Alternative uses of water in buildings – An affordable sustainable solution
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Abstract
Water is the most precious resource of mankind, usually regarded as a commodity and seldom given its true value. The aim of this study is to analyze the differences, starting from the project phase, between options leading to recycling, reuse or use of alternative sources of water. A simple building solution incorporating non-conventional water supply solutions was inserted in a real architecture and engineering project and compared with the situation where this is not accounted for. Recycling or reuse gray water and use of rainwater are considered along with the technical solutions given by the current state of the art. An evaluation is performed in order to illustrate that this solution is affordable and even shows that investments in initial stage allows savings over time in terms of maintenance and operation, with simultaneous minimization of the environmental impact.

Keywords: Water recycling, water supply in buildings, gray water, rain water, sustainability

1. Introduction - The water cycle in buildings
1.1. Water and sustainability
Essential to life on Earth, water is a precious and rare item today. Although water is the most abundant material in our planet (around 1.360 million cubic kilometers), it should be noted that 95.5% consists of salt water and 2.2% is presented in the form of ice. Only 2.3% consist of freshwater, not always accessible, usable and having the required quality for the intended use. Indeed, over decades, both the growth economic model and exponential population growth, together with intensification of agriculture and industrial activities, were decisive for the pollution of available water through discharges and infiltration of contaminants. Hence, there is a strong need to rethink the water cycle strategy and its sustainability [1]. In buildings, the use of rainwater and reuse or recycling of grey waters can be very important as measures for the aimed sustainability of this resource.

1.2. Use of rainwater in buildings
Rainwater is part of human life and the history of mankind, and many examples can be found about his capture and storage for consumption. Nowadays, in an apparently contradictory way, justified perhaps by the easy access granted by modern life [1,2], this water strategies are rarely used in urban areas, although an increasing global water stress is noted as a trend.

The concept of water stress refers to the difference between the usable water and the available natural resources. Prospects in this respect show that many countries in the world, including the ones in the Mediterranean basin (as Portugal), risk a very high water stress (more than 80% within a few decades).
It should be noted that the increasing of water consumption rate is two times faster than the population growth. According to the United Nations, by 2025, it is estimated that two thirds of the population of the planet (approximately 5500 million people) are living in countries that suffer from serious water shortages. The progressive awareness of sustainability in the use of resources is introducing new ways to design buildings and cities, for instance, integrating the recovery of rainwater, not necessarily for all purposes but for uses that do not require high quality water (food) [1,2].

1.3. Rules for the design and installation of rainwater harvesting systems

The design of a system of use of rainwater should bear in mind the following rules (Figures 1 and 2):

- Adoption of a specific calculation model to assess the needs in water amounts for each project.
- Admit as useful collection areas those that are not in regular contact with people, animals or machines.
- Adopt filtering systems that reject the first waters ("first flush") after long periods without average rainfall (rejection of average 0.5 liters per m²).
- Predict cutting valves at the beginning of the system, with diversion to the rainwater collector, in order to allow verification, maintenance or replacement.
- Predict reflux valves, with anti-rodents membrane at the exit (due to sewage overflow) of the storage deposit, which must be connected to the rainwater collector.
- Use a storage deposit with walls free of porosity and without leading to chemical reactions. High density polyethylene is nowadays the material in use for this application.
- The deposit should be buried, ensuring that rain water is protected from light and temperature variations. In this the formation of algae and the development of certain microorganisms are also prevented.
- The deposit should have a buffered opening that allows access to its interior for maintenance.
- The water entry in the deposit should be made from the bottom to the surface through a special accessory that will not cause turbulence. In this way, oxygenation of water can also be done whenever new water flux comes in.
- The water collection by pump in the interior of the deposit should happen around ten or fifteen centimeters below the top level to ensure good quality.
- The system must provide that overflow in the deposit happen three to five times per year, ensuring a good water renewal.
- In the case of rain water supplying some equipment inside the building (WC tanks, for example) there should be independent channeling without possibility of crossing with others. The automatic valves doing the switching of the deposit to the normal grid must ensure that there is no entry of rainwater by reflux into the potable water supply grid.
- All taps feed by rain water must be marked with labels indicating "not drinking water or improper for consumption". These should only be handled by a security key.
The maintenance and cleaning system should focus on the time of the year before and after the rains.

The main physical-chemical parameters of water stored in the deposit should be checked with intervals of six months.

Every five years total deposit emptying and washing is recommended. [3,5]

Figure 1 – A simplified scheme of the system for rainwater use in a house [5]

Figure 2 – Detail of a rainwater harvesting system [5]

1.4. Reuse and recycling of grey water

The wastewaters can be subdivided in black and grey waters. Although some authors refer other classifications, waters which are mixed with organic matter (toilets) are usually named as black waters.
They require chemical or biological treatment and sometimes disinfection before being used again. In principle, these waters should only be reused outdoors, for instance, in gardens or green areas. Reuse or water recycling in situ offers many opportunities for rationalizing water consumption in buildings [6]. Unfortunately, nowadays all water used in buildings and gardens is drinkable.

The opportunities of reusing or recycling grey waters vary according to the location where one lives. The houses are usually linked to a centralized sewer system but, in isolated homes with gardens, this opportunity becomes more evident. The grey waters, with appropriate treatment for discharges, may serve for toilet cisterns, gardens, patios and washing. It is important to stress that the reuse or recycling of wastewater decreases the volume of effluents, reducing overloads in the centralized sewer system and extending its life time.

Unfortunately, because water in the public network is not presented with its real cost (in Portugal), installation and maintenance of water reuse systems may result in a solution with an extended payback period. This period can vary with the extent of services of the existing local wastewater treatment and with the type of system that will be installed. Anyway, it is always beneficial to reuse or recycle the water, at least in terms of sustainability.

In order that reuse or recycling of grey water is possible, it is necessary to separate the discharge pipes of grey and black waters and install the system for treatment of water (Figure 3).

In fact, the grey waters can be directly shifted from the drain of shower and washbasin to be reused only in flushing. However, it cannot be stored more than 2 hours before it is reused, which brings pre-treatment as the more convenient option. In table 1, values are shown for the daily produced typical volumes for grey and black water in a typical residential building [7].
### Table 1- Consumption per day and per person of black and grey water

<table>
<thead>
<tr>
<th></th>
<th>Volume (liters/person/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Black waters</strong></td>
<td></td>
</tr>
<tr>
<td>Toilet flush</td>
<td>22</td>
</tr>
<tr>
<td><strong>Grey waters</strong></td>
<td></td>
</tr>
<tr>
<td>Shower</td>
<td>56</td>
</tr>
<tr>
<td>Washbasin</td>
<td>6</td>
</tr>
<tr>
<td>Kitchen basin</td>
<td>12</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>5</td>
</tr>
<tr>
<td>Laundry tank</td>
<td>7</td>
</tr>
<tr>
<td>Laundry washer</td>
<td>27</td>
</tr>
<tr>
<td>Grey water total</td>
<td>113</td>
</tr>
<tr>
<td><strong>Total (black and grey water)</strong></td>
<td><strong>135</strong></td>
</tr>
</tbody>
</table>

1.5. Water efficiency

In Portugal, the need for an efficient use of water has been recognized as a national priority through the publication of the Government Resolution nº 113/2005 of 30/June, approving the National Program for the Efficient Use of Water [7]. This program also proposes the labeling of devices in buildings (cisterns, showers, taps and so on) to make consumers with more knowledge on their water efficiency. It is proposed in the program that this measure will be compulsory after a transitional period [3]. Logically, it is becoming urgent to define and implement a model in Portugal for water efficiency certification and labeling for buildings. The certification and water efficiency labeling of products already exist in Portugal and have been implemented in various countries on a voluntary basis. In some cases, for example in the United States or in the Nordic countries, these adopted systems refer to one efficiency value and in other systems (Australia and Ireland), the labels provides a variable classification of product efficiency. In Portugal, these water efficiency labels are already studied and proposed by a National Association (ANQIP) [3]. This work aims to integrate simple water use efficiency strategies in a building project and analyze the economical and environmental impact of such proposals.

2. Experimental – Project description

The starting point of this project, designed as a common living building, refers to a single isolated villa with two floors above the ground. The architecture project is set on a flat and sandy terrain in the surroundings of a medium town, where there are no need for operations of landscaping in terms of soil movement. The foreseen construction and implantation area are around 350 m² and 506 m², respectively. Building volume is 1811 m³ with a typical height of 6 m. The building constitution and inner design was set accordingly to regulations and in order to satisfy the requirements of the owner. The architectural solutions were developed into two floors with a supplementary or annex building. The ground floor involves an entrance area as a distribution lobby, a living room, a bedroom with a private bathroom, a common use toilet and a kitchen with a smaller living room attached. The access to the first floor is done through a vertical connection, stairs that are accompanied by a small
indoor garden. The space in the first floor presents two bedrooms, a common bathroom, a small reading room and an office space.
The annex or supplementary building attached to the main building is constituted by a double garage, a laundry area, a toilet and a kitchen.
The house simple structure is built by a system of steel reinforced concrete pillars and beams supported on direct foundations with lightweight concrete slabs. The masonry walls are in standard ceramic bricks placed with common cement mortar. The flat roof is based on lightweight concrete slab. Table 2 show the different building areas and its costs. The estimated total cost of the works is around 150 000 €.

| Table 2: Characterization of areas in the building space. |
|---------------------------------|----------|----------|----------|
| Floors                          | Area (m²) | Cost     | Partial cost |
| Main building                   |          |          |            |
| Ground                          | 166.83   | 480€/m²  | 78 638.40€ |
| First floor                     | 102.52   | 480€/m²  | 49 209.60€ |
| Annex building                  |          |          |            |
| Ground                          | 50.75    | 180€/m²  | 9 135.00€  |
|                                 | 30.45    | 180€/m²  | 5 481.00€  |
| Fence walls                     |          |          |            |
| Ground                          | 50€/m    | 3750.00€ |
| Storage annex                   |          |          |            |
| Underground                     | 20.35    | 370€/m²  | 7 536.00€  |

In order to achieve this work objective, simple alterations were performed in the project water distribution and drainage systems to contemplate not only a rainwater harvesting and a reuse system for grey water. Its implications in the project architecture and construction costs are then discussed.

3. Application of water efficiency solutions – Results and discussion
The alterations in the sewer and water distribution systems are firstly shown in Figures 4 to 6. These were modifications necessary to make in order to establish rainwater harvesting and also for the grey water reuse. In terms of architecture no major modifications were introduced. Only the use of the small storage underground annex was partially changed. The rainwater harvesting and grey water deposits were placed there with the connections to the traditional water grid. There is still some available space for general storage.

Figure 4 shows the drainage system for residual water (normal distribution and rainwater), foreseen in the building ground floor, before and after introduction of changes related to water efficiency. The grid is set accordingly to Portuguese rules and using traditional solutions (Figure 4A).

In Figure 4(B), the new solution for water drainage is presented at the ground floor level, which includes the rainwater harvesting and also the grey water reuse from bath and washbasin only.

As it can be observed, the rainwater is lead to a storage reservoir after going trough first flush and leaves filters. Waters deviated in this filters also go to the rainwater basic grid. The storage reservoir also contains an overflow device for the rainwater grid system and a pump system towards the new grid used only for non-drinkable or food purposes (cisterns flush, garden, etc.).
Figure 4: Ground floor - Water distribution system before (A) and after (B) water efficiency measures; deposits (orange crossed boxes) are for rainwater harvesting (square) and grey water treatment (rectangle); Purple lines in (B) represent modifications related to the grey water system. Green (dashed) and blue lines represent the rainwater and sewer normal distribution systems.
Figure 5: Underground floor technical area - Water efficiency measures; Deposits are for rainwater harvesting (square) and grey water recycling (rectangle) and connections between them
Figure 6: Ground floor - Water distribution system before (A) and after (B) water efficiency measures; Green (dashed) lines represent the modifications in the distribution systems due to the reuse of grey water and the use of rainwater.
Grey water coming from baths and washbasins are lead to a small treatment unit including filtration, biotreatment and ultraviolet disinfection. After treatment, these waters are connected to the non-drinkable water circuit, coming from the rainwater deposit (Figure 5). The water treatment and harvesting deposits had to be placed in this storage technical area in the underground floor, specially adapted for this use. It is a small space, with an area around 20 m², with an access for maintenance operations.

Figure 6(A) shows the traditional solution for water distribution in the ground floor. Figure 6(B) presents the new solution considering the distribution of rainwater and grey water from baths and wash basins to toilet cisterns, exterior gardening and laundry applications.

The modifications in the entire building project, in terms of construction costs, are not relevant since the construction areas were not increased considering the ones that were foreseen in the project (Table 2).

If one compares both solutions, a slight increase in drainage system (around 10%) and duplication of part of the water distribution system (around 40%) exist that, obviously, result in some initial investment increase. There is still the investment in terms of the rainwater and grey water deposits and equipment. There are already systems in the market that perform the functions described here and set in the modified architecture project, meaning, rainwater harvesting and reuse and also the grey waters recycling. A typical system for both functions would have an investment cost around 6500 €.

If the acquisition and construction costs of the modifications in the drainage system and in the water distribution system are added, one can estimate a total investment cost around 8000 €.

On the other hand, one can estimate average savings up to 60% of water for a region with a normal rain fall situation. Other solutions of water harvesting can be set according to the region nature. However, taking into account savings in the order of 50% and that a normal bill for this kind of building can reach monthly values of 70€, it is possible to translate direct savings of 35€ per month (or 420€ per year). Apart from the economical benefit, it is even more important the environmental aspect of these simple measures, since it is clear today that, for some Mediterranean countries including Portugal, the risk for water stress is very high in the near future. Moreover, it is also expected that the water bills for buildings will also tend to increase significantly with time due to the way costs will be assessed and due to the water stress levels. Therefore, it is expected a payback period between 12 and 15 years.

4. Conclusions
The example presented allows you to prove that it is easy to implement water efficiency measures in the construction of buildings. This case study allowed us to think about simple decisions that can significantly alter the way to build in a more sustainable but affordable way. The small investments we do today may have a high impact tomorrow economically, socially and in the environment.

Indeed, our case study showed that an initial investment cost increase of less than 8000 € in an overall value for the building of around 150000 € is quite small and it simultaneously generates lower monthly
costs throughout the building life.
Apart from this economical facts, the environmental impact in an age of water stress demand a conscientious decision towards water efficiency. Considering a normal water consumption of 135 liters/person/day and that a building like this one is usually occupied by four persons, one can easily estimate a monthly consumption up to 20 m³ and an annual saving of more than 100 m³. Reproducing this value for millions of buildings one can quickly grasp the important water savings that simple measures can generate.

5. References