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Novel performance assessment indices for domestic water use

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Abstract

This paper presents a novel methodology for evaluating the efficiency of indoor domestic water use based on performance assessment functions that convert state variables (e.g. flow rate, volume) into performance indices ranging from 0 (the lowest performance) to 300 (excellent performance). Performance functions have been developed for the most common water use devices in the household. An overall household water use index was obtained from the individual water use device indices by weighting each device in accordance with the consumption structure of the household. The application of this methodology to 43 households allowed the quantification of potential water savings and the identification of device-specific measures to increase the water use efficiency.

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Keywords: Performance assessment; performance indices; water use devices; domestic water use efficiency

Nomenclature

$I_{household}$	household water use efficiency index
I_{WDi}	efficiency index for the water use device *i*
W_{WDi}	weight of the water use device *i* in the household consumption structure
n	number of water use devices in the household

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1. Introduction

In the last decade, performance assessment has been a topic of growing importance in the water industry due to the fact that water utilities have been incorporating sustainability and continuing improvement principles in their practices [1, 2]. Performance assessment methodologies have been developed throughout the world and include the use of performance indices which are quantitative measures of the performance of a system, *i.e.*, they evaluate the distance from an optimum situation. For example, several performance indices have been used to assess the performance of water distribution networks [3, 4], of sewer systems [5] and of water treatment plants [6].

The concern about the efficiency of household water use is increasing worldwide driven, for example, by climate change and demand management policies. Currently, there is still a need for systematic and detailed approaches to assess the performance in domestic uses in terms of water use efficiency. This paper presents a novel quantitative and standardized methodology for evaluating the efficiency of indoor domestic water use based on a performance assessment approach. Performance indices are obtained by converting state variables (e.g., flow rate, volume) into indices through performance functions (also called penalty functions). Finally, the methodology is applied to a full scale case study, considering the most common water use devices in the household: showers, WC, bathroom taps, kitchen taps, dishwashers and washing machines. Most relevant results are presented.

2. Methodology

2.1. Methodology overview

The proposed methodology is based on performance functions that specifically apply to domestic water use devices. Fig.1 shows the main steps of the methodology.

In Step 1, ranges of flows and volumes considered efficient in the literature and in several labelling schemes are identified for each water use device in the household. Based on these ranges, performance functions are built and are used to determine performance indices that allow for the classification of the water use devices efficiency (Step 2). Finally, in Step 3, an overall household efficiency index is obtained and the household water use efficiency is assessed.

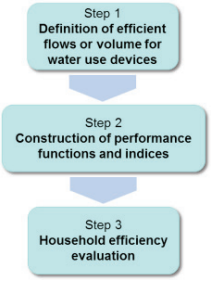

Fig.1. Methodology for the performance assessment of the domestic water use

2.2. Efficient ranges for water use devices

In order to assess the efficiency of the water use devices in terms of their flow rate or volume, efficient ranges for each device were defined based on the classifications available in the literature and in several water efficiency labelling systems developed at national or international levels (e.g. [7], [8], [9]).

Fig.2 shows an example of efficient ranges considered by different labelling systems for showers. All efficient ranges that were defined in this work can be found in [10]. The colour scheme used in Fig. 2 varies from green (the most efficient) to red (the inefficient). Each intermediate colour corresponds to a different range from each labelling system. These ranges show some variations among them. Some labelling systems distinguish efficient and inefficient flow rates or volumes with just two labels, while others attribute more than two efficiency classes to flow values.

The minimum and maximum values observed for showers' flow rate are 0 and 32 litres/min, respectively. The majority of the sources considered as efficient values bellow 8 litres/min and inefficient values above 15 litres/min.

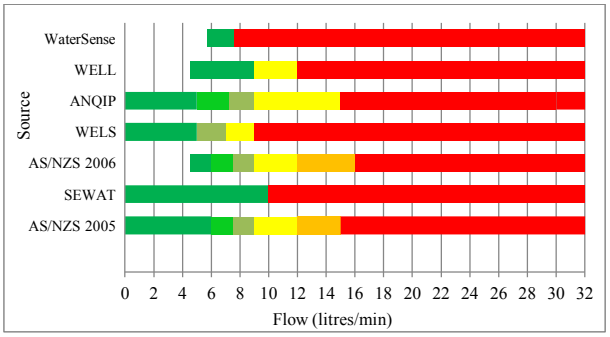

Fig.2. Efficient ranges for showers from literature and labelling schemes.

For each water use device, unique ranges of efficient values (Table 1) were built considering the different ranges from all the labelling systems presented in Fig. 2.

Table 1. Ranges of efficient flows or volumes for household water use devices.

Water use device	Range of efficient values
Shower (litres/min)	6.9-12.1
Bathroom tap (litres/min)	3.7-8.6
Kitchen tap (litres/min)	5.6-11.6
Dishwasher (litres/wash)	12.2-17.8
Washing machine (litres/wash)	44-66
WC single flush (litres/flush)	4.1-6.0
WC dual flush - total discharge (litres/flush)	4.0-6.3
WC dual flush - low volume discharge (litres/flush)	2.8-4.0

2.3. Construction of performance functions and indices

Performance indices are obtained by converting state variables (e.g., flow rate, volume) into indices through performance functions. These functions are built considering the ranges of efficient flow rates or volumes of the water use devices presented in section 2.2. These performance functions are penalty functions since the performance decreases as the water consumed through the device increases.

One performance function was defined for each of the most common water use devices in the household, namely for showers, WC, bathroom taps, kitchen taps, dishwashers and washing machines. An example of a performance function is given in Fig. 3 for dishwashers.

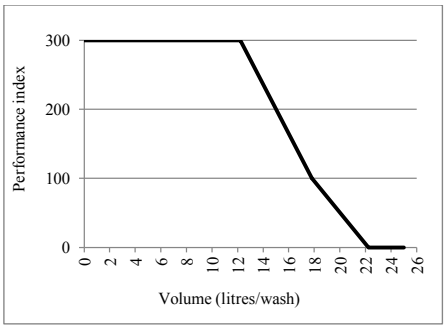

Fig.3. Example of a performance function (dishwasher).

The general approach followed by [6] was adopted for the construction of performance functions and indices and a 0 to 300 grading scheme was used for classifying efficiency: the performance index value of 300 corresponds to the maximum performance (i.e., the water use device is the most efficient in terms of water used); values in the range of 300 to 200 correspond to a "good" performance and in the range 200-100 to "acceptable" performance; the 100 value is the minimum acceptable performance and values below 100 mean that performance is "unacceptable" as the water use device has a flow rate/volume higher than the range of the efficient values presented in Table 1.

For each water use device in the household, a performance index was calculated by applying the performance function to its flow or volume and a classification was given corresponding to its level of efficiency. Furthermore, the several devices were compared to each other within a household or among different households.

2.4. Efficiency assessment of the household

The overall efficiency of a household is assessed through a household water use efficiency index. This overall index is obtained by combining the individual indices of all the existing water use devices (Equation 1). As the devices differently contribute to the consumption structure of each household, weights were considered in this calculation. Weights were determined based on the household consumption structure of each consumer from the case study.

$$I_{household} = \sum_{i=1}^{n} I_{WDi} \times W_{WDi} \tag{1}$$

in which

$I_{household}$: household water use efficiency index;
I_{WDi} : efficiency index for the water use device *i*;
W_{WDi} : weight of the water use device *i* in the household consumption structure;
n : number of water use devices in the household.

2.5. Case study

The methodology developed has been applied to 43 households, mostly located in the Lisbon urban area and surrounding municipalities, corresponding to approximately 100 participants. All households had extensive measurements (flow rate and volume of water use devices) and detailed event records of all indoor water uses, and were surveyed to collect information on socio-demographic background and on the existing water use devices.

3. Results

3.1. Performance assessment of the water use devices

Table 2 shows the results obtained for the performance assessment of each water use device in the case study households. Performance indices were obtained through performance functions by entering the flows and volumes from each consumer's data on their water use devices.

Table 2. Ranges of performance indices for the water use devices.

Performance assessment		Water use devices							
		Shower	Bathroom taps	Kitchen taps	Dishwasher	Washing machine	Single flush WC	Dual flush WC - total discharge	Dual flush WC - low volume discharge
Performance indices	Minimum	0	0	0	0	0	0	0	0
	Average	184	161	226	54	77	9	6	76
	Maximum	300	300	300	300	300	99	56	267
Number of households with unacceptable performance (0-100)		5	13	3	26	30	31	10	7
Number of households with acceptable performance (100-200)		18	9	10	3	5	0	0	2
Number of households with good performance (200-300)		19	20	29	3	7	0	0	1

Except for WC, the performance indices for the water use devices are distributed by all three performance ranges (0–100, 100–200 and 200–300), which shows that, in this sample, there is a wide range of water use efficiencies. The single and the dual flush WCs are the most inefficient devices in the case study, followed by machines (dishwasher and washing machine) as shown by lowest performance indices (average = 6–76 for WC and 54–77 for machines). The water use devices that have better performance are taps (both bathroom and kitchen taps) and showers, as shown by the highest performance indices (average = 161–226 for taps and 184 for showers).

On average, showers and taps are reasonably efficient (performance index = 184, 161 and 226, respectively), and more than 45% of the households have devices with good performance. Dishwashers and washing machines and dual flush WC – low volume discharge have unacceptable performances (average performance index = 54, 77 and 56, respectively) in more than 70% of the households. All single flush WC and dual flush WC – total discharge perform poorly as shown by all indices below 100.

3.2. Overall efficiency assessment for the household

Results obtained for the households' overall water efficiency indices are presented in Fig.5 for the 43 households analysed. There is a wide variation among households shown by the range of households' performance indices between 2 and 219. The average value is 125, corresponding to an acceptable performance. The majority of the households (28 households, 65%) have their water use devices classified as acceptable (index in the range 100-200) but still a large number (12 households, 28%) have unacceptable performance (index below 100). There are three households equipped with the most efficient devices and that have overall indices above 200.

These results show that, in the case study, a large potential for water savings exists and that water use efficiency can be increased by the installation of more efficient water use devices.

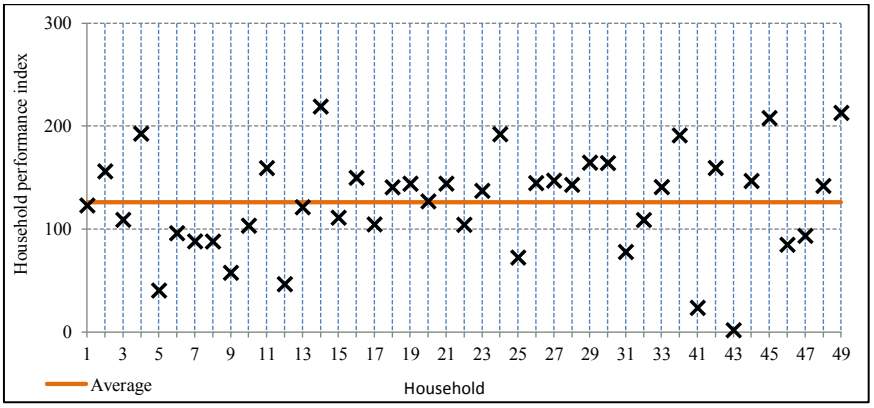

Fig.5. Household performance index for all consumers of the case study.

4. Conclusions

The objective of this paper was to present and to show an example of application of a novel methodology to assess the overall households' water use efficiency in indoor domestic water uses, based on assessment of the performance of water use devices. An approach based on performance indices was adopted. For each water use device, a performance index was calculated and a classification of qualitative nature expressed in three discrete categories (excellent, acceptable, unacceptable) was given corresponding to its level of water use efficiency. This methodology has the following advantages for evaluating water use efficiency:

- Performance indices can transmit judgments in terms of higher or lower performance through performance levels.
- Individually, different types of water use devices can be compared to each other, in terms of efficiency, within a household but can also be compared among households.
- An overall performance index for the household can be obtained by weighting the individual performance indices for the water use devices in the household;
- For a set of households and based on the overall performance indices for the household, the percentage of users in each performance level can be determined and conclusions can be drawn about the most efficient (i.e., which households have the most efficient devices). Furthermore, potential savings for each household can be quantified and device-specific measures to increase the water use efficiency can be identified;
- The methodology can easily be extended to other water use devices not considered in this paper.

For the current case study, the water use devices that have lower performance are dishwashers, washing machines and WC. The water use devices that have better performance are taps and showers. However, the average household performance indices always corresponds to acceptable performances, revealing that water use devices are not yet the most efficient ones available in the market. Results show that a large potential for water savings exists and that the main components in which consumers should act to improve their household efficiency level are the replacement of water use devices with lower performance indices by more efficient ones or the adoption of other type of measures to reduce their total consumption (e.g. to place a bottle inside the WC to reduce the flushed volume).

The main innovative contribution of this work is the construction and implementation of performance functions for domestic water use devices which return performance indices and allow for the classification of the water use devices efficiency. Performance indices have already been applied in several studies but, to the authors' knowledge, the concept has never been applied to water use devices in the household, measuring its efficiency level and giving it a performance value. This knowledge is of the utmost importance, since high water use efficiency appliances have been well-known for their positive impact on residential water consumption.

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