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Evaluation of rainwater harvesting in Portugal: Application to single-family residences

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ABSTRACT

Because water is a key at-risk resource, improved water management is essential. In terms of quantity, the two major alternatives in water management can be grouped into: (i) improving efficiency in water use; and (ii) exploring alternative water sources. Rainwater harvesting (RWH) is one of the most promising alternative water sources, since rainwater can easily be collected and used without significant treatment for non-potable purposes. However, the economical viability of these systems is not always assured. This paper examines the most relevant technical and economical issues in designing domestic RWH systems, evaluating the technical feasibility and economical viability of this technology in the particular weather and water use in Portugal. The evaluation is performed for a single-family residence, where the water use pattern was monitored. The precipitation pattern is characterized for two locations in Portugal, Porto and Almada, since they represent two different scenarios for RWH. The RWH and water savings efficiency were assessed and payback period estimated for both cities. It was found that, for an optimum rainwater tank, the water savings potential are similar for both locations, despite the differences in the average annual precipitation. A simple rule for estimating the optimum tank capacity for single-family households in Portugal is proposed. A sensitivity analysis shows an important influence of water fees on the economical viability of RWH systems in single-family houses in Portugal, namely when compared to changes in the consumption pattern.

1. Introduction

The goal of reducing by half the proportion of people without sustainable access to safe drinking water until 2015 set in 2000 by UN Millennium Development Goals is far from being fulfilled in some parts of the globe (UN, 2013). Currently, it is estimated that roughly one billion people do not have access to safe drinking water (Helmreich and Horn, 2009). This is more critical in developing countries, particularly in poor rural areas, where at least one-third of the population has little or no access to safe drinking water and results in major health problems from waterborne diseases (WHO, 2002; UN, 2013). In addition, several parts of the globe already face water scarcity, most notably in Africa, and it is estimated that by 2025 two thirds of the world's population will face water related challenges (UNEP, 2002). Therefore, water is a key at-risk resource and improved water management of it is essential since resource optimization benefits the economy, environment and society (UN-HABITAT, 2005; White et al., 2007).

In Europe, generally, the risk of water scarcity is smaller. However, providing public water supply consumes a significant amount of other resources, e.g., building, maintaining, operating and rehabilitating/replacing the supporting infrastructures (USDE, 2006; Arpke and Hutzler, 2006). Consequently, even in countries with a favorable balance between water demand and water availability, there is interest in evaluating alternatives for improving the efficient use of water. Therefore, organizations with responsibilities in the water sector have been motivated to promote a more efficient water use. In developed nations, there has been a stabilization or reduction of the water use in various sectors (e.g., residential; industry; agriculture) due to the combined implementation of structural (e.g., reduction of water losses) and non-structural (e.g., education campaigns) measures (Dworak et al., 2007).

In order to optimize water management, two main categories of solutions can be identified: (i) reduction of water consumption; and (ii) identification of new water sources. The former includes solutions that promote changing consumption habits and the adoption of lower consumption devices, such as low-flush toilets. The latter includes exploring alternative sources for public water supply. For buildings in general, and residential buildings in particular, one of the most common alternative sources is the rainwater – the

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scope of the present paper. This reviews the most relevant technical and economical issues in designing domestic rainwater harvesting systems, evaluating the technical and economical feasibility of implementing this technology in Portugal. The evaluation is performed for single-family residences from data gathered by Carvalho (2011).

2. Literature review

2.1. General context of rainwater harvesting

Rainwater harvesting (RWH) comprises the collection, storage, treatment and use of rainwater as either a principal or supplementary source of water. This water source has been used for thousands of years throughout the world for both potable and non-potable applications (Fewkes, 2006). In developing countries such as Bangladesh, Botswana, China, India, Kenya, Mali, Malawi or Thailand (UN-HABITAT, 2005; TRCA, 2010), RWH is being used mostly to cope with water shortages for potable and non-potable use (Meera and Ahammed, 2006). In developed countries such as Belgium, France, Germany, Japan, New Zealand, Singapore or United States, RWH use is being promoted mainly to complement conventional systems for non-potable use, namely for toilet flushing, clothes washing, outside washes and irrigation (Herrmann and Schmida, 1999; CWWA, 2002; de Gouvello et al., 2005; UN-HABITAT, 2005; Brandes et al., 2006; Government of France, 2008; Kloss, 2008; Schets et al., 2010; Golay, 2011), but also for potable uses (e.g., Australia – MPMSAA, 2008). RWH is not limited to residential buildings and large scale systems are also found in collective housing and other types of buildings in countries such as Japan (Zaizen et al., 1999), the UK (Chilton et al., 1999; Hills et al., 2001) and Germany (UNEP, 2002).

In Portugal, the DL 23/95 states that non-potable water use is authorized by the public water supplier exclusively for pavement washing, irrigation, firefighting and nonfood-related industrial production, provided that public health is safeguarded. The Water and Waste Services Regulation Authority (ERSAR) guidelines on water use efficiency also present options for using harvested rainwater limited to non-potables uses, mainly irrigation (Almeida et al., 2006). A technical document (ETA 0701, 2012) has been published recently by ANQIP (National Association for the Quality of Building Installations – a non-profit organization promoting water sustainability at a building level) describing the procedures to take into account when installing RWH systems in buildings in Portugal.

Along with the legal limitations, initial cost, social acceptance and treatment requirements have been some of the most relevant obstacles in implementing RWH systems. The most relevant stimuli for using RWH as an alternative water source are usually related to sustainability concerns, which include water scarcity issues (e.g., climate changes, population growth, pollution) and the total costs of public water supply (investment, operation, maintenance and rehabilitation/replacement or disposal).

2.2. Rainwater harvesting solutions

While the sophistication of RWH system components are generally different between developed and developing countries, a typical RWH system in both cases comprises three basic elements: (i) the collection surface; (ii) the conveyance system; and (iii) the storage and distribution systems. The collection surface usually corresponds to roofs and terraces, with the configuration and material of the collection surface affecting the rainwater quality and quantity. After collection, rainwater goes through the conveyance system to treatment, which normally includes a first flush device and a filtration device. The first flush device diverts the initial precipitation volume that tends to be more contaminated due to washing of the pollutants deposited on the collection surface over the preceding dry weather period. The filtration device provides some degree of treatment to the rainwater, but it is limited mostly to the physical characteristics. After filtration, the rainwater is stored in a tank, from which it is conveyed to the end-use-point by a distribution system.

A RWH system may have distinct storage and distribution tanks, or only one tank for both functions. At least one of the tanks should be connected to another water source, usually the public water system when it exists, to assure supply when rainwater is not sufficient. An air gap must be guaranteed to prevent contamination of the public system water. Depending on the location of the tanks, elevated or underground, and of the end-use-point, a pumping system may be required to provide adequate water pressure at delivery.

Optionally, additional treatment stages can be included before the storage tank to assure rainwater quality, but this is not generally required for non-potable uses.

2.3. Previous studies

The investigation on RWH was divided into two categories of studies: water savings and water quality. The former was further divided into general evaluation studies, evaluating water saving potential of RWH solutions, usually at a wide spatial scale (e.g., city, region, country), and specific evaluation studies, more focused in technical and economical viability of RWH solutions for particular well defined cases. Tables 1 and 2 present a review of some of general evaluation and specific evaluation studies on RWH for domestic use, respectively. The studies in Table 2 report to a building scale, but Farreny et al. (2011a) also considered a neighborhood scale and found that, for the case study analyzed, the options were economically non-viable or had very large payback periods (31 and 51 years). Jensen et al. (2010) also evaluated the performance and urban scale showing the benefits of RWH for water supply and stormwater management. Some authors also evaluated RWH for other types of buildings (e.g., petrol stations: Ghisi et al., 2009; airports: Neto et al., 2012).

In Portugal, this topic has received limited interest so far. Oliveira (2008) developed a tool for assessing the economical viability of RWH systems using a 10 years precipitation series. Barroso (2010) and Amado and Barroso (2013) evaluated the potential of RWH in residential houses, estimating water savings of 43.2% for single-family buildings and 31.5% for multi-family buildings. These authors estimated investment periods over 30 years for single-family buildings in three locations throughout Portugal (Faro, Lisbon and Porto). The present paper extends the findings of a research work by Carvalho (2011). The harvested water is contaminated by a variety of pollutants and pathogenic organisms depending on the type of roof and the antecedent dry weather period, amongst other factors (Meera and Ahammed, 2006; Evans et al., 2007; Kus et al., 2010b; Farreny et al., 2011b). Comparing with the results of Mendez et al. (2011), it is clear that the rainwater quality depends on the location. Kus et al. (2010a) found that diverting the first 2 mm of rainfall assures compliance with the Australian Drinking Water Guidelines (ADWG) standards except for lead and turbidity, which required bypassing approximately the first 5 mm of rainfall. A first flush system improves the physicochemical quality of collected rainwater but it cannot avoid microbial contamination of stored rainwater (Gikas and Tsihrintzis, 2012). Despite the contamination, rainwater has been identified as a major source also for drinking, cooking and sanitary purposes (Duncker, 2000) since it does not present increased risk of gastrointestinal illness when compared with water from public supply systems in some regions of the globe (Heyworth,