Journal of Environmental Management 93 (2012) 147–153

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

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

Design and operational parameters of a rooftop rainwater harvesting system: Definition, sensitivity and verification

J.S. Mun[a], M.Y. Han[b,*]

[a] Rainwater Research Center, Seoul National University, 599 Gwanangno, Gwanak-gu, Seoul 151-742, Republic of Korea
[b] Department of Civil and Environmental Engineering, Seoul National University, 599 Gwanangno, Gwanak-gu, Seoul 151-742, Republic of Korea

ARTICLE INFO

Article history:
Received 13 January 2011
Received in revised form
1 August 2011
Accepted 17 August 2011
Available online 5 October 2011

Keywords:
RWH system
Design parameters
Operational parameters
Sensitivity analysis

ABSTRACT

The appropriate design and evaluation of a rainwater harvesting (RWH) system is necessary to improve system performance and the stability of the water supply. The main design parameters (DPs) of an RWH system are rainfall, catchment area, collection efficiency, tank volume and water demand. Its operational parameters (OPs) include rainwater use efficiency (RUE), water saving efficiency (WSE) and cycle number (CN). The sensitivity analysis of a rooftop RWH system's DPs to its OPs reveals that the ratio of tank volume to catchment area (V/A) for an RWH system in Seoul, South Korea is recommended between 0.03 and 0.08 in terms of rate of change in RUE. The appropriate design value of V/A is varied with D/A. The extra tank volume up to V/A of 0.15 ~ 0.2 is also available, if necessary to secure more water. Accordingly, we should figure out suitable value or range of DPs based on the sensitivity analysis to optimize design of an RWH system or improve operation efficiency. The operational data employed in this study, which was carried out to validate the design and evaluation method of an RWH system, were obtained from the system in use at a dormitory complex at Seoul National University (SNU) in Korea. The results of these operational data are in good agreement with those used in the initial simulation. The proposed method and the results of this research will be useful in evaluating and comparing the performance of RWH systems. It is found that RUE can be increased by expanding the variety of rainwater uses, particularly in the high rainfall season.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

Water shortages are relevant not only to water scarce regions but also to those with an appropriate water supply infrastructure in place, due to the need to secure a stable water supply that allows for rising water demand, rapid urbanization and climate change. Rainwater harvesting (RWH) constitutes one of the most feasible solutions to coping with present conditions, and several countries are reappraising its value (Hatt et al., 2006; Han et al., 2009; Zhang et al., 2009; Rygaard et al., 2011). RWH is also expected to contribute to restoring the urban water cycle and alleviating water-related disasters, in addition to increasing the water supply (Coombes et al., 2002; Han and Kim, 2007; Kim and Han, 2008).

Many researchers have measured the quality of the water in RWH systems (Evans et al., 2006; Magyar et al., 2007; Lye, 2009), and several measures to improve that quality have been proposed and investigated (Han and Mun, 2008; Amin and Han, 2009). Securing a sufficient quantity of rainwater and controlling the quality of that water are important issues in ensuring that an RWH system achieves the rainwater management goal of saving water and improving the safety of the water supply. Rainwater tank capacity is one of an RWH system's most significant design parameters (DPs). The tank volume to catchment area ratio recommended by the Korean Ministry of the Environment (2008) is 0.05 m^3/m^2. The amount of rainwater collected and the level of demand for non-potable water uses must also be taken into account (ARSIT, 1998; German Institute for Standards, 2001). Ward et al. (2010) have evaluated the design of two different RWH systems using three system design methods and presented necessity of sophisticated continuous simulation tools. Hence, determining the optimal tank capacity of an RWH system requires evaluation of system performance by the operational parameters (OPs) that represent that system's efficiency.

A roof RWH system, which collects runoff from the roof, generally consists of a catchment area, a filter, a storage tank, a supply facility, pipes and an overflow unit (Han and Mun, 2008). As a consequence, the principal DPs that affect operational efficiency are the amount of rainfall, the catchment area, tank volume,

* Corresponding author. Tel.: +82 2 880 8915.
E-mail addresses: jsmun21@gmail.com (J.S. Mun), myhan@snu.ac.kr (M.Y. Han).

0301-4797/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvman.2011.08.024

water demand, and the efficiency of runoff collection and the filter. The major components of an RWH system and the DPs related to them are shown in Fig. 1.

Water saving efficiency (WSE) is the OP usually employed to evaluate RWH system performance in households, commercial buildings, sports complexes and residential area (Chilton et al., 1999; Fewkes, 1999; Zaizen et al., 1999; Villarreal and Dixon, 2005; IWA, 2008). Dixon et al. (1999) showed changes in WSE by household occupancy, roof area, appliance type and storage volume in a combined rainwater and greywater reuse system using model simulation.

In the design of an RWH system, although various OPs should be introduced to evaluate system performance and devise effective design measures, the evaluation of system operational efficiency has primarily been conducted in terms of WSE. Sensitivity analysis examining the effects of DPs on RWH system performance is rare. Furthermore, these effects still require verification on the basis of data gained from an operational RWH system.

This paper defines the OPs that are employed to evaluate RWH system performance, analyzes sensitivity of DPs on OPs and suggests the recommended range of DPs for improving RWH system design and operation, and, finally, verifies a water-balance based design method for RWH systems using operational data from the RWH system of the dormitory complex at Seoul National University (SNU) in the Republic of Korea.

2. Materials and methods

2.1. Design and evaluation method for RWH systems

The design and performance efficiency of an RWH system is primarily based on the mass balance of water in the tank, taking into account such factors as runoff from the roof, the water supply and overflow, as shown in Fig. 2.

The water balance equation for the conditions described in Fig. 2 can be expressed as follows.

$$V_{t_k} = \sum_{t=t_0}^{t_k} (Q_{i,t} - Q_{o,t} - Q_{s,t}) \quad (1)$$

where Q_i is runoff from the roof (m^3/day), Q_o is overflow from the tank (m^3/day), Q_s is the rainwater supply (m^3/day), V is tank volume (m^3), t is elapsed time (in days) and Vt is the storage volume of the rainwater in tank (m^3) at time t.

This study mainly covered the effects of building and RWH system factors and daily rainwater demand on RWH system performance at the given site. Rainfall data for Seoul where is the capital of South Korea shown in Fig. 3 were obtained from the Korea Meteorological Administration and used for simulation. The station used in this study is Seoul station of which ID is 108. The station elevation is 85.5 m with Latitude N 37°34′ and longitude E 126°57′.

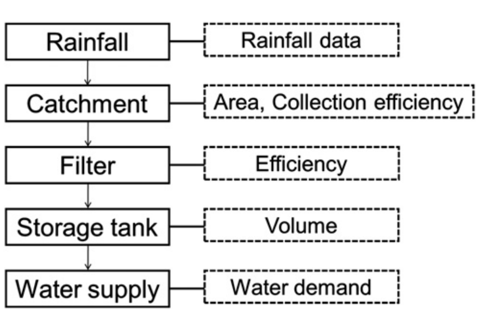

Fig. 1. Components of an RWH system and their design.

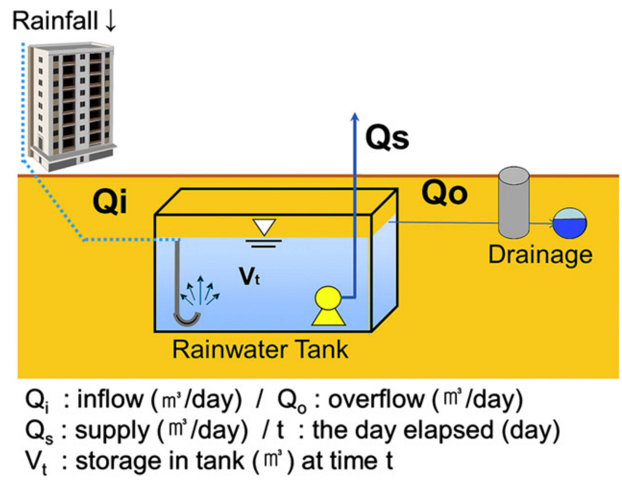

Fig. 2. Schematic diagram of water flow in a rainwater tank.

Seoul has the relatively high and biased annual rainfall pattern typical of a monsoon climate. About 70% of the year's rainfall is usually concentrated in the summer season. The mean and coefficient of variation (C.V) of annual rainfall and mean annual temperature from 1981 to 2010 are 1450.5 mm, 0.26 and 12.5 °C respectively. Daily rainfall data in 2007 was used for sensitivity analysis. And the data from 2004 to 2007 was used for verification. Studies carried out at different sites could thus be expected to produce different results.

The OPs (output) of the RWH system under various DPs (input) were calculated through computer simulation using the algorithm shown in Fig. 4.

Three OPs, rainwater use efficiency (RUE), WSE and cycle number (CN), were defined and employed to design and evaluate the RWH system. RUE indicates the proportion of total rainwater supply to amount of collected rainwater in a given catchment area and period. A high RUE value means that rainwater is collected and used efficiently in the RWH system. WSE refers to the proportion of total water demand that is satisfied by rainwater. A high WSE value indicates that rainwater has the potential to become a major water

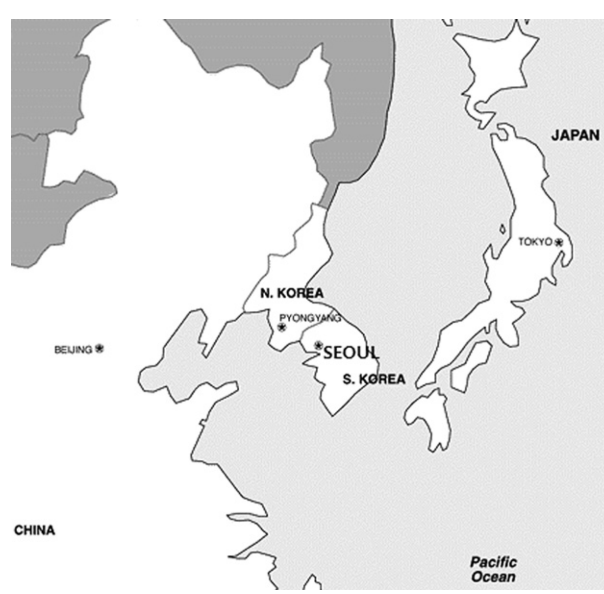

Fig. 3. The location of Seoul, South Korea.

Download English Version:

https://daneshyari.com/en/article/1056976

Download Persian Version:

https://daneshyari.com/article/1056976

Daneshyari.com