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Integration of technologies and alternative sources of water and energy to promote the sustainability of urban landscapes

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ABSTRACT

Recent research has highlighted the positive role of green areas in urban environments, providing numerous social, environmental and economic services, such as mitigation of the urban heat island effect, storm attenuation, increased water infiltration into the soil, reduction of noise and air pollution, among others. However, the maintenance of green areas may result in high consumption of water, reaching 50% of the total consumption in some municipalities, and energy, becoming a reason of concern. The present study aimed to integrate techniques and technologies that promote the automatic and efficient irrigation of urban landscapes, using alternative sources of energy and water, toward its sustainability. The conceptual unit was able to reduce in 64% the water consumed in irrigation. Rainwater met 69% of the demand and the photovoltaic system supplied all the energy required. The economic feasibility analysis showed that the conceptual unit is financially unfeasible, under the conditions of this study. However, with some interventions for reusing the surplus energy and water, and considering the higher fees charged by other cities, the investment became attractive. In this new scenario, the internal rate of return (15 years) was 27.3% and the discounted payback period was 4.9 years.

1. Introduction

Recent research has shown the positive role of green areas in urban environments, providing numerous social, environmental and economic services (Zhang et al., 2012; Tratalos et al., 2007; Klok et al., 2012; Millward and Sabir, 2011; Conway and Urbani, 2007; Soares et al., 2011). Some authors highlight the relationship between green areas and the mitigation of the urban heat island effect, since the treetops are able to effectively intercept and reflect the insolation, dissipating the heat (Takebayashi and Moriyama, 2007; Alexandri and Jones, 2008; Gill et al., 2007). Among other benefits, green areas attenuate storms, since the rainfall interception by trees and the temporary retention of water within their canopy reduce runoff peak flows (Xiao and McPherson, 2002) and increase soil infiltration (Inkiläinen et al., 2013). In addition, they reduce the air pollution (Jim and Chen, 2008) and sequester CO_2 to form woody and foliar biomass (Nowak et al., 2006). They also increase the attractiveness of the communities, reduce noise, improve wildlife habitat and provide recreational opportunities (Jim and Chen, 2008; McPherson and Simpson, 2002).

However, green areas are often associated with high water requirements, particularly during periods of dry weather. This is the case of some municipalities in the western U.S., where irrigation consumes 50% of municipal water (Lowry et al., 2011); in the west of Australia it reaches 56% of domestic consumption (Syme et al., 2004); in Texas, this is the third largest use (Cabrera et al., 2013). Salvador et al. (2011) evaluated the water consumption for the irrigation of 102 home gardens in Zaragoza, Spain, and found that 60% of the houses consumed more water than necessary. This is reason for concern since the use of potable water in such activities has become increasingly strict due to scarcity of such resource (Strutt et al., 2008). All this indicates the need to increase water use efficiency in urban landscapes as well as to search for alternative sources.

Automatic irrigation using moisture sensors has improved the efficiency of the process (O'Shaughnessy et al., 2012; Romero et al., 2012; Coates et al., 2013). These sensors may reduce consumption in up to 75% compared with manual irrigation. Besides conserving water, some of these studies have reported an improvement in the visual quality of the landscape (Hunt et al., 2001; Devitt et al., 2008). However, an efficient irrigation requires a link between the real-time reading of the sensor and the landscape actual demand,

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in order to identify the exact moment when the water replacement is necessary.

The water demand of urban landscapes is quite different from agricultural crops due to the specific conditions of such spaces (Costello et al., 2000; Nouri et al., 2013). They present various plant species with different water needs, as well as different microclimates and densities. Therefore, it is necessary to adopt specific indexes for each landscape (Costello et al., 2000; The Irrigation Association—Water Management Committee, 2005; Snyder and Eching, 2004, 2005; Allen et al., 2007). Estimating the irrigation need of areas with mixed vegetation is a challenge, and local climatic and metabolic aspects of plants should be taken into account (Salvador et al., 2011; Costello et al., 2000; Costello and Jones, 1994).

Another disadvantage of green area maintenance is related to the consumption of electricity for water pumping, which can be solved, however, by the use of alternative energy sources. The high price of oil, added to concerns about the environmental impact of burning fossil fuels and strong government incentives, have made renewables the fastest growing energy source (USEIA, 2011). Solar energy is an alternative source that can supply with great advantage most of the energy needs. Solar photovoltaic (PV) technology remains, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity, and is expected to grow 22% until 2017 (EPIA (European Photovoltaic Industry Association), 2013). The estimated time necessary for the incident solar energy to equal the world annual energy demand is of approximately 12 min. In three weeks, the incident solar energy on the Earth's surface equals to all known reserves of fossil fuels such as oil, natural gas and coal (Rüther, 2000).

Therefore, despite some research studies on the efficiency of urban landscape irrigation (Nouri et al., 2013; Johnson and Belitz, 2012; McCready et al., 2009), which have evaluated the use of rainwater for several purposes (Neto et al., 2012; Liang and Dijk, 2011; Yuan et al., 2003; Bocanegra-Martínez et al., 2014; Hashim et al., 2013) and used photovoltaic energy as an alternative source (Bouzidi, 2011; Hamidat and Benyoucef, 2009; Meah et al., 2008), there are no studies that integrate such approaches in order to make irrigation self-sufficient.

The present study had the objective to integrate techniques and technologies to promote the automatic irrigation of urban landscape using alternative sources of water and energy towards the sustainability of the system.

This integration was investigated through the construction of a compact and replicable conceptual unit, which makes urban irrigation efficient and independent. The unit is capable of automatically producing its own inputs from natural resources and requires minimum supervision and intervention.

2. Methodology

The premise of the conceptual unit was the use of alternative sources of water and energy to make sustainable urban landscapes, using automatic and optimized irrigation with minimum intervention and supervision.

Three independent systems were designed: one responsible for rainwater harvesting, storage and treatment; another for the automation and optimization of the irrigation system; and the third one for providing electric power to the unit with the use of photovoltaic panels, as shown in Fig. 1.

2.1. Study area characterization

The conceptual unit was installed at the Laboratory of Sanitary and Environmental Engineering (LESA) of the Federal University of Viçosa, state of Minas Gerais, at UTM coordinates 722924 E, 7702003 S, 23 K zone. The building has 380 m^2 covered with fiber cement roofing and front and side gardens with a total area of 288 m^2, where the experiment was conducted.

Viçosa is at an average altitude of 670 m, with a relief ranging from wavy to mountainous. The climate is Cwa, mesothermal humid with rainy summers and dry winters, according to the Köppen classification. There is water deficit from April to September and surplus between November and March. According to the National Institute of Meteorology—INMET (2013), for the period between 2004 and 2012, Viçosa presented annual average rainfall of 1281 mm, average temperature of 20.0 °C, average radiation of

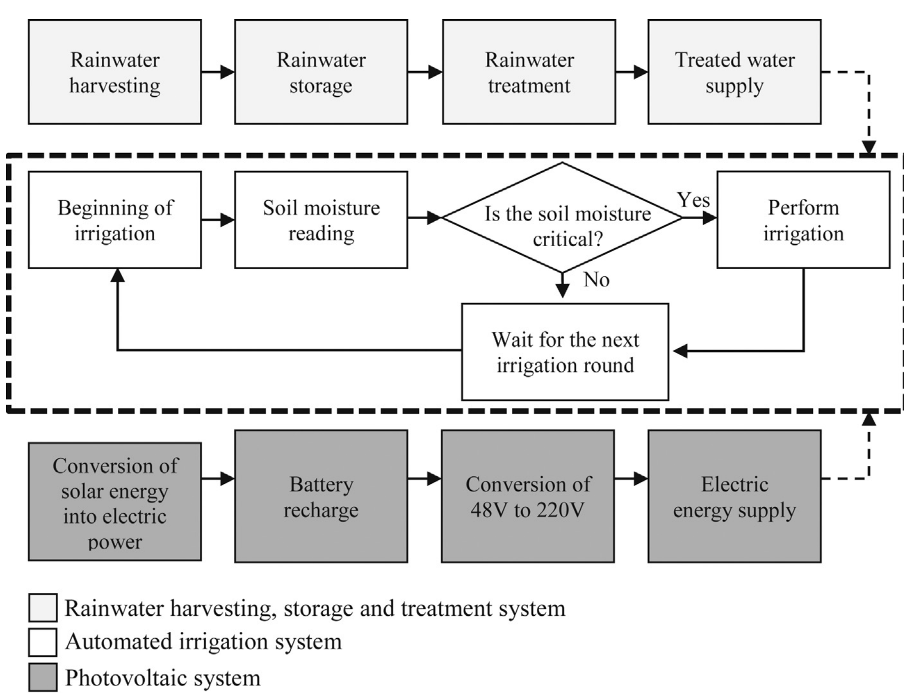

Fig. 1. Integrated systems flowchart.