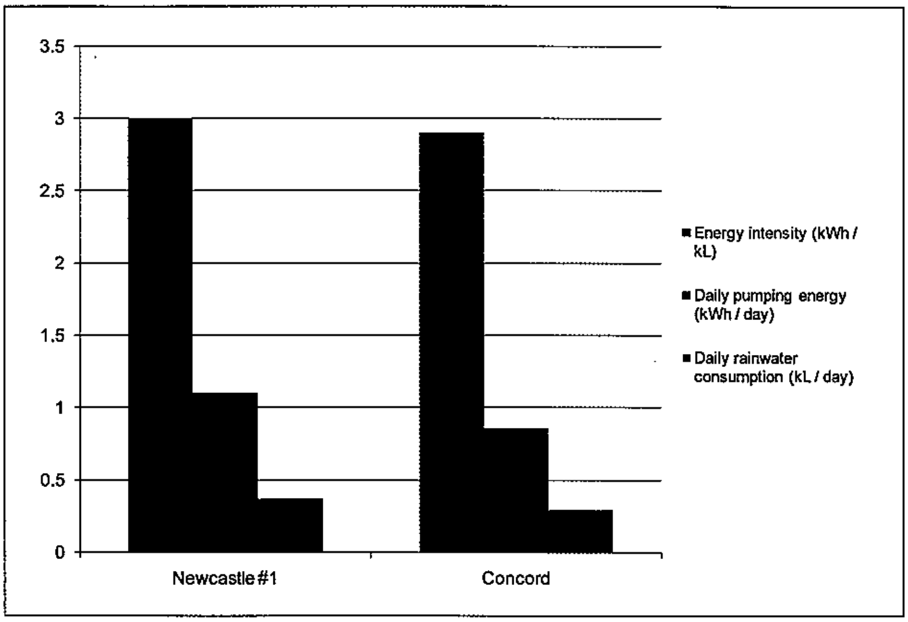

Figure 5. Energy intensity and daily energy and rainwater use for two households using a variable speed pump (rainwater is used for all household end uses).

below its design intention. After the pump manufacturer adjusted the pressure set point and tolerance interval, the energy intensity dropped to 3.0 kWh/kL. Even with adjustments, the energy intensity and total energy consumption of household systems using variable speed pumps was far higher than for households using standard fixed speed pumps. Pumps from different manufacturers may yield different results.

As mentioned previously in the comparison between the systems at Enmore and Padstow, the dominant type of end use affects the energy intensity of a system. This is due to the fact that household rainwater pumps are primarily fixed speed and use the same power regardless of the flow rate. For example, energy is not being used effectively when a pump set to deliver rainwater at a rate of 20 L/min is primarily used to fill a toilet cistern requiring a flow rate of only 5 L/min. In principle, this issue of mismatched flow rates would be remedied by the use of a variable speed pump. However, the results at these two households appear to indicate that there is significant opportunity for improvement in the design of variable speed pumps for household applications.

Systems with and without pressure vessels

At two of the monitored households in inner city Sydney it was possible to add and remove pressure vessels in order to examine the difference in performance. The existing system at the house in Newtown had an unusual configuration in that it used a venturi jet pump (fixed speed) to supply rainwater to the whole house. The venturi pump was used to draw water from a rainwater storage bladder located under the house. The unusual pump used a lot of energy in standby, and this combined with very low water usage resulted in a very high energy intensity of 4.9 kWh/kL. When the pressure vessel was introduced, the energy intensity dropped to 3.4 kWh/kL, with water consumption remaining roughly the same. That is, the energy intensity appeared to drop by approximately a third with the introduction of the pressure vessel.

The system at Enmore used a pressure vessel in addition to the standard configuration of a fixed speed pump and automatic switching system, which resulted in an energy intensity of 1.6 kWh/kL. When the pressure vessel was removed, the energy intensity increased to 2.3 kWh/kL; similarly indicating that the energy intensity reduced by approximately a third with the inclusion of a pressure vessel. As mentioned previously, the house at Enmore used rainwater primarily for low flow end uses, such as an efficient toilet and washing machine. It appears that the pressure vessel effectively reduced pump cycling for these low flow end uses and reduced both energy intensity and total energy use.

A study on the energy intensity of rainwater systems at Silva Park (Beal *et al.* 2008) noted that the number of pump start-ups were a significant factor in increasing energy intensity. This would imply a higher peak in energy consumption at the beginning of each end use event. Such peaking in energy use was not observed for any of the households in this study; however, this issue may warrant further investigation.

The energy intensities, daily water and daily energy consumption of these

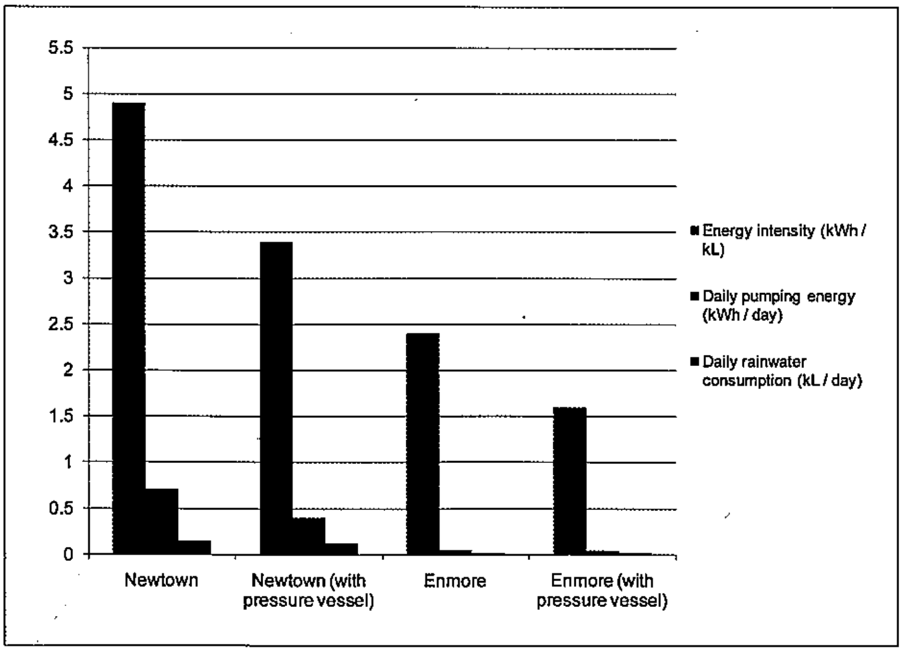

Figure 6. Energy intensity and daily energy and rainwater use for two households with and without a pressure vessel (for all end uses at Newtown and for toilets, laundry and outdoors at Enmore).

rainwater systems both with and without a pressure vessel are shown in Figure 6.

At another household (Newcastle 2), a 24 L pressure vessel was added to the existing system which included a fixed speed pump and trickle top up system. However, the pressure settings of the pump and the pressure vessel were not matched and consequently the user experienced significant variation in water pressure, which became particularly evident during showering. This was an unacceptable loss of service and the pressure vessel had to be removed. This incident highlighted the difficulty in retrofitting a pressure vessel to an existing system. Many householders would not be aware of the need to buy a pressure vessel that matches the pressure settings on their pump. The coupling of pumps and pressure vessels by manufacturers may be useful if pressure vessels are to be used to their full potential.

The results from these tests indicate that pressure vessels may be effectively used to reduce the energy consumption of rainwater systems. However, if the pressure vessel is not matched to the pump, then there may be a reduction in the level of service.

Table 2. Water use characteristics and energy intensities for three households with similar rainwater system configurations and end uses.

House	Balmain	Padstow	Enmore
Characteristics of water use (data observations)	Mix of long and short duration events, mostly low flow	Longer duration, high flow events	Short duration, low flow events
Outdoor use	Garden watering	Significant garden watering	Almost no garden watering
Energy Intensity (kWh/kL)	1.7	0.9	2.3*
Rainwater use per person (L/person/day)	18	57	31
Pump power (Watts)	890	890	890

**Note: this energy intensity resulted from a test without a pressure vessel*

Results for households using rainwater for the same end uses

Results for systems using rainwater for toilet, laundry and outdoor

Three of the households that were monitored used rainwater for the toilet, laundry and outdoors. These households also share the same system configuration with fixed speed pumps and automatic mains switching devices and are therefore readily comparable. The results from these households are set out in Table 2 along with some observations from the data.

Two of these households (Balmain and Enmore) are located in the inner city with small gardens and highly efficient appliances. The house at Padstow differs from the other two as it has a larger garden, a less efficient toilet and washing machine, and consumes more water. The water usage data at Padstow also reveals more high flow, long duration end use events which are an indication of garden watering or other outdoor water use. The presence of more high flow rate end use events appears to have reduced the overall energy intensity for the rainwater system at Padstow.

On the other hand, the dominance of short duration, low flow end use events at Enmore has driven up the energy intensity, as rainwater is primarily being used for efficient toilet flushing and an efficient washing machine.

These observations suggest that the flow rate required by end uses could be more effectively matched to the design pump flow rate in order to improve energy efficiency.

The results shown in Table 2 have been plotted along with energy use per person in Figure 7. Daily pumping energy use per person and water use per person correspond to the left hand axis, while energy intensity corresponds to the right hand axis.

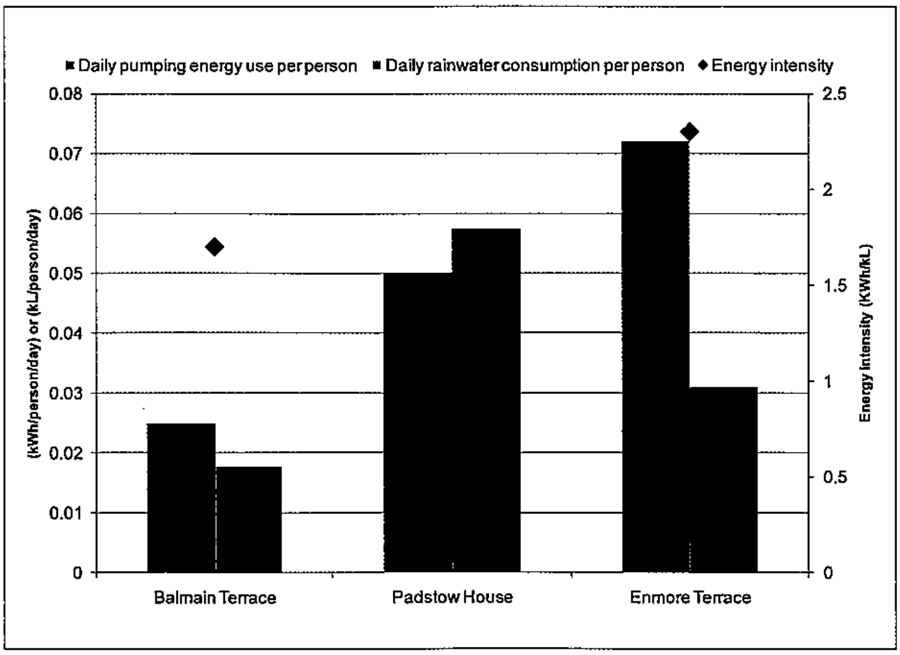

Figure 7. Energy intensity, daily energy use per person and daily rainwater use per person for three households using rainwater for the same end uses.

This graph illustrates a few things. The results for Padstow show that low energy intensity is not always an indicator of low energy use. Water efficiency is still an important factor in reducing energy consumption as can be inferred from the results for Balmain and Padstow. The results for Enmore highlight the inefficiency of using a high flow pump for primarily low flow end uses.

Conclusions

The energy intensity of a household rainwater system is affected by the types of end uses and the efficiency of water use within the household as well as the system configuration. A typical household rainwater system supplying rainwater to the laundry, toilet and garden appears to have an average energy intensity of approximately 1.5 kWh/kL. The range of energy intensities recorded, however, indicate that there may be many variations on system types which use a lot more energy per kilolitre.

More research is required to define the elements of an energy efficient rainwater system configuration. Once these elements are understood, the next steps might be to develop standards and guidelines for system design and installation to ensure that the energy efficiency of new systems is optimised. This may include advice on choosing a pump that matches the most likely end uses to improve efficiency. It may also include a shift in the industry towards more efficient pumps and where possible the use of gravity systems, including header tanks and gutter storages which can be integrated within household upper walls at the construction stage.

Results from this preliminary monitoring study indicate that pressure vessels could be used to reduce the energy consumption of rainwater systems. Further technical development of variable speed pumps at the household scale may also lead to improved energy efficiency together with the matching of end uses to pump flow rates. Alternatively, low flow pumps dedicated to low flow end uses may be a good option for some households. Aside from the systems themselves, efficient water use has also emerged as an important means of reducing overall energy consumption.

All except one of the household rainwater systems that were monitored had higher energy intensities than mains water supply. The current mains water supply in Sydney has an energy intensity of approximately 1 kWh/kL (Kenway *et al.* 2008), and this is set to rise when the desalination plant comes online. With the energy intensity of our water supplies rising, it is vitally important that energy efficiency is maximised in emerging water systems such as those being installed at the estate and household scales. Distributed systems have enormous potential to aid the water industry in diversifying water supply and potentially increasing the resilience of the system. However, these systems must be monitored and evaluated, so that where possible, design modifications can be made and guidelines set to ensure that the trade-off between water and energy use is optimised.

ANOTHER STUDY: SIMILAR RESULTS

Julian Shortt, Water Conservation Group

As noted in E-News, South East Water Ltd and Water Conservation Group have also studied the energy consumption of residential rainwater systems in South East Melbourne. The study included 31 residences, 11 of which were equipped to have both rainwater and energy consumption monitored every minute, while 20 of the residences were equipped to have the rainwater supply monitored every minute and the total energy recorded over the entire monitoring period. The monitoring period was for at least 3 months.

The results obtained indicate an average specific energy of 3.12kWh/kL and a median specific energy of 1.98kWh/kL. Both these figures compare unfavourably with traditional water treatment and distribution methods (particularly for Melbourne, at 0.14kWh/kL), but are still well below desalination needs (3.6kWh/kL);

A key parameter which the study found to cause energy inefficiency was pump sizing. because pumps are generally oversized for the intended end use. While this effect minimised the effect of other parameters, the results also suggested that the end use of rainwater and the system configuration have an effect on energy efficiency. The significance of these effects warrants further investigation.

In accordance with this conclusion, the study recommends that pumps used in rainwater systems should be correctly sized for the flow rates they will typically be delivering, and that pump manufacturers should optimise their systems for typical rainwater applications which use small amounts of water, such as toilet flushing.

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