

MULTI TANK MODEL FOR ENERGY EFFICIENT RAIN WATER HARVESTING

¹S. Sendanayake, ²M. T. R Jayasinghe

¹Postgraduate Student, Department of Civil Engineering, University of Moratuwa, Moratuwa, Sri Lanka.

¹E-mail: sisuru@civil.mrt.ac.lk

¹Telephone: +94-11-2650567-8 (Ext.2021) ; Fax: + 94-11-2651216

²Professor, Department of Civil Engineering, University of Moratuwa, Moratuwa, Sri Lanka.

²E-mail: thishan@civil.mrt.ac.lk ; mtrjayasinghe@yahoo.com

²Telephone: +94-11-2650567-8 (Ext.2006 - 2001) ; Fax: + 94-11-2651216

Abstract: 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 RWH is to proliferate it should be able to operate in par with centralized service water, supplying collected rain water to user points reliably. This is usually achieved by pumping the collected rain water to service points utilizing electricity, which in fact could negate the positive gains of RWH with regard to 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 tank first and then cascades through multiple tanks in multi story 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.

Key words: *Rainfall, Cascading, Multi tank, Sustainability*

1. Introduction

Any conventional RWH system consists of a rain water collector (usually the roof), a storage tank and a piping network to convey the collected rain water to the storage as the main components. Of the three main components mentioned above, the storage tank has drawn most of the attention due the size, positioning and the capital outlay required on it thus subjecting it to the bulk of research on RWH. Though various studies have been carried out to optimize the size of the tank (Fewkes)(9) with regard to the water saving efficiency (WSE) of the composite system, no alternative has been found to position the tank other than at or below the ground level, requiring energy consuming pumping to feed the collected rain water to service points. Positioning the tank in between the roof and the service points is a partial solution but the space requirement and the structural support required hinders the proliferation of RWH. This study introduces 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.

2. Energy requirement in multi tank RWH systems

For a given 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), the water saving efficiency (WSE) η can be found from generalized curves for WSE, developed by Fewkes (9).

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 ;

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

Then for the i^{th} floor (i^{th} tank),

When the demand is D_i , supply is $(AR)_i$

But, $(AR)_i = (AR)_{i+1} - Y_{i+1}$

Since $Y_{i+1} = D_{i+1} * \eta_{i+1}$

$$(AR)_i = (AR)_{i+1} - D_{i+1} * \eta_{i+1} \quad [2]$$

Further, if the total demand is D ,

$$D = \sum_{i=1}^n D_i \quad [3]$$

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 ,

$$Q = \sum_{i=1}^n Q_i - \sum_{i=1}^n Q_i (1 - \eta_p) = \sum_{i=1}^n Q_i * \eta_p$$

From Equation 3.2,

$$Q = \eta_p \left\{ \sum_{i=1}^n D_i - \sum_{i=1}^n D_i \eta_i \right\} \quad [4]$$

When,

$$(AR)_i = AR - \sum_{i=i+1}^n D_i * \eta_i \quad [5]$$

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 $\sum D_i = D$,

$D_1 = D_2 = \dots = D_n = D/n$

Therefore, from equations 3.5 and 3.6,

$$Q = \eta_p \left\{ \sum_{i=1}^n D_i - \sum_{i=1}^n D_i \eta_i \right\}$$

$$Q = \eta_p D \left\{ 1 - \frac{1}{n} \sum_{i=1}^n \eta_i \right\} \quad [6]$$

$$(AR)_i = AR - D/n \sum_{i=1}^n \eta_i \quad [7]$$

Energy required in pumping collected rain water in two types of houses, namely single story and two story houses, are analyzed for daily demands of 200 L, 300 L, 400 L and 600 L. In the single story house, two tanks are employed with the upper tank of 1 m³ capacity located at the eve level, just below the roof collection area. Three tanks are employed in the 2 story house with the upper tanks located at eve and first floor levels and the parent tank at ground level. In the two story house, the demand is taken as equally divided between the two floors. The energy required is shown as a percentage of energy required to pump collected rain water from a single tank at ground level against D/AR, where A is the collector area in m² and R is the annual average rainfall in m for a particular geographical region. Use of the parameter D/AR will give more flexibility to use any combination of A and R, for a given constant AR value. Fewkes (1999) generalized curves validated for Sri Lanka (Sendanayake & Jayasinghe, 2006), is used to determine WSE for a given demand and storage volume. All storage tanks located at upper levels are of 1 m³ capacity.

The roof collection area is taken as 50 m² in the wet climatic region of Sri Lanka, where the annual average rainfall is 2500 mm (Meteorological Department of Sri Lanka). Therefore, AR is calculated as 125 m³ and for maximum WSE, S_p is taken as 0.1 AR, i.e. 12.5 m³. As the generic curves for WSE is valid for 0.25(AR)_i ≤ D_i ≤ 2.00, the maximum possible demand is calculated as 600 L/day. The amount of rain water that can be pumped up when only the parent tank is employed is denoted as Q₀. The value Q/ Q₀ is representative of the energy requirement in pumping as a percentage. Q/ Q₀ values are plotted against D/AR to determine the operating characteristics of CMTRWH systems, where D is the total daily demand. This will effectively compare the CMTRWH situations for two and three tank models with conventional single tank RWH systems under the same A, R and D.

Table 3.1: *Energy requirement % vs. Demand in Two Tank model*

D L/day	D m ³ /yr	D/AR	η ₀	η ₁	Q	Q ₀	Q/Q ₀ %
200	73	0.58	100	67.5	23.73	73	33
300	109.5	0.87	90	50	49.28	101.28	48
400	146	1.17	65	45	52.2	116.8	44
600	219	1.74	35	32	44	122.64	36

Table 3.2: *Energy requirement % vs. Demand in Three Tank model*

D L/day	D m ³ /yr	D/AR	η ₀	η ₁	η ₂	Q	Q ₀	Q/Q ₀ %
200	73	0.58	100	92.5	77.5	10.95	73	15
300	109.5	0.87	92.5	77.5	55	36.96	101.29	36
400	146	1.17	80	67.5	52.5	35.04	116.8	26
600	219	1.74	56	50	42.5	28.06	122.64	23

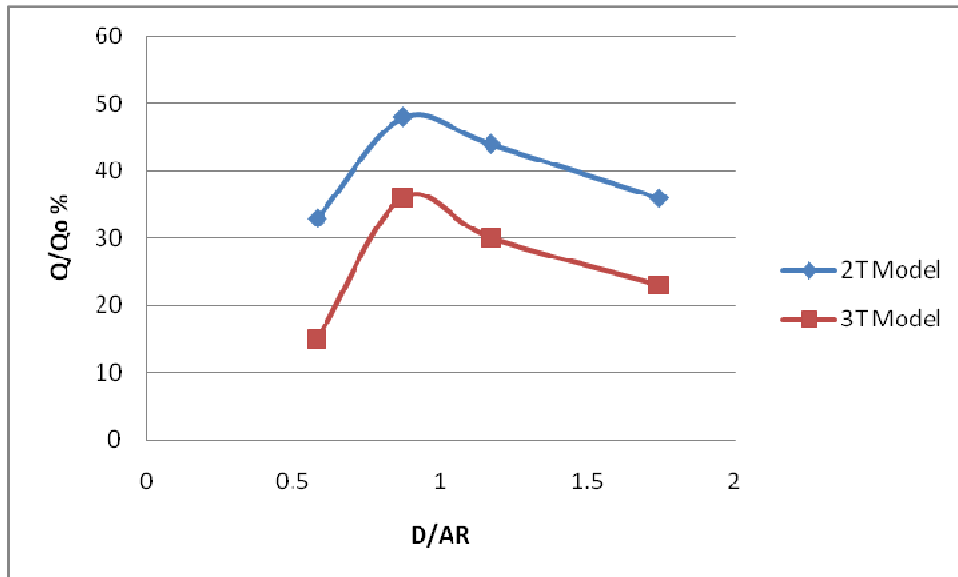


Chart 3.4: Energy requirement % vs. Demand in Two and Three Tank models

3. Discussion

From the Chart 1 it can be seen that for a desired total demand D - equally distributed among the floor levels- and for a given storage capacities, the energy requirement of the system as a percentage of the energy requirement when the same storage is used in a conventional rain water harvesting (RWH) system increases and maximizes when $D/AR = 1.00$. This implies that when D/AR increases, the quantity of collected rain water that can be pumped up (Q) increases maximizing at $D/AR = 1.00$. However, when $D/AR > 1.00$, Q decreases, indicating that the system is under-performing. The behavior of the system with regard to increase of D/AR can be further explained referring to equations 1-4 and Fewkes generalized curves for WSE. It can be seen that when D/AR increases, WSE of upper tanks as well as the composite system drops with the latter dropping at a lesser rate. This can be clearly seen by referring to the generalized curves of WSE, where the storage capacity of the composite system $S > S_i$ and S_i/AR falling in the critical zone of the WSE chart, i.e. when $S/AR < 0.01$. Further, when $D/AR > 1.00$, though both η_i and η_o decreases, the WSE chart indicates that η_o decreasing rapidly hence dropping the overall performance of the system at a much higher rate. From equations 3 and 4 and Fewkes generalized curves for WSE it can be deduced that for any number of floor levels Q maximizes when $D/AR = 1.00$ implying that the shape of the percentage pumping energy curve is governed by the characteristic curves of WSE. Therefore, it indicates that for a given set of system parameters D , A , R and S , the maximum yield that can be extracted from the system occurs when $D = AR$. In other words, it is clear that when $D < AR$ the full potential of the system is not harnessed and when $D > AR$ the system is underperforming. Hence it is important to focus on the energy efficiency of the RWH system when $D = AR$, i.e. when the system is operating at optimum conditions, to introduce energy efficient pumping so that the overall system performance is optimized.

References

1. ABS 2000, Australian Bureau of Statistics, Aust-Stats, Environmental Issues: Peoples' Views and Practices, Water use and Conservation. www.abs.gov.au/auststats.
2. ABS 2000, Australian Bureau of Statistics, Aust-Stats, Water Account for Australia, 1993-94 to 1996-97.
3. Adger, W.N., (2006), "Vulnerability," *Global Environmental Change*, Volume 16, Issue 3, Pages 268-281.
4. ADWG 1996, Australian Drinking Water Guidelines, (1996), National Water Quality Management Strategy, NHMRC & ARMCANZ., www.health.gov.au/nhmrc/publications.
5. Appan, A. (1999), "A dual mode system for harnessing roof water for non-potable uses", *Urban Water*, 1(4): 345-54.
6. Chilton, J.C., Midment, G.G., Marriott, D., Francis, A., Tobias, G. (1999), "Case study of a rainwater recovery system in a commercial building with a large roof", *Urban Water*; 1(4): 345-54.
7. Coombes, P. (2002), "Rainwater tanks revisited. New opportunities for urban water cycle management." PhD Thesis, University of Newcastle, Australia.
8. Edwards, D., Keller, K. (1984), "A workshop design for rainwater catchment systems (Training Guide) & appendix. "Rainwater Harvesting for Domestic Water Supply in Developing Countries," La Paz, UNESCO/ROSTLAC, UNICEF.
9. Fewkes, A. (1999a), "Modeling the performance of rainwater collection systems towards a generalized approach", *Urban water*, 1, 323-333.
10. Fewkes, A. (1999b), "The use of rainwater for WC flushing: The field test of a collection system", *Building & Environment*, 34, 765-772.
11. Gould, J., Nissen-Peterson, E. (1999), "Rainwater catchment implementation", London, Intermediate technology publications.
12. Hermann, T., Schmida, U. (1999), "Rainwater utilization in Germany: efficiency, dimensioning, hydraulic and environmental aspects", *Urban water*, 1, 307-316.
13. Jayasinghe, M.T.R., Jayawardene, A. I., Attalage, R. A. (2001) "Concepts for sustainable residential developments for urban and suburban areas in Sri Lanka", *Engineer, Journal of Institution of Engineers, Sri Lanka*, vol xxxiv, No.2, pp 63-77.
14. Jewitt, G., (2002), "Can Integrated Water Resources Management sustain the provision of ecosystem goods and services?" *Physics and Chemistry of the Earth, Parts A/B/C*, Volume 27, Issue 11-22, Pages 887-895.
15. Miller, G., Yu, Bofu., Gardner, T. (2003), "Rainfall catch efficiency for domestic water supply," 28th International Hydrology and water resources Symposium, Wollongong, NSW, Australia, Institution of Engineers, Australia.
16. Mwenge Kahinda, J.m., Taigbenu, A.E., Boroto, J.R.,(2007), "Domestic rainwater harvesting to improve water supply in rural South Africa," *Physics and Chemistry of the Earth, Parts A/B/C*, Volume 32, Issue 15-18, Pages 1050-1057.
17. Villareal, E.L., Dixon, A. (2004), "Analysis of a rainwater collection system for domestic water supply in Ringdansen, Norrkoping, Sweden", *Building & Environment*, 40, Elsevier Ltd.
18. Zobrist, J., Muller, S.R., Amman, A., Bucheli, T. A., Mottier, V., Ochs, M., Shoenenberger R., Engster, J., Boller, M. (2000), "Quality of roof run-off for Ground water infiltration", *Water Resources*, vol.34, No.5, pp 1455-1462.

Acknowledgements

The technical staff of the Department of Civil Engineering, Messers S.P.Madanayake, S.L Kapuruge assisted this project at the concept development stage.

About the Authors

S. SENDANAYAKE, B.Sc. Hons. Moratuwa., M.Sc. Moratuwa is currently reading for his Ph.D. at the Department of Civil Engineering, University of Moratuwa.

M. T. R. JAYASINGHE, B.Sc. Hons. Moratuwa., Ph.D. Cambridge., MIE (SL), C.Eng. is a Professor at the Department of Civil Engineering, University of Moratuwa. His research interests are in the areas of tall buildings, energy efficiency, sustainable development and disaster resistant structures.