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EFFECT OF VARYING ROOF RUN-OFF COEFFICIENT VALUES AND TANK SIZE ON RAINWATER HARVESTING SYSTEM'S WATER SAVINGS IN MALAYSIA

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ABSTRACT

This study investigates the effect of using different roof run-off coefficient values in an office building in Malaysia on the water savings provided by rainwater harvesting system which is used to supply water for toilet flushing and irrigation purposes. In this paper rainwater harvesting system model is developed which reads the hourly rain fall data and calculates water consumption and savings. The harvesting tank sizes and roof run-off coefficient values were varied. It is found that as the values of roof run-off coefficient decreased, the amount of water saved remains almost unchanged for all investigated tanks sizes. A correlation is developed which relates roof run-off coefficient, volume of water saved and the tank sizes which can be used as useful design and sizing tool by buildings' designers to predict the amount of water saved for a specific rain water harvesting size.

Keywords: rainwater harvesting, roof run-off coefficient, water saving.

INTRODUCTION

Reoccurring water shortages across several states in Malaysia are becoming a serious issue, especially due to the increase in water demand by the growing population [1] and the wasteful use of the sources. Malaysia is known to have high water consumption per capita of more than 300 litres per day for domestic use [2] whereby the total amount of water usage recommended by the United Nations is only 200 litres per day. For any green building which aims to achieve higher rating, rain water harvesting should be included in the building. However, determining the cost effectiveness and system effectiveness is not really well developed for specific countries.

It has been established that the one of the major investment in the system is the storage tank due to the increasing cost when the tank size increase. Hence, in order to determine the perfect amount of investment of the system, the tank size must be optimized to meet all requirements. A case study conducted in Melbourne simulated two different tank sizes; 180 m^3 and 110 m^3 [3]. They analysed the effectiveness of the tanks based on different roof conditions and concluded that both tanks were more effective during average and wet years but less effective during dry years.

Water balance models paired with a sensitivity analysis was also conducted in a study to optimize the best tank size [4]. It was concluded that a suitable storage tank size to meet a demand of 200 residential units was 160 m^3 with a reliability of 60%. The sensitivity analysis also showed that larger roof catchment areas will provide better water savings with both smaller and larger tank sizes. In a different study, dimensionless methodology was used to achieve an optimal design of the storage tank [5]. The dimensionless parameter allowed an improved description on the rainfall pattern which included ratios of storage fraction and demand fraction. Another study developed an estimated storage tank size by meeting several requirements of fixed roof areas and water use patterns [6].

Materials of the catchment area, normally the roof of the building are another important factor in determining the harvested quantity. The smooth roofs that are found to have a runoff coefficient of 0.9 are known to reduce the total amount of spillage, evaporation and better surface wetting [7]. In one study four types of roof which three of them were sloping; clay tiles, metal sheet and polycarbonate plastic and one flat gravel roof were analysed.

The quality and quantity of the rainwater captured in Spain was identified and concluded that large roof run-off coefficients are provided by smooth sloping roofs with values more than 0.9, and may harvest 50% more rainwater compared to coarse and flat roof of coefficients of only 0.62 [8].

The same conclusion was also met when comparing asphalt fiberglass singles, metal, concrete tiles, cool and green roofs in Austin, Texas [9] where metal roofs proven to have better water collection properties.

As seen, there are several parameters that may affect the system effectiveness which are the tank size and roof run-off coefficient values for a specific building. A common error in planning for an efficient rainwater harvesting system is that a larger tank size will provide better savings as it is able to store more water. Creativity in building's design may require the use of lower roof run-off coefficient, therefore studying the combined effect of the roof run-off coefficient, and tank size for a specific building is of high importance. To the author's knowledge, rain water harvesting research in Malaysia was performed on residential houses by using hourly rain fall data [4]. Some published research, relies on monthly rain fall data which may compromise the accuracy of their results.

Recently Nasif and Roslan [10] performed their study on rain water harvesting system for commercial

office building. They found when the value of rain water run-off decreases, increasing the rain water harvesting tank will have no effect on water saving.

This research is continuation of Nasif and Roslan [10] study, where further investigation were performed to study the effect of roof catchment area, roof runoff coefficient and tank size on the amount of water discharged to the drain from the water tank which may not be possible to store it in the tank due to excessive rain falls. A correlation is developed which relates roof run-off coefficient, volume of water saved and the tank sizes which can be used as useful design and sizing tool by building designers to predict the amount of water saved for a specific rain water harvesting size.

MODELLED RAIN WATER HARVESTING SYSTEM

A simulation was carried out relating the amount of rainwater collected against the amount of water used in the building and the amount of excess water to the drainage system by using mass balance in the water movements (Figure-1). An office building located in the Kuala Lumpur region is selected as the model of which the system simulation is conducted. The rainfall collected in the harvesting tank will be used for non-potable purposes which are for toilet flushing and indoor irrigation. Water demand in the building is mapped hourly to determine peak and average usage [11] against hourly values of rainfall collected from the Metrological Department of Malaysia. The length of the simulation is completed for a year to obtain a better visual of water movement in the tank based on the water demand and the rainfall cumulative amount. A range of roof run-off coefficients were selected between 0.25 and 0.9 [12] as one of the main factors affecting the total amount of rainwater harvested.

The tank is designed to have an overflow pipe in cases of continuous heavy rainfall which would lead to excess water in the tank which can be directed to the external drainage system of the building. Design guides require that tanks are to have a minimum of 20% to 30% of water at all times to allow water to be supplied to meet the demands and to evade damages related to the pumps [13]. If no rainfall is available at a given hour and the total water demand in the building requires more water than the minimal storage, a potable water supply from the main water supply pipe will be added to the tank to avoid the water levels from dropping beyond the aforementioned limit.

The above calculation is performed at 1 hour time step, where the hourly rain fall data of Kuala Lumpur provides the rain fall at each hour. Water mass balance calculations are performed to calculate the amount of water used, amount of water supplied from water main and amount of water discharged to the drain.

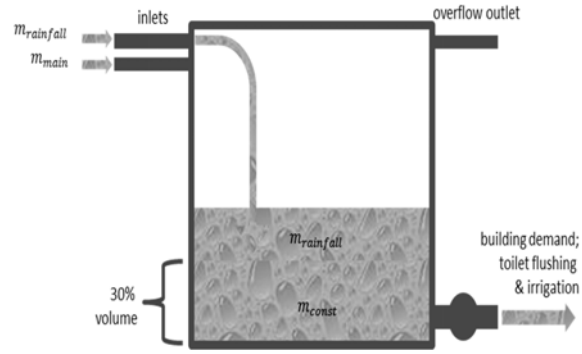

Figure-1. Mass balance movement of the rainwater storage tank.

WATER DEMAND

As pre-mentioned, a 5 storey office building having a total floor area of 27500m^2 located in Kuala Lumpur with a total capacity of 440 persons was selected as the developed model. Each person is assumed to consume 45 L of water daily, with only 32% of the total consumption per capita to be of toilet flushing use [13]. Irrigation water demand is calculated via extrapolation charts given by design guides that require the average temperature and relative humidity of Kuala Lumpur which is 28 °C and 82% respectively [13]. The hourly water consumption throughout the day varies at each hour. The amount of hourly water consumption for office building was published by Aquacraft Inc. [11]. Water consumption for toilet flushing was determined and it is estimated to be 32% of the hourly water consumption [13]. The hourly water consumption for the modelled office was calculated by multiplying the hourly water flushing requirement by the total hourly water consumption obtained from the Public Health Guide G [13].

Hourly water balance calculations will be performed by associating the total hourly rainfall, hourly water demands of the building and the cumulative amount in the tank. The model will return the total amount of water that can be saved and total overflow to the drain by using the system. The tank sizes used in this study are 16, 23 and 32 m^3.

RESULTS AND DISCUSSIONS

Annual, monthly and hourly water savings

The total annual volume of water required from the local town main supply is shown in Figure-2 as the size of storage tank and roof material is varied accordingly.

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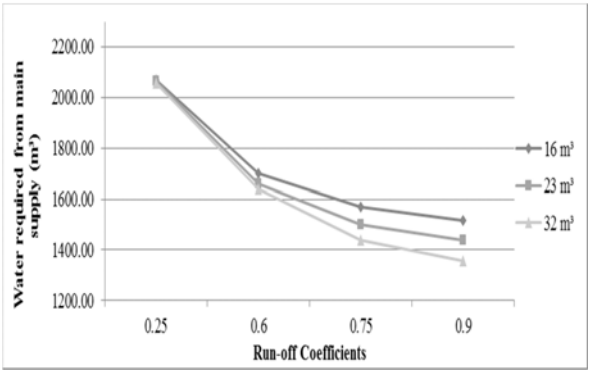


Figure-2. Annual volume of water required from the main town supply using different roof run-off coefficients and tank sizes.

Figure-2 shows that an increase in roof run-off coefficients will lead to less amount of main water supply usage when paired with larger tank sizes. A significant decrease in the annual main water supply usage is observed across roof run-off coefficients of 0.25 and 0.6. The decrease in the total amount of main water supply usage is due to the consumption of accumulated rainfall by the rainwater harvesting system to meet the building demands that also leads to the total annual amount of water that can be saved by the system seen in Figure-3.

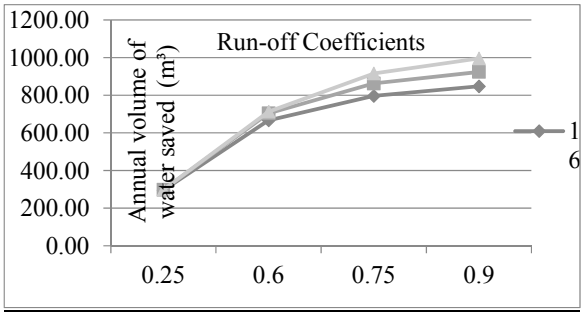
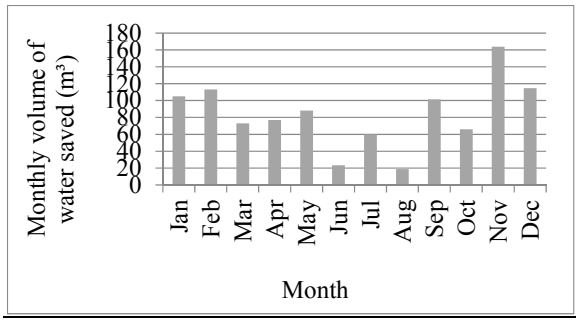


Figure- 3. Annual volume of water saved using different roof run-off coefficients and different tank sizes.

Figure-4 (a) demonstrates the total amount of water savings per month for a system where months of June to August are seen to have the least savings due to less rain in the dry seasons and higher amounts through September through February during the wet seasons.



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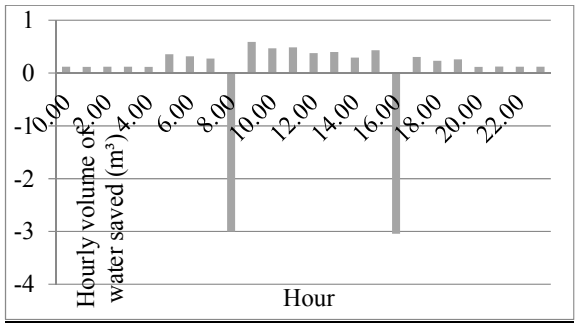
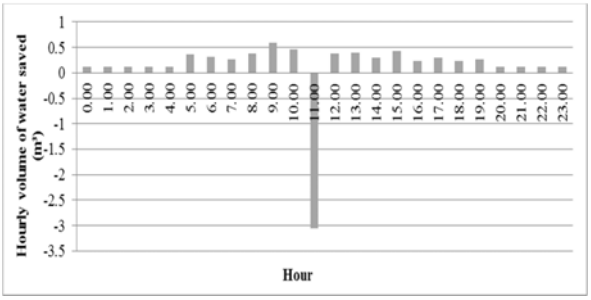


(b)



(c)

Figure-4. (a) Monthly volume of water saved (b) Hourly volume of water saved for non-rainy day (c) Hourly volume of water saved for rainy day with roof run-off coefficient of 0.6 and tank size of 32m^3.

In Figure 4 (b) and (c), negative amounts of water saved indicate the total amount of water from the main supply required to fill the tank when levels reach a critical low of 20% which requires the water supply from the water main. Rainy days such as that seen in Figure-4 (c) indicate less amount of main water supply required to top up the tank with only one negative value compared to that of non-rainy days with two negative values in Figure-4 (b). The positive variance in the hourly water savings is due to the water demand profile of a specific building. At times between 20:00 pm and 4:00 am the water demand focuses on the irrigation while the other times are human non-potable uses of toilet flushing. The total volume of water discharge to the drain during heavy downpours or tank limitations are shown in Figure-5.

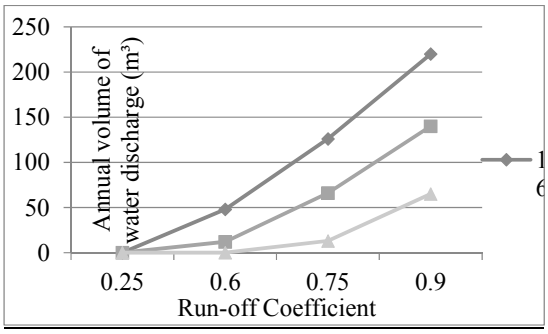


Figure-5. Annual volume of water discharge to drain using different roof run-off coefficients and tank sizes.

Further analysis on the amount of water discharged through the overflow pipe showed that as the roof run off coefficient value decreased, the amount of water discharged to the external drain decreased. This indicates that lower roof run-off coefficients have less amount of discharge even if the tank size is changed. This is due to the reduced amount of rain water stored in the tank at very low run –off coefficient values. Hence, the amount of water stored will be significantly less which makes the stored water at low run-off coefficients just adequate for building use without any excess water. This explain the reason for lower roof Run-off Coefficient values caused the amount of water, saved remains almost unchanged for all tanks sizes.

ROOF RUN-OFF COEFFICIENT, TANK SIZE AND WATER SAVING CORRELATION

MATLAB software was used to develop a correlation that relates the amount of water saved with roof run-off coefficient values and tank volume Figure 6 (a) and (b). The correlation is useful sizing tool for rain water harvesting system to predict the amount of water saved.

By running the simulation, a linear polynomial model was generated Equation. (1) with a regression of R^2 =0.9957:

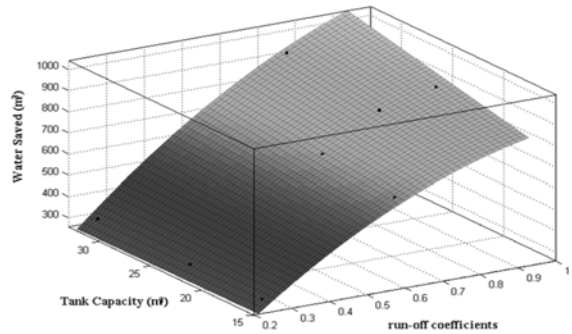
$$Z = -5.167 + 1360X - 3.834Y - 662.3X^2 + 15.85XY \qquad (1)$$

where
X : Run-off Coefficients
Y : Tank Capacity (m^3)
Z : Water Saved (m^3)

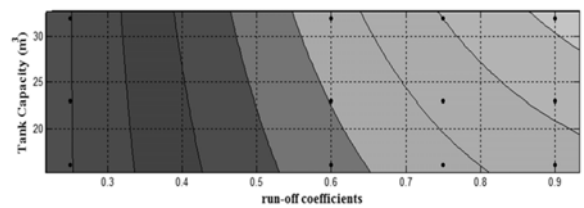
Figure-6 shows that when the tank size increased at low run-off coefficient values, the amount of water saved remains almost unchanged for all tanks sizes.

This means, at low run-off coefficient values, increasing the rain water harvesting tank volume will have minor or almost no effect on the amount of water and energy saved.

Figure-6 showed that as the roof run-off coefficient values decreased, the amount of water overflow from the tank to the external drain decreased and became zero at run-off coefficient value of 0.25. This is attributed to the low rain water flow directed to the tank.



(a)



(b)

Figure-6. (a) Correlation of XYZ variables and (b) Contour of X-Y variables.

The developed correlation is useful sizing tool for buildings' designers to predict the amount of water saved for a specific rain water harvesting size. However, this correlation is applicable for office buildings with a size and occupancy similar to the modelled building.

CONCLUSIONS

A range of roof run-off coefficients from 0.25 to 0.9 was selected to analyse the change in the annual amount of water savings and water run-off to the drain across different tank sizes. The water was specified for non-potable uses which are toilet flushing and irrigation purposes. It is found that higher roof run-off coefficients paired with larger tank sizes yields more water savings and rainwater run-off to drainage of about 2892 m^3 and 220 m^3 respectively. In addition, as the value of roof run-off coefficient decreased, the amount of water saved remains almost unchanged for all tanks sizes indicating that increasing the tank size will have no water saving benefits. This is attributed to the amount of overflow water discharged to the external drain which was significantly decreased when the roof run-off coefficient values decreased. A correlation which relates the tank size, roof run-off coefficient and amount of water saved is developed with good accuracy.

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