Water Efficiency in Buildings:
A Contribute to Energy Efficiency

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Abstract

In the last decades the urban growth leads to a great consumption of energy and water. This contributes for a high amount of greenhouse gas (GHG) emissions, including CO₂ and to the risk of hydric stress. Annually, buildings are responsible for approximately 40% of total world energy consumption. Most of this energy is for the provision of lighting, heating, cooling, air-conditioning and hot water. On the other hand, the housing is responsible for 8% of the global water consumption whose heating contributes to increase the energy consumption and the GHG emissions, because nearly 50% of energy consumption in residential buildings is due to heating sanitary hot water. So, it is essential to promote the water efficient use in housing through the use of efficient products (taps, showers, etc.), among other measures.

The reduction in consumption in buildings contributes to decrease the volume of water extracted, treated and pumped in the public systems of water supply and to decrease the volume of effluents pumped and treated in public systems of drainage, consequently contributing to an increase of energy efficiency also at this level.

The aim of this study is to evaluate the overall contribution of the buildings water efficiency for the energy efficiency and for the reduction of greenhouse gases emissions.

Keywords

Water efficiency; energy efficiency; water supply.
1 Introduction

It is increasingly considered the recognition of water as an ecological and social value, essential to most economic activities and essential to the quality of life. The populations growing levels and standards of living led to a high demand for water resources transforming the water into a scarce recourse with great economic importance. This substantial development of the society, especially in the twentieth century, also brings serious environmental concerns due to its high production of waste, most of them discharged in the environment, often through surface and groundwater, contaminating water resources.

It is estimated that currently the amount of water withdrawn from rivers, lakes and aquifers, is about 4000 km³ per year. In Portugal, the demand for water is estimated at about 7500 x 10⁶ m³ per year, with the highest consumption of water in the agriculture sector. Most of this water is used in spite of a significant percentage of the abstracted volumes are associated with losses and inefficiencies, contributing to higher costs to the society.

In the last 60 years water consumption has tripled in the planet, and approximately 70% is for food production, 22% for industrial use and 8% for domestic use.

This demand for water has led the Man to the execution of numerous hydraulic projects, especially dams and water transfers between river basins and groundwater abstractions. So, it is recognized the significant responsibility of the Man, by altering the hydrological cycle and flow regimes on a global scale, and the consequences of these interventions are now being experienced. It is imperative, therefore, the implementation of systems and measures to achieve an efficient use of water.

2 The importance of the efficient use of water

2.1 Current efficiency in water use

Water is an indispensible resource for quality of living and development of various economic sectors including agriculture and industry.

In Portugal, in terms of water demand by sector, it appears agriculture as the biggest user, with a total volume of 6550 x 10⁶ m³/year, representing 87% of total consumption. As the second largest user appears the supply for urban population consume, about 570 x10⁶ m³/year, which represents 8% of total consumption. The sector with the lowest water consumption is the industry, which corresponds to 5% of the total consumption [1].

However, not all the abstracted water is effectively used because there is a significant portion associated with losses and inefficient use. It is estimated that losses could represent approximately 40% of the abstracted water.

2.2 Imperative to water

The Earth’s surface is composed by two-thirds of water, being 97% salt water and the remaining 3% fresh water. Of these 3%, 2.1% are stored in polar ice and only 0.9% is underground in rivers and lakes and susceptible of exploitation. Although man only can consume fresh water simply a tiny part of the existing water around the globe is available for consumption.

In Portugal, even though there are no serious problems of water scarcity in normal hydric conditions, there may be occasional situations of drought, seasonal or localized, and there are perspectives of water stress in the south of the country in the short / medium term. That kind of phenomena can occur as a result of periods of greater water scarcity or due to reduced water availability with the quality needed, following cases of pollution.

2.3 Imperative to energy

In the last century the high population growth led to a strong dependence of man in relation to water, which had to develop different forms and techniques to locate and capture water in order to meet their basic needs. After the extraction of water, it is necessary to have a water supply and distribution system with several components, which generally requires the use of energy to ensure that water reaches the users.
In order to guarantee the quality of water intended for human consumption, water treatment facilities were set up to ensure that all un-desirable parameters indicating toxicity are within the limits established by law. So, to the processing of water occurs successfully the application of energy assumes a central role, i.e., increased water requirements require higher energy consumption. It can be said that when it comes to energy saving, closing a tap is like turning off the lights.

2.4 Environmental imperative

In the quest for environmental sustainability, efficient use of water is presented as one of the primary requirements.

The water treatment process for human consumption involves the production of waste including sludge that can be harmful to the environment. Accordingly, the increase of water efficient use contributes to the decrease of waste production arising from their treatment, and to an increase of environmental sustainability.

The reduction of GHG emissions is also an environmental priority. The efficient use of water, implying a decrease in the energy used in their abstraction, transport and treatment, can lead to a significant reduction of GHG emissions, especially CO₂, indirectly linked to water consumption.

2.5 Economic imperative

Economically, the efficient use of water may represent costs reduction that arises from the more efficient water processes of distribution, abstraction and treatment.

In accounting for costs of water use in Portugal for the different sectors, it appears that the urban water supply sector has the highest cost, about 875 x10⁶ /year, representing 46% of the total costs, followed by agriculture with 524 x10⁶ /year, representing 28% of the total, and industry with 484 x 10⁶ /year, 26% of the total [1].

The water savings in the different sectors can enhance a highly significant economic benefit. The agriculture sector contains inefficiencies around 88% of the total water losses, followed by the urban supply system with 8%, and the industry with 4% of the total. Calculating the economic value of these inefficiencies, it is clear that the urban sector has the greatest potential economic savings, about 369 x 10⁶ / year, followed by agriculture with 219 x 10⁶ /year, and by industry with 140 x 10⁶ /year. In Portugal, these savings can mean a reduction equivalent to 0.64% of the Gross National Product [1].

3 Impact of water use in energy consumption

3.1 At the level of the distribution network

Energy is needed at all stages of the urban water cycle. The provision of drinking water supply and wastewater drainage and treatment to the populations implies an intensive use of energy. So, the urban water cycle is very dependent on energy as their main source of movement.

Energy consumption in the urban water cycle can be divided mainly into five stages: abstraction, treatment, distribution, drainage and wastewater treatment. In each stage the amount of energy used may vary depending on the specific location and of the population to be served.

Every step of the urban water cycle has associated specific energy intensity. This may vary depending on the type of step in question, but is also depending on few key factors, such as the water source, the volume of water transported, distance and topography. The energy intensity can reach low values or even zero for systems supplied by gravity, but can also reach high values when the
systems need the use of pumps to transport the water or the wastewater. The energy intensity can be defined as the amount of energy consumed per unit of flow, associated with each stage of the urban water cycle.

Table 1 shows the change of energy intensity in each step of the urban water cycle, excluding the final stage of use of water. This study was conducted by the California Energy Commission, depicting the energy intensity of the urban water cycle in California [2].

### Table 1 - Energy intensity in various steps of the urban water cycle

<table>
<thead>
<tr>
<th>Urban water cycle</th>
<th>Range of energy intensity (KWh/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstraction and transport of water</td>
<td>Low 0</td>
</tr>
<tr>
<td>Water treatment</td>
<td>Low 0.03</td>
</tr>
<tr>
<td>Water supply</td>
<td>Low 0.19</td>
</tr>
<tr>
<td>Drainage and treatment of wastewater</td>
<td>Low 0.29</td>
</tr>
<tr>
<td>Wastewater discharge</td>
<td>Low 0</td>
</tr>
<tr>
<td>Treatment and distribution of recycle water</td>
<td>Low 0.11</td>
</tr>
</tbody>
</table>

### 3.1 At the level of the final consumption

Energy use associated with urban consumption of water is also a concern in a demand for energy and environmental sustainability. At the urban level, water consumption is divided in three major sectors, namely the residential, the industrial and the commercial.

Water consumption in the residential sector can be associated with various activities such as personal hygiene (shower, bath and wash basin), toilets, washing machines, dishwashers, irrigation, pools and jacuzzis, etc. The expenditure of energy to perform some of these activities is significant. This energy can be associated with activities such as the production of hot water, water circulation in swimming pools, pressurization, etc.

Depending on the type of activity undertaken, the type of energy power may differ, being the electricity, the natural gas and the butane the most used.

In the USA, a study to quantify the percentage of energy used in housing water consumption concludes that the use of the shower consume the highest percentage of energy, about 41% of the total, followed by taps and machines washing with 24% and dishwasher with 11% of total energy consumed [2].

### 3.2 Sanitary hot water (SHW)

In Europe, about 25% of energy consumption in housing is associated with the use of SHW, being this value in Portugal, according to the Portuguese energy operator (EDP), relatively lower, around 22% [3]. It is understood by hot water all the drinking water whose temperature exceeds 35°C used for bathing, cleaning, cooking and other specific purposes, prepared in an appropriated device, using conventional energy sources or renewable.

The most frequent sources of energy utilized to heat housings in Portugal, are fossil fuels, particularly natural gas, liquefied petroleum gas - LPG, better known as butane and propane, and sometimes solid fuels. Solar energy, a renewable energy alternative to fossil fuels used to produce SHW, is also used in Portugal.

The LPG is presented in the form of butane and propane for use in SHW and can be consumed in bottles, piped or in bulk. The butane gas only comes in bottles, and propane comes in all forms of consumption that have been mentioned. The butane is especially for domestic use, more sensitive to demands for safety, efficiency, cleanliness and economy, while propane is ideal for more intense needs of consumption, particularly in the area of restaurants and hotels.

Natural gas for domestic use has as purpose the heating of water and the interior space. Taking advantage of its features in the ecological point of view, as in economy and security, the natural gas now appears as the energy of first choice for most homeowners. In Portugal, natural gas was introduced in 1997 and currently supplies more than 750 000 domestic customers.

The electrical power is one of the energies more used by man, due to its portability and low rate of energy loss during conversions. In Portugal, the electricity is produced mostly from oil, representing about 50% of the total consumption of primary energy in 2009. In the residential sector can be used in lighting, water heating and other equipment (washing machine and dishwasher, refrigerator, television, etc.). Water heating can account for up to 25% of the total housing electricity consumption. Table 2 depicts the average cost of the different types of energies used to produce SHW in Portugal.

### Table 2 – Cost of energies used to produce SHW

<table>
<thead>
<tr>
<th>Type of energy</th>
<th>Cost(€/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butane gas</td>
<td>0.14</td>
</tr>
<tr>
<td>Propane gas</td>
<td>0.17</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.06</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.12</td>
</tr>
</tbody>
</table>
4 CO₂ emissions resulting from the use of water

The urban water cycle is intrinsically linked to energy consumption that assumes a key role in the success of the processes. Associated with this energy consumption are the GHG emissions to the atmosphere, particularly CO₂.

With the growing economic development of nations and world’s population the increase of water consumption became inevitable, which consequently results in the use of larger amounts of energy and the emission of large quantities of CO₂. About 2 to 3% of the total world energy consumption is associated with the use of water.

Housing CO₂ emissions from the use of water are almost the resulting of heating water. But there are also significant CO₂ emissions related to heat losses, called fixed losses. These can occur on cylinder for hot water storage and piping for hot water circulation. The improvement of thermal insulation of pipelines and storage tanks of hot water are two of the energy efficiency measures that may be applied to reduce these losses.

Despite the water consumption in dwellings having kept constant over the past 10 years, the habits of water use have been changing. Several efficiency improvement measures of energy and water use in dwellings were introduced; however, there is a tendency for families to use water in larger time intervals and in large quantities, particularly due to the increasing frequency of the shower use and increase flow of water.

A study of the Energy Saving Trus, in the United Kingdom, to quantify CO₂ emissions associated with water consumption, showed that 89% of CO₂ emissions are due to the use of water in housing and the remaining 11% are related to the abstraction, treatment and distribution of water and wastewater treatment. According to this study, are emitted an average of 6.2 Mega tones of CO₂ per liter of water per housing, equivalent to 2.2 kg of CO₂ per day. The same study indicate that 77% of the CO₂ emissions are associated with the use of hot water for housing heating and the remaining 23% resulting from heating water for consumption.

Although CO₂ emissions in housing are mostly associated with the hot water volume consumed, it is necessary to take into account the type of energy used for water heating. The different energy used and the different efficiencies led to different CO₂ emissions. So, dwellings with the same hot water consumption, but using different energies for heating will present distinct values of CO₂ emissions.

Table 3 depicts the different types of energy used for SHW heating and the corresponding CO₂ emissions per kWh of energy produced, taking into account each one of the CO₂ emission factors [4].

<table>
<thead>
<tr>
<th>Energy type</th>
<th>CO₂ emission factors</th>
<th>CO₂ emission (Kg /kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>0.36 Kg CO₂/kWh</td>
<td>0.36</td>
</tr>
<tr>
<td>Natural gas</td>
<td>2.17 Kg CO₂/m3</td>
<td>0.21</td>
</tr>
<tr>
<td>Butane gas</td>
<td>2.95 Kg CO₂/Kg</td>
<td>0.23</td>
</tr>
<tr>
<td>Propane gas</td>
<td>2.92 Kg CO₂/Kg</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Water users’ behavior can have great differences that are crucial in housing water consumption and in consequent CO₂ emissions. The amendment of some of these behaviors, such as reduce shower time, can mean a decrease of 200 kg of CO₂ per user, in a year.

5 Measures for the efficient use of water

With the increasing scarcity of drinking water supply for the population, in particular in times of drought, it becomes essential to find methodologies to conserve water and use it efficiently. Traditionally the management of water resources has focused on developing new installations of water supply and treatment giving little importance to how water is used. However, the habits of continuous waste water may exhaust its reserves faster than it can be replaced. Thus, the development of conservation and efficient use of water can change this type of behavior, contributing not only to the reduction of water consumption but also to the reduction of energy consumption, GHG emissions and water operating costs.

5.1 At the housing level

The application of housing water efficiency measures significantly contributes to a domestic reduction of water consumption. With specific objectives, these measures mainly focus on the promotion of proper use of water by users, the widespread promotion of the use of efficient devices and equipments and in reducing losses and waste of water. In Portugal, the reference intakes in a housing considering a moderate use of water, without significant waste, and using efficient technology in terms of water use, indicates the greatest percentage of consumption of water taps with 41% of the total volume of water, followed by the shower with 39%, the toilet flushing systems with 11%, the washing machine with 7% and the dishwasher with 2% of the total.

The use of housing hydric efficient equipment can substantially reduce the water consumption. Accordingly, a Portuguese NGO dedicated to the promotion of quality and efficiency in buildings services - ANQIP (National Association for Quality in Building Services), decided to launch in 2008...
a certification and labeling model for water efficiency of products. In this labeling system “A” represents the efficiency that is considered ideal. It also takes into account the devices friendliness-user and the performance and public health aspects. The A+ and A++ ratings are intended for special or regulated applications (Figure 1). The products covered by this classification are the showers and shower systems, flushing cisterns and taps [5].

5.1 At the level of the public water supply network system

The public water supply system always have losses of water that can reach a large proportion of total consumption, because its length and complexity of existing organs and joints. The water distribution systems are not completely waterproof, so the occurrence of water losses is inevitable, but high losses have negative environmental and economic consequences. The increase of environmental sustainability is one of the consequences of the water losses reduction, thereby contributing to the efficient use of water and energy. The reduction of GHG emissions to the atmosphere that arise from the energy consumption associated with water is one of the main factors that contribute for sustainable development. The identification of water losses in a supply system can also be reflected in financial economy not only for the managing body as well as for the consumer.

6 Water use impacts assessment in energy consumption and CO₂ emissions

In order to determine the energy, environmental and economic impacts of the water use, it was analyzed, in Portugal during the 2010 year:

- the volume of abstracted and distributed water by the companies responsible for the supplying of drinking water;

- the volume of wastewater edits by the companies responsible for the wastewater drainage and treatment;

The replacement of the washing machines and dishwashers for more efficient ones is other measure to achieve the reduction of water consumption. Its replacement by a more energy and hydric efficient equipment led not only to the reduction of water consumption but also to the reduction of wastewater production and energy consumption. This measure may represent a decrease of almost 18% of water consumption in the washing machine.

The rainwater use in housing is another measure which may imply a potential savings of water consumption. There are systems that can be installed on new or existing buildings which use is viable to the gardens irrigation, cars and decks washing. In some cases, the use of rain water in domestic uses led to a reduction of 50% of the potable water. In Portugal, where the average annual rainfall can reach values close to 1500 mm, particularly in the North, has a high potential for the use of this type of systems.

The gray water reuse is also a solution to increase the housing efficient use of water. It can be reuse from bathtubs, showers, washbasins, bidets after appropriate treatment. The more viable usages of gray water are in the discharge of flushing cisterns, irrigation systems, floor and vehicles washes, and firefighting systems. The gray water reuse allows not only the reduction of the consumption of drinking water in a dwelling but also the reduction of wastewater flow. This type of exploitation is already recognized in several countries as an effective measure in reducing urban consumption of drinking water. However, there are also some countries that limit this type of system claiming that there is a risk of public health problems that can arise from its use.
and the energy consumptions by these companies associated with these activities. Companies belonging to the waters of Portugal group – AdP, which participate in this study represent 67.3% of the total of water supply companies and 61.1% of all wastewater enterprises in Portugal.

It was also examined the volume of housing water distributed by the water company of Oporto in 2010.

Analyzing the energy consumption of water supply companies it is concluded that for each m³ of water produced the energy differs according to the company, with an average of 0.51 kWh/m³ of water produced. The same was verified in wastewater companies, with an average of 0.45 kWh/m³ of energy consumed per m³ of wastewater treated.

According to the Portuguese energy operator - EDP, the GHG emission factor for electricity is 361 g/kWh for the CO₂, 2.28 g/kWh for SO₂ and 1.08 g/kWh for NOₓ. As CO₂ represents the most significant participation in GHG emissions it was estimated the contribution on CO₂ emissions of the Group AdP companies. The water supply companies analyzed have an average emission of 0.18 kg/CO₂ per m³ of water produced and the wastewater companies an average of 0.16 kg/CO₂ per m³ of wastewater edits.

In order to demonstrate the potential reduction of real losses in water supply systems in high, it was estimated the actual losses and the consequent energy consumed and CO₂ emissions. The calculation of actual losses was performed by subtracting the volume of water delivered to the volume of water produced. CO₂ emissions associated with energy consumption were determined using the emission factor of 361 g/kWh of energy consumed.

The total of actual losses in the water supply systems in high is equal to a volume of 36 408 344 m³ of water, with an associated energy consumption of 8 397 721 kWh and 3 032 t CO₂ emissions.

According to EDP in Portugal, the average value of the electrical energy cost is 0.12 €/kWh. So, the total cost of the energy associated with the actual losses of water is around 1 007 726 € for the 2010 year.

In Portugal, is expected to decrease in 50%, up to 2015, the value of the water supply network losses and consequently the associated energy consumed and CO₂ emissions.

After it was analyzed the CO₂ emissions associated with the housing hot water consumption using different types of energy, considering the Oporto water supply company data. The volume of water distributed by this company in 2010 was equal to 11 019 839 m³. Considering that the housing hot water consumption is associated with the shower, which represents 39% of domestic water consumption, its volume is about 4 297 737 m³.

In order to compare the CO₂ emissions and the cost of the different types of energy (Butane, Propane, Natural gas and Electricity) used to heat domestic hot water, it was considered the use of each type of energy in 100% of dwellings. Admitting that to heat 1 m³ of water at 37°C [6] are required 30 kWh of electrical energy, 2.37 Kg of butane gas, 2.33 Kg of propane gas and 2.85 m³ of Natural gas, it was determined the energy consumption associated with the volume of hot water in housing, for each type of energy (Table 4).

Table 4 – Hot water volume and associated energy consumption

<table>
<thead>
<tr>
<th>Hot water volume (m³)</th>
<th>Electricity Consumption (kWh)</th>
<th>Butane Gas Consumption (Kg)</th>
<th>Propane Gas Consumption (Kg)</th>
<th>Natural Gas Consumption (m³)</th>
</tr>
</thead>
</table>

To calculate the CO₂ emissions associated with the use of the different types of energy, it was considered the CO₂ emission factor for electricity equal to 0.00036 tCO₂/kWh, for Natural gas equal to 0.00217 tCO₂/m³, for Butane gas equal to 0.00295 tCO₂/Kg and for Propane equal to 0.00292 tCO₂/Kg (Table 5).

Table 5 – CO₂ emissions associated with the energy consumption in water heating

<table>
<thead>
<tr>
<th>CO₂ emissions (t)</th>
<th>Gas</th>
<th>Gas</th>
<th>Gas</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>Butane</td>
<td>Propane</td>
<td>Natural</td>
<td></td>
</tr>
<tr>
<td>46.544</td>
<td>30.048</td>
<td>29.240</td>
<td>26.580</td>
<td></td>
</tr>
</tbody>
</table>

Table 6 – Costs of the different types of energy used to heat SHW

<table>
<thead>
<tr>
<th>Costs (€)</th>
<th>Electricity</th>
<th>Butane</th>
<th>Propane</th>
<th>Natural</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas</td>
<td>Gas</td>
<td>Gas</td>
<td>Gas</td>
</tr>
<tr>
<td>15 471 854</td>
<td>18 130 434</td>
<td>21 529 515</td>
<td>8 573 986</td>
<td></td>
</tr>
</tbody>
</table>

Analyzing Table 4 and Table 5 it is concluded that Natural gas is the energy that produces a reduced amount of CO₂ emissions in water heating and is the cheapest one.
In order to analyze the impact of the water efficiency measures implementation in the domestic sector, it was considered that housing has an average occupation of 2.7 people and the average consumption of water in the shower is 0.15 l/s [6]. Replacing the usual shower by a labeled one with a hydric efficiency category A it can be reduced its flow rates to 0.08 l/s, representing a decrease of approximately 47% of the volume of the hot water initially consumed, i.e. the volume of SHW would be 2 277 801 m³. Consequently the different types of energy consumed in water heating would also be reduced by 47% as well as the resulting of CO₂ emissions and associated costs.

8 References


The results obtained underscore the importance of proper management of water consumption in our planet that can not only prevent water scarcity in future, but also prevent the increase of global warming, in particular through the reduction of CO₂ emissions.

7 Conclusions

The water consumption reduction and the water resources conservation can strongly contribute to the reduction of energy consumption, of CO₂ emissions and of economic costs. So, it is essential a better urban water cycle understanding to develop and implement efficient hydric measures and solutions that enable the efficient water use, the reduction of energy consumption and CO₂ emissions.

The distribution network of drinking water presents itself one of the main steps of the urban water cycle. In this cycle the inefficient water use is a consequence from the occurrence of losses and water leakage in the network. Current losses in the systems of public water supplies reach values in the order of 40% showing a high potential for falling not only water savings but also energy consumption and associated CO₂ emissions. The reduction of water losses also contributes to the diminution of financial costs of the management water supply enterprises.

The domestic water consumption sector also represents a high potential for reducing water consumption. At the building level there is a wide field of activities that permit to reduce losses and waste of water. The use of hydric efficient products, the rainwater use and the grey water reuse are fundamental measures to be adopted for the housing water efficient use.

As CO₂ emissions represent one of the main greenhouse gases its reduction is particularly important in achieving environmental sustainability. Water consumption is entirely related with energy consumption and as a result of this CO₂ emissions are unavoidable. So, the efficient water use can significantly contribute to the reduction of these emissions.