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EFFICIENCY ANALYSIS OF RAINWATER HARVESTING METHODS ON MEGA-SCALE: A REVIEW

Arvind Pratap Singh*; Archana Negi**

*Department of Agricultural Sciences,
Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, INDIA
Email id: arvinds.agriculture@tmu.ac.in

**Department of Agricultural Sciences,
Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, INDIA

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ABSTRACT

A novel rainwater harvesting (RWH) system dependability model is used to evaluate the reliability of collected rainwater for toilet flushing, irrigating gardens, and topping up air conditioners servicing residential apartment buildings in various cities. Rainwater collection is becoming a more important component of the toolbox for sustainable water management. Despite a multitude of studies modeling the feasibility of using rainwater harvesting (Rainwater management) systems in specific settings, there is still a substantial lack in information in terms of comprehensive empirical performance evaluations. Domestic systems have been discussed in the literature to a limited extent, notably in the United Kingdom, but there are few contemporary longitudinal studies of larger non-domestic systems. The findings of a longitudinal empirical performance evaluation of a domestic and non - domestic RWH system in a UK office complex are presented in this article. It also compares actual performance to predicted performance using two British Standards Institute-recommended methods: The Intermediate (basic computations) and Advanced (simulation-based) Strategies.

KEYWORDS: *Domestic systems, Demand Management, Harvesting, Rainwater Collection, Rainwater.*

1. INTRODUCTION

Rainwater harvesting systems are becoming an increasingly important component of the ‘toolkit' for sustainable storm water management. However, increased awareness of the environmental and life cycle effects of such systems has necessitated the use of more precise system designs. This is done not just to save money on capital, but also to save money on materials used in industrial systems, as well as the expenses and resources needed for system building and operation.

1.1 Rule of thumb

Suppliers and other water-related stakeholders often employ ‘rules of thumb' (principles that are not meant to be completely precise or trustworthy in every circumstance) or basic mass balance methods to RWH system design when developing RWH systems. The current British Standard for RWH recommends both basic (‘Simplified', ‘Intermediate') and more sophisticated (‘Detailed') approaches in the UK context. Calculating the roof area draining to the tank, obtaining the estimated annual rainfall depth for the location under consideration, selecting the number of household occupants, and then using one of the look-up charts provided in the BS document are all part of the ‘Simplified' approach for tank sizing estimation(1–4)

1.2 Intermediate method for Rainwater collection

The ‘Intermediate' method is similar to the simplified method(5,6), but it utilizes two equations to compute 5% of the annual rainfall production and 5% of the annual non-potable demand, respectively. The percentage of 5 percent was selected because it corresponds to around 18 days of yearly storage, which is needed to account for daily rainfall fluctuation. The tank size required is then decided by the smaller of the two estimated numbers(7–10). YR = A*e*h*X 0:05 (1) where YR is the yearly rainwater yield (L), A is the collecting area (m2), e is the yield coefficient (percent), h is the rainfall depth (mm), and X is the hydraulic filter efficiency. DN= Pd*n*365*0.05 (2) where DN denotes the yearly non-potable water demand (L), Pd is the daily need per person (L), and n denotes the total number of people. The Simplified and Intermediate techniques should only be used in residential structures. Finally, where demand is irregular (as in commercial or industrial buildings), yield is uncertain (due to integration with green roofs, sustainable drainage systems, or similar), the system is particularly complex, or the anticipated tank size is likely to be large and thus costly, the ‘Detailed' approach is recommended for sizing RWH system storage tanks.

1.3 Performance during the payback period

The Detailed Approach relies on a computer model that uses continuous simulation (a model that tracks the system response over time using a set of equations) in conjunction with the highest resolution and length of rainfall data (for example, daily data for at least 5 years) and the most accurate demand data. Simpler techniques and technologies may not offer the precision and detail needed to correctly design RWH systems, resulting in unrealistic payback times or excessively optimistic whole life cost scenarios (Roebuck and Ashley, 2007). Furthermore, despite a multitude of research modeling the (11–14)in certain settings (a limited sample of which have been summarized in Table 1), there is a substantial lack in information in terms of comprehensive empirical performance evaluations.

1.4 Overview

Domestic systems have been studied in the literature to a limited extent, notably in the United Kingdom. However, in the United Kingdom, there have been few recent longitudinal investigations of bigger non-domestic systems. Furthermore, there are just a few recent studies that compare pre-installation modeled performance estimates to post-installation monitoring data that represents real performance. This article provides the findings of a longitudinal empirical performance evaluation of a non-domestic RWH system situated in an office building in the United Kingdom in order to close this knowledge gap. The article builds on the model-based design assessment by comparing the system's estimated (modeled) water saving efficiency (ET) to the actual (measured) ET during an eight-month period from December 2008 to July 2009.

TABLE 1 SUMMARY OF STUDIES ACCESSING THE WATER SAVING EFFICIENCY OF RAINWATER HARVESTING SYSTEM

Location of study/ system type	**Water saving(%)actual (a) or estimate (e)**
1. Hilly communities of Taipei Taiwan/rural domestic	21.6 a
Beijing, China/urban domestic	25 e
Eco-housing development, Daegu	65 e
Korea/urban domestic Berlin, Germany/urban domestic	70 a
Brazil/urban domestic	48e 100 e (depending on region)
Australia/urban domestic	6e74 e (depending on region)

Tokyo, Japan/urban commercial	59 a

Table 1 shows a substantial lack in information in terms of comprehensive empirical performance evaluations.

A variety of well-known equations and computations were applied to a big structure with a RWH system in the United Kingdom. The next sections go through each of them in detail.

1. RWH system and monitoring data in a case study

The Innovation Centre, an office building in Exeter, UK, where the case study RWH system was monitored. The system's collected rainwater is utilized to flush toilets (also known as 'WCs') and is supplemented by a mains water top-up. Water meters were installed on the mains water and rainfall inlets to the header tanks inside the Innovation Centre to monitor RWH system performance and evaluate ET. A header tank is a temporary storage tank for indirect pumped RWH systems that is placed in a building's roof area. Water is pushed from the main storage tank to the header tank and then gravity supplied from the header tank to the place of usage (Ward, 2010). The Innovation Centre is divided into two wings, each with its own header tank. Separate measurements were taken.

During the monitoring period, the West wing had a larger percentage of the building's permanent inhabitants, thus water consumption from the West header tank was expected to be considerably higher than from the East header tank. (15,16)

2. Calculating water savings efficiency

ET stands for "water saving efficiency" and is a percentage of mains water saved compared to total demand. Only the ET of the WCs was taken into account in this research, which was determined by dividing the volume of rainwater used inside the WCs by the total demand of the WCs. ET was computed using the technique described by Dixon et al. (1999) ET 14 100 V=D (3), where V is the volume of rainwater used (m3) and D is the total WC demand (m3) for this building.(17). ET stands for volumetric reliability, which is defined as the amount of water delivered by the RWH system divided by the total amount of water demand requested from the RWH system for the time period in question.

3. Demand Management:

Between December 2008 and July 2009, readings were collected over an eight-month period. Readings were taken manually (monthly) and automatically (15 minutes), with the latter being centralized within the Innovation Centre's building management system (BMS). A building management system (BMS) is a computer-based control system that monitors the mechanical and electrical systems of a building (in this case, water meters).(18,19).Because of problems with the BMS (as reported in Ward, 2010), the manual readings were utilized as the main data in the analysis presented in this article; a snapshot of BMS data was only used to validate the manual readings. The ET for the Innovation Centre RWH system was calculated using the Rain Cycle modelling tool, which implements the BS Detailed Approach, using the measured rainwater and mains water data for the Innovation Centre. This was then compared to the ET approximated in the prototype inspection tasks using the Rain Cycle modelling tool, which implements the BS Detailed Approach.

2. DISCUSSION

Figure 1 summarizes the average WC mains water plus rainfall usage data. It is evident that the system continuously supplied enough collected rainwater to nearly meet the whole WC requirement during the winter. The system failure that occurred in April, when mains water top-up surpasses rainwater used, is plainly visible, as is the drop in WC demand owing to the Christmas vacation time. A peak in May may also be seen, when the Innovation Centre hosted a conference.

The existence of the café and conference facilities, as well as a larger number of permanent inhabitants in the West core, resulting in a higher amount of water being used in that wing, as conjectured from the East and West wing statistics. During the 8-month monitoring period, the total quantities of harvested rainwater and mains water top-up used were 193.07 m3 and 50.50 m3, respectively, with a mean of 0.86 m3 per day and a standard deviation of 0.49 m3 per day for harvested rainwater. During the 8-month monitoring period, the manually read average ET for the whole building was 79 percent.

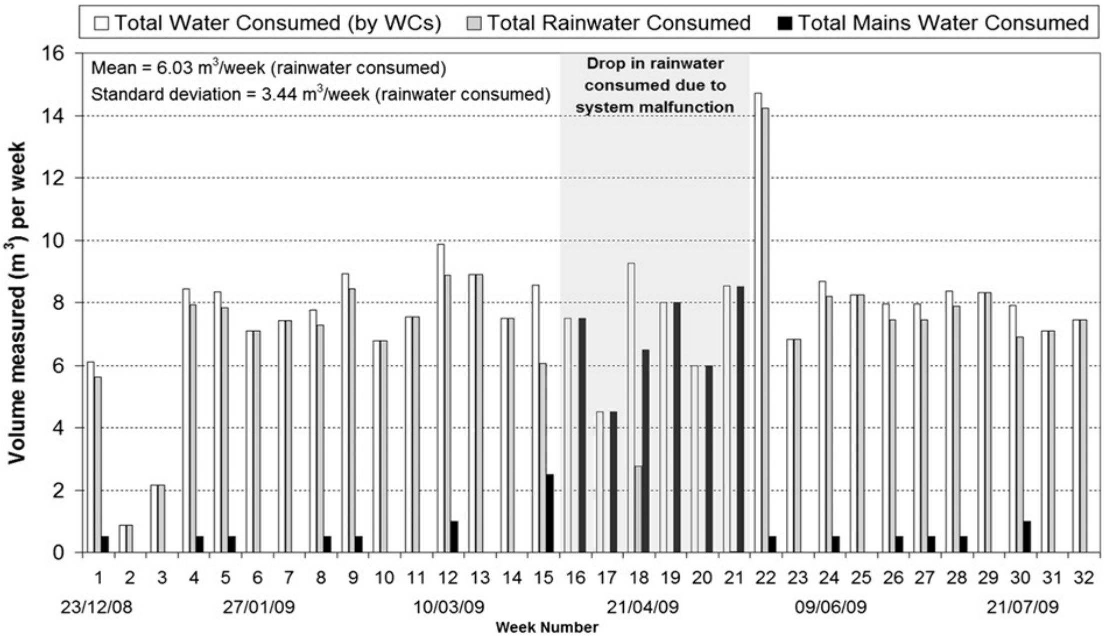

Figure 1: Total weekly WC rainwater and mains water consumed volumes for the Innovation Centre.

The manually read average ET during the 8-month observation period was 79 percent, as previously stated. However, owing to maintenance stakeholder disputes, there was a time wherein the system malfunctioned and was delayed to be addressed. When this part of data is removed, the average ET for the monitored period is 97 percent, with a range of 87e100 percent throughout the 8-month period and no difference between the East and West wings. This is comparable to, but greater than, that seen in prior research (Table 1). The fact that the system was built for a much greater building occupancy explains this. The actual occupancy, at 111, was approximately one-third of the planned occupancy (300 permanent residents plus extra temporary tenants), indicating a lower demand overall. It should be emphasized, however, that data was only gathered during the winter, spring, and a portion of the summer. As a result, the ET throughout the course of the summer might have been lower owing to lesser rainfall or greater due to decreased building occupancy over the summer vacation period(20–22). As a result, the average ET over the course of a year may vary from the range shown above. As a consequence, the findings presented here should be viewed with this restriction in mind.

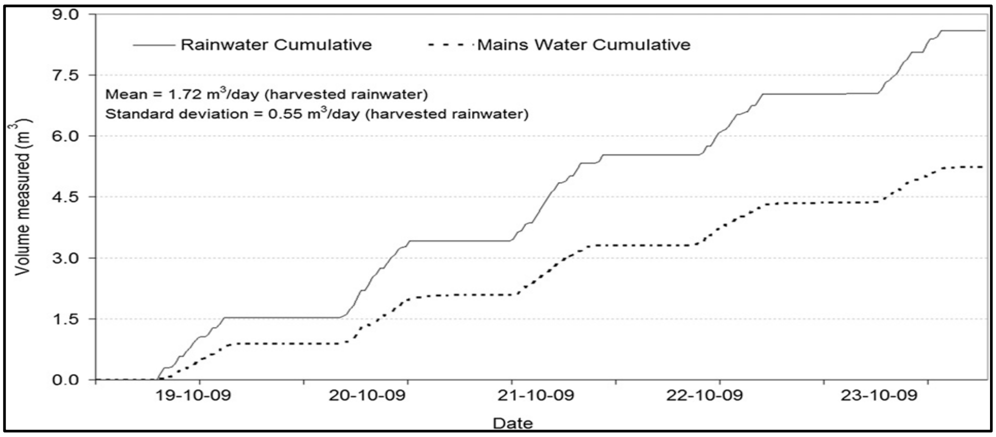

Figure2: Cumulative harvested rainwater and mains water consumption data from the Innovation Centre BMS (23rd October 2009).

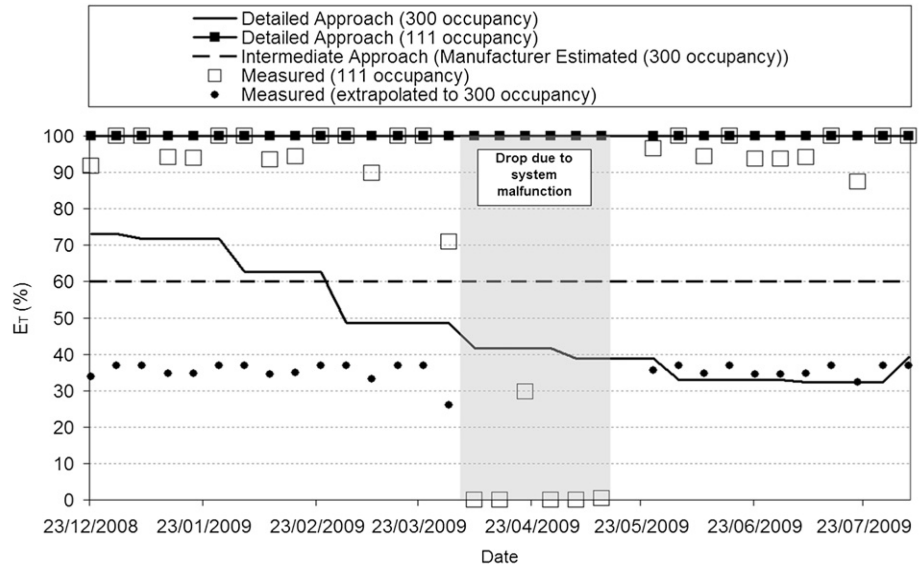

Figure 3: Actual water saving efficiency (ET) of the Innovation Centre RWH system compared with modeled values.

Figure 2 depicts the cumulative harvested rainwater and mains water consumption data from the Innovation Centre Building Management system BMS (23rd October 2009). Whereas Figure 3 provides actual water saving efficiency in graphical form carried out at innovation Centre in contrast with modeled values.

3. CONCLUSION:

The following findings and suggestions were drawn from an objective validation of a large RWH system and a comparison is made with a prototype design and testing: A RWH system saved a considerable amount of water. In an office building, the efficiency (ET) of WC flushing is measured. Because of the potential high ET and efficiency gains, RWH should be promoted in office buildings. The energy expenses of pumping the collected rainwater into such an office complex were negligible. Concerns about energy usage may be alleviated even further by promoting creativity in RWH system design, such as gravity-based systems. The best estimate of real RWH application performance and payback time came from a continuous simulation. Those designing RWH systems must move to more thorough design techniques (continuous simulations) and consumption profiles (especially for non-domestic buildings); using the design occupancy of a planned building in estimating demand. Because of the high demand, the storage tank was over-sized, even though the actual occupancy of the structure was much smaller. When developing a system for commercial/office buildings with possibly varying occupancies, a sensitivity analysis may be helpful to determine the range of container sizes that should be considered.

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