WATER AND ENERGY REQUIREMENTS AT A TENANTED RESEARCH HOUSE

B Kele, K Hoffman, N Orr, P Wolfs, I Tomlinson, D J Midmore

Abstract

Research House, built in the sub-tropical city of Rockhampton, is part of the Queensland Department of Housing's 'Towards Healthy and Sustainable Housing Research Project'. The aim of the venture was to construct a house with passive sustainable building design and to monitor how the features worked with a rental clientele, who would have minimal interest in the outcomes, in contrast to other 'sustainable houses' occupied by environmentally concerned owners. Both water and energy usage have been collected and collated for two groups of tenants.

Keywords: Energy usage, housing design, sustainability, user patterns, water consumption

Figure 1. Artist's Impression of Research House Floor Plan.

Introduction

Research House is part of the 'Towards Healthy and Sustainable Housing Research Project', an initiative of the Queensland State Government. The Queensland Department of Housing has a 'Smart Housing Program' that aims to develop housing designs that have social, environmental, and economic sustainability (QG, 2005). A 'Smart House' is safe, livable, resource efficient, and cost-efficient over-time. Research House is intended to trial one of the 'Smart House' designs (QG, 2004).

Research House has been constructed in the sub-tropical city of Rockhampton, using environmentally friendly materials (such as fly ash blocks), has been designed to be responsive to natural breezes, has innovative approaches to insulation and ventilation, and uses energy and water efficient infrastructure (see Figure 1) (QG, 2005). As part of the social sustainability program the mechanisms which Research House uses to conserve resources are passive in nature (QG, 2005). Research House is a rental property and part of the Queensland Department of Housing public housing stock. The tenants who live in Research House have been taken from the normal public housing waiting list and are not selected on the basis of environmental awareness. Since Research House was built there have been several changes in tenancy (QG, 2004). The technology used at Research House must be robust and have limited maintenance requirements as legislation *(Residential Tenancy Authority Act)* restricts the access that landlords, or people acting on their behalf, have to a rental property.

Data on a 'sustainable' public housing project.

Research House is an extremely valuable tool as it provides information on how members of the general public can live in a sustainable manner. Many sustainable housing research projects take place in private dwellings using householders who are already committed to a resource-efficient lifestyle (Gardner and Millar, 2003). While these studies are valuable they may overestimate the potential resource savings of a housing design due to the user patterns and behaviour of the householders. As the tenants change over time in Research House, different user patterns and behaviours will be able to be assessed. The infrastructure at Research House will also be able to be assessed on how its efficiency performance degrades overtime. Studies at resorts/hotels have shown that drips and leaks maintenance programs are required on some infrastructure for it to maintain its efficiency (Kele *et al.*, 2003).

This paper describes the water efficient infrastructure installed at Research House, the water consumption of each individual component and its energy requirements.

Infrastructure and Data Collection

There were two design philosophies used to ensure that the basic criterion of economic sustainability was met for the water infrastructure; water efficiency and volume fill (QG, 2004). It was understood that while most items in the house could be built using water-efficient infrastructure, some items, such as the bath, were filled by people to a desired depth regardless of the tap-flow rate. So the cost of installing flow restrictors on the bath taps was never going to be recouped. Economics is quite often

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thought of in the broad scale but ignored for smaller items (Beatty *et al*., 2005); (Choe and Fraser, 1998). The entire water and energy efficient household infrastructure was purchased with the intention that any excess money spent on a more expensive item (such as hot water system) or a new stand-alone item (such as a flow restrictor) would be recorded and a pay-back period in years would be calculated using the money saved from reduced water bills (QG, 2004). This type of calculation is required to provide an economically sustainable determination of the house design (Icke *et al*., 1999).

All wastewater-generating infrastructure was equipped with a water meter (see Table 1). If the item used electricity an energy sensor was installed. The water and energy efficiency of each appliance was theoretically determined.

At Research House a 75-channel data logger was established to collect water, energy, temperature, and weather sensor information. The data from the fifteen water-flow sensors and four relevant energy sensors will be discussed in this paper. Water volume was measured using water turbine transducers (QG, 2004). As water flowed through the transducers, turbine blades rotated interrupting a laser light from a digital optical transmitter, which in turn creates a digital pulse that is recorded and converted into a water volume (QG, 2004). This form of data collection allows for precise knowledge on a minute-to-minute basis as to what volume of water was used in specific locations within Research House. Problems with suspended solids in the reticulated water supply were encountered in the earlier months of the trial. An in-line filter to remove the solids was installed directly after the water-mains entry to the property and the problem was solved (QG, 2004). The major electrical components were individually metered; smaller appliances could not be metered but a formula for electrical requirements was calculated (QG 2005). All the logged data were compiled and presented through LabVIEW™.

Table 1. Wastewater Generating Infrastructure, Data Collection, and Efficiency Rating.

Item	Water Sensor (Y/N)	Water Efficiency Rating	Energy Sensor (Y/N)	Energy Efficiency Rating
Hot Water Unit	Y	Unrestricted Volume fill	Y	5 stars
Ensuite Toilet	Y	3/6 L dual flush	N	N/A
Ensuite Shower	Y	9 L/min	N	N/A
Ensuite Vanity	Y	6 L/min	N	N/A
Toilet	Y	3/6 L dual flush	N	N/A
Toilet Vanity	Y	Automatic Sensor Tap	N	N/A
Bath	Y	Unrestricted Volume fill	N	N/A
Kitchen Sink	Y	9-12 L/min	N	N/A
Dishwasher	Y	AAA 8 L/min	Y	4 stars
ZIP hot/cold Tap	Y	Unrestricted Volume fill	Y	Unavailable
Bathroom Vanity	Y	6 L/min	N	N/A
Bathroom Shower	Y	9 L/min	N	N/A
Washing Machine	Y	AAA 8 L/min	Y	4 stars
Laundry Tub	Y	Unrestricted Volume fill	N	N/A
Mains	Y	Unrestricted	N	N/A

Results and Discussion

The water use figures from two different tenancies are presented in this report. Information from Tenants A was collected from the 1st of December 2002 to the 30th of November 2003. There were two adults and three teenage children, one of the teenage children was only present for part of the year (QG 2004). Tenants B moved into Research House on the 1st of January 2005. Eight months worth of Tenants B data are presented in this report. The data collection computer suffered a malfunction that resulted in the loss of 7 weeks worth of records. Two adults and three teenage children moved into the house and were joined by another person at the end of September 2005. Data comparison with other reports for water and energy consumption is difficult as most articles detail information on a per household basis rather than a per capita. The number of people living inside a household can be a major factor when considering water and energy usage. While the data are reported as a household figure, a per capita figure can be obtained for the presented data by dividing by 4.67 for Tenants A and by 5.16 for Tenants B.

The energy meters attached to the dishwasher and washing machine showed that actual electrical requirements were significantly different to the manufacturer's predicted energy label usage for the period between December 2002 and November 2003 (see Table 2).

The dishwasher (Dishlex - Electrolux Australia) used approximately 17% more electricity than envisaged and the washing machine (Front-loader Westinghouse - Electrolux Australia) 10% less. There has been much debate in the water industry about sustainable housing design and washing machines in particular, such as top-loader versus front-loader machines (see http://www.nrm.qld.gov.au/list_archives/water-recycling/index.html). Much of the information for this debate has been obtained from the manufacturer's energy label rather than from machines in households and field-tested data. The manufacturer's information is based on a projected daily figure achieved under ideal minimum energy performance standards conducted under a controlled laboratory environment (QP 2005). Householders can use resource-efficient infrastructure quite inefficiently, and vice-versa. The dishwasher may have used more electricity because it was overloaded or the householders may have been using specific high-energy wash-cycles. The information shows that in relation to energy it may be more sustainable to have smaller more frequent washes. The debate between front-loading and top-loading washing machines is largely meaningless if user patterns and behaviours are not considered. Educating householders on proper usage is still important even in a passive designed house with resource-efficient infrastructure.

In Table 3 the yearly energy usage for Tenants A on selected items at Research House are presented. The house did not have any air-conditioners (ceiling fans are present) or heating mechanisms. The non-wastewater generating energy use within the

Table 2. Predicted Energy and Actual Energy Use for Selected Whitegoods for Tenants A.

Item	Energy Label kWh/yr	Actual Energy Use kWh/yr
Dishwasher	256	307
Washing Machine	225	205

house was lights, fans and entertainment devices (36%), freezer, clothes dryer, and microwave (14%), refrigerator (14%) and electric oven (10%) (QG 2005). For Tenant B the energy used by the washing machine, dishwasher, and zip hot/cold water tap was available, but at the time of this publication the relative percentages could not be calculated.

Table 3. Water Related Infrastructure Energy Use for Tenants A.

Item	Percentage of Energy Use
Washing Machine	2.3%
Dishwasher	3.4%
Zip Hot/Cold Tap	6.8%
Hot Water System	13.5%

The hot water system used at Research House for the first year of the trial utilised a heat pump technology (Quantum), where heat is drawn out of one space and discharged into another (QG 2004). The Quantum hot water system does not have a heating coil at the base like most other systems, but instead has a heating coil that runs the full length of structure. This equates to an even water temperature throughout the system and less water wastage from people letting water run through a tap until it is warm (QG 2004). Over time the hot water technology at Research House will be changed so that different systems can be tested. The Quantum technology will be replaced by an electric boosted solar hot water system (Solahart), which in turn will be substituted with an instantaneous gas system (Bosch). The Quantum system used approximately 60% less energy than is reported for an average Queensland off-peak electric hot water system (QG 2005). This equates to a saving of about 777 kg per annum of green house gases (GHG). The energy efficiency of a Quantum hot water system can be expressed as a coefficient of performance (COP), The Quantum system at Research House had a mean COP of 3.09 which means that for each unit of electricity supplied from the mains another 3.09 was supplied free from the environment. Depending on the volume of water heated the Quantum system would take between 5-7 years before the added cost of its installation would be paid back in relation to a standard off-peak system. The long payback period isn't of great concern as the system has a tank-life warranty of fifteen years; which is considerably longer than most off-peak electric technologies. The Quantum system does produce a noise from the compressor, which is about 52 dBa at a distance of 1.5 m or approximately that of a new standard domestic refrigerator. From the data collected the heat pump system appeared to be a more sustainable option than conventional boilers for the heating of domestic water.

Table 4 describes the water usage figures for Tenants A and B and compares the data with the Australian averages. The water usage for the hot water system could not be separately described in Table 4 as the hot water was used in a variety of items. It is known that the hot-water system used 129 L of water/day (11% of total use) over the Tenant A period (QG 2004) and 242 L of water/day (10% of total use) during Tenant B.

It is important to note that the data for Tenants A and B are collected over two different times, so the percentages give a better indication of user patterns than the raw water-use figures. It can clearly be seen that the majority of the reticulated water at Research House was used for outdoor purposes. Tenants A and B both used higher percentages of water outdoors than the Australian average; with Tenants B using nearly three-quarters of their total water outside. While the majority of outdoor use for both Tenants is assumed to be for garden irrigation it also includes car washing and other outdoor water activities. The garden at Research House was designed to have minimal water requirements (drought-proof plants) and a water efficient irrigation mechanism (automated irrigation system) (QG 2004). However, it was observed that the tenants did water the garden themselves through sprinklers, garden hoses and soakage hoses. The householders also applied additional irrigation water to the yard from the two rainwater tanks. It was not possible to quantify the amount of irrigation water supplied from the rainwater tanks (QG 2004). The volume of water used for outdoor activities highlights the importance of householder education in regards to user patterns and behaviours. Drought resistance plants should not have required this amount of water so it is possible that the plants were over-watered As many people consider watering the garden to be therapeutic how does this practice fit into the concept of resource efficient housing design?

Inside Research House the largest water consumption was from showers and baths (approximately 211 L/day) for Tenants A, and the toilet for Tenants B (approximately 214 L/day). The differences in indoor percentage of use between Tenants A and B clearly shows that user patterns can have a big difference as to where and when water is used and wastewater is produced. The flow-meters recorded an average shower time of less than 5 minutes for Tenants B, while for Tenants A it was closer to 10 minutes. Tenants B used the bath less than twice a month and Tenants A on a weekly basis. The amount of water used by Tenants A in the showers and bath closely corresponds with the Australian average. This is not the case with Tenants B but it must be considered that their high outside

Table 4. Water Use Figures for Tenants A (12 months) and Tenants B (8 months) compared to Australian Average.

Item	A Water Use (L)	A % of Total Water Use	A % of Indoor Water Use	B Water Use (L)	B % of Total Water Use	B % of Indoor Water Use	Australian Average % Total Use
Outdoor Use	214 620	51%	N/A	616 464	74%	N/A	44%
Indoor Use	205 130	49%	N/A	156 448	26%	N/A	56%
Showers and Bath	77 015	18%	37%	30 689	5%	19.5%	20%
Kitchen Sink	46 720	11%	23%	18 458	3%	12%	5%
Toilet	42 340	10%	21%	51 975	8.5%	33%	15%
Washing Machine	15 695	4%	8%	43 481	7.5%	27.5%	10%
Dishwasher	10 585	3%	5%	9152	1.5%	6.3%	3%
Laundry Tub	9 490	2%	4%	1092	0.2%	0.7%	3%
Zip Hot/Cold Tap	3 285	1%	2%	1 601	0.3%	1%	N/A

Australian averages adapted from ABS (2004) water use skews the percentage results. Tenants B are more water efficient in the showers and baths than Tenants A and the Australian average. Toilet usage is very much dependent of the individual; however the flow-meter data showed that both sets of tenants used the 3L/6L flush in much the same pattern and that the differences in usage figures was not a result of inefficient use of the flush system. Tenants A used the kitchen sink much more than the Australian average, while Tenants B volumes were similar to the Australian average.

For Tenants A the washing machine only used 8% of the indoor water and 2.3% of the total electricity, while for Tenants B the washing machine used 27.5% of the indoor water and less than 6% of the total energy. It could be seen by the flow meters that the majority of the washing loads conducted by Tenants B were hot-water washes. This accounted for the bulk of the hot-water used by these tenants. While there is a debate about washing machine designs in the Australian water industry, the data from Research House show that washing machines are only responsible for a small amount of the total resource use for this specific dwelling. With the refrigerator using 14% (Tenants A) and the hot water system 13.5% (Tenants A) of the total energy usage there may be more benefit in seeking energy efficiency from the infrastructure that uses the most energy rather than focusing on small percentage energy savings from items such as the washing machine and the dishwasher. The dishwasher used more energy than the washing machine and significantly less water (with both groups of tenants); it is thought that the difference was due the heating of the water in the dishwasher. The amount of water used by the Tenants A and B in the dishwasher was similar and compared closely to the Australian average; especially if the skew towards outside water use by Tenants B is taken into account. The amount of electricity used by the dishwasher increased during the tenancy of Tenants B to almost double the previous amount. As water use figures were similar between the two groups; wash settings on the dishwasher must have been altered to account for the increase in electrical usage.

The laundry tub was used more by Tenants A than by Tenants B, even though the washing machine was used 3.5 times more often by Tenants B. This once again highlights the differences that user patterns can create. The Zip hot/cold water tap was used infrequently by both groups of tenants. The Zip hot/cold water tap used only 1% or less of the water but required more electricity than the washing machine and the dishwasher put together (Tenant A data). It cost $70/year to run although the cost of this may have been offset as the refrigerator was not used to chill water and no kettle was required (QG 2005). Whether $70 worth of electricity would have been used to boil water in a kettle or to chill water in a refrigerator is unknown.

Table 5. Daily Wastewater Production Per Capita at Research House compared to EP.

Research House	Average Daily Total Water Use	Average Daily Indoor Water Use	Average Daily IndoorPer/Person Water Use	Standard Equivalent Person (EP) Water Use
Tenants A	1150 L	562	120 L	250 L
Tenants B	3181 L	644	125 L	250 L

The daily water usage per capita at Research House is of interest where sustainable housing design and integrated water management is concerned. The water supply and wastewater treatment requirements of urban developments are based on an Equivalent Person (EP) calculation. While there is a variety of different definitions for the exact volume of an EP one standard definition is that one EP equals 250 L of wastewater. The fact that various State Governments and Local Government Authorities in Australia have slightly different definitions of EP has caused considerable confusion and the historical and scientific basis for the calculation of EP is not well known. The data from Research House show that on a daily per capita basis the volume of indoor water use from which wastewater will be produced is only 120 L for Tenants A and 125 L for Tenants B (see Table 5).

The figures from Table 5 show that while the average daily use between the tenants groups is significantly different, the indoor water use is much closer, and the water use per person almost identical. When the differences in user patterns between Tenants A and B shown in Table 4 is considered the similar per person indoor water use volumes is remarkable. The water efficient infrastructure appears to keep overall indoor water usage relatively low, even with markedly different user patterns.

The average daily total water use is strongly influenced by the amount of water used outside. As all of the outside water use measured at Research House was from the potable reticulated supply, potentially large savings of drinking water would be possible if recycled water was used for safe outside use.

Resource efficient infrastructure and its widespread acceptance by Government authorities and the general public are relatively new. While some organisations have altered EP values for resource efficient developments this has been done on an ad-hoc basis with very little consistency. The indoor water use volumes do not take into account potable use and spillage so the actual amount of wastewater produced per capita/day would be smaller. A reassessment of the EP calculation and how it applies to resource efficient designs needs to be undertaken. This process needs to occur on a national basis and be applied consistently. Wastewater treatment systems, whether they are part of a reticulated sewage treatment plant or an on-site system are not efficient, economic and may not supply quality treatment if they are over-sized for the required task. It is important to note that basing a new EP volume on bench-top studies without evaluating the impacts of people's user patterns and behaviours would not produce a realistic alternative. A 'Smart House' needs to be part of a 'Smart Development' and designing new resource efficient houses without reassessing the parameters used to design water supply and wastewater treatment is not a sustainable practice.

Conclusions

Research House will be a valuable tool for the long-term assessment of resource efficient sustainable housing design. It is hoped that the continuing information will be important in determining whether infrastructure maintains the same level of water and energy efficiency over time, or if it degrades in performance, and if so at what rate. Examinations of the infrastructure will be conducted when the house is vacant between tenants so that the exact volumes used (per minute or otherwise) can be calculated. The multiple data collection points have reduced the need for theoretical water and energy usage calculations within the house and provide real-time infrastructure specific information. The data collection computer and sensors are in the process of being upgraded and renewed. The changing tenancy patterns allow for appraisals on usage patterns and behavioural differences of the general public. It was clearly shown that the infrastructure was used very differently by Tenants A and B although per capita usage was near identical. The ability to make precise per capita calculations and compare them with yearly total use figures allows for some realistic field analysis of potential new EP calculations for sustainable developments. Data from dwellings such as Research House have the ability to provide relevant information for the long-term sustainable planning of Queensland's housing development. It would be interesting to see if education sessions with the tenants, for example after 6-months tenancy, would have any impact on the water usage figures, especially in regards to the outside water use volumes and whether any changes in user patterns can be maintained over time or be short-lived.

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The Authors

Ben Kele (b.kele@cqu.edu.au) is a PhD candidate with the Plant Sciences Group (PSG) of the Central Queensland University (CQU), **Professor Peter Wolfs** is Associate Dean of Engineering, **Nicola Orr** a research officer, **Ian Tomlinson** an Engineering Technician (and the most water efficient of the authors), and **Professor David Midmore** is Director of PSG CQU. **Kevin Hoffman** is an electrical engineer with Queensland Department of Public Works.

References

ABS (2004) In *Cat. No. 4610.0* Australian Bureau of Statistics, Canberra.

Beatty, R., O'Brien, S. and Stuart, B. (2005) In *Ozwater Convention and Exhibition* AWA, Brisbane.

Choe, C. and Fraser, I. (1998) *The Australian Journal of Agricultural and Resource Economics,* **42**, 269-302.

Gardner, T. and Millar, G. (2003) *In On-Site '03* (Eds, Patterson, R. A. and Jones, M. J.) University of New England, Armidale, pp. 145-152.

Icke, J., VanDerBoomen, R. M. and Aalderink, R. H. (1999) *Water, Science and Technology,* **39**, 211-218.

Kele, B., Midmore, D. J., Harrower, K., Hood, B., McKennariey, B., Doyle, G., Saunders, D. G. and Macey, P. (2003) In *Water Recycling Australia - 2nd National Conference* (Eds, Gardner, T. and McGarry, D.) Australian Water Association, Brisbane.

QG (2004) Queensland Government; Queensland Department of Public Works and Queensland Department of Housing, Brisbane. http://www.housing.qld.gov.au/ - initiatives/researchhouse/publications/ index.htm

QG (2005) Queensland Government; Queensland Department of Public Works and Queensland Department of Housing, Brisbane. http://www.housing.qld.gov.au/ initiatives/researchhouse/publications/ index.htm