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Water consumption characteristics at a sustainable residential development with rainwater-sourced hot water supply

Pei Ru Chao [a,*], Shivanita Umapathi [b], Wasim Saman [a]

[a] *Barbara Hardy Institute, University of South Australia, Australia*
[b] *SA Water Centre for Water Management and Reuse, School of Natural and Built Environments, University of South Australia, Mawson Lakes, SA 5095, Australia*

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ABSTRACT

The use of water-efficient appliances and inclusion of alternative water sources in urban residential developments is becoming increasingly necessary to meet the growing demands on conventional urban water supplies. As an initiative commissioned by the South Australian State Government in 2009, Lochiel Park is a recent model designed to embrace sustainable planning principles and technologies in a domestic context. An extensive post-occupancy monitoring program of actual residential water and energy usage was conducted. The study aimed at analysing and quantifying the water consumption at 59 houses through real-time monitored data collected over 3 years between 2010 and 2013, incorporating the monitored usage of mains water, collected rainwater and hot water usage. The analysis shows that the annual average total water consumption per household at Lochiel Park is significantly lower than both the Adelaide and national averages by about 24% and 16% respectively, while average mains water consumption is lower by 36% and 29% respectively. Rainwater contributes 6–10% of the total water use in summer and up to 26% in winter, with an average annual contribution of around 14%. A significant part of the saving is attributed to the increased minimum rainwater tank capacity from the 1 kL specified in the Building Code of Australia to 1.5 kL, and feeding rainwater into the hot water supply in a climate where rainfall occurs in winter. Although a reduced hot water demand is also prompted by having efficient fixtures and rainwater supply depends on climate, rainwater fed into hot water supply saves 40% of hot water consumption annually. Greater rainwater utilization in hot water is possible if rainwater tank sizing and a greater roof catchment area can match household winter hot water demand, rather than having a single minimum requirement across all households as in the current regulation. The study provides an understanding of the performance of alternative urban water systems. The outcomes verify the effectiveness of the Water Sensitive Urban Design (WSUD) features implemented and will be useful for future strategic planning and design initiatives for implementation of similar developments on a larger scale.

1. Introduction

In order to address the future of water security in urban environments, a combination of various adaptive approaches will be necessary to integrate with existing water infrastructure (Fielding et al., 2013; de Loë et al., 2001). Frequent drought conditions and increasing water demands arising from various factors such as rapid urbanisation, changing landscapes and changing weather patterns have triggered major Australian cities to invest heavily in harvesting and management of alternative water sources such as rainwater, stormwater and wastewater (Imteaz et al., 2012). Previously, emerging water scarcity has prompted direct government interventions in dealing with the water crises (Talebpour et al., 2014). In recent years the concept of sustainable homes with reduced water demands and low energy impact has gained popularity in Australia and worldwide (Harrington et al., 2008; Pearce et al., 2014). Individual water users, such as homeowners, are playing a significant role by changing their water-use behaviour and installing water-efficient appliances to reduce individual consumption (NWC, 2012b; Fielding et al., 2012; Willis et al., 2010). Water demand management through adoption of water

* Corresponding author. University of South Australia, Mawson Lakes Campus, Australia. Tel.: +61 424411092.
E-mail addresses: simplica1@hotmail.com, peiru.chao@sa.gov.au (P.R. Chao).

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conservation practices by residents is essential for sustainable management of potable mains water in urban environments (Brooks, 2006). As decentralized systems based on Water Sensitive Urban Design (WSUD) principles increase, alternative urban water supply systems are likely to impact on the water supply dynamics of mains water supply networks in greenfield urban developments (Sharma et al., 2013). Detailed research into these systems is necessary to assess their long term economic and environmental sustainability.

Over the past decade, several research methodologies were adopted to analyse and estimate the performance characteristics of domestic rainwater harvesting systems, specifically those comprising rainwater tanks both in Australia (Coombes and Kuczera, 2003; Loh and Coghlan, 2003; Beal et al., 2011; Chong et al., 2011; Willis et al., 2011) and worldwide including Sweden (Villareal and Dixon, 2005), Brazil (Ghisi et al., 2007; Ghisi, 2006), and India (Mukherjee et al., 2010). Household rainwater consumption has also been analysed on a 'fit-for-purpose' basis to optimise design of rainwater collection systems using water demand patterns and rainwater catchment areas (Fewkes, 1999). In recent years, research into household water consumption is increasingly being conducted by disaggregation of water flows in order to conduct end-use studies through incorporation of smart water and energy meters (Heinrich, 2008; Talebpour et al., 2011), a method that was first adopted by Mayer et al. (1999) to study the residential end-uses of water in households spread across North America. Previous studies (Ferguson, 2012; Umapathi et al., 2013) have highlighted the use of smart metering methods to collect real-time water use data for water supply from multiple sources within a household in small time steps ($t \leq 1$ min) to conduct end-use analyses of rainwater collected in domestic rainwater harvesting systems, hence determining their corresponding savings in centrally supplied mains water. Smart metering techniques can be regarded as a reliable and accurate means by which to monitor and assess the water consumption characteristics in new and upcoming ecologically sustainable developments with alternative water supply in terms of various dependant factors including socio-demographic, hydrological, climatic and environmental.

Extensive detailed research has been conducted using aforementioned metered monitoring methods in Queensland (Beal et al., 2012; Umapathi et al., 2013) and Sydney (Ferguson, 2012) regions. The studies were based on new homes built independently following the respective state water efficiency rules designed for new homes (QDC, 2008; BASIX, 2004). In estate developments such as Currumbin (Diaper et al., 2007; Hood et al., 2010) and Silva Park Estate (also known as Payne Road development) (Gardner et al., 2006; Beal et al., 2008) in south east Queensland, the household samples are located in the same suburb with the same climatic conditions, rainfall, water quality, infrastructure and common house design guidelines which altogether allow for a more homogeneous sample set. Similarly, Lochiel Park is an estate/suburban development with detailed monitoring conducted in individual houses segregating various types of water supply and the usage at 5-second intervals. The considerable monitoring time of 3 years (and on-going until 2019) provides sufficient data for reliable statistical analysis for observing consumption trends. While in many other cases rainwater feeds the non-potable water uses such as toilets, laundries and irrigation, rainwater collected at Lochiel Park feeds the solar hot water system and is used as a potable water source. This has been permitted by the South Australian appendix of the Building Code of Australia (ABCB, 2012). In addition to the individual household rainwater tanks, Lochiel Park includes a communal stormwater recycling facility to feed the non-potable water uses. However since the stormwater recycling facility is still under construction, the recycled stormwater data is excluded from the analysis presented in this paper. The analysis is based on available data of total mains water, hot water, mains hot water (top-up wherever rainwater is low) and calculated rainwater data. In this paper the research questions are:

- What are the trends of average total, mains, rainwater and hot water consumption per household and per capita in such an eco-development in a dry climate?
- How effective are the WSUD features implemented on the whole in terms of water efficiency?
- What percentage of mains and hot water supply can be expected to be replaced by the utilization of collected rainwater per household, with rainwater being plumbed into a hot water tank?
- What implications would the results have in terms of future development?

A comparison of the per-capita water consumption as well as overall household water consumption in Lochiel Park with the greater Adelaide area, the Australian and other international averages was conducted to allow the evaluation of the development in meeting its broader sustainability goals.

2. Background of the case study

Adelaide city is known for its hot, dry summers and cool, wet winters, with few inland water sources and perennial streams. The majority of these streams rarely reach the sea due to the dry climate (Daniels, 2010; Rutherfurd and Finlayson, 2011). Due to a decade-long drought from the year 2000, water-saving strategies were introduced by State and Local Governments. Nationally, an average reduction of 21% between 2004 and 2009 was observed (Rutherfurd and Finlayson, 2011). In South Australia, a reduction of 34% of daily water consumption per household was achieved between 2000 and 2010 (ABS, 2011a). This reduction occurred without sacrificing the standard of living, suggesting a significant elasticity of domestic water usage levels. Much of this reduction was due to the State promotions of restricting outdoor water uses through Stage 2 Water Restrictions (pre-2003), Permanent Water Conservation Measures (2003), and Stage 3 Water Restrictions (2007). Stage 3 was eventually replaced by the less severe Water Wise Measures in December 2010 (Maier et al., 2013; Arbon et al., 2014).

In response to the need for more environmentally sustainable living and the limited natural freshwater supply in South Australia, Lochiel Park project was commissioned in 2009 with an aim of promoting sustainable urban development. The project was intended to be a living laboratory that followed stringent urban and building design principles focusing on energy and water-efficiency. The project is located on 15 ha of protected natural land located along the Torrens River. The majority of the lot sizes range between 200 and 400 m^2, considerably smaller than the current average lot size of 425 m^2 in Adelaide (ABS, 2010). The houses are required to meet specifically developed design guidelines to achieve an energy performance of 7.5 stars, well above the then 5 star energy rating stipulated by the Building Code of Australia. Upon completion, the residential part of the project will consist of 106 dwellings covering just 28% of the site, suggesting the focus of an 'urban forest'. The small residential area allows a part of the site to be used for a natural water filtration process of stormwater storage and recycling via an aquifer storage and recovery system, to produce non-potable water supply to the houses.

Water-saving guidelines were designed to reduce potable water demand at Lochiel Park (Blaess et al., 2006; LMC, 2009). The approach exceeds the minimum standard stipulated by the