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Feasibility Study of Water Saving Measures in Higher Education Buildings: A Case Study of the University of Aveiro

A. Silva-Afonso[1,2], C. Pimentel-Rodrigues[2], I. Meireles[1*] and V. Sousa[3]

[1]Department of Civil Engineering, RISCO, University of Aveiro, Campus Universitario de Santiago, 3810-193 Aveiro, Portugal.
[2]ANQIP (Portuguese Association for Quality and Efficiency in Building Services), Operacional Centre at the University of Aveiro, Campus Universitario de Santiago, 3810-193 Aveiro, Portugal.
[3]Department of Civil Engineering, Architecture and GeoResources, CERis/ICIST, Instituto Superior Tecnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisbon, Portugal.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Evaluate the water savings potential and financial viability of water saving measures in in higher education buildings

Study Design: The study follows an observational approach to characterize the current performance of existing buildings in terms of water consumption and evaluate the potential for increasing water efficiency.

Place and Duration of Study: Buildings of the Chemistry, Civil Engineering, Communication and Arts, Environment and Planning, and Mathematics Departments and the Pedagogic Complex of the University of Aveiro, Portugal, between May 2013 and July 2014.

Methodology: Water efficiency audits complemented with limited monitoring and simulation of investment scenarios.

Results: The payback period of the investment required to implement the measures was found to be less than 7 months in all the cases, with average water savings potential of 28% and ranging from 9% up to 37%.

Conclusion: Water savings measures are attractive solutions for university buildings in Portugal, particularly the older ones, because of their environmental and financial performance and the low investment required.

**Corresponding author: E-mail: imeireles@ua.pt;*
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1. INTRODUCTION

Since their genesis with the publication of the Brutland Report [1], the concepts of "sustainability" and "sustainable development" have become increasingly present in the majority of human endeavours. In particular, the environmental dimension of the sustainability concept became an issue of deep global concern throughout the latter half of the 20th century and continued into this new millennium. Amongst the various environmental issues, fresh water shortages and pollution are two of the most critical global problems, furthermore with the growth in population and demands, and the effects of global warming scenarios. Many organizations and conferences concerning water resource policy and issues have reached the consensus that water shortages may cause war in the 21st century [2].

The substantial water consumption increment recorded during the last century was due to an increase in both the population and water demand for various purposes [3]. This was not uniform throughout the globe, with the more developed countries accounting for the biggest share. In addition, making water available for consumption requires significant amounts of other resources to build, maintain, operate and rehabilitate/replace the supporting infrastructures [4-6]. Consequently, even in countries with favourable conditions in terms of water demand and availability ratio, there is an interest in evaluating and exploring alternatives for improving the efficient use of water resources.

In order to optimize water management, two main categories of solutions can be identified: i) efficient water use; and ii) exploitation of alternative water sources. At a building level, the former includes solutions that promote changing consumption habits (non-structural solutions) and/or the adoption of lower consumption devices (structural solutions), whereas the latter includes exploring alternative sources of water.

These vectors underpinned the stabilization or even reduction of the water use over the last years in various sectors (urban; industry; agriculture) of the developed countries due to the combined implementation of structural (e.g., use of alternative water sources; reduction of water losses; use of more efficient equipment and fixture) and non-structural (e.g., information and education campaigns; consumption based water charges) measures [7-8].

Nonetheless, the per capita water consumption in developed countries is still extremely high and water is considered to be a key at-risk resource. Improved water management is essential to tackle the water challenge due to the economic advantage of dealing with it by optimizing the use of available resources rather than by increasing the volume of supplied water [9]. The advantages of an optimized water demand management are not restricted to economy, but extend to the environment and the society, being considered the most sustainable option [10]. For instance, reduction of water use will contribute to reduce water-related energy use and, consequently, the associated GHG emissions [11-13].

In Portugal, urban consumption represents only 8% of the total volume of water consumed, but its cost accounts for 48% of the total expenses on water supply. Within urban consumption, water consumption in buildings represents the largest share [14-15]. In Portugal, despite the various initiatives of ANQIP (Portuguese Association for Quality and Efficiency in Building Services), a Portuguese non-governmental organization dedicated to the promotion of quality and efficiency in water, wastewater and stormwater systems in buildings, very few studies have been published in international journals dealing with the Portuguese context [16-19]. Following previous studies by the authors [20], the present study evaluates the viability of system optimization and water conservation measures in the buildings of the Chemistry, Civil Engineering, Communication and Arts, Environment and Planning and Mathematics Departments and the Pedagogic Complex of the University of Aveiro, Portugal. Given the few limited studies on water end-use consumption in Portugal and, to the best of our knowledge, the inexistence of any for university buildings, a monitoring campaign was carried out to characterize the water end-use pattern in the Civil Engineering Department building.

2. WATER CONSUMPTION

Water consumption depends on economic, social and environmental variables both at an individual or group level [21]. Within the scope of the present paper, it was considered that a group represents a community or society sharing common features (e.g., socio-economic, cultural, educational) and responding similarly to the variables affecting water consumption. Complementarily, it is assumed that an individual consumer can be a single individual or a group that share the same facility and/or activity. This option introduces some cross effects, since a facility can be used by a group of individuals from different community or society backgrounds, but allows to break the analysis into the overall water performance of a community or society.

At country, region or community level, the water consumption depends on factors such as the development level (e.g., underdeveloped, developing or developed country; technical innovation), the weather and climate (direct - temperature; indirect - evapotranspiration and precipitation amount), the type (e.g., rural, urban) and the characteristics (e.g., population; housing type) of the community, the activities (e.g., tourism; industry; services) and technology (e.g., equipment; fixture), the water availability (e.g., losses; pressure; service level; sources; treatment required) and policies (e.g., pricing; regulations), amongst others [22-24].

An important indirect factor that can be used to characterize water consumption at a country, region or community level is the economy. According to the OECD [25], the economic growth was one of the most important factors underlying the water consumption increase in the last decades since it allowed an improvement in terms of the buildings served by public water supply and wastewater drainage systems and enhanced access to water consuming appliances (e.g., dishwasher; washing machines).

Using this as a starting point, Flörke and Alcamo [26] related the average domestic water consumption (DWC, in cubic meters per person per year) in the European countries with the corresponding Gross Domestic Product (GDP, in Euro-Base 2000 per capita) obtaining high correlations in most cases. For Portugal, these authors obtained an index of agreement of 0.73 in the relation between DWC and GDP using a sigmoid function. However, the validity of this type of relationships is limited to a development stage of the community or society. For instance, the water consumption in Portugal has stabilized or decreased since 2000 (Fig. 1), despite the increase of the GDP until 2009. The year of 2009 was extremely hot, with the driest spring since 1931, 3 heat waves in the summer and two more in the autumn, which may help to explain the water consumption [27]. Furthermore, the economic crisis since 2008 resulted in a decrease of the GDP which was not reflected on a decrease on water consumption. This may be partially due to the fact that the level of service was already high in 2000 (90%) and increased to 96%. Since the major water supply infrastructures already existed in 2000, this increase resulted from small investments and the migration of part of the rural population without public water supply to the large urban centres where the service level is virtually 100%. This maturity in the water supply system allowed a shift in priorities from increasing the service level to improving the service performance, in particular, reducing losses and using the water more efficiently.

Despite the decreasing trend of the water consumption with the water price [29], the dispersion of the water consumption for the lower water prices is very significant. For residential buildings, recent research demonstrates that, in most cases, water demand is largely price inelastic because of its low relative cost when compared to other life essential goods [30-32]. Nevertheless, water price is invariably a statistically significant determinant in water consumption studies and there are several examples demonstrating a strong influence, but the reported results are extremely variable [24] and, thus, must be considered highly context specific. In addition, the effect of water price depends on the interaction with several other factors, being the income the most relevant. In fact, water demand is found to be most often elastic regarding income and as the income increases the water demand becomes even less more inelastic regarding water price [24].

Within the scope of the present paper, it was considered that an individual consumer can be a single individual or a group that share the same facility and/or activity (e.g., household, school). As such, the characteristics of the group (e.g., family; staff; students) and the nature of the activity (e.g., domestic; academic) will determine the water consumption. No studies were found dealing with the determinants for water consumption in university buildings at an individual consumer level, but in residential buildings the water consumption is influenced by the occupants and the house characteristics. The former include factors such as the number, the age, the education levels and the attitudes,

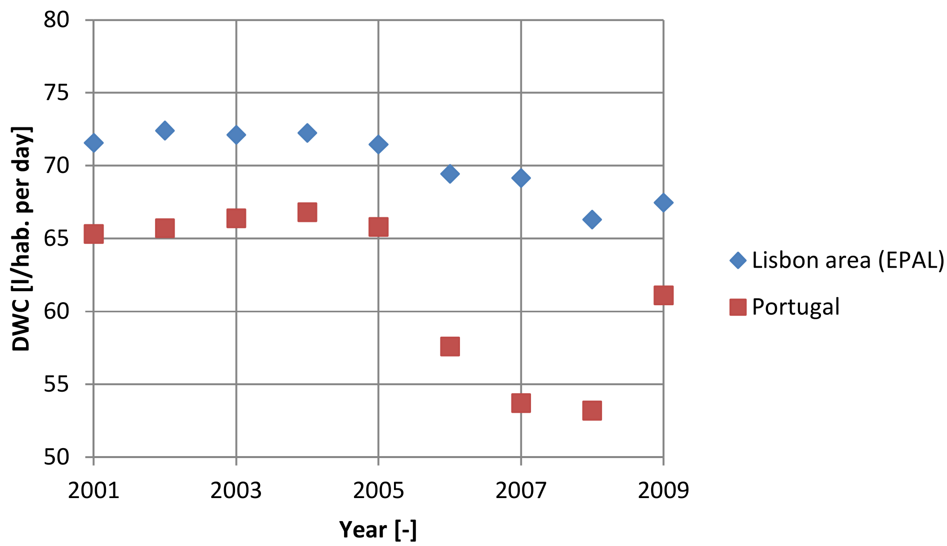

Fig. 1. Evolution of the domestic water consumption (DWC) in Lisbon area and in Portugal between 2001 and 2009 [28]

beliefs and behaviours of the occupants, and the latter include the lot size of properties, the number of bathrooms, the existence and size of the garden, the existence of a swimming pool and the efficiency of water consuming devices (i.e. clothes washers, shower heads, tap fittings, dishwashers and toilets, irrigation solutions) [24,26,33-36]. Since in university buildings the users do not pay for the water directly, these factors may gain relevance and will be analyzed in detail in future studies. Preliminary results indicate that the water consumption behaviour between staff and students and between men and women are distinct.

3. PRESENTATION OF CASE

According to EPA [37], approximately 6% of the total water used in commercial and institutional facilities in the United States takes place in educational facilities. EPA [31] and Meireles et al. [38] indicate that, in the United States and in Portugal, respectively, the main consumption of water in education facilities takes place in the restrooms. In order to achieve campus sustainability, several universities already implemented environmental management systems to improve their water efficiency [39].

This situation, along with the expected scenarios of water stress and scarcity in the near future, justify the development of new strategies for water conservation in universities, as part of an environmental management system, and are the motivation of the present study, focused on the study of water saving measures in university restrooms.

The Santiago campus of the University of Aveiro extends for an area of over 460 000 m^2 and is composed by 42 buildings. Each department has its separate building and there are also individual buildings for other services in the university (e.g., library, sports, central administration, student's dormitory, canteen).

3.1 University of Aveiro Buildings

The buildings of the Chemistry (built in 1993), Civil Engineering (built in 1997), Communication and Arts (built in 1996), Environment and Planning (built in 1979), and Mathematics (built in 1993) Departments and the Pedagogic Complex (built in 2000) of the University of Aveiro were chosen for the present study (Fig. 2). Since the focus of the study was to capture the behaviour of the students, the administrative buildings and sport facilities were ruled out since they have a much distinct type of occupation. The buildings cover a wide range of construction dates (from 1979 to 2000) and the two major groups of programs in the University: i) exact sciences and engineering; and ii) social sciences. The range of construction dates relates to the technology of the water appliances and fixtures.

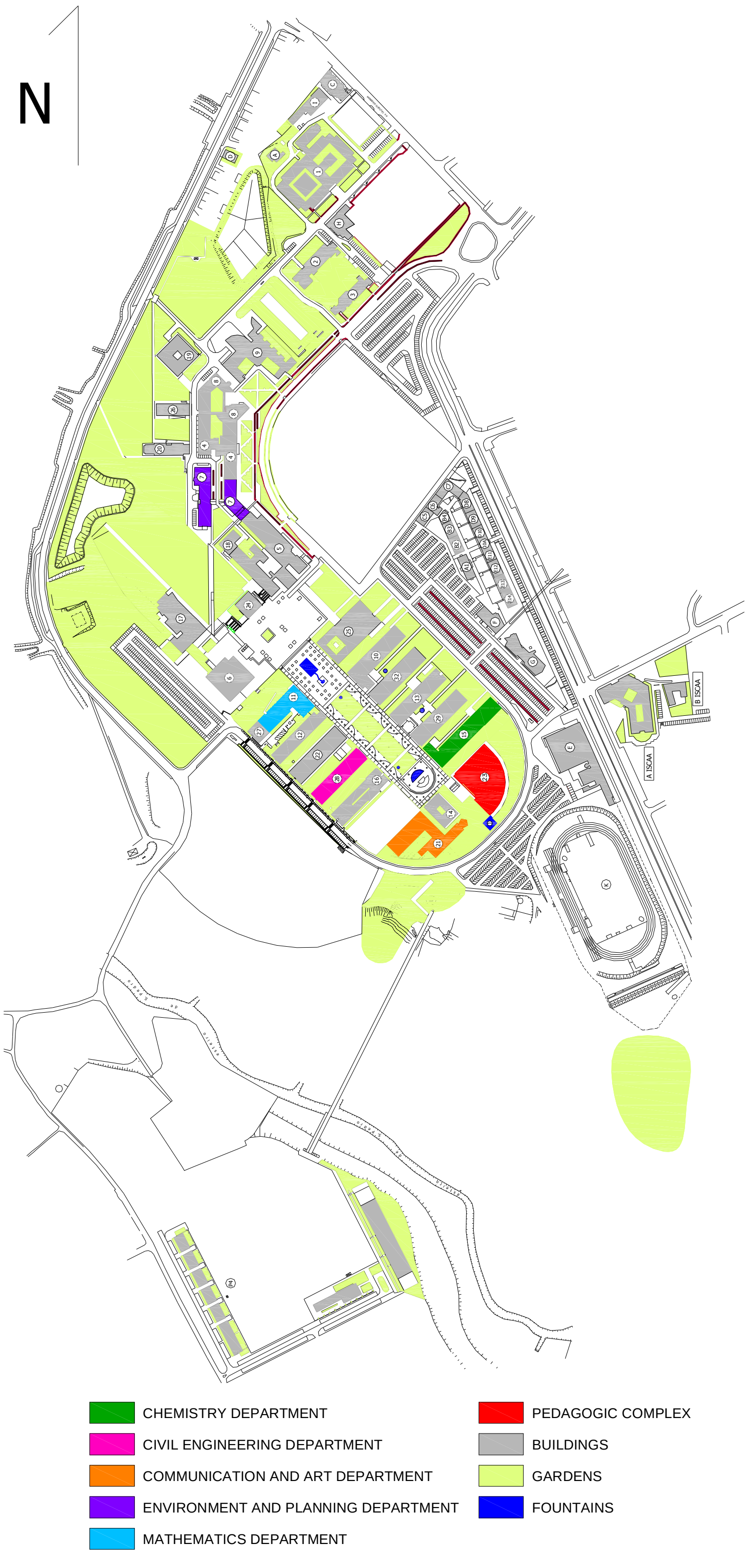

Fig. 2. Santiago campus of the University of Aveiro layout with location of the audited buildings

3.2 Methodology and Base Information

The first stage of the audits was a detailed visual inspection of the facilities to identify the fixtures characteristics (e.g., brand; type) and conditions (e.g., defects/malfunctions). Afterwards, measurements were made to determine the discharges/volumes: i) taps discharges were measured either directly, using a flow meter, or indirectly, by measuring the time to fill a container, depending on the maximum discharge; ii) flushing cisterns water consumption were measured by determining the flushed volume; and iii) urinal flushing volumes were directly measured, in the Civil Engineering (CED) department building, or, in the Chemistry (CD), Communication and Arts (CAD), Environment and Planning (EPD) and Mathematics (MD) departments buildings and the Pedagogic Complex (PC) building, considered equal to 2.5 l, which corresponds to the average flush volume of 258 urinals measured in an audit to 26 public buildings of the region of Aveiro. The results are presented in Table 1.

Consumption patterns were determined using a hybrid approach. The detailed study performed in the Civil Engineering Department building [38] was used as the base to determine the distribution of water per type of use (in restrooms, in laboratories, cleaning and others) and the number of uses per type of fixture, as a function of the building total water use. The extrapolation of the results to the remaining buildings was complemented with limited direct observation and information from hourly water consumption records, users and managers.

In the Civil Engineering Department, 70% of the water is consumed in the restrooms. According to the characteristics of the buildings, types of use and occupants the average restroom water consumption in the other studied buildings ranged from 70% to 96% of the total water use, with exception of the Chemistry Department where, due to the large number of laboratories and highly intensive laboratory activities, only 30% of the water consumed in the building is allocated to restroom usage (Table 2).

Due to the large amount of water consumed in the laboratories of the Chemistry Department building, this study also focused on the water consumed in that particular activity. In this

Table 1. Number of consumption points and consumption per use in each building

Consumption points and rate	Buildings					
	PC	**EPD**	**CAD**	**CD**	**MD**	**CED**
Number of consumption points						
Restrooms						
Washbasins	21	15	43	15	22	22
Toilets	23	15	32	17	31	17
Urinals	12	12	18	6	7	14
Laboratories						
Sinks				39		
Water consumption per use						
Restrooms (l)						
Washbasins	1.7	4.3	1.5	5.0	3.6	2.4
Toilets	6.0	7.8	9.3	12.0	5.8	7.2
Urinals	2.5	2.5	2.5	2.5	2.5	1.5
Laboratories (l/min)						
Sinks				15		

Table 2. Annual water consumption

Water consumption (m^3/year)	Buildings					
	PC	**EPD**	**CAD**	**CD**	**MD**	**CED**
Total	1679	497	1007	7784	535	636
Restrooms	1175	398	967	2335	514	445
Washbasins	361	194	217	1013	256	167
Toilets	603	160	612	1125	189	236
Urinals	211	44	138	197	69	42
Laboratories and cleaning	504	99	40	5449	21	191
Sinks				2335		

Table 3. Annual number of uses per type of fixture

Fixtures	Buildings					
	PC	EPD	CAD	CD	MD	CED
Restrooms (number of uses x 1000)						
Washbasins	217	45	142	203	71	71
Toilets	100	21	66	94	33	33
Urinals	84	17	55	79	27	27
Laboratories (minutes of use x 1000)						
Sinks				156		

regard, the water consumed in these laboratories was divided in water consumed in activities where the volume of water is relevant and in activities where the volume of water is irrelevant. For instance, to fill a bucket is an activity where the volume of water is relevant and for the activity of washing hands the volume of water is irrelevant. According to the characteristics of the lab activity, a proportion of 4:3 was selected based on staff sensibility.

The water volume determined for each building based on the previous information and considering a relation between occupancy and the total number of uses was compared with the water consumption records and the distribution for each type of use was adjusted in proportion (Table 3 above).

Given that most consumption takes place at faucets and toilets, only water efficient solutions for these fixtures were evaluated. In addition, the financial appraisal of this type of solutions is always a local problem because the cost, both of the water and the solutions, can vary significantly. Considering the water efficiency labelling scheme developed by ANQIP [40], the discharge of water efficient fixtures and their corresponding cost (including the installation) were obtained from manufacturers with factories in the Aveiro region.

With the results from audits as a basis, it was possible to identify potential water efficiency interventions. Since the majority of the consumption in most buildings was in the restrooms, the measures considered in the scope of this study were mostly focused on reducing the domestic water consumption type in the buildings. The evaluated water efficiency measures consisted of the installation of discharge reducers (cost: 9.50€) in the faucets, capable of reducing the water consumption per use in the bathroom to 1.0 l and the discharge in the laboratory sinks to 6 l/min; and the installation of toilet flushing volume reducer bags (cost: 5.00€) in the toilets cisterns, capable of reducing the water consumption per use to 6 l. In the present paper it was assumed that these interventions would not change the use pattern, for instance due to decreased comfort in the case of the discharge reducers or the cleaning efficiency in the case of the volume reducer bags. The validity of this assumption is presently being studied in the sequence of this research, in particular the relation between comfort and use pattern of the water faucets. Regarding the volume reducer bags, the international and national experience is that it is possible to reduce from 9 l to 6 l without compromising the cleaning efficiency of the toilet flushing. However, this discharge reduction may have an impact on the public wastewater systems, both in the network and the wastewater treatment plants, but that's outside of the scope of this research at this point.

4. RESULTS AND DISCUSSION

The water savings, totalling to around 3 700 m^3 per year, are presented in Table 4 and were determined based on the difference between the water consumption with and without the water efficiency measures and the use of each fixture. Considering the average total water consumption presented in Table 2, the water saving potential represents a reduction ranging from 9% in the Pedagogic Complex building to 37% in the Environment and Planning Department, with an average of 28% for the entire sample of studied buildings.

Analysing the water-energy nexus, the water savings will also contribute to reduce energy consumption and CO_2 emissions, since, energy is consumed: i) in buildings, to pressurize water and heat sanitary hot water, and ii) in public systems, in the catchment, pumping and treatment of water and wastewater. In the present study, Aveiro Public Water Systems data has been adopted to quantify energy and carbon emissions associated with water consumption. The amount of energy required to treat and supply one cubic meter of water and to transport and treat one meter cube of wastewater has been taken as 0.838 kWh and of 0.818 kWh, respectively [41]. 1 Kwh of energy consumption was estimated to generate CO_2 emissions of 361 g [42]. The energy consumed in buildings was not taken into consideration since none of them needs extra pressurization for hot water. Combining this unit energy consumption with the water savings from Table 2, an estimated total of 6 MWh per year could be saved in the analysed 6 buildings (Table 5), which corresponds to an average reduction of over 2 tons on CO_2 emissions per year (Table 6).

Table 4. Water savings potential

Water savings (m^3/per year)	Buildings					
	PC	**EPD**	**CAD**	**CD**	**MD**	**CED**
Restrooms						
Washbasins	145	149	76	810	185	96
Toilets		36	218	563		40
Urinals						
Laboratories						
Sinks				1401		

Table 5. Energy savings potential

Energy savings (kWh/year)	Buildings					
	PC	**EPD**	**CAD**	**CD**	**MD**	**CED**
Restrooms						
Washbasins	240	247	125	1342	307	160
Toilets	0	60	362	932	0	67
Urinals	0	0	0	0	0	0
Laboratories						
Sinks				2320		

Table 6. CO_2 emissions reduction potential

CO_2 reductions (kg of CO_2/year)	Buildings					
	PC	**EPD**	**CAD**	**CD**	**MD**	**CED**
Restrooms						
Washbasins	86	89	45	484	111	58
Toilets	0	22	131	336	0	24
Urinals	0	0	0	0	0	0
Laboratories						
Sinks				838		

Table 7. Financial appraisal potential

Financial appraisal	Buildings					
	PC	**EPD**	**CAD**	**CD**	**MD**	**CED**
Investment (€)						
Restrooms						
Washbasins	200	143	409	143	209	209
Toilets		75	160	85		85
Urinals						
Laboratories						
Sinks				371		
Savings (€/per year)						
Restrooms						
Washbasins	542	559	283	3038	695	361
Toilets		136	819	2110		152
Urinals						
Laboratories						
Sinks				5253		
Payback period (months)	4.4	3.8	6.2	0.7	3.6	6.9

Since the cost of the water from the public network is only of 3.75 €/m^3, the yearly saved amount of money is not very significant in most cases. Nevertheless, given the low investment cost of the water efficient measures, they are still highly viable in financial terms (Table 7). The low payback period (less than 7 months for every building) and the low investment (less than 600€ in each building) makes it a very attractive investment in terms of relative financial performance.

5. CONCLUSIONS AND GENERAL REMARKS

The study shows that investment in water efficiency, namely in water efficient fixtures, for the case study has the potential to be highly viable, both in financial and environmental terms. In fact, the low payback period and low investment indicate that investment in water efficient solutions is a very attractive and achievable option. In addition, considering the long life cycle of these buildings, the total savings may be significant depending on the building scale. For the case study, considering a 10 year period and a discount rate of 3% leads to the conclusion that the investment in water efficiency measures of less than 2 100 € for the 6 studied buildings yields a net present value of almost 117 000 €. Furthermore, the environmental benefits are far more relevant if the climate changes scenarios for the Mediterranean region are taken into consideration. In fact, despite the stabilization or even reduction in both population and per capita water consumption witnessed in the last years and forecasted for the future, the changes in the hydrologic patterns predicted for Portugal (more extreme events and slightly drier climate) may induce significant water stress. As such, in addition to the financial and environmental benefits of water efficiency, there is also an increased resilience to climate changes. Considering the characteristics of Portugal, in particular its small size, the cultural and behavioural homogeneity, and the concentration of the population along the west coast, north of Lisbon, where the climate is very similar, it is reasonable to assume that investing in water efficiency is viable in most university buildings.

As expected, the most recent building presents the lowest saving potential with the installation of water efficient fixtures, since it already has the most efficient fixtures amongst the audited buildings. Also, it is interesting to notice that the Civil Engineering Department building presents the next lowest potential, despite the construction date being similar to the buildings presenting the highest potential. This may be due to some behaviour change resulting from both the topics lectured and the works carried out in the topic of water efficiency in buildings by several students, both in classes assignments and in master theses.

Considering the studied buildings representative of the classes and departments buildings of the University of Aveiro, if expanded to all buildings, the presented water efficiency measures would correspond to an annual total saving of 11 x 10^3 m^3 of water, 18 MWh of energy and 7 tons of CO_2 emissions. It should be noted that this is a rather rough estimate since the potential savings depend on several factors, including the construction year of the building (Fig. 3). The values would increase significantly if the measures were extended to the other buildings of the campus, especially to those where sanitary hot water is used (e.g., residences, sports buildings, kindergartens, coffee shops, canteens and restaurants).

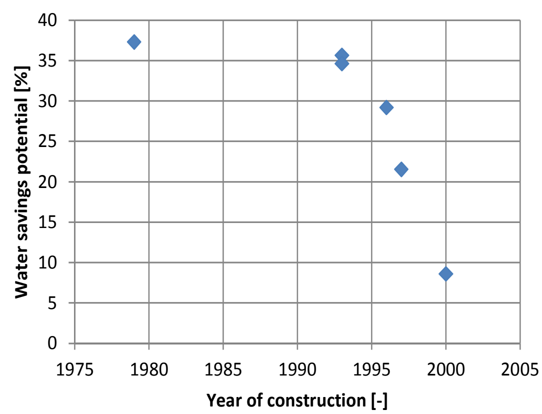

Fig. 3. Relation between the building's construction year and the water savings potential

Despite the financial viability, environmental benefits and the low investment required, the stringent budget limitations faced by the majority of the Portuguese universities limit the investment capability. As a consequence, urgent investments and investments that have higher total direct savings potential or more external financial support are considered a priority by the university management.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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