EFFICIENCY ASSESSMENT OF THE HOUSEHOLD WATER USE

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Environmental Engineering

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ABSTRACT

The aim of the current thesis is the development and testing of a comprehensive methodology to assess the overall households' water use efficiency in indoor domestic water use. This methodology comprises an efficiency evaluation based on efficient patterns, peer comparison and water devices performance.

The proposed methodology is composed of three main modules: Module *1. Efficient patterns comparison*, Module *2. Peer comparison* and Module *3. Evaluation based on performance indices of water devices.* The three modules should be applied in a complementary way in order to assess most aspects of water efficiency in the household, but can also be applied independently, as each module returns an individual different type of assessment. The methodology was applied to a case study composed of 43 households, mostly located in the Lisbon urban area and surrounding municipalities, corresponding to approximately 100 persons. All households have extensive measurements and detailed event records of all indoor water uses, and were surveyed to collect information on their socio-demographic characteristics and on the existing water devices in the households (WC, shower, taps, dishwasher and washing machine). The methodology was further tested with an additional small case study carried out with three volunteer consumers.

The development of a systematic and detailed methodology for the assessment of domestic consumers' behaviour both in terms of their own consumption and their level of efficiency relatively to their peers constitutes the main novel contribution of this work. This efficiency assessment allows the identification of potential savings and, thus, the methodology enables the promotion of a more efficient use of water by domestic consumers. Furthermore, it is also useful for the water utilities to optimize the supply systems operation and to improve the quality of service through a better knowledge of consumption profiles.

Keywords: Water use efficiency, household, domestic consumption, efficient patterns, peer comparison, water devices

RESUMO

A presente dissertação tem como objetivo principal o desenvolvimento e teste de uma metodologia para avaliar a eficiência global do uso da água na habitação em espaços interiores, que incorpora a avaliação da eficiência baseada em padrões eficientes, a comparação entre pares e a avaliação de desempenho dos dispositivos de uso de água.

A metodologia proposta encontra-se estruturada em três módulos: Módulo *1. Comparação com padrões eficientes*, Módulo *2. Comparação entre pares* e Módulo *3. Avaliação de desempenho dos dispositivos de uso de água*. Os três módulos devem ser aplicados de forma complementar, de modo a avaliar a maioria dos aspetos da eficiência de uso da água na habitação, mas podem também ser aplicados independentemente, uma vez que cada tipo de análise fornece um tipo diferente de avaliação individual. A metodologia foi aplicada a um caso de estudo composto por 43 habitações, maioritariamente localizadas na área urbana de Lisboa e municípios vizinhos, correspondendo no total a, aproximadamente, 100 pessoas. Todas as habitações realizaram extensas medições e registos detalhados de todos os usos da água no interior da habitação, e foi recolhida informação, através de questionários, sobre as características sociodemográficas e dispositivos de uso de água existentes (autoclismo, chuveiro, torneiras, máquina da loiça, máquina da roupa). A metodologia foi adicionalmente testada num pequeno caso de estudo realizado com três consumidores voluntários.

O desenvolvimento de uma metodologia detalhada e sistemática para avaliar o comportamento dos consumidores domésticos em termos do seu próprio consumo e do nível de eficiência quando comparados com os seus pares, constitui a principal contribuição inovadora deste trabalho. Esta avaliação de eficiência do uso da água permite a identificação de potenciais de poupança, promovendo assim um uso mais eficiente da água por parte dos consumidores domésticos. Além disso, é também útil para as entidades gestoras, em termos de otimização da operação de sistemas de distribuição de água e da melhoria da qualidade do serviço através de um melhor conhecimento dos perfis de consumo.

Palavras-chave: Eficiência no uso da água, habitação, consumo doméstico, padrões eficientes, comparação entre pares, dispositivos de água

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NOTATION

Abbreviation	Meaning
ANQIP	National Association for Quality in Building Installations
CSH	Code for Sustainable Homes
DHA	Hydraulics Department
EPA	Environmental Protection Agency
LNEC	National Laboratory for Civil Engineering
PNUEA	National Programme for the Efficient Use of Water
SEWAT	System to Evaluate the Water Consumption at Home
WC	Water Closet
WELL	Water Efficiency Label
WELS	Water Efficiency Labelling and Standards scheme

LIST OF SYMBOLS

Symbol	Meaning	Units
P	Global performance index	[-]
W	Generalization function of the performance elementary values	[-]
w_i	Weight of each elementary component	[-]
p_i	Performance value in element i	[-]
PC_H	Per capita consumption (average value per household)	[litres/(person.day)]
DC_H	Average daily consumption per household	[litres/day]
NI_H	Number of inhabitants in the household	[person]
C_{ED1}	Efficient consumption in bathroom and kitchen devices in the reference period	[litres]
F_{DE}	Water devices efficient flow	[litres/min]
t_E	Efficient time per use	[min]
f_U	Frequency of use in the reference period	[No/day]
C_{ED2}	Efficient consumption of dishwashers, washing machines and WC in the reference period	[litres]
V_{DE}	Water devices efficient volume per use	[litres]
H_E	Household efficiency level	[%]
$MEPC_H$	Minimum efficient per capita consumption (average value per household)	[litres/(person.day)]
Cl	Cluster average or minimum	[litres]
C_{CD}	Consumption based on consumers' data	[litres]
H_I	Household water use efficiency index	[-]
I_{WDi}	Water device index of element i	[-]
W_{WDi}	Water device weight in the consumption structure of element i	[%]
N	Number of devices in the household	[-]
V_{WDi}	Total volume used in a water device i	[litres]
V_H	Total volume used in the household	[litres]

1 INTRODUCTION

1.1 Context and motivation

"Water has become a highly precious resource. There are some places where a barrel of water costs more than a barrel of oil" (Lloyd Axworthy, Foreign Minister of Canada, 1999 - News Conference).

Currently, the quality and availability of water can be compromised due to climate changes and increasingly more frequent droughts and floods together with an inefficient use and management of water resources. Thus, it is of the utmost importance to develop and implement strategies to control water losses and to promote the efficient use of water resources, which have significant costs to the utilities, the society and the environment.

Water losses reflect an inefficient use of water, which corresponds to the difference between the water volume used and the volume that is effectively necessary to achieve the goals of its use in different sectors, such as industrial, commercial and domestic. In Portugal, domestic consumers are the largest component of urban water consumption, corresponding to 64% of the total water used (APDA, 1999 cited by Camacho, 2010) as shown in Figure 1.

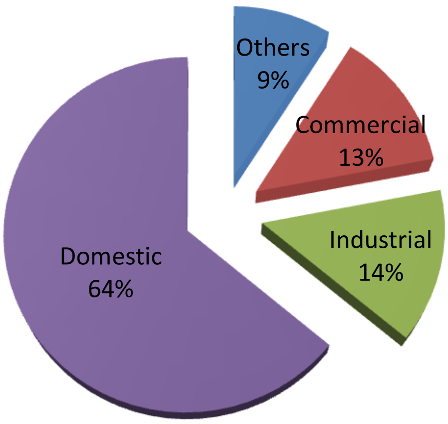


Figure 1 – Urban water consumption distribution (Camacho, 2010)

Household water use can significantly vary from one residence to another, depending on personal habits, socio-economic, cultural and climatic conditions, that are determinant to household consumption patterns (Vieira *et al.,* 2007).

A large set of measures to improve the domestic water use efficiency (in indoor and outdoor uses) is available and is widely published in literature (*e.g.,* Baptista *et al.,* 2001; Vieira *et al.,* 2007; Willis *et al.,* 2013; Gutierrez *et al.,* 2014). However, there is a need for the development of approaches that allow the identification of efficiency targets, the estimation of water savings associated with the implemented measures and the assessment of consumers behaviour, in terms of their own consumption and their level of efficiency when compared to efficient patterns (behavioural and relative to domestic water use devices) or to other consumers.

The lack of systematic and robust methodologies for the evaluation of the efficiency in domestic water use, taking into consideration indoor domestic water uses and featuring social-demographic factors, which have a great influence on consumption is the main motivation for the development of this thesis.

1.2 Objectives

The main objective of the present research is the development and test of a methodology for the evaluation of the efficiency in domestic water use, supported in efficient use patterns. To evaluate the differences between real consumption and efficient consumption and to identify potential savings, real case studies will be analyzed using the proposed methodology.

This thesis provides a better perception of domestic water efficiency at an individual consumer level or of a group of consumers with a certain profile, with the goal of reducing the global water consumption, minimizing the water losses.

To achieve the proposed goal, the research has the following specific objectives:

i. development of a state-of-the-art review about: approaches to evaluate the efficiency of water and energy use, goals for water efficiency in several household uses, approaches for the construction of water use profiles and methods for performance assessment;

ii. collection, processing and analysis of consumption and socio-demographic data, consumers' behaviour and data on the water use devices from case studies that belong to real water supply systems;

iii. definition of efficient water use patterns for different types of domestic consumers, considering the explanatory variables of the consumption that were previously identified;

iv. definition and calculation of metrics to evaluate the efficiency of water use for domestic consumers;

v. identification of the most efficient consumers by comparison between them or with efficient patterns. Previous definition of the consumers groups through the study of relations between consumption and socio-demographic variables that influence water consumption.

1.3 Thesis structure

This thesis is organized in the following seven chapters:

- Chapter 1 introduces the context of the problem to be studied and describes the goals and the structure of the present work.

- Chapter 2 provides an overview of the approaches that have already been developed for efficiency assessment in the water and energy domains, efficient patterns, performance indices and most relevant socio-demographic and consumption variables.
- Chapter 3 explains the methodology developed and its sectioning in multiple modules, each one assessing different points of view of water use efficiency.
- Chapter 4 describes the real case study and characterizes the consumption taking into account the main explanatory variables.
- Chapter 5 presents the results of the application of the methodology to the case study described in chapter 4 and makes a comparative analysis of the various modules.
- Chapter 6 presents the results of the test of the methodology through a recent small case study based on some volunteer consumers.
- Chapter 7 summarizes the most relevant conclusions of the study and provides suggestions for future developments of the work.

2 STATE-OF-THE-ART

2.1 Introduction

The current chapter presents a state-of-the-art review on consumption studies about efficiency evaluation of the water and energy use, goals for water efficiency in several household uses, socio-demographic variables that have importance in domestic consumption, approaches for the construction of water use profiles and methodologies to evaluate the performance. A summary of the state-of-the-art is presented at the end of the chapter.

2.2 Approaches to evaluate the efficiency of the water and energy use

2.2.1 Water use efficiency

Nowadays, there is an increasing discussion among specialists about water use efficiency and the best measures to improve it (Matos *et al.,* 2013). Therefore, a large set of measures have already been developed by the water sector.

Matos *et al.* (2013) presented a method to find out with details the pattern of water use in dwellings, therefore it would be possible to evaluate different alternatives available to decrease potable water consumption in buildings. For this study, a quantitative characterization of daily water uses for each domestic device was performed, as well as the volume consumed in each utilization of each domestic device. Three case studies were analysed in Portugal (Vila Real, Valpaços and Oporto). Indoor water use patterns were obtained for each domestic device as well as daily cycles in the different cities in order to evaluate possible influences of socio-demographic characteristics. Conclusions of this study revealed that bathroom taps in washbasins and kitchen taps were the domestic devices with more number of uses followed by toilet flushes, bathtubs and machines. The uses observed for the machines showed that the volunteers do not switch them on every day. Considering the washbasins, hand washing, teeth brushing and face washing are the uses occurring more times per day. The shower had a higher number of uses when compared with bathtubs. The domestic device that spent more volume on a daily basis was the kitchen tap, followed by the bathtub and the toilet flush (Matos *et al.,* 2013).

It is known that household consumption structure largely varies across the different studies. Matos *et al.* (2013) showed that, on a daily basis, it follows the distribution: kitchen taps (38%), bathtub (26%), toilet flush (14%), bathroom taps (12%), washing machine (8%) and dishwasher (2%). Other studies that present households consumption structures, in different conditions, are:

- Beal *et al.* (2013): shower (29.5%), clothes washer (21%), taps (19%), toilet (16.5%), leak (6%), irrigation (5%), dishwasher (2%) and bathtub (1%);
- Willis *et al.* (2013): shower (33%), clothes washing (19%), taps (17%), toilet (13%), irrigation (12%), bathtub (4%), dishwasher (1%), leak (1%);

- Loh and Coghlan (2003): bath and shower (33%), washing machine (27%), toilet (21%), taps (16%), other (3%);
- Almeida and Butler (1999): toilet flushing (31%), bath and shower (28%), washing machine (16%), bathroom taps (13%);
- André and Pelin (1999): toilet flushing (31%), bath and shower (17%), washing machine (8%), dishwasher (0.3%).

Some of these distributions are presented in Figure 2.

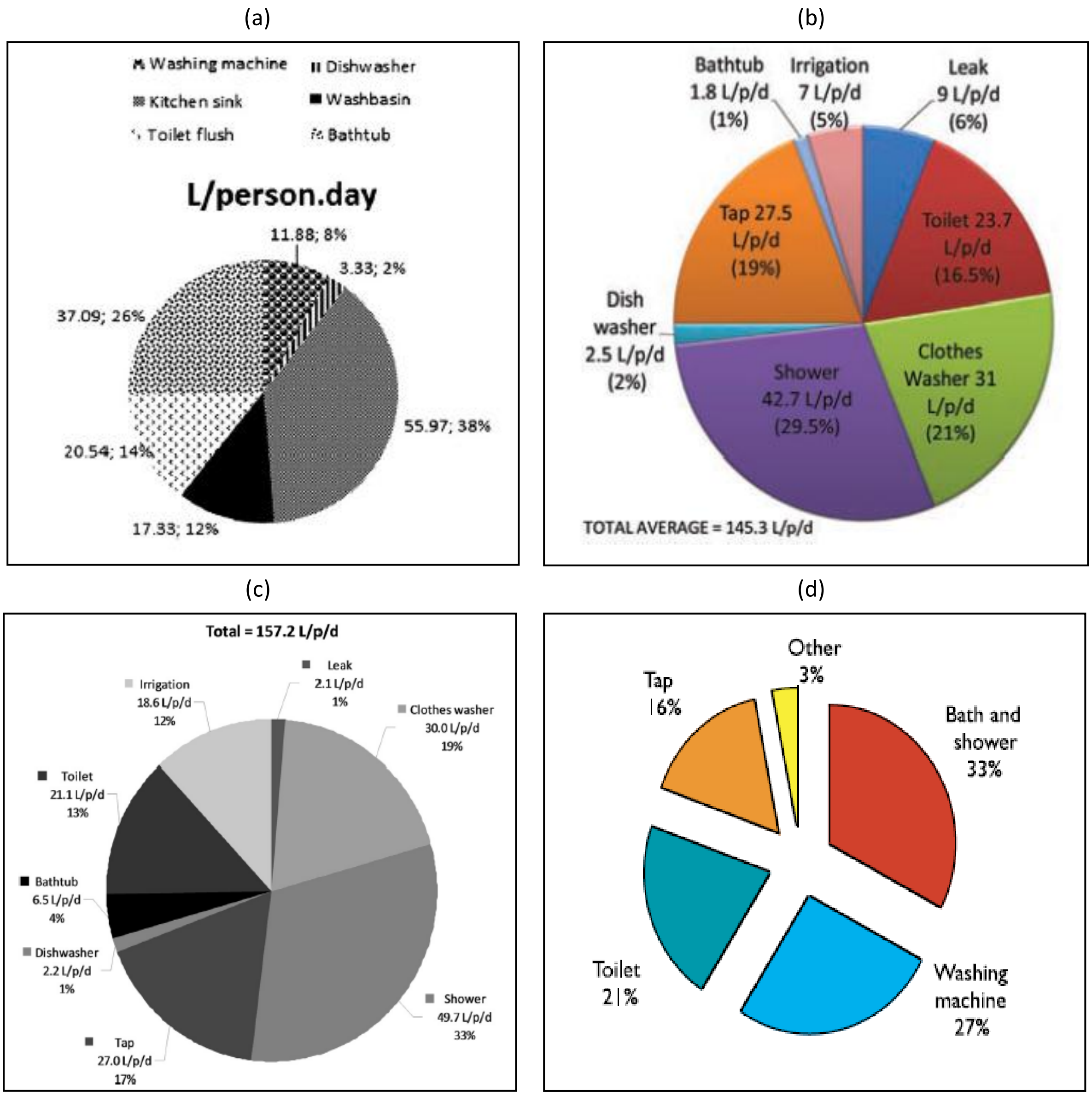


Figure 2 – Consumption structures: (a) Total daily volume distribution per domestic device (L/day and %) (Matos *et al.,* 2013); (b) Average daily per capita water end use (Beal *et al.,* 2013); (c) Average daily per capita consumption (L/p/d) (Willis *et al.,* 2013); (d) Single residential in-house water usage (L/house/day) (Loh and Coghlan, 2003)

In response to increasing water demand, Miami-Dade Country, USA, implemented water conservation incentives for the residential consumers. A four-year longitudinal study was carried out by Lee *et al.* (2011)

to evaluate the water savings and water use trend shifts of the costumers, after the implementation of the water conservation practices rebate programmes.

High water use efficiency appliances have been well-known for their impact on residential water demand. The consumers who had more than one type of water efficient appliance experienced higher water savings. Water savings for water use efficiency measures were about 28 (10.9%), 34.7 (13.3%) and 39.7 (14.5%) gallons per household per day for showerhead, toilet and clothes washer programs, respectively. Adoption of more than one type of water efficient appliance contributed to additional savings in residential water use (Lee *et al.,* 2011).

Beal *et al.* (2013) carried out a high resolution smart metering study with a detailed end use event registry as well as psycho-social and socio-demographic surveys, stock inventory audits and self-reported water diaries for 252 households located in South-east Queensland, Australia. The study considered that, as the end use of water is influenced by a number of subjective or manual water use practices within a household (*e.g.,* duration of showering, water level in the bathtub and frequency of tap use), surveys or questionnaires are key components of any end use study. End use data in combination with such socio-demographic information facilitated the identification of correlations between water behaviours and key demographical subsets within a population (*e.g.,* income, age, gender and family composition). This study has also shown that householders' perceptions of their water use often do not correspond to their actual water consumption. The methodology followed is shown in Figure 3.

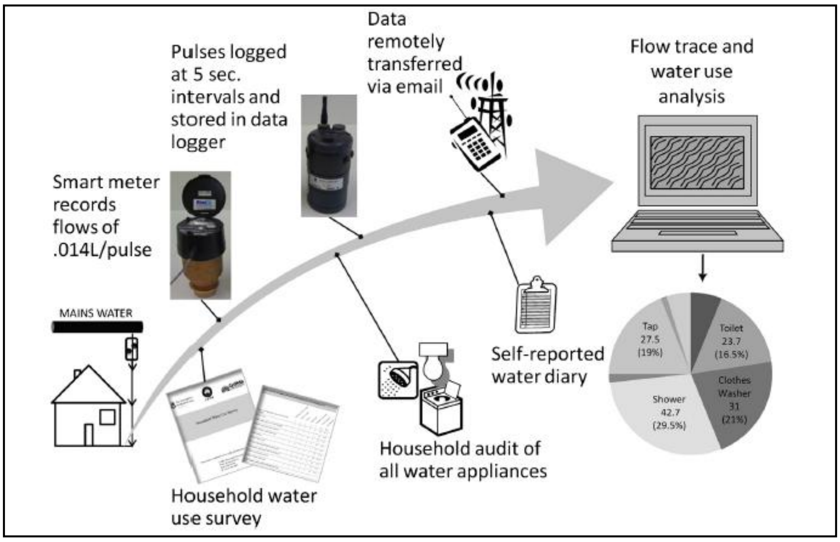


Figure 3 – Schematic flow of process for acquisition, capture, transfer and analysis of water flow data (Beal *et al.*, 2013)

Loh and Coghlan (2003) carried out a study where one of the Water Corporation of Western Australia regulators (Water and Rivers Commission) came with a further incentive to update knowledge of domestic water use. The Water and Rivers Commission is responsible for the management and protection of Western Australia's' water resources which includes allocating available water resources to uses such as public water supply. Water and Rivers Commission approval to develop new sources would be subject to the Corporation implementing a mutually acceptable water use efficiency programme which sets realistic savings targets. More specifically, objectives of the new Domestic Water Use Study were:

- to collect data on household water usage;
- to identify water use patterns and trends;
- to develop a demand forecasting model and a water use efficiency programme at a later stage.

The study was divided into two phases: Phase 1 for single residential households and Phase 2 for multi-residential households. In Phase 1, households' data were collected from 720 volunteer households across the Perth metropolitan area which comprised:

- a Pilot Group of 120 households at which special metering equipment was installed to continuously monitor water use from November 1998 to June 2000;
- a Main Group of another 600 households at which total monthly water usage was recorded from November 1998 to February 2000.

All the household consumers (720 in total) completed three questionnaire surveys covering demographics, appliance ownership and attitudes to water use (Loh and Coghlan, 2003).

In Phase 1, data on household characteristics and attitudes were collected using three separate questionnaires. All Pilot Group households had meters and data loggers (referred to as smart meters) installed on their water services to continuously record water usage patterns. All water usage data were stored on a data logger which was downloaded every six weeks and validated for timing, total usage and data quality. Data were then further processed using special software called 'Trace Wizard' to a format suitable for analysis of usage patterns (Figure 4).

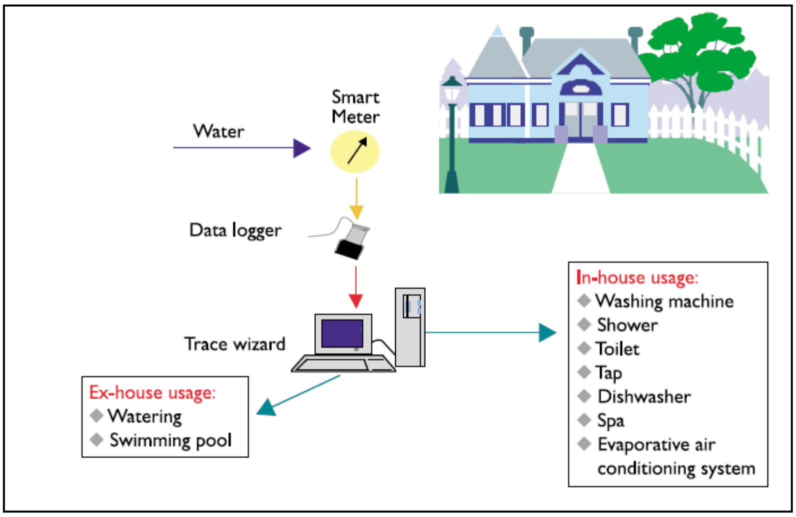


Figure 4 – Smart Metered Household (Loh and Coghlan, 2003).

Some of the important conclusions of the study were the following:

- the domestic sector accounted for about 70% of Perth's total demand;
- toilet usage had decreased from 32 to 21% of in-house usage due to increased ownership of dual flush toilets;
- washing machine usage had increased from 18% to 27%. This is due to the increase in the ownership of automatic washing machines;
- small increases in the ownership levels of other in-house appliances including dishwashers, evaporative air conditioners and spas was observed;
- the increase in usage associated with these fixtures along with that attributable to washing machines equalled the savings that have been achieved through the regulation of dual flush toilet cisterns;
- average component usages for in-house use per household (Table 1).

Table 1 – Average component usages for in-house use per household (Loh and Coghlan, 2013)

Component	L/house/day	% in-house	% total use	L/person/day
Bath and shower	171	33	14	51
Washing machine	139	27	11	42
Toilet	112	21	9	33
Tap	83	16	7	24
Other	18	3	1	5
Total in-house	523	100	42	155

Gutierrez *et al.* (2014) developed a model and its corresponding application to evaluate the efficiency of water consumption in Spanish residential buildings, known as System to Evaluate the Water Consumption at Home (SEWAT). With the input of water bill information, the model allows consumers to check if their water consumption is efficient. The selected sample was composed of 64 no-garden building apartments, located in four different villages in the east coast of Spain, and the measurements were performed during 807 days. The final water use distribution obtained in this study was the following: faucets (38.6%), toilets (22.2%), showers (19.9%), clothes washers (9.7%), leaks (8.9%) and, finally, dishwashers (0.6%). To assess whether water consumption is efficient or not, it was necessary to establish different levels and the tool allows consumers to obtain a water label (Table 2). After the evaluation, the application provides recommendations for the users to reduce their water consumption (Gutierrez *et al.,* 2014).

Table 2 – Water label as a function of the water consumption per person per day (Gutierrez et al., 2014)

Water Label	Water Level	Consumption (Liters per person per day)
	Level 1	Consumption ≤ 90
	Level 2	90 < Consumption ≤ 110
	Level 3	110 < Consumption ≤ 130
	Level 4	130 < Consumption ≤ 150
	Level 5	150 < Consumption ≤ 170
	Level 6	Consumption > 170

According to Fidar *et al.* (2010) one approach that may help water efficiency goals was to set a performance target for individual microcomponents such as WCs, showers, basin taps, kitchen taps, baths, dishwashers and washing machines. Microcomponent based water demand management is seen as step forward to reduce per capita water consumption without necessarily changing users' behaviour. In England, for example, this approach is included in the Code for Sustainable Homes (CSH), which is performance based and sets various environmental criteria against which the sustainability level of a new building is measured (Fidar *et al.,* 2010).

Vieira *et al.* (2007) carried out a study in order to obtain information that could help support the definition of water conservation measures for household use, within the scope of the preparation of the National Programme for the Efficient Use of Water (Baptista *et al.,* 2001). This study is described with detail in Chapter 4.

2.2.2 Energy use efficiency

Reducing the household energy consumption has also been a subject frequently studied by experts. As in the water sector, there are several methodologies applied to improve the consumer awareness, and socio-demographic variables are also considered by their influence on energy consumption.

With the 20% reduction in energy consumption by 2020, ordered in 2006 by The European Commission, several projects focusing on the improvement in energy use have been launched (Rey *et al.,* 2011).

Increasing energy efficiency in households through targeting awareness and behavioural change has been the topic of many studies.

In countries like Sweden where wages are high, energy awareness is driven mainly by environmental concerns. However, energy awareness is usual amongst consumers with low-income or foreign background (Vassileva and Campillo, 2014). In a study conducted in Sweden, with low-income households, the methodology consisted of extended paper questionnaires, posteriorly collected and analyzed. An average yearly electricity consumption has also been included. Only consumers living in one home type (apartment) have been included. The sample consisted of two groups, each in a different city. Results showed that the main differences between the two low-income groups were found in their preferences for ways of providing consumption feedback and the use of standby power, being these the differences mainly attributed to the age of the participants and their understanding of technological devices and appliances. Low-income consumers generally have lower consumption levels than those with high income but they still have the interest to learn how to save energy and improve their consumption (Vassileva and Campillo, 2014).

Another study, conducted by Lucas *et al.* (2001) with the aim of increasing knowledge about the behavioural factors of inhabitants in the residential sector that influence the energy consumption levels, on suburban houses, was applied at the San Juan area, Argentina. The methodology included a survey in the following topics: the composition of the family group (details of family members, their ages and type of work); the time they stayed at home and activities of each member (timetable of weekends and working days in winter and summer); electric and gas equipment in each room (type and timetable of usage in working days and weekends of winter and summer); places felt to have greater thermal or lighting comfort; criteria applied in the selection of the house (location, orientation, comfort, materials, structure, aesthetics, flexibility, etc.); consciousness of energy saving (type of equipment, source, rational use of the house, taxes); and income levels. The study concluded that the longest times at home are registered by housewives, persons older than 60 years and children younger than 3 years. During holidays, the time inhabitants stay at home is higher, which increases the energy consumption of the family. The number of inhabitants was a factor that influenced the energy consumption more than the average time stayed at home. The age of inhabitants also had an influence on energy consumption, with increased energy consumption for families with members between 6 and 42 years and slow decrease in energy consumption for families with a greater range of ages concomitant with a reduction in the number of devices used (Lucas *et al.,* 2001).

Olmos *et al.* (2011) study applied the analytical framework and methodology developed to characterize the reaction of consumers in the Austrian system to different smart meters related actions. The study characterized changes to consumption behaviour caused by the application of actions according to the resulting reduction in households' peak load and the decrease in their overall electricity use (Olmos *et al.,* 2011).

Comparing the several studies in the water field with this literature review for energy, there are many similarities in the socio-demographic variables influencing consumption that must be taken into account and it is also clear that all field studies shown that it is of the utmost importance that consumers are informed and aware of the water/energy efficiency issue.

2.2.3 Water efficiency labelling systems

In order to assess the efficiency of the water devices in terms of their flow or volume, efficient ranges for each device can be found in the literature mainly associated with water efficiency labelling systems, developed at a national or an international level:

- WaterSense.
- National Association for Quality in Building Installations (ANQIP).
- Water Efficiency Label (WELL).
- Water Efficiency Labelling and Standards scheme (WELS).
- Code for Sustainable Home (CSH).
- Australian/New Zealand Standard – (AS/NZS 6400:2005) and its amendment (2006).
- System to Evaluate the Water Consumption at Home (SEWAT).

WaterSENSE

WaterSense was launched in 2006 by the United States of America Environmental Protection Agency (EPA), and offers the possibility to the consumers to acquire products, services and new households with a water efficiency label (Figure 5). The programme main goals are to promote the consumers attention to the importance of saving water and to encourage sustainable consumption habits (EPA, 2013 cited by Figueiredo, 2013).

Until today, the programme applies to showers, toilet flushes, flowmeters, taps, irrigation controllers and, more recently, to new residences (EPA, 2013).

The integrity and credibility of the label are assured by independent agencies that, periodically, test and verify the products with the specifications defined by EPA in terms of efficiency, performance and correct use.

Figure 5 – WaterSense efficiency label

WaterSense labelled products show a 20% efficiency reduction when compared with the conventional devices of the same category.

ANQIP

ANQIP is a Portuguese non-profit association, founded in 2007, that includes several universities, companies from the water sector, management organisations and self-employed technicians. Its main goal is to promote and ensure water quality and efficiency in water supply, drainage fittings and fixtures of buildings (Afonso and Rodrigues, 2008).

In accordance with the proposals of the National Programme for the Efficient Use of Water (PNUEA), ANQIP introduced a voluntary product certification system, along with a water efficiency labelling scheme, in Portugal.

The labelling system (Figure 6) uses the base colours green and blue. "A" refers to the highest efficiency and there is a graphic indication by means of drops for a better understanding of the symbol, and a small informative bar at the side. The A+ and A++ ratings are meant for special applications (Afonso and Rodrigues, 2008).

ANQIP conducts an initial certification of the internal control of production and carries out random tests at intervals of labelled products on the market.

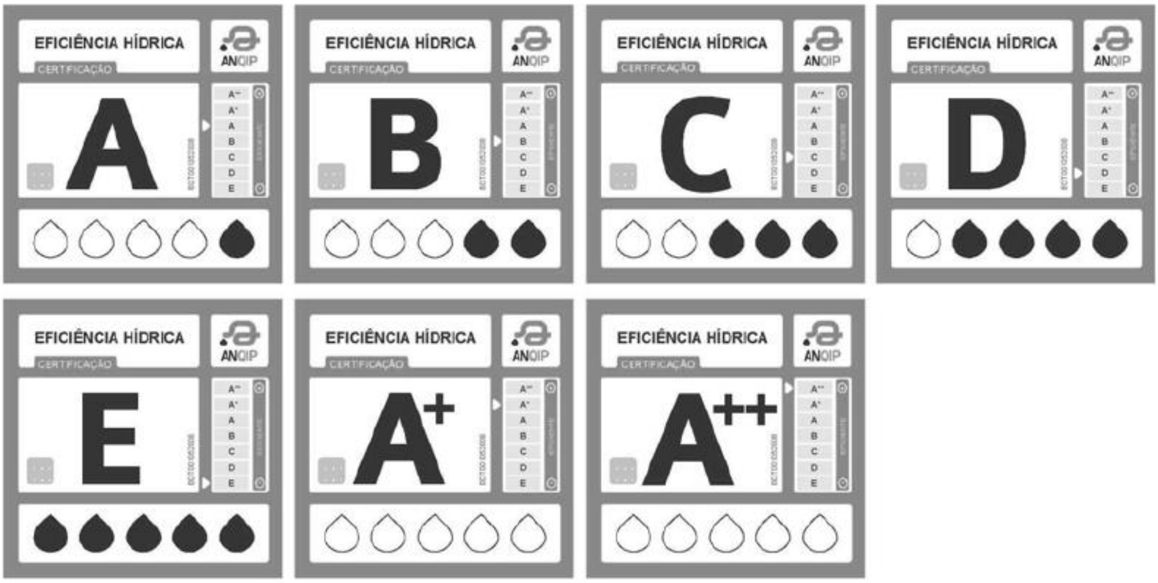


Figure 6 – ANQIP labelling system

WELL

WELL is a voluntary labelling system developed by the European Association of valves makers (EUnited Válvulas) which is used to help global consumers on the purchase of efficient water devices (EUnited, 2011).

The labelling system (Figure 7) is valid for the following devices: bathroom taps, kitchen taps, shower, bath systems, toilet flushes; flowmeters and accessories.

There are three types of labels:

- Home – private use.
- Public – public sector.
- Upgrade – for universal use accessories.

The labelling consists of a star rating to identify the efficiency level of the device. At the "Home" category, the most efficient devices receive a 4 stars rate (A to D efficiency levels). Public and Upgrade categories receive a similar star rating.

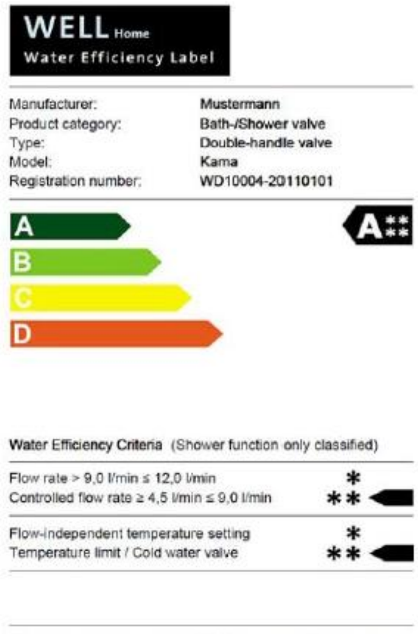


Figure 7 – WELL Home labelling system

WELS

WELS is a mandatory efficiency certification system applied in Australia since June of 2005. Its main goals are to give information to the consumers about the products efficiency and to encourage more sustainable water uses in order to promote water conservation (Australian Government, 2014).

The labelling system (Figure 8) has evolved along the years and today, it can be applied to: showers, taps, toilet flushes, flowmeters, dishwashers and washing machines.

From 2005, WELS features a star rating label. The most efficient device is labelled with 6 stars. Once the product is rated, it is registered in an on-line data base, available for purchase.

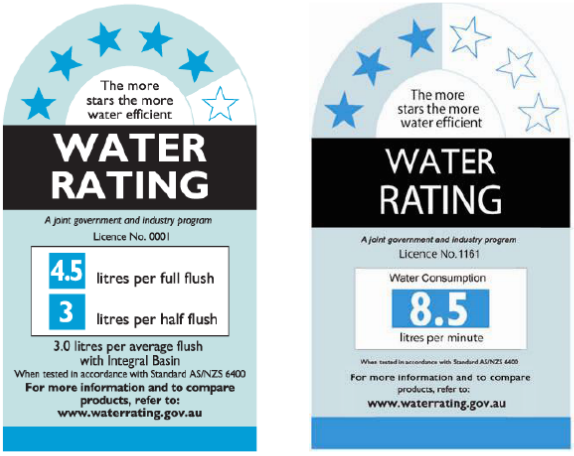


Figure 8 – WELS labelling system

CSH

The Code for Sustainable Homes was developed to enable a step change in sustainable building practice for new homes. It was prepared by the UK Government in close working consultation with the Building Research Establishment and Construction Industry Research and Information Association (Code for Sustainable Homes, 2006).

Its main goal is to guide industries in the design and construction of sustainable homes.

The design categories included within the Code are:

- energy/carbon dioxide;
- **water**;
- materials;
- surface water run-off;
- waste;
- pollution;
- health and well-being;
- management;
- ecology.

The water labelling consists of a star rating method, with a maximum of six stars (code levels). In the water category, the home will have to be designed to use no more than about 120 litres of water per person per day (one star, level one). This could be achieved by fitting a number of items such as: 6/4 dual flush WC; flow reducing/aerating taps throughout; 6-9 litres per minute shower; 18 litres maximum volume dishwasher; 60 litres maximum volume washing machine.

The Code benefits social housing providers by lowering running costs, improving the comfort and satisfaction and raising the sustainability credentials (Code for Sustainable Homes, 2006).

Australian/New Zealand Standard (AS/NZS 6400:2005)

This Standard specifies requirements for the rating of products in terms of water efficiency and includes the associated registration, labelling and, where applicable, minimum performance requirements (AS/NZS 6400:2005).

The Standard applies to: showers, dishwashers, washing machines, lavatory equipment, urinal equipment, tap equipment and flow controllers.

The Standard was published in 2005 and then revised in May 2006. The labelling system is very similar to the WELS system.

The main changes in the revision include (AS/NZS 6400:2005):

- the rating and labelling of all products in the specified categories, whether or not they comply with specific performance requirements;
- a revision of the product definitions;
- a revision of the product rating algorithms;
- new water efficiency ratings and labels based on "stars" instead of "A's";
- new assessment procedures;
- new certification conditions.

SEWAT

SEWAT is a model, applied in some cities in Spain, to evaluate the efficiency of water consumption in the household. With the input of water bill information, the model allows consumers to check if their water consumption is efficient (Gutierrez *et al.,* 2014).

The objective of the programme is to guide water policies towards ensuring the sustainability of use, in terms of quantity and quality, raising the efficiency in water use and minimizing the costs of supplying.

To assess the household efficiency, the labelling (Figure 9) consists of a "drop" rating system. The most efficient house receives a maximum of six drops.

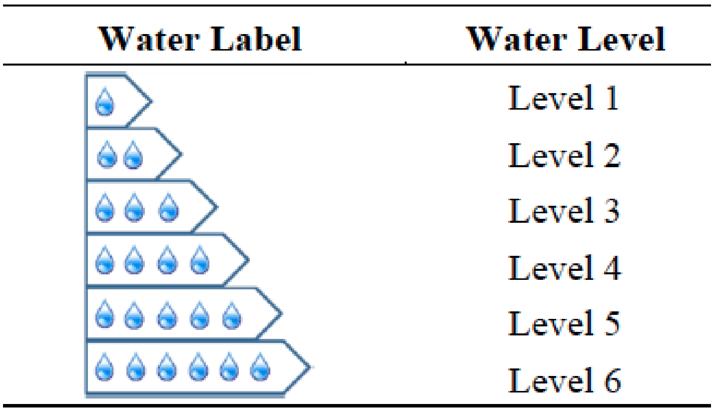


Figure 9 – SEWAT drop rating system

2.2.4 Devices efficiencies according to the different data labelling systems

A range of efficient values was applied for each water device based on the classifications for each water device available in the labelling systems previously presented in this section. The colour scheme adopted in the following figures, varies from green (more efficient) to red (non efficient), and the intermediate colours vary depending on the several ranges from each labelling system.

Figure 10 shows the different ranges considered by the different labelling systems for showers.

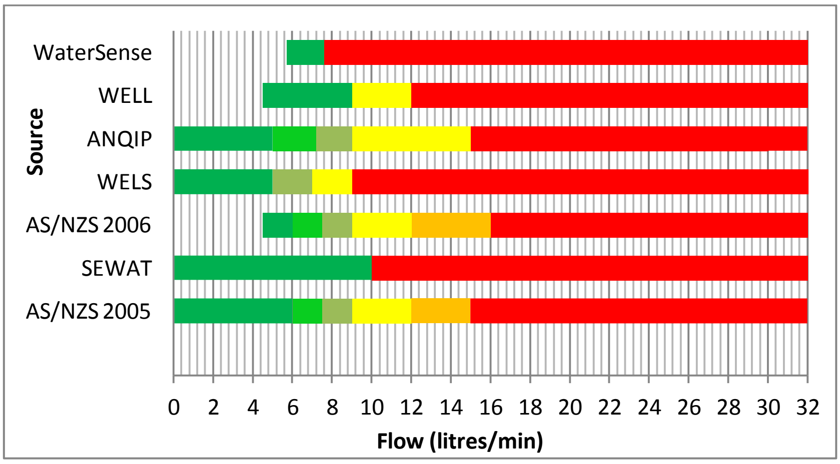


Figure 10 – Efficient ranges for showers from literature

The ranges from the different labelling systems show some variations among them. Some sources distinguished efficient and non efficient flows in just two labels, while others divided the flow values by different efficiency classes. The minimum and maximum values observed are 0 and 32 litres/min, respectively. The majority of the sources considered, approximately, as efficient values those which are bellow 8 litres/min and inefficient values above 15 litres/min. Values between 8 and 15 litres/min correspond to intermediate labels between efficient and non efficient flows.

Figure 11 shows the different efficient ranges considered by the different labelling systems for bathroom taps.

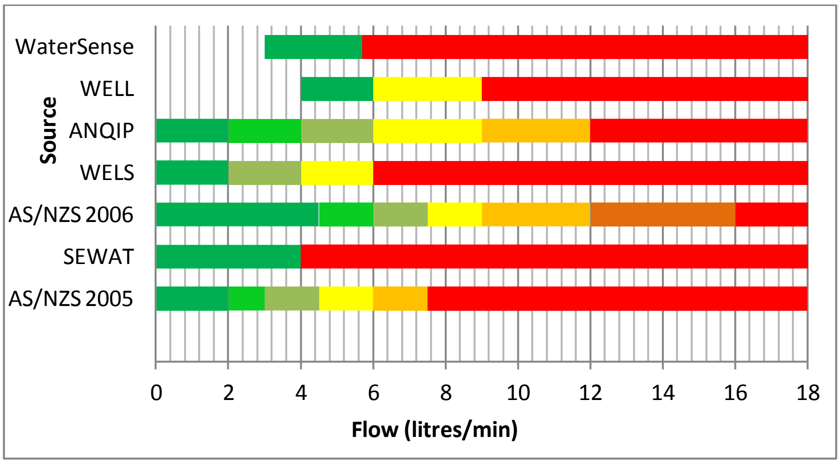


Figure 11 – Efficient ranges for bathroom taps from literature

For bathroom taps the different labelling systems also have different ways to divide the flow values. The minimum and maximum values observed are 0 and 18 litres/min, respectively. The majority of the labelling systems considered, approximately, as efficient values those which are bellow 4 litres/min and as inefficient values above 9 litres/min. Values between 4 and 9 litres/min correspond to intermediate labels between efficient and non efficient flows.

Figure 12 shows the different efficient ranges considered by the different labelling systems for kitchen taps.

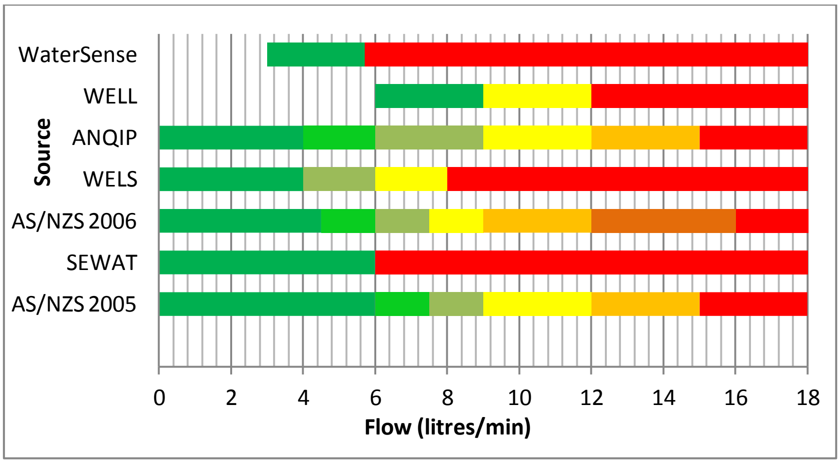


Figure 12 – Efficient ranges for kitchen taps from literature

Similarly to bathroom taps, the minimum and maximum values observed for kitchen taps are 0 and 18 litres/min, respectively. Most of the sources considered, approximately, as efficient values those which are bellow 6 litres/min and as inefficient values above 12 litres/min. Values between 6 and 12 litres/min correspond to intermediate labels between efficient and non efficient flows.

Figure 13 shows the different efficient ranges considered by the different labelling systems for dishwashers.

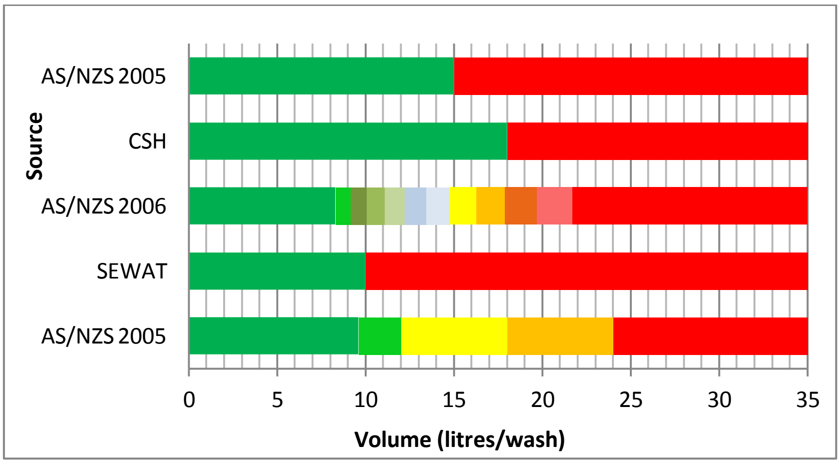


Figure 13 – Efficient ranges for dishwashers from literature

For dishwashers, the minimum and maximum values observed are 0 and 35 litres/min, respectively. Most of the labelling systems considered, approximately, as efficient values those which are bellow 12 litres/min and as inefficient values above 20 litres/min. Values between 12 and 20 litres/min correspond to intermediate labels between efficient and non efficient flows.

Figure 14 shows the different efficient ranges considered by the different labelling systems for washing machines.

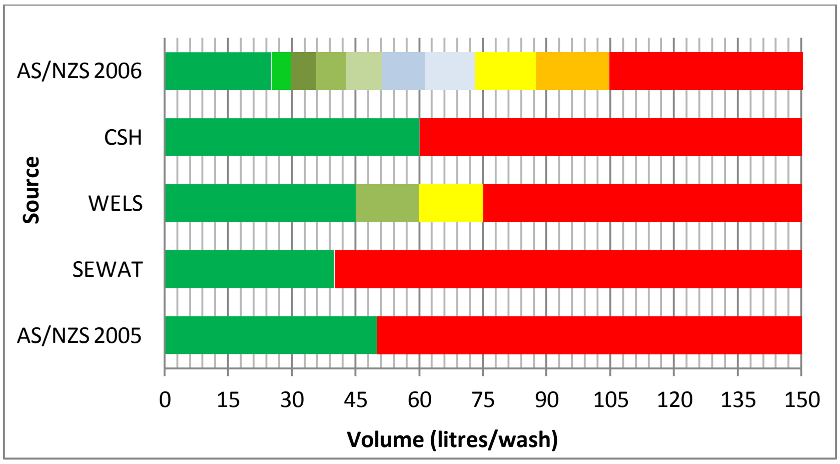


Figure 14 – Efficient ranges for washing machines from literature

The minimum and maximum values for washing machines are 0 and 150 litres/min, respectively. The majority of the labelling systems considered, approximately, as efficient values those which are bellow 40 litres/min and as inefficient values above 70 litres/min. Values between 40 and 70 litres/min correspond to intermediate labels between efficient and non efficient flows.

Figure 15 shows the different efficient ranges considered by the different labelling systems for single flush WC.

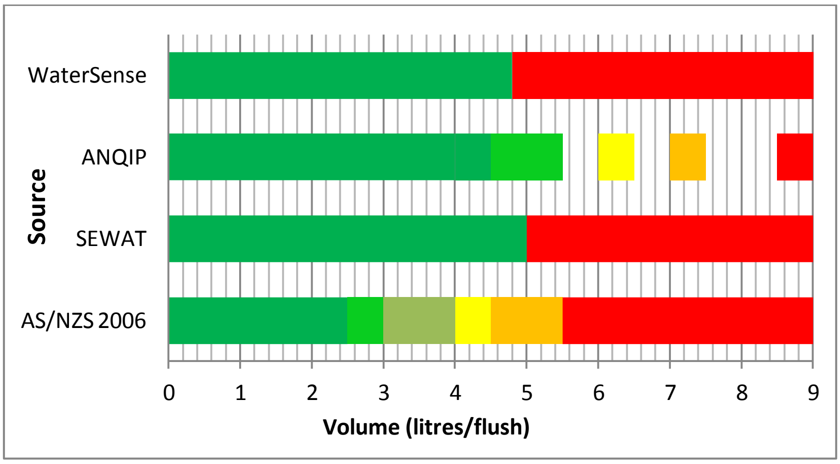


Figure 15 – Efficient ranges for single flush WC from literature

For single flush WC, the minimum and maximum values observed are 0 and 9 litres/min, respectively. Most of the labelling systems considered, approximately, as efficient values those which are bellow 4 litres/min and as inefficient values above 6 litres/min. Values between 4 and 6 litres/min correspond to intermediate labels between efficient and non efficient flows.

Figure 16 shows the different efficient ranges considered by the different labelling systems for dual flush WC.

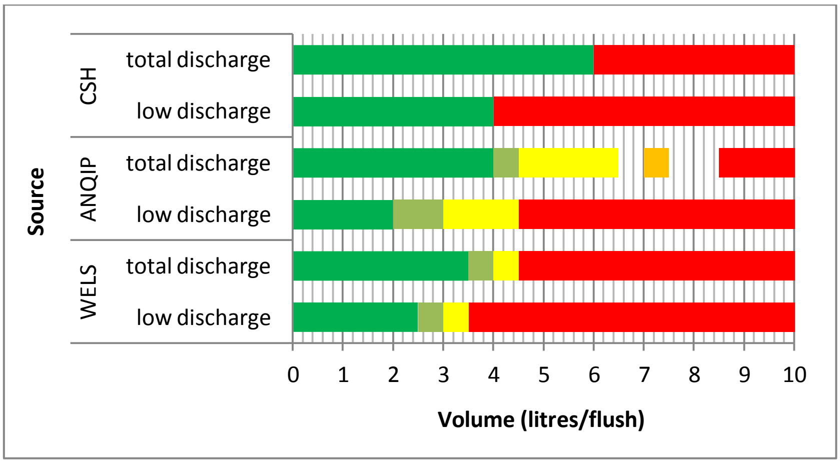


Figure 16 – Efficient ranges for dual flush WC from literature

For dual flush WC, ranges for total and low discharge are presented. For total discharge, most of the labelling systems considered, approximately, as efficient values those which are bellow 4 litres/min and as inefficient values above 6 litres/min. Values between 4 and 6 litres/min correspond to intermediate labels between efficient and non efficient flows. For low discharge, efficient values are those which are bellow 3 litres/min and inefficient values are above 4 litres/min. Values between 3 and 4 litres/min correspond to intermediate labels between efficient and non efficient flows. The minimum and maximum values observed are 0 and 10 litres/min, respectively.

The different ranges for the water devices from labelling systems allowed the construction of a unique range that combines all the values. Results are presented in Chapter 3 (Table 4).

2.3 Socio-demographic variables that most influence domestic water consumption

Empirical studies that quantify relationship between socio-demographic factors and the water end use patterns inside buildings are still largely lacking (Matos *et al.,* 2014).

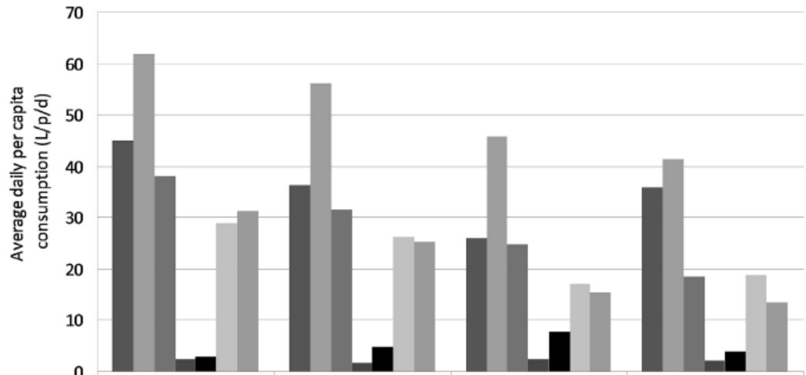
According to Matos *et al.* (2014), any strategy of water demand management needs the collaboration of the population involved and so it is important to know characteristics such as residence area, number of residents, presence or absence of children or elders, income level, and educational level, among others, may influence the use of water. The main research goal was to establish indoor water end use patterns per domestic device and to evaluate possible relations between these patterns with the socio-demographic characteristics. Significant correlations were found between the presence of children in the household and the use in the dishwasher. This correlation may be explained by the fact that those who have children naturally use the dishwasher more often, once the use of dishes in the presence of children is higher. Income can have a positive indirect effect on water savings as a result of its relationship with education. In the dishwasher, the distribution of uses revealed that medium class uses more this device than the higher class. This may be related to the fact that people with this level of income have more meals out in restaurants. The lowest class income did not use the dishwasher, maybe because they did not have it (Matos *et al.,* 2014).

Although the important contribution of the results presented in the study, correlations discussed, could be subject of further research to find other factors that might be important as well, like the permanence of the inhabitants in the household. Another important question to be answered is if water conservation is more likely when individuals believe that water is scarce or when they perceive that other consumers are also conserving water (Matos *et al.,* 2014).

Despite the potentially beneficial effects of consumers' participation in the assessment of the real end use of water, there are some limitations of survey research already noted by Bruvold (1977). One of the most important is the effects of confounding variables, and so, these results must be analysed considering these types of limitations (Matos *et al.,* 2014).

In few studies that do exist on this matter, it seems that older people tend to spend less water per capita than the younger. Moreover, families with children and teenagers are expected to use more water, but mainly in external uses (Corbella and Pujol, 2009). However, Lyman (1992) showed that older people tend to spend more time at home which leads to greater water consumption.

Willis *et al.* (2013) proceeded with a study on the Gold Coast (Australia) to assess water savings in households using efficient devices and focussed on the relationship between a range of socio-demographic and household stock efficiency variables and water end use consumption levels. The study provided evidence as to the potential savings derived from efficient appliances as well as socio-demographic clusters having higher water consumption across end uses. The objectives of this study were to determine a household and per capita water consumption end use break down for a sample of Gold Coast households, to explore the relationship between household stock survey efficiency rating clusters and water end use consumption levels and ascertain demographic information of water users and to determine if socio-demographic factors influence water consumption. Questionnaire surveys were developed to obtain socio-demographic information of each household to allow for clustering and analysis between varying demographic indicators. Surveys were distributed to each smart metered household. The Water Efficiency Labelling and Standards (WELS) was consulted to obtain relevant water usage volumes for different fixtures particularly clothes washers, showerheads and dishwashers to assist in data analysis and to determine the relative water efficiency of devices. For the socio-demographic results, the study revealed that: as income increased, so did water consumption increased; clothes washer and toilet end use consumption showed an opposite trend with these end uses being higher in large families than in small families; there was a general decrease in consumption per capita as family size increases (Willis *et al.,* 2013). Figure 17 shows the relationship between household characteristics and water end use consumption.



	Single person	Couple	Small family	Large family (> 4)
Clothes washer	45.1	36.3	26	35.9
Shower	61.8	56.1	45.6	41.3
Tap	38.0	31.4	24.7	18.6
Dishwasher	2.3	1.6	2.5	2.1
Bathtub	2.8	4.9	7.6	3.9
Toilet	28.8	26.2	17.0	18.7
Irrigation	31.2	25.2	15.3	13.5

Figure 17 – Relationship between household characteristics and water end use consumption (Willis *et al.,* 2013)

Pinheiro (2008) considered that in several studies where it is proposed to determine the water consumption per inhabitant, the socio-demographic variable 'family composition' at the household is taken into account. It is expectable that the higher family dimension is, the higher the total household consumption becomes. However, due to economies of scale, a decreasing in per capita consumption is noted (Edwards and Martin, 1995; Höglund, 1999; Arbués *et al.,* 2000). Arbués *et al.* (2003) argued that there is an optimum household size, and beyond a specific edge these economies of scale tend to disappear.

The increase of residences number, for a constant population, leads to a water consumption increase in the same area (Arbués *et al.,* 2000). In the presence of families with children, it is expected water consumption to be more careless, with more frequency of showers and clothes washing. Also outdoor uses are expected to be higher if children are present. Older people have shown the opposite behaviour, having fewer showers and being more careful with water uses (Nauges and Thomas, 2000).

Alegre (1992) also concluded, from a study on domestic water uses in Lisbon, that socio-demographic characteristics deeply affect the water consumption.

March *et al.* (2010) argued that the number of persons living in the household appears to be the most important driver of consumption, regarding demographic variables.

The age of the residents is also a considerably powerful explanatory variable for modelling domestic water consumption, but it is not always used in studies that address this subject (Garcia *et al.,* 2013).

White *et al.* (2003) identified that younger properties (<15 years old) had a higher consumption than older properties (40–50%), however Tso and Yau (2003) indicate that older homes use more water due to potential leaks.

Russac *et al.* (1991) classifies households into two types: small households (one or two persons) and large households. These authors verified that in small households the water consumption was practically the same as the large households. It means that, in what relates to per capita consumption, people that live in smaller households tend to spend more water than people that live in larger ones. This difference could be explained through a more efficient use of the water devices (*e.g.,* dishwasher and washing machine) by people who live in the larger households, because several activities require the same amount of water independently of the number of inhabitants in the household.

Another factor that influences the water consumption is the number of generations living in the household. According to Kim *et al.* (2006) who carried out a study, in 145 households in Korea, the domestic consumption increases with the number of existing generations.

Loureiro (2010), Mamade (2013) and Cabral (2014) concluded that socio-demographic variables (such as elderly families, educational level and economic mobility), are the most explanatory and relevant variables to characterized the domestic consumption in long-term, at a District Metered Area level.

Table 3 summarizes the socio-demographic variables that influence domestic water consumption according to the different authors.

Table 3 – Socio-demographic characteristics and their influence on water consumption

Author	Main conclusions
Russac *et al.* (1991)	Larger dwellings and isolated households tend to spend more water, while smaller houses and apartments tend to spend less water.
Bryant and Tillman (1998)	Households with a higher number of rooms are larger and more occupants who inhabit them tend to spend more water.
Mayer and DeOreo (1999)	Dwellings with higher occupancy, lot size and older water devices consumes more water.
Kenney *et al.* (2008)	Individuals that are wealthier, older and live in new and larger homes consume more.
Garcia *et al.* (2013)	The age of the residents is a considerably powerful explanatory variable for modelling domestic water consumption.
Tso and Yau (2003)	Older homes use more water due to the possibility of leaks.
White *et al.* (2003)	Younger properties (<15 years old) had a higher consumption than older properties (40–50%).
March *et al.* (2010)	The number of persons living in the household appears to be the most important driver of consumption, regarding demographic variables.
Willis *et al.* (2013)	Water consumption increases with income, however this factor have a bigger influence at outdoor uses. Per capita consumption decrease with increasing of family size.
Hassel and Carry (2007)	Educational level may also have impact on water use since the water use patterns highly depend on the consideration of sustainable water consumption practices and on the understanding of its importance to environment itself.
Nauges and Thomas (2000), Corbella and Pujol (2009)	Older people tends to use water carefully than young people, consuming less than young people.
Lyman (1992)	Older people tend to spend more time at home by which may lead to greater water consumption.
Murdock *et al.* (1991)	Age structure of a given population is a relevant driver of domestic water consumption.
Shaw (2007)	Higher water prices lead to lower consumption.

To sum up, it is of the utmost importance to consider socio-demographic variables in studies of water consumption assessment. Characteristics like number of people in the household, household, size, household age, income and educational level, professional situation, among other factors, largely influence water consumption.

2.4 Methodologies to evaluate the performance

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 management practices (Vieira *et al.,* 2010).

A set of some definitions related to performance are shown bellow:

"**Performance assessment** is any approach that allows evaluating the efficiency or the effectiveness of a process or activity through the production of performance measures"

Alegre (2006).

"**Performance indicators** are quantitative efficiency or effectiveness measures of the activity of an utility. A performance indicator consists of a value expressed in specific units, and a confidence grade which indicates the quality of the data represented by the indicator"

Alegre (2006).

"**Performance indices** are quantitative measures of the performance of a system, *i.e.*, they evaluate the distance from an optimum situation for which performance is the best. Performance indices can be used to analyze future scenarios and can transmit judgments in terms of higher or lower performance"

Vieira (2009).

"**Performance levels** are performance measures of a qualitative nature, expressed in discrete categories (*e.g.,* excellent, good, fair, poor)"

Alegre (2007).

"**Performance functions** convert state variables into performance indices"

Vieira *et al.* (2010).

The conversion of the state variables into a performance value can be carried out by a performance function or performance curve, penalty function or penalty curve. The function associates to each value of the state variable a performance index. Through the application of a generalization function to the performance elementary values of all state variables, it is possible to obtain an index that shows the global performance of the system (Vieira, 2009).

The type of generalization function depends on the analysis that has been carried out and can be described by (Alegre, 2007 cited by Vieira, 2009):

$$P = W\ (p_i) = \sum_{i=1}^{N} (w_i \times p_i) \tag{1}$$

in which:

P	Global performance index	[-]
W	Generalization function of the performance elementary values	[-]
w_i	Weight of each elementary component	[-]
p_i	Performance value in element i	[-]

An example of a performance function is shown in Figure 18.

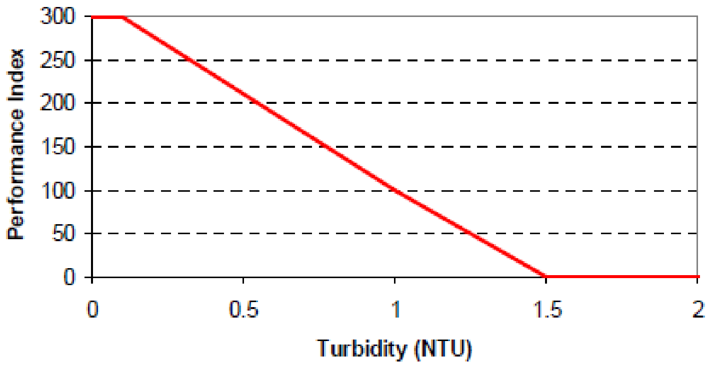


Figure 18 – Performance function for turbidity of treated water (Vieira *et al.,* 2010)

Methodologies for measuring service performance have been developed throughout the world. For example, structured performance indicators systems (*e.g.,* Ofwat, 2005; Alegre *et al.,* 2006) are increasingly applied for performance assessment of the whole water utility service, mainly considering management and economic issues. Other approaches are specific for some parts of the water supply systems and take into account the engineering aspects of their operation. Alegre (1992) and Coelho (1997) developed methodologies for performance evaluation of water distribution networks. Performance indices were proposed to assess the systems' behaviour under different demand loads and operational conditions. Cardoso *et al.* (2007) developed similar indices for sewer systems and Vieira (2009) for water treatment plants.

2.5 Conclusions, gaps of knowledge and motivation

The current chapter presented a state-of-the-art review on the methodologies already developed to evaluate water and energy efficiency, on the factors that influence the water consumption and on the methodologies to evaluate performance.

Many studies are already developed to give feedback to consumers' about their water and energy consumption. Several methodologies to make a quantitative characterization of daily water uses for each domestic device were developed. Performance assessment studies were also developed but the issue continues to be a topic of growing importance in the water industry.

Despite a large set of measures to improve the domestic water use is published in literature, there is a need for the development of a detailed and systematized methodology that evaluates consumers' efficiency in domestic water use, taking into account their behaviour and their water devices. Socio-demographic characteristics are also a subject that needs further research. To help fill this gap, with the current methodology presented in Chapter 3, the level of consumers' efficiency can be assessed in relation to efficient patterns and other consumers' in a similar situation, showing feedback to understand if consumers will save water when they know that other consumers are also conserving water.

The performance indices have already been applied in several studies but, to the authors' knowledge, the concept has never been applied to water devices in the household, measuring its efficiency level and giving it a performance value.

3 PROPOSED METHODOLOGY

3.1 Introduction

The current chapter presents the proposed methodology for the evaluation of the water use efficiency at an indoor domestic consumer level, supported in efficient use patterns. The aim is to develop a comprehensive methodology for assessing the efficiency of domestic consumers, considering three different approaches and taking into account consumers' daily behaviour and existing water devices in the household. The first approach is based on the comparison of consumers' consumption data with efficient patterns presented in published studies. The second approach divides consumers in clusters according to their socio-demographic and consumption characteristics and compares their individual consumption with the one from their peers, from the same cluster. The third approach focuses on the consumption of the water devices and evaluates the water use efficiency based on novel performance indices. The following sections present the description of the general methodology as well as of the three approaches followed.

3.2 General methodology

Figure 19 presents the proposed methodology to assess consumers' efficiency in domestic water use. This methodology attempts to better assess consumers' efficiency by joining the performance of existing water devices with consumers' behaviour which provides a detailed and complete evaluation of the overall water use efficiency in the household.

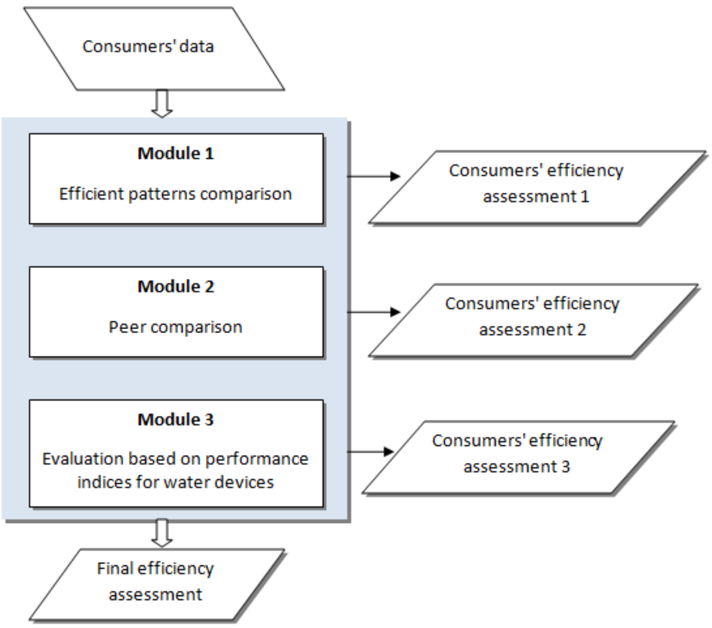


Figure 19 – Proposed methodology for efficiency assessment in domestic water use

The methodology is composed of three modules, namely:

- Module 1 – Efficient patterns comparison.
- Module 2 – Peer comparison.
- Module 3 – Evaluation based on performance indices for water devices.

Module 1, *Efficient patterns comparison*, focuses on the comparison of consumers' consumption data with consumption based on efficient patterns. These efficient patterns are obtained from values found in the literature for: efficient water devices flows or volumes, efficient time per use and frequency of use.

Module 2, *Peer comparison*, divides consumers into socio-demographic and consumption groups by cluster analysis. The classification of consumers according to consumption classes is also made. The goal of this module is to compare consumers with their peers (*i.e.*, with other consumers with similar characteristics).

Module 3, *Evaluation based on performance indices for water devices,* enables an efficiency assessment of the water devices in each household, as the last and fundamental component to analyse global efficiency. Performance functions are built based on efficient flows or volumes of the devices obtained in literature. A performance index is returned that classifies the water device giving an idea of its level of efficiency. At the end, an overall performance index is obtained from the individual indices of all the water devices.

Information produced by all the modules on efficiency of water devices and on efficient behaviours allows the identification of potential water savings in the household.

The three modules can be applied independently, as each returns an individual assessment. However, in order to obtain an overall assessment of the consumer efficiency they should be applied in a complementary way as each module assesses different points of view of water use efficiency. All the calculations are carried out using Microsoft Excel automatic sheets.

The scope of the present methodology is indoor water uses in domestic consumers and considers the following water devices: shower, single flush WC and dual flush WC (total flush volume and low volume discharges), bathroom taps, kitchen taps, dishwasher and washing machine.

The following sections present a detailed description of the three modules.

3.3 Module 1 – Efficient patterns comparison

3.3.1 Main structure

Module 1 compares consumers' consumption data with efficient patterns. Figure 20 shows the main steps of Module 1.

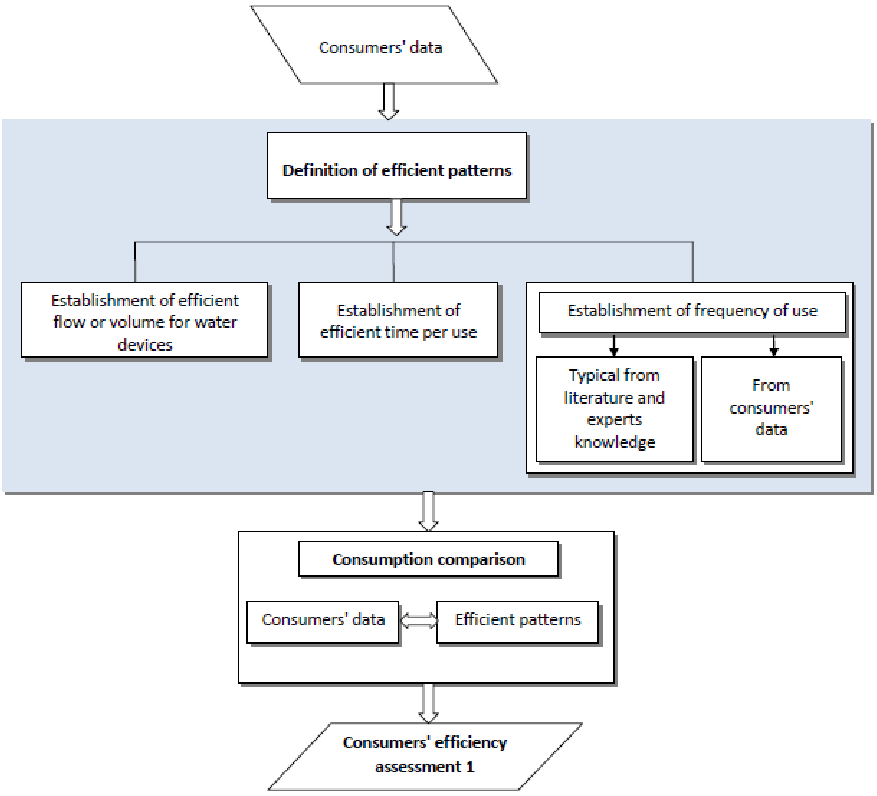


Figure 20 – Module 1: Efficient patterns comparison

In Module1, *Per capita consumption* is the consumption variable chosen to be analysed due to people in general having more sensibility to this variable. It should be highlighted that the approach described in this module can be extended to other consumption variables (*e.g.,* weekly consumption or monthly consumption). The *per capita consumption* is described by:

$$PC_H = \frac{DC_H}{NI_H} \qquad (2)$$

in which

PC_H	Per capita consumption (average value per household)	[litres/(person.day)]
DC_H	Average daily consumption per household	[litres/day]
NI_H	Number of inhabitants in the household	[person]

Efficient patterns are divided into three main categories:

(i) Efficient flow or volume of the water devices.

(ii) Efficient time per use.

(iii) Frequency of use.

Efficient patterns are obtained by multiplying the water devices flow or volume by the efficient time per use and by the frequency of use. The frequency of use can be calculated in two ways: in a first analysis, typical frequencies of use from the literature are considered or, for a more precise evaluation, consumers' data on frequency of use are applied.

Efficient consumption in bathroom and kitchen devices, like taps and showers, is calculated as follows:

$$C_{ED1} = F_{DE} \times T_E \times f_U \tag{3}$$

in which

C_{ED1}	Efficient consumption in bathroom and kitchen devices in the reference period	[litres]
F_{DE}	Water devices efficient flow	[litres/min]
t_E	Efficient time per use	[min]
f_U	Frequency of use in the reference period [1]	[No/day]

Dishwashers, washing machines and WCs do not have an efficient time per use and an efficient flow associated. Instead, these devices are characterized by an efficient fixed volume per use. Thus, the Equation to calculate efficient consumption of these two water devices is:

$$C_{ED2} = V_{DE} \times f_U \tag{4}$$

in which

C_{ED2}	Efficient consumption of dishwashers, washing machines and WC in the reference period	[litres]
V_{DE}	Water devices efficient volume per use	[litres]
f_U	Frequency of use in the reference period	[No/day]

[1] Depends on the recording time of each case.

3.3.2 Water devices efficient flow or volume

The *efficient flows and the efficient volumes per use of water devices* were obtained from the literature, for the different water devices considered in this analysis. Table 4 shows the final efficient ranges that will be used in further analysis.

Table 4 - Efficient flows or volumes for several water devices from the literature

Water devices	Range of efficient values	
	Minimum	Maximum
Shower (litres/min)	6.9	12.1
Bathroom taps (litres/min)	3.7	8.6
Kitchen taps (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 discharge (litres/flush)	2.8	4.0

3.3.3 Efficient time per use

The *efficient time per use* is a behavioural characteristic of each consumer, and it is considered for the following water devices and uses:

- shower;
- kitchen taps (uses: food washing, meal preparation, hand washing);
- bathroom taps (uses: hand washing, face washing, teeth brushing).

Baptista *et al.* (2001) refers that showers are more efficient than baths, therefore, showering was the water use considered herein to calculate an efficient time per use. Baptista *et al.* (2001) also refers that washing dishes using a dishwasher is more efficient than manually washing, thus the first procedure was the one considered, when dishwashers are present in the household.

Table 5 shows the efficient times per use adopted in the methodology. Values in this table correspond to the period of time when water is running.

Table 5 – Efficient time per use

Device	Water use	Efficient time per use	Data source
Shower		3 - 5 min	Baptista *et al.* (2001) Measurements carried out by volunteers
Kitchen taps		10 - 20 s	Measurements carried out by volunteers
Bathroom taps	Face washing	10 - 15 s	Measurements carried out by volunteers
	Hand washing	10 - 20 s	Measurements carried out by volunteers
	Teeth brushing	11 - 21 s	Measurements carried out by volunteers

In order to obtain some values for the efficient time per use, measurements were carried out by volunteer consumers in the scope of this research (outside of the case study sample). During these measurements, volunteers adopted the following efficient behaviours:

- Shower: running water only at the beginning of the shower and to rinse after soaping. The taps is closed for soaping (Baptista *et al.,* 2001).
- Teeth brushing: use of a glass for teeth brushing (Baptista *et al.,* 2001). Running water time is the time necessary to fill the glass.
- Hand and face washing: running water only to rinse and to clean the soap. The tap is closed for soaping (Baptista *et al.,* 2001).

For bathroom taps, a volume of 10 litres/week calculated from the measurements made by the consumer volunteers is additionally considered for house cleaning (*e.g.,* floor, bench and bathroom cleaning).

The results of these measurements presented in Table 5 correspond to an average value of the volunteer consumers.

3.3.4 Frequency of use

Typical frequencies of use from literature and experts knowledge

The frequency of use of the various water devices is directly related with the presence of the consumers in the household (Pinheiro, 2008). The consumers' presence is related to their professional situation, which can be active (working or studying) or inactive (retired or unemployed). As in this works' case study, this information is not available, two consumers' profiles are proposed based on consumers' age:

- $\leq$ 65 years – active workers and children;
- $>$ 65 years – inactive workers.

For both profiles, the water devices frequency of use considered is presented in Table 6.

Table 6 – Typical number of water uses for the two consumers' profiles

Water use	Number of uses/(day.person)		Number of uses/(week.person)		Data source
	Age ≤ 65	Age > 65	Age ≤ 65	Age > 65	
Showering	1	1			*
Hands washing	4	7			*
Face washing	1	1			*
Brushing teeth	2	3			AS/NZS 6400:2005
WC flushing [1]	3	5			*
Kitchen taps	4	8			*
Washing machine			1	1	*
Dishwasher			1	1	BOSCH (2014)

[1] Including single and dual flush (total and low discharge).

* Values were obtained in a brainstorming carried out with a group of experts.

In this analysis, it is considered that all the inhabitants are at home during the weekend. As such, on Saturdays and Sundays, all consumers have the same frequency of use as an inactive worker. However, in further analysis, calculations can be changed if information about the mobility of the inhabitants during the weekend is available.

Personal hygiene uses of each person increase proportionally with the number of inhabitants. The same does not occur with dishwashers and washing machines due to economies of scale effect (Willis *et al.,* 2013).

For an efficient use of the dishwasher, it should be run with full load (BOSCH, 2014). A normal dishwasher has 12 place settings, this means it can hold (BOSCH, 2014):

- dinner plate – 12 units;
- dessert plate – 12 units;
- glasses – 12 units;
- tea cups – 12 units;
- knives, forks, soup spoons, dessert spoons and teaspoons – 12 units each;
- serving plates and serving spoons – 3-4 units;
- bowls – 12 units.

The weekly use of the dishwasher was calculated considering only the main meals (lunch and dinner), one plate[2] per person and that dishwasher is run with full load.

- For example, for the working days there are ten plates used by each person with more than 65 years, and a half for those with less or equal to 65 years. During the weekend four plates is used by each person independently of the group. Therefore, fourteen plates are used during working days and nine plates during the weekend. If dishwasher takes twelve plates for full load, than it is easy to notice that it must be used once per week for both cases.

During the working days, if people with less than 65 years only have dinner at home and people with more than 65 cook all the meals at home, then for a higher number of persons present in the household, the same method is applied to count the dishes used.

There are a large number of consumers that do not have or do not use a dishwasher. Therefore, in these cases, the following efficient procedure to manually wash the dishes is considered: fill the sink two times, the first to wash and the other to rinse (ADP, 2011). To calculate the volume of water used in this procedure, some consumer volunteers were requested to measure their sink capacity. The average volume was 25 litres. Accordingly, 50 litres are spent to manually wash the dishes in this efficient procedure.

For the washing machine, run with full load, the following number of uses is considered typical:

- 1 to 2 inhabitants – once per week[3];
- 3 to 4 inhabitants – twice per week[3];
- 5 to 6 inhabitants – thrice per week[3].

Finally, Equations (3) and (4) can be applied for each household and a range of efficient values for per capita consumption can be obtained. An efficiency assessment of the household (Table 7) is made by the comparison between consumers' consumption data on per capita consumption referred in (2) and the range of efficient values determined using Equations (3) and (4).

Table 7 - Example of consumers' efficiency assessment

Household	Per capita consumption [litres/(person.day)]	Efficient per capita consumption [litres/(person.day)]		Consumers' efficiency assessment
		Maximum efficiency	Minimum efficiency	
1	102	67	83	There are potential savings
2	88	72	90	Efficient household
3	126	68	84	There are potential savings

[2] Plates are used for simplification, but the same applies for the other kitchen utensils.
[3] Values obtained in a brainstorm meeting carried out with a group of experts.

A household efficiency level (which relates the deviation of each household consumption to its minimum efficiency value) can also be calculated through Equation (5):

$$H_E = 100 + \frac{MEPC_H - PC_H}{PC_H} \times 100 \qquad (5)$$

in which

H_E	Household efficiency level	[%]
$MEPC_H$	Minimum efficient per capita consumption (average value per household)	[litres/(person.day)]
PC_H	Per capita consumption (average value per household)	[litres/(person.day)]

Frequencies of use obtained from consumers' data

It is possible to control water inefficient uses through the installation of more efficient water devices and the adoption of better practices in terms of efficient times per use. However, it is not fair to limit the frequency of use, since everyone has each own use needs.

Therefore, if information is available, the procedure for the application of Equations (3) and (4) using frequencies of use obtained from consumers data is explained. For each household, an average frequency of use of each water device [No./(person.day)] is calculated. For example, if there are three inhabitants in a household and thirty showers are taken for one week of recording time, an average of 1.4 showers per day, for each person, is achieved.

For this method, the same procedure of the previous analysis, *Typical frequencies of use obtained from literature and experts knowledge*, regarding the efficient procedure to manual dish wash is applied, for consumers' that do not record dishwasher uses.

The consumption value based on consumers' data is also compared with the efficient consumption range obtained with frequencies of use obtained from consumers' data and an efficiency assessment of the household is made, similarly to what is presented in Table 7, as well as the calculation of the household efficiency level through Equation (5).

3.4 Module 2 – Peer comparison

3.4.1 Main structure

Figure 21 presents the structure of Module 2.

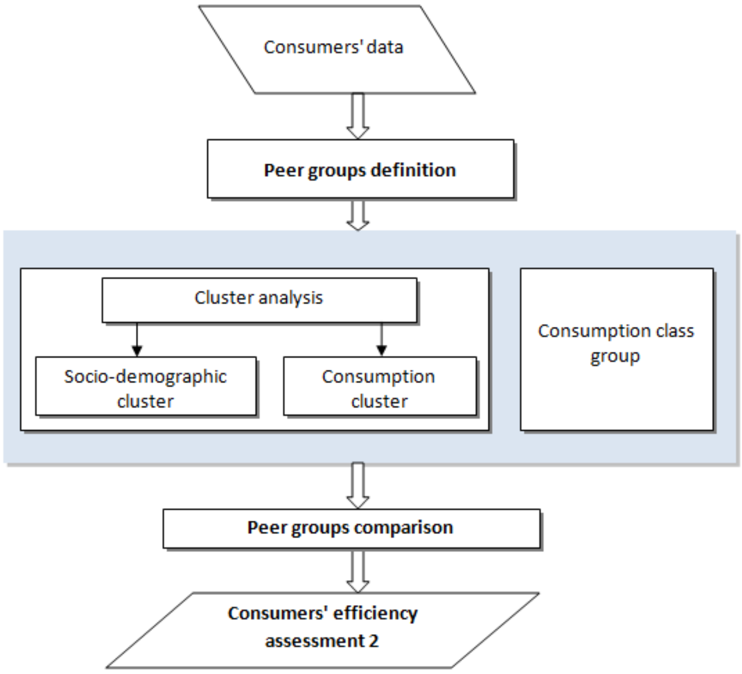


Figure 21 – Module 2: Peer comparison

The goal of this module, *Peer comparison*, is to carry out a different type of efficiency assessment, in which consumers are compared with each other through their own consumption based on consumers' data. This comparison is made with well-defined peer groups. The definition of peer group analysis is presented bellow:

"Each individual is selected as a target and is compared to all the other individuals. Based on this comparison, individuals which are similar to the target are chosen as a peer group. Then the event (or behaviour) of the peer group is summarized by each subsequent point in time, and the event (or behaviour) of the target is compared to the summary of the peer group"

(Bolton and Hand, 2001 cited by Hong and Sohn, 2013).

In this methodology, peer groups are identified by their consumption (weekly, per capita consumption) and by their socio-demographic characteristics (property type, professional situation, family dimension). These variables are chosen for their major influence on domestic consumption (Chapter 2). Through the analysis of consumer surveys, it is possible to identify the consumption and socio-demographic variables in each case study.

In Module 2, the statistical data analysis is performed with the software STATISTICA® and SPSS®. Correlation matrices are built to support the decision about variables that correlate the most between each other. Thus, initially, the correlation between the independent and dependent variables is verified. Correlation coefficients vary between -1 to +1. Values close to these limits mean that high correlation between the variables are observed, influencing negatively or positively, depending on the value being negative or positive, respectively (Pestana and Gageiro, 2003). Table 8 shows an example of a correlation matrix.

Table 8 – Correlation matrix (adapted from Pinheiro, 2008)

		Household		Family members	
		Floor number	Property type	Family dimension	Average age
Household	Floor number	1	0.39	0.2	0.06
		N=95	N=95	N=95	N=92
		p=---[1]	0	0.05	0.56
	Property type	0.39	1	0.65	0.04
		N=95	N=95	N=95	N=92
		0	p=---[1]	0	0.7
Family members	Family dimension	0.2	0.65	1	-0.29
		N=95	N=95	N=95	N=92
		0.05	0	p=---[1]	0
	Average age	0.06	0.04	-0.29	1
		N=92	N=92	N=92	N=92
		0.56	0.7	0	p=---[1]

[1] p-value is not applicable in these cases (same variable).

The first row in the table represents the Pearson coefficient (r-value) that indicates strength and direction (±) of the correlation. Higher coefficients correspond to stronger correlations. By convention, $r<0.2$ indicates a very low linear association; r between 0.2 and 0.39 shows low linear association; between 0.4 and 0.69 moderate linear association; between 0.7 and 0.89 high linear association; and between 0.9 and 1 a very high linear association. Similar logic applies to negative correlations (Pestana and Gageiro, 2003). The second row, N, is the number of participants with valid responses/data that is used to calculate the statistic r of Pearson. The third row, p-value, represents the reliability of the correlation. For $p<0.05$ the values show reliable results and for $p\geq0.05$ the correlation is not reliable.

3.4.2 Cluster analysis

By using the correlation matrix results, a cluster analysis may be carried out. The definition of a cluster analysis is shown bellow:

"Cluster analysis is a collective term covering a wide variety of techniques for delineating natural groups or clusters in data sets"

(Anderberg, 1973).

The results of a cluster analysis can be shown by using dendrograms (*i.e.,* tree diagrams), as the example presented in Figure 22. The analysis is carried out using the Ward's method and Euclidean distances and the clusters are obtained by selecting a cut-off line (Pestana and Gageiro, 2003).

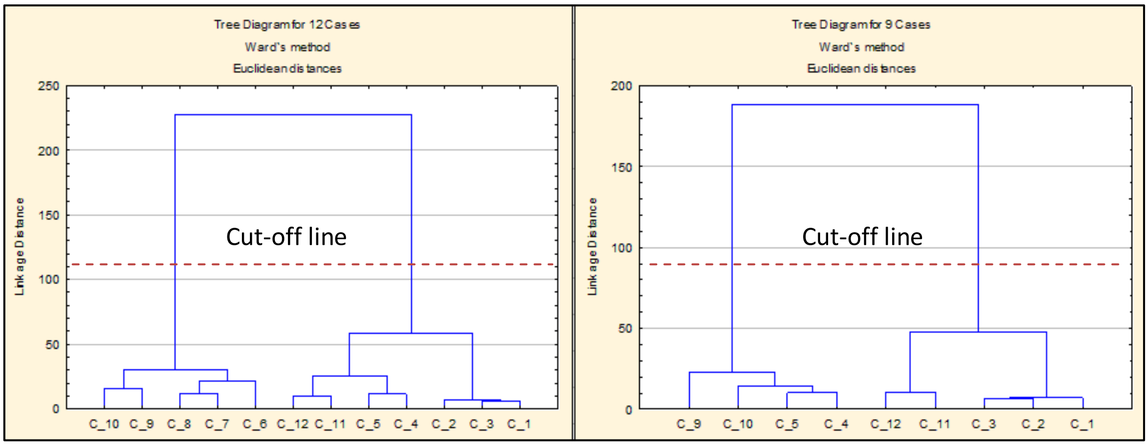


Figure 22 – Example of a clusters dendrogram with the cut-off line (Mamade, 2013)

If the correlation coefficient is high, the variables are not independent and one of them should be discarded for the cluster analysis. This high value shows that variables have large multicollinearity and should not be considered simultaneously as independent variables (Cabral, 2014). If this happens, it is not recommendable to carry out a cluster analysis with these variables, once conclusions will not be reliable, since a variable directly influences the other.

Table 9 and Table 10 depict examples of a socio-demographic cluster and a consumption cluster, respectively.

Table 9 – Example of socio-demographic clusters

Cluster	Household	Monthly consumption [litres/(household.month)]	Average age	Property type
1	3	32179	35	4
	15	17468	39	3
	21	21709	46	3
	24	69759	43	4
	Average	**35279**	**41**	**4**
	Minimum	**17468**	**35**	**3**
2	7	18865	52	3
	5	15316	60	3
	8	10099	42	4
	Average	**14760**	**51**	**3**
	Minimum	**10099**	**42**	**3**

Table 10 – Example of consumption clusters

Cluster	Household	Per capita consumption [litres/(person.day)]
1	1	174
	2	192
	9	171
	21	196
	22	194
	Average	**186**
	Minimum	**171**
2	3	87
	15	95
	23	102
	Average	**95**
	Minimum	**87**
3	8	200
	14	206
	42	128
	Average	**178**
	Minimum	**128**

Table 9 shows the comparison of a given household consumption with the socio-demographic cluster in which it is inserted (this cluster is constructed by family members average age and property type – number of bedrooms in the households). In Table 10 households are grouped depending on their similarities in terms of per capita consumption.

This kind of analysis has been applied in some studies. An example is Willis *et al.* (2013) that applied this analysis in the Gold Coast Residential End Study (Australia) which focussed on the relationship between a range of socio-demographic and household stock efficiency variables and water end use consumption levels. For that purpose surveys were developed to obtain socio-demographic information of each household to allow clustering and analysis between demographic indicators (Chapter 2).

3.4.3 Consumption classes

Module 2 also includes a comparison between consumers based on their consumption classes. This approach can be applied even if there is no information on the socio-demographic characteristics of the consumers. Consumers are divided in groups corresponding to the consumption classes defined for water pricing and are compared with these which are in the same class.

3.4.4 Efficiency assessment

Each consumer is compared to the minimum and to the average of the respective cluster. The comparison is carried out by using the following Equation (6):

$$H_E = 100 + \frac{Cl - C_{CD}}{C_{CD}} \times 100 \quad (6)$$

in which

H_E	Household efficiency level	[%]
Cl	Cluster average or minimum	[litres]
C_{CD}	Consumption based on consumers' data	[litres]

3.5 Module 3 – Evaluation based on performance indices for water devices

3.5.1 Main structure

Figure 23 shows the procedure for module 3 application.

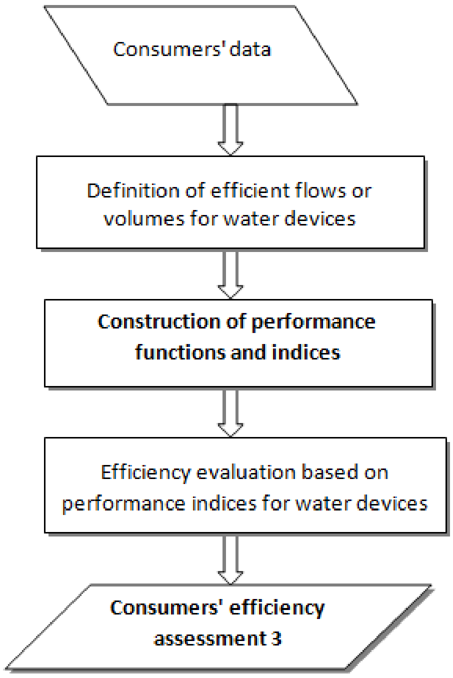


Figure 23 – Module 3: Evaluation based on performance indices for water devices

In this module, water devices efficiency of each household is analyzed. The efficient flow or volumes (see section 3.3.2, Table 4) are the variables used to build the performance functions. A performance index is the quantitative representation of the performance.

3.5.2 Construction of performance functions and indices

Performance indices are quantitative measures of the performance of a system, *i.e.*, they evaluate the distance from an optimum situation for which performance is the best. Performance indices can be used to analyze future scenarios and can transmit judgments in terms of higher or lower performance (Vieira, 2009).

To allow the conversion of a variable value into a performance index, performance functions are constructed. In terms of water use efficiency, the indices are a measure of the performance of each water device.

In Module 3, the general approach followed by Vieira (2009) was adopted for the construction of performance functions and indices. Performance indices range from 0 to 300, where:

- 300: Maximum performance, and classifies the water device in terms of flow/volume as "excellent";
- 300 to 200: Water devices performance is considered as "good";
- 200 to 100: The performance is "acceptable"; 100 corresponds to the "minimum acceptable";
- smaller than 100: "unacceptable" performance, including 0.

Vieira (2009) considered this scale (from 0 to 300 with three ranges) so that the good performance zone would not be more benefitted than the penalization in the unacceptable performance zone. The scale is the same for all the variables, so that all performance indices calculated can be comparatively assessed.

Therefore, to assess the performance of the water devices in terms of their own efficiency, the following steps are carried out:

i. Definition of the performance functions that apply to the flow or volume variables of the water devices. One performance function is defined for each water device.

ii. Conversion of the variable value into a performance index through the performance functions previously defined.

Figure 24 gives a generic example of a performance function representation.

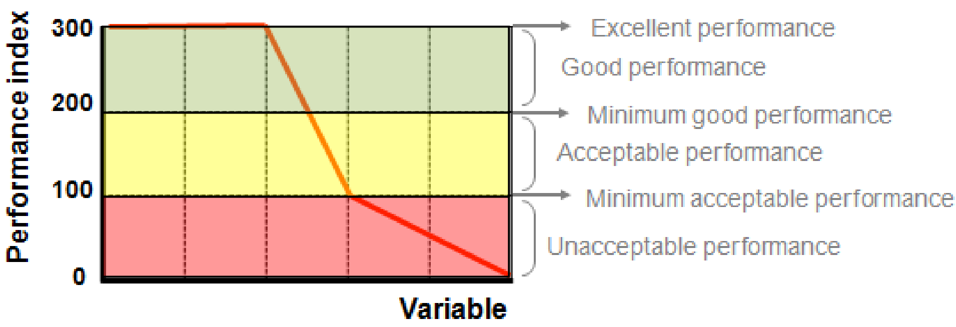


Figure 24 – Example of a performance function (Vieira, 2009)

The water devices flows or volumes presented in section 3.3.2 were considered to build the performance functions. These functions are constructed considering four levels:

1. index level of 300: 0 flow/volume value to maximum efficient value considered in the literature (performance functions are continuous, that is the reason why this level is considered even if the device does not achieve the goal for a too low flow or volume);
2. index level of 300 to 100: extremes of the range recommended in the literature (maximum and minimum efficient);
3. index level of 100 to 0: minimum efficient level of the literature × 0.25 (a 25% tolerance was adopted similarly to Vieira, 2009);
4. index level of 0: for values higher than (0.25 × minimum) efficient level of the literature.

Figure 25 presents the performance functions for the water devices considered in the present work.

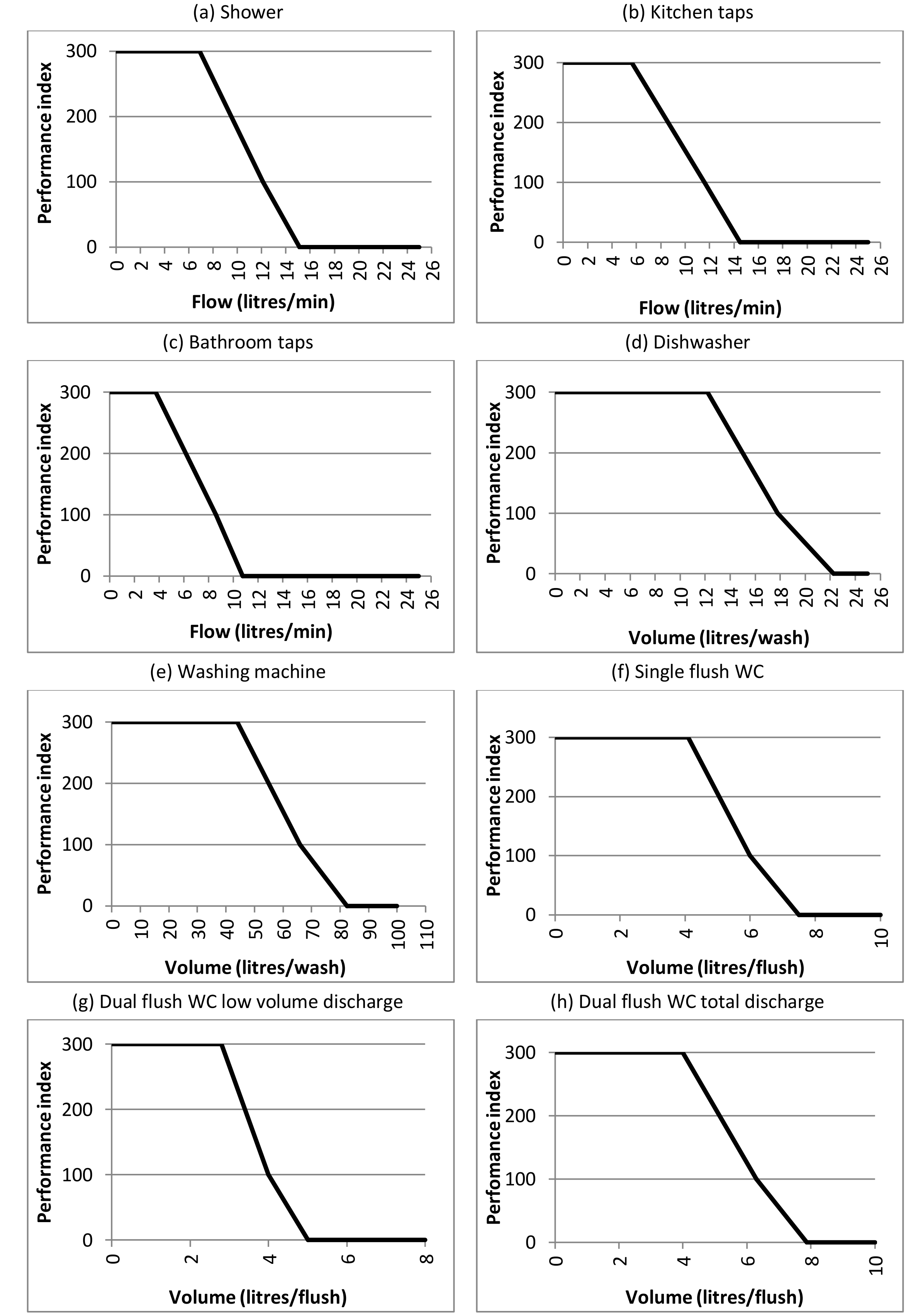


Figure 25 – Performance functions for different water devices: (a) shower; (b) kitchen taps; (c) bathroom taps; (d) dishwasher; (e) washing machine; (f) Single flush WC; (g) Dual flush WC low volume discharge; (h) Dual flush WC total discharge

3.5.3 Efficiency assessment of water devices in the household

For each water device, a performance index is calculated and the several devices can be compared to each other, from household to household.

The overall efficiency of a household is assessed through a household water use efficiency index taking into account all the existing water devices. As the devices contribute differently to the consumption structure of each household, it is necessary to consider weights in the calculation of the index (Equation (7)):

$$H_I = \sum_{\mathrm{i}=1}^{\mathrm{N}} I_{WDi} \times W_{WDi} \tag{7}$$

in which

H_I	Household water use efficiency index	[-]
I_{WDi}	Water device index of element i	[-]
W_{WDi}	Water device weight in the consumption structure of element i	[-]
N	Number of devices in the household	[-]

Attributed weights of each water device in the consumption structure can be determined by three different methods:

- Method I: Household weight for each case study;
- Method II: Average weight of each device of the case study sample;
- Method III: Typical values published in the literature.

These methods are described in the following sections.

Method I: Household weight for each case study

The first method uses the devices weights of the water devices from the case where the methodology is being applied. This is only applicable if information about the total household water volume spent (and the volume correspondent to each device) from the consumers' data is known. In this case, Equation (8) can be applied to calculate the weights:

$$W_{WDi} = \frac{V_{WDi}}{V_H} \times 100 \tag{8}$$

in which

W_{WDi}	Water device weight in the consumption structure of element i	[%]
V_{WDi}	Total volume used in a water device i	[litres]
V_H	Total volume used in the household	[litres]

This is the fairest method to calculate the weights since it uses the consumers' data from each case analysed.

Method II: Average weight of each device of the case study sample

Figure 29 (see Chapter 4) shows a consumption structure obtained for the case study sample to which this methodology was applied (DHA, LNEC), that can be a good approach when applying the methodology to other cases with similar characteristics (see Chapter 4) and if there is no information to apply the case own structure.

Method III: Typical values published in the literature

Table 11 shows the household consumption structure for several countries. The green highlighted uses correspond to uses considered in this work.

Table 11 – Household water use structure in several countries (values refer to percentage of total household consumption) (adapted from Vieira *et al.,* 2007)

Domestic consumption component	Germany (Bucker and Zimmer, 1999)	Sweden (SAPESB, 2000)	Switzerland (SAPESB, 2000)	U.K (Almeida and Butler, 1999)	U.K. (André and Pelin, 1999)	U.K (Anonym, 1996)	U.K. (SAPESB, 2000)	U.S.A. (Gray, 1999)	U.S.A. (AWWA, 1999)	U.S.A. (SAPESB, 2000)	U.S.A. (SAPESB, 2000)	Mexico (SAPESB, 2000)	Colombia (SAPESB, 2000)	Brazil (SAPESB, 2000)	Australia (Loh and Coghlan, 2003)	Average (%)
Indoor use																
Personal hygiene	36	-	37	-	-	20	37	25	-	30	-	-	-	-	-	31
bath	-	-	-	16	15	-	-	-	2	-	2	-	-	-	-	9
shower	-	19	-	12	2	-	-	-	17	-	17	30	30	55	-	**23**
other (face, hand and teeth washing)	-	-	-	13	-	-	-	-	-	-	15	-	-	8	-	**12**
Toilet flushing	24	27	40	31	31	33	37	35	27	40	26	35	40	5	21	**30**
Clothes washing	12	-	4	-	-	-	11	10	-	15	-	-	-	-	-	10
machine	-	-	-	16	8	12	-	-	22	-	25	-	-	-	27	**18**
manual	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	3
Dish washing	6	-	-	-	-	-	11	-	-	-	-	-	10	-	-	9
machine	-	-	-	-	.3	2	-	-	1	-	3	-	-	11	-	**4**
manual	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	3
Ingestion (drinking, cooking)	4	-	11	13	-	3	4	15	-	10	-	-	5	18	-	9
House cleaning	-	-	-	-	-	-	-	-	-	-	-	-	15	-	-	15
Taps	-	-	-	-	-	-	-	-	16	-	-	-	-	-	16	**16**
Losses	-	-	-	-	-	-	-	-	14	5	12	-	-	-	-	10
Other	9	-	-	-	37	27	-	-	2	-	-	-	-	-	3	16

Based on household consumption structures, an average structure was obtained (Figure 26). This average structure can be used as an approach of a household water use consumption structure for indoor uses, in case there is no information when applying Module 3. However, it should be kept in mind that this average takes into account countries with different climates and consumption habits.

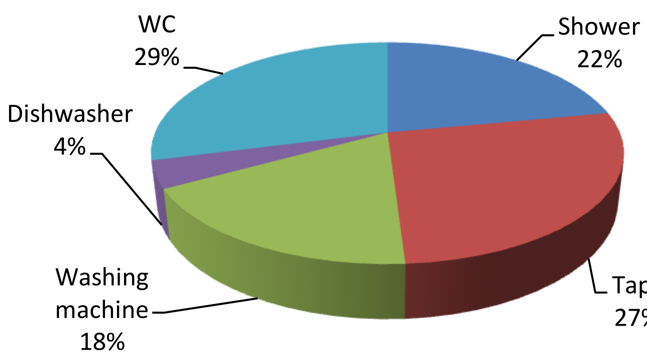


Figure 26 – Average distribution of household indoor water use based on literature review

In summary, for each water device, the real flow or volume can be transformed into a performance index by means of a performance function. The sum of each individual index multiplied by the respective household weight will result in the overall household water use efficiency index.

After the performance indices for each household are calculated, it is possible to draw conclusions like the percentage of users in each level and a global vision about which are the households with the most efficient devices. All these combined with the conclusions from the previous modules show, for each household, the water devices and the consumers' behaviours that need to be changed and improved.

4 CASE STUDY

4.1 Introduction

The current chapter describes the case study to which the methodology presented in Chapter 3 has been applied. It includes the household characterization in terms of water consumption, socio-demographic characteristics and existing water devices.

The case study is of the utmost importance for the application of the methodology. Additionally, it is composed of detailed and diversified data due to the extremely active participation of consumers in the survey.

4.2 Case study description

The case study analyzed and used for testing the proposed methodology in the current thesis had already been studied by Vieira *et al.* (2007), within the scope of the preparation of the National Programme for the Efficient Use of Water (Baptista *et al.,* 2001) and due to the need of Portuguese data on quantitative characterization of domestic water consumption. The purpose of that study was to obtain information to support the definition of water conservation measures for household use and followed the general methodology presented in Figure 27.

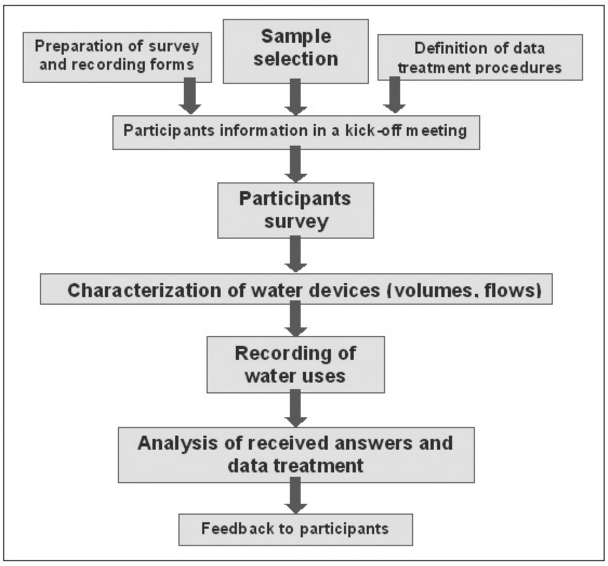


Figure 27 – Methodology followed by Vieira *et al.* (2007) to study the household water use in LNEC case study

A referred survey was conducted in the Hydraulics Department (DHA) of the National Laboratory for Civil Engineering (LNEC), Lisbon, Portugal, in 2001. The number of participants in the survey corresponds to 43 residences (approximately 100 persons), mostly located in the urban area of Lisbon and surrounding municipalities.

In order to account for the factors that could explain variations in consumption patterns, the selected sample included the following variables: property size, type and age; household size and composition; socio-economic level of the participants; education level of the participants.

In this study, participants had to characterize of their appliances by measuring flows and volumes. They were also asked to make detailed recordings of all water uses in the household, during one week in spring (June). The data collection period was the same for all participants.

Data used in the current thesis include information on:

- family dimension (number of persons in the household) and family composition by age;
- property type and size;
- water devices number and type;
- daily recordings of water uses (number and duration);
- weekly consumption based on water meter readings.

The water use devices included in the survey were: shower, bathroom taps, kitchen taps, WCs (single and dual flush), dishwasher and washing machine.

4.3 Case study characterization

4.3.1 Socio-demographic characteristics

Table 12 summarizes the main socio-demographic characteristics of the case study. Property type in this case study varies between T1 (property with one single bedroom) and T4 (property with four bedrooms). Inhabitants' number varies between 1 and 5. Inhabitants' age ranges from less than 1 year and 75 years, with an average age of 35 years.

Table 12 – Socio-demographic characteristics of the case study

Socio-demographic characteristic	Minimum	Average	Maximum
Property type	T1	(-)	T4
Family dimension	1	3	5
Family composition by age (years)	0.6	35	75

4.3.2 Consumption characteristics

The weekly consumption per household was determined based on water meter readings at the beginning and at the end of the survey week. The per capita consumption (average value per household) was obtained from weekly consumption.

A weekly consumption was also calculated based on consumers' records of water uses and devices characteristics presented in Table 13.

Table 13 – Data recorded for each water use (adapted from Vieira *et al.,* 2007)

Water use	Recordings	Characteristics of water devices measured
WC flushing	Number of flushes	Cistern capacity
Shower, taps (bathroom, kitchen)	Number of uses	Average flow
	Duration of each use	
Dishwasher, washing machine	Number of uses	Volume used per wash
	% of full load in each use	

To assess the confidence associated with the records, the weekly consumption value calculated based on consumers' records was compared with the meter based value. Observed differences were not relevant (less than 30%) and could be explained by some uses not being recorded and by the fact that water devices flow and capacity when "in use" could differ from the average values measured for their characterization (Vieira et al., 2007).

Table 14 shows the average, minimum and maximum for the two consumption variables, for the case study sample.

Table 14 – Characteristics of consumption in the case study

Consumption characteristic	Minimum	Average	Maximum
Weekly consumption per household (litres) [1]	473	3014	9966
Per capita consumption [litres/(person.day)]	50	138	286

[1] Based on water meter readings in the beginning and end of one week.

Data in this table show a per household consumption ranging between 50 and 286 litres/(person.day), with an average of 138 litres/(person.day). These values were expected considering the different factors influencing consumption and that the period of records was associated to nearly summer conditions, in which high temperatures occurred.

4.3.3 Water devices characteristics

Table 15 shows a statistical characterization of water devices in the case study sample.

Table 15 – Household water devices (adapted from Vieira *et al.,* 2007)

Water device	Number of water devices per household		
	Minimum	Average	Maximum
Washing machine	1	1	1
Dishwasher	0	0.8	2
WC (single flush)	0	1.5	3
WC (dual flush)	0	0.1	1
Shower	1	1.2	2
Bathroom taps	2	4.9	11
Kitchen taps	1	1.2	2

Other important information related to water devices is their average flow (Table 16) and their use frequency, as depicted in Figure 28.

Table 16 – Water devices characteristics

Parameter/characteristics	Minimum value	Average value	Maximum value
WC			
Total flushing volume (litres)	6	8.9	12
Dual flush WC - low volume discharge (litres)	3	4.7	6
Taps			
Bathroom taps flow (litres/min)	2.4	7.2	16.2
Kitchen tap flow (litres/min)	2.3	7.7	15.0
Shower			
Shower flow (litres/min)	6.3	10.1	20.0
Washing machine			
Volume per wash (litres)	17	79	150
Load (%)	50	92	100
Dishwasher			
Volume per wash (litres)	10	30	98
Load (%)	10	93	100

Table 16 shows that, in terms of average values, the highest flow corresponds to showers (around 10 litres/min) and the lowest flow to kitchen and bathroom taps, which have similar flows (7.7 litres/min and 7.2 litres/min, respectively).

On average, consumers from this case study use dishwashers and washing machines with almost full loads (92-93%) but situations can be found with very low values – 10% for dishwashers and 50% for washing machines.

Volumes per wash vary significantly from 17 to 150 litres for washing machines and from 10 to 98 litres for dishwashers, corresponding to a range of newer and older models.

Although dual WC flush is more efficient, in this case study, the majority of the households still have conventional WC flush installed.

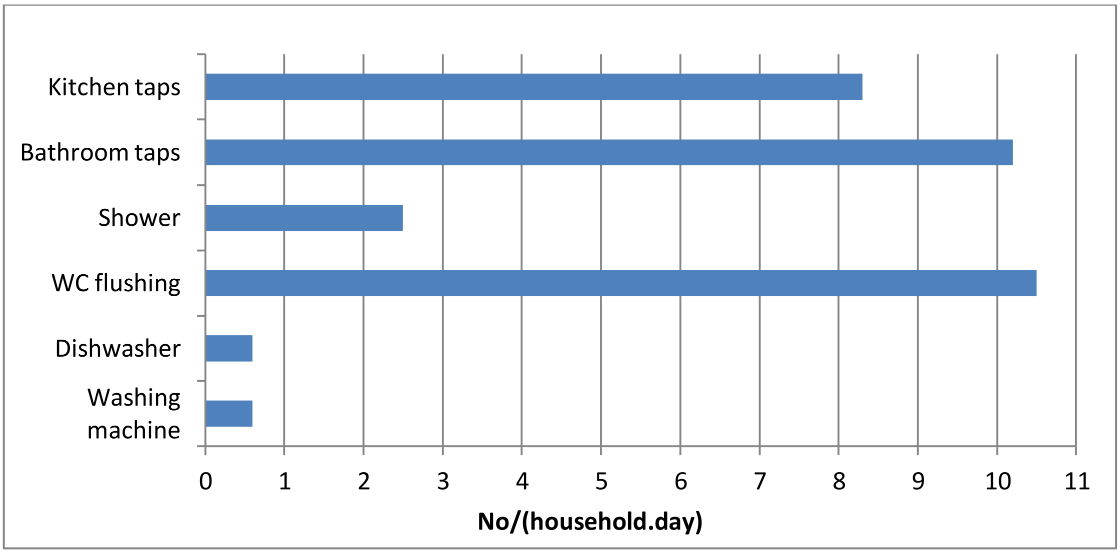


Figure 28 – Daily average frequency of use per household

Figure 28 shows that water devices mostly used are taps [10.2 uses/(household.day)] for bathroom taps and 8.3 uses/(household.day) for kitchen taps) and WC flushes [10.5 flushes/(household.day)]. Washing machines and dishwashers are normally used only every other days [0.6 uses/(household.day)].

It should be noted that records of taps uses have more errors associated than all other types of uses, due to the characteristic short duration (see Table 17) and consecutive individual use. Thus, real frequency values for taps use are probably higher than those presented (Vieira *et al.,* 2007).

Table 17 – Duration of water uses

Water Device	Minimum time per use (min)	Average time per use (min)	Maximum time per use (min)
Shower	1.7	5.7	9.6
Bathroom taps	0.2	0.8	4.4
Kitchen taps	0.3	1.5	8.3

The time per use of showers and taps was also measured (Table 17). As expected, showering has higher duration (average duration of 5.7 minutes) than taps (average duration of 1 minute).

4.4 Consumption structure

Based on volume or flow characteristics of the water devices and on their frequency of use, the total water volumes consumed in each device and the corresponding consumption percentage of total household consumption were determined. Figure 29 presents the average household consumption structure. This consumption structure does not take into account water losses inside the household (Vieira *et al.,* 2007).

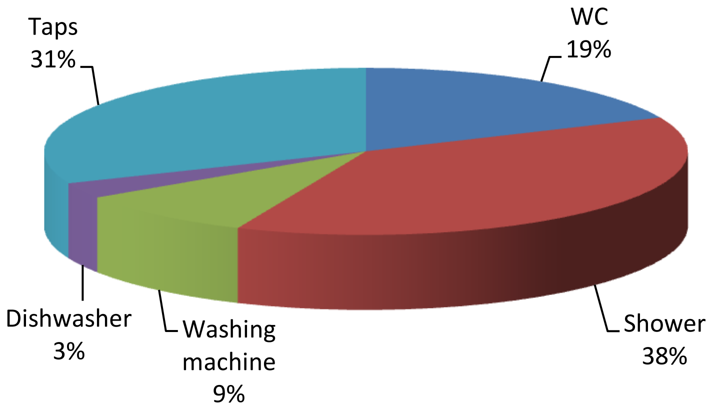


Figure 29 – Average distribution of household indoor water use for the case study

Shower and taps are the most water consuming uses (38% and 31%, respectively), followed by WC (19%). Laundry and dish washing machines contribute the least for total water consumption (9% and 3%, respectively).

5 RESULTS OF METHODOLOGY APPLICATION

5.1 Introduction

The current chapter analyzes and discusses the results obtained from the application of the methodology described in Chapter 3, to the case study presented in Chapter 4. Results are shown according to the modules of the proposed methodology.

For Module 1, two types of results about consumers' efficiency are shown, both comparing actual consumption to efficient consumption patterns – one with frequencies of use published in literature and another one with frequency of use based on consumers data. Advantages and disadvantages of using the two methods for patterns comparison are identified.

For Module 2, the following results are presented: statistical analysis of the correlations between the explanatory variables, various clusters and groups formed and the efficiency assessment of the consumers.

For Module 3, results on the water devices performance for all case study sample are obtained, by using the household water use efficiency index (H_I).

Finally, some conclusions about the case study sample overall water efficiency are presented, as well as about the application of the methodology.

5.2 Application of Module 1 – Efficient patterns comparison

In Module 1 the weekly consumption per household, determined based on water meter readings for the 43 residences (approximately 100 persons), was divided by seven days of the week and then per capita consumption (average value per household) was obtained by Equation (2) (Chapter 3). Results about the consumption characteristics for the current case study are shown in Table 14 (see section 4.3.2) and presented with detail in Table 49 (Appendix A).

With the per capita consumption obtained from consumers' data, the two paths of the methodology to assess the efficiency of water use based on efficient patterns (water devices flow or volume, efficient time per use and frequency of use) were applied. Results from the two ways to evaluate efficiency are presented bellow.

5.2.1 Assessment using typical frequencies of use obtained from literature and experts knowledge

As explained in section 3.3.4, two consumers' profiles based on age were adopted, taking into consideration the presence of consumers at home. From the total of 43 households, 38 (88%) have residents with a ≤ 65 years profile, 2 (5%) with a > 65 years profile and 3 (7%) with both profiles. Table 18 summarises the characteristics for the two profiles.

Table 18 – Characteristics of the two consumers' profiles based on age

Devices	Water use	Typical number of uses per day and per person	Typical number of uses per day and per person	Typical number of uses per week and per person	Efficient time per use
All ages	All ages	Age ≤ 65 years	Age > 65 years	All ages	All ages
Shower		1	1	–	3 - 5 min
Bathroom taps	Hands washing	4	7	–	10 - 15 s
	Face washing	1	1	–	10 - 20 s
	Brushing teeth	2	3	–	11 - 21 s
WC	WC flushing	3	5	–	
Kitchen taps	–	4	8	–	10 - 20 s
Washing machine	–	–	–	1	–
Dishwasher	–	–	–	1	–

From the total of 43 households, 12 (28%) do not have a dishwasher. Therefore, as explained in section 3.3.4, the manually washing was the efficient procedure considered, for these cases, in further analysis within this module.

Efficient patterns were obtained for the 43 households (for the two profiles considered) based on the typical frequencies of use and the efficient time per use from Table 18 and on the water devices efficient flows or volumes from Table 4 (section 3.3.2). From each household, the real per capita consumption was compared with the efficient consumption and the consumers' efficiency in water use was assessed. The results are presented in Table 19.

Table 19 – Household efficiency assessment for typical frequencies of use from literature and experts knowledge

Household	Profile	Per capita consumption [litres/(person.day)]	Efficient per capita consumption [litres/(person.day)]		Consumers' efficiency assessment
			Maximum efficiency	Minimum efficiency	
1	≤ 65 years	174	62	83	There are potential savings
2	≤ 65 years	128	61	81	There are potential savings
3	≤ 65 years	87	61	81	There are potential savings
4	≤ 65 years	97	103	128	Efficient household
5	≤ 65 years	154	77	98	There are potential savings
6	≤ 65 years	181	61	81	There are potential savings
7	≤ 65 years	164	59	79	There are potential savings
8	≤ 65 years	50[1]	65	85	Efficient household
9	≤ 65 years	114	61	81	There are potential savings
10	≤ 65 years	89	65	85	There are potential savings
11	≤ 65 years	104	61	81	There are potential savings
12	≤ 65 years	127	59	78	There are potential savings
13	≤ 65 years	83	59	79	There are potential savings
14	≤ 65 years	112	77	98	There are potential savings
15	≤ 65 years	286	103	128	There are potential savings
16	≤ 65 years	111	59	79	There are potential savings
17	≤ 65 years	132	103	128	There are potential savings
18	≤ 65 years	236	59	79	There are potential savings
19	Both	141	78	99	There are potential savings
20	≤ 65 years	144	59	79	There are potential savings
21	≤ 65 years	196	62	83	There are potential savings
22	Both	194	66	89	There are potential savings
23	≤ 65 years	77	65	85	Efficient household
24	≤ 65 years	74	59	79	Efficient household
25	≤ 65 years	205	61	81	There are potential savings
26	Both	132	60	81	There are potential savings
27	≤ 65 years	147	62	83	There are potential savings
28	≤ 65 years	133	59	79	There are potential savings
29	≤ 65 years	68[1]	103	128	Efficient household
30	≤ 65 years	114	61	81	There are potential savings
31	≤ 65 years	135	59	79	There are potential savings
32	≤ 65 years	214	61	81	There are potential savings
33[2]	> 65 years	259	86	110	There are potential savings
40[2]	≤ 65 years	72	62	83	Efficient household
41	≤ 65 years	131	62	83	There are potential savings
42	> 65 years	128	137	167	Efficient household
43	≤ 65 years	76	59	79	Efficient household
44	≤ 65 years	107	59	79	There are potential savings
45	≤ 65 years	152	61	81	There are potential savings
46	≤ 65 years	144	61	81	There are potential savings
47	≤ 65 years	141	59	79	There are potential savings
48	≤ 65 years	178	61	81	There are potential savings
49	≤ 65 years	158	59	78	There are potential savings
Minimum		**50**	**59**	**78**	
Average		**138**	**68**	**79 89**	
Maximum		**256**	**137**	**167**	

[1] These households have a per capita consumption lower than the maximum of the efficiency consumption pattern, therefore they were considered as efficient households.

[2] The households 34 to 39 have been removed from the initial sample as collected data were not consistent and these households were considered outliers.

Table 19 shows that only 8 (18%) of the total evaluated households are considered to be efficient and, thus, the majority of the households (82%) show a potential for savings, as shown in Table 19 and Figure 30.

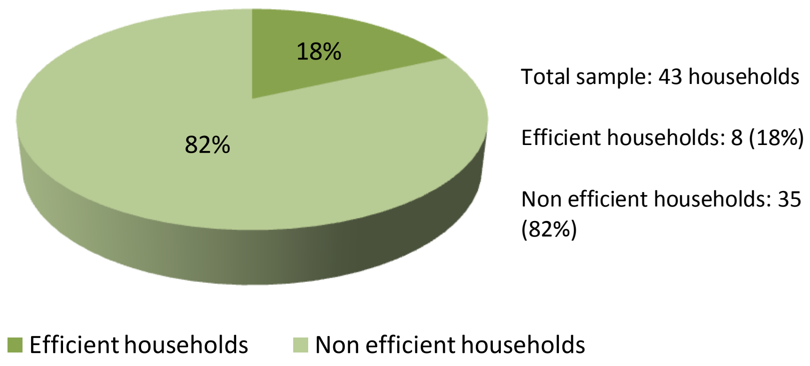


Figure 30 – Household efficiency assessment using typical frequencies of use obtained from literature and experts knowledge

By analysing the average values for the per capita consumption, in Table 19, the value obtained for efficient patterns (79 litres/(person.day)) is almost half of the value based on consumers' data (138 litres/(person.day)). The minimum value is lower in the case of per capita consumption based on consumers' data (50 litres/(person.day)) than for efficient patterns (59 litres/(person.day)). However, if it is assumed that people of this household spend little time at home and this value is neglected, the minimum becomes slightly higher (68 litres/(person.day)).

Table 20 presents some characteristics of the households classified as efficient.

The efficient households have an average age of 38 years, 3 persons per household and only three of the eight households have a dishwasher. Therefore, the majority of the efficient households do not have a dishwasher, contrarily to what is said in literature. A reason for this might be that the dishwashers of the case study sample are not efficient as they use an average volume of 30 litres/wash (see Chapter 4, Table 16), and the efficient volume is, on average, 15 litres/wash.

Table 20 – Characteristics of efficient households' for typical frequencies of use obtained from literature and experts knowledge

Efficiency assessment	Average family dimension	Average age	Number of households with dishwashers'
Efficient households (8 out of 43)	3	38	3

Figure 31 shows the level of efficiency of each household, which relates the deviation of each household consumption to its minimum efficiency value. On average, the total sample is on level "68% efficient", with potential water savings of 32% to reach level "100% efficient".

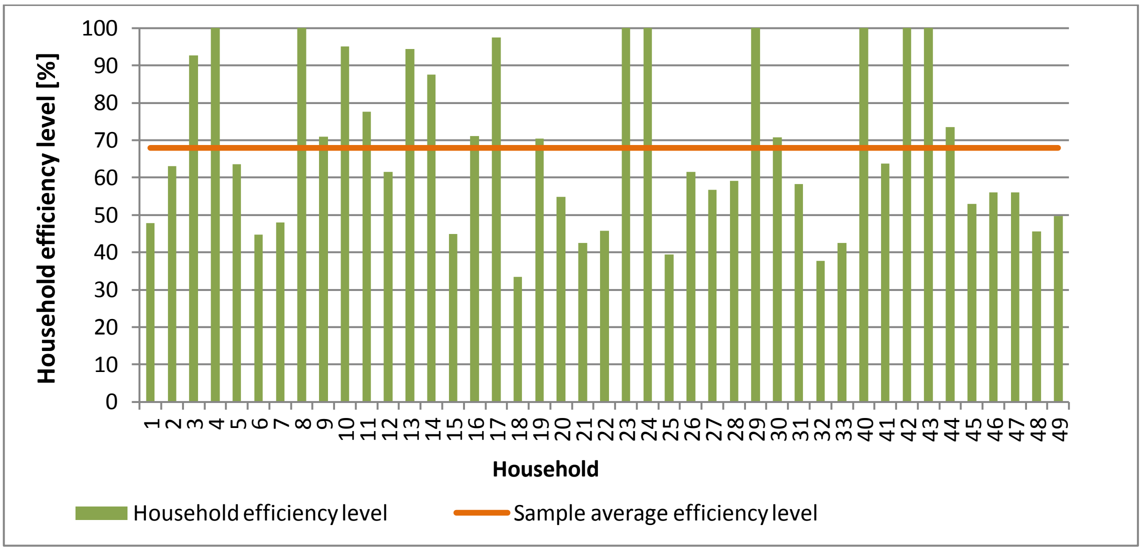


Figure 31 – Households' efficiency level based on efficient patterns for typical frequencies of use from literature and experts knowledge

The results presented in Figure 31 also show that eight households are considered as efficient with a household efficiency level of 100%. There are 11 households that have an efficiency level bellow 50%, which demonstrates that they should more than double their water savings, comparing to the current situation. Households 18, 25 and 32 are the worst classified consumers of the sample for the assessment based on efficient patterns from literature and experts' knowledge, with an efficiency level bellow 40%.

5.2.2 Assessment using frequencies of use obtained from consumers' data

Table 21 shows the average frequencies of use for the sample.

Table 21 – Average frequencies of use obtained from consumers' data

Water device	Shower	Bathroom taps	Kitchen taps	WC	Dishwasher	Washing machine
Frequency of use [No/(household.day)]	2.5	10.2	8.3	10.5	0.6	0.6
Frequency of use [No/(person.day)]	1	3	3	3	0.2	0.2

Considering the same water uses, efficient times per use and water devices flows or volumes as in section 5.2.1, Equations (3) and (4) are applied considering the frequencies of use obtained from consumers' data (Table 21). The results are presented in Table 22.

Table 22 – Consumers' efficiency assessment for frequencies of use obtained from consumers' data

Household	Per capita consumption [litres/(person.day)]	Efficient consumption [litres/(person.day)]			Consumers' efficiency assessment
		Maximum efficiency		Minimum efficiency	
1	174	89		124	There are potential savings
2	128	39		54	There are potential savings
3	87	52		74	There are potential savings
4	97	95		119	Efficient household
5	154	66		86	There are potential savings
6	181	53		74	There are potential savings
7	164	89		123	There are potential savings
8	50[1]	52		70	Efficient household
9	114	40		56	There are potential savings
10	89	40		53	There are potential savings
11	104	39		54	There are potential savings
12	127	34		48	There are potential savings
13	83	38		53	There are potential savings
14	112	60		77	There are potential savings
15	286	130		169	There are potential savings
16	111	28		40	There are potential savings
17	132	72		88	There are potential savings
18	236	69		97	There are potential savings
19	141	91		115	There are potential savings
20	144	50		73	There are potential savings
21	196	65		90	There are potential savings
22	194	80		111	There are potential savings
23	77	49		65	There are potential savings
24	74	55		79	Efficient household
25	205	91		128	There are potential savings
26	132	39		55	There are potential savings
27	147	60		82	There are potential savings
28	133	70		96	There are potential savings
29	68[1]	115		145	Efficient household
30	114	71		100	There are potential savings
31	135	60		82	There are potential savings
32	214	64		91	There are potential savings
33	259	78		104	There are potential savings
40	72	47		66	There are potential savings
41	131	62		85	There are potential savings
42	128	115		140	Efficient household
43	76	52		72	There are potential savings
44	107	56		78	There are potential savings
45	152	52		73	There are potential savings
46	144	50		70	There are potential savings
47	141	57		79	There are potential savings
48	178	63		87	There are potential savings
49	158	60		85	There are potential savings
Minimum	**50**	**28**		**40**	
Average	**138**	**64**	**75**	**86**	
Maximum	**256**	**130**		**169**	

[1] These households have a per capita consumption lower than the maximum of the efficiency consumption pattern, therefore they were considered as efficient households.

Only 5 (12%) of the total evaluated households are considered to be efficient and, thus, the majority of the households (88%) evidence a potential savings, as shown in Table 22 and Figure 32.

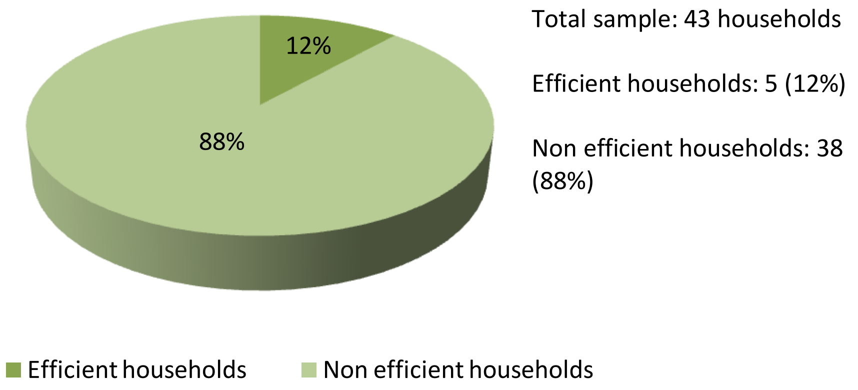


Figure 32 – Household efficiency assessment using frequencies of use obtained from consumers' data

The value obtained for efficient patterns (75 litres/(person.day)) is largely lower than the value for frequencies of use obtained from consumers' data (138 litres/(person.day)). The minimum value for the efficient patterns is too low (28 litres/(person.day)). However, it is possible that people of this household did not correctly registered their water devices frequency of use, since all of them are very low.

Table 23 presents some characteristics of the households classified as efficient. The efficient households have an average age of 41 years, 3 persons per household and only one of the five households have a dishwasher. Once again, the majority of the efficient households do not have a dishwasher, contrarily to what is said in literature, probably due to the fact that dishwashers of this case study sample are not efficient (see Chapter 4, Table 16).

Table 23 – Characteristics of efficient households for frequencies of use obtained from consumers' data

Efficiency assessment	Average family dimension	Average age	Number of households with dishwashers'
Efficient households (5 out of 43)	3	41	1

Figure 48 shows the level of efficiency at each household, which relates the deviation of each household consumption to its minimum efficiency value. On average, the total sample is on level "64% efficient", with potential water savings of 36% to reach level "100% efficient".

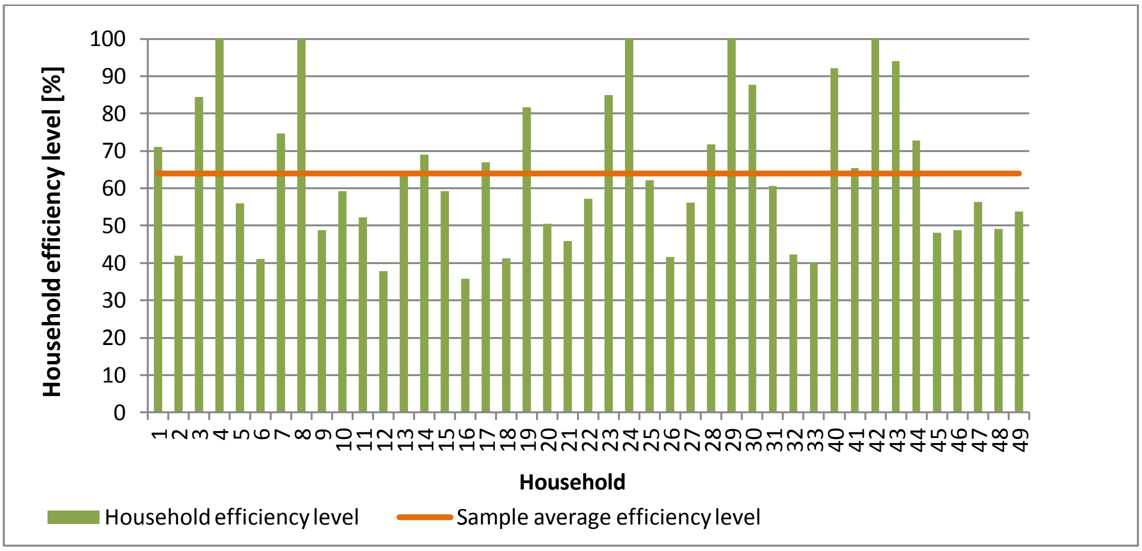


Figure 33 – Households' level of efficiency based on efficient patterns for frequencies of use obtained from consumers' data

The results presented in Figure 33 also show that five households are considered as efficient with a household efficiency level of 100%. There are 13 households with an efficiency level bellow 50%, which demonstrates that they should more than double their water savings, comparing to the current situation. Households 12 and 16 are the worst classified consumers of the sample considering the assessment for frequencies of use obtained from consumers' data, with an efficiency level bellow 40%.

5.2.3 Comparative analysis of the two methods for assessment based on efficient patterns

The two approaches used for household efficiency assessment based on efficient profiles are very useful to a better and consistent water efficiency evaluation at the consumer level. In total, there are five households that are classified as efficient by the two methods, since the first method considered more three households efficient than the second method. Therefore, the results presented in section 5.2.1 and 5.2.2 show that the application of each method leads to slightly different conclusions. Thus, the methods should be applied in accordance with the available data in each case and considering the advantages and disadvantages that both have.

Figure 34 presents the overall efficiency evaluation for Module 1, comparing the two approaches.

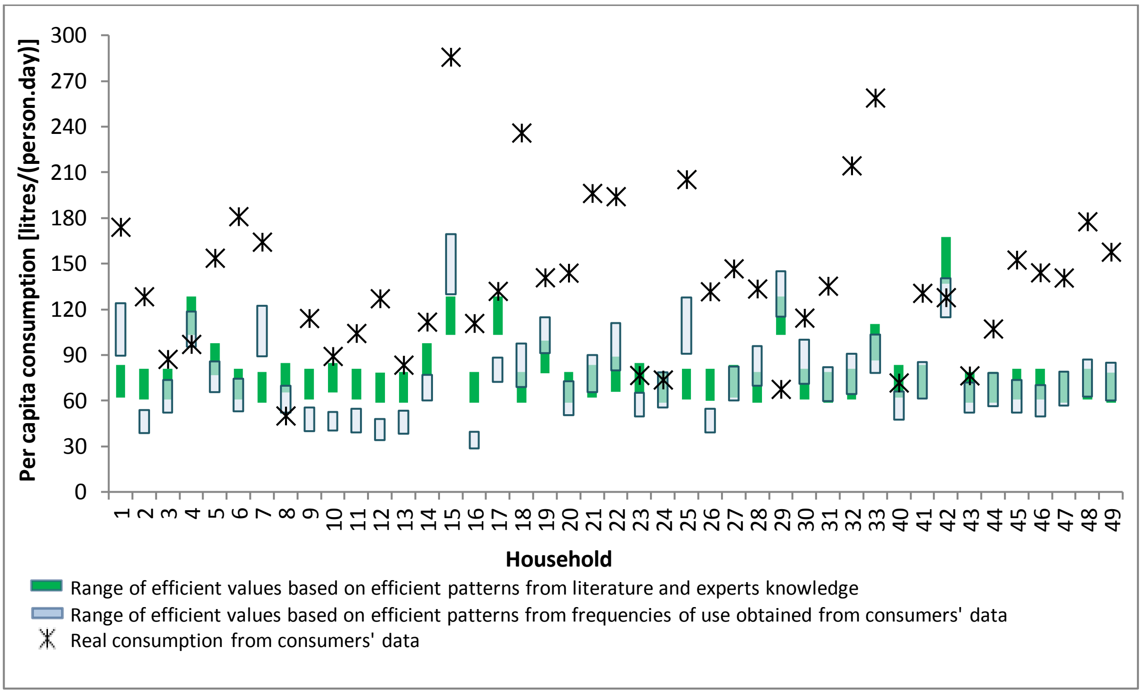


Figure 34 – Module 1: overall efficiency assessment

Figure 34 shows that most households are not classified as efficient according to the methodology of Module 1. However, there are more efficient households considering frequencies of use based on literature and experts knowledge than frequencies of use obtained from consumers' data. These results suggest that:

- Knowledge about the consumers' absence in the household is very important for efficiency assessment. Thus, the application of Module 1 would benefit from information about consumers mobility.
- Recording errors should be minimized as the frequencies of use recorded by consumers influence results.

The two existing approaches allow the application of the methodology to the basis consumers' data of each case. However, both have advantages and disadvantages. The frequencies of use based on literature and experts knowledge define situations considered "normal". This approach can be understood as limiting consumers' uses. Although, frequencies of use obtained from consumers' data can be subject to consumers' recording errors, which can also influence results.

In summary, the majority of the households from this sample reflect an inefficient use of water, which means that the water volume used is higher than the volume that is effectively necessary to achieve consumers' needs. Therefore, the results reveal a large potential for water savings and improvement can be achieved through changes in consumers' behaviour, in the performance of water devices or in the combination of both. Results from Module 3 will allow to identify in which of these two components the consumer should act to increase water savings.

5.3 Application of Module 2 – Peer comparison

5.3.1 Correlation matrix

To apply Module 2 of the methodology to the current case study, it is very important to take into account socio-demographic and consumption variables (see Chapter 4, Table 12 and Table 14).

To form the peer groups for consumers' comparison, a correlation matrix was obtained, in order to determine which variables are more correlated. Table 24 shows the correlation matrix obtained. The correlation analysis included all socio-demographic and consumption variables in the current case study.

Table 24 – Correlation matrix for the case study socio-demographic and consumption variables

Correlation Matrix		Weekly consumption [litres/(household.week)]	Per capita consumption [litres/(person.day)]	Family dimension	Family composition by age	Property type
Weekly consumption [litres/(household.week)]	Pearson Correlation	–	.542**	.592**	-.039	.404**
	p-value	–	.000	.000	.806	.007
	N	–	43	43	43	43
Per capita consumption [litres/(person.day)]	Pearson Correlation	–	–	-.171	.288	-.053
	p-value	–	–	.273	.061	.736
	N	–	–	43	43	43
Family dimension	Pearson Correlation	–	–	–	**-.361***	.470**
	p-value	–	–	–	**.018**	.001
	N	–	–	–	43	43
Family composition by age	Pearson Correlation	–	–	–	–	**.072**
	p-value	–	–	–	–	**.647**
	N	–	–	–	–	43
Property type	Pearson Correlation	–	–	–	–	–
	p-value	–	–	–	–	–
	N	–	–	–	–	–

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

The three socio-demographic variables considered in the analysis and for which there was information available for this case study were: *property type*, *family dimension* and *family composition by age*. The strongest correlations were observed for the variables: *property type* and *family dimension* (Table 24).

Family dimension and *family composition by age* have also shown a negative correlation but with a low linear association (see section 3.4).

5.3.2 Assessment using clusters based on socio-demographic characteristics

For cluster analysis, variables with a strong correlation were neglected, namely, property type and family dimension, since they directly influences the other. Therefore, the socio-demographic clusters were built with one or two socio-demographic variables not highly correlating with each other. The following clusters were obtained:

- family dimension clusters;
- property type clusters;
- family composition by age and family dimension clusters;
- family composition by age and property type clusters (As the differences among cases in the different clusters were not reliable ($F_{41} = 0.2$; $p = 0.65$), this cluster analysis was not taken into account in further analysis).

The goal of the socio-demographic clusters is to allow comparison among peer consumers' in terms of their consumption characteristics. Results are presented for per capita consumption and weekly consumption.

Family dimension clusters

Cluster analysis was carried out by using the software SPPS®. Four clusters reliably different were obtained based on family dimension characteristics. Table 25 shows the characteristics of these clusters. The first cluster contains five households with one member, the second cluster include eight households with two members, the third one has twenty seven households with three and four members and, finally, the last cluster is formed by the three households with the largest family dimension in this sample (*i.e.*, with more than five inhabitants).

The major difference between the clusters is due to weekly consumption, since per capita consumption does not reliably varies among the four clusters. This was an expected result because when the number of people in the household increases, the weekly consumption also increases.

It should be highlighted that single member households and large families have a different behaviour regarding the remaining ones.

Table 25 – Characteristics of the family dimension clusters

Cluster	Number of households	Family dimension	Per capita consumption [litres/(person.day)]			Weekly consumption [litres/(household.week)]		
			Minimum	Average	Maximum	Minimum	Average	Maximum
Cluster 1	5	1	68	**142**	286	473	**994**	2000
Cluster 2	8	2	72	**147**	196	1004	**2047**	2747
Cluster 3	27	3, 4	50	**135**	259	1400	**3378**	9966
Cluster 4	3	5	127	**139**	158	4294	**5684**	8000

Figure 35 and Figure 36 present per capita consumption and weekly consumption of the four clusters, as well as the household efficiency level that compares the efficiency of the consumers in relation to their peers in the cluster they belong to. This comparison was made in relation to the clusters minimum and average values.

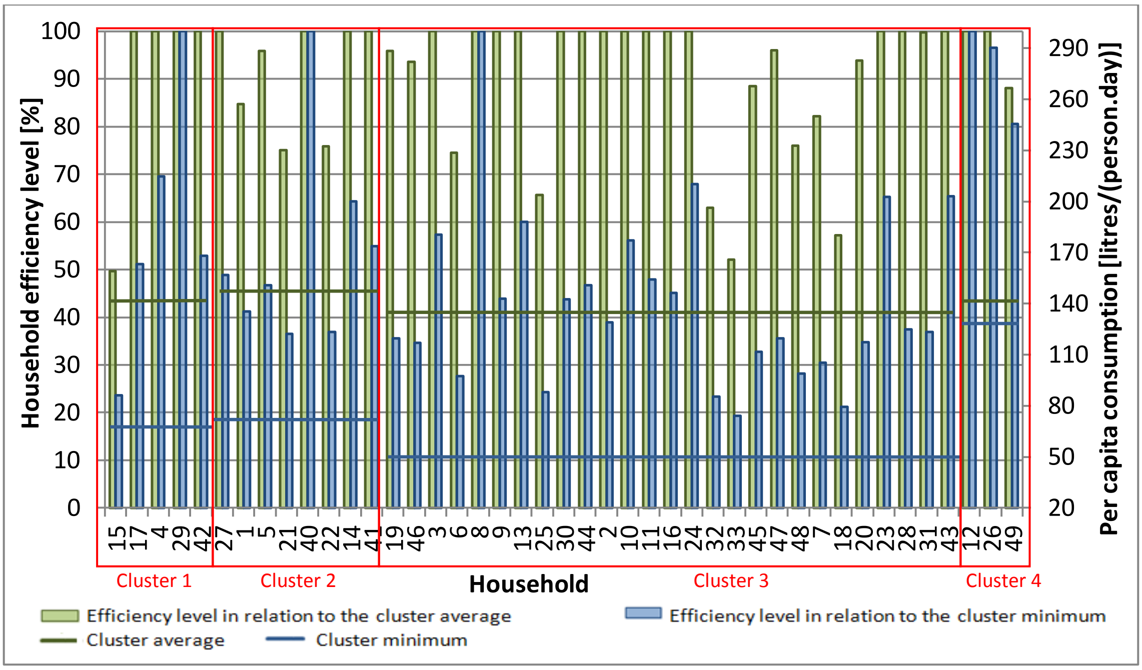


Figure 35 – Family dimension cluster: per capita consumption analysis

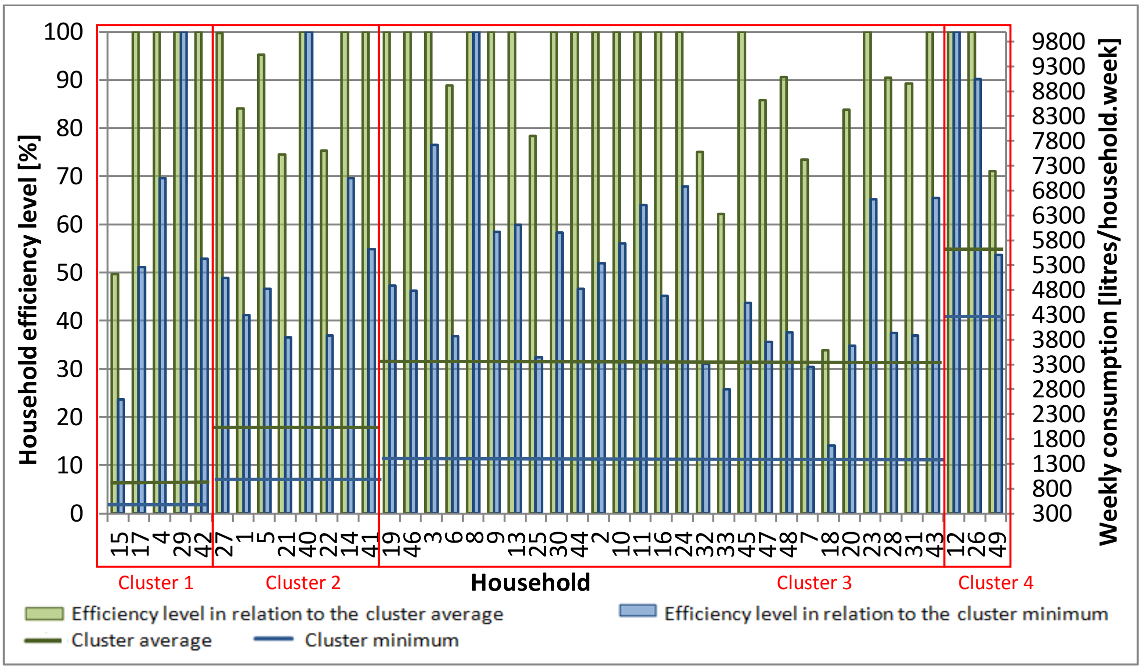


Figure 36 – Family dimension cluster: weekly consumption analysis

Through this analysis, consumers can verify their deviation to the average and minimum of their respective cluster, and their performance when compared to the other consumers with a similar family dimension.

Property type clusters

Table 26 shows the characteristics of the obtained property type clusters. The first cluster is composed of nineteen T1 and T2 households. The second cluster is composed by twelve T3 households and the last cluster is composed by twelve T4 households.

Similarly to family dimension clusters, the major differences between the three property type clusters are related with the weekly consumption. The correlation matrix (Table 24) shows a high linear association between property type and family dimension, which justifies the results obtained to both variables, since households with a higher number of residents correspond, in general, to larger dwellings.

Table 26 – Characteristics of the property type clusters

Cluster	Number of households	Property type	Per capita consumption [litres/(person.day)]			Weekly consumption [litres/(household.week)]		
			Minimum	Average	Maximum	Minimum	Average	Maximum
Cluster 1	19	T1, T2	50	**134**	286	473	**2206**	4311
Cluster 2	12	T3	74	**148**	259	2062	**3363**	5437
Cluster 3	12	T4	55	**135**	236	894	**3943**	9966

Figure 37 and Figure 38 present per capita consumption and weekly consumption for the property type clusters, as well as the household efficiency level.

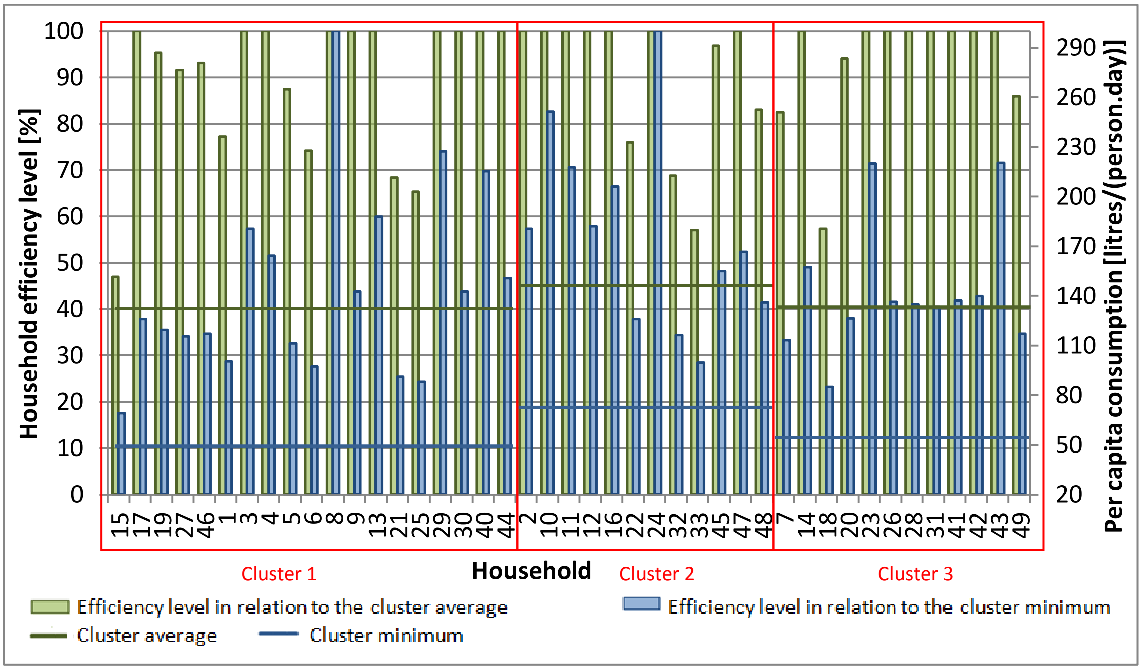


Figure 37 – Property type cluster: per capita consumption analysis

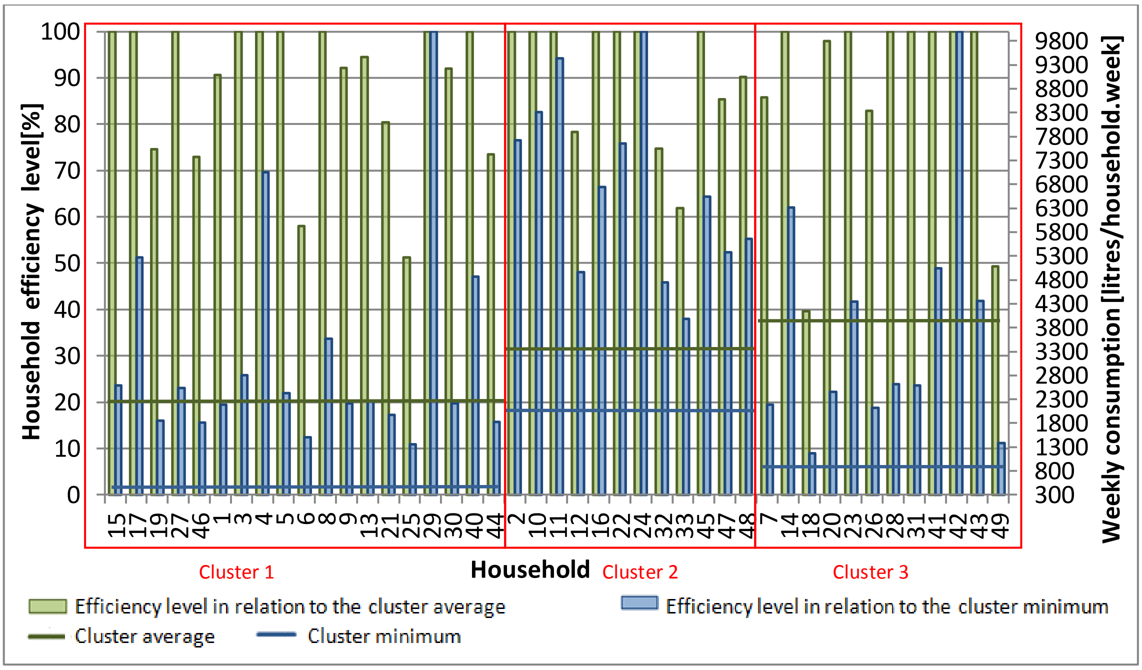


Figure 38 – Property type cluster: weekly consumption analysis

Family dimension and family composition by age clusters

Table 27 presents the characteristics obtained for the two clusters of family dimension and family composition by age.

The first cluster corresponds to larger families and younger members and the second cluster corresponds to smaller families and older family members. However, the clusters are mainly formed on age differences. Therefore, the differences are more reliable in terms of the per capita consumption than the weekly consumption. These two clusters show that older people tend to have higher consumption probably due to their more constant presence at home, which has already been referred in Module 1.

Table 27 – Characteristics of the family dimension and family composition by age clusters

Cluster	Number of households	Average age	Average family dimension	Per capita consumption [litres/(person.day)]			Weekly consumption [litres/(household.week)]		
				Minimum	Average	Maximum	Minimum	Average	Maximum
Cluster 1	31	28	3.2	50	**129**	286	473	**2958**	9966
Cluster 2	12	53	2.8	128	**163**	259	894	**3158**	5437

Figure 39 and Figure 40 show the per capita consumption and the weekly consumption for the family dimension and family composition by age clusters, as well as the household efficiency level.

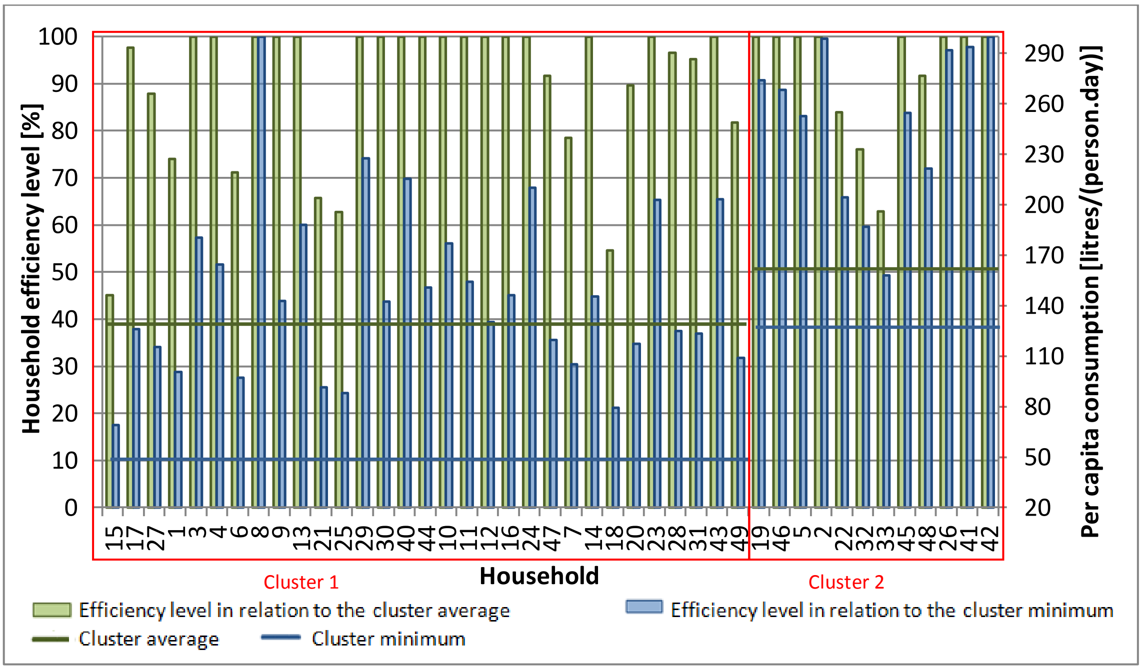


Figure 39 – Family dimension and family composition by age cluster: per capita consumption analysis

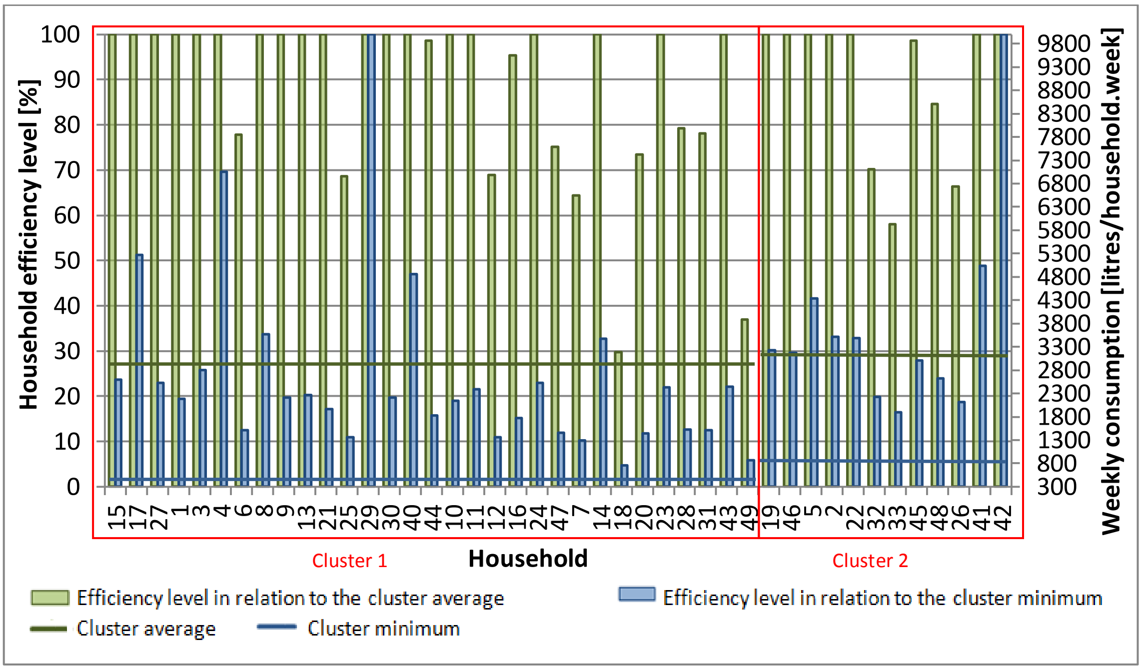


Figure 40 – Family dimension and family composition by age cluster: weekly consumption analysis

5.3.3 Assessment using clusters based on consumption characteristics

The two consumption variables considered for this analysis are per capita consumption and weekly consumption. Consumers are organized by clusters in these two categories to better understand the distribution of the households by the consumption levels.

Weekly consumption clusters

Table 28 presents the characteristics of four reliably different clusters obtained which divide the households according to their weekly consumption.

The majority of the households (clusters 2 and 3) have a weekly consumption between 2000 [litres/(household.week)] and 5500 [litres/(household.week)]. Cluster 1 represents the nine households of the sample that consumes the least. Cluster 4 contains the two households with the highest consumption.

Table 28 – Characteristics of the weekly consumption clusters

Cluster	Number of households	Weekly consumption [litres/(household.week)]		
		Minimum	Average	Maximum
Cluster 1	9	473	**1164**	1831
Cluster 2	20	2000	**2512**	3201
Cluster 3	12	3729	**4243**	5437
Cluster 4	2	8000	**8983**	9966

Figure 41 shows the weekly consumption for the four clusters as well as the household efficiency level.

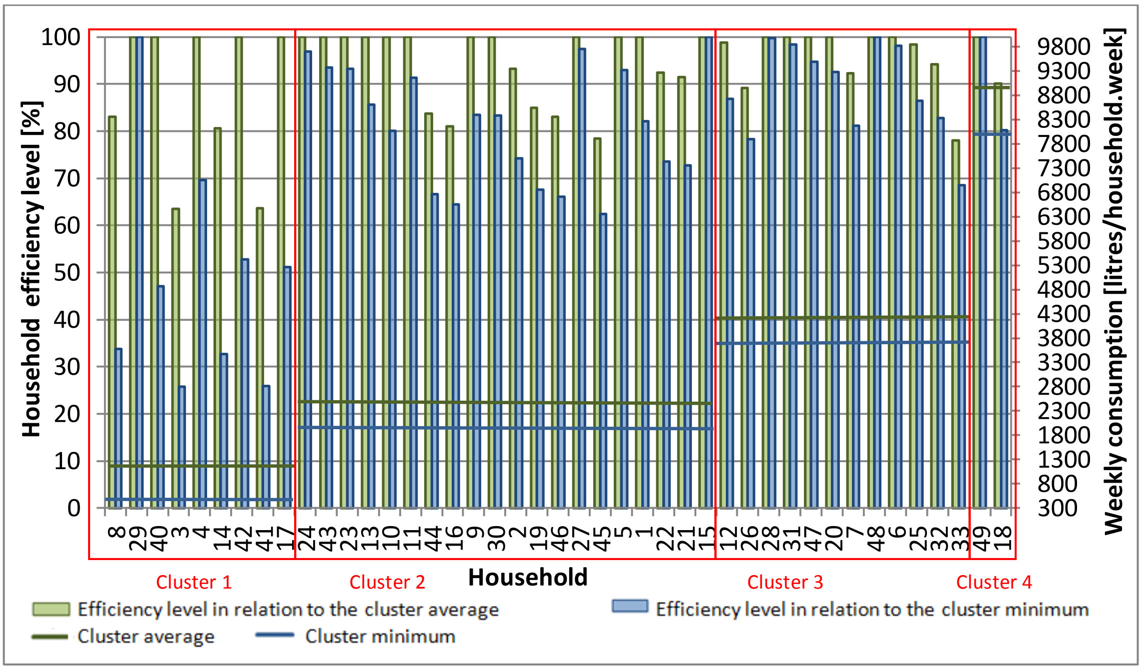


Figure 41 – Weekly consumption clusters

Per capita consumption clusters

Table 29 shows the characteristics of the obtained four per capita consumption clusters. Most of the households (Cluster 2, 3 and 4) have a per capita consumption between 100 and 200 [litres/(person.day)]. Cluster 1 and 5 represent the households that have the lowest and the highest per capita consumptions, respectively.

Table 29 – Characteristics of the per capita consumption clusters

Cluster	Number of households	Per capita consumption [litres/(person.day)]		
		Minimum	Average	Maximum
Cluster 1	9	50	**75**	89
Cluster 2	7	97	**108**	114
Cluster 3	16	127	**139**	158
Cluster 4	8	164	**188**	214
Cluster 5	3	236	**260**	286

Figure 42 shows the per capita consumption of the four clusters, as well as the household efficiency level.

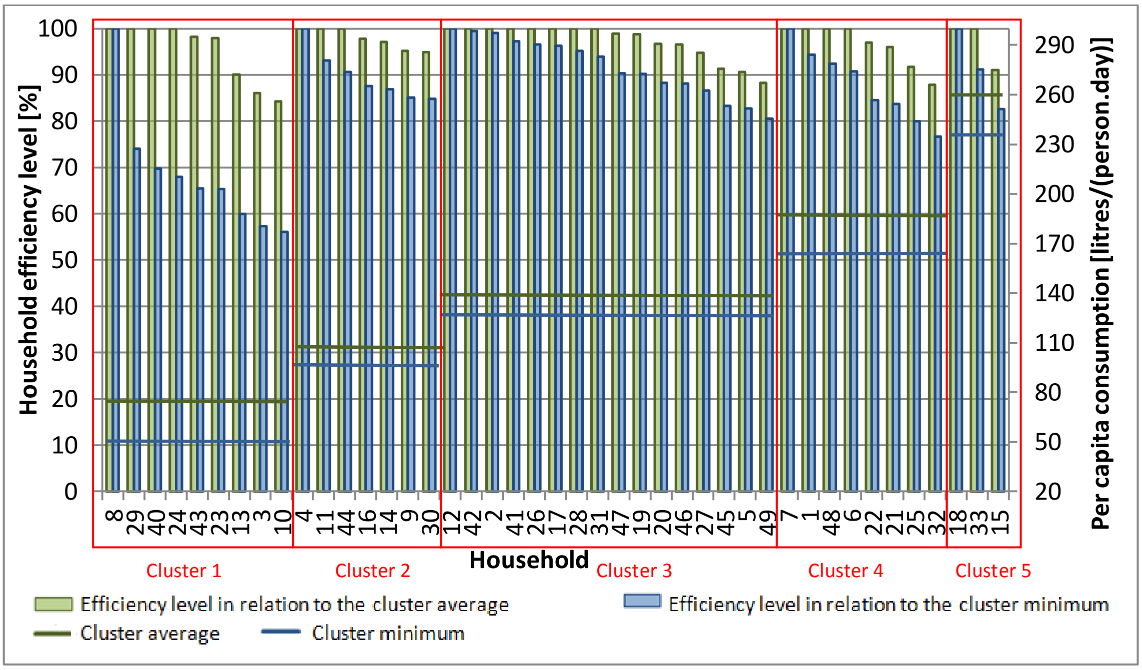


Figure 42 – Per capita consumption clusters

5.3.4 Assessment using consumption class groups

A simpler way to assess the efficiency that does not involve cluster analysis is to group consumers according their consumption classes and to make a comparison between those in the same class. Table 30 shows the consumption classes considered by the water supplier of the case study – EPAL (2013). The values presented were later converted to litres per week.

Table 30 – Consumption classes from the water supplier of the case study (adapted from EPAL, 2013)

Consumption class	Volume used (m^3/30 days)
Class 1	**< 5**
Class 2	**6 to 15**
Class 3	**16 to 25**
Class 4	**> 25**

The households analysed (43 in total) were divided in four groups, corresponding to the four classes of consumption, and consumers were compared with the others in the same group and with the minimum and the average values of their consumption class.

Table 31 presents the results obtained for the consumption class groups.

Table 31 – Characteristics of the consumption class groups

Group	Number of households	Consumption class	Weekly consumption [litres/(household.week)]		
			Minimum	Average	Maximum
Group 1	5	1	473	**794**	1004
Group 2	28	2	1400	**2564**	3800
Group 3	8	3	3938	**4483**	5437
Group 4	2	4	8000	**8983**	9966

Figure 43 shows the distribution of the households by the four groups and the comparison between them, as well as the household efficiency level.

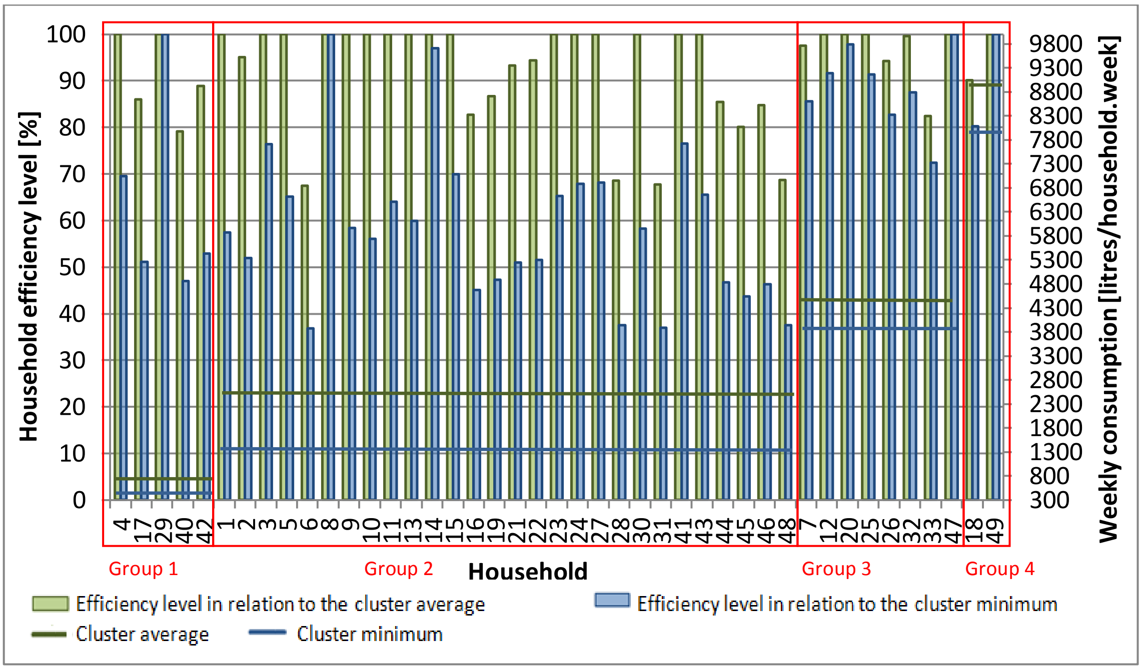


Figure 43 – Consumption class groups

5.3.5 General considerations concerning the application of Module 2

The results from sections 5.3.3 and 5.3.4 show that the efficiency assessment based on consumption class groups and based on weekly consumption clusters do not vary significantly, suggesting that, if there is no information to carry out a cluster analysis, grouping by consumption classes is a good way to compare consumers among them in what regards their total consumption.

In this sense, there is not a unique and a "better way" to carry out the peer comparison, since all the chosen arrangements lead to different conclusions about the efficiency of each household, depending on the characteristics of the respective cluster or on the consumption group where a certain household is included. For example:

- household 18 is considered as 100% efficient in the per capita consumption cluster, and it has an efficiency level bellow 50% in what concerns the property type cluster (weekly consumption analysis);

- household 49 has an efficiency level bellow 40% within the family dimension and family composition by age cluster (weekly consumption analysis), however it is 100% efficient within the weekly consumption cluster and consumption class group;
- household 15 has a satisfying level of efficiency inside group 2 of consumption classes, but it has an efficiency level bellow 50% in the respective family dimension and family composition by age cluster (per capita consumption analysis).

In what concerns peer comparisons, the socio-demographic clusters should be preferred if information is available, since consumers' are more fairly evaluated. In future applications of the methodology, the cluster analysis should be carried out for each case under study as clusters are dependent on the specific socio-demographic and consumption characteristics of the sample.

5.4 Application of Module 3 – Evaluation based on performance indices for water devices

5.4.1 Performance functions

Module 3 was applied to the case study considering the following water devices: shower, bathroom taps, kitchen taps, WCs (single and dual flush), dishwasher and washing machine.

Performance functions were created for each one of these water devices based on the reference ranges for efficient flows and volumes (Table 4). As explained in section 3.5.2 the functions were constructed in four levels using the flows and volumes from each consumers' data on their water devices. The respective performance function returns a performance index for each water device. Figure 25 presents the performance functions used in Module 3. Module 3 was implemented in Microsoft Excel for automatic calculation. The results obtained are presented bellow.

5.4.2 Assessment of devices performance

Table 32 and Figure 44 show the results obtained for the performance assessment of all water devices.

Table 32 – Performance assessment for all water devices

Performance assessment		Water 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	100	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

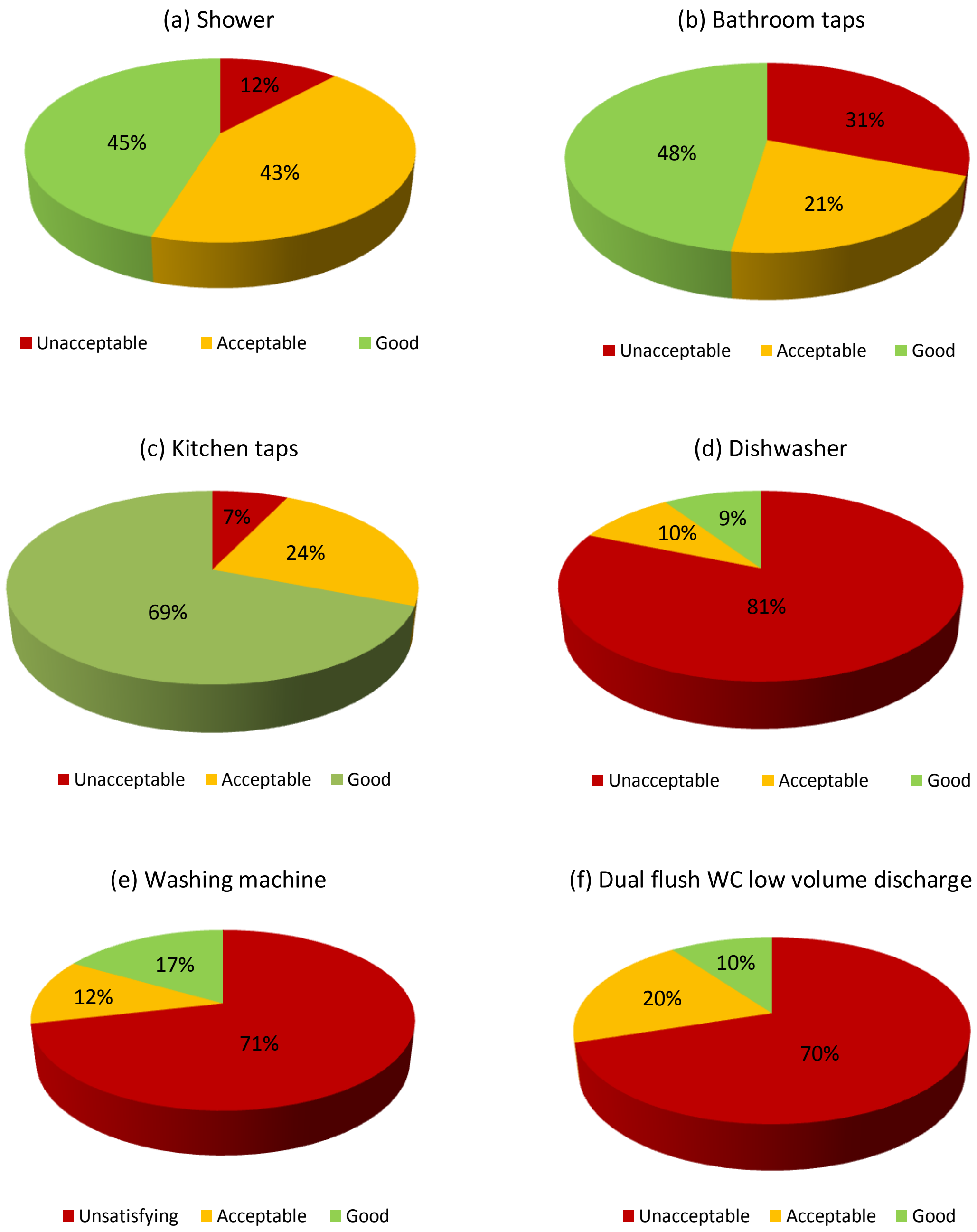


Figure 44 – Water devices performance distribution: (a) Shower (b) Bathroom taps (c) Kitchen taps (d) Dishwasher (e) Washing machine (f) Dual flush WC - low volume discharge

The performance indices obtained for showers vary between 0 and 300, which shows that, in this sample, there is a wide range of showers performances. However, in average (performance index = 184), showers are reasonably efficient.

For bathroom taps the performance indices obtained vary between 0 and 300, which shows that, in this sample, there is a wide range of bathroom taps performances. In average (performance index = 161), bathroom taps are reasonably efficient, existing more devices classified as "good" than showers and also more classified as "unacceptable".

Once again, performance indices obtained for kitchen taps vary between 0 and 300, which shows that, in this sample, there is a wide range of kitchen taps performances. In average (performance index = 226), kitchen taps are efficient and most devices are classified as "good".

Despite performance indices obtained for dishwashers varying between 0 and 300, in average (performance index = 54) the majority of dishwashers have an unacceptable performance. These results also explain why, in Module 1, the majority of the efficient households that are classified as efficient do not have a dishwasher.

The performance indices obtained for washing machines vary between 0 and 300, however, in average (performance index = 77) the majority of washing machines have an unacceptable performance, similar to dishwashers.

The WCs in the current case study sample were either single flush WC (76%) or dual flush WC (24%). Therefore, the performance analysis for WC is divided into these two types of WC. For dual flush WC, the analysis also considered the total volume discharge and the low volume discharge.

The performance indices obtained for single flush WC only varies between 0 and 100, which shows that, in this sample, all devices have an unacceptable performance (2 single flush WCs have a minimum acceptable (100)). The average value is 9 which demonstrate the inefficiency of single flush WCs.

The performance indices obtained for WC dual flush total discharge vary between 0 and 56 and all devices are an unacceptable performance. The average value is 6 which shows that dual flush WC total discharge are not efficient.

For dual flush WC low volume discharge the indices vary between 0 and 267, but almost all devices have an unacceptable. The average value is 76 and results are slightly better than for the total discharge.

5.4.3 Comparative analysis of all water devices

Figure 45 resumes the performance indices for all water devices.

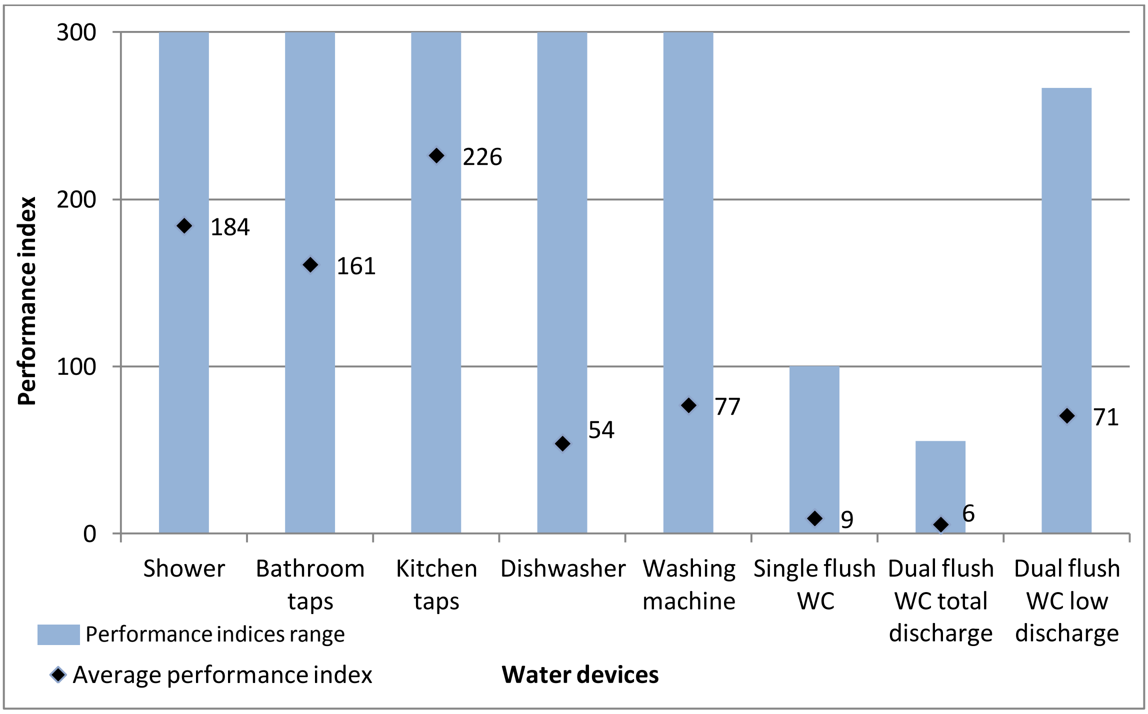


Figure 45 – Ranges of performance indices for the water devices in the case study

Except for WCs, the remaining water devices are distributed by all three performance indices ranges (0–100, 100-200 and 200-300). WCs are the most inefficient devices in the case study, followed by machines (dishwasher and washing machine). The water devices that have better performance are taps (bathroom and kitchen) and shower. In the consumption structure of the case study (Figure 29, Chapter 4), shower and taps are the largest water users (38% and 31%, respectively), followed by the WCs (19%); washing machine and dishwasher are the ones that least contribute for total water consumption (9% and 3%, respectively). These results suggest that consumers do not efficiently use the water devices with better performance.

5.4.4 Overall efficiency assessment for the household

As explained in section 3.5.3, there are three methods to attribute consumption weights in order to calculate the household water use efficiency index (H_I), depending on available data of each specific case. For the case study sample, it was possible to apply the most appropriated method to calculate weights (*Method I*) and exemplify the other two methods. Results are presented bellow.

Method I – Household weight for each case study

For the current case study, information about the total household water volume used and the volume used by each water device is known from the consumers' data. Therefore, Equation (8) was applied to define each water device weight in the household consumption structure and results are shown in Figure 46 for each household performance indices considering its own water devices weights.

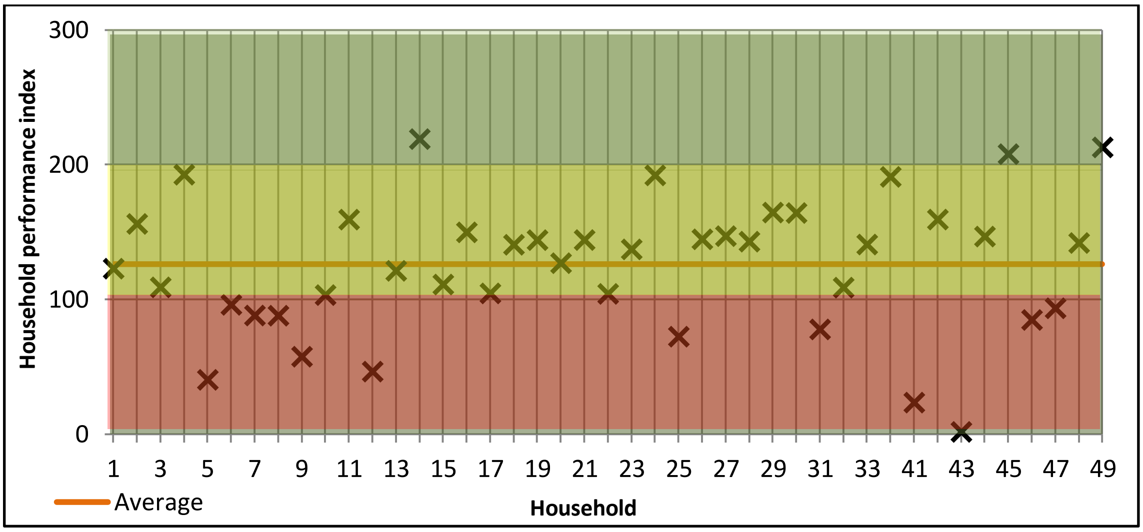


Figure 46 – Household performance index applying *Method I*

Figure 46, Figure 47 and Table 33 show that the majority of the households (65%) have their water devices classified as "acceptable" but still a large number (28%) have unacceptable performance. The households' performance indices vary between 2 and 219 and the average value is 125, corresponding to an acceptable performance. These results show that large potential for savings exists, and that water use efficiency can be increased through the installation of more efficient water devices. However, installing more efficient water devices does not change users' behaviour, and then domestic consumption assessments must be always applied together.

Table 33 – Households performance indices results applying *Method I*

Household performance indices	
Minimum	2
Average	125
Maximum	219
Number of households with unacceptable performance (0-100)	12
Number of households with acceptable performance (100-200)	28
Number of households with good performance (200-300)	3

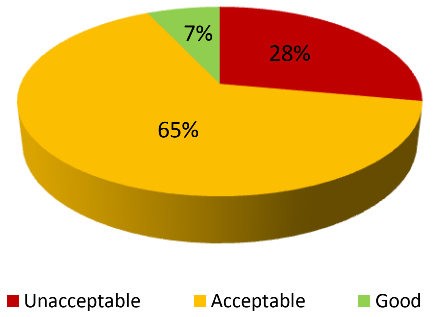


Figure 47 – Household performance distribution applying *Method I* in Module 3

Method II – Average weight of each device of the case study sample

Figure 29 (Chapter 4) shows the consumption structure for the current case study, presenting the average weight values for each water device. Using these data, performance indices were calculated for each household. Table 34 and Figure 48 show the results obtained.

Table 34 – Households performance indices results applying *Method II*

Household performance indices	
Minimum	1
Average	138
Maximum	235
Number of households with unacceptable performance (0-100)	8
Number of households with acceptable performance (100-200)	30
Number of households with good performance (200-300)	5

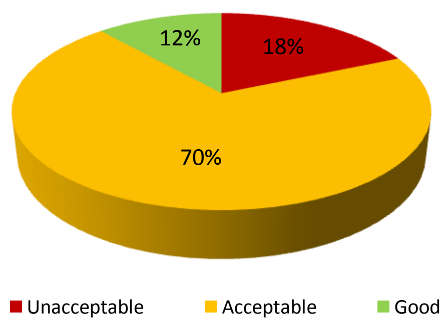


Figure 48 – Household performance distribution applying *Method II* in Module 3

Results do not vary significantly from the results obtained with *Method I*. The households' performance indices vary between 1 and 235, and the average value is 138, maintaining the majority of the households with an acceptable performance. Therefore, despite *Method I* is the best way to apply weights in the performance indices evaluation, these results prove that *Method II* can be a good approximation to simplify calculations or when the methodology is applied to cases in similar conditions.

Method III – Typical values published in the literature

Figure 26 (Chapter 3) shows the average values from some water uses structures and it can be an approach to calculate weights, in case of there is no more information available on the case.

Table 35 and Figure 49 show the results obtained for each household performance index considering the typical values published in the literature.

Table 35 – Household performance indices results applying *Method III*

Household performance indices	
Minimum	2
Average	111
Maximum	196
Number of households with unacceptable performance (0-100)	15
Number of households with acceptable performance (100-200)	28
Number of households with good performance (200-300)	0

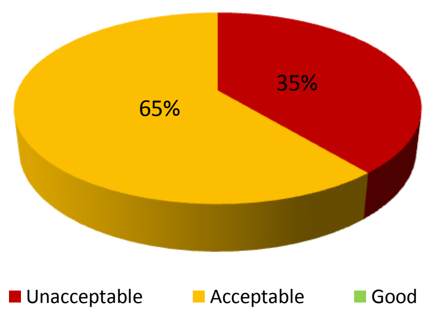


Figure 49 – Household performance distribution applying *Method III* in Module 3

The results from *Method III* differ most from Methods *I* and *II*. The households' performance indices vary between 2 and 196, and the average value is 111. The average performance still corresponds to an acceptable performance, however no household has good performance and the number of households with unacceptable performance has increased. *Method III* is the worst approach to calculate weights and should be used only if there is no specific information on the consumption structure available for the case sample under assessment.

5.5 Efficiency assessment – final remarks

The current chapter presented the results from the application of the proposed methodology (Module 1, Module 2, and Module 3) to the case study composed of 43 households with different socio-demographic characteristics. The efficiency assessment based on efficient patterns was carried out, peer groups comparison was made and performance indices were determined to evaluate the efficiency of households' water devices. Therefore, some general conclusions about efficiency evaluation can be drawn taking into account the three modules.

Table 36 shows a comparative analysis of the results from Module 3 (household performance indices) and from Module 1 (efficiency assessment based on frequencies of use from literature and experts knowledge) for the consumers classified as efficient in Module 1. The household performance indices considered herein are those obtained through *Method I*.

Table 36 – Comparative analysis of the results from Module 3 (household performance indices) and from Module 1 (efficiency assessment based on frequencies of use from literature and experts knowledge)

Module 1	Module 3
Efficient consumers (efficiency assessment based on frequencies of use from literature and experts knowledge)	**Household performance index (H_I)**
23	137
24	192
40	191
43	2
4	193
8	88
29	165
42	159
Average	**141**

The eight consumers considered to be efficient by the assessment carried out in Module 1 have an average household index of 141, which suggests that the high efficiency of these households is not only justified by the efficiency of the water devices but is also due to the adoption of efficient behaviours.

An individual analysis of the consumers' shows that households 43, 24, 40 and 4 deviate from this average situation. Household 43 was considered as efficient only due to the users' behaviour since the household performance index is very low. The performance indices of households 24, 40 and 4 are very close to a good performance (200–300), therefore their water devices efficiency have a higher contribution to the household efficiency than in the remaining households.

Table 37 shows a comparative analysis of the results from Module 3 (household performance indices) and from Module 2 (weekly consumption clusters). Average values for each cluster are shown.

Table 37 – Comparative analysis of Module 2 (weekly consumption clusters) and Module 3 (households' performance indices)

Module 2		Module 3
Cluster	Weekly consumption [litres/(household.week)]	Household performance index (H_I)
1	1164	139
2	2512	125
3	4243	107
4	8983	177

With the exception of cluster 4, weekly consumption increases as the household performance indices decrease. This shows that households with higher consumption also have water devices with lower performances. However, the higher cluster consumption (cluster 5) is essentially related to inadequate users' behaviours as the efficiency of water devices is rather acceptable (household index between 100 – 200).

Table 38 shows a comparative analysis of the results from Module 3 (household performance indices) and from Module 2 (per capita consumption clusters). Average values for each cluster are shown.

Table 38 – Comparative analysis of Module 2 (per capita consumption clusters) and Module 3 (household performance indices)

Module 2		Module 3
Cluster	Per capita consumption [litres/(person.day)]	Household performance index (H_I)
1	75	123
2	108	156
3	139	120
4	188	110
5	260	131

For the three intermediate clusters (clusters 2, 3 and 4), household performance indices decrease as per capita consumption increases. Cluster 1 and 5 have a different tendency and lower per capita consumptions are due to more adequate users' behaviour than to a good performance of the water devices.

Table 39 shows a comparative analysis of the results from Module 3 (household performance indices) and from Module 2 (shown family dimension and family composition by age clusters). Average values for each cluster are shown (only family composition by age was analyzed since family dimension is similar for the two clusters). These results show that households with younger family dimension tend to have more efficient water devices.

Table 39 – Comparative analysis of Module 2 (family dimension and family composition by age clusters) and Module 3 (household performance indices)

	Module 2	Module 3
Cluster	**Family composition by age**	**Household performance index (H_I)**
1	28	131
2	53	121

Table 40 shows a comparative analysis between the most and the least efficient consumers from Module 1 and from peer groups in Module 2. These results aim to compare the consumers' efficiency at their own household and when they are compared with other consumers from the several peer groups. The most efficient consumers in Module 1 are the eight more efficient households obtained from the assessment using the frequencies of use from literature and experts' knowledge (households 4, 8, 23, 24, 29, 40, 42 and 43) and the least efficient consumers are the five households which were considered less efficient in each method of efficiency assessment from Module 1 (households 12, 16, 18, 25 and 32).

Table 40 – Comparative analysis between the most and the least efficient households (Module 1) and peer groups (Module 2)

Module 1		Clusters and groups from Module 2								
		Property type		Family dimension		Family dimension and family composition by age		Per capita consumption	Weekly consumption	Consumption class
		Per capita	Weekly consumption	Per capita consumption	Weekly consumption	Per capita consumption	Weekly consumption			
Most efficient households (8 out of 43)	**% of efficiency to the cluster average**	100	100	100	100	100	100	99	98	96
	% of efficiency to the cluster minimum	73	67	78	78	72	58	80	74	71
Least efficient households (5 out of 43)	**% of efficiency to the cluster average**	78	69	77	77	79	67	96	92	95
	% of efficiency to the cluster minimum	41	36	43	43	38	12	89	80	79

In what concerns the comparison to the average value of each cluster, most efficient consumers from Module 1 are better classified than the least efficient consumers. These results suggest that when consumers' are more efficient in their own households, the efficiency level is also better, when compared to their peers.

In what concerns the comparison to the minimum value of each cluster, for the socio-demographic clusters, the most efficient consumers' from Module 1 are also better classified, in relation to the most efficient household of the cluster, than the least efficient consumers. However, to consumption clusters and consumption class groups, the least efficient consumers are slightly better classified in relation to the most efficient consumer of the cluster (or group) than the most efficient consumers. To these consumption clusters and consumption class groups, the efficiency levels are higher due to these clusters are organized by the consumption variables which distribute the households to clusters or groups with similar consumptions.

In average, consumers classified as efficient in their own households (Module 1) also tend to be more efficient when compared to their peers (Module 2), but the opposite behaviour can also be verified.

In summary, the following conclusions can be drawn from the application of the proposed methodology described in Chapter 3 to the case study presented in Chapter 4:

- Module 1: Both approaches for efficiency assessment based on efficient patterns concluded that the majority of the households are still far from an acceptable level of efficiency and, thus, significant potentials for efficiency improvements exist.
- Module 2: For the current case study, it is important to compare consumers' within peer groups of similar family dimension, family composition by age, property type and consumption characteristics, for a different efficiency analysis. For the current case study, it is important to compare consumers within peer groups of similar family dimension, family composition by age, property type and consumption characteristics, for a different efficiency analysis. However, if the methodology is applied to other cases, a specific cluster analysis should be made as the clusters built depend on the socio-demographic characteristics of the studied sample.
- Module 3: For the current case study, the water devices that have lower performance are: dishwasher, washing machine and WCs. The water devices that have better performance are: taps (bathroom and kitchen) and shower. However, the average household performance index always corresponds to an acceptable performance, revealing the need for replacement of water devices by more efficient ones.

For the case study sample, there is evidence of a large potential for water savings both in terms of users' behaviours and in terms of water devices performance improvements.

Results also prove that the methodology should be applied in a complementary way, providing a more complete assessment. For each case analyzed, some considerations about the households' performance can be taken by comparing the results of the three modules, as each module evaluates different points of view related to the household water use efficiency, namely consumers' behaviour, peer comparison and water devices performance.

6 RESULTS OF METHODOLOGY TESTING

6.1 Introduction

The current chapter aims to present the results of the test of the proposed methodology, described in Chapter 3, in a recent and small case study, carried out with three volunteer households.

The main goal is to test the methodology and carry out a comparative analysis between consumers' behaviours and their water devices performance, establishing a temporal evolution of the domestic consumers' efficiency. Results are shown according to the methodology modules.

6.2 Case study characterization

The number of participants in this small case study corresponds to three residences (8 persons in total), located in the urban area of Lisbon and surrounding municipalities. The consumers were surveyed using the same questionnaire of the case study presented in Chapter 4, with exception of two additional variables related to consumers' professional situation and domestic habits (number of main meals made at home). Detailed recordings of all water uses in the household were also carried out, during one week of September 2014.

In what concerns the socio-demographic variables, all households have the property type T3 (property with three single bedrooms), the inhabitants' number varies between 1 and 4, the Inhabitants' age ranges from 5 and 52 years, with an average age of 30 years. All adult inhabitants are active workers.

In terms of the consumption variables, the weekly consumption per household and the per capita consumption (average value per household) were obtained as explained in section 4.3.2 and the average values are 2117 [litres/(household.week)] and 118 litres/(person.day)], respectively (Table 41).

Table 41 – Consumption characteristics for the small case study

Household	Family dimension (persons/household)	Weekly consumption [litres/(household.week)]	Per capita consumption [litres/(person.day)]
1	1	911	130
2	4	2957	106
3	3	2483	118
Average	2.7	2117	118

The procedure to characterize the water use devices was the same as the main case study. The water devices considered were: shower, bathroom taps, kitchen taps, dishwasher, washing machine and WCs (single and dual flush). Table 42 shows a statistical characterization of the water devices in this case study.

Table 42 – Water devices characterization for the small case study

Water device	Average number per household	Average flow (litres/min)	Average volume (litres/wash)	Average volume (litres/flush)	Average frequency of use [No/(household.day)]	Average duration of water use (min)
Shower	2.3	8.9	–	–	2.4	7.2
Bathroom taps	5.3	7	–	–	9.7	0.9
Kitchen taps	1	7	–	–	4.8	1.5
Dishwasher	1	–	18	–	0.8	–
Washing machine	1	–	58	–	0.5	–
Single flush WC	1.3	–	–	8.5	8.8	–
Dual flush WC - total volume discharge	1	–	–	8	0.9	–
Dual flush WC - low volume discharge	1	–	–	4	6.3	–

Figure 50 presents the average household consumption structure for the small case study.

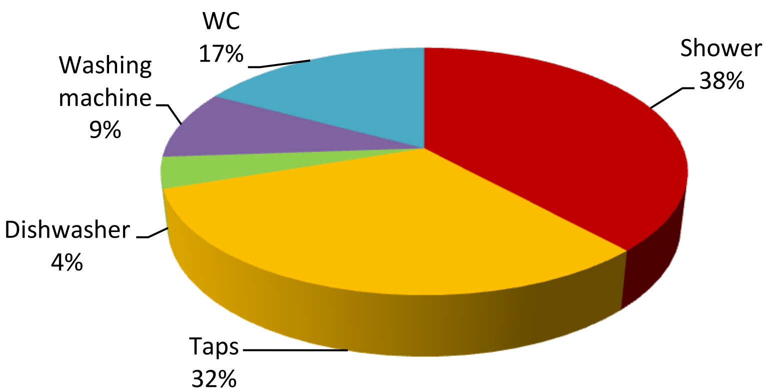


Figure 50 – Average consumption structure for the small case study

Showering and taps are the largest water consuming uses (38% and 32%, respectively), followed by WC (17%). Washing machines and dishwashers contribute the least for total water consumption (9% and 4%, respectively). These results are very similar to those from the main case study presented in Chapter 4.

6.3 Application of Module 1 – Efficient patterns comparison

6.3.1 Introduction

The two paths of the methodology to assess the efficiency of water use based on efficient patterns (water devices flow or volume, efficient time per use and frequency of use) were applied. Similarly to the analysis carried out in Chapter 5, results from the two ways to evaluate efficiency are presented bellow.

6.3.2 Assessment using typical frequencies of use obtained from literature and experts knowledge

For this small case study, as information about professional situation of the consumers' is available, there was no need to divide people into two profiles as explained in Chapter 3. Therefore, the typical number of uses per person and per day for each household was applied without a profile distribution (Table 6). However, since, in this case study, information about the number of meals that consumers cook at home is available, a more precise calculation of the number of dishwasher use can be made. For the other uses, it is considered that all the inhabitants are at home during the weekend, having the same frequency of use as an inactive worker. All households have a dishwasher, therefore, the efficient procedure to manually wash the dishes was not considered.

Efficient patterns were obtained for the three households based on the typical frequencies of use, the efficient time per use and the water devices efficient flows or volumes from Table 4 (section 3.3.2). For each household, the real per capita consumption was compared with the efficient consumption and the consumers' efficiency in water use was assessed. The results are presented in Table 43.

Table 43 – Consumers' efficiency assessment based on typical frequencies of use from literature and experts knowledge for the small case study

<table>
<tr><th rowspan="2">Household</th><th rowspan="2">Per capita consumption [litres/(person.day)]</th><th colspan="2">Efficient per capita consumption [litres/(person.day)]</th><th rowspan="2">Consumers' efficiency assessment</th></tr>
<tr><th>Maximum efficient</th><th>Minimum efficient</th></tr>
<tr><td>1</td><td>130</td><td>72</td><td>98</td><td>There are potential savings</td></tr>
<tr><td>2</td><td>106</td><td>59</td><td>79</td><td>There are potential savings</td></tr>
<tr><td>3</td><td>118</td><td>60</td><td>80</td><td>There are potential savings</td></tr>
<tr><td>Average</td><td>118</td><td colspan="2">64   75   86</td><td></td></tr>
</table>

None of the total evaluated households is considered to be efficient and, thus, all of them show potential for savings, as shown in Table 43. The average value for the per capita consumption, obtained for efficient patterns (75 litres/(person.day)) is largely lower than the value based on consumers' data (118 litres/(person.day)).

Figure 51 shows the level of efficiency at each household, which relates the deviation of each household consumption to its minimum efficiency value. On average, the total sample is on level "73% efficient", with potential water savings of 27% to reach level "100% efficient".

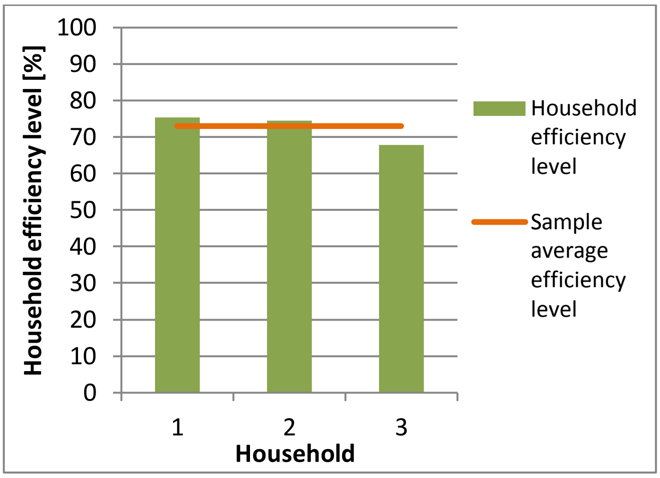


Figure 51 – Households' efficiency level based on typical frequencies of use from literature and experts knowledge for the small case study

The results presented in Figure 51 shows that the three households have similar household efficiency levels and that all households can improve their water savings in comparison to the current situation.

6.3.3 Assessment using frequencies of use obtained from consumers' data

Table 44 shows the average frequencies of use for the sample.

Table 44 – Average frequencies of use based on consumers' data from the small case study

Water device	Shower	Bathroom taps	Kitchen taps	WC	Dishwasher	Washing machine
Frequency of use [No/(household.day)]	2.4	9.7	8.2	4.8	0.8	0.5
Frequency of use [No/(person.day)]	0.9	3.9	3.3	2.0	0.3	0.2

Considering the same water uses, efficient times per use and water devices flows or volumes, Equations (3) and (4) (Chapter 3) are applied considering the frequencies of use obtained from consumers' data. The results are presented in Table 45.

Table 45 – Consumers' efficiency assessment for frequencies of use obtained from consumers' data for the small case study

Household	Per capita consumption [litres/(person.day)]	Efficient per capita consumption [litres/(person.day)]		Consumers' efficiency assessment
		Maximum efficient	Minimum efficient	
1	130	79	110	There are potential savings
2	106	64	89	There are potential savings
3	118	41	58	There are potential savings
Average	**118**	**61 74**	**86**	

For this method, none of the total evaluated households are considered efficient and, thus, all of them show potential for savings, as shown in Table 45. The average value for the per capita consumption, obtained for efficient patterns (74 litres/(person.day)) is largely lower than the value based on consumers' data (118 litres/(person.day)).

Figure 52 shows the level of efficiency at each household, which relates the deviation of each household consumption to its minimum efficiency value. On average, the total sample is on level "72% efficient", with potential water savings of 28% to reach level "100% efficient".

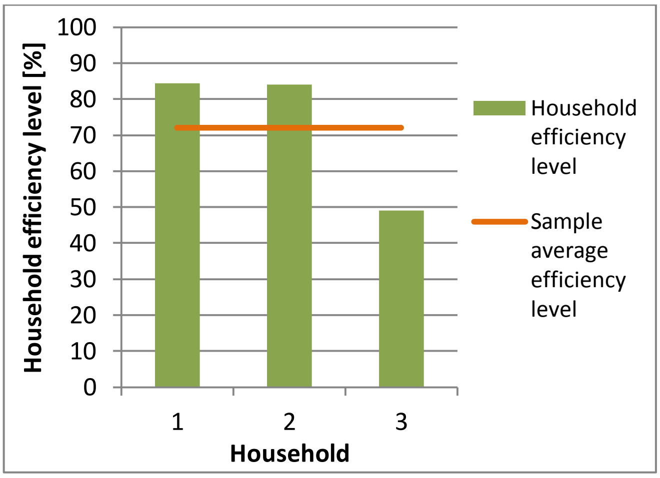


Figure 52 – Households' efficiency level based on frequencies of use obtained from consumers' data for the small case study

The results presented in Figure 52 shows that households 1 and 2 have similar household efficiency levels with this assessment using typical frequencies of use obtained from literature and experts knowledge. Household 3 has an efficiency level bellow 50%, revealing that it could improve its water savings more than the double of the current situation. This result for household 3 is different from the one presented in section 6.3.2, a reason to explain this fact could be the recording errors or the absence of consumers at home. However, it was reported from consumers of household 3 that there were some leaks in the washbasins of their bathrooms during the recording week, which can contribute for household 3 being the most inefficient household of this sample. All households can improve their water savings in comparison to the current situation.

6.3.4 Comparative analysis of the two methods for assessment based on efficient patterns and of results from both case studies

With the application of the two approaches used for household efficiency assessment based on efficient patterns it is possible to conclude that none of household is considered efficient. However, the results presented in section 6.2.2 and 6.2.3 (and similar to the Chapter 5 results) show that the application of each method leads to slightly different conclusions. Thus, the methods should be applied in accordance with the available data in each case and considering the advantages and disadvantages that both have (see Chapter 5, section 5.2.3).

Figure 53 presents the overall efficiency evaluation for Module 1, comparing the two approaches.

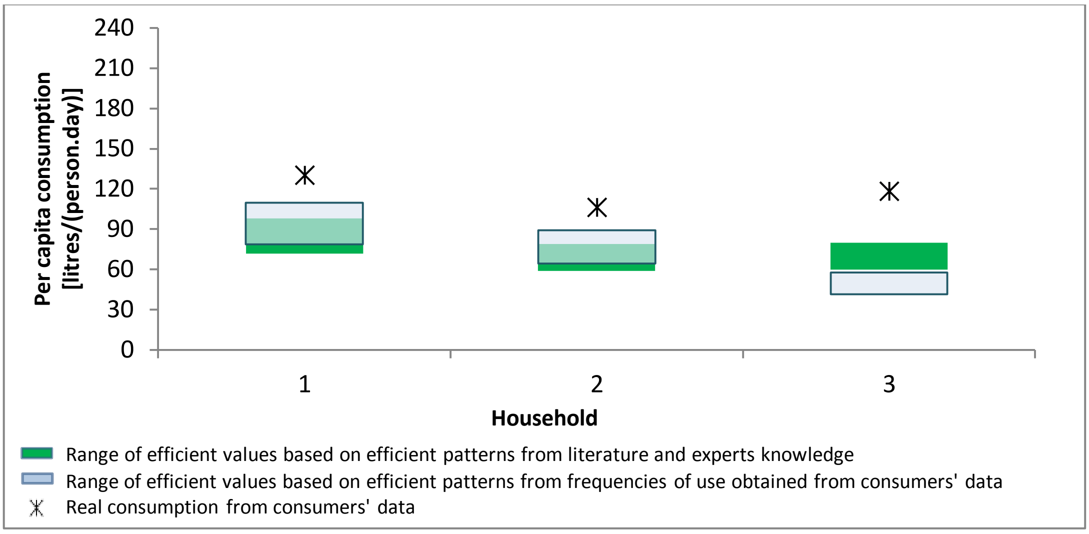


Figure 53 – Module 1: overall efficiency assessment for the small case study

Figure 53 shows that most households are not classified as efficient according to the methodology of Module 1, reflecting an inefficient use of water, with higher volumes than those that is effectively necessary to achieve the consumers' needs. Therefore, the results reveal potential for water savings and improvement can be achieved through changes in consumers' behaviour, in the performance of water devices or with the combination of both. However, the household efficiency levels for consumers from this small case study are higher than in the main case study (Chapter 5), suggesting that, recently, people need to improve less their water savings to reach minimum efficiency, than in the past study. Results from Module 3 will allow to identify if this conclusion is due to better consumer's behaviours or to more efficient water devices and will also allow to see where consumers should act to increase water savings.

6.4 Application of Module 2 – Peer Comparison

Since the case study sample is composed of only three households, it is not statistically reliable to make a cluster analysis (Pestana and Gageiro, 2003). However, Module 2 was applied to this case study through the analysis of consumption class groups. The consumption classes used were the same as in Chapter 5 (see Table 30).

Household 1 belongs to the first consumption class and households 2 and 3 belong to the second consumption class. Therefore, a comparative analysis between household 2 and 3 inside the same group was carried out. The households were compared with each other and with the minimum and average of their consumption class group. Table 46 presents the results obtained for the consumption class groups.

Table 46 – Characteristics of the consumption class groups

Group	Number of households	Consumption class	Weekly consumption [litres/(household.week)]		
			Minimum	Average	Maximum
Group 1	2	2	2483	**2720**	2957

Household 3 has a weekly consumption of 2483 litres/week and is the most efficient consumer of the group (household efficiency level = 100%). Household 2 is the least efficient consumer of the group and their household efficiency level is 92% to the group average and 84% to the group minimum, which corresponds to potential savings of 8% and 16%, respectively, to achieve 100% efficiency compared to the group average and minimum.

The results also show that household 2, which has higher household efficiency level according to Module 1 analysis than household 3, is worst classified in the consumption class analysis. This confirms that, despite, in general, most efficient consumers in their own household are more efficient when compared to their peers, the opposite behaviour can also be verified.

6.5 Application of Module 3 – Evaluation based on performance indices for water devices

6.5.1 Assessment of devices performance

Module 3 was applied similarly to the case study analyzed in Chapter 5 and considering the same water devices.

Table 47 and Figure 54 show the results obtained for the performance assessment of all water devices.

Table 47 – Performance assessment for all water devices for the small case study

Performance assessment		Water 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	173	81	237	0	76	0	0	100
	Average	223	165	253	200	174	17	–	–
	Maximum	277	206	287	300	282	33	0	100
Number of households with unacceptable performance (0-100)		0	1	0	1	1	2	1	1
Number of households with acceptable performance (100-200)		1	0	0	0	1	0	0	0
Number of households with good performance (200-300)		2	2	3	2	1	0	0	0

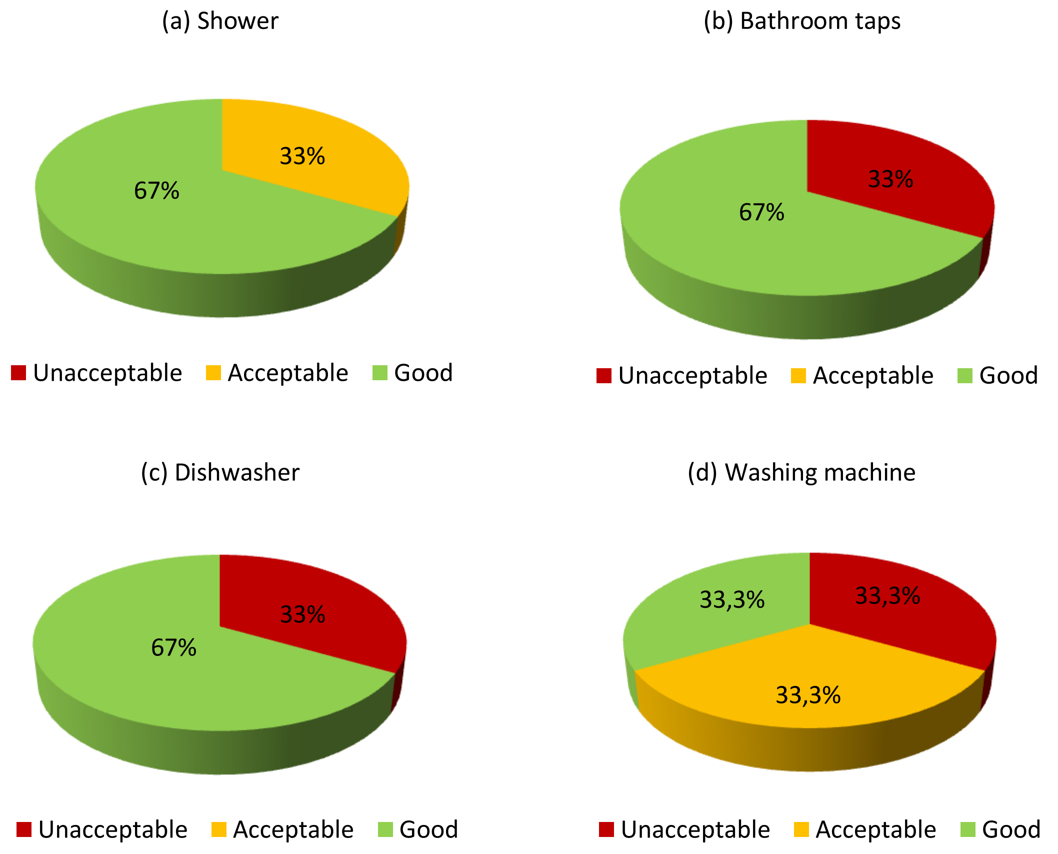


Figure 54 – Water devices performance distribution: (a) Shower (b) Bathroom taps (c) Dishwasher (d) Washing machine

The performance indices obtained for showers vary between 173 and 277, showing that, in this sample, showers are all distributed for "acceptable" and "good" performance levels. On average (performance index = 223), showers are classified as efficient.

For bathroom taps, the performance indices obtained vary between 81 and 206. On average (performance index = 165), bathroom taps are reasonably efficient.

All performance indices obtained for kitchen taps have a value of 300, which shows that, in this sample, all households have efficient kitchen taps (all devices are classified as "good").

For dishwashers, performance indices vary between 0 and 300, however, on average (performance index = 200) the dishwashers have a good performance.

The performance indices obtained for washing machines vary between 76 and 282 and, on average (performance index = 174), washing machines have an acceptable performance.

Similarly to Chapter 5, the WCs for this small case study were either single flush WC (67%) or dual flush WC (33%). Therefore, the performance analysis for WC is divided into these two types of WC. For dual flush WC, the analysis also considered the total volume discharge and the low volume discharge.

All the performance indices for single flush WC and dual flush WC total discharge show that they have an unacceptable performance. For dual flush WC low volume discharge, the index (100) shows a minimum acceptable performance.

6.5.2 Comparative analysis of all water devices

Figure 55 resumes the performance indices for all water devices.

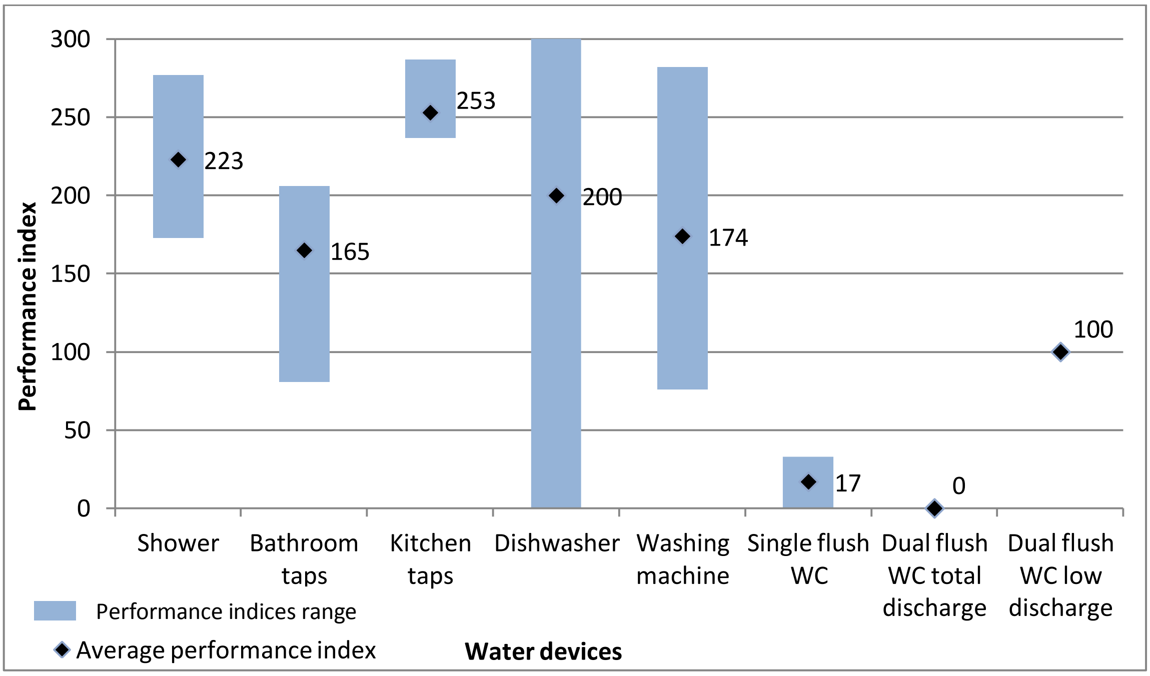


Figure 55 – Ranges of performance indices for the water devices in the small case study

Shower, dishwasher and kitchen taps are the most efficient devices for the small case study. The water devices that have worst performance are the WCs. In the consumption structure of the current case study (Figure 50, section 6.2), shower and taps are the most water consuming uses (38% and 32%, respectively). These results may suggest that consumers' are not efficiently using the water devices with better performance.

For this small case study, the analysis of the performance for water devices shows that there is a slight tendency for consumers to have more efficient water devices. This behaviour change is driven by the market developments in the last decade that is now focussing on the production and commercialization of more efficient devices, following the increasingly demanding requirements included in new product standards.

6.5.3 Overall efficiency assessment for the household

Since data was available for this case study, the calculation of the household water use efficiency index (H_I) to assess the overall efficiency for the household was made using the most appropriate method (*Method I*) to attribute consumption weights (section 3.5.3) Results are presented bellow.

For the current case study, information about the total household water volume used and the volume used by each water device is known from the consumers' data. Therefore, Equation (8) was applied to define each water device weight in the household consumption structure and results are shown in Figure 56 for each household performance index considering its own water devices weights.

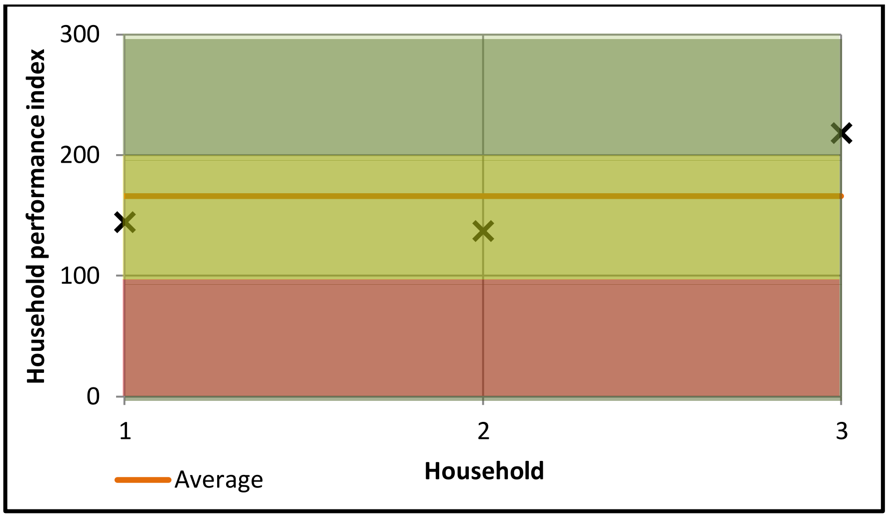


Figure 56 – Household performance index applying *Method I* for the small case study

Figure 56 and Table 48 show that the majority of the households (67%) have an acceptable performance and (33%) have good performance. The households' performance indices vary between 137 and 218 and the average value is 166, corresponding to an acceptable performance. None of the households have a performance index classified as unacceptable; however, these results show that there is still potential for savings and that water use efficiency can be increased through the installation of more efficient water devices, specially, WCs, or through the implementation of other saving measures to reduce the volume of the existing WCs.

Table 48 – Households performance indices results applying *Method I* for the small case study

Household performance indices	
Minimum	137
Average	166
Maximum	218
Number of households with unacceptable performance (0-100)	0
Number of households with acceptable performance (100-200)	2
Number of households with good performance (200-300)	1

6.6 Efficiency assessment – final remarks

The current chapter presented the results from the application of the proposed methodology (Modules 1, 2, and 3) to a small case study composed of three households with different socio-demographic characteristics.

The application and testing of the proposed methodology described in Chapter 3 to the small case study concluded that all households are inefficient considering both approaches for efficiency assessment based on efficient patterns and, thus, significant potentials for efficiency improvements exist (Module 1). The water devices that have lower performance are the WCs and the ones with better performance are shower, dishwasher and kitchen taps. Despite none household is classified as efficient, the results from Module 3 are better for the small case study than for the past study; this could influence the higher household efficiency levels obtained for this current case (Module 1).

In summary, based on the analysis of this recent case study sample, it can be noted that consumers continue to have an inefficient behaviour and that there is a slightly tendency to install more efficient water devices in the households. The latter could be the main cause for the higher household efficiency levels, since the frequencies of use and times per use of the water devices are very similar in both cases.

The application to this small case study proved some flexibility aspects of the methodology: two variables were introduced in the analysis (professional situation and number of main meals at home) allowing a more precise water efficiency assessment; modules and methods in each module were applied according to the available information from the case under study.

7 CONCLUSIONS

7.1 General considerations

The main objective of this work was to develop and test a comprehensive methodology to assess the overall households' water use efficiency in indoor domestic water uses, by making an efficiency evaluation based on efficient patterns, peer comparison and water devices performance. This methodology was applied to two case studies that belong to real water supply systems, one composed of 43 households from a previous study carried out in 2001 at LNEC and another one composed of 3 households from volunteer consumers studied in 2014.

An extensive state-of-the-art review was carried out in terms of factors that influence domestic water consumption, methodologies that have already been developed to evaluate water and energy efficiency as well as methodologies to evaluate performance. The application of the methodology provided an assessment of consumers' efficiency in relation to efficient patterns and to consumers with similar characteristics, highlighting the most and the least efficient consumers in the different aspects of the indoor domestic water use efficiency assessment. Three different outputs to consumers' assessment were obtained each one corresponding to those different aspects and, at the end, a final assessment was reached. The methodology was further tested in a small and recent case study which suggested that the households' water efficiency changes through time.

Results show that a large potential for water savings exist and that the main components in which consumers should act to improve their household efficiency level are: the replacement of water devices with lower performance indices by more efficient ones or adoption of other measures to reduce their total used volume (*e.g.,* placing a 1-1.5 litres plastic bottle filled with water in the WC cistern to reduce flush water); and behavioural changes (*e.g.,* adoption of more efficient time per use).

7.2 Novel contributions

The objective of this work was successfully achieved and the main novel contributions were the following:

- The development of a systematic and comprehensive methodology that incorporates most aspects of water use efficiency which allowed three types of efficiency assessment, applied in a complementary way or in individual parts.
- Application and testing of the proposed methodology in real scale case studies.
- The construction and implementation of performance functions for domestic water devices which return performance indices and allows for the classification of the water devices efficiency.
- The overall households' efficiency assessment, divided in its several components, constitutes a more effective way to provide feedback to consumers.

7.3 Future developments

During the development of the current research, the following gaps have been identified as topics for future research work:

- The extension of the methodology by incorporating outdoor water uses.
- The study of other variables that influence water consumption, such as climate related variables and new socio-demographic variables (*e.g.,* income, educational level, professional situation, presence of housemaid in the household, property age).
- The incorporation of leakage in the household consumption structure.
- The development of a computer application to implement the developed approach.
- The implementation of smart metering systems associated with each water device to allow the measurement of consumption during specific time periods and to minimize recording errors by the occupants of the household.

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APPENDIX A – CONSUMPTION CHARACTERISTICS OF THE CASE STUDY

Purpose: this appendix presented the consumption characteristics for the case study described in Chapter 4.

Table 49 – Consumption characteristics for the main case study

Household	Family dimension (persons/household)	Weekly consumption [litres/(household.week)]	Per capita consumption [litres/(person.day)] [1]
1	2	2436	**174**
2	3	2695	**128**
3	3	1831	**87**
4	1	679	**97**
5	2	2151	**154**
6	3	3800	**181**
7	4	4597	**164**
8	4	1400	**50**
9	3	2395	**114**
10	4	2495	**89**
11	3	2188	**104**
12	5	4294	**127**
13	4	2335	**83**
14	2	1443	**112**
15	1	2000	**286**
16	4	3101	**111**
17	1	923	**132**
18	4	9966	**236**
19	3	2957	**141**
20	4	4028	**144**
21	2	2747	**196**
22	2	2717	**194**
23	4	2145	**77**
24	4	2062	**74**
25	3	4311	**205**
26	5	4759	**132**
27	2	2053	**147**
28	4	3736	**133**
29	1	473	**68**
30	3	2400	**114**
31	4	3787	**135**
32	3	4501	**214**
33	3	5437	**259**
40	2	1004	**72**
41	2	1828	**131**
42	1	894	**128**
43	4	2138	**76**
44	4	3000	**107**
45	3	3201	**152**
46	3	3025	**144**
47	4	3938	**141**
48	3	3729	**178**
49	5	8000	**158**

[1] Average value per household (daily consumption/number of persons per household).