COST EFFECTIVE CASCADING MULTI-TANK RAINWATER HARVESTING SYSTEMS FOR MULTI-STOREY BUILDINGS

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ABSTRACT

Rainwater harvesting (RWH) is a practice which is gaining ground to ensure water security in areas where reticulated service water supply is not viable or reliable. Much research has been done to optimize a conventional RWH system, maximizing the Water Saving Efficiency (WSE) and minimizing the storage tank capacity. The conventional RWH system has been upgraded by the introduction of cascading multi-tank model, to feed service water points through gravity in multi-storey building situations by distributing the storage capacity among different floor levels. However, the multi-tank model is in requirement of a pumping unit to re-circulate the collected rainwater intermittently, as and when needed, to keep the cascading cycle sustained to maintain a desired WSE, incurring a running cost on power. By eliminating the need for pumping, a significant improvement can be made to the model in reducing both the capital investment and the running cost, which would proliferate the use of RWH for multi-storey buildings while enhancing the system reliability.

Keywords: Rainwater, cascading, multi-tank, multi-storey, re-circulate, proliferate

INTRODUCTION

For a given average daily demand, annual average rainfall and roof capture area, a set of generalized curves have been developed to determine the optimum size of the storage tank [2], Fig. 1. The curves depict the Water saving Efficiency (WSE) or η against a storage fraction S/AR for a given demand fraction D/AR and are valid for $0.25 \leq D/AR \leq 2.0$ and $S/AR \geq 0.01$. Any rain water harvesting (RWH) system needs its storage tank positioned below the collector surface in order to get the roof collection conveyed by gravity. In many situations, this compels the storage tank to be placed at or below ground level or in a few cases to place it in between the roof collection surface and the service points posing spatial, structural and aesthetic problems hindering the proliferation of RWH. By placing the storage tank at or below ground level on the other hand require pumping, negating the principles of sustainability espoused by RWH. In multi storey buildings, particularly, one way of addressing the problem has been identified as the introduction of multi-tank rainwater harvesting systems where the storage capacity of the RWH system is distributed among the floor levels using smaller capacity tanks, feeding the service points by gravity and using a pumping unit to maintain the desired WSE by lifting up the collected rainwater in the parent tank to the uppermost feed tank keeping the cascading cycle sustained [6], Fig 2. However, there are many remote locations where grid power is not available or installing of a pumping unit, even with an alternative power source, is not viable for RWH applications thus requiring a model which would be meeting the service water demand at each floor level only through gravity, eliminating the need of a pumping unit. Besides, such a model will not require a larger parent tank at the ground level reducing the total cost of the system further. This research focuses on finding the threshold values for service water demands in order to achieve total supply reliability of harvested rain water fed only through gravity where no pumping is required.

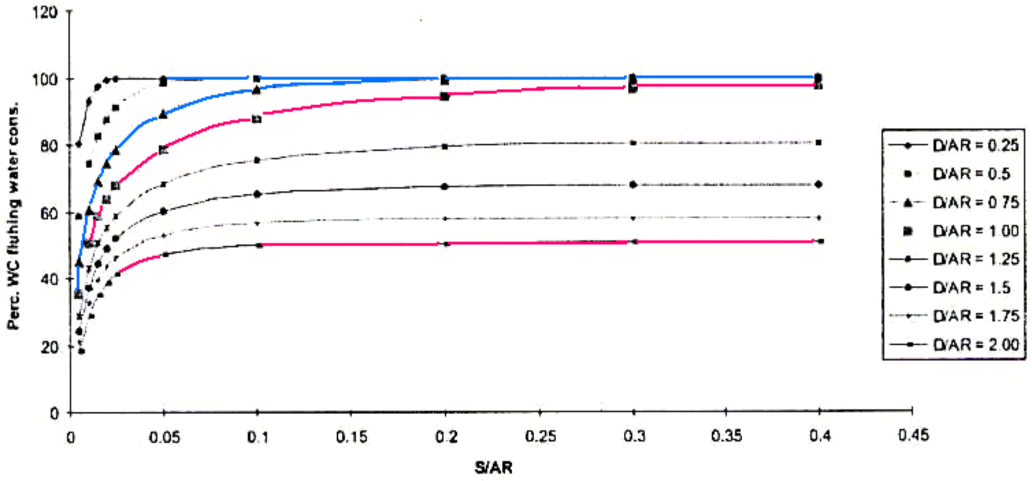

Figure 1: Generalized curves for WSE [2].

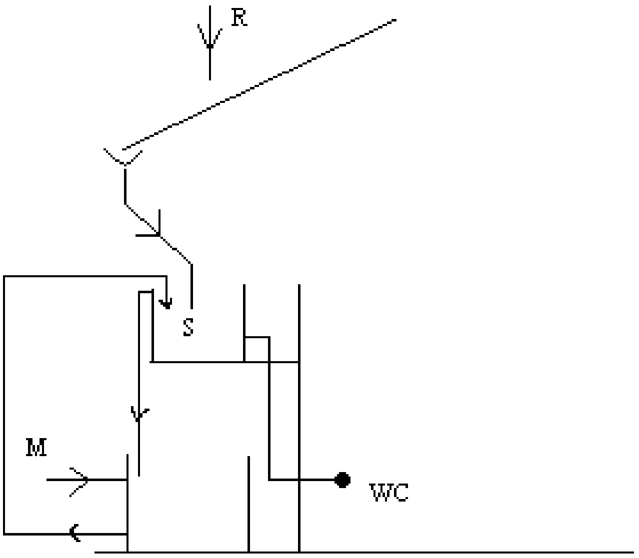

Figure 2: Schematic drawing of a CTTRWH model

OBJECTIVE

The objective of the study is to develop and validate a set of equations that would satisfy the conditions where a Cascading Multi Tank Rain Water Harvesting (CMTRWH) system installed in a multi-storey building would be capable in maintaining a 100% WSE without relying on a pumping unit and a parent tank to maintain the cascading cycle.

METHODOLOGY

Using the system algorithm equations for CMTRWH systems [2] and the boundary conditions of generalized equations for WSE [6], a set of equations are formulated indicating the maximum annual service water demand that can be entertained by the system for total water security in a multi-storey building of ‘n’ levels for a given annual volume of harvested rainwater. Prototype CMTRWH systems are installed in 2 and 3 storey buildings 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 capture area of 50 m^2. Storage tanks of volume 5 m^3, confirming to the condition $S/AR \geq 0.05$, are installed at each level with captured rainwater gravity fed to service points. Daily yields, subject to the theoretical maximum daily demands at each level, and daily roof collections are measured to compare the annual yields against the calculated maximum annual demands for given roof collections.

CALCULATIONS

The contribution of the roof collection to any i^{th} level of a multi-storey building of 'n' levels is given by (1) [6].

$$(AR)i = AR - \sum_{i=i+1}^{n} Di * \eta i \qquad (1)$$

However, for equal demands at all 'n' levels,

$$(AR)_i = AR - D/n \sum_{i=i+1}^{n} \eta i$$

But for $n \geq 2$, $\sum_{i=i+1}^{n} \eta i = n-1$ for all $\eta_i = 1.00$

Therefore,

$$(AR)i = AR-D(n-1)/n \qquad (2)$$

From the generalized curves for WSE, it can be seen that,
For $0.25 \leq (D/AR)_I \leq 0.5$ and $(S/AR)_i \geq 0.05$, WSE is 100%.
It implies therefore, that if a CMTRWH system can be designed with $S_i/AR \geq 0.05$ for individual tanks at upper stories, total supply reliability can be ensured for all $D/AR \leq 0.5$.

Since for each i^{th} level, demand is D/n and (AR)i = AR-D(n-1)/n,
And $\eta = 1.00$ when $S/AR \geq 0.05$ for $0.25 \leq D/AR \leq 0.5$,
$D/n(AR-D(n-1)/n) \leq 0.5$, for $S/AR \geq 0.05$

$$D/AR \leq n/(n+1) \qquad (3)$$

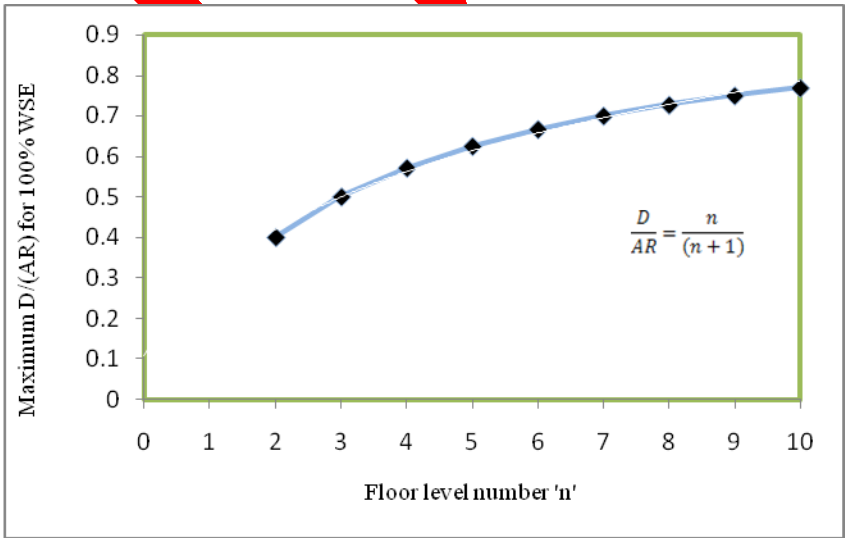

Chart 1: Upper limiting values for D/AR for different floor levels

It can also be shown from WSE curves that;
$\eta = 1.00$ when $S/AR \geq 0.05$ for $D/AR \leq 0.5$

In multi storey situations, $S_{Total} = \sum_{i=1}^{n} Si$

Therefore, for housing units of 2 storey, for $\eta_o = 1.00$ and $\eta_i = 1.00$
$D/AR \leq 0.67$ for $S_i/AR \geq 0.05$
And for housing units of 3 storey, for $\eta_o = 1.00$ and $\eta_i = 1.00$
$D/AR \leq 0.75$ for $S_i/AR \geq 0.05$

For example, for a two storey house in Colombo, Sri Lanka, where R = 2000 mm/year and a roof collection area of 50 m^2, when all S_i are selected as 5.0 m^3, the total demand can be a maximum of 0.67*AR, i.e. 67 m^3 per year at 183.6 L/day. Such a demand will ensure that both floor levels are supplied with collected rain water at 100% WSE. It implies that, by increasing the roof collection area A, an increased demand can be met for a CMTRWH system without the requirement of a pump. However, in designing the system, taking into account that in certain months the rainfall could be so low, the month with the lowest average rainfall for a given location can be selected to calculate the annual rainfall for a foolproof design, though with the disadvantage of having to select a sub-optimum roof collector area.

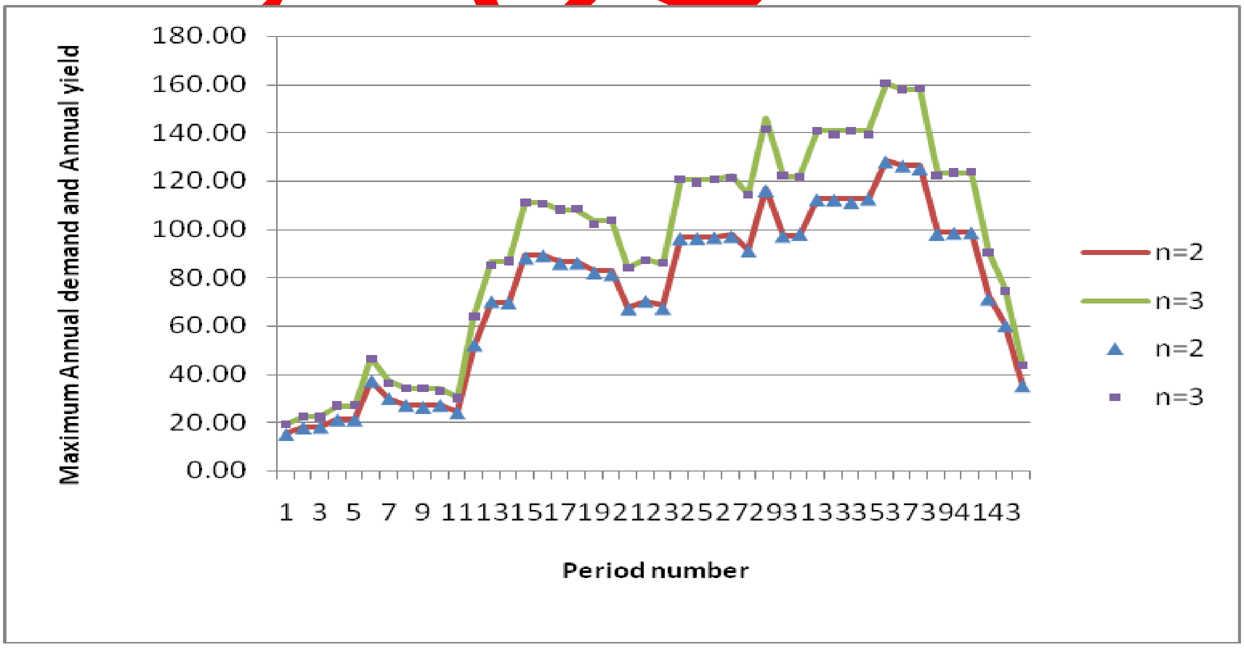

Chart 2: Annual maximum demand and yield values (in m^3) for a given roof collector in 2 & 3 storey buildings

RESULTS AND DISCUSSION

Using the moving average method, where 30 consecutive days are considered a month, a large number of data points are obtained with regard to annual yield and the roof collection (AR). The respective annual yields (S) are compared with the corresponding maximum demand values determined from the equations and plotted for 2 and 3 storey building situations. The demand and the yield values for the corresponding periods are almost coalescing, indicating a WSE of 100%. In the study, the collection losses incurred at the capture area are not considered and the maximum demand possible for a given scenario therefore, should be adjusted accordingly. However, in the validation, the maximum demand was calculated using the actual roof collection volume, taking into account the capture losses.

From (3), the limiting value for D/AR for the system to function totally under gravity is obtained as a function of the number of floor levels, 'n'. It implies that when D/AR is below the limiting value $D/AR \leq n/(n+1)$, the system is capable of operating without the requirement of a parent tank and a pumping unit, thereby significantly reducing the capital outlay on the system in addition to zero running cost in energy and maintenance. Therefore, a cascading multi tank rain water harvesting (CMTRWH) system with D/AR below the threshold value could be ideal for high rise buildings when the demand can be catered with increased roof collection area (A) for a given annual rainfall (R). However, it is important to note the variation of the storage capacity of the composite system (S) as well as the capacities of individual feed tanks (S_i) with the increase of floor levels for the threshold value of D/AR. It can be seen from (1), for the system to function totally under gravity, $\sum\eta_i$ should be maximum requiring $\eta_i = 1.00$ for $i = i+1$ to n. Further, the water saving efficiency (WSE) of the composite system η_o should also be 1.00. Therefore, two limiting values for S and S_i can be considered. From generalized curves for WSE [2] it can be seen that as $S_i = S/n$, for $n \geq 2$, and $S/AR \geq 0.05$ for $D/AR \geq 0.67$. Similarly, $\eta_o = 1.00$ for all S when $S/AR \geq 0.05$ for all $D/AR \geq 0.67$. From Chart 1 it can be seen that when the number of floor levels 'n' increases, the threshold value for D/AR increasing.

This increment of D/AR is compensated by the increasing capacity of the composite system S, so that when the number of floor levels increase $\eta_o = 1.00$. However, since the WSE curves are valid only for $D/AR \geq 0.25$, a minimum value for S_i can be determined when $S_i/AR \geq 0.05$, $D/AR \geq 0.67$ for $\eta_i = 1.00$. Therefore, for any CMTRWH system totally relying on gravity feed of collected rain water, should have its upper level feed tanks with capacities greater than 0.05AR. However, it implies that if the collection area A is increased for a given annual rainfall R to compensate for the increased demand D, the increased size and hence the weight of feed tanks would pose a problem of accommodating upper level tanks within the building envelop.

CONCLUSIONS

CMTRWH systems can be effectively used without a ground level parent storage tank at ground level and a pumping unit subject to a maximum annual demand for a given AR value and for a given number of floor levels ‘n’. Such a model by not utilizing energy for pumping not only will allow rainwater harvesting fully conforming to sustainable principles but will also be cutting down the total cost of the system by eliminating the need of a parent tank and a pumping unit. Further, the elimination of pumping reduces the amount of collected rainwater that would be retained in the piping network affecting the overall WSE of the system. The proposed model, however, needs all the storage tanks filled up at the commencement of the operation to reduce the time required for the system to be fully functional, with the cascading effect taking place. As all the service points are gravity fed, with the tanks for each level located at only one level up, the service pressure could be low and may have to be boosted if necessary.

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