Assessing the impact of water efficiency in energy efficiency and reducing GHG emissions: A case study

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***Abstract*—**Nowadays humanity uses about 50% of existing drinking-water, but in the next 15 years this percentage will reach 75%. Consequently, hydric stress risk will rise significantly across the entire planet. Accordingly, several countries will have to apply efficient hydric measures in the water-supply sector, including at the building level. These measures, in addition to reducing water consumption, will contribute towards increasing energy efficiency and decreasing the emission of greenhouse gases (GHG), especially CO2 emissions. This paper is focused on the study of a region in the center of Portugal (Aveiro). Its aim is to assess the impact of the implementation of efficient devices in buildings in the urban water cycle, as well as improving energy efficiency and reduce GHG emissions.

***Keywords*—**Hydric efficiency, efficient water devices, energy efficiency, GHG emissions.

I. Introduction

Water has become a resource of the utmost importance. Demographic growth and, most especially, economic development and today's lifestyles have rendered drinking water scarce, and its status has changed over the past decades from that of a community and national asset to that of an economic one [1].

Climate change has worsened the situation and the risk of hydric stress is increasing significantly across the entire planet. This problem is most severe in areas like Mediterranean Basin, the Middle East, East Coast of the USA and the West Coast of Australia.

In Europe, some countries of the South are particularly affected, such as Spain and Portugal. Accordingly, very serious problems are likely to appear in the short to medium term in most of the territory of these countries [1].

This situation could be critical and needs urgent intervention through the application of measures of efficiency for all interveners in the water cycle, including buildings.

On the other hand, cities generally have a high concentration of energy demand and consequently are responsible for a high amount of greenhouse gas (GHG) emissions, including CO2 [2].

The Directive 2002/91/EC - Energy Performance of Buildings Directive (EPBD) of the European Parliament and Council on energy efficiency of buildings was adopted, on 16th December 2002 and came into force on 4th January 2003 [3].

The EPBD is considered a very important legislative component of energy efficiency activities of the European Union designed to meet the Kyoto commitment and respond to issues raised in the Green Paper on energy supply security [4].

Globally, buildings are responsible for approximately 40% of total annual world energy consumption. Most of this energy is for the provision of lighting, heating, cooling and air-conditioning [5].

In the European Union, considering their whole life cycle (construction, operation and use or demolition), buildings consume about 50% of total energy demand and contribute almost 50% of CO2 emissions, the basic gas responsible for the greenhouse effect [6].

To obtain a reduction of CO2 emissions, effective measures must be taken during its use or operation phase, because the latter represents 80-90% of the total energy consumed throughout its entire life cycle [7].

The EU Action Plan for Energy Efficiency identifies energy efficiency in the building sector as a top priority. The EPBD has a key role for realising the potential savings in the building sector, which is estimated at 28% and which in turn can reduce the total EU final energy use by around 11% [8].

In Portugal, the building sector presents the second highest growth rate of energy consumption, immediately following the transport sector [9].

The Portuguese regulations [10] [11] [12] require that new buildings comply with minimum requirements on energy performance and must have an energy performance certification through which an energy efficiency label is attributed to the housing (Figure 1).

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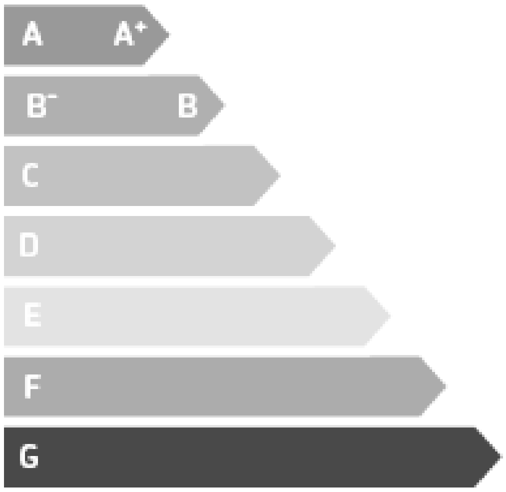

Fig. 1: Energy efficiency label [10]

According to recent data from energy balances of the General Ministry for Energy and Geology [13], residential and service buildings are responsible for the consumption of about 30% of total energy and for more than 60% of total electricity consumed at the national level.

Nearly 50% of energy consumption by residential buildings is due to heating sanitary hot water (SHW) [6].

It should be noted that increased efficiency in water use in buildings leads to the reduction of water consumption and decrease wastewater effluents, increasing energy efficiency and contributing to the reduction of GHG emissions [1][14][15].

Thus, the increase of water efficiency in buildings – in addition to being a strategic necessity in many countries – should be seen as a key measure to consider for the overall sustainability of buildings.

This paper, studying a municipality located in the central region of Portugal as a case study (Aveiro, with 73000 inhabitants), evaluates the impact of the use of efficient products in buildings to reduce consumption of drinking-water in the urban water cycle, to increase energy efficiency and to reduce emissions of greenhouse gases.

II. Water Efficiency in Buildings

An efficient water cycle in buildings can be summarized by analogy with the 3R principle (used for waste) which is known as the 5R principle [1] (Figure 2).

- Reduce consumptions
- Reduce losses and inefficiencies
- Re-use water
- Recycle water
- Resort to alternative sources

} ***- Water efficiency in buildings***

Fig. 2 – The 5R principle for water efficiency in buildings [1]

The need of an efficient water use has already been recognized in Portugal as a national priority through the publication of a National Program for Efficient Water Use (PNUEA) [16].

In Portugal, the overall global waste in water use is presently estimated at over 3 x 10^9 m^3/year, which is around 39% of the country's total water requirement.

With specific reference to the urban supply sector (public and building systems), total waste is reckoned to be 250 x 10^6 m^3/year, costing about 600 x 10^6 €/year.

In terms of figures per person, this amounts to waste of more than 25 m^3/year, i.e., near 70 m^3/year per family (average family consist of 2,7 persons in Portugal).

Bearing in mind the short- /medium-term water stress forecasts this situation needs urgent intervention through the application of measures to rationalize water use.

Amongst the actions suggested in the PNEUA to reduce consumption is the proposal for labeling building devices (flushing systems, showers, etc.) in order to provide consumers with information about water efficiency.

The Plan suggests that this measure be made compulsory after a transitional period.

The water efficiency labelling of products has generally been implemented voluntarily in various countries.

In some countries efficiency is not graded, but an efficiency label is awarded when consumption is less than a specific amount. This is the labelling system in use in the US and Scandinavia, for example.

In Australia and Ireland (Dublin), however, the label indicates a classification that varies with the product's efficiency [1].

The PNUEA predicts the involvement of companies, management organizations, and non-governmental organizations for the implementation of the referred measures in Portugal.

Accordingly, a Portuguese NGO dedicated to the promotion of quality and efficiency in building services – ANQIP (National Association for Quality in Building Services) – decided to launch a certification and labeling model for the water efficiency of products.

Figure 3 shows the labels used [1].

"A" represents the efficiency that is considered ideal.

It also takes into account the user-friendly devices, performance, and aspects of public health.

The A+ and A++ ratings are intended for special or regulated applications.

The base colours, which cannot be seen in the Figure, are green and blue.

ANQIP has drawn up Technical Specifications (ETA) for different products to create and establish the necessary benchmark values to be assigned to each letter. These Technical Specifications also establish the certification testing conditions.

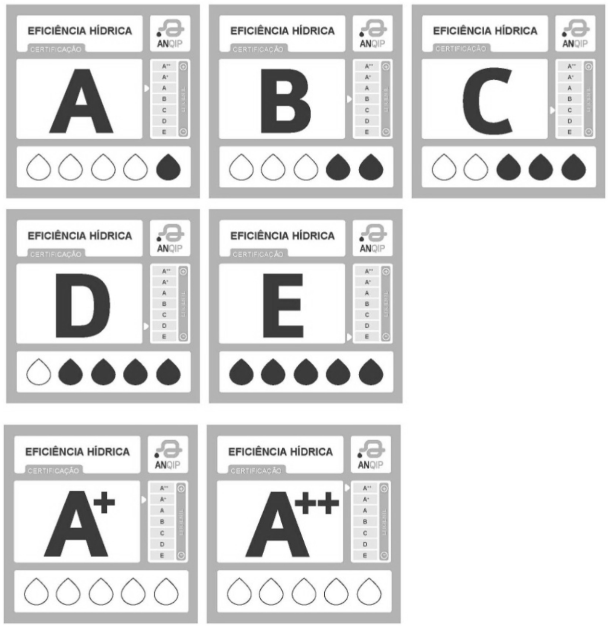

Fig. 3: Portuguese water efficiency labels [1]

Firms signing up to the system will sign a protocol with ANQIP which will define the conditions under which they can issue and use the labels.

ANQIP controls the process by randomly testing labelled products on the market, from time to time. These tests are performed by accredited laboratories or by laboratories which are recognised by the Association.

In this process of labelling, cisterns were regarded as a priority since toilet flushing cisterns are one of the biggest consumers of water in buildings in Portugal.

As there is a project for a European Standard for WC and urinal flushing cisterns (prEN 14055:2007), it was decided that the labels of water efficiency to be used in Portugal should comply with this Standard, where applicable.

The following mechanisms are also regarded as water-saving devices, under this Standard:

a) Double-action mechanisms (interruptible): one action initiates flushing and a second action stops the flush;

b) Dual-control mechanisms: one control releases the full flush volume and another control releases a reduced flush volume.

The reduced volume cannot be greater than two-thirds of the maximum flush.

Table I presents the categories defined in the Technical Specification ANQIP ETA 0804 for flushing cisterns.

The minimum permitted volume or discharge amounts in current facilities are limited for reasons linked to performance, user-friendliness and public health.

The use of 4-litre flushing cisterns, for example, has led to problems in the flushing of solids in building and public networks in Portugal.

Therefore, their usage requires an alteration of the usual criteria of the design of the drainage system (which is incompatible with many existing drains).

In addition, the European Norm EN 12056-2 does not allow the use of 4-litre flushing systems in building systems whose design comply with System I of the said Norm, and this is precisely the most common system in Portugal, allowed by the General Regulation.

Furthermore, it must be ascertained if the discharge volume is compatible with the other characteristics of the cistern toilet. Product performance is usually ensured by compliance with European Norms, meaning that any water efficiency certification must require prior compliance with the existing norms in terms of the product's respective performance (in the case of flushing cisterns, as mentioned above, it is the prEN 14055).

Based on these facts, ANQIP established low volume flushing cisterns belonging to water efficiency categories A+ or A++, but with the obligation that the label should warn users of the need to guarantee the performance of the system and compatibility of the drainage conditions in the building system (Figure 4).

Table I: Water efficiency categories for the labelling of flushing cisterns

Nominal volume (litres)	Type of flush	Water efficiency rating	Tolerance (Maximum volume – complete flushing)	Tolerance (Minimum volume for water-saving flushing)
4.0	Dual control	A++	4.0 – 4.5	2.0 – 3.0
5.0	Dual control	A+	4.5 – 5.5	3.0 – 4.0
6.0	**Dual control**	**A**	**6.0 – 6.5**	**3.0 – 4.0**
7.0	Dual control	B	7.0 – 7.5	3.0 – 4.0
9.0	Dual control	C	8.5 – 9.0	3.0 – 4.5
4.0	Interruptible	A+	4.0 – 4.5	-
5.0	Interruptible	A	4.5 – 5.5	-
6.0	Interruptible	B	6.0 – 6.5	-
7.0	Interruptible	C	7.0 – 7.5	-
9.0	Interruptible	D	8.5 – 9.0	-
4.0	Complete	A	4.0 – 4.5	-
5.0	Complete	B	4.5 – 5.5	-
6.0	Complete	C	6.0 – 6.5	-
7.0	Complete	D	7.0 – 7.5	-
9.0	Complete	E	8.5 – 9.0	-

Fig. 4: Examples of water efficiency labels for low volume flushing cisterns

The water efficiency certification and labelling system for flushing cisterns was implemented in the last quarter of 2008. Many companies and consumers have complied with the system, and it now covers about 75% of the national market, corresponding to 110 commercial references. [1]

Table II summarises the certifications awarded per category.

Table II: List of certified flushing cisterns according to category

CATEGORY	NO. OF CERTIFICATIONS AWARDED
A++	0
A+	2
A	103
B	5
C	0
D	0
E	0

The situation presented in Table II was expected (i.e. no certifications awarded to the less efficient categories).

In fact, because compliance with the system is voluntary, manufacturers/importers do not usually request labelling for less efficient categories.

This is not negative for the system; quite the contrary. Since so many companies and consumers complied with the system, the lack of certification of the said flushing cisterns will gradually lead to their removal from the market, thus contributing towards ANQIP's goals.

Table III presents, the categories defined in the Technical Specification ANQIP ETA 0806 for showers and shower systems.

It should be noted that shower systems and showers represent near 30% of the daily average of domestic water consumption in Portugal [17] [18] [19] [20].

At this level, efficiency reduces both water consumption and the energy consumption required for hot water production.

The classification of these devices considers the following:

- Shower heads (showers), individually;
- Shower taps equipped with a hose and a shower head or with a fixed shower head (shower systems).

For shower systems and showers, the model implemented considers the ideal usage (letter A) to represent a water usage of between 5,0 litres/minute and 7,2 litres/minute.

The A and A+ labels applied to shower heads with a discharge which is 5 l/min or less must bear the indication "Recommended for usage with thermostatic taps", due to the increased risk of scalding.

In products which can be regulated by the consumer, certification may be awarded on the basis of the most efficient position, as long as the criterion is clear to the consumer, without any risk of confusion, and it must be marked next to the label.

Due to the fact that discharge is dependent on residual pressure, the established reference residual pressure for all ratings and for the tests was 300 kPa, which represents the average pressure in Portugal and is the pressure selected by several recognised laboratories for various tests.

The taps for bathtubs were not rated, because water consumption in this case depends on the volume of the tub when full, and not on the device discharge.

Table III: Water efficiency ratings for the labeling of showers and shower systems [11]

Discharge (Q) (l/min)	Showers	Shower systems	Shower system with a thermostatic tap or an eco-stop function	Shower system with a thermostatic tap and an eco-stop function
$Q \leq 5$	A+	A+	A++ (1)	A++ (1)
$5.0 < Q \leq 7.2$	A	A	A+	A++
$7.2 < Q \leq 9.0$	B	B	A	A+
$9.0 < Q \leq 15.0$	C	C	B	A
$15.0 < Q \leq 30.0$	D	D	C	B
$30.0 < Q$	E	E	D	C

(1) The use of an eco-stop is not considered in these cases

Tables IV and V presents the categories defined in the Technical Specification ANQIP ETA 0808 for lavatory taps and kitchen taps.

Taps are the most common device, both in homes and in collective facilities. In an average home, there are at least 3 to 5 taps installed in the kitchen and bathrooms [1]. They are used frequently, and their usage is difficult to quantify and varies greatly in time and space. This variation also applies to the length of time of use, which can stretch from a few seconds to several minutes.

No specific reference is made to self-closing taps, because according to recent studies carried out in the United States of America, they do not lead to significant water savings since, although they might run for less time, the discharge is always at maximum level. The advantage of such taps lies in their safety aspect and not in water saving.

The case of self-closing taps with a sensor is similar. The advantage of these taps over traditional ones is that they are more hygienic, but they are no more efficient, usually.

On average, it is estimated that water from taps represents approximately 16% of consumption in homes in Portugal.

In the case of bathroom taps (in homes), the model which is currently being studied considers ideal usage (letter A) to be a level of water consumption of 2.0 l/minute, taking into account the studies performed and proposals made in countries where water efficiency labelling has already been implemented.

For kitchen taps, the model considers ideal usage (letter A) to be a level of water consumption of 4.0 l/minute.

Taps with an aerator are recommended for categories A++ and A+.

Kitchen taps with a discharge of under 4 litres per minute and bathroom taps with a discharge of under 2 litres per minute (in homes) must bear a label with an advisory note recommending that they be utilised only with an aerator.

In public areas, however, the usage of taps discharging a volume higher than or equal to 2 litres per minute might be advisable (usually letter B or above for basic models).

Table IV: Water efficiency ratings for the labelling of bathroom taps (in homes)

Discharge (l/min)	Bathroom taps	Bathroom taps with an aerator or an eco-stop function	Bathroom taps with an aerator and an eco-stop function
Q≤ 2.0	A	A+	A++
2.0 < Q ≤ 4.0	B	A	A+
4.0 < Q ≤ 6.0	C	B	A
6.0 < Q ≤ 8.0	D	C	B
8.0 < Q	E	D	C

Table V: Water efficiency ratings for the labelling of kitchen taps

Discharge (l/min)	Kitchen taps	Kitchen taps with an aerator or an eco-stop function	Kitchen taps with an aerator and an eco-stop function
Q ≤ 4.0	A	A+	A++
4.0 < Q ≤ 6.0	B	A	A+
6.0 < Q ≤ 8.0	C	B	A
8.0 < Q ≤ 10.0	D	C	B
10.0 < Q	E	D	C

III. Evaluation of the Impact of the Use of Efficient Products

ANQIP has developed a study to analyze and estimate water consumption reductions and corresponding energy savings in a typical house with efficient products (letter A), making a comparison with a house equipped with non-efficient products, which is a common occurrence in Portugal [1].

This study assumed an average occupancy of 2,7 persons per house, and can be easily transposed to the region that is the subject of the present study (the municipality of Aveiro).

Taking into account the accumulated time of usage or the usual number of uses per person, water and energy consumptions and costs were obtained as depicted in Table 6.

It was considered that a typical house should be equipped with showers, washbasins, WC flushing, sink dishwasher and washing machines.

With regard to water tariffs, the value adopted in Aveiro is currently 1,1 €/m3.

Regarding energy costs, and considering the use of electricity, the price in Portugal is about 0,12 €/kWh. For natural gas, the value is approximately the same. Note that these figures are "conservative", because VAT and fixed terms are not included.

Accordingly, in order to heat 1 m3 of water to 37ºC, 30 kWh of energy are required; 0,0036 €/l are thus spent using gas or electricity.

The Tables VI and VII show the results of the application of these values.

For washing machines and dishwashers, weighted average values were adopted from the catalogs of the manufacturers (1,20 kWh and 1,05 kWh per wash, respectively).

Table VI: Water and energy costs in a typical house with conventional products

Product	Total (l/day)	Water cost (0,0011 €/l)	Energy cost (0,0036 €/l)	Total cost (€/day) Water + Energy	Total cost (€/month) Water + Energy	Total cost (€/year) Water + Energy
Shower	121,5	0,134	0,437	0,571	17,13	208,42
Bathroom tap	64,8	0,071	0,233	0,304	9,12	110,96
Kitchen tap	60,0	0,066	0,216	0,282	8,46	102,93
Product	Total l/day	Water cost (0,0011 €/l)	Energy cost (€/per cycle)			
Flushing cisterns	145,8	0,160	-	0,160	4,80	58,40
Washing machine	90,0	0,099	0,140	0,239	7,17	87,24
Dishwasher	22,0	0,024	0,130	0,154	4,62	56,21
TOTAL	504,1	0,772	1,156	1,71	37,93	624,16

Table VII: Water and energy costs in a typical house with efficient products (letter "A")

Product	Total (l/day)	Water cost (0,0011 €/l)	Energy cost (0,0036 €/l)	Total cost (€/day) Water + Energy	Total cost (€/month) Water + Energy	Total cost (€/year) Water + Energy
Shower	81,0	0,089	0,292	0,381	11,43	139,07
Bathroom tap	19,4	0,021	0,070	0,091	2,73	33,22
Kitchen tap	18,0	0,020	0,065	0,085	2,55	31,03
Product	Total l/day	Water cost (0,0011 €/l)	Energy cost (€/per cycle)			
Flushing cisterns	97,2	0,107	-	0,107	3,21	39,06
Washing machine	45,0	0,050	0,071	0,121	3,63	44,17
Dishwasher	16,0	0,018	0,060	0,078	2,34	28,47
TOTAL	276,6	0,305	0,558	0,843	25,89	315,02

Analyzing these tables, it was concluded that the total estimated savings for a medium-sized house are extremely significant, amounting to approximately 45% (227,5 l/day = 83 m3/year) considering only water savings in volume, or 50%, considering the cost of water and energy (309 €/year per family).

The showers represent, in Portugal, near 30% of water consumption in buildings and the main consumption of sanitary hot water (SHW).

So, the Portuguese Government is planning to introduce the use of efficient products as a factor to consider for the energy certification of buildings.

Considering only these type of device, it is now possible to compare the savings obtained using efficient showers and showers systems (Table VIII), in comparison with conventional ones (Table IX).

Table VIII – Energy costs (sanitary hot water) in a house with conventional products

Convent. Products	Total consumpt. l/day	Energy cons. (0,03 kWh/l)	Energy cost (0,0036 €/l)	Total energy cost (€/ /month)	Annual energy consumpt. (kWh/year)	Energy annual cost (€/year)
Shower (family)	121,5	3,645	0,437	13,11	1330,64	159,51
Per person	45,0	1,350	0,162	4,86	492,83	59,13

Table IX– Energy costs (sanitary hot water) in a house with products in category "A"

Efficient Products	Total consumpt. l/day	Energy cons. (0,03 kWh/l)	Energy cost (0,0036 €/l)	Total energy cost (€/ /month)	Annual energy consumpt. (kWh/year)	Energy annual cost (€/year)
Shower (family)	81,0	2,43	0,292	8,75	886,00	106,43
Per person	30,0	0,90	0,108	3,24	328,15	39,42

As depicted in these tables, a saving of 33% per person (15 l/day = 5,5 m3/year) is achieved, corresponding to a decrease of about 445 kWh/year and family (or 165 kWh/year and person).

As the municipality of Aveiro has 73000 inhabitants (27000 homes), if these measures were applied to the whole population, the result would involve an energy saving of about 12x106 kWh/year.

This is not however the only saving obtained, because the reduction of water consumption in buildings implies a reduction of the volume abstracted treated and pumped, and also a reduction in the volume of treated and pumped wastewater.

In the municipality of Aveiro, energy consumption in the public network is 0,838 kWh/m3 for water supply, and 0,818 kWh/m3 for wastewater drainage and treatment.

Moreover, the percentage of water losses in the public water supply system of the municipality of Aveiro is almost 38%, i.e., for every m3 in the consumers' home, 1,38 m3 must be produced at the origin.

Regarding wastewater, it is estimated in Aveiro that approximately 90% of normal domestic water consumption reaches the sewers; the explanation for this is that some water consumption refers to expenditure deriving from garden watering, washing of pavements, etc.

However, the water saving obtained with efficient products corresponds to volumes that in general are going to be conducted to public sewers, and should thus in this case be considered 100%.

Returning to Tables 6 and 7, and considering these figures, it can be concluded that a saving of 83 m3/year per family implies a potential reduction in the production of drinking-water of 115 m3/year per family, i.e. a total of about 3,1x106 m3/year for the Aveiro municipality (considering 27000 homes). For wastewater, the value is 83 m3/year per family, i.e. a total reduction of about 2,24x106 m3/year.

Taking into account energy consumption per cubic meter, a saving of 2,6x106 kWh/year was obtained in the water supply system, and 1,8x106 kWh/year in the drainage and treatment system, representing a total saving of 4,4x106 kWh/year.

Considering, in addition, prior economy (Tables 8 and 9) in the heating of SHW in buildings (only for showers), a very significant value of 16,4x106 kWh/year is obtained for global potential saving.

IV. Energy saving and reduction of GHG

Savings in the public system of water supply and wastewater are thus 4,4x106 kWh/year, as determined previously.

The type of energy used in public systems is electrical power.

In Portugal, electric power is produced from a mix of technologies, including hydro, coal, wind, nuclear, natural gas and others, involving also importation (Figure 5).

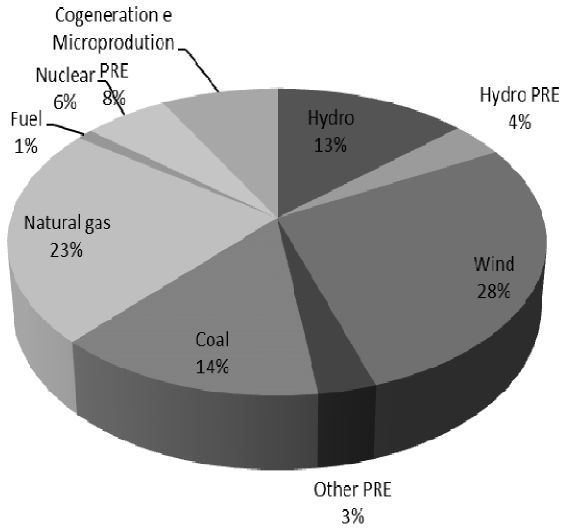

Fig. 5: Electricity origin in Portugal

The most significant contribution to GHG emissions in Portugal, in the energy sector, corresponds to CO2.

According to the Portuguese Energy operator (EDP), emissions of CO_2 are weighted to 369,23 g/kWh of electricity.

Other gases such as SO_2 (1,60 g/kWh) or NOx (1,06 g/kWh) have a negligible contribution.

In this scenario, it is easy to conclude that energy savings in these systems allow for a reduction in CO_2 emissions close to 1625 tons/year.

In building systems, the energy source mostly used in the Aveiro region for heating SHW is LPG (propane or butane), although electricity is also significant. More recently, solar energy and natural gas have also undergone increasing applications.

There are no known studies that examine the corresponding percentages for each of these sources in the region of Aveiro.

So, this paper takes as a reference the LPG, because its emissions are lower than those of electricity and other sources are not yet prevalent.

For LPG, CO_2 emissions of around 248 g/kWh can be considered.

Taking into account the estimated savings on heating SHW, according to Tables IV and V, a reduction in CO_2 emissions of almost 3000 tons/year can be obtained.

In summary, it can be argued that the widespread implementation of water efficiency measures can lead, for a population of around 70000 inhabitants, to a reduction of GHG emissions of 4625 tons per year, meaning about 66 kg CO_2 per inhabitant and year.

V. Conclusion

Efficient water use is an environmental priority in all countries of the world. However, in some countries, such as Portugal, the development of measures in this field has become urgent because the availability of water could be significantly reduced in the short or medium term.

Special attention must therefore be given to the use of efficient products, and consumers must be able to identify these efficient products, leading to the need for a labelling system which is easy to understand.

In Portugal, ANQIP, a non-profit NGO, has decided to launch a voluntary water efficiency labelling system for products, similar to those developed in other countries.

Regarding the sustainability rating systems for buildings, whose application is increasing today, it should be noted that the efficient use of water should be reflected not only in relation to water parameter, but also in relation to the energy.

In Portugal, the use of efficient products, can provide a saving close to 45% in water consumption, but should be reflected not only in relation to the parameter of water, but also in relation to energy efficiency.

Indeed, an estimate of savings through the use of efficient products in housing in Portugal (about 10 millions of inhabitants) could reach more than 1,15 billion Euros per year, considering water and energy (309 €/year and family).

A study conducted in the city of Aveiro (in the center of Portugal), with a population of 70000 inhabitants, has revealed that the potential savings in terms of energy spending in the urban water cycle and in the heating of water in the residential sector, with the use of efficient products, can afford a reduction in CO_2 emissions of about 4625 tons/year, i.e. about 66 kg CO_2 per inhabitant and year.

These results underscore the importance of water efficiency in buildings, not only as a means for rational use of water, but also for its significant contribution to the energy efficiency of buildings and reducing the emission of greenhouse gases.

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