Performance evaluation of conventional and water saving taps

A. M. Fidar, F. A. Memon and D. Butler

Centre for Water Systems, College of Engineering, Mathematics and Physical Sciences, University of Exeter, North Park Road, Harrison Building, Exeter, EX4 4QF, UK

Highlights

- Original analysis of 13000 *high resolution* observations in field at two sites providing novel insights into water tap use
- Results surprisingly indicate:
  - limited difference b/w the consumption by conventional & efficient taps
  - A strong co-relation between the duration of flow and the volume discharged from taps.
  - flow rate has very limited/no impact on the actual water consumption.
- Tap usage duration needs to be optimised and is very much linked with the tap user behaviour.
- Almost 80% of tap use is to deliver hot water with considerable energy and carbon implications

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A. M. Fidar

Centre for Water Systems, College of Engineering, Mathematics and Physical Sciences, University of Exeter, EX4 4QF, United Kingdom

Eamil: afidar2@gmail.com

F. A. Memon

Associate Professor, Centre for Water Systems, College of Engineering, Mathematics and Physical Sciences, University of Exeter, EX4 4QF, United Kingdom (Corresponding author), Email: f.a.memon@exeter.ac.uk

D. Butler

Professor and Co-Director Centre for Water Systems, College of Engineering, Mathematics and Physical Sciences, University of Exeter, EX4 4QF, United Kingdom

Email: d.butler@exeter.ac.uk

ABSTRACT

The rapid pace of urbanisation comes with considerable environmental implications including pressures on already stressed limited water resources. In urban areas, most of the water use is associated with water consumption in buildings. The second largest use of water is via taps. It is often assumed that water taps with *low flow* rates can contribute to reduced per capita water consumption. However, this is based on very little evidence. This paper presents the synthesis of a 13000 high resolution observations made to investigate the **actual** water consumption of innovative (water saving) electronic taps and conventional mixer taps. High resolution flow-meters and data loggers were fitted into two washrooms in two different buildings of a higher education institution to record the water use through the basin taps. The recorded data provided information on duration, frequency of use and volume of water consumption per use. The data was helpful in identifying trends in hot and cold water use and therefore can be useful in estimating energy for producing hot water and associated greenhouse gas emissions. Analysis of the observed data suggests that the low flow taps have greater mean water consumption per event than the conventional taps and water consumption is more influenced by user behaviour rather than the technology.

Key words: event duration; low flow rates; taps; water efficiency; energy consumption; carbon emissions; micro-components

1.0 INTRODUCTION

Water is one of the world's most precious resources and is crucial for sustaining life. However, while water resource is arguably constant in quantity, pressures on the resource are set to increase (Defra, 2008) as its demand is rising. Rapid population increase, especially in urban areas, increasing household number, changes in life style and climate change are believed to be the main factors that are driving water demand (EA, 2009a).

Water demand management is viewed increasingly by governments, agencies and water utilities, not only as a potential means of aiding the security of the future water supplies, but also as a tool to reduce the resulting environmental implications (Beal and Stewart, 2014). Reducing water consumption saves energy either directly on site at household level or offsite at water abstraction, treatment and distribution points. For example, using less water at household level reduces the amount of energy needed to abstract the water, process at a treatment plant, pump it from a storage tank and heat it at home. It also saves the energy required to treat it at a wastewater treatment plant and pump it for disposal.

In the UK, for example the concept of the water demand management or water efficiency is progressively gaining recognition and has led to a number of initiatives established by the government to promote efficient and sustainable water use. For example, in England and Wales, the twin track approach, which seeks a balance of resources development and demand management, is considered as necessary to maintain supplies in the future and to help improve resilience against climate change (EA, 2009a). With such approach, options that reduce demand rather than increase resources is considered first, as they provide benefits for adapting to and limiting the extent of climate change and the principles of sustainable development. Similarly, the government's Future Water (Defra, 2008) aims reducing per capita consumption of water to an average of 130 litres per person per day by 2030, or possibly even 120 litres per person per day depending on new technological developments and innovation.

A microcomponent-based approach is a favoured water demand management strategy, widely proposed and sometimes implemented. For example, as part of Preston Water Efficiency Initiative, new dual flush toilets and low flow showers were installed into a number of dwellings, while water efficient urinals and push taps were fitted into a school and leisure centre (Boarder, *et al*, 2009). It was reported that the installation of dual flush toilet and low flow showers had resulted in 25% water saving. UK water service providers are required to use microcomponent data in demand forecasts and planning (EA, 2009b; Ball *et al*, 2003). Similarly, the importance of water efficient technologies in reducing domestic water consumption is expected to be reflected in the revised Building Regulations, via the inclusion of New National Technical Standards (SES, 2015). Water efficiency levels will also be part of independent certification schemes such as Home Quality Mark (HQM) (BRE, 2015). Additionally, in an effort to encourage businesses to invest in water saving and water quality improvement technologies, the UK government introduced in 2001 an Enhanced Capital Allowance scheme (HRM&C, 2014). The Scheme enables businesses to claim 100% first year capital allowances on investments in technologies and products that improve sustainable water use.

Domestic taps (kitchen and basin taps) are the most frequently used water using microcomponents, representing more than one-third of the domestic water consumption (MTP, 2008a). Their daily water consumption is determined by the frequency of use, duration of use (event-duration) and the flow rate of the tap. The frequency of use and the event duration are dependent on user behaviour, while the flow rate is determined by the technology and is governed by several physical factors, including water pressure and specific tap design.

In the UK, the flow rates of taps are measured against British Standard BS5412. The current requirement for flow rates in taps is based around minimum rather than maximum flow rates, which makes the availability of data on maximum flow rates limited (Marshallsay *et al*, 2007). In the USA and Australia, different standards and ratings apply to taps intended for different uses. An American basin and kitchen taps (faucets) are supposed to deliver 8.3

litres/minute and 9.5 litres/minute at a pressure of 4 bar, respectively (FEMP, 2002). Similarly in Australia, a basin tap with a flow rate of between 3.0 and 4.5 litres/minute achieves an AAA rating, but the same rating (AAA) is awarded if a kitchen tap delivers between 7.5 and 9 litres/minute (Wilkenfeld and Associates, 2003). Therefore, as the water efficiency rating of a product is awarded relative to its application, manufacturers are required to mark their taps with their intended purposes (e.g. basin tap, kitchen spout, etc).

As mentioned above, water consumption through domestic taps constitutes a significant proportion of the total domestic water use. It is believed that water flow from tap outlets is often in excess of what is required. Therefore, more water efficient taps could in principle lead to reduction in domestic water use, compared to standard taps.

The proportion of water consumption by taps is likely to rise in the coming years as other water efficient microcomponents, such as WCs and white goods are increasingly installed. Consequently, a number of low flow taps, designed to be water efficient, are increasingly coming into the market. There is a considerable number of water saving tap technologies featuring in the qualifying ECA technologies list (Defra, 2009).

There is a growing claim by manufacturers that water saving taps can reduce water usage by 50% - 85%. However, recent studies conducted on water use draw widely varying conclusions, and as a result, there are widely varying estimates about the extent to which installing or retrofitting low flow taps saves water. Neve (2006) reported significant water saving (50%) resulting from retrofitting push taps. Similarly, Mayer *et al* (2000) estimated modest savings (13%) after installing tap (faucet) aerators, to reduce flow rates of taps, as part of retrofit. Conversely, Hills *et al* (2002) concluded that water efficient (low flow) taps have greater water consumption per event than the conventional taps. Because of the uncertainties surrounding water use of taps, Gleick *et al* (2003) chose not to model any savings from installing low-flow taps. Instead, they provided an estimate of overall water use by taps, based on the finding of the “residential end use of water” (REUW) study – 41 (10.9 gallon) litres/capita. day. They assumed that this rate of water use would not change in the future. Keeping in view of such conflicting results, it was decided to carry out an independent study to examine the actual water consumption associated with conventional and innovative water efficient taps and the results have been discussed in this paper.

2.0 METHODOLOGY

To evaluate the implications of the flow rates of taps on their performance in terms of resources consumption, the water use of conventional taps and innovative water efficient electronic taps were monitored. For this purpose, high resolution flow meters and data loggers were installed in two of the University of Exeter’s toilets – one in Newman Building Lecture Hall male toilet and one in Harrison Building ground floor female toilet.

Four conventional mixer taps are in the Harrison Building toilet. The taps are deck mounted single-taphole with dual controls – one for the cold water and one for the hot water (Figure 1).

Similarly, four (mains powered) deck mounted electronic taps with pressure compensating aerators (Figure 2) are installed in the Newman Building toilet. When a user puts their hands under the tap, an infra red sensor detects their hands and a solenoid valve opens. The tap remains open whilst there is motion in front of the sensor and once the user removes their hands, the electronic automatically closes the solenoid valve. In addition to this, thermostatic valves (Figure 3) have been incorporated into the system, which have sensors that activate the cold water flow if the temperature of the flowing hot water reaches about 38ºC.

Figure 1 Conventional mixer tap

Figure 2 Electronic tap

Figure 3 Thermostatic mixer valve

Two multi jet water meters were fitted in each of the toilets – one for cold water and one for hot water. Over 150 tests were carried out to calibrate the performance of the flow meters and it was found that they provide one pulse output per 0.25 litres (+/- 5%).

An Eltek 1000 Series Squirrel data logger was fitted to register the pulses produced by the flow meters. The loggers can store 250,000 readings and the logging interval of the data loggers was set to two seconds. This short logging interval was intended to provide sufficient information on water use characteristics of the monitored taps. The collected data was processed with Darca Software, which is designed to communicate with the data logger. The software performed two functions: downloading data from the data logger and exporting it into spreadsheets.

To distinguish between two distinct tap use events, in this study, if the time between two pulses was equal to or less than ten seconds, it was considered as one "use event" and the water consumption of that use event was assumed to be the sum of the flows (water used in the sub-events). Similarly, if the interval between two pulses (openings) was greater than ten seconds, they were considered as separate "use events".

3.0 RESULTS

The monitoring equipment provided information on the characteristics of the water use events such as volume of water used per event, event duration (tap running time), and hot/cold water split. The flow rate (litres/minute) of each use event was estimated by dividing the event's volume of water use by its duration (running time).

3.1 Conventional mixer taps

For the conventional mixer taps, more than 6400 events were recorded. The total water consumption during these events was approximately 4403 litres, about 92% of which was through the hot water tap. In Figure 4, the pulses recorded in the data logger were translated into volume of water used per event. Based on the recorded events, the estimated mean water consumption was 0.68 litres per event. As the figure indicates, more than 95 percent of the events used less than two litres.

Figure 4 Distribution of water consumption per use event for conventional mixer taps

As the figure shows, the observed data of the water consumption per event skewed positively (with skewness value of 1.9). With more than 2200 events, the mode was found to be 0.25 litres per event, while the median was 0.5 litres per event.

The duration of each event was also recorded and summarised in Figure 5. The figure illustrates that event durations vary widely ranging between 3 and 45 seconds per event. However, (with 2288 events) 3 seconds was found to be the mode, while 5 and 7 seconds per event were the median and the mean of the recorded event duration, respectively. More than

94 percent of the events lasted for less than 18 seconds. As with the water consumption, the figure indicates that the recorded data of the event durations was highly skewed right (2.6).

Figure 5 Distribution of event duration for conventional mixer taps

There are two factors which influence the amount of water used by the taps for any given event – the flow rate of the tap and the event duration. In addition to the tap design, certain physical parameters such as the local pressure at the time of event and the degree to which the tap has been turned on determine the flow rate. The flow rates of recorded water use events were analysed and the mean flow rate was found to be 5.5 litres/minute, whilst both the mode and the median were 5 litres/minute. However, the flow rate of certain extreme events was as high as 11.6 litres/minute and as low as 3.2 litres/minute as shown in Figure 6 (3 day sample).

Figure 6 Sample of the estimated flow rates of events for conventional taps

The influence of the flow rate on the water consumption of the events was evaluated (Figure 7). The figure illustrates that high flow rate does not necessarily lead to greater water consumption. Based on the observed data, there are many events with high flow rates which use less water than low flow events.

Figure 7 Influence of flow rates on water consumption for conventional taps

Figure 8 compares the water use of events with their running time (event duration). Clearly there is a strong relationship between the duration of an event and its water consumption. The event duration of an event is mainly determined by user behaviour and as shown in Figure 9, is largely independent of tap flow rate. Therefore, this indicates that installing water saving tap technologies alone is not sufficient to achieve the required water efficiency level.

Figure 8 The relationship between event duration and water consumption for conventional taps

Figure 9 The influence of the tap flow rate on event duration

3.2 Electronic taps

Some 7489 use events were recorded for the electronic taps, in which approximately 5258 litres of water were consumed. The records showed that more than 4679 litres (89%) were from the hot water system. Figure 10 summarises the distribution of the events' water consumption, which ranged between 0.25 to 3.25 litres. The arithmetic mean, the mode and the median of the recorded per event water use were found to be 0.7, 0.5 and 0.5 litres, respectively. The skewness value of the recorded data for water consumption per event was found to be 1.86 (positively skewed).

Figure 10 Distribution of water consumption per use event for electronic taps

It was observed during the monitoring that on certain (rare) occasions, the electronics failed to close the solenoid valve and the tap remained open well after the user removed their hands, resulting in longer running times thereby leading to a relatively higher volume of water consumption. However, since only three of these events were recorded, their inclusion or exclusion from the analysed data did not have significant influence on the statistical properties of the events' water use.

In addition to the technology-defect caused incidents, during the monitoring programme, it was observed that two or more taps were sometimes used simultaneously. Clearly, these events provide greater pulses per logging interval. In the data processing stage, these events were identified with the number of pulses per logging interval. Recording more than one pulse per logging interval suggests more than one tap use.

The event duration with electronic taps varies significantly ranging from 3 to 37 seconds per event (Figure 11). The mean, the mode and the median of the event duration were found to be 9, 3 and 7 seconds per event, respectively. However, the figure shows that, as with the conventional taps, the observed data of the event durations was positively skewed (with skewness value of 1.8).

Figure 11 Distribution of event duration for electronic taps

As discussed earlier, the water consumption per event is a function of the flow rate and the event duration. The estimated flow rate of the recorded events with the electronic taps ranged from 3.5 litres/minute to 7.1 litres/minute. The mean flow rate, the mode and the median were all 5 litres/minute. As shown in Figure 12, the flow rates of the electronic taps were relatively uniform compared to those of the conventional mixer tap. Unlike the conventional mixer taps (with which the users could influence the flow rate by manipulating the flow controls), the flow rate of an electronic taps is governed by the design factors (such as inserts/aerators) and the local pressure at the mixing valve. It was found that events which used cold water normally had higher flow rates than the events which used hot water alone.

Figure 12 Sample the estimated flow rates for the electronic taps

Similar to the conventional mixer taps, the event duration has significant influence on the event water consumption (Figure 13), while there is weak relationship between the flow rate and the taps' water use per event (Figure 14).

Figure 13 Influence of event duration on water consumption for electronic taps

Figure 14 Influence of flow rates on the water consumption for electronic taps

3.3. Comparing the performance of the two types of taps

A summary of the statistical analysis of the recorded data is shown in Table 1.

The mean water consumption per event associated with the conventional and electronic taps were found to be 0.68 and 0.7 litres, respectively. Similarly, the mean flow rates of taps were 5.5 litres/minute and 5 litres/minute for conventional mixer taps and electronic taps, while their mean event durations were 7 and 9 seconds, respectively. Note that the electronic taps have a delayed shut-off time of about 2 seconds, which causes an extra water flow thereby offsetting any savings that might result from the slightly lower average flow rate.

A number of *t-test* tests were conducted on the two data sets, assuming unequal variance, to evaluate the statistical significance of the difference between the conventional and electronic taps in terms of their water use characteristics such as water consumption per event, event duration and flow rate. For example, the observed data of the two types of taps showed that electronic taps have slightly higher mean water consumption per event than the conventional taps. The result of the *t-test* indicated this higher mean water consumption associated with the electronic taps is statistically significant at the 95% confidence level. Similarly, the electronic taps have longer mean event duration than the conventional taps, which (based on the result of the *t-test*) is statistically significant (Table 1). It is important to note that electronic taps have a delayed shut-off time of about 2 seconds, which causes an extra flow thereby offsetting any savings that might result from the slightly lower average flow rate. The higher mean water consumption per event associated with the electronic taps is perhaps as a result of this longer mean event duration.

Table 1 Summary of the statistical analysis of the taps water use data

4.0 DISCUSSION

As domestic water consumption consists of several microcomponents (e.g. WCs, showers, baths, basin taps, kitchen taps, dishwashers and washing machines), progress in water saving technologies is considered important for achieving water efficiency measures. For example, the compliance of water efficiency targets in independent certification schemes (e.g. HQM) and building regulations is assessed based on the characteristics of the water using micro-components installed (CLG, 2010; UK Government, 2010). Domestic taps (kitchen and basin taps) form part of such water using micro-components – particularly hot water using ones. Therefore, as residential end uses of water can be responsible for substantially more greenhouse gases emissions than upstream (water supply and delivery) and downstream (wastewater) operations put together (EA, 2008), strategies aimed at reducing energy consumption and greenhouse gases emissions in the urban water cycle could benefit from improving the water efficiency of domestic taps.

The per "use event" water consumption by domestic taps is determined by the tap's flow rate (litres/minute) and the event duration (minutes). Therefore, it is clear that if the running time is kept constant, taps with low flow rates will result in reduced per event water consumption. However, it was observed during the monitoring that the **actual** flow rate of the conventional mixer taps is almost always lower than their nominal[1] flow rates. This is in agreement with the conclusions of the Market Transformation Programme (MTP, 2008b). It also confirms the basics of the water efficiency assessment methodology of the recently withdrawn Code for Sustainable Homes (CSH). In the CSH, the actual flow rate of a conventional tap is assumed

[1] The maximum flow rate of the tap within the nominal working conditions - the flow rate when the tap is fully opened.

to be two-third of its nominal flow rate. However, of the observed data, it appears that predominantly the actual flow rate is at or below one-third of the nominal flow rate.

4.1 Comparison of the results with past studies

(a) Water consumption per event

The water consumption per “event use” observed in this research is significantly lower (0.68 and 0.7 litres/event for conventional and electronic taps, respectively) than the findings of the Millennium Dome study. The Millennium Dome study carried out to evaluate the water efficiency of certain water using micro-components, concluded that the conventional swivel taps use significantly less water per washroom-visit than the purported water efficient electronic taps (Hills *et al*, 2002). The study showed that the average water consumption per washroom-visit by conventional taps and electronic taps were 0.9 and 1.8 litres, respectively.

The difference between the results of the two researches can be attributed to their difference in methodologies. One of such differences lies in the logging intervals – the Millennium Dome study adopted 5-minute logging interval compared to 2-second interval with the study presented in this paper. In addition to this, the Millennium Dome experiment assessed the water use of various micro-components including WCs, taps and urinals using water meter and entrant reading. Therefore, it was not possible to determine the exact water consumption by each micro-component in the washroom. A correction coefficient was applied to take account of the fact that not all washroom entrants used all micro-components.

(b) Average flow rates and events duration

A research conducted by the WRc reported considerably lower average flow rate (3.54 litres/minute) and significantly higher average event durations (39.27 seconds) for internal taps (MTP, 2008c) compared to the findings of the study presented in this paper. Roberts (2005) found an average taps flow rate of 3.3 litres/minute and average event duration of between 20 and 25 seconds. However, in Roberts study, the majority of the events lasted in 5 or 10 seconds. Both of the studies were conducted in residential buildings where, in addition to hand washing, taps fulfil many functions such as vessel/kettle filling, dish washing, shaving etc. These functions could affect the water use characteristics of taps and could be responsible for average larger durations.

Additionally, differences in research tools and methodologies (such as water meter resolutions and data logger intervals) can contribute to the difference between the measured results of the researches. As mentioned earlier, the water meters used in our study provided one pulse output per 0.25 litres and the data logger interval was set to two seconds. In Robert's study, the data logger interval was set to five seconds and the water meters produced 72 pulses per litre. Logging interval can influence the estimated event duration which is inversely related to the flow rate – that is for a given volume of water use, the flow rate decreases as the event duration increases. With regard to WRc's, water use characteristics of taps were estimated based on data derived from whole house water consumption rather than a data collected at micro-component level (Clarke et al, 2009).

In addition to this, it was observed that with both types of taps, the relationship between the flow rate and the volume of water use per event was weak (Figures 7 and 14). This is in contrast with the widely held view that per capita daily water consumption rises linearly with the flow rate. But it supports the findings of researches conducted to evaluate the performance of water efficient micro-components including internal taps. Mayer *et al* (2003) reported no water savings resulting from retrofitting pressure compensating aerators (with 8.8 litres/minute and 6 litres/minute for kitchen and basin taps, respectively) into conventional taps.

As more than 60% of the time, the manually operated conventional tap users turn on the taps to a level that could deliver a flow rate ranging between 5 and 6 litres/minute, it can be assumed that this range of flow rate is the optimum one for hand-washing function. It can therefore, be concluded that no significant water savings can be obtained from installing/retrofitting tap technologies delivering 5 litres/minute or above. It was because of this reason, together with the longer event duration that the electronic taps have higher per event water consumption than the (monitored) conventional taps, despite the latter's considerable greater nominal flow rate. However the performance of taps with flow rates below this range (5 – 6 litres/minute) requires further investigation.

Analysing the observed data shows that the amount of water consumed per event increases with the event duration (Figures 8 and 13). As mentioned earlier, the event duration is governed mainly by the user behaviour and is independent of the tap's flow rate (Figure 9). The fact that event duration has such significant implications on taps' water use brings focus on the importance of non-structural water efficiency measures such as user education or pricing.

5.0 THE IMPLICATIONS OF THE STUDY FINDINGS

With regard to taps water consumption, the microcomponent-based water efficiency assessment approaches assume a linear relationship between the volume of water used, the nominal flow rate of the tap under consideration, the frequency of use and the event duration. However, this study confirmed the less predictable and rather complex user behaviour is the most significant variable in forecasting the water use of the taps, particularly in commercial (non-residential) buildings. Clearly, while it is easy to determine the flow rate of a tap under given water pressure, the actual pattern in which it will be used is more complex than is commonly modelled. Note, the current national water efficiency calculator considers the user behaviour as constant (CLG, 2009).

In addition to this, this study has confirmed that the flow rate of the taps during the use is lower than their nominal flow rate. This is an important finding in the context of water efficiency assessment approaches as the investigated water low flow taps are highly unlikely to result in reduced water consumption. This is because; the vast majority of the uses or the optimum flow rates are already equal or well below the flow rates of the innovative water saving taps.

The observed data shows that over 80% of the water consumption was via hot water taps. The amount and source of energy (e.g. gas, electricity) required to produce hot water has a direct bearing on the extent of greenhouse gas/carbon emissions. Assuming that there is a very marginal difference in the volume of water discharged through the two studied types of taps, calculations were made to quantify the proportional contribution of each micro-component in terms of its water and energy use and resulting carbon emissions (Figure 15). The figure suggests that although the second largest water consumption is via taps, the energy and carbon footprint of water use via taps is the highest among all the micro-components.

Previously very rightly low flush volume WCs were promoted to achieve reductions in per capita water consumption but their net contribution to carbon reduction targets is negligible, since they do not use hot water. The Climate Change Act 2008 commits the UK to reducing emissions by at least 80% in 2050 from 1990 levels (Committee on Climate Change, 2015). Water efficiency via taps can potentially contribute towards reduction in carbon emissions. However, this would probably require the implementation of measures that can influence water users' behaviour rather than the promotion of low flow taps.

Figure 15 Relative share of micro-components towards water and energy consumption and resulting carbon emissions (adopted from Fidar et al, 2010)

6.0 CONCLUSIONS

The analysis of the observed data indicated statistically significant difference between the conventional mixer taps and low flow electronic taps in terms of their water use characteristics such as volume of water per event, event duration and flow rate. The study found that low flow rate electronic taps have higher mean per event water consumption than conventional taps. It was also estimated that conventional taps have greater flow rate than the electronic taps, while the latter have longer mean event duration. Similarly, it was observed that the event duration is governed mainly by the user behaviour and is independent of the taps' flow rate. The findings suggest that as water consumption of domestic taps does not increase or decrease linearly with the nominal flow rate of taps, the performance of the low flow taps require to be carefully assessed.

The data of the recorded events provided information that indicates that practically event durations have greater implications on the water consumption by domestic taps than the nominal flow rate. This brings the focus on the importance of non-structural water efficiency measures (measures that can influence user behaviour) such as user education or pricing in achieving the required water efficiency targets. In addition to this, the observed data shows that over 80% of the water consumption was via hot water taps. The amount and source of energy (gas electricity) required to produce hot water has a direct bearing on the extent of greenhouse gas/carbon emissions.

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8.0 REFERENCES

Ball, A., Styles, M. Stimson, K., and Kowalski, M. (2003). Measuring microcomponents for demand forecasting. In Maksimovic C, Butler D and Memon F A (eds). .*Advances in Water Supply Management.* Proceedings of the International Conference on Computing and Control for Water Industry, London Belkens Publisher. 673-680.

Beal, C. D. and Stewart, R. A. (2014) Identifying Residential Water End-Uses Underpinning Peak Day and Peak Hour Demand. *Journal of Water Resources Planning & Management*, DOI: 10.1061/(ASCE)WR.1943-5452.0000357

BRE (2015). "New Home Quality Mark puts consumers at the heart of house building," Building Research Establishment (BRE) briefing note. http://www.bre.co.uk/news/New-Home-Quality-Mark-puts-consumers-at-the-heart-of-house-building--1059.html (May 19, 2015)

Boarder, P., Murphy, A., and Hooper, B. (2009). Preston Water Efficiency Initiative. Final Report. [Online]. Waterwise. Available from: http://www.waterwise.org.uk/data/resources/31/preston-water-efficiency-initiative-final-report-march-2009-waterwise-with-partners.pdf . Accessed on 13/03/2015.

Clarke, A., Grant, N. and Thornton, J. (2009). Quantifying the energy and carbon effects of water saving. [Online]. The Environment Agency and Energy Saving Trust. Available from: http://www.elementalsolutions.co.uk/wp-content/uploads/2012/08/i-2504_EST_Water_report_.pdf . Accessed on 13/03/2015.

CLG. (2009). The Water Efficiency Calculator for new dwellings. [Online]. Department of Communities and Local Governments. Available from: http://www.planningportal.gov.uk/uploads/br/water_efficiency_calculator.pdf. Accessed on 13/03/2015.

CLG (2010). Code for Sustainable Homes: Technical Guide. [Online]. Department for Communities and Local Governments. Available from: http://www.planningportal.gov.uk/uploads/code_for_sustainable_homes_techguide.pdf . Accessed on 13/03/2015.

Committee on Climate Change (2015). "The Climate Change Act and the UK regulations." (http://www.theccc.org.uk/tackling-climate-change/the-legal-landscape/global-action-on-climate-change /) (May 19, 2015).

Defra (2008). Future Water. The Government's Water Strategy for England. [Online]. Department for Environment, Food and Rural Affiars. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69346/pb13562-future-water-080204.pdf . Accessed on 13/03/2015.

Defra (2009). Enhanced Capital Allowance (ECA) Scheme for Water Efficient Technologies. [Online]. Department for Environment, Food and Rural Affiars. Available from: http://www.defra.gov.uk/environment/quality/water/conserve/documents/signed-wtl-product-list-2009.pdf. Accessed on 13/03/2015.

Environment Agency (2008). Greenhouse gas emissions of water supply and demand management options. [Online]. Environment Agency. Available from: http://publications.environment-agency.gov.uk/pdf/SCHO0708BOFV-e-e.pdf Accessed on 13/03/2015.

Environment Agency (2009a). Water for People and the Environment. Water resources strategy for England Wales. [Online]. Environment Agency. Available from: http://publications.environment-agency.gov.uk/pdf/GEHO0309BPKX-E-E.pdf. Accessed on 30 June 2010.

Environment Agency (2009b). The Environment Agency's Representation on Dee Valley Water's Draft Water Resources Management Plan. [Online]. Environment Agency. Available from http://publications.environment-agency.gov.uk/pdf/GEHO0509BQCF-E-E.pdf Accessed on 01 July 2010

FEMP (2002). Domestic Water Conservation Technologies: [Online] US Federal Energy Management Programme: Office of Energy Efficiency and Renewable Energy. DOE/EE-0264. [Online]. Available from: http://www1.eere.energy.gov/femp/pdfs/22799.pdf Accessed on 13/03/2015.

Fidar A., Memon F.A. and Butler D. (2010). Environmental implications of water efficient micro-components in residential buildings. *Science of the Total Environment*; 408 (23), 5828 – 5835

Gleick, P., Haasz, D., Henges-Jeck, C., Srinivasan, V., Wolff, G., Cushing, K. and Mann, A. (2003). Waste not, Want not: The Potential for Urban Water Conservation in California. [Online]. Pacific Institute. Available from: http://www.pacinst.org/wp-content/uploads/sites/21/2013/02/waste_not_want_not_full_report3.pdf . Accessed on 13/03/2015

Hills, S., Birks, R., and Mckenzie, B. (2002). The Millennium Dome "Watercycle" experiment: *Water Science and Technology*, 46 (6-7), 233-340

HMR&C (2014). Enhanced capital allowances schemes for energy saving and water efficient technologies. Enhanced Capital Allowances for Water Efficient Technologies. . Available from: https://www.gov.uk/government/publications/enhanced-capital-allowances-schemes-for-energy-saving-and-water-efficient-technologies Accessed on 13/03/2015.

Marshallsay, D., Trew, J., and Waylen, C. (2007). Assessing the cost of compliance with the code for sustainable homes. [Online]. Environment Agency. Available from: http://www.environment-agency.gov.uk/static/documents/Business/scho0107bltree_1746081.pdf Accessed on 30 June 2010.

Mayer, P., DeOreo,W., and Lewis, D. (2000). Seattle Home Water Conservation Study: the impacts of high efficiency plumbing fixture retrofits in single-family homes. Seattle Public Utilities and the United States Environmental Protection Agency.

Mayer, P., DeOreo, W., Towler, E., and Lewis, D. (2003). Evaluation of High Efficiency Indoor Plumbing Fixture Retrofits in Single-Family Homes in the East Bay Municipal Utility District Service Area. East Bay Municipal Utility District and the US Environmental Protection Agency.

McDonald, A., Bellfield, S., and Fletcher, M. (2003). Measuring microcomponents for demand forecasting. *Advances in Water Supply Management*. Proceedings of the International Conference on Computing and Control for Water Industry, London. Maksimovic C, Butler D and Memon F A(eds). Belkens Publisher. 683-691.

MTP (2008a). BNWAT22: Domestic water consumption in domestic and non-domestic properties. [Online]. Market Transformation programme. Version 1.0. Available from: http://www.mtprog.com/cms/product-strategies/subsector/water-using-products Accessed on 29 June 2010.

MTP (2008b). BNWAT26: Household Tapware – an overview. [Online]. Market Transformation programme. Version 1. Available from: http://www.mtprog.com/cms/product-strategies/subsector/water-using-products Accessed on 29 June 2010.

MTP (2008c). BN DW Taps: Briefing Note relating to projections of internal tap water consumption. [Online]. Market Transformation programme. Version 1. Available from: http://www.mtprog.com/cms/product-strategies/subsector/water-using-products Accessed on 29 June 2010.

Neve, A. (2006). Water Efficient Studies. Annual Report 2005/2006. [Online]. Portsmouth Water. Available from: http://www.portsmouthwater.co.uk/environment/WtrEfficStudiesJuly2006.pdf. Accessed on 30 June 2010

Roberts, P. (2005). 2004 Residential End Use Measurement Study. [Online]. Yarra Valley Water Australia. Available from: http://www.manuelectronics.com.au/pdfs/YarraValleyWater2004REUMS.pdf. Accessed on 13/03/2015.

SES (2015). "How will the New National Technical Standards (NNTS) affect you?" Stanstead Environmental Services (https://www.linkedin.com/pulse/how-new-national-technical-standards-nnts-affect-you-daniel-judd (May 19, 2015).

UK Government (2010). The Building Regulations 2000. Part G: Sanitation, hot water safety and water efficiency. [Online]. H M Government. Available from: http://www.planningportal.gov.uk/uploads/br/100312_app_doc_G_2010.pdf. Accessed on 13/03/2015.

Wilkenfeld and Associates Pty Ltd (2003). A Mandatory Water Efficiency Labelling Scheme for Australia. [Online]. Environment Australia. Available from: http://www.waterrating.gov.au/resource/final-report-mandatory-water-efficiency-labelling-scheme-australia . Accessed on 13/03/2015.

Figure 1   Conventional mixer tap

Figure 2 Electronic tap

Figure 3 Thermostatic mixer valve

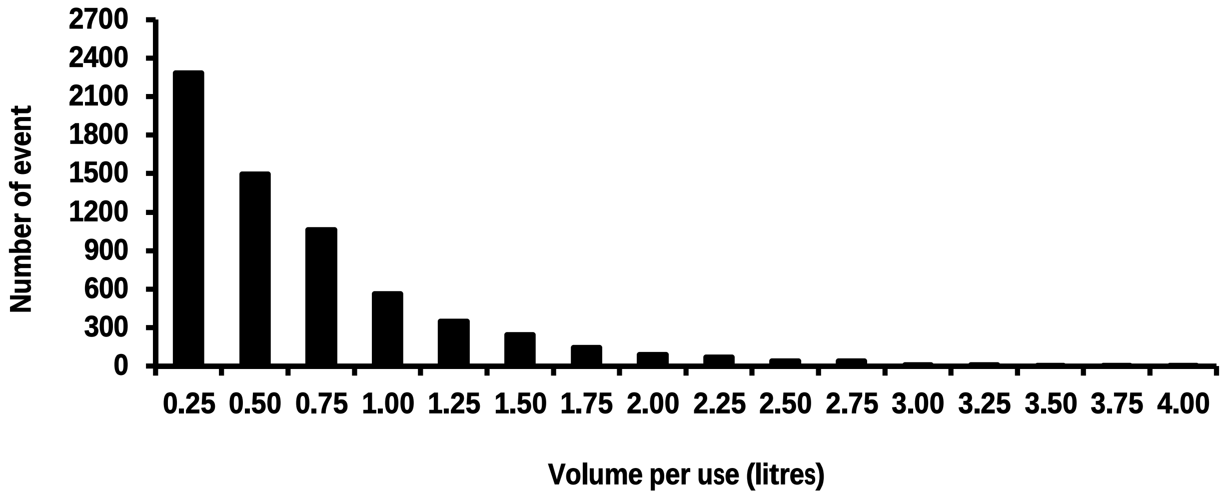

Figure 4 Distribution of water consumption per use event for conventional mixer taps

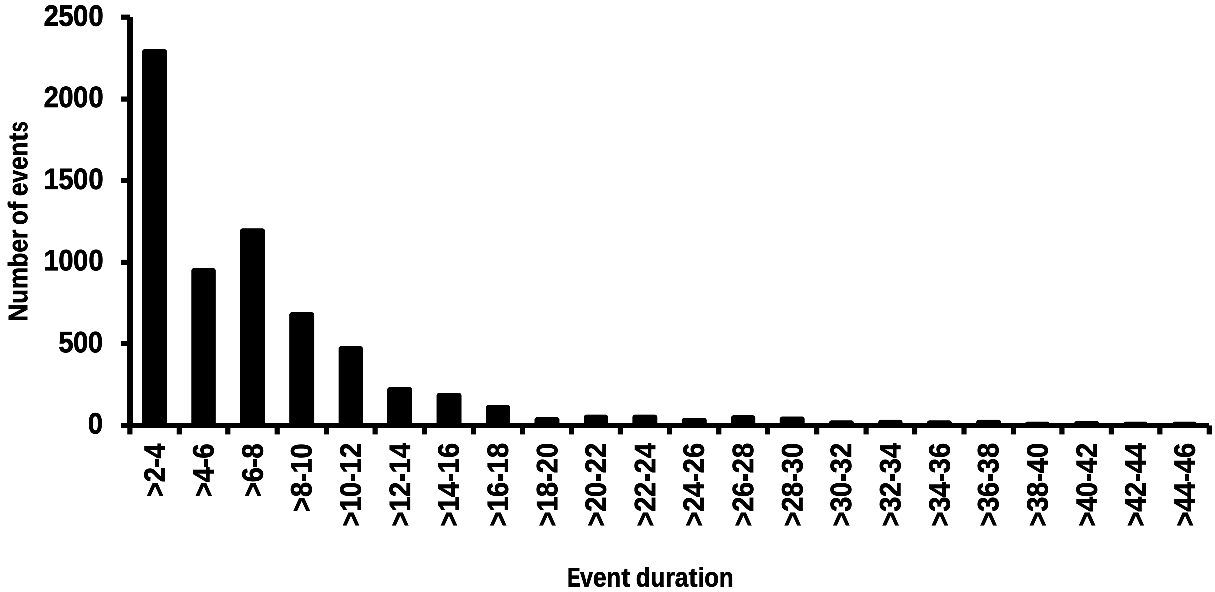

Figure 5 Distribution of event duration for conventional mixer taps

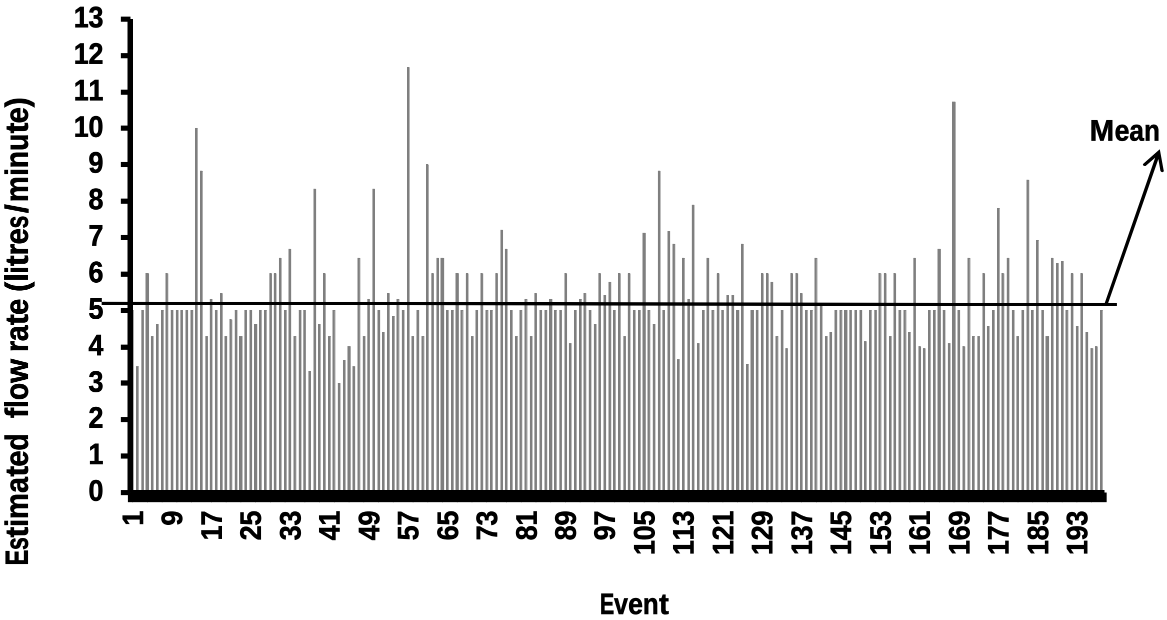

Figure 6 Sample of the estimated flow rates of events for conventional taps

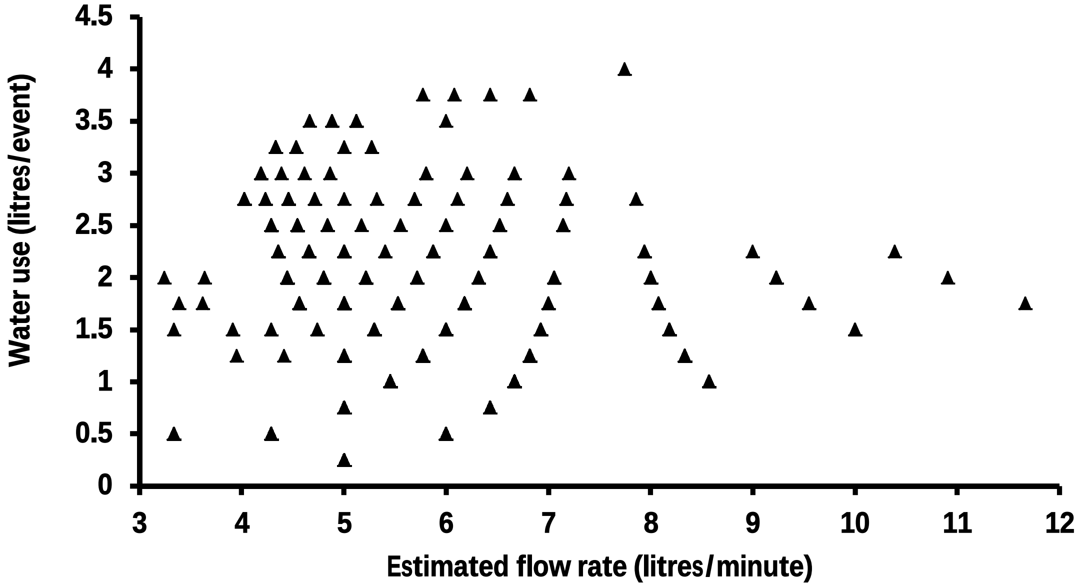

Figure 7 Influence of flow rates on water consumption for conventional taps

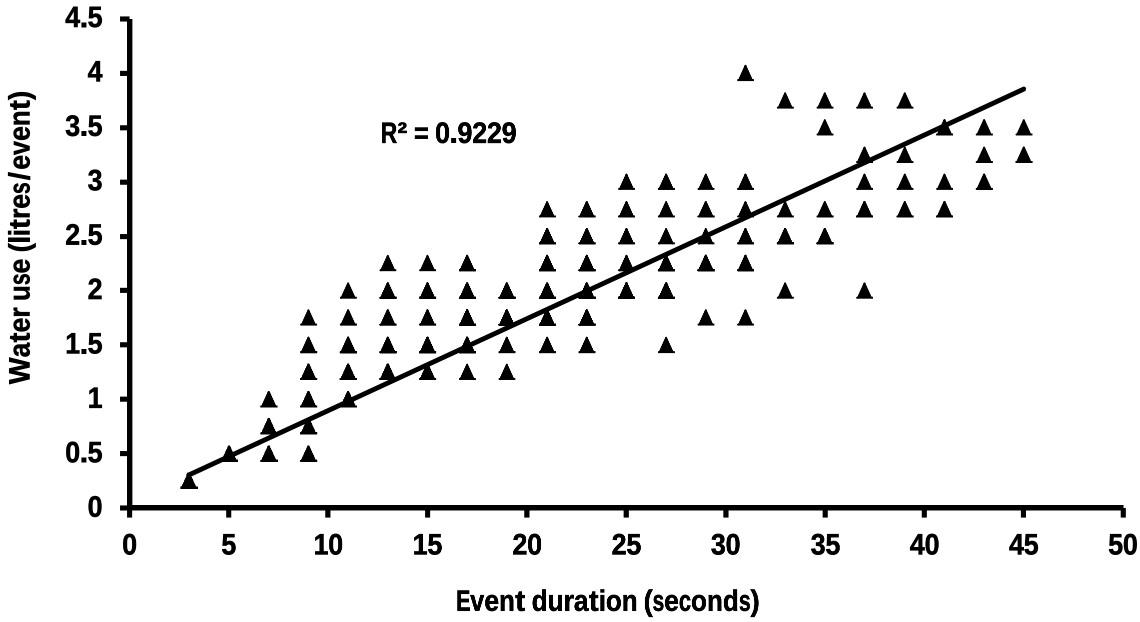

Figure 8 The relationship between event duration and water consumption for conventional taps

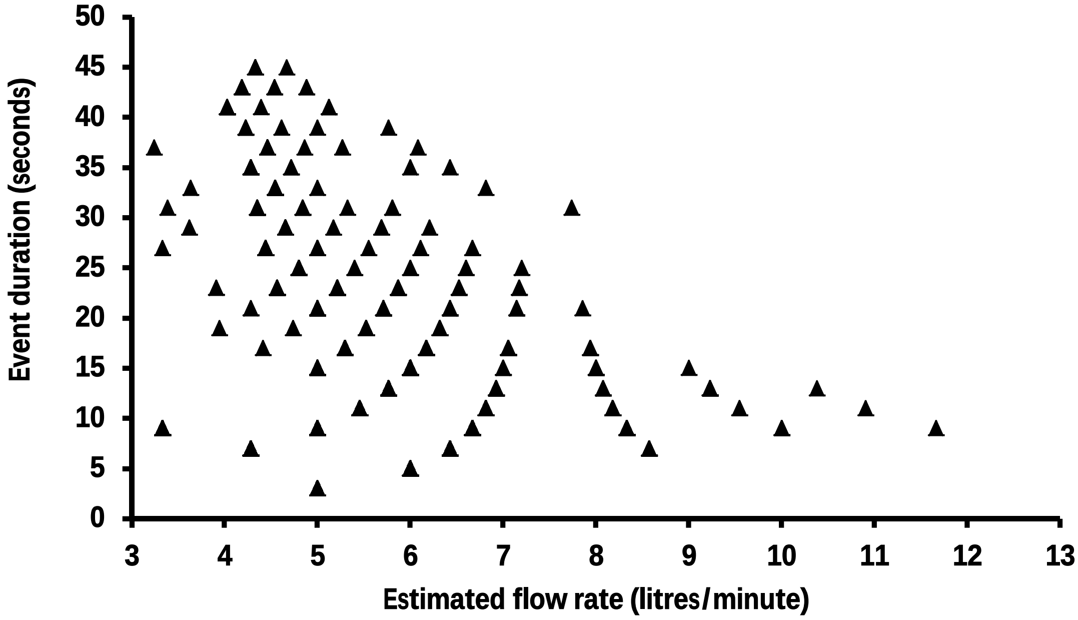

Figure 9 The influence of the tap flow rate on event duration

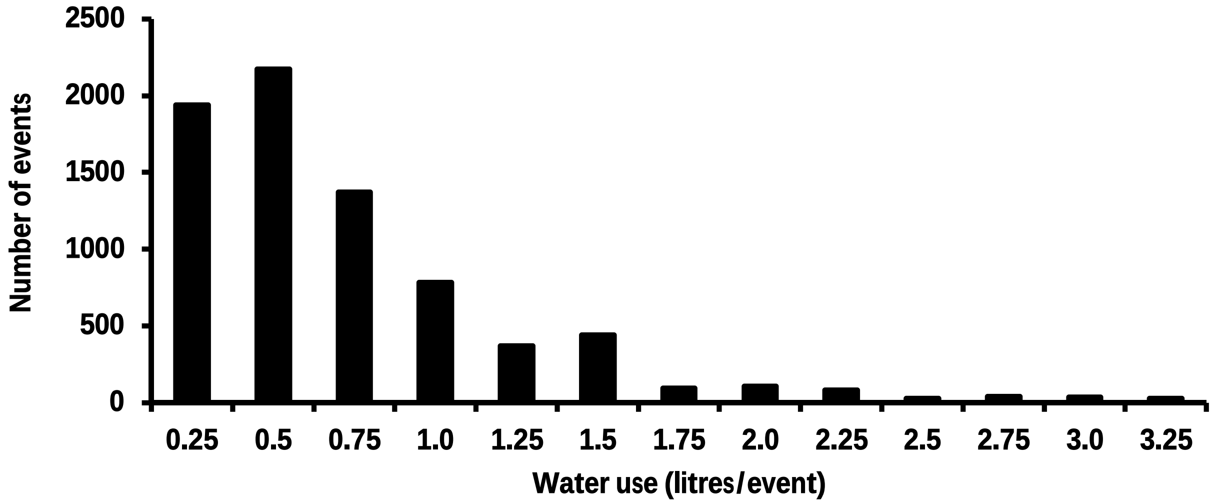

Figure 10 Distribution of water consumption per use event for electronic taps

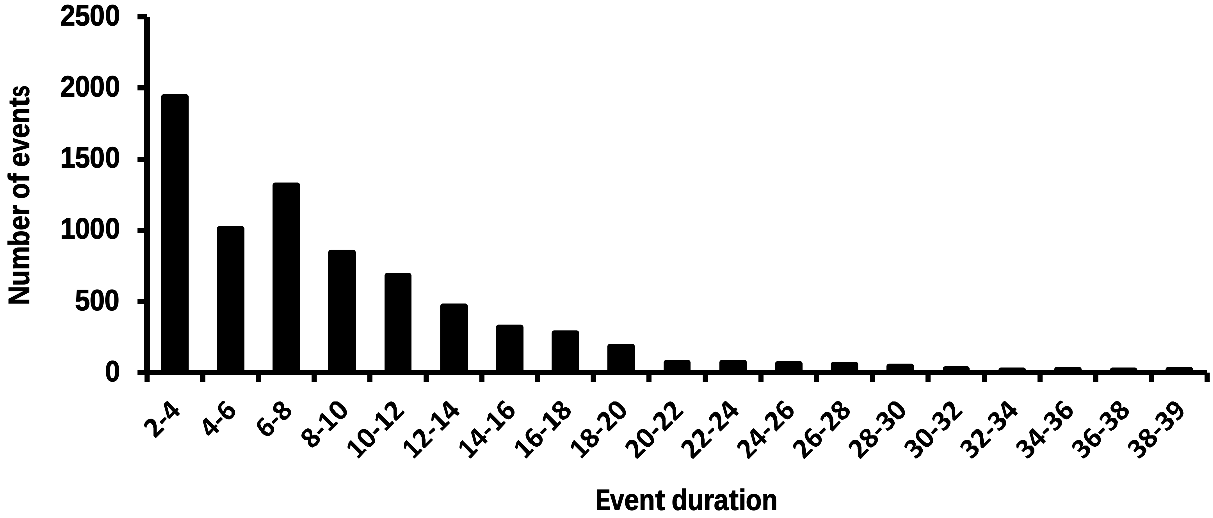

Figure 11 Distribution of event duration for electronic taps

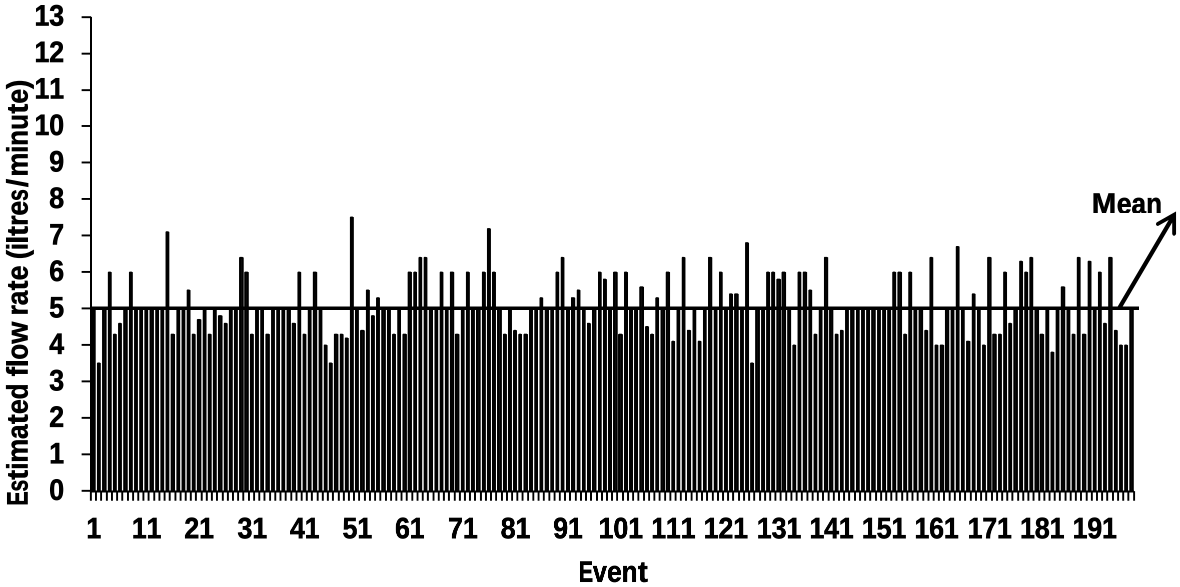

Figure 12 Sample the estimated flow rates for the electronic taps

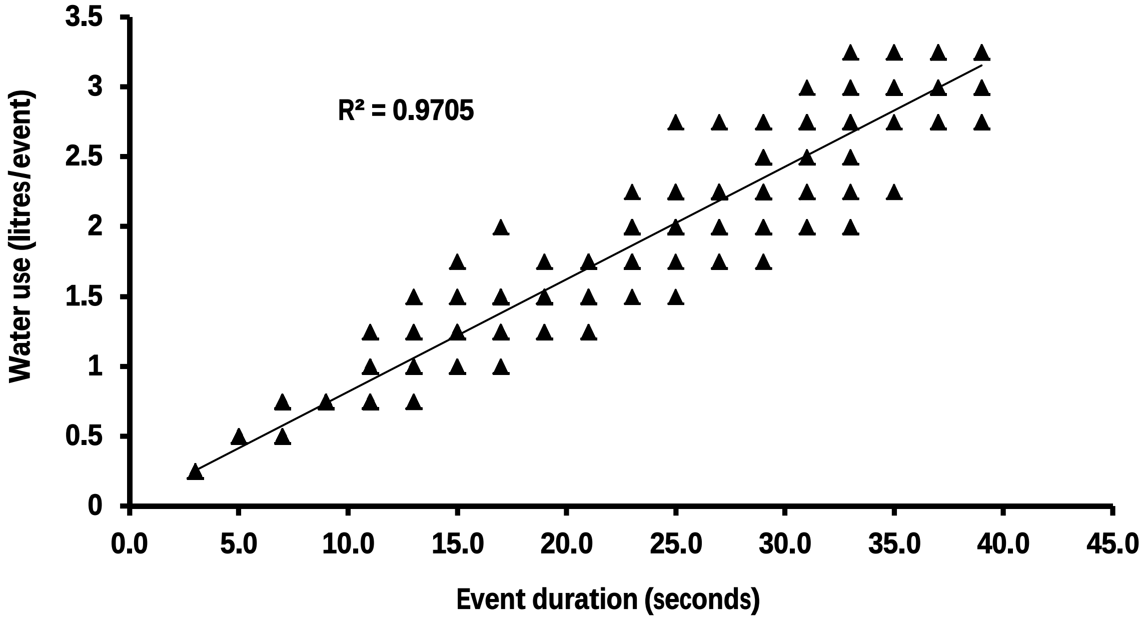

Figure 13 Influence of event duration on water consumption for electronic taps

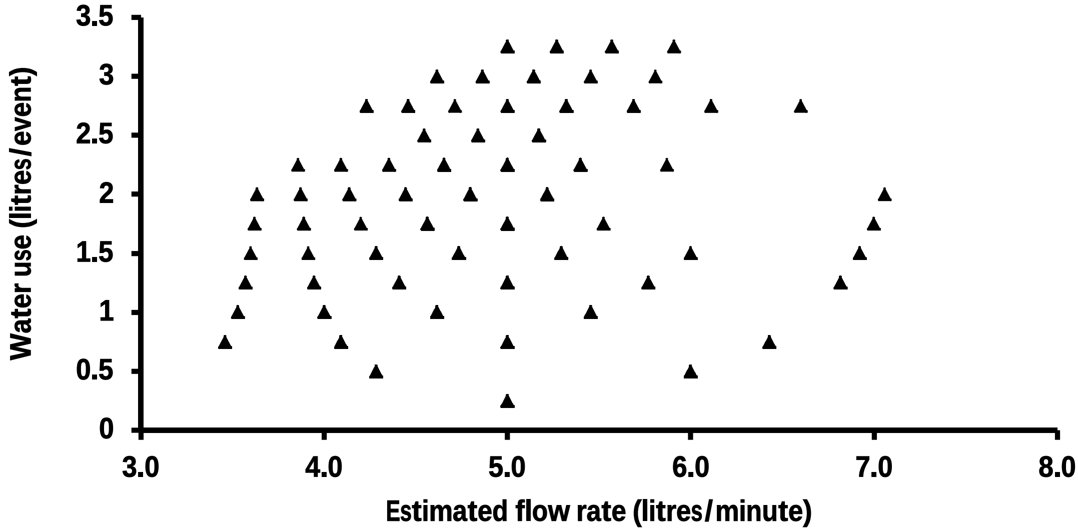

Figure 14 Influence of flow rates on the water consumption for electronic taps

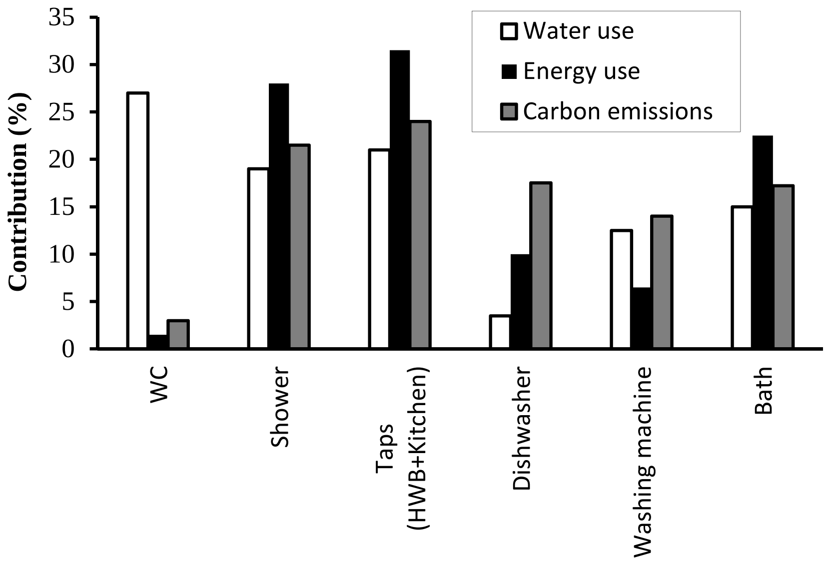

Figure 15 Relative share of micro-components towards water and energy consumption and resulting carbon emissions (adopted from Fidar et al, 2010)