Journal of Environmental Management 206 (2018) 28–39

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Environmental benefit analysis of strategies for potable water savings in residential buildings

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ARTICLE INFO

Article history:
Received 16 May 2017
Received in revised form
17 August 2017
Accepted 6 October 2017
Available online 19 October 2017

Keywords:
Environmental benefit
Rainwater harvesting
Greywater
Water-efficient appliances
Residential buildings

ABSTRACT

The objective of this study is to assess the environmental benefit of using rainwater, greywater, water-efficient appliances and their combinations in low-income houses. The study was conducted surveying twenty households located in southern Brazil, which resulted in water end-uses estimation. Then, embodied energy, potential for potable water savings and sewage reduction when using the different strategies were estimated. The environmental benefit analysis of these strategies was performed using an indicator that includes embodied energy, potable water savings, reduction of sewage and energy consumption in the water utility, and sewage production during the life cycle of the system. The results indicated that the strategy with the greatest environmental benefit is the use of water-efficient appliances, which resulted in substantial water savings and reduction of sewage, causing low environmental impact due to lower embodied energy over the life cycle.

1. Introduction

Water availability and potable water supply have become issues of concern around the world, mainly due to rapid population growth and population concentration in some regions. The intense and rising damage to the environment are increasingly compromising the quality and quantity of available water resources. Furthermore, mismanagement of resources, changes in water consumption patterns and drought have led to the shortage of drinking water in many parts of the world.

Given this scenario, government authorities, public and private institutions emphasize the need to implement alternative water sources and water conservation practices to meet the growing demand for water in cities (Morales-Pinzón et al., 2012; Marinho et al., 2014). Water savings by using different strategies have been studied by many researchers from different countries as follows:

- water-efficient appliances (Willis et al., 2013; Kordana et al., 2014; Gao et al., 2017; Fidar et al., 2016);
- rainwater harvesting (Umapathi et al., 2013; Shimizu et al., 2013; Hajani and Rahman, 2014; Lee et al., 2016; Siems and Sahin, 2016; Lopes et al., 2017);
- greywater reuse (García-Montoya et al., 2016);

Rainwater use in different building types have been widely explored worldwide, demonstrating potential for potable water savings. For example, in the literature were found works dealing with:

- homes (Zhang et al., 2009; Jones and Hunt, 2010; Rahman et al., 2012; Palla et al., 2012; Ghisi and Schondermark, 2013; Mehrabadi et al., 2013; Bocanegra-Martínez et al., 2014; Silva et al., 2015; Haque et al., 2016; Fonseca et al., 2017);
- hotels in China (Deng, 2003);
- schools in Taiwan (Cheng and Hong, 2004; Cheng, 2003);
- single-family homes and buildings in Australia (Zhang et al., 2009; Liaw and Chiang, 2014; Gurung and Sharma, 2014) and the UK (Ward et al., 2012);
- others (Devkota et al., 2015; Morales-Pinzón et al., 2015; Sample and Liu, 2014; Thomas et al., 2014; Mahmoud et al., 2014; Campisano and Modica, 2012; Ghisi et al., 2012; Rahman et al., 2012; Domènech and Saurí, 2011; Jones and Hunt, 2010).

There are also studies about greywater reuse, alone or in combination with rainwater harvesting, showing the potential for

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https://doi.org/10.1016/j.jenvman.2017.10.004
0301-4797/

potable water savings, such as Chrispim and Nolasco (2017), Leong et al. (2017), García-Montoya et al. (2016), Gois et al. (2015), Maimon et al. (2014), Oron et al. (2014), Proença and Ghisi (2013), Couto et al. (2013), Proença et al. (2011), Muthukumaran et al. (2011), Mandal et al. (2011), Rozos et al. (2011), Li et al. (2010), Godfrey et al. (2009), Ghisi and Oliveira (2007).

The analysis of the embodied energy in building materials is of great importance to determine the total embodied energy in different systems of the building. Embodied energy includes all phases from extraction of the raw material until it is ready to be delivered from the manufacturer. Considerable amount of energy is spent in the manufacturing processes and transportation of various building materials. Conservation of energy becomes important in the context of limiting greenhouse gases emission into the atmosphere and reducing costs of materials (Venkatarama Reddy and Jagadish, 2003).

There are also some studies that have addressed water savings by considering environmental impact, life cycle and embodied energy. Taborianski (2002) calculated the embodied energy (in kWh) for manufacturing components in water heating systems. Nazer et al. (2010) performed an economic, environmental and social assessment of several options for domestic water savings in the West Bank (Middle East). Racoviceanu and Karney (2010) used a hybrid method based on life cycle analysis to assess residential water conservation strategies. Angrill et al. (2012) evaluated several solutions of rainwater harvesting in urban areas with different densities in the Mediterranean in order to determine the most environmentally profitable strategy. Kalbusch and Ghisi (2012, 2016) proposed a method based on the concepts of life cycle analysis to quantify the energy consumption of water appliances. Morales-Pinzón et al. (2012) conducted a financial feasibility study and an analysis of potential environmental impacts of rainwater harvesting used in different household typologies built in different urban areas in Spain. Ghisi et al. (2014) conducted a study to classify potable water saving strategies on the basis of energy consumption indicators, and water and financial savings. Ghimire et al. (2014) proposed a method to perform life cycle assessment of domestic rainwater harvesting and agricultural rainwater harvesting systems.

In the international scenario, studies approaching the environmental benefits of using rainwater, greywater, water-efficient appliances and their combinations in low-income houses are unusual (Chidya et al., 2016; Laskari et al., 2016). The majority of studies assess water consumption reduction in single-family and multi-family residences of medium income.

Currently, there are few studies available in the literature addressing strategies for water savings, alone or in combination, in low-income households in Brazil (Peters et al., 2006; Cohim et al., 2008; Rupp et al., 2011; Franci and Gonçalves, 2012; Vieira, 2012; Garcia et al., 2013). The implementation of actions for the rational use of water in low-income households is a challenge because some factors such as the small roof area against the number of inhabitants (high occupation and small built area), and the limitation of space for installation of the rainwater tank, could limit the use of rainwater. The potential for potable water by using rainwater in low-income households tends to be lower than in medium and high standard buildings (Ghisi and Ferreira, 2007; Vieira, 2012). However, with the development of new public housing policies in Brazil, the rational use of water in low-income houses has the potential to reduce demand on public water utility and sewage systems. Thus, the objective of this paper is to assess the environmental benefit of adopting strategies for water savings (rainwater harvesting, greywater reuse, water-efficient appliances) in low-income homes in southern Brazil. Such assessment includes embodied energy, potable water savings, reduction of sewage and energy consumption during the life cycle of the strategies.

2. Method

First, a sample of homes was selected for analysis of water end-uses. Subsequently, the strategies for water savings were defined and the potential for potable water savings, the reduction of domestic sewage and the embodied energy in the production phase of the components of each strategy were estimated for a household model that represents the sample of houses. Finally, the environmental benefit analysis of each strategy considering the potable water savings, the reduction of sewage and the embodied energy over the life cycle was assessed for the household model.

2.1. Sample of houses and household model

Twenty single-family houses were selected for the water end-uses analysis. The houses are located in low-income areas in *Jardim Eldorado* and *Jardim Aquarius* neighbourhoods, city of Palhoça, metropolitan region of Florianópolis, State of Santa Catarina, southern Brazil. Fig. 1 shows the location of both areas. The criteria for the selection of the low-income areas were:

- Low-income houses located in the same neighbourhood (e.g. slums, shanty towns, or suburbs with a high concentration of low-income houses);
- Household monthly income less than or equal to 3 minimum wages (3 x R$ 622.00 = US$ 987.30 in April 2012);
- Households construction funded by the programme *Minha Casa Minha Vida*[1] or other Brazilian public housing programme for low-income households.

The average monthly rainfall over the period 2000–2006 was 133 mm/month and the average annual rainfall was 1595 mm/year. The highest average rainfall occurs in summer and the lowest rainfall in winter (June to August). Fig. 2 shows the average monthly rainfall over 2000–2006.

A series of seven-year rainfall with daily temporal resolution was used because simulations carried out using series equal to or greater than ten years did not present significant differences for the results referring to the potential for potable water savings when using rainwater (Ghisi et al., 2012).

A household model with roof catchment area and built area equal to the average of the areas noted in the sample of houses was selected to represent the households. The assessment of the potential for potable water savings and sewage reduction, as well as the environmental impacts resulting from the implementation of different strategies for water savings occurred through theoretical analysis of the household model.

Thus, a single-family house (single storey) with 62 m^2 of built area and 80 m^2 of roof catchment area was selected as the household model. Fig. 3 shows the household model design.

The number of occupants ranged from two to five per household, and the average number of occupants was three people per house. Family income was equal to or less than four minimum wages (on 11 April 2016 four minimum wages accounted for R$3520.00, £692.03, US$985.35).

The following water appliances were found in each household:

[1] The programme *Minha Casa Minha Vida* - Brazilian largest low-income housing governmental programme - was launched in 2009 by the Department of Cities of the Brazilian Federal Government. Through this programme, R$ 71.7 billion (US$ 42.8 billion) were invested to build two million low-income houses in the period 2010–2014 (BRAZIL, 2011).