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# In situ evaluation of water and energy consumptions at the end use level: The influence of flow reducers and temperature in baths

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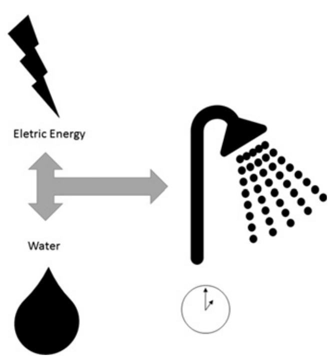
## HIGHLIGHTS

- Domestic consumption of water and electricity in the baths were assessed;
- Presence of flow reducers decreases water/electricity consumption;
- Presence of flow reducers increases the duration of the baths;
- Lower temperature in water-heater, decreased water/electricity consumption and the baths duration;
- Flow reducer and lower temperature, had a significant influence on electricity consumption and on the baths duration.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Nowadays, water and energy consumption is intensifying every year in most of the countries. This perpetual increase will not be supportable in the long run, making urgently to manage these resources on a sustainable way. Domestic consumptions of water and electric energy usually are related and it's important to study that relation, identifying opportunities for use efficient improvement. In fact, without an understanding of water-energy relations, there are water efficiency measures that may lead to unintentional costs in the energy efficiency field. In order to take full advantage of combined effect between water and energy water management methodologies, it is necessary to collect data to ensure that the efforts are directed through the most effective paths.

This paper presents a study based in the characterization, measurement and analysis of water and electricity consumption in a single family house (2 months period) in order to find an interdependent relationship between consumptions at the end user level. The study was carried out on about 200 baths, divided in four different scenarios where the influence of two variables was tested: the flow reducer valve and the bath temperature.

Data showed that the presence of flow reducer valve decreased electric energy consumption and water consumption, but increased the bath duration. Setting a lower temperature in water-heater, decreased electric consumption, water consumption and bath duration. Analysing the influence of the flow reducer valve and 60 °C temperature simultaneously, it was concluded that it had a significant influence on electric energy consumption and on the baths duration but had no influence on water consumption.



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## 1. Introduction

Increasing energy consumption is expected over the next few decades due to urbanization on a global scale. The water issue is so urgent that it is thought that by 2050, about 75% of the world's population may find a shortage of fresh water available (Chen and Chen, 2016).

With the increase of world population, social demands of water and energy are increasing significantly. In fact, by 2030 global energy consumption is expected to growth by 50%. This will substantially aggravate the world's water and energy shortages, especially in some regions and countries with energy and/or water scarcity. An integrated approach to the energy-water nexus is needed to study the inseparable relationships between water and energy, which have increased substantially in recent years (Zhang and Vesselinov, 2016).

The residential sector is a large consumer of both energy and water. Worldwide, the domestic water consumption has increased along the last two decades what involves increased energy consumptions and represents about 40% of the total world energy consumption. Most of this energy is used for lighting, water heating, cooking and air-conditioning (Duarte et al., 2010). The overall contribution of water heating in housings is huge. As an example, in Queensland, Australia, heating and cooling home spaces accounts for 39% of residential energy use while hot water heating alone accounts for 27% (Larkin, 2011). In the USA, 14–25% of the energy supplied to residences heats water. In the United Kingdom, in 2009, domestic hot water consumption accounted for about 18% of the total domestic energy consumption (Boait et al., 2012). Kenway et al. (2008), refer that in Australia, the energy use for residential hot water is five (Adelaide) and eleven (Melbourne) times more than the energy required to deliver urban water services. Kenway et al. (2011) estimate that, on average, residential end-use of water accounts for approximately 30% of the energy used during the urban water cycle, and energy for water heating accounts for approximately 23% (Binks et al., 2016).

According to INE (2010) in Portugal there are several types of sources for energy and for water heating, namely butane and propane gas, natural gas, solar, diesel, wood and off course electricity. Most of the energy is from butane (34.5%) and natural gas (27.9%). 3.4% of the energy for water heating is delivered by electricity.

Ramos et al. (2010) refer that, according to the typical load curves for water and energy consumption, the periods of highest consumption of water and energy occur at approximately the same time and so, water conservation is directly linked to energy conservation.

In Portugal, building sector presents the second highest growth rate of energy consumption, immediately following the transport sector (Silva-Afonso et al., 2011). Nearly 50% of energy consumption by residential buildings is associated to water heating. Thus, the increase of water efficiency in buildings will lead to the reduction of energy spent in it.

In addition, >50% of the consumption could be reduced if efficiency measures are put in practice (ADENE, 2011), such as the use of efficient water use products. Indeed, one way of reducing consumption is the use and certification of efficient products. United Kingdom, Ireland or the Nordic countries are examples of European countries where this certification is already applied. Outside Europe, there are several examples that can be referenced, including Australia, USA, Japan, among others.

In Portugal, the need of an efficient water use was described in the National Programme of Efficient Water Use (PNUEA, 2001). ANQIP (National Association for Quality in Building Services) decided to introduce in Portugal a certification system for products, through the labelling of efficient products. Initially, this certification model was only implemented for cisterns, as these are the products of higher consumption in buildings in Portugal (Silva-Afonso and Rodrigues, 2008). Today, the model is already being implemented, in addition to the cisterns, to showers, taps and flush valves.

The potential for energy demand management through water efficiency measures has been documented (Beal et al., 2012). However, without an understanding of water energy relations, these is a risk that efforts to rise efficiency on one resource (e.g. water) and cut efficiency of the other (energy) (Binks et al., 2016).

Alternative choices of water end use may have very different implications for energy demands. In the residential sector, various appliances and processes are major water consuming, like faucets, washers, showers and toilets. End use energy intensity is very high and human behavioural aspects has a determinant role in setting water related energy consumption (Plappally and Lienhard, 2012).

Individual behaviour, lifestyle, psychological, cultural and social factors and gender preferences are some factors that may influence end use energy consumption in a residential sector (Yu et al., 2011). The average showering time for an individual in the UK and Australia was 7.2 min (Walker and Higgins, 2007; Willis et al., 2010). Walker and Higgins (2007) reported that people below the age of 18 spent more time under showers than the 18–34 age group; there was not much change in showering time with respect to gender. Showering, using faucets and bathing in bathtubs on average consumed 5.4 $kWh/m^3$ of electricity in Arizona (Hoover and Scott, 2009).

According to Plappally and Lienhard (2012), Gleick (1996) found that household water use also changes with climate. This researcher described that the water use in a house hold in a humid developing nation may reach the 0.02–0.04 $m^3/(capita \cdot d)$ and in a dry region the value increases to 0.06–0.08 $m^3/(capita \cdot d)$.

In this context, the main focus of this work is to study the relation between water and related energy consumptions in households. In order to take full advantage of combined effect between water and energy water management methodologies, it is necessary to collect data to ensure that the efforts are directed through the most effective paths. This is a very ambitious goal and so the study started with the characterization, measurement and analysis of the water and electricity consumption during the baths in order to obtain some references values that may allow the work progress. This was performed in a single-family dwelling, with three members, for a period of 2 months and the results are presented in this paper. The option of start with the baths monitoring is related with the fact that baths are the domestic energy to water-related activity that spends the higher part of the domestic water consumptions.

The option of analysing the electric energy is related to the household chose to perform the study. Other energy sources are used for this end-use, and this will be included in future works.

To determine the relationship of water and electric energy consumption two variables were introduced: bath temperature and introduction of a flow reducer valve. These variables allowed to produce different scenarios and to found some relations between the water use and the energy consumption.

Despite the fact that this is a single house characterization, and so it does not represent a large case study (involving several dwellings and various types of water uses), are presented fundamental results once besides establishing important reference values, are also identified the influence of the use of flow reducing valves and temperature control in water and energy consumptions and in the duration of the bath. Additionally, it is important to refer the complexity of the sampling method used to quantify the amount of hot water and related energy spend in a bath. This sampling method as it is referred further ahead required discipline and motivation by the users, which is not very easy to guarantee. This was one of the main reasons that take the authors to perform the study in a single house.

The results obtained will allow to identify procedures that reduce the consumption of water and energy associated with this consumption without, however, jeopardizing the comfort of the user.