A4 - OPTIMIZING WATER CONSUMPTION IN BUILDINGS. A STUDY ON THE ALTERNATIVES TO POTABLE WATER SUPPLY

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Abstract

To preserve and maintain water resources for future generations, measures to reduce water consumption such as encouraging changes on people's habits, implementation of efficient equipment and alternatives to potable water supply, including rainwater harvesting and greywater reuse systems, have to be taken. Doubts and insecurity about the performance, potential water savings, investment costs and payback that can be expected from installations of water saving and reutilization, are still a barrier to their further development and full integration on urban water supply systems.

This article presents a study on the implementation of rainwater harvesting and greywater reuse systems in different types of building, based on a decision support tool prepared to size the collection tank volume, analyze the performance in terms of potable and non-potable water consumption and calculate investment costs and the expected payback time.

This study shows that rainwater harvesting and greywater reuse systems promote a significant reduction on potable water consumption and are more profitable in large buildings comparing with smaller ones having lower non-potable water consumptions. The specific costs (the installation cost divided by the volume of non-potable water consumed) of larger systems are lower and the payback time is shorter.

Keywords

Sustainable water consumption; rainwater; greywater; decision support tool.

1 Introduction

In spite of significant efforts taken on environmental conservation, the way people use water nowadays does not consent the sustainability of water resources. The rising demand for potable water has led to over exploitation on fresh surface and ground water. As a consequence, stress, and restrictions on water supply have become a reality in many countries (European Environment Agency, 2009).

The impacts resulting from anthropogenic activity on the environment have been affecting water cycle over the years. In urban areas the main problems are the increase of potable water demand, discharges of wastewater, reduction on water infiltration to the groundwater aquifers and evapotranspiration, increasing the surface runoff and pollution (Naji, Lustig, 2006).

To preserve and maintain water resources for future generations there must be a reduction on water consumption, by the increase of efficiency, promotion of water saving measures and to reuse as an alternative resource (Friedler *et al.,* 2005). To achieve these goals, it is necessary to encourage changes on people's habits and implement efficient equipments and alternative water supply to non-potable purposes, such as rainwater harvesting and greywater reuse. These measures will have not only environmental benefits but also economic implications. The expected decrease on potable water demand will be reflected in consumer's water bills and in the costs of public wastewater and rainwater drainage infrastructures and treatment. Also with the decrease on potable water demand, in the future public main water supply, sewerage and rainwater systems may be smaller, less expensive to build and easier to maintain.

Some insecurity about the performance, potential water savings, investment costs and payback time that can be expected from rainwater harvesting and greywater reuse systems, are still a barrier to their further development and full integration on urban water supply systems. In this article a study on the implementation of such systems in different existing buildings is presented. The main objective is to evaluate the benefits and feasibility of them through a 10 years operation simulation. The study was based on a developed decision support tool: SAPRA (the initials for the portuguese translation of software to size and analyze rainwater harvesting and greywater reuse systems in buildings), which assesses the system performance for different configurations and simulation periods.

The analysis made by SAPRA is processed in two modules (Figure 1). The first module calculates a recommended volume for the collection tank and the water consumption performance for the provided tank size, or for any other volume that the user might prefer. This calculation is made in accordance to the building type and location (and consequent daily rainfall values recorded on the area throughout the selected simulation period), number of occupants, purposes to supply with non-potable water, collection area and daily greywater production.

If the analyzed system is a rainwater harvesting one, the program uses the *Maximum Rainwater Used* approach to calculate the volume of the collection tank (Mierzwa *et al.*, 2007). This method provides the minimum tank volume from which there is no increment on the volume of rainwater used on non-potable purposes. If the system is a greywater reuse or a mixed one (rainwater and greywater), to ensure the recycled water quality and once there is generally a ready supply of untreated greywater, the program restricts the tank volume to the daily non-potable water demand. This condition is in accordance with the *British Standard for Greywater Systems* (BSI, 2010) and *fbr – Information Sheet H201* about Greywater Recycling in Germany (Fachvereinigung Betriebs- und Regenwassernutzung e.V., 2005). In a mixed system, if greywater produced is not enough to supply the non-potable water demand, a bigger collection volume might be installed (BSI, 2010).

The second module of SAPRA analyses the economic feasibility of the proposed system, comparing the investment costs and the reduction on water bill, resulting the expected payback time. To the analysis, the program requires some inputs for each case study, like the plumbing materials and extensions, pumping head, the type of the collection tank and other expected costs.

For the calculations on both modules, the program has a database with values required for the simulation process, like the daily rainfall values for each region on a maximum 10 years registration, obtained from the Portuguese National Water Institute monitoring network (INAG, 2010). There are also suggested values for water demand and breakdown water consumption ratios on dwellings, residential buildings, commercial and office/public buildings which are described on Table 1. The database also provides values for water demand for irrigation, water prices and costs for plumbing materials, pumps, and treatment equipments.

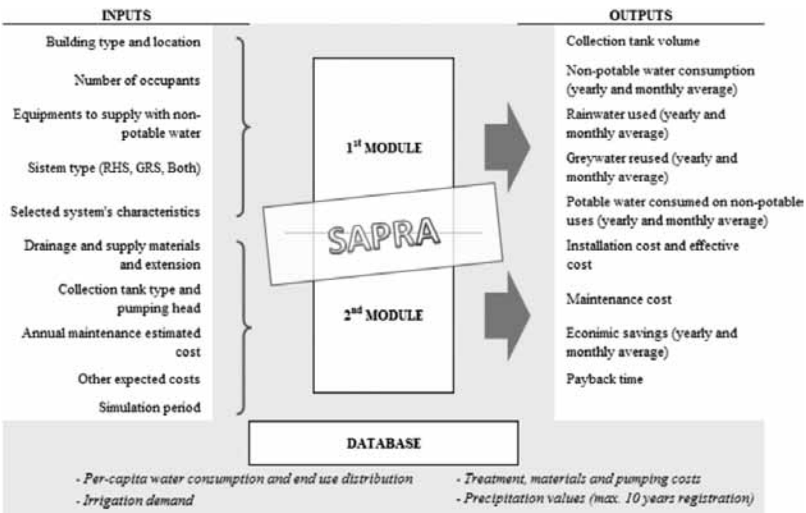

Fig. 1: Comparison of runoff hydrographs of the scenarios pre and post development, and also after the implementation of LID solutions.

Table 1 - Water demand values and breakdown water consumption ratios presented on SAPRA database.

Per-capita water consumption [1] (l/person/day)			End use distribution					
			Potable			Non-potable		
	Dwellings	Resid. buildings		Dwellings [2]	Resid. buildings [2]		Dwellings [2]	Resid. buildings [2]
Mon	88	83	**Showers/ Bath tubes**	31,0%	36,0%	**Toilets**	28,0%	30,0%
Tue	85	79	**Washing basins**	10,0%	9,0%	**Pavement washing**	5,0%	2,0%
Wed	84	81	**Bidet**	1,0%	1,0%	**Irrigation**	7,0%	-
Thu	106	83	**Kitchen sinks**	5,0%	4,0%	**Washing machine**	8,0%	9,0%
Fri	102	79	**Dishwasher**	2,0%	2,0%			
Sat	138	95						
Sun	114	88						
Per-capita water consumption [1] (l/person/day)			**End use distribution**					
			Potable			**Non-potable**		
	Commerc. buildings	Office / public buildings		Commerc. buildings [3]	Office / public buildings [4]		Commerc. buildings [3]	Office / public buildings [4]
Mon	5,69	33	**Tenants**	43,0%	-	**Cooling towers**	23,0%	31,0%
Tue	5,65	36,5	**Washing basins & showers**	2,0%	17,0%	**Toilets**	16,8%	27,1%
Wed	5,58	37,6	**Canteens**	-	5,7%	**Urinols**	4,2%	12,6%
Thu	5,67	37,4				**Irrigation**	9,0%	6,0%
Fri	5,91	34				**Pavement washing**	2,0%	0,6%
Sat	6,73	4						
Sun	6,3	3,9						

[1] (Santos, 2010b)
[2] Addapted form Almeida *et al* (2001)
[3] (Santos, 2010a)
[4] Addapted form Friedler and Alfiya (2010)

The implementation of rainwater harvesting and greywater reuse systems is an important measure to promote sustainable water consumption in urban areas, particularly in buildings. It is important to study carefully different solutions for each system, once the investment costs are significant. In this scope, a decision support tool is essential to assess different solutions and optimize them, providing the expected economic and environmental benefits. Six different case studies were analyzed in this study, with a SAPRA simulation to assess their performance and feasibility. Results may help to understand which performances and benefits can be expected.

2 Studied buildings

In order to achieve the proposed goals for this work, different case studies of new and existing buildings with different uses and dimensions were studied using SAPRA. The most important characteristics of each one, needed for the intended simulations are presented below.

2.1 Dwelling

In this study a dwelling located in Porto, Portugal, that is being renovated was analyzed. New owners wish to collect rainwater and use it to supply toilets, irrigation and a washing machine (Figure 2).

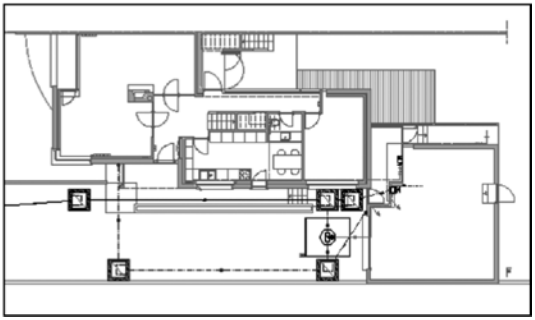

Fig. 2: Comparison of runoff hydrographs of the scenarios pre and post development, and also after the implementation of LID solutions.

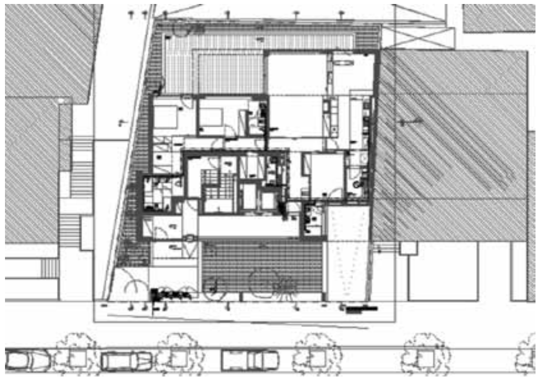

Fig. 3: Layout of the studied residential building.

The house will have four occupants and the collection area (only the roof) has around 130 m^2 of area. The per capita consumption values for the different days of the week were the ones presented on SAPRA database (Table 1). The registered rainfall values and the water prices were the ones corresponding to Porto city.
Due to the house configuration and existing infrastructures, it is planned to use a compact rainwater harvesting system with an underground tank and a control system that will manage the pump and the backup supply from potable water system in which prevention of indirect cross-connection will be provided.

2.2 Residential Building
The studied residential building (Figure 3) is also located in Porto, Portugal. It is a recent building with six residential floors and three underground floors for parking, having six luxury apartments and a total of 30 inhabitants are expected. Also for this case, the per capita values used were the ones suggested by the program.

Figure 3 – Layout of the studied residential building.
The objective of this case was to study a greywater reuse system to supply recycled water for toilet flushing and pavement washing. It was considered a treatment unit installed on -3 floor and the need to change the pumping system to collect water only from washing basins, showers and bathtubs.

2.3 Commercial buildings
Two commercial buildings were studied to assess the benefits and payback of implementing rainwater harvesting and greywater reuse systems. The first one is located in Lisboa, Portugal, and is an existing huge building, fully operational, with three commercial floors and three underground parking floors (Figure 4).
The managers wanted to reduce water consumption in the air condition cooling towers, by implementing a rainwater harvesting system. The number of occupants was estimated throughout the racio of 1 occupant/2,5 m^2 of sales area (Macintyre, 1996) resulting a value of 61 622 occupants, corresponding to an approximate sales area of 154 000 m^2. The simulation and the economic assessment made on this study consider the redesigning of the rainwater drainage network and the need to build a new collection tank on the underground floor. The rainfall registered values and the water prices were the ones corresponding to Lisboa district.

Fig. 4: Studied commercial building – Lisboa.

The second studied commercial building is located in S. João da Madeira, Portugal. It has an approximate value for sales area of 23 470 m^2 and thus, the estimated number of occupants is 9 388 (Figure 5). It is a recent building, constructed with concerns on promoting sustainable water consumptions, and already has a rainwater harvesting system that supplies non-potable water to toilet flushing, urinals and irrigation of flower planters. Although the managing team wanted to assess the feasibility of implementing a greywater reuse system in order to obtain even smaller potable water consumptions and so a 10 years simulation was made with SAPRA considering a mixed system with rainwater harvesting and greywater reuse.

Fig. 5: Studied commercial building – S. João da Madeira.

To make the economic assessment, the purchase of a greywater treatment plant was considered, as well as the changes needed on the wastewater drainage network. The water pricing used was the one presently used on the city and the precipitation values were the ones registered in Aveiro district.
For both buildings, the used per capita demand values and breakdown ratios were the ones provided by the managing team, in order to make the simulation as close as possible to reality.

2.4 Hotel

The hotel studied is located in Vila Nova de Gaia, Portugal. Expecting great water consumptions that normally are associated with luxury hotels, the promoters wanted to install a mixed system with rainwater harvesting and greywater reuse for toilet flushing and irrigation of about 13 500 m^2 of green areas (Figure 6).

Fig. 6: View from the studied hotel.

The hotel has 81 rooms with an estimated occupancy of 122 guests. The objective is to collect rainwater from the roofs, about 1 800 m^2, and greywater from a part of the hotel with a total of 25 showers, 3 bathtubs and 15 washing basins. This system will consider a tank to collect rainwater previous to filtration and a greywater treatment unit. Treated greywater and filtered rainwater will then be stored in a non-potable tank and supply the irrigation system and toilets.
The economic analysis was based on the water pricing of Vila Nova de Gaia city and the rainfall registration values used were the ones from Porto district. For this case the per capita consumption presented on SAPRA database was not considered, and was replaced by the value of 350 l/person/day (Macintyre, 1996) for the particular case of a hotel consumption.

2.5 Public building

In this study, it was also analyzed a new public building in Terceira island, Azores, Portugal, which will be a health centre to serve the local population (Figure 7). This health center will have a total of 740 occupants, considering public users and technical staff. For this building, the design team wanted to consider the supply of rainwater to toilets and urinals and thus, around 8 400 m^2 of a green roof area will collect rain water and the drainage system will store it in an underground tank.

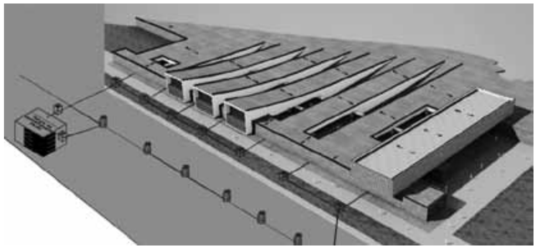

Fig.7: 3D image of the designed public building.

Due to the impossibility in this case to have a 10 years rainfall record for that region, the simulation was made only for 3 years. The water pricing used was the one currently in use on the island.

3 Results and discussion

The presented cases were simulated with SAPRA in order to evaluate the performance and benefits of each system. Table 2 presents the recommended storage volume resulting from SAPRA. In some cases, there was no space for such a huge volume so it was assumed a smaller one. In the particular case of S. João da Madeira commercial building, the greywater recycled was delivered to the existing rainwater tank and so the volume considered was bigger than the one recommended by the program.

Table 2 – Sizing and performance analyzes: results from SAPRA.

Case studies		System type	Collection Tank: Resulting Volume (m^3)	Collection Tank: Assumed Volume (m^3)	Performance: V_{NP} (m^3/year)	Performance: V_{RH} (m^3/year)	Performance: V_{GW} (m^3/year)	Performance: V_{Pot} (m^3/year)
Dwelling		RHS	50	4,5	85	42	-	43
Residential Building		GRS	10	-	294,3	-	294	-
Commercial buildings	Lisboa	RHS	500	150	92650	9596	-	830445
	S. João da Madeira	GRS	40	130	12765	4947	876	6935
Hotel		RHS+GRS	45	-	6335	942	1825	3565
Public building		RHS	345	130	2857	2589	-	236

Legend:
RHS - Rainwater Harvesting System
GRS - Greywater Reuse System
V_{NP} - Non-potable water consumption
V_{RH} - Rainwater used
V_{GW} - Greywater reused
V_{Pot} - Potable water consumed on non-potable uses

The performance results are yearly averages from the simulation period and whenever the *Assumed Volume* field is filled, the simulation is made for that volume and all results are based on it.

The results show that it is possible to optimize water consumption in buildings by reducing significantly the potable water volumes used on non-potable purposes like toilets, urinals, irrigation and cooling towers. It is noted that more than half of the annual water consumption on the simulated purposes can be supplied by rainwater or greywater. However, in the commercial building of Lisboa only 10% of the non-potable consumption will be supplied by rainwater, which was an expected result, taking into account that this is a very large building and the consumption in cooling towers is really high, as it can be seen on Table 2.

In spite of water savings that these systems provide, the only way to know if they are feasible investments is making an economic assessment. For each case studied, the second module of SAPRA was used and the results are showed on Table 3. The installation costs are referred to the cost increase resulting from the implementation of the rainwater harvesting and/or the greywater reuse system, with regard to a traditional system that could be built in the particular case. On the other hand, savings are related to the global water consumption estimated for the building and the reduction resulting from the use of non-potable water.

Observing Table 3, it is clear that larger buildings have smaller payback times. The commercial building in Lisboa was the case study with less potable water consumption reduction but in contrast is the one with smaller payback time. In this case, the installation cost is rapidly compensated by the amount of rainwater consumed and the resulting savings on water bills, provided by the system.

This decision support tool also provides the specific costs (installation cost divided by the volume of non-potable water consumed) of the analyzed systems, which are referred by Friedler and Alfiya (2010) to be lower, for greywater reuse systems, in office and public buildings than in residential homes. The specific costs resulting from this study show clearly that the cost to collect, treat and supply non-potable water is lower in large buildings also for rainwater and mixed systems, since the non-potable water demand is significantly higher.

On the other hand, the dwelling does not present a reasonable payback time and is the less viable system of all case studies. This is due to the small volumes consumed on non-potable purposes supplied by the system and so, smaller savings are resulting: an average of only 58 €/year. The residential building has also a high payback time, especially because of the high investment cost. In the future it is possible that, with the increase of installation of these systems, their production cost may be lower and this fact, combined with a possible raise on water prices in the years ahead, will probably reduce the expected payback time for small scale applications.

Table 3 – Assessment of economic feasibility: results from SAPRA.

Case study		System type	Economic feasibility			
			Installation cost (€)	Specific cost (€/m^3)	Saving (€/year)	Payback (year)
Dwelling		RHS	9.778	231,00	58	204
Residential Building		GRS	43.656	148,00	1.110	40
Commercial buildings	**Lisboa**	RHS	109.010	11,36	20.361	5
	S. João da Madeira	GRS	57.023	9,79	2.463	23
Hotel		RHS+GRS	160.536	58,00	11.000	14
Public building		RHS	85.225	32,92	5.485	15

The commercial building in S. João da Madeira is a special case about the implementation of a greywater reuse system in a building that already had a rainwater harvesting system. As it can be seen in Table 2, the higher portion of non-potable water supplied is rain water, therefore savings resulting from the transformation to a mixed system are not very high, about 2.400,00 €/year and that results on a relatively long payback time of 23 years (knowing that it requires a significant investment cost for the greywater treatment unit and for the changes on drainage plumbing).

It is expected that savings on monthly water bills will not be constant, because the non-potable water consumption, greywater production and collected rainwater fluctuates during the year. The 10 years simulation made by SAPRA allows to calculate and save monthly values and provides the average result for each month. The saving patterns for all case studies are presented in Figure 8.

Observing Figure 8, it is noted that rainwater harvesting systems have a monthly saving pattern that is quite smaller in summer months, as rainwater collected volumes reduce considerably. This situation is also observed in the commercial building of S. João da Madeira where the biggest non-potable water proportion supplied is rainwater. In the public building the situation is slightly different. Although it is also a rainwater harvesting system, in the Azores Island the rainfall patterns, characterized by rare periods without rain, allows to have a constant collection of rainwater and only in August a significant drop on water savings is noted.

Greywater reuse systems and mixed systems have a more constant pattern of monthly water savings, due to a continuous production and consumption of non-potable water. The biggest fluctuations are observed when irrigation is also supplied by non-potable water.

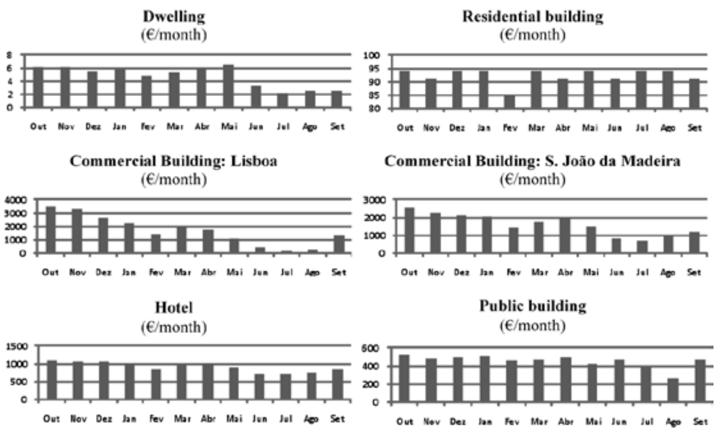

Fig.8: Average monthly savings for each case study.

4 Conclusions

The implementation of rainwater harvesting and greywater reuse systems brings great benefits related to the decrease of potable water consumption, wastewater production and in large scale applications contributes to stormwater control. Has it can be seen on the presented case studies, a significant part of water consumption in non-potable purposes can be supplied by rainwater or treated greywater. However, it is important to consider that they represent additional investment costs, when comparing with traditional solutions.

A decision support tool like SAPRA represents in this scope an important role providing the optimized volume for the collection tank, predictable costs and benefits for different scenarios, and the expected payback time for each one. In some cases it is impossible to build the collection tank with the volume calculated by SAPRA. In those cases, the simulation is based on the assumed volume, that is mostly smaller than the one suggested by the program and, even thought, good results on water and money savings as well as short expected payback times are observed.

Large buildings have smaller specific costs and shorter payback times, while residential buildings and dwellings are expected to have very high payback periods which can make it impracticable to install these systems, unless the owners' main objective is to reduce water consumption, not really mattering the low economic savings. On the other hand, payback time for large buildings is very attractive, especially because of the significant reductions on water bills that will remain after the payback period.

The high payback times estimated in this study for the dwelling and residential building may however decrease in the future if the costs of production and purchase of greywater and rainwater treatment and control units reduce coinciding with a rise on water prices. To compensate high investment costs and encourage people to implement these systems at their homes, governments can play an important role creating incentives, like tax reductions and sponsorship for installation costs.

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