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

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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.

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). Marshall 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.
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)).

\[
(AIC)_i = \frac{(PV)_O + (PV)_O - (PV)_{OSi}}{(PV)_{WSi}}
\]  

(1)

Where, 

For each micro-component under consideration, \((AIC)_i\) is the Average Incremental Cost (£/m³), \((PV)_O\) is the present value of its capital cost (£), \((PV)_O\) 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 (m³). 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 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)).

\[
AC_i = C \left[ \frac{r}{1 - (1 + r)^{-n}} \right]
\]

(2)

\[
AC_i = \frac{A_Ci + O}{W}
\]

(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 (m³), \(AC\) the is annualised unit cost (£/m³) 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 Scenarios | 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 Marshallsey 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/m³ and £1.39/m³, 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 heating systems depend on the volume of water used and the temperature difference between the cold and hot water. For showers, internal taps, baths and WCs, the energy consumption is calculated using Equation (4) (Gettys et al. 1989),

\[ E = \frac{mc\Delta T}{3.6 \times 10^6 \eta} \] (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), \( \Delta T \) is the change in water temperature (°C), and \( \eta \) 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 resource 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

| Micro-components | Water use characteristics | Water use range | Energy use range (kWh/use) | Capital cost (£) |
|------------------|---------------------------|----------------|--------------------------|-----------------|
| Washing machine  | litres/use                | 39.0 – 92.0    | 0.85 – 1.15              | 157.0 – 1,350.0 |
| Dishwasher       | litres/use                | 8.0 – 19.0     | 0.64 – 1.24              | 184.0 – 1,099.0 |
| Bath             |                           | 3.4 – 6.1      | N/A                      | 131.0 – 414.0   |
| Shower           |                           | 3.4 – 12.0     | N/A                      | 30.0 – 428.0    |
| Kitchen tap      | Litres/min                | 2.0 – 12.0     | N/A                      | 76.0 – 562.0    |
| Basin tap        |                           | 1.7 – 8.6      | N/A                      | 40.0 – 190.0    |
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.
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 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 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 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 £113, £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.

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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 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 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.

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“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).

\[ S_A = \frac{A_X + O_X}{100} \times S_X \]  
\[ S_a = \sum_{x=1}^{N} S_A \]

where,

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

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

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.

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