Water Reuse for Domestic Consumption
A Key Element For Environmental and Economic Sustainability

José Coimbra
University of Minho, School of Engineering, Department of Civil Engineering, Campus de Azurem, 4800-058 Guimaraes, Portugal
josepaulocoimbra@gmail.com

Manuela Almeida
University of Minho, School of Engineering, Department of Civil Engineering, Campus de Azurem, 4800-058 Guimaraes, Portugal
malmeida@civil.uminho.pt

ABSTRACT: In a context of increasing social awareness about resources conservation, residential water management is essential in ensuring environmental and economic sustainability. An adequate management is attained with integrated solutions, which simultaneously reduce potable water consumption at least in 25% and enable the storage of recovered water.
The recovery and storage of underground water can be ensured with the installation of a groundwater drainage network and an underground water deposit, which will supply the residential toilet cisterns and the automatic irrigation systems through independent piping. These solutions aim to achieve high levels of water conservation with the aid of known materials, components and techniques, with as little interference as possible in residential comfort. They also reduce the interference in the water cycle, since less public water is used for residential consumption and the surrounding surface permeability is assured in order to allow the infiltration of rainwater into the soil.
Due to water reuse, the cold potable water consumption in residential buildings can be reduced in up to 50% when compared to average consumption in buildings without recovery systems. Therefore, the environmental and economic impact analysis of water reuse leads to the conclusion that the investment has a five year payback period, after which it represents a real gain for residents.

1 INTRODUCTION

Fresh water is a scarce and valuable resource in the XXI century, due to population growth, climate changes and environmental pollution. About 25% of world population lives in areas with shortage of drinking water, which has led to an uneven distribution of water, lack of food and humanitarian catastrophes (Molden, 2007). The availability of water depends on the amount of rainfall, the collecting area and the quality and length of treatment and distribution infrastructures (Halliday, 2009).
Predicting that there will be a drought stress equal or superior to 40% in 2025, according to World Water Council (WWW, 1996), it is necessary to take important measures, one of which being presented in this study is to increase water efficiency in buildings.
Research has been made in cooperative buildings which have the capability of reusing water. Furthermore, we have determined and compared results, which have been obtained in the context of sustainable construction under controlled costs, aimed at residents of the Portuguese cooperative housing. Knowing that sustainable construction is nowadays an international recurrent concern, we focused on saving resources and environmental impact reduction on the current use of the heritage building cooperative, as well as the future construction of new cooperative projects.

2 WATER MANAGEMENT IN RESIDENTIAL BUILDINGS

The main goal of sustainable water management is to ensure the effectiveness of its use and minimization of pollution, so that water returns to the environment in a benign way (Roaf et al., 2007). In what concerns residential buildings, demand for water has been increasing due to exponential construction of dwellings and to the use of water consuming appliances such as washing machines by almost every families. The establishment of gardens and recreational green areas involves the construction of irrigation networks and also a marked increase in drinking water consumption.

Regarding water quality, all the water that enters each building has got the quality of drinking water, but all of it comes out as sewage. An increase in its use affects the infrastructure, the storage requirements and the necessary energy to distribution and purification. Generally, water is inefficiently used, for example, by mixing and dissolving waste throughout the entire cycle.

The reduction in water consumption, although it can be made economically (by reducing the price of water) and sociologically (by environmental education), it is essentially ensured by technical means, through the efficiency of the products (toilets, showers, washing machines). Thus, the sustainable use of water in buildings must pass through "water efficiency of products" (Rodrigues & Silva-Afonso, 2007).

By reducing water consumption in buildings, water cost and waste water treatment cost will be smaller, and the following benefits will be achieved (Nicholls, 2008; Todd, Benjamin & Todd, 2007):

- Reduced consumption of hot and cold water, which corresponds to energy saving;
- Reduction of energy used to treat and pump water supplies and waste water;
- Reducing the amount of chemicals used in water treatment;
- Reduced maintenance costs as a result of water recovery;
- Reducing the impact on the water supply infrastructure;
- Improving environmental protection and therefore preserving water resources.

The water stress risk has increased very quickly on the planet. In countries, such as Portugal, it may occur, in 2025, a very serious situation of water shortage. In terms of water saving chances in Portugal, it is currently estimated that the total of water use inefficiencies is higher than 3 x 10^6 m³ / year (National Program for the Efficient Use of Water). The economic value of these inefficiencies will exceed 750 x 10^6 € / year, representing about 0,64% of Portugal's Gross Domestic Product. About half of this amount can be considered as savings opportunities in the urban infrastructures and in water systems in residential buildings.

Groundwater and rainwater have traditionally been collected for reuse in gardens. However, according to Nicholls (2008) and Halliday (2009), for internal uses this water should be diverted wherever possible, filtered and stored in an underground storage water tank.

As groundwater and rainwater are not allowed to be used as drinking water, their use is restricted to toilet flushing and garden watering. The pipe systems shall be clearly marked to avoid the risk of cross contamination. All tests and water facilities shall be made, under regulations, to ensure that the system is safe and presents no health risks.

In Portugal, the use of rainwater presents two important constraints:

1 - Water distribution managing authorities do not authorize the use of non-potable water within a dwelling, according to article 86 of the Law-Decree n º 23/95 of 23rd of August. However, for cooperative ventures promoted in the municipalities of Porto and Vila Nova de Gaia, after submission of a technical study of recovered water for flushing toilets and irrigation, they were exceptionally accepted in favor of cooperation between public authorities and sustainable cooperative construction. Even so, the supply was only authorized if a direct monotubular pipe was used to supply toilets, embedded throughout its course without tees or taps.

2 - In residential buildings, a storage cistern for recovered ground and rainwater would be installed in the basement and sub-basement, below the level of the street pavement that gives access to the basement. In accordance with paragraph 2 of Article 205 ° and 206 ° of the Law Decree 23/95 of August the 23rd, the waters gathered below the street pavement, even if located

above the collector public, should be raised to a level equal to or higher than the street. This arrangement would involve the installation of an hydropneumatic group for pumping rainwater in excess on storage, which is not sustainable in case of normal rainfall or, worse, in possible situations of peak rainfall, leading to flooding of the particular basement.
Due to the previously described circumstances, it appears that the use of rainwater is only possible in very particular cases (Ponte da Pedra, 2007), in which the storage tank could be placed above the level of surrounding streets.
In other situations, in which it is not possible to place a storage tank above street level, it can be considered that water recovery is only feasible after confirmation, via surveys or geological and geotechnical studies, of the existence of groundwater located at the level or above the basement, whose waters can be drained directly to the storage tank. The durability and permanence of groundwater must be confirmed by measuring heights for a consecutive year, in order to determine dimensions and flow rates compatible with the supply to the building intended (Guifões, 2007; Madalena, 2008). If so, given that this water would need to be collected, in all cases, in a well on the ground floor and pumped to the outside, it will be advantageous to proceed to the design and construction of storage tanks for later re-use the water.

3 METHODOLOGY

The case study was based on the comparative analysis of the consumption of drinking water of four cooperative housing developments.
As a sample of a multiple case study we considered four housing projects, chosen from the set of cooperative ventures promoted by Housing Cooperatives under controlled costs. The samples were divided into two groups: the projects completed after 2006, representing sustainable construction, and developments completed before 2006, representing a traditional construction, non-sustainable:

- Madalena (Vila Nova de Gaia) - 2 buildings, 39 dwellings (2009)
- Fontainhas (Porto) - 1 building, 27 dwellings (2009)
- Leça da Palmeira (Matosinhos) - 1 building, 29 dwellings, (2007)
- Azenha de Cima (Matosinhos) - 1 building, 36 dwellings (1993)

In this research, it was carried out monitoring, comparison and analysis between building performances, regarding the consumption of drinking water, comparing building systems and equipment used in the three projects referred to as sustainable construction (Madalena, Fontainhas and Leça da Palmeira) with the building identified as traditional construction (Azenha de Cima).
For the analysis and comparison between quantitative data, monthly consumptions of drinking water for the total amount of 131 dwellings were collected and analyzed.
A comparison matrix of relationship between building systems of the two groups of cooperative enterprises and their performance has been made. This matrix focused on the field of saving drinking water, as well as in the improvement of environmental comfort for residents (with a consequent increase in the quality of life of residents cooperative - the social aspect), and in the reduction of harmful emissions into the atmosphere and reducing the consumption of potable water per capita (with the consequent impact on improving the environmental impact of sustainable construction – the environmental aspect) .
Regarding the economic aspect, this focused on the analysis of the annual amount in savings of drinking water. The calculation of the annual consumption of drinking water, according to the records of actual consumption of the four projects under study was aimed at defining the level of resource requirements considered adequate for the normal use of the buildings by the 131 families.

4. ANALYSIS AND DISCUSSION OF RESULTS

4.1 *Analysis of building systems and equipment*

In Table 1 we presented the main systems and equipment included in building construction, which were observed on site. In this table are presented the four cooperative projects, three sustainable and one non-sustainable.

Table 1 – Systems and equipment for water management included in building construction

System	Madalena	Fontainhas	Leça da Palmeira	Azenha de Cima
Bathtubs with thermostatic valves for controlling water temperature	Yes	Yes	Yes	No
Toilets with dual flush mechanism	Yes	Yes	Yes	No
Taps with aerators	Yes	Yes	Yes	No
Underground tank of recovered water for garden watering, garage washing and toilets of dwellings.	Yes	No	No	No

It was given particular importance, during construction of sustainable buildings, to water management, according to the increasing sensitivity of the population to saving resources. The concern to ensure appropriate management of water, especially during its use by the residents, aimed at:

- Achieving high levels of water conservation, using techniques, materials and components already known, interfering as little as possible in the comfort of home;
- Limit interference with the natural cycle of water, reducing the amount of water pumped, and increasing the use of rainwater and transferring to the water cycle via local infiltration;
- Reduction of at least 25% of drinking water consumption compared to the current consumption patterns.

The above targets were achieved by the implementation of an overall solution, in terms of building equipment and housing, in order to, on one hand, reduce the consumption of drinking water and, on the second hand, store recovered water.

The recovery and storage of groundwater have been achieved through the construction of a drainage network of groundwater and an underground concrete tank, which supplies, by an independent pipeline, recovered water to the all the toilets of both Madalena buildings.

The water stored in the concrete tank comes from infiltration into the soil from rainfall, groundwater and water that is formed at the level of the floors of garages, which, by ground ascension, is captured by drains. This procedure is defined as "reuse" water is generally low cost of use and construction, but requires the use of water soil quality consistent with the purpose for which they are intended (Roaf et al. 2007). The soil water analysis, performed during the study the geological and geotechnical ground indicated that the water is free from harmful materials presented to any contact with humans. This water is used for the supply of toilets and for watering private gardens of the buildings.

The pipeline of recovered water within the dwellings is entirely separated from public supply of drinking water, intended only to toilet flushing.

We present, on Figure 1, a schematic drawing of distribution of recovered water to the toilets of one entrance of each Madalena buildings.

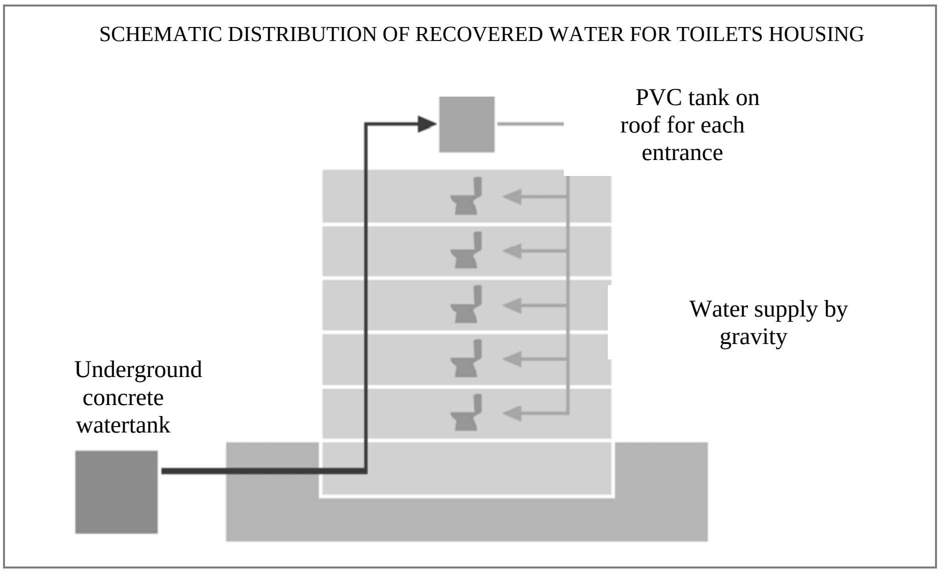

Figure 1 - Schematic distribution of recovered water for toilets housing

Regarding water savings, there were showers installed and equipped with thermostatic valves for temperature control, in bathtubs and shower trays as well as toilets with dual flush system. Thermostatic valves diminish the waste of water between the opening of the tap water and heating to the desired temperature. The possibility to adjust temperature and maintain fixed for future use, causes the water to exit at the desired temperature by the user without the need to manually adjust the temperature.

4.2 *Analysis of cold water records and consumption*

Records of water consumption were carried out for a whole year period for the existing sample of the four projects: Madalena (39 dwellings), Fontainhas (27 dwellings), Leça da Palmeira (29 dwellings) and Azenha de Cima (36 dwellings).
From the monthly records of cold water meters, figures were drawn of monthly consumption by dwelling. As an example of the monthly water consumption of housing for each project, is presented in Figure 2, their monthly consumption.

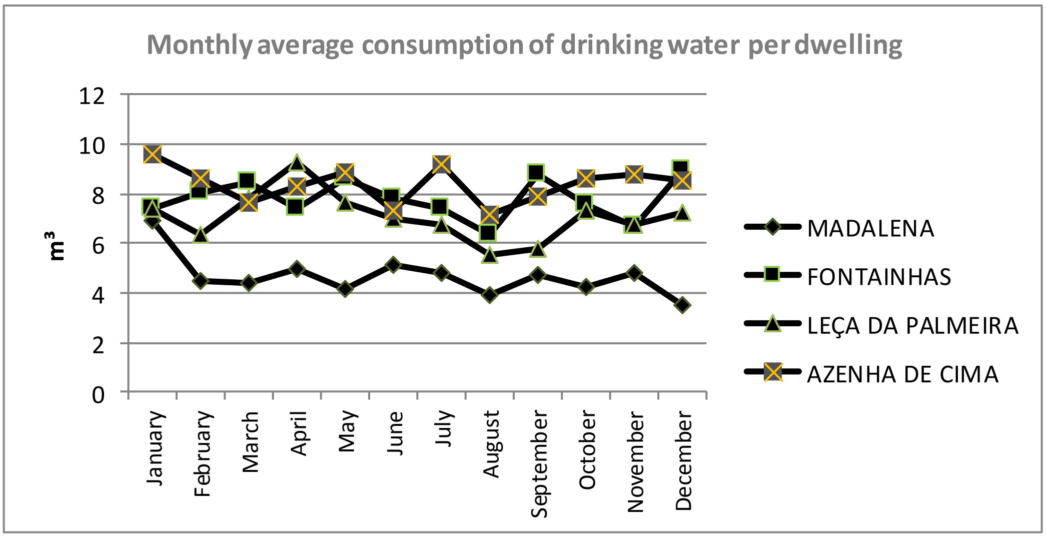

Figure 2 - Variation of the monthly average consumption of drinking water for each dwelling

By analyzing consumption, it is possible to draw some conclusions about the monthly average consumption of cold water by dwelling. The monthly distribution of consumption is done on a regular basis, around a mean value, which is as follows:

- Madalena: 4.67 m³ per month;
- Fontainhas: 7.78 m³ per month;
- Leça da Palmeira: 7.08 m³ per month;
- Azenha de Cima: 8.37 m³ per month.

There is a substantial difference in water consumption between Madalena and the other buildings. As explained before, the water used in toilet comes from the recovered water tank and is not therefore recorded in the water meters; in the 2nd case, all water consumed in the dwelling is registered on the counter.

This means that the residents of Madalena pay less for drinking water than residents of other ventures, because the water that supplies the toilets is free of cost. It is important to quantify this benefit, in what concerns the volume of drinking water saved and its cost saving, the analysis of the reduction of water stress, as well as the reduction of the cost of using the dwelling.

To support this fact, the records show that during the year 2011 in Madalena, passed by the totalising counters, an alternative to supplying drinking water to toilets when there is a shortage of recovered water, in July and August, months in which there wasn't any supply of recovered water, 117 m³ of water intended for flushing. Being 39 dwellings inhabited in Madalena, this means that each dwelling spent, per month, an average of 1.5 m³ of water for the toilets only. And we must conclude that, knowing that July and August are months in which residents spend their holidays, most of them leaving home for a fortnight or even a month, this figure is smaller than it shoud be if they were permanently at home.

With regard to average annual consumption, as shown in Figure 3, it is found that in Madalena, this is 56.00 m³ / year and per dwelling, and that for the other three projects, is 93.34 m³ / year and per dwelling in Fontainhas, 84.93 m³ / year and per dwelling in Leça da Palmeira, and 100.39 m³ / year and per dwelling in Azenha de Cima.

The main conclusion of this analysis is that it is possible to assess the impact that the use of recovered water in toilets of Madalena has in the consumption of drinking water of dwellings. At first sight it is observed that, in Madalena, each dwelling consumes 28.93 m³ less than in Leça da Palmeira (less 34%) and 37.34m³ (40%) less than in Fontainhas. In a second analysis, considering the ratios of inhabitants per dwelling (Madalena = 3.03; Fontainhas = 2.63; Leça da Palmeira = 2.76), drinking water consumption, per capita, it appears that, in Madalena, each inhabitant consumes an average of 18.5 m³ of drinking water per year. This corresponds to 48% less than in Fontainhas (35.5 cubic meters per person per year) and 40% less than in Leca da Palmeira (30.8 cubic meters per person per year).

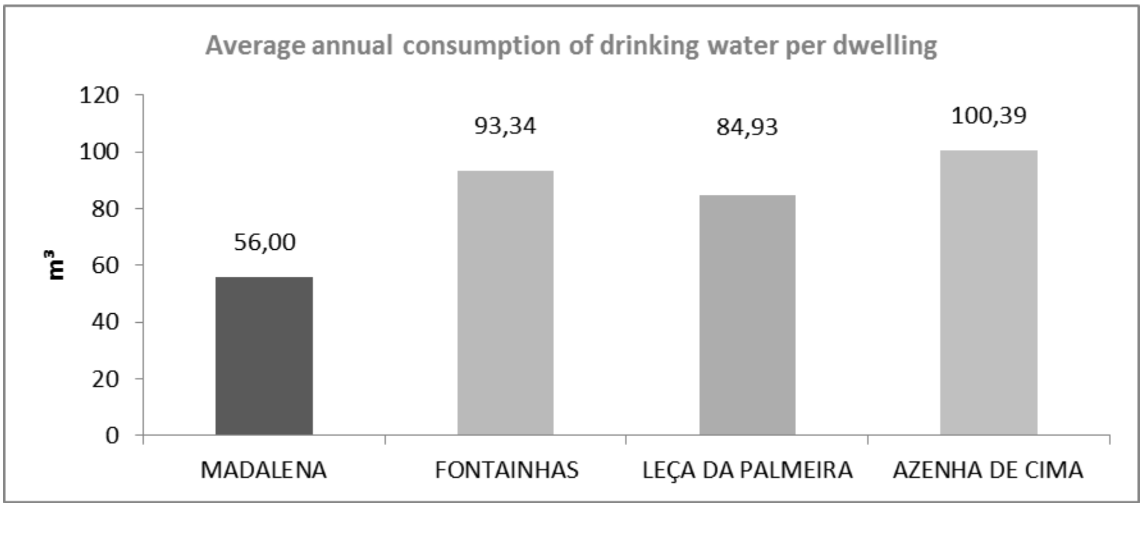

Figure 3 - Average annual consumption of drinking water per dwelling

Thus, the difference that appears between the average annual per capita consumption, in both types of ventures (with and without recovered water), corresponds to annual savings in the consumption of drinking water, due to the existence of recovered water, which corresponds to an average value of 36 m³ of water per year, equal to the difference between the annual consumption of Madalena and the annual average of the other three buildings.

4.3. *Analysis of savings by using recovered water*

It is expected to calculate the estimated annual savings of using recovered water in the dwellings. For calculating savings, consumption is established between drinking water consumption in standard projects and Madalena. By comparing this average consumption with the average consumption of the remaining three projects that do not have such a system, it is possible to calculate the mentioned annual savings.

For this purpose, we use the values from monitoring of consumption: to determine the number of inhabitants of the building, we use the occupancy of 2 persons for the T1, T2 for 3 persons, 4 persons for T3 and T4 for 5 people, multiplying by the number of types described in Table 1, the total volume of water consumed per year in each project, it uses the value of the average annual consumption per capita, given in section 4.2. In this case, the building of Madalena, who has recovered water, consumes 18.51 m³ of water per year per inhabitant. The remaining three projects, which have not recovered water, consume, by determining the average, 92.00 m³ of water per year per inhabitant, as shown in Table 2.

Table 2 - Annual savings in using recovered water for consumption

	Madalena (sustainable)		Average (non-recov.water)		Savings per dwelling and year		
Type	Consumption m³/inhabitant	inhabitants	Consumption m³/inhabitant	inhabitants	m³ /.year	€ / m³	€ per year
T1	56.00	2	92.00	2	72.00	1.14	82.08 €
T2	56.00	3	92.00	3	108.00	1.14	123.12 €
T3	56.00	4	92.00	4	144.00	1.14	164.16 €
T4	56.00	5	92.00	5	180.00	1.14	205.20 €

By consulting the table mentioned above, it appears that, for a cooperative housing T1 with recovered water and two occupants, the annual expected savings in drinking water is 82.08€, corresponding to the difference in consumption per occupant presented above. Similarly, it is possible to carry out similar calculation for the other types, as shown in the same table.

4.4 *Payback period of sustainable water management*

This study shows that it is possible to measure cost benefits in sustainable cooperative construction. It is expected that a sustainable cooperative dwelling spends on drinking water, per year and per inhabitant, 41.04 € less than a dwelling of traditional cooperative construction. This difference is due mainly to a system of water recovering and the existing of a large capacity storage tank.

Consulting technical and financial data of Madalena project, it is possible to present the cost of this system, which is described in Table 3. As none of these materials and equipment was used in the other projects, it is possible to assume that the values shown in Table 3 represent the increase of cost associated to the implementation of sustainable water management.

The costs of these materials and equipment, for the 100 dwellings of Madalena buildings, were calculated in 68.725,54 €. This means that the cost of sustainable water management due only to water recovery, per inhabitant, is of 226.82 €. This value results from the calculation of the total inhabitants of Madalena buildings, which are 303. Assuming that Madalena building of spends less 41.04 € per inhabitant and per year than the other three buildings, and energy and maintenance costs are 2.11 € per inhabitant and per year, the payback period is of 226.82 €/ (41.04 € - 2.11 €) = 5.8 years, as shown in Table 3.

Table 3 – Cost of efficient materials and equipment of Madalena project and payback period for sustainable construction with standard comfort energy consumptions

	Cost (€)
Concrete watertanks	12,332.54
Water pumps	6,117.34
Pipe network for toilets and garden watering	47,002.84
VAT	3,272.82
Complete system of recovered water	**68,725.54**
Increase of cost per inhabitant due to recovered water	226.82
Savings in drinking water per inhabitant and per year due to recovered water	41.04
Cost of energy and water pump maintenance per inhabitant and per year	2.11
Payback period for water management with recovered water	**5.8 years**

5. CONCLUSIONS AND RECOMMENDATIONS

The study proves that sustainable housing cooperative built to provide high quality environmental, reduces the use of drinking water through the use of efficient building systems and equipment. For this purpose, design must gather sustainability criteria, enabling efficient management of water, with the application of devices that allow the reduction of consumption and the collection and storage of underground and rain water.

By monitoring performed to cooperative residential buildings, it was possible to conclude that the low monthly consumption of drinking water indicates that cooperatives have already developed an efficient use of their homes. However, it is possible to improve the efficiency of the use of resources, through the adoption of specific rules of behavior for savings in the consumption of drinking water. These savings, which positively affect the family budget, also decrease the pressure on infrastructure funding, production and distribution facilities in Portugal, reducing their demand and their costs, which contributes to a better environmental balance.

Therefore, it is essential to improve, in the future, the awareness of residents to the effective use of water. The decrease in water stress passes mainly through dissemination of concepts and rules conducive to the effective use of water. Housing cooperatives, using their newsletters and manuals of use and maintenance of their property, have contributed to arise awareness of the residents. Nevertheless, this type of information should be repeated at regular intervals, as though to result in significant water savings, these decrease as the behavior of water consumption patterns back to previous sensitization.

Finally, it is noteworthy, given the current economic and social, that the adoption of these and other practices of sustainable use of water and other resources, the ordinary citizen, is an individual and collective commitment.

REFERENCES

Halliday, S. (2009). *Sustainable Construction* (Reprinted, 1st ed. 2008). Burlington: Butterworth-Heinemann.

Molden, D. (2007). *Water for Food, Water for Life – A Comprehensive Assessment of Water management in Agriculture.* International Water Management Institute. London: Earthscan.

Nicholls, R. (2008). *The Green Building Bible*. *The Low Energy Design Technical Reference* (4th ed., vol. 1 e 2). Llandysul: Green Building Press.

Roaf, S., Fuentes, M. & Thomas, S. (2007). *Ecohouse* (3d edition). Oxford: Elsevier Architectural Press.

Rodrigues, C. & Silva-Afonso, A. (2007). A Qualidade na Construção ao Nível das Instalações Prediais de Água e Esgotos. Situação e Perspectivas em Portugal. Proceedings – *Congresso Construção 2007*. Coimbra: FCTUC.

WWW (1996). *World Water Forum.* World Water Council [online 10-5-12], http://www.worldwatercouncil.org/index.php?id=92&L=0%2Findex.php%3Fid%3D32%20target%3D%20title%3D