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MULTI TANK MODEL FOR ENERGY EFFICIENT RAIN WATER HARVESTING

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ABSTRACT

Specifically, the study attempted to estimate the extent of the various components of price. The study was Rain Water Harvesting (RWH) to supplement service water is an important aspect of sustainable development. As such, much research has been carried out on optimizing the system components of RWH systems so that a maximum Water Saving Efficiency (WSE) can be reached with a minimum storage capacity, enabling the outlay on capital minimized. However, if the system is to be used in a multi-storey building, either the storage tank has to be placed near the roof at an elevated position, which would require structural reinforcements and would be disturbing the aesthetics of the building, or it has to be placed at ground level with a pumping arrangement to feed the service points at different floor levels. If the pumping option to be practiced, the energy utilization should be minimized to uphold the principles of sustainability. By introducing a multi tank model, where a smaller tank is installed for each floor at its roof level in addition to the main storage tank, a solution can be reached with superior system performance. In the model, the roof collection enters the top most storage tank first and then cascades through multiple tanks in multi-storey situations, before being collected in the main storage tank, vastly improving the overall energy efficiency of the system. The model, not only addresses the space and structural issues of the building but also ensures that the aesthetics of the building envelop is not disturbed due to smaller sizes of the upper tanks. By developing a system algorithm, the effective run-off and pumping requirements can be determined, which could be a significant design tool to analyze the performance of the model for energy efficient rainwater harvesting.

KEYWORDS: Rainwater, Cascading, Multi-tank, Sustainability, Centralized

INTRODUCTION

Any conventional RWH system consists of a rainwater collector (usually the roof), a storage tank and a piping network to convey the collected rainwater to the storage tank as the main components. Of the three main components mentioned above, the storage tank has drawn most of the attention due to the size, positioning and the capital outlay required on it thus subjecting it to the bulk of research on RWH. Various studies have been carried out to optimize the capacity of the storage tank with regard to the water saving efficiency (WSE), defined as the percentage annual yield against a given constant annual demand, of the composite system. However, even with the optimization, proliferation of RWH systems is not widespread, primarily due to the associated cost of pumping the collected rainwater to individual service points, affecting the perception of RWH systems as effective alternatives to reticulated service water supply. This study introduce a methodology where the main storage capacity is distributed among the floors in a multi-storey building so that the roof collection cascades down to a parent tank through a series of tanks, each collecting and feeding individual floors while contributing to the composite system. As the tanks at upper levels feed the corresponding floors under gravity, the energy required for pumping is minimized. In the model, introduced as Cascading Multi-Tank rainwater Harvesting (CMTRWH) system, rainwater is fed first to the uppermost tank, the overflow of which cascading down to the lower tanks finally ending up in the parent tank at ground level. Supply to each floor is from individual smaller capacity tanks by gravity flow and make-up water is pumped from the parent tank to the top most storage tank as and when required (Figure 1.0). In developing an algorithm for the operation of a CMTRWH system, the following are assumed to be valid; the daily demand for service water at any given floor level remains constant for a given set of operating parameters, no loss of water occurring in system operation. i.e., in cascading down or pumping up of collected rain water and the storage tanks installed at each floor level other than the ground level taken as of equal capacity.

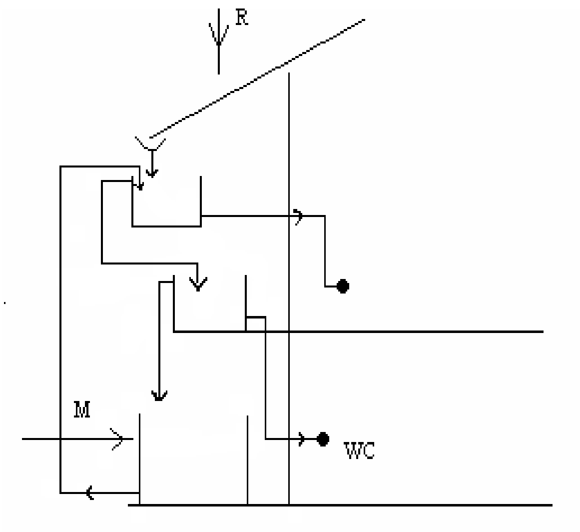

Figure 1.0: CMTRWH system for a two storey house

OBJECTIVE

The objective is to evaluate the viability of a Cascading Multi-Tank Rain Water Harvesting (CMTRWH) system as an energy efficient alternative solution to that of a generic RWH system, in reducing the pumping requirement of collected rainwater to service points in multi-level situations while maintaining a minimum disturbance to the structural and aesthetic aspects of the building envelop.

METHODOLOGY

An algorithm for the performance of a CMTRWH system is developed based on the Yield After Spillage (YAS) behavioral model for generic RWH systems (Jenkins et.al, 1978) with annual demand (D), storage capacity (S), collector area (A) and annual average rainfall (R) as variables. Equations are formulated to determine the amount of collected rainwater that can be pumped up and the amount of roof run-off received by tanks at each level. Generalized curves of WSE for a generic RWH (Fewkes, 1999b), for a given demand fraction (D/AR) are used to select the optimum storage capacities. A prototype CMTRWH system is installed in a setting at which the generalized curves for WSE are validated and the performance of the system evaluated to determine the validity of the developed algorithm.

Development of an Algorithm for CMTRWH Systems

In developing the algorithm, storage tanks at all levels are taken as individually and collectively obeying the Yield After Spillage (YAS) form of the reservoir operating algorithm used in RWH system simulation models. The capacity of each tank is to be determined according to the generalized curves developed for the water saving efficiency (WSE) η, defined as the percentage of yield against demand for a given constant service water demand D (in m^3/year), roof collection area A (in m^2), annual rainfall R (in m) and storage capacity S (in m^3). Shown as a percentage WSE against a storage fraction (S/AR) ranging from 0.005 to 0.40 for a series of demand fractions (D/AR) of 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75 and 2.00, the generalized curves, depicted in Figure 2.0 and validated for tropical countries (Sendanayake et.al, 2014), are used effectively to select the optimum individual storage capacities, for a desired WSE and demand independent of spatial and temporal variations due to different roof collection area and rainfall figures. It is also seen that the system performance is valid and effective within the limits of $0.25 \leq D/AR \leq 2.00$ (Fewkes, 1999b).

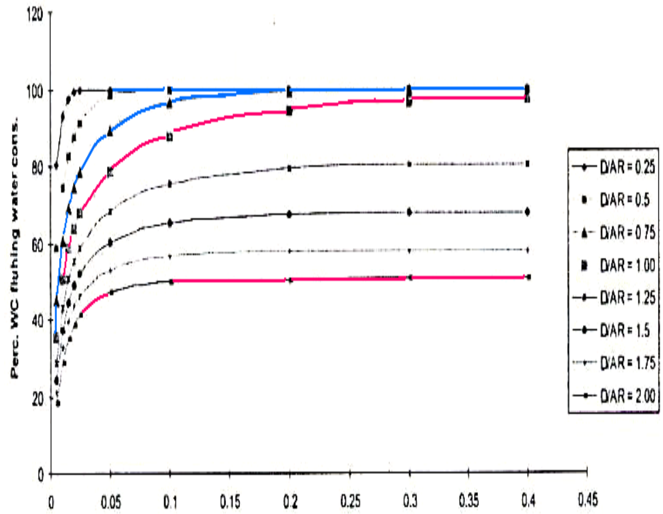

Figure 2.0: Generalized curves for WSE (Fewkes, 1999b)

In order to analyze the performance of the system, the effective roof collection fed into each tank and the amount of water that can be pumped up from the lower tank to the uppermost tank for given WSE values has to be determined. If the water saving efficiency (WSE) of the upper tanks are η_i and the parent tank is η_p for a given capture area A (m^2), annual rainfall R (m) and demand D (m^3/year), and the tank capacities are S_i and S_p respectively, from YAS algorithm and generalized curves for WSE;

$$\eta_i = f\{S_i, D, A, R\}$$
$$\eta_p = f\{S_p, D, A, R\}$$

This can be used to determine the optimum storage tank capacities for the system.

Considering the tank at the lowermost level, called the parent tank, from where pumping is to occur, for a given A, R and D, D/AR can be calculated. Then for a desired efficiency (η_p) the optimum tank size, S_p can be found using the generalized curves for WSE.
As space and weight restrictions dictate the installation of a smaller capacity tanks for the upper

floor levels, a suitable tank size, S_i is selected. Then for each $(AR)_i$ and D_i, η_i can be found from the curves.

Effective Run-Off and Pumping Requirement

For cascading multi tank situations, the following algorithms are valid.
For each floor, If the yield is Y_i, for i = 1 to n
Pumping requirement Q_i ;

$$Q_i = D_i - Y_i = D_i(1- \eta_i) \quad [1.1]$$

Then for the ith floor (ith tank),
When the demand is D_i, supply is $(AR)_i$
But, $(AR)_i = (AR)_{i+1} – Y_{i+1}$
Since $Y_{i+1} = D_{i+1} * \eta_{i+1}$

$$(AR)_i = (AR)_{i+1} – D_{i+1} * \eta_{i+1} \quad [1.2]$$

Further, if the total demand is D,

$$D = \sum_{i=1}^{n} Di \quad [1.3]$$

The overall WSE for the system is denoted as η_o
Therefore, if the number of floors are n and the ground floor is taken as i = 0,
it can be shown that;
The amount of water that can be pumped up in CMTRWH system, Q,

$$Q = \sum_{i=1}^{n} Qi - \sum_{i=1}^{n} Qi\,(1- \eta_P) = \sum_{i=1}^{n} Qi * \eta_P$$

From Equation 3.2,

$$Q = \eta_P \{ \sum_{i=1}^{n} Di - \sum_{i=1}^{n} Di\eta i \} \quad [1.4]$$

When,

$$(AR)i = AR - \sum_{i=i+1}^{n} Di * \eta i \quad [1.5]$$

System Equations for Equal Loads at Each Floor Level

When the demand at each floor level is taken as D_i, and the total system demand is taken as D, for i = 1 to n;
Since $\sum D_i = D$,
$D_1 = D_2 = ……….. = D_n = D/n$
Therefore, from equations 1.4 and 1.5,

$$Q = \eta_P \{ \sum_{i=1}^{n} Di - \sum_{i=1}^{n} Di\eta i \}$$

$$Q = \eta_P D\{1 – 1/n \sum_{i=i+1}^{n} \eta i \} \quad [1.6]$$

$$(AR)_i = AR – D/n \sum_{i=i+1}^{n} \eta i \quad [1.7]$$

Determining the Validity of CMTRWH System Algorithm

To determine the validity of the algorithm developed for CMTRWH systems, the performance of such should be evaluated under different operating conditions. A prototype cascading multi tank model with three tanks are installed in a two storey house located in Colombo, Sri Lanka ($6^0$54'N, $79^0$51'E) where the annual average rainfall is 2000 mm (National Meteorological Department of Sri Lanka), with a roof collection area of 50 m^2. The roofing material is of cement asbestos with a negligible absorption of incident rainfall. The capacity of the parent tank is taken as 12.5 m^3 and the upper tanks at 1 m^3 each to ensure storage fractions S/AR to be of value greater than 0.005 so that they are within the acceptable limits of the generalized curves for WSE and also to ensure a reasonable overall WSE value for the system.

The upper tanks are placed elevated above each floor level to allow collected rainwater to be fed to service points under gravity, while the parent tank is placed at the ground level. System performance is monitored for a daily demand of 200 L per floor with the yield from each upper tank measured and tabulated daily with the pump in operation. The pump is connected to floater switch arrangement to cut-in when the water level in the closest tank to the parent tank drops. The above methodology makes use of the generalized curves for WSE (Fewkes 1999b), validated for Sri Lanka (Sendanayake et. al, 2014), as given in Chart 1.0. Annual yield from the upper tanks and rainwater collection AR, are calculated using 15 day moving average method. The moving average method uses a technique where the average value of a number of consecutive data are averaged and developing a progression of average values so that a vastly higher number of data can be obtained from a limited number of data. If the system follows the algorithm, then the maximum yield possible from the total system, i.e. $D\eta_o$ should be delivered by the two upper tanks.

Therefore, $Y_o = \sum_{i=1}^{i=n} Yi$ generally and $Y_o = Y_1 + Y_2$ in this case.
If so, η_o calculated for $\eta_o = \Sigma Y/\Sigma D$ from measured $(Y_1 + Y_2)$ should be equal to η_o obtained from generalized WSE curves for a set of given D, S and AR.

RESULTS AND DISCUSSION

The results obtained are shown in Chart 1.0.

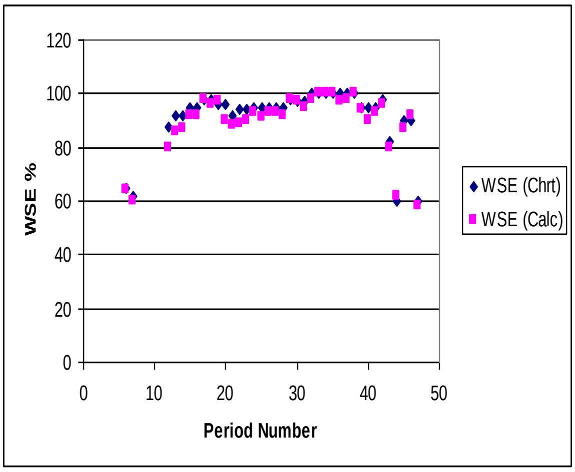

Chart 1.0: Comparative WSE values obtained from prototype CMTRWHS

From the results, it can be seen that the calculated WSE, WSE(Calc) and the WSE obtained from the generalized curves, WSE(Chrt) are almost the same with the margin of error attributed to system losses. The system confirms to the same WSE values achieved by that of a conventional RWH system under varying AR values for a given constant daily demand.

CONCLUSIONS

In the CMTRWH system, the service points at each floor level are fed by gravity and the pump operates only when the composite system is in need of such. The algorithm developed can be used to simulate the performance of the system, particularly to estimate the fraction of roof collection feeding to each tank and the amount of collected rainwater at the parent tank that can be pumped up. The model allows the flexibility of varying the WSE desired for a given demand fraction, limited only by the spatial and structural allowances in a given building envelop. It also provides a means of determining the amount of makeup water from the reticulated mains service water supply required to maintain the water security of the building. The CMTRWH system with storage tanks at each floor level, optimized for a desired WSE against a constant daily demand, therefore is a viable solution to minimize the energy requirement to provide collected rainwater to service points by pumping. As the study was carried out for a two storey building, the effect of the quantity of water circulating in the pipe lines to the overall system performance was considered as negligible. However, as the number of floor increase, the impact of such has to be considered. It will also be useful to analyze the system performance for an uneven demand_at different floor levels.

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