UNDERSTANDING AND MANAGING WATER-RELATED ENERGY USE IN AUSTRALIAN HOUSEHOLDS

Preliminary results of a research project being carried out by The University of Queensland and the Smart Water Fund

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ABSTRACT

Water- and energy-efficient households are a necessary element of sustainable cities. Water-related energy usage in households is a point of overlap where water and energy utilities could work together. Improving the combined efficiency of water and energy management requires a better understanding of the inter-relationships between these systems and associated water and energy use. It also requires collaboration with householders.

In order to progress understanding of water-energy links within households, a research project has commenced with the Smart Water Fund and The University of Queensland. With funding support from the Australian Research Council, the research focuses on elucidating and quantifying water-carbon-energy links in individual households in Melbourne, as well as collective groups of households in a district. The work is a new initiative for Australian water utilities, in that it looks in detail at how water industry actions and policies influence energy use in private households. In this way, the work goes beyond the boundary of traditional water utility energy use analysis, which typically assesses the energy implications directly connected with the utilities themselves, such as the energy demands of the water and wastewater infrastructure and assets. The project runs between 2013 and 2016. This paper presents the background and objectives of the work, including preliminary results.

BACKGROUND: THE WATER-ENERGY CHALLENGE FOR AUSTRALIA

The growing energy demand for water and wastewater services provision in Australian cities poses a large management challenge: by 2030, energy consumption is expected to grow to 200–250% of 2007 levels (Kenway *et al.*, 2008b; Kenway *et al.*, 2014 (In press, accepted 12 November 2013); Kenway *et al.*, 2008a).

If the water sector is to adopt the Australian Government target to reduce greenhouse gas (GHG) emissions to 80% below 2000 levels by 2050 (Australian Government Department of Climate Change and Energy Efficiency, 2012), then the equivalent of over 90% of the projected 2030 energy consumption levels needs to be cut, or the GHG intensity of the energy used similarly reduced, or offsets paid (Kenway, 2013). The total energy bill paid by water utilities is anticipated to rise even faster. Because energy costs are rising, the energy expenditure of Australian water utilities is anticipated to grow to 300–500% of 2007 levels by 2030 (Cook *et al.*, 2012). This represents a significant business risk to both the water sector and to communities relying on energy-intensive water services (Victorian Water Industry Association, 2011).

Water-related energy use in Australian cities is significant, accounting for some 13% of Australia's electricity use and 18% of Australia's natural gas use (Kenway *et al.*, 2011). Urban water management directly and indirectly influences over 8% of Australia's GHG emissions. The direct energy used by water utilities, while significant, is only approximately 10% of total urban water-related energy use. In comparison, residential water use is responsible for more than four times the water-related energy consumption. Therefore, there is a substantial indirect or "hidden" impact of water-related energy usage on the urban environment. In part, the effect is difficult to observe, because the influence of each individual household is small, compared to industrial or commercial sites. However, collectively, the effect of many households in cities is very large.

Water end-use research has enabled utilities to refine their conservation messages, informing utilities and customers where to target change. Industry has responded through innovation to improve appliance efficiencies. High uptake of water-efficient measures such as low-flow shower nozzles, dual-flush toilets and front-loader clothes-washers has achieved considerable water savings for both utilities and customers. However, recent research has shown that some efficiency measures can result in unintended outcomes.

For example, Kenway et *al.* (2013) show that changing from a top-loading washing machine (plumbed to gas-heated hot water) to a water-efficient front-loading machine (plumbed to cold water only, with internal electric heating) can double GHG emissions from the clothes-washer. This can happen if plumbing configurations force a change in the heating energy from hot water systems to electricity (supplied from coal-fired plants) within the clothes-washer.

The electricity sector also faces many related challenges. Electricity prices have doubled between 2005 and 2013, significantly impacting users. Capital expenditure to meet peak demand accounts for some 45% of total network costs; however, severe peak demand only occurs for a few hours on a few days per year. Ergon Energy estimates that around six per cent of its multi-billion dollar network is used for less than nine hours a year. The Productivity Commission (Productivity Commission, 2013) has

Table 1. Summary of preliminary results from the seven households evaluated.

Parameter	Units	HH1	HH2	HH3	HH4	HH5	HH6	HH7
Location[a]	–	Melb	Melb	Melb	Melb	Melb	Bris	Bris
Analysis Period	Start	Apr–12	Apr–12	Apr–12	Apr–12	Apr–12	Oct–11	Jan–07
	End	Mar–13	Mar–13	Mar–13	Mar–13	Mar–13	Sep–12	Dec–09
Occupancy	(Adult/Child)	4/0	4/0	2/2	2/2	2/0	4/0	2/2
Hot Water System[b]	–	SGI	SGI	GS	GS	GI	ES	GS
Average Cold Water Temperature	°C	16.7	16.9	16.3	15.6	16.9	21.3	21.3
Water Use, Total	L/hh.d	730	860	410	650	175	460	465
Water Use, Shower	L/hh.d	360	490	130	165	100	240	150
Electricity Use, Total	kWh/hh.d	10	15	10	10	10	30	10
Natural Gas Use, Total	kWh/hh.d	90	20	30	50	20	Nil	10
Solar Energy Use, Total	kWh/hh.d	10	15	Nil	Nil	Nil	Nil	Nil
Energy Use, Total	kWh/hh.d	110	50	40	60	30	30	20
Water-Related Energy Use, Total[c]	kWh/hh.d	15	20	10	10	5	10	10
	% of total	15%	40%	25%	15%	20%	30%	50%
	kWh/p.d	3.75	5	2.5	2.5	2.5	2.5	2.5

[a] Melb – Melbourne Australia, Bris – Brisbane, Australia, [b] SGI – Solar with Gas Instantaneous Booster, GS – Gas Storage, GI – Gas Instantaneous, ES – Electric Storage, GS – Gas Storage. [c] Includes the solar component of water-related energy use; Source: (Binks et al., 2014 (in press, accepted 25 October 2013)).

highlighted that asset utilisation has been falling in the electricity sector and this trend must be changed.

A PROJECT TO UNDERSTAND WATER-ENERGY INTERCONNECTIONS

In order to help utilities reduce water-related energy in households, this project aims to shed light on the "black box" of households and develop detailed knowledge of the influence of all factors on water-related energy in homes, including policy, technology and behaviour. Research objectives include:

- Understanding the connections between water and energy usage in individual households (Objective 1);
- Understanding city-scale water-related energy and GHG emissions in the residential sector, including characterisation of "household types" (Objectives 2 and 3); and
- Identifying opportunities to reduce water-related energy consumption (Objective 4).

CHARACTERISATION OF INDIVIDUAL HOUSEHOLDS (OBJECTIVE 1)

Seven households (HH1–HH7) were surveyed in detail, including behavioural interviews with householders and technical audits of fittings, fixtures and appliances within the households and diverse literature review (Binks et *al.*, 2014 (in press, accepted 25 October 2013)).

Long-term billing records for water, energy and natural gas use were assembled. Amphiro shower energy and flow meters were also installed to collect data on frequency, duration, temperature and flow rate of shower events due to their substantial impact on water and energy usage.

This information was used to generate probability distribution functions for 139 water and energy use input parameters for a Mathematical Material Flow Analysis (MMFA) model. Preliminary results indicate that water-related energy usage ranges from 5–20 kWh/hh.d (kilowatt hour per household per day). This accounts for 15–50% of total household energy use; or 2.5–5.0 kWh/person.d in the households studied (Table 1). For perspective, 37 eleven-watt light bulbs will consume 407 watt hours (per hour), or approximately 10 kWh/d of electrical energy.

One aim of Objective 1 is to identify factors (input parameters) that have the greatest impact on water-related energy use. Local sensitivity analysis on these parameters (changing individual parameters) helps identify factors with the greatest influence on water-related energy usage within the existing "system". Through this analysis, the following parameters have been identified as having substantial impact on household water-related energy use (see also Table 2): (i) the temperature of cold water entering the house, (ii) the number of adults, (iii) the temperature of the hot water system, and (iv) the temperature, duration and frequency of showering. Wider scenario analysis, which involves changing more than individual parameters and considering system reconfiguration (for example, plumbing solar hot water systems to provide all end uses including clothes-washer and dishwasher warm water needs), is a follow-on task.

Small changes to water management can have a surprisingly large impact on energy use for the consumer as well as for water and wastewater treatment and transport. For example, in HH4 and HH5 a 10% reduction in the frequency, duration or flow-rate of water for showers would reduce household energy use by approximately 0.3 kWh/hh.d. The temperature of cold water has a particularly significant impact: a 10% change (~ 2°C), influences 0.3-0.7 kWh/hh.d of household energy use. Consequently, accurate characterisation of cold-water temperature is an important factor in quantifying water-related energy consumption.

For the five Melbourne households studied, reducing one kWh/hh.d use over an entire year would reduce household costs by $70–$125 for electricity or $16–$30 for natural gas.

Table 2. Summary of preliminary key local sensitivities influencing water-related energy in households 3, 4, and 5*.

Six most influential parameters on water-related energy consumption	Impact of a 10% change in the parameter on water-related energy consumption (kWh/hh.d)
Household Three	
• Decreasing the temperature of cold water	0.63
• Increasing the temperature of hot water at hot water system	0.40
• Increasing the number of adults per household	0.39
• Increasing the temperature of baths for child	0.36
• Increasing the number of children per household	0.25
• Increasing the temperature of showers for child	0.23
Household Four	
• Decreasing the temperature of cold water	0.58
• Increasing the number of adults per household	0.58
• Increasing the temperature of showers for adults	0.53
• Increasing the flow rate per shower for adults	0.33
• Increasing the flow duration per shower for adults	0.33
• Increasing the number of showers per adult per day	0.33
• Increasing the temperature of baths for children	0.31
Household Five	
• Increasing the temperature of showers for adults	0.52
• Increasing the number of adults per household	0.36
• Decreasing the temperature of cold water	0.29
• Increasing the number of showers per adult per day	0.31
• Increasing the flow rate per shower for adults	0.31
• Increasing the flow duration per shower for adults	0.31

Analysis for HH1 and HH2 is currently being finalised.

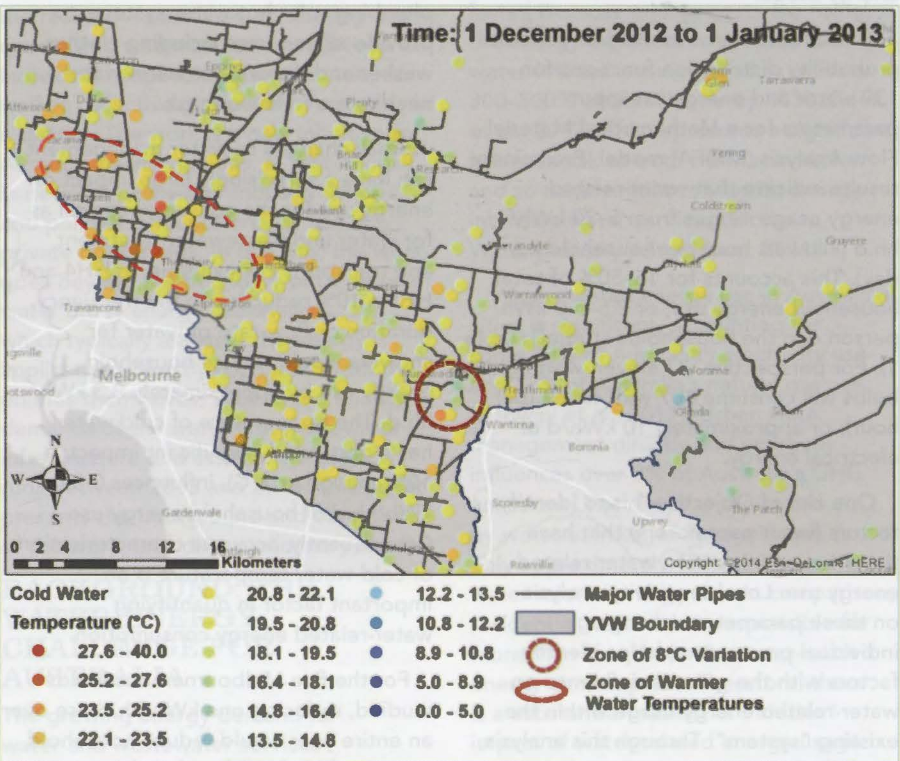

Figure 1. Spatial variability in cold-water temperature for part of the Melbourne water network in December 2012.

CITY-SCALE ANALYSIS OF WATER-RELATED ENERGY (OBJECTIVES 2 AND 3)

Robust city-scale simulation of water-related energy requires consideration of a wide range of information, including data on:

a. Household occupancy (e.g. the number of occupants including visitors and absences);

b. Physical environment (e.g. the water temperature entering the house and the ambient air temperature);

c. Plumbing configuration (e.g. does the washing machine have both hot and cold intakes and does it draw energy from the hot water system or heat water internally?);

d. Hot water system type and fuel type;

e. Associated GHG emission intensities;

f. Water-using technologies and fittings;

g. Occupant behaviour.

Guided by the detailed modelling of individual households (Objective 1), the project is systematically compiling spatial data on key influential parameters so that a large grouping of households (a district) can be collectively simulated and understood. For example, preliminary analysis of water temperature (42,900 data points spanning the month of December 2012) in the Melbourne water network has been used as an input to the MMFA modelling (Bors and Kenway, 2014). This modelling indicates significant temporal and spatial variability: temperature can vary as much as 8°C (from 15°C to 23°C) within 3 km (Figure 1). Such variability could influence 2–4 kWh/hh.d energy use considering HH3 and HH4 (Table 2). A zone of warmer water north of central Melbourne was observed in the water temperature data sampled within the Yarra Valley water distribution area over this time period. The cause of this warm water zone is not yet known.

Finally, measured water temperature values indicate that the AS/NZS 4234:2008 *'Heated Water Systems – Calculation of Energy Consumption'* (AS/NZS 2008), can be improved. Preliminary analysis suggests measured water temperature values were up to 5°C warmer than the Standard. Measured values averaged 2.5°C warmer than the Standard through 2012–13.

In addition to supporting improved analysis of water-related energy, knowledge of cold-water temperature could be beneficial for management of delivered water quality and performance analysis of hot water systems. Cold water temperature can be influenced by many factors, including: (i) environmental factors such as air temperature; (ii) water system factors such as the temperature of source water, or pipe infrastructure characteristics such as depth of pipe cover. Water temperature records can also be affected by (iii) sample program design such as the time and location of measurements. Finally, water temperature can be influenced by (iv) the method of sample collection. For example, changes in the amount of water being flushed through above-ground pipes, prior to temperature measurement, can influence the result.

Understanding how such factors contribute to water-related energy in a city is a substantial challenge. Importantly, in addition to providing necessary input to the MMFA, cold-water temperature has demonstrated that estimating water-related energy is a very complicated problem. The effect of just one variable (cold water) is large, complex, and dynamic.

OPPORTUNITIES TO REDUCE WATER-RELATED ENERGY (OBJECTIVE 4)

The research aims to evaluate the impact of a range of scenarios on water-related energy usage, such as:

- Increased uptake of high-efficiency appliances and fixtures (e.g. new washing-machine and dishwasher models);
- Introduction of emerging technologies, such as recirculating showers that rapidly treat and recirculate warm water, resulting in energy and water savings;
- Changes to plumbing configurations (e.g. hot and cold water intake to appliances from hot water systems connected to solar hot water systems and/or heat pumps, thereby maximising the use of low cost and carbon renewable energy sources);
- Changes to incentives, information availability and anticipated costs, which shift end-use patterns (e.g. installation of energy flow meters on water end uses using substantial energy such as showers);
- Altered behaviours including selection of 'ecofriendly' cycles on washing machines and dishwashers and/or setting hot water system thermostats at cooler temperatures;
- Combinations of technological, behavioural and cost changes.

Scenarios will initially be considered for individual HHs to determine their potential impact in diverse conditions. Ultimately, scenarios will be evaluated at the city scale, such as:

- New building stock including an increased proportion of high-density apartments;
- Opportunities to influence the cold-water temperature in the network through pipe-laying design criteria;
- District heating systems that capture waste heat from energy generation and provide centralised hot water services to communities.

ANTICIPATED OUTCOMES FROM THE PROJECT

The work will help understand how changes in technology, infrastructure, and behaviour influence HH water-related energy use, associated costs and GHG emissions. This will have a broad range of implications and policy uptake points for Water and Energy Utilities, State and Federal Government and individual households.

For Utilities: An overview of the research aims to inform policy, which is directed at improving efficiency within utilities, are as summarised in Table 3.

Increased dialogue between the water and energy sectors could ultimately lead to improved collaborative planning, improved asset utilisation, aligning of refurbishment and maintenance planning,

Table 3. Summary of potential outcomes for utilities and preliminary examples from the work to date.

Description	Example of desired outcome for utilities
Identify options that have <u>greatest influence on water-related energy</u> (and GHG emissions) to enable effective policy.	The research will quantify the potential for water management to reduce household energy use. This would help reduce the potential for unexpected outcomes such as water conservation strategies leading to increased GHG emissions. By quantifying a range of household conditions it will be possible to understand how "average" versus "tailored" policy will impact on different households. Quantification of energy impacts of water will also enable utility energy-management strategies (e.g. on a $/kWh basis) to be compared to options that mitigate household energy use. This would enable least-cost options to be identified considering alternatives within and beyond utility boundaries. This information is perceived as critical to the business case for utilities to continue to invest in water conservation. While this project is focused on understanding residential households, the work also provides insight into the influence of water on energy use in commercial and industrial premises. For example, for some customers who may want either cooler or warmer water, provision of these specifications via the water asset could be beneficial.
Reduce cost and <u>improve efficiency</u> of service delivery leading to increased overall industry productivity.	Insight into different asset design and management practices could achieve different energy outcomes. For example, variation in the temperature of water delivered in Melbourne now is influencing household energy costs differently in different regions. It is possible that design and management of water infrastructure differently could impact household energy costs. The research already provides substantive data to understand heat transfers in the water system which could also impact on wastewater temperatures. Industry is already considering a number of heat-exchange and recovery options including precinct hot water delivery. Understanding temperature in the water network will further enhance these options. Quantifying the overall energy impact of water, is a starting point for quantifying dynamic influences such as water impacts on peak electricity use. While many water utilities already adjust water pumping and storage to reduce utility costs (e.g. overnight or off-peak pumping) little consideration is currently given to how utility policy impacts household water use, and resultant flows of water, wastewater, and related peak electricity consumption.

leading to higher efficiency across both sectors. This would be a big step towards integrated infrastructure planning. In the longer term it is possible that cross-sectoral targets could be developed. For example, this could include targets for total water-related energy, or targets for the proportion of water/wastewater energy use within peak electricity demand periods. Elsewhere, for example in Oakland, California, water and energy utilities are combining to provide integrated reporting and invoicing to households across water and energy performance. Such action could lead to new products and services such as home water and energy efficiency solutions.

For State and Federal Government: The work aims to inform the efficient design, monitoring, and management of buildings and cities of the future. Understanding water and energy flows in cities (the metabolism of the city) could lead to city-based targets. By identifying least-cost solutions for communities, it is more likely that policy options will orient towards achieving solutions. The Prime Minister's Science Engineering and Innovation Council (PMSEIC) (PMSEIC, 2010) recently identified that "Resilient pathways will simultaneously reduce greenhouse gas emissions, lower overall water demand, maintain overall environmental quality and allow living standards to continue to improve". This project is one step towards finding such resilient solutions.

For households: Our aim for the project is to provide information enabling communities to make informed choices about water-related energy usage (in particular, the most direct pathways to increased efficiency as well as cost and GHG-minimisation). Moreover, we hope our work motivates changes within related government agencies toward water and energy cost stabilisation. There would appear to be opportunities for appliance and household goods manufacturers to draw on the information to help identify future product development areas that reduce water-related energy.

The project continues to the end of 2015. Further information is available from the Smart Water Fund website www.smartwater.com.au/knowledge-hub/climate-change/energy-water-nexus/water-energy-carbon-links-in-households-and-cities-a-new-paradigm.html, or from project Leader, Dr Steven Kenway.

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