Energy to water nexus in domestic consumptions

Matos, C.(1,2,*), Bentes, I.(1,2), Cunha, A. (1,3), Pereira, S. (1,2), Faria, D. (1,2), Gracio, J., (1), Briga-Sá, A. (1,2)

(1) ECT- School of Science and Technology, University of Trás-os-Montes e Alto Douro UTAD, Quinta de Prados, 5000-801 Vila Real, Portugal

(2) C-MADE—Centre of Materials and Building Technologies, University of Beira Interior, 6201-001 Covilhã, Portugal

(3) INESC TEC (formerly INESC Porto) and UTAD – University of Trás-os-Montes e Alto Douro, 5000-801 Vila Real, Portugal

* Corresponding author: University of Trás-os-Montes e Alto Douro (UTAD), Escola de Ciências e Tecnologia, 5000-801 Vila Real, Portugal. Mail: crismato@utad.pt ; www.utad.pt.

Abstract

Presently, water and energy consumption is intensifying every year in most of the countries and this increase will not be maintainable in the long run, making urgent to manage these resources on a sustainable way. Studies stated that water heating is equivalent to 14% of the total energy consumption in residential buildings in the European Union.

In Portugal there is a lack of information about the use of water and related energy consumption inside the dwellings. There are several studies that investigate the total water and energy spend per inhabitant but the partitioning of this per domestic device is yet unknown. Water and energy end-use may be identified as one of the key questions in sustainable buildings design and sustainable use of resources.

In order to clarify this distribution, a quantitative characterization of water and energy use per domestic device was conducted in the North of Portugal. Main results will be presented in this paper.

Keywords

Paper style; environment; format.
1 Introduction

Domestic water use in advanced countries arrays from 100 to 180 L/person.day, corresponding to 30-70% of the amount needed in an urban area (Friedler & Hadari, 2006). In the last 20 years, this amount has increased due to a serious and global overexploitation, leading to high values of water stress, specifically in Europe. The water issue is so imperative that it is thought that by 2050, about 75% of the world's population may find a lack of fresh water available (Chen & Chen, 2016).

Domestic consumptions of water and electric energy usually are related. By 2030 global energy consumption is expected to growth by 50%. This will substantially exacerbate the world's water and energy shortages, especially in some regions and countries with energy and / or water scarcity. A joined approach to the energy-water nexus is desirable to study the attached interactions between water and energy, which have increased substantially in recent years (Zhang & 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. 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). Also 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).

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 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. Indeed, it is crucial to discriminate which are the domestic uses where consumers use more hot water and related energy, in order to propose water and energy efficient measures at the end use level.
There is an undergoing research project, called ENERWAT, where the authors take part of the research team, and it aims to analyse the energy consumption related with the water consumption for urban and rural environments at the domestic end use level. It is carrying out the characterization, measurement and modelling of those consumptions.

In this context, the focus of this paper is to present the study of the consumptions of water and related energy in households, according with the different end-uses. 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 uses in order to obtain some references values that may allow the work progress.

The overall project (ENERWAT) involves one year of measurements, in 9 different households (4 in rural and 5 in urban environment) still in progress, however in this paper the authors will only present one week results in one urban household, just as an example of what these project will involve.

2 Methods

2.1 Case study description

The case study was developed in a single house, type T3, occupied by three people, located in an urban area, in the center of Vila Real, Portugal.

In this house, the only source of energy for water heating is natural gas.

The household is occupied by a Portuguese standard family, consisting of 3 elements.

2.2 Data Collection

The study considered an observation period of 1 full week between 10\textsuperscript{th} and 16\textsuperscript{th} of September of 2018. In this period, all the events using water were monitored. The Fig. 1 present a diagram that models the different uses of water and energy in a dwelling (defined by the ENERWAT project).

![Diagram of water and energy uses in a dwelling](image)

Fig. 1 Model of water and energy uses in a dwelling.

A continuous measurement of the water and energy consumptions was carried out in situ using WATERS system (defined by the ENERWAT project).
The acquisition system is composed by three main components: central nodes, sensors and cables, and central server (Cunha, A. et al, 2017). Nodes are small board computers (SBC) placed at each dwelling strategic sectors (e.g. kitchen, WC), according to the specified model of uses. They are responsible for acquire data from sensors, store it locally and periodically transmit it to the central server through a secure channel (VPN). Sensors are responsible for convert physical events into electrical signals. It was decided to use only two types of sensors: On/off sensors placed in all relevant usage points to signed water usage, e.g. taps, showers, washing machines (Fig. 2); and webcams for reading water and energy consumptions from the dwellings meters. Cables are used to connect sensors to nodes.

Fig. 2. On/off sensor installation scheme and application for mixer faucet and for cistern flush.

2.2 Data treatment

All the data collected, was treated in Excel in order to out put the results obtained, that are presented in the following section. Consumptions measured in continuous of water and gas and electricity are presented, for all the week. Water and energy consumptions per day and per domestic device are presented too. The indicator kWh/m$^3$ was calculated.

3 Results and Discussion

The typical load curves for both water and energy consumption reveal that the periods of highest consumption values for energy and water occur at approximately the same time. In Figure 3 is presented an example of the output obtained by the WATERS monitoring system. As it may be observed there is a continuous monitoring of water and energy (in this case natural gas) consumptions along the day.
Fig. 3: Continuous consumptions of water and gas in showers.

In the particular case of baths, there is a corresponding consumption of water and gas along the day. The major consumptions in this end-use are, as expected, during the morning and in the end of the day. Doing an analysis of this data it was observed a linear correlation between water and energy consumption in showers ($R^2=0.9945$).

In the particular case of this household, the handwash basin has the hot water device disconnected and so, there are no consumptions of energy associated with this end-use.

In the case of the washing machine (WM) (Fig. 4) there is also a match between the registrations of water and energy (electricity) consumptions. However as the measurement scale only measure values higher than 1kWh (smallest value registered on the dwelling meter), there are energy consumptions that were not registered and so, linear correlation between these two consumptions was not verified.

In this household, this domestic device works preferentially during the morning hours.
Fig. 4: Continuous consumptions of water and electricity in the washing machine. The same may be said relatively to the dishwasher (DW) (Fig. 5). Observing Fig. 4 and 5 it may be assumed that the energy consumption in the washing machine and dishwasher was always the same (around 1 kWh), when in fact this is not real, once there are consume values between 1 and 2 kWh that were not registered, once, as said, the small scale on the counter is 1kWh.

Fig. 5: Continuous consumptions of water and electricity in the dishwasher.
In the dishwasher, the use is more disperse along the hours of the day. Some days it ran in the morning, others at lunch and other at dinnertime.

Analyzing the daily consumptions of water and energy (per person) during the monitored week, per domestic device (Fig. 6), the shower use is the responsible for the greatest values of water and energy spend inside the household. The dishwasher is in charge with big energy consumptions, but the same does not happens with water. The washing machine registered smaller values of energy consumptions. It is important to say that the dishwasher is older than the washing machine and so its energy classification is probably worst. There are domestic devices that do not use energy, however registered high values of water consumption (Toilet flush, handwash basin). Considering the variation of water and energy consumption during the week it was not possible to identify differences between the consume patterns in weekdays and weekend, possibly because this paper only involves one week of observations. A larger serie of data would probably guarantee the identification of important differences on this matter.

![Fig. 6: Daily consumptions per person of water and energy (gas and electricity) in the domestic devices monitored.](image)

When the relative water consumptions were calculated (Fig.7), “shower” occupied 44% of the total water consumption per person, followed by the “washing machine”, toilet flush, handwash basin and finally dishwasher.

![Fig. 7: Partitioning of the water consumption by the domestic devices monitored.](image)
Relatively to energy consumption (kWh/person), as expected “shower” occupied 56% of the total, followed by the “Dishwasher” 31% and finally the “washing machine” (Fig.8).

![Energy consumption (kWh/person)](image)

**Fig. 8: Partitioning of the energy (gas and electricity) consumption by the domestic devices monitored.**

Table 1 presents the mean values of daily water and energy consumptions in the monitored domestic device. Table 2 indicate the value of the calculated kWh/m$^3$ of water used, by domestic device.

**Table 1: Water and energy consumption (mean values) in the monitored domestic devices.**

<table>
<thead>
<tr>
<th>Device</th>
<th>Water consumption l/person.day</th>
<th>Energy consumption (kWh/person.day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shower</td>
<td>37,10</td>
<td>1,05</td>
</tr>
<tr>
<td>Handwash</td>
<td>11,41</td>
<td>-</td>
</tr>
<tr>
<td>Toilet flush</td>
<td>11,95</td>
<td>-</td>
</tr>
<tr>
<td>WM</td>
<td>18,36</td>
<td>0,24</td>
</tr>
<tr>
<td>DW</td>
<td>5,60</td>
<td>0,60</td>
</tr>
</tbody>
</table>

**Table 2: kWh/m$^3$ by domestic device.**

<table>
<thead>
<tr>
<th>Device</th>
<th>kWh/m$^3$/person</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shower</td>
<td>0,028</td>
</tr>
<tr>
<td>Handwash</td>
<td>0,000</td>
</tr>
<tr>
<td>Toilet flush</td>
<td>0,000</td>
</tr>
<tr>
<td>WM</td>
<td>0,013</td>
</tr>
<tr>
<td>DW</td>
<td>0,106</td>
</tr>
</tbody>
</table>

Comparing these values with the bibliographic values indicated in Table 3, it may be observed that the values of water consumption found for the washing machine (l/person.day), are smaller than the ones proposed by Jiang et al, (2016) and by Kenway et al, (2013), but higher than the ones proposed by Binks et al (2016). This may be justified by the different properties of the monitored washing machines. In what concerns
to energy consumption, the value found in the present work is higher than the one presented by Jiang et al, (2016). Again, the energy efficiency class of the monitored washing machine is crucial in this matter.

The value of kWh/m\(^3\) presented by Hoover & Scott in 2009, for the washing machine, is not comparable with ours, because our value is by person.day and the one presented in the bibliography is for one year. However, knowing that the monitored household has three persons, the value found of kWh/m\(^3\) would be 14.235 for one year, higher than the one presented by the colleagues in 2009.

Relatively to showers the values of water and energy consumption per person a day found herein follow within the ones pointed out by Binks et al (2016).

The values presented here for the water and energy consumptions in the dishwasher are higher than the one found in the bibliography (Binks et al, 2016) and this may be due to the age of the dishwasher monitored.

**Table 3: Some bibliographic values for energy and water consumptions by domestic device.**

<table>
<thead>
<tr>
<th>Type of use</th>
<th>Water consumption</th>
<th>Water-related energy consumption</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Washing machine</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.27 Per capita (L/d)</td>
<td>0.22 Per capita (kWh/d)</td>
<td>Jiang et al.(2016)</td>
</tr>
<tr>
<td></td>
<td>144L/cycle (impeller type)</td>
<td>0.128 kWh/cycle (impeller type)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>120L/cycle (drum-box type)</td>
<td>2.1 kWh/cycle (impeller type)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>180L/cycle (double cylinder type)</td>
<td>0.16 kWh/cycle (double cylinder type)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60 L/cycle (Europe)</td>
<td>1 kWh/cycle (Europe)</td>
<td>Pakula C &amp; Stamminger R. (2010)</td>
</tr>
<tr>
<td></td>
<td>141 L/cycle (North America)</td>
<td>0.41 kWh/cycle (North America)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>109 L/cycle (Australia)</td>
<td>0.35 kWh/cycle (Australia)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 L/cycle (China)</td>
<td>0.1 kWh/cycle (China)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>120 L/cycle (Japan)</td>
<td>0.9 kWh/cycle (Japan)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.45 kWh/m(^3).year</td>
<td></td>
<td>Hoover &amp; Scott (2009)</td>
</tr>
<tr>
<td></td>
<td>0.0-40.2 L/hh.d or 0.0-10.7 L/p.d (Melbourne)</td>
<td>0.5-2.5 kWh/hh.d or 0.3-0.8 kWh/p.d (Melbourne)</td>
<td>Binks et al. (2016)</td>
</tr>
<tr>
<td></td>
<td>60 L/hh.d</td>
<td>2 kWh/hh.d</td>
<td>Kenway et al. (2013)</td>
</tr>
<tr>
<td></td>
<td>0.038 (m(^3)/capita)</td>
<td></td>
<td>Pelli &amp; Hitz (2000)</td>
</tr>
<tr>
<td></td>
<td>70 L/(person day)</td>
<td>4.68 kWh</td>
<td>Shu Z. (2008)</td>
</tr>
<tr>
<td></td>
<td>0.033 (m(^3)/capita)</td>
<td></td>
<td>Pelli &amp; Hitz</td>
</tr>
<tr>
<td></td>
<td>80 L/hh.d</td>
<td>3.5 kWh/hh.d</td>
<td>Kenway et al. (2013)</td>
</tr>
<tr>
<td></td>
<td>15.2-278.4 L/hh.d or 4.4-113.5 L/p.d (Melbourne)</td>
<td>0.8-14.1 kWh/hh.d or 0.2-4.7 kWh/p.d (Melbourne)</td>
<td>Binks et al. (2016)</td>
</tr>
<tr>
<td></td>
<td>0.003 (m(^3)/capita)</td>
<td></td>
<td>Pelli &amp; Hitz (2000)</td>
</tr>
<tr>
<td></td>
<td>20 L/hh.d</td>
<td>1 kWh/hh.d</td>
<td>Kenway et al. (2013)</td>
</tr>
<tr>
<td></td>
<td>0.0-6.8 L/hh.d or 0.0-2.5 L/p.d (Melbourne)</td>
<td>0.4-1.8 kWh/hh.d or 0.1-0.5 kWh/p.d (Melbourne)</td>
<td>Binks et al. (2016)</td>
</tr>
</tbody>
</table>
4 Final remarks

This paper presented an overview of the type of results that will be obtained in the continuous in situ monitoring system of ENERWAT project. As said, this project has the final aim of analyze the energy consumption related with the water consumption for urban and rural environments at the domestic end use level. It is expected that the results obtained during the project allow to establish the interlinking between energy and water and to identify the main influence factors, such as the social and seasonal behaviors that lead to the consumption of large amounts of water and energy. This data will also contribute to define a simulation model that will be able to predict the user’s behaviors, in the end, in what concerns to consumptions in urban and rural environments.

Water and energy systems were largely treated independently. However, in recent years, with the rapid population growth and increasing awareness of independent changes in climate and water cycle, there has been a growing need for integrating the planning and design of energy and water systems. The interdependencies between water and energy have been recognized and the discussion about it has been intensified. However, it is still necessary to continue the research in this field.

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5 Presentation of Author(s)

Cristina Matos is a Professor of Hydraulics on Trás-os-Montes and Alto Douro University (Portugal), Department of Civil Engineering, Science and Technology School. She is specialist in Water Reuse and Urban Hydraulics. In this latter field she is working on rainwater and greywater reuse systems and water efficient use in buildings.
Isabel Bentes is an Associated Professor in University of Tras-os-Montes and Alto Douro (UTAD). It has been very active teaching and research in the field of hydraulics, water resources and the environment, particularly in fluid mechanics, sanitation, reuse, quality and treatment of wastewater and sewage and solid waste management.

António Cunha is Assistant Professor at the University of Trás-os-Montes and Alto Douro (UTAD). He graduated in 1993 and started working at STCP, the Public Transport's operator of Porto. He made his master's thesis in 1998, and obtained his doctorate in 2005, in the area of computer vision related to control of automated guided vehicles. He is member of Centre for Biomedical Engineering Research (C-BER), INESC TEC since 2015. He works in Electrical Engineering, Electronics & Computers, with a particular focus on computer vision, pattern recognition and biomedical image processing.

Sandra Pereira is an Assistant Professor at University of Trás-os-Montes e Alto Douro (UTAD) in Engineering Department – School of Sciences and Engineering, Doctor in Civil Engineering. Researcher at the Center of Materials and Technologies (C-MADE) in the fields of energy efficiency and building energy consumption, has also some experience in budgets in the construction sector and in projects investment analysis. Currently she is IR of the project ENERWAT - Characterization, modeling and measures for the reduction of urban and rural household consumption.

Diana Faria has a master on Civil Engineering from University of Trás-os-Montes e Alto Douro. She has a research scholarship in ENERWAT project and within this context has co-authored several scientific publications on this subject.

João Gracio is research fellow in the project ENERWAT and has a higher graduation on Computer Engineering from the University of Trás-os-Montes e Alto Douro.

Ana Briga-Sá, Professor at the University of Trás-os-Montes e Alto Douro (Portugal), School of Science and Technologies, Department of Civil Engineering and researcher at the Center of Materials and Technologies (C-MADE). Her main research is in sustainable construction, physical buildings, energy efficiency of buildings and passive solar systems.