Urban Water Journal

ISSN: 1573-062X (Print) 1744-9006 (Online) Journal homepage: http://www.tandfonline.com/loi/nurw20

Economic implications of water efficiency measures I: assessment methodology and cost-effectiveness of micro-components

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

To cite this article: A. M. Fidar, F. A. Memon & D. Butler (2016): Economic implications of water efficiency measures I: assessment methodology and cost-effectiveness of micro-components, Urban Water Journal, DOI: 10.1080/1573062X.2016.1223859

To link to this article: http://dx.doi.org/10.1080/1573062X.2016.1223859

URBAN WATER JOURNAL, 2016
http://dx.doi.org/10.1080/1573062X.2016.1223859

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS

Economic implications of water efficiency measures I: assessment methodology and cost-effectiveness of micro-components

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

Centre for Water Systems, University of Exeter, Exeter, UK

ABSTRACT
Economic efficiency has recently become one of the primary objectives of water management decisions. In particular, as vulnerability of freshwater systems has become evident and there is a trend for water supply managers to look towards water demand management, identifying the cost of such measures is becoming increasingly important. In England and Wales, Part G of the Building Regulations requires that water consumption of a new dwelling should not be more than 125 litres/capita.day. However, while compliance with this is determined by the water use characteristics of the installed micro-components (WCs, showers, basin taps, kitchen taps, baths, dishwashers and washing machines), the cost to consumers resulting from installing water efficient micro-components is not clear. This paper evaluates the potential economic implications of water saving micro-components, assessed from the consumers' perspective. A methodology has been developed and implemented to assess the cost-effectiveness of several types of water efficient micro-components. A range of cost assessment methods was applied, and critically reviewed comparing their outcomes. It was found that conventional cost assessment methods are unsuitable for identifying the least cost options to consumers. Of the applied methods, the modified annualised assessment method appears to be a relatively better option.

ARTICLE HISTORY
Received 31 October 2015
Accepted 11 July 2016

KEYWORDS
Water demand management; annualised cost; average incremental cost; economic efficiency; energy use; micro-components; sustainability; water consumption

Introduction

In recent years, economic efficiency has become one of the primary objectives of water management decisions (Mitchell *et al.* 2007, Hajkowicz and Higgins 2008, Aulong *et al.* 2009). In conventional cost analysis, urban water decision makers seek to optimise resources consumption for a given programme, while minimising the resulting undesirable consequences. This requires water management interventions to go through a rigorous and systematic appraisal which have technical, economic, environmental and social dimensions (Herrington 2003).

In particular, as the vulnerability of freshwater systems has become evident (Arnell and Delaney 2006, Cromwell *et al.* 2007, Dworak *et al.* 2007, EEA 2007, Mukheibir 2008), there is a trend for water supply managers to look towards water demand management (WDM) (Smith *et al.* 2015). Study of micro-components (WC, showers, baths, basin taps, kitchen taps, dishwashers and washing machines) provides a fundamental basis for evaluating the effectiveness of a range of WDM strategies (Beal *et al.* 2013). The long term monitoring of water efficiency programmes based on water efficient micro-components have shown considerable water savings (Lee and Tansela 2011). In the UK, water service providers are required to use micro-component based data in demand forecasts and planning (EA 2009). The regulatory initiatives aimed at reducing per capita water consumption such as Home Quality Mark (BRE 2015) and New National Technical Standards (SES 2015) consider micro-components based WDM strategies as a way forward.

However, while compliance with this is determined by the water use characteristics of the installed micro-components, the cost to consumers, resulting from installing water efficient micro-components is not clear. Assessing such costs will require an agreed and consistent approach that can enable calculating the unit cost of water consumed or saved through a given set of micro-components.

Most of the earlier studies conducted to evaluate the cost of urban WDM strategies focused on water supply and wastewater operations (White and Howe 1998, White and Fane 2002, Fane *et al.* 2003, Mitchell *et al.* 2007, Aulong *et al.* 2009, Chong *et al.* 2008, Hughes *et al.* 2009, Maurer 2009). Marshallsay *et al.* (2007) investigated the capital cost of water efficient micro-components for the *Code for Sustainable Homes* (DCLG 2008), whereas Bochereua *et al.* (2008) and the EA (2007) examined the cost of retrofitting certain water saving micro-components/fittings from the perspective of water service providers.

This paper evaluates the potential economic implications of water efficient micro-components from the perspective of households. It also analyses the suitability of the various economic assessment methods in evaluating the performance of water using micro-components from the perspective of consumers. The analyses have resulted in the development of a modified approach to quantify unit costs of micro-components keeping in view the water consumer's perspective.

CONTACT F. A. Memon f.a.memon@exeter.ac.uk

Methodology

Cost-benefit analysis, payback period and cost-effectiveness analysis are broadly used to evaluate the economic performance of an activity. *Cost-benefit analysis* is inappropriate for the evaluation of investments that generate social or environmental externalities (Gerasidi *et al.* 2003). Therefore, *cost-effectiveness and payback period* methods are used in this study.

The *payback period* method seeks to answer the question of "how long will it take for savings (relative to the baseline) to pay for the cost of water efficiency measures employed.

Cost-effectiveness analysis compares alternative ways of achieving given ends rather than whether an alternative is economically beneficial in its own right (Herrington 2003, Mitchell *et al.* 2007). *Average Incremental Cost* and *Annualised Cost* are the two most commonly used methods (Mitchell *et al.* 2007) to evaluate performance of urban water systems.

Average Incremental Cost (AIC)

The Average Incremental Cost (or levelised cost) method uses life cycle analysis approach to estimate the cost per volume of water (supplied or conserved), based on the difference between the alternative and a baseline (Smout *et al.* 2008). Least cost alternatives are those with the lowest incremental difference or "least cost" relative to this baseline. The Average Incremental Cost (AIC) is calculated by dividing the net present value (NPV) of all the costs, including capital and operational expenditures by the net present value of the volume of water consumed or saved each year over the anticipated lifespan of the alternative (Equation (1)).

$$(AIC)_i = \frac{(PV)_{Ci} + (PV)_{Oi} - (PV)_{OSi}}{(PV)_{WSi}} \tag{1}$$

Where,

For each micro-component under consideration, $(AIC)_i$ is the Average Incremental Cost (£/m^3), $(PV)_{Ci}$ is the present value of its capital cost (£), $(PV)_{Oi}$ is the present value of the operational cost, $(PV)_{OSi}$ is the present value of the *avoided cost* (i.e. cost saved as a result of reduced water consumption) resulting from not using water saved by the micro-component (£) and $(PV)_{WSi}$ is the net present value of the volume of water saved by the micro-component (m^3). In Equation (1), the denominator (total water supplied/conserved) has been discounted.

The method is widely used in the water industry (White and Howe 1998, White and Fane 2002, Fane *et al.* 2003, Smout *et al.* 2008) and is considered as the most appropriate metric for comparing urban water options where a study considers options that are additional to an existing system (Mitchell *et al.* 2007). The AIC method has also become a standard for water supply and WDM measures in the UK (EA 2012).

In this study, the capital cost of micro-components is based on the average retail prices at the time of the data collection. It was assumed that manufacturers' warranties cover the maintenance cost of showers, internal taps, baths and WCs. Regarding white goods (dishwashers and washing machines), extended manufacturers' warranties have been assumed to cover the anticipated life-span of the goods. The average life span of micro-components found in the literature varies widely. For example, the average life span of washing machines ranges from 8 to 16 years (Gleick *et al.* 2003, EA 2007, MTP 2008). Similarly, Presutto *et al.* (2007) found the average economic lifetime of dishwashers to be 10 – 12 years. The average age of more than 1700 dishwashers in European countries was found to be around 4.7 years (Presutto *et al.* 2007). MTP (2010) assume the typical lifespan of a dishwasher as approximately 13 years. In this study, an average life span of 10 years has been used.

In addition, a discount factor of 4.5% has been used to take the time value of the money into account, which is consistent with UK water industry planning guidelines (EA 2009).

In the new developments, where micro-components are yet to be installed, a base case is required to compare the cost of the various water efficient strategies. Table 1 provides the details of the water use characteristics of the micro-components selected as a base case. For each micro-component, the least water efficient model considered in the study was selected.

As the operational cost is a function of the resources consumption, the amounts of water and energy use through various micro-components were quantified.

Annualised cost

The annualised unit cost approach, widely used for WDM options (Gleick *et al.* 2003, A & N Technical Services Inc and Gary Fiske and Associates 2006, Mitchell *et al.* 2007, Aulong *et al.* 2009), spreads the capital cost of an alternative across the anticipated lifespan of that alternative (Equation (2)). The approach takes the time value of money into account by annualising the initial cost at a particular discount rate (Fane *et al.* 2003). This capital cost is then added to annual operating and maintenance costs that are assumed to be constant (Equation (3)).

$$A_{Ci} = C\left[\frac{r}{1-(1+r)^{-n}}\right] \tag{2}$$

$$AC_i = \frac{A_{Ci} + O}{W} \tag{3}$$

Where,

For each micro-component, A_{Ci} is the annualised capital cost (£), C is the acquisition cost (£), O is the ownership cost (£), n is the life time of the technologies/option (years), W is the volume of water consumed (m^3), AC_i is the annualised unit cost (£/m^3) and r is the discount factor. Equation (3) uses a constant volume of water annually as represented by the denominator (W).

Table 1. Water use characteristics of the base case micro-components (adopted from Memon *et al.* 2015).

Micro-components	Water use characteristics	Base case Scenario water use	Event duration (min/use)	Frequency of use (uses/capita/day)
WC	litres/use	6.0	N/A	4.8
Bath		220.0		0.4
Washing machine		60.0		0.31
Dishwasher		19.0		0.28
Shower	litres/min	12.0	5.0	0.6
Basin tap		8.0	0.67	7.2
Kitchen tap		8.0	0.67	7.2

Assessing the operational cost

In this study, water and energy consumptions are the primary factors determining the costs of ownership associated with any particular micro-component.

Water consumption

The water consumption for each micro-component has been calculated based on its water use characteristics – volume per use and frequency of use. For showers and internal taps (kitchen and basin taps), the water use is related to the flow rates and running time (event duration), assuming a linear relationship between the nominal flow rates and water consumption. Regarding baths, it has been assumed that bathing involves filling the bath to 40% of its overflow capacity (DCLG 2008). The water consumption characteristics of the micro-components are shown in Table 1.

To compare the performance of the WCs with different flushing mechanisms (single flush and dual flush), the concept of effective flushing – a ratio of full flush to part flush – has been used. A wide range of ratios (from 0.4:1 to 1:3) has been found in the literature (Roberts 2005, BRE 2006, Marshallsay *et al.* 2007, MTP 2011b). A ratio of 1:1 has been used in this study – that is for every two flushes one will be a full flush and one a part flush.

For internal taps, the study used average event duration of 0.67 minutes, which is in agreement with Marshllsay *et al.* (2007). Similarly, the average showering duration applied in the study was 5 minutes (DCLG 2008).

In the UK, water rates vary between suppliers (OFWAT 2011). There is also a difference between metered and unmetered charges. In this study, the analysis is based on the variable element of the metered option, which is determined by the volume of water supplied. The volume charges for water supply and wastewater services were assumed to be £1.24/m^3 and £1.39/m^3, respectively. The values represent the medians of the charges by the different service providers and are likely to vary in time.

Energy consumption

The energy consumption of the hot water using devices depends on the volume of water used and the temperature difference between the cold and hot water. For showers, internal taps and baths, the ratio of hot and cold water is assumed to be 1:1. The temperature rise is determined with the assumption that the preferred tap water temperature is 40 °C (Fidar 2010).

White goods (washing machines and dishwashers) and electric showers considered in this research use electricity to heat water internally. The energy consumption of the white appliances is based on the manufacturers' energy efficiency labelling and has been calculated to reflect the energy requirement for different wash programmes. For example, for washing machines, it has been assumed that a 60 °C wash (standard programme) uses 40% less energy than a 90 °C wash programme, and the 40 °C wash programme uses 40% less than a 60 °C. Similarly, for dishwashers, it has been estimated that the standard wash programme (65 °C) uses 34.6% more energy than the 55 °C programme (Fidar 2010, MTP 2011a, 2011b).

The energy consumption (in kWh) of the other micro-components (showers, internal taps and baths) is calculated using Equation (4) (Gettys *et al.* 1989),

$$E = \frac{mc\Delta T}{3.6x10^{6}\eta} \tag{4}$$

Where E is the energy requirement(kWh), m is the mass of the water used (kg), c is specific heat capacity of water (4190 J/kg/°C), ΔT is the change in water temperature (°C), and η is the efficiency of the heating system. The constant is the conversion factor from Joules to kWh.

In the UK, as gas and electricity tariffs vary with location, service providers and the amount of energy used, it is difficult to derive a value that could represent the whole country. Therefore, in this study, typical values for the London region have been used which are 19.86 Pence/kWh and 7.577 P/kWh for electricity and gas, respectively. These are likely to change in response to fluctuations in oil and gas prices.

Results and discussion

Influence of water and energy use on capital cost

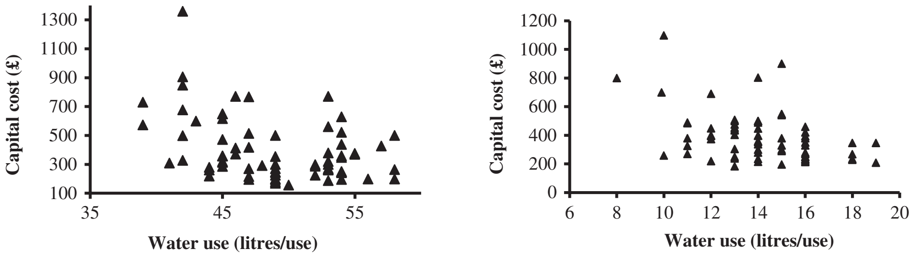
An extensive market survey was done on the availability of different models of water using appliances/micro-components with a view to collect information on their respective costs and water/energy saving potential. Thousands of alternatives were found in the market, but 537 models have been selected in this analysis, based on their performance in terms of resources consumption and capital costs (Table 2).These micro-components were populated in a technology library serving as a search space for an assessment tool as explained in Fidar *et al.* (2016).

The capital cost of the models varies considerably and was found to be independent of their water and energy consumption. For example, Figure 1 shows the capital cost of the devices as a function of their resources consumption. Some of the less resources efficient white goods were found to be more expensive than some of the energy and water efficient ones.

Similarly, the capital cost of showers and internal taps is independent of the micro-components' water efficiency – that is low

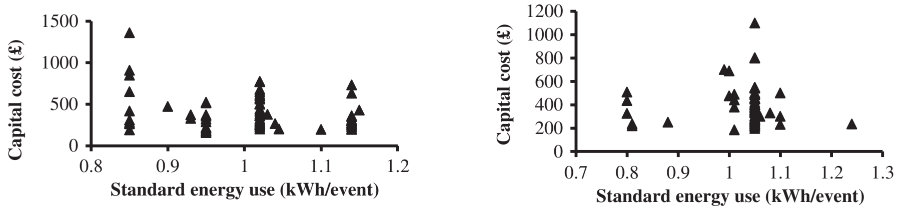
Table 2. Characteristics of the micro-components in the study.

Micro-components	Population sample	Water use characteristics	Water use range	Energy use range (kWh/use)	Capital cost (£)
Washing machine	117.0		39.0 – 92.0	0.85 – 1.15	157.0 – 1,350.0
Dishwasher	103.0	litres/use	8.0 – 19.0	0.64 – 1.24	184.0 – 1,099.0
Bath	69.0		99.0 – 220.0	N/A	100.0 – 628.0
WC	32.0		3.4 – 6 l	N/A	131.0 – 414.0
Shower	72.0		3.4 – 12.0	N/A	30.0 – 428.0
Kitchen tap	85.0	Litres/min	2.0 – 12.0	N/A	76.0 – 562.0
Basin tap	59.0		1.7 – 8.6	N/A	40.0 – 190.0



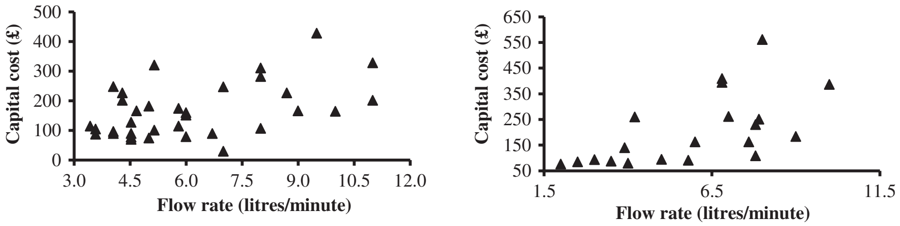
(a) Water use of washing machines and their capital cost

(b) Water use of dishwashers and their capital cost



(c) Energy use of washing machines and their capital cost

(d) Energy use of dishwashers and their capital cost



(e) Flow rate of showers and their capital cost

(f) Flow rate of internal taps and their capital cost

Figure 1. The relationship between resources consumption of the white goods and their capital cost.

flow devices are not necessarily more expensive than high flow models. Commonly, the capital cost of the water using micro-components tended to reflect design, fashion and brand, rather than their resource efficiency. An investigation into the other factors influencing the cost/price of micro-components was beyond the scope of the undertaken research.

Economic evaluation of micro-components using the Average Incremental Cost (AIC) assessment method

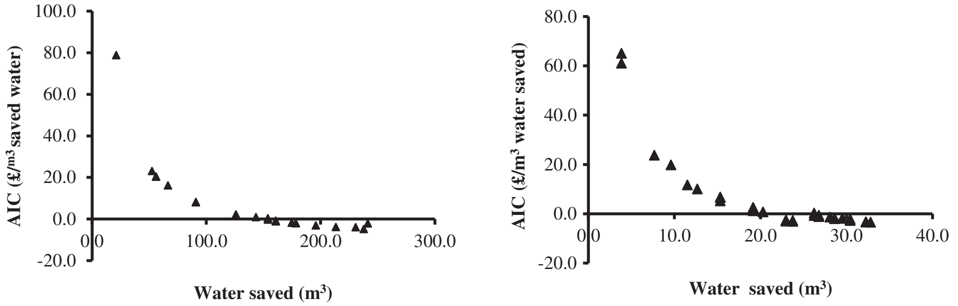
The AIC of the individual micro-components showed an inverse, non-linear relationship with the volume of water saved, compared to the baseline. That is, the AIC associated with a given model of micro-component increases as the amount of water saved by the model under consideration decreases. The performances of the various micro-components are illustrated in Figure 2. The negative values in certain cases indicate cost savings compared to the baseline model as shown in Table 1.

The results presented in the figure indicate that, for each individual micro-component, water saving models perform better than less resource efficient ones. However, the cost of achieving the desired water efficiency through the less frequently used micro-components such as baths, dishwashers and washing machines was found to be considerably higher.

In particular, white goods have become much more water and energy efficient over the past two decades (EA 2007), reducing the volume of water and energy saved and hence the avoided cost resulting from options under consideration and ultimately increasing the AIC per unit water saved (Equation (1)). The average incremental cost of water saved through micro-components was found to be insensitive to the capital cost of the appliances.

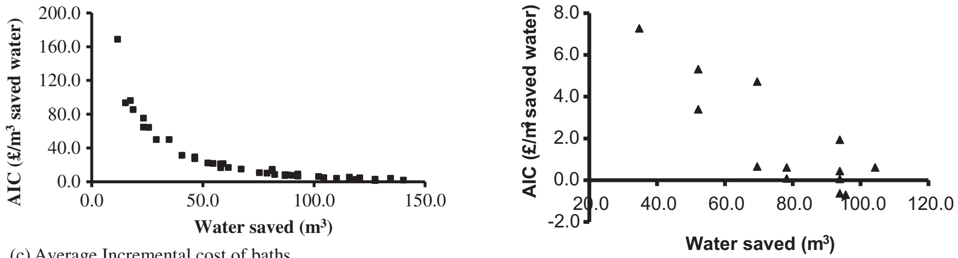
It was also observed that the AIC assessment method ranks options differently from the annualised method. This is because the annualised unit cost method uses a constant single figure for yearly water consumption in the calculation, whereas the AIC applies the net present value of the volume of water conserved each year by the option under consideration over its anticipated lifespan. The annualised assessment method favours the options that result in higher water consumption and is therefore suitable to evaluate the performance of the water supply options. Conversely, the AIC method favoured options which led to greater water savings. In addition, the AIC method can be used for both water supply and WDM options.

The AIC method appears to be inappropriate for new buildings where micro-components are being purchased for the first time or in existing buildings where an older micro-component has to be replaced. This is because water efficient micro-components are not necessarily more expensive than conventional ones, eliminating the additional cost and consequently violating the basics of the AIC cost assessment method. Gleick *et al.* (2003) assumed water efficient devices were more expensive than conventional ones. In such cases, the additional capital cost associated with the water saving device could be considered as the marginal capital cost. The approach considers the capital cost of the conventional device/micro-component as a sunk cost, as it cannot be avoided.



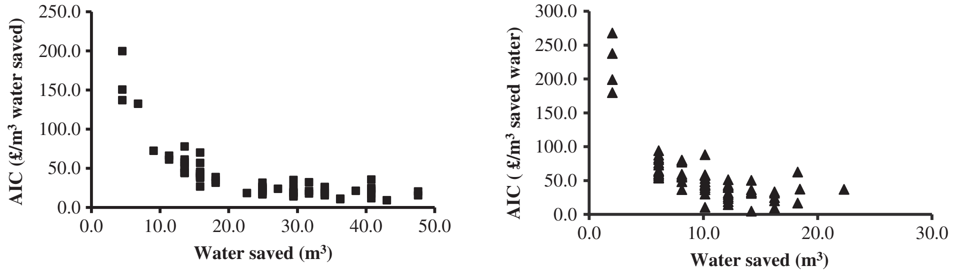
(a) Average Incremental cost of internal taps

(b) Average Incremental cost of showers



(c) Average Incremental cost of baths

(d) Average Incremental cost of WCs



(e) Average Incremental cost of washing machines

(f) Average Incremental cost of dishwashers

Figure 2. Average Incremental Cost of water saved by different micro-components.

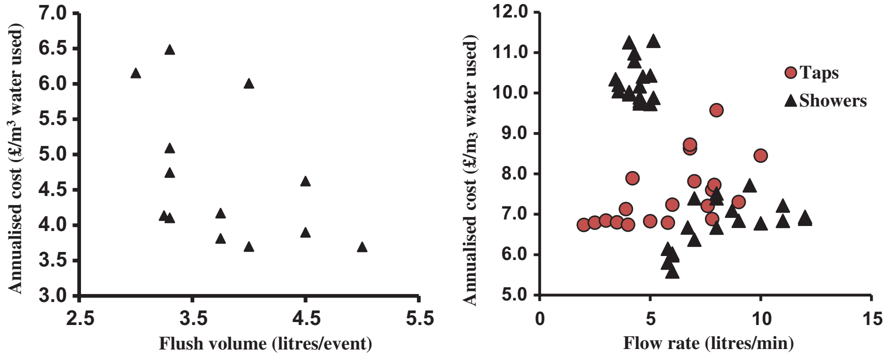
Another drawback with this method is discounting future water demand to its present value. It is unrealistic to discount the services provided by the water using micro-components, as the demand for the services cannot be brought forward. For example, WC flushing or dishwashing will be required in the future as much as they are required at present.

Additionally, at water company level, the volume of water saved can have direct cost implications, but at consumer level the case becomes more complicated. On other occasions, the marginal capital cost is too high to be offset by the operational cost savings associated with using less water and energy, making the water efficient measures less attractive to consumers.

Economic evaluation of micro-components using the annualised assessment method

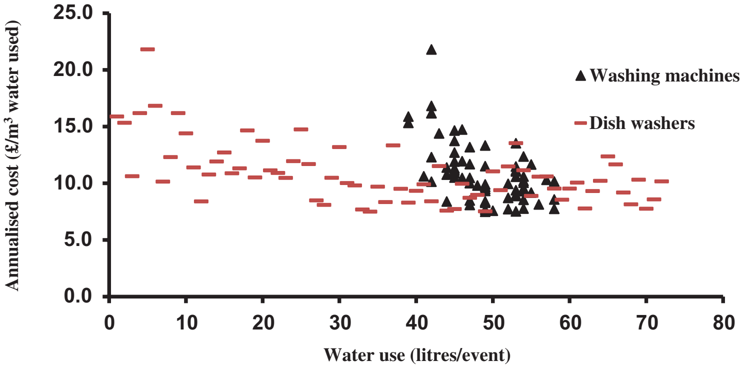
The annualised unit cost of water used is inversely proportional to the volume of water used (Equation (3)). Those micro-components with a higher water consumption, such as internal taps, showers and WCs, have a reduced unit cost (Figure 3) compared to those with relatively lower water consumption such as dishwashers and washing machines. Among the individual micro-components, water efficient models with a high capital cost resulted in a greater unit cost. For instance, two models of basin taps had similar capital costs but different flow rates – one delivered 2 litres/minute and the other 4.2 litres/minute. Interestingly, the tap with the lower flow rate led to a 20% higher unit cost. In addition, the study found that electric showers lead to significantly greater annualised unit cost of water used than the mixer showers, despite the fact that, in most cases, electric showers have a lower flow rate and hence reduced water consumption than mixer showers. For example, the annualised cost of 1 m^3 of water used through a 10.5[1] kW electric shower, a mixer shower with a flow rate of 6 litres/minute and a mixer shower delivering 8 litres/minute were found to be £11.3, £5.8 and £6.3, respectively. The capital costs of the showers were £75, £160 and £107 for the electric shower and the mixer showers with the flow rate of 6 and 8 litres/minute, respectively.

It is important to highlight that, based on the water and energy charges used in the assessment, the annual household operational cost associated with the electric shower and the 8 litres/minute mixer shower were £177 and £191, respectively. It is therefore clear that, when assessed from the perspective of customers, the reduced annualised unit cost associated with the less water efficient models does not indicate an improved economic efficiency. Rather it is indicative of a waste of resources as the decreased unit cost of water consumed does not increase the quantity or arguably the quality of services provided by the resource. Such outcomes indicate the inability of the method to



(a) The influence of flush volume of WCs on the annualised cost of water

(b) The influence of flow rate of taps and showers on the annualised cost of water



(c) The influence of water use of white goods on the annualised cost of water

Figure 3. The influence of micro-components' water use on the annualised cost of water.

assess the cost-effectiveness of micro-component-based water efficiency measures from the perspective of consumers.

Economic evaluation of micro-components using payback period method of assessment

The performance of the micro-components, in terms of their payback period, varies widely. Factors influencing the payback period include the capital cost of the model under consideration and the operational costs. The water efficient and cheaper models tended to have a shorter payback period. But the application of the payback method gets complicated in new buildings, as the water efficient models are not necessarily more expensive than the standard models.

The payback periods estimated in this study suggest that the white goods have a significantly longer payback than their anticipated life span, indicating that there is not a sensible economic justification for accelerated replacement of a reliably working machine with a new model unless it is used very often and water and energy charges are very high. This is in agreement with the conclusion of Herrington (2003) and Grant and Howarth (2003).

In addition, this study confirms the conclusions of earlier studies that criticise the method for overlooking the total savings generated over the entire life span of the options (Gleick *et al.* 2003, Herrington 2003). While "the shorter the payback, the better concept" is misleading, the method is still practiced in the water sector (Elemental Solution 2003).

It should be noted that, the unit cost varies based on what the water has been used for. Therefore, based on the philosophy that customers actually demand the services that the resource provides, and not the resource itself, assessing the cost of services rather than the volume of water consumed or saved by a particular measure appears more realistic. This requires a new economic approach which can deal with the above problems. Therefore, the annualised unit cost was modified to reflect this and is discussed below.

Economic evaluation of micro-components based on modified annualised cost method

In conventional cost analysis, urban water managers and decision makers seek to optimise resource consumption for a given project or programme, while minimising the resulting environmental and/or societal damage. In particular, within the context of least cost planning, water service providers consider water efficiency measures as an alternative to new or expanded water supply infrastructure. Therefore, logically, they implement water efficiency measures only when the unit cost associated with the water efficiency measure is less than that of the lowest-cost option for the new or expanded water supply. However, based on the philosophy that customers do not necessarily demand the resources, but rather they demand the services that the resource provides, there exists a need to focus on assessing the cost of services rather than the volume of water consumed or saved by a particular measure. To reflect this, the annualised unit cost technique was modified as shown in Equation (5). The modified approach addresses the cost of services provided rather than the unit cost of water supplied or saved, helping the "least cost planning" approach focus on the efficiency of water using micro-components, which constitutes the intersection between the system users and water systems. From this bottom-up approach, it is indeed easier and more realistic to assess the cost-effectiveness of a given micro-component-based water efficiency measure and identify the contributions of the various end-uses to the overall economic implications of the measure. Further details on the modified method and Equation (5) are in Fidar (2010).

The total cost per *composite strategy* (i.e. combination of micro-components delivering desired daily per capita water consumption) use can be determined with Equation (6) and is further discussed in Paper 2 (Fidar *et al.* 2016).

$$S_A = \frac{A_X + O_X}{100 * S_X} \tag{5}$$

$$S_\alpha = \sum_{A=1}^{N} S_A \tag{6}$$

where,

S_A = Annualised service cost (pence/event) associated with the chosen technology.

A_X = Capital cost (£) of the technology.

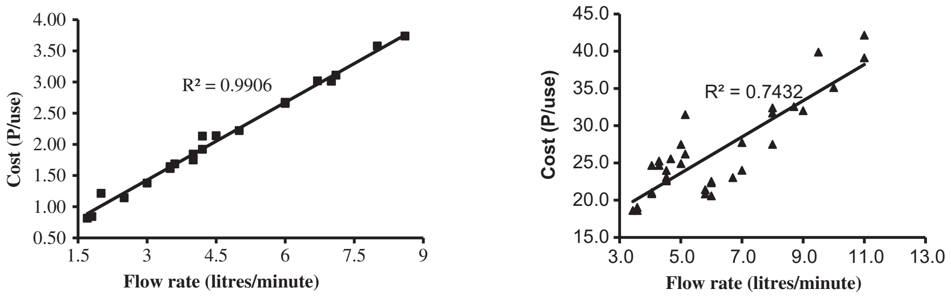
O_X = Annual operational cost (£) resulting from the technology.

$S_{X,}$ = Number of services provided by the technology.[2]

S_α = Annualised service cost (pence) per composite strategy use.

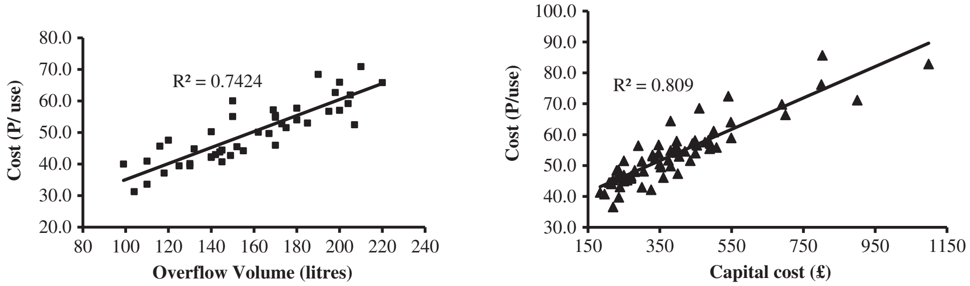
Based on the modified annualised assessment method, it was identified that the operational cost dominates the overall cost "per event" associated with showers, baths and internal taps. The cost per event associated with these micro-components increases linearly with their respective water consumption – with a correlation coefficient ranging from 74 to 99% (Figure 4).The cost per use associated with baths was higher than that of showers. This is because baths commonly have a higher capital cost and are less frequently used than showers. As noted earlier, the less frequently used micro-components tended to have relatively higher cost per use. Further systematic analysis and comparisons between different micro-components could help in quantifying the relative cost-effectiveness and facilitating prioritisation for different micro-components retrofitting/installation.

Approximately 80% of the cost per event associated with white goods is attributable to the capital cost variation of the micro-components (Figure 4). Due to their higher capital cost



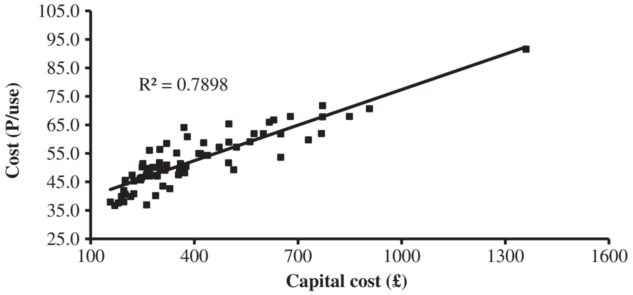
Relationship between the flow rate of internal taps and their cost per use

Relationship between the flow rate of showers and their cost per use



Relationship between the overflow capacity of baths and their cost per use

Relationship between capital cost of dishwashers and their cost per use



Relationship between capital cost of washing machines and their cost per use

Figure 4. Relationship between the flow rate of micro-components and their cost (pence) per use.

and lower frequency of use, the white goods are characterised by a greater cost per event.

Conclusions

This paper presented a methodology for the economic assessment of conventional and water saving micro-components of water use in buildings. The methodology involved an extensive survey of water using devices and fittings with respect to their water saving potential, energy consumption and associated costs. Economic implications have been assessed using three different techniques and their respective limitations are discussed. Finally, a modified assessment approach, focused on the delivery of service, has been proposed. The key messages emerging from the presented work include:

- The market survey on the micro-components' attributes suggests that the resource (energy/water) efficient micro-components are not necessarily more expensive than conventional devices.
- The conventional cost assessment methods, which focus on comparing the cost of volume of water supplied or conserved through a number of technically feasible approaches, appear to be unsuitable at consumer level.
- From the consumers' perspective, there exists a need to focus on assessing the cost of services rather than the volume of water consumed or saved by a particular measure. To address this the, modified annualised cost method has been proposed that takes into account the number of uses for each micro-component rather than the volume of water consumed per use.
- The operational cost dominates the cost per use associated with the internal taps, showers and baths. With regard to white goods, it was found that the capital cost dominates the cost per use.

This paper has mainly discussed the cost-effectiveness of individual micro-components. However per capita consumption in buildings results from a number of water using activities/micro-components and water efficiency targets require reduction in per capita consumption. Therefore optimum water efficiency requires the selection and implementation of composite strategies (i.e. a combination of different types of micro-components) which are cost-effective collectively. To address this, as a next step, there is a need to apply an integrated approach to holistically assess the cost-effectiveness of composite strategies and is discussed in the next paper.

Notes

1. A 10.5 kW electric shower can deliver 5 litres/minute, when the temperature difference between cold water and hot water is 30 °C.
2. The volume of water consumption (denominator) in Equations 3 was replaced with the number of uses or services per year provided by the water using micro-components.

Funding

The work was funded by the UK Engineering and Physical Sciences Research Council (EPSRC) and its support is thankfully acknowledged.

References

A & N Technical Services, Inc and Gary Fiske and Associates, 2006. *Water utility direct avoided costs from water efficiency*. The California Urban Water Conservation Council. Available from: http://www.water.ca.gov/calendar/materials/cuwcc_avoid_cost_model_user%27s_guide_16296.pdf [Accessed 29 March 2015].

Arnell, N. and Delany, E., 2006. Adapting to climate change: Public water supply in England and Wales. *Climate Change*, 78, 227–255.

Aulong, S., Bouzit, M., and Dörfliger, N., 2009. Cost-effectiveness analysis of water management: Measures in two river basins of Jordan and Lebanon. *Water Resources Management*, 23, 731–753.

Beal, C.D. and Stewart, R.A., 2013. 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

Bochereau, N., Murray, D., Prescott, C., Waylen, C., Marshallsay, D., and Ashton, V., 2008. *Evidence base for large-scale water efficiency in homes*. Waterwise. Available from: http://www.waterwise.org.uk/data/2008_Waterwise_evidence_base.pdf [Accessed 29 March 2015].

BRE, 2015. *New home quality mark puts consumers at the heart of house building*. Building Research Establishment (BRE) briefing note. Available from: http://www.bre.co.uk/news/New-Home-Quality-Mark-puts-consumers-at-the-heart-of-house-building–1059.html [Accessed 19 May 2015].

BRE, 2006. *Ecohomes (2006) -The environmental rating for homes*. The Guidance – 2006/Issue 1.2.Building Research Establishment Ltd. Available from: http://www.breeam.org/filelibrary/Technical%20Manuals/EcoHomes_2006_Guidance_v1.2_-_April_2006.pdf [Accessed 29 March 2015].

Chong, J., Kazaglis, A., and Giurco, D., 2008. *Cost-effectiveness analysis of WELS: The water labelling and standards scheme*. Department of the Environment, Water, Heritage and the Arts. The Australian Government. Available from: http://www.waterrating.gov.au/system/files/publications/2012/10/110/cost-effectiveness-wels.pdf [Accessed 29 March 2015].

Clarke, A., Grant, N., and Thornton, J., 2009. *Quantifying the energy and carbon effects of water saving*. Final Report. 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 29 March 2015].

Cromwell, J., Smith, J., and Raucher, R., 2007. *Implications of climate change for urban water utilities*. Washington, DC: Association of Metropolitan Water Agencies. Available from: http://www.amwa.net/galleries/climatechange/AMWA_Climate_Change_Paper_12.13.07.pdf [Accessed 29 March 2015].

DCLG, 2008. *Code for sustainable homes: Technical guide*. Department for Communities and Local Governments Publications. Available from: http://www.planningportal.gov.uk/uploads/code_for_sustainable_homes_techguide_april08.pdf [Accessed 29 March 2015].

Dworak, T., Berglund, M., Laaser, C., Strosse, P., Roussard, J., Grandmougin, B., Kossida, M., Kyriazopoulou, I., Berbel, J., Kolberg, S., Rodríguez-Díaz, A., and Montesinos, P., 2007. *EU water saving potential: Part 1 – Final report*. ENV.D.2/ETU/2007/0001r. Ecologic - Institute for International and European Environmental Policy. Available from: http://ec.europa.eu/environment/water/quantity/pdf/water_saving_1.pdf [Accessed 29 March 2015].

Elemental Solution, 2003. The economics of water efficient products in the household. Environment Agency. Available from: http://www.elementalsolutions.co.uk/wp-content/uploads/2012/08/economics-of-water-efficient-products-in-the-household-2.pdf [Accessed 29 March 2015].

EA, 2007. *Water efficiency in the South East of England. Retrofitting existing homes*. Available from: http://www.thenbs.com/PublicationIndex/DocumentSummary.aspx?PubID=215&DocID=282629 [Accessed 29 March 2015].

EA, 2009. The Environment Agency's representation on Dee Valley Water's draft water resources management plan. Available from: http://publications.environment-agency.gov.uk/pdf/GEHO0509BQCF-E-E.pdf [Accessed 29 March 2015].

EA, 2012. *Water resources planning guidelines*. Available from: http://www.thameswater.co.uk/wrmp/about-us-wrmp14-water-resource-planning-guideline.pdf [Accessed 29 March 2015].

EEA, 2007. *Climate change and water adaptation issues*. Technical Report No 2/2007. Available from: http://www.eea.europa.eu/publications/technical_report_2007_2 [Accessed 23 March 2015].

Fane, S., Robinson, J. and White, S., 2003. The use of levelised cost in comparing supply and demand side options. *Water Supply*, 3 (3), 185–192.

Fidar, A., 2010. *Environmental and economic implications of water efficiency measures in buildings*. Thesis (PhD). University of Exeter, UK.

Fidar, A.M., Memon, F.A. and Butler, D. (2016). Economic implications of water efficiency measures II: Cost effectiveness of composite strategies. *Urban Water*. doi: 10.1080/1573062X.2016.1224361

Gerasidi, A., Katsiardi, P., Papaefstathious, N., Manoli, E., and Assimacopoulos, D., 2003. Cost-effectiveness analysis for water management in the Island of Paros, Greece. *8th International Conference on Environmental Science and Technology*. September 2003, Lemnos Island, Athens, Greece.

Gettys, W., Keller, F. and Skove, M., 1989. *Physics: Classical and modern*. New York, NY: McGraw-Hill.

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*. Pacific Institute for Studies in Development, Environment and Security. Available from: http://www.pacinst.org/wp-content/uploads/sites/21/2013/02/waste_not_want_not_full_report3.pdf [Accessed 29 March 2015].

Grant, N. and Howarth, D., 2003. The economics of water efficient products in households. *In:* C. Maksimovic, D. Butler and F.A. Memon, eds. *Advances in Water Supply Management*. Avereest: Balkema, 581–589.

Hajkowicz, S. and Higgins, A., 2008. A comparison of multiple criteria analysis techniques for water resource management. *European Journal of Operational Research*, 184 (1), 255–265.

Herrington, P., 2003. The economics of water demand management. *In:* D. Butler and F.A. Memon, eds. *Water Demand Management*. London: IWA Publishing, 236–279.

Hughes, N., Hafi, A. and Goesch, T., 2009. Urban water management: Optimal price and investment policy under climate variability. *The Australian Journal of Agricultural and Resource Economics, l*, 53, 175–192.

Lee, M. and Tansela, B., 2011. Influence of residential water use efficiency measures on household water demand: A four year longitudinal study. *Resources, Conservation and Recycling*, 56 (1), 1–6.

Marshallsay, D., Trew, J., and Waylen, C., 2007. *Assessing the cost of compliance with the Code for Sustainable Homes*. Bristol: Environment Agency.

Maurer, M., 2009. Specific net present value: An improved method for assessing modularisation costs in water services with growing demand. *Water Research*, 43, 2121–2130.

Memon, F.A., Fidar, A.M., Ward, S., Butler, D., and Alsharif, K., 2015. Energy and carbon implications of water saving micro-components and grey water reuse systems. *In:* F.A. Memon and S. Ward, eds. *Alternative Water Supply Systems*. London: IWA Publishing, chapter 13, 265–285.

Mitchell, C., Fane, S., Willets, J., Plant, R., and Kazaglis, A., 2007. *Costing for sustainable outcomes in urban water systems: A guidebook*. Salisbury: The Cooperative Research Centre for Water Quality and Treatment.

MTP, 2008. *BNW05: Assumptions underlying the energy projections for domestic washing machines*. London: Market Transformation Programme – Department for Environment, Food and Rural Affairs (Defra).

MTP, 2010. *BNW DW01: Dishwashers government standards evidence base 2009: Key inputs*. London: Market Transformation Programme – Department for Environment, Food and Rural Affairs (Defra).

MTP, 2011a. *BNWAT 06: Domestic water use in new and existing buildings. Supplementary briefing: Version 1.0*. London: Market Transformation Programme – Department for Environment, Food and Rural Affairs (Defra).

MTP, 2011b. *Market transformation programme – Briefing notes (Water sector)*. Available from: http://efficient-products.ghkint.eu/cms/document-library/index.html [Accessed 23 March 2015].

Mukheibir, P., 2008. Water resources management strategies for adaptation to climate-induced impacts in South Africa. *Water Resources Management*, 22 (9), 259–1276.

OFWAT, 2011. Your Water and Sewerage Bill – 2011-12: Information for household customers. Available from: http://www.ofwat.gov.uk/consumer-issues/chargesbills/prs_lft_charges2011-12.pdf [Accessed 29 March 2015].

Presutto, M., Stamminger, R., Scialdoni, R., Mebane, W., and Esposito, R., 2007. *Preparatory studies for eco-design requirements of EuPs. Tender TREN/D1/40-2005. Lot 14: Domestic washing machines and dishwashers. Final report: Draft version. Tasks 1–2*. Berlin: Bundesanstalt für Materialforschung und -prüfung (BAM).

Roberts, P., 2005. *2004 Residential end use measurement study*. Yarra Valley Water. Available from: https://www.yvw.com.au/yvw/groups/public/documents/document/yvw1001680.pdf [Accessed 29 March 2015].

Smith, N.J., McDoland, G.W. and Murray, C.F., 2015. The cost and benefits of water demand management: evidence from New Zealand. *Water and Environment Journal*, 29, 180–189.

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

Smout, I., Kayaga, S., and Muñoz-Trochez, C., 2008. *Financial and economic aspects of water demand management in the context of integrated urban water management. 3rd SWITCH Scientific Meeting*, Belo Horizonte, Brazil. Available from: http://www.switchurbanwater.eu/outputs/pdfs/W6-0_PAP_BH_Session7c_Economics_of_demand_management.pdf [Accessed 29 March 2015].

White, S. and Fane, S., 2002. Designing cost-effective water demand management programs in Australia. *Water Science and Technology*, 46 (6–7), 225–232.

White, S. and Howe, C., 1998. Water efficiency and reuse: A least cost planning approach. *Proceedings of the 6th NSW Recycled Water Seminar*, Sydney, Australia. Available from: http://cfsites1.uts.edu.au/find/isf/publications/whitehowe1998waterefficiencyreuse.pdf [Accessed 15 September 2016].