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Performance of a Rainwater Harvesting Tank Under Under Varying Non-Potable Demand: Case Study in Kubang Semang, Penang

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ABSTRACT

Rapid development and climate change has endangered the availability of water resources worldwide. This study look into the potential of the applying a rainwater harvesting system (RWHS) for non-potable water usage in a double-storey residential terrace house using Tangki NAHRIM 2.0 (TN2.0). TN2.0 is a web application that adopt the yield-after-spillage (YAS) convention to identify the optimum rainwater tank size. It is found that for a house of size 86.86 m^2, the optimum tank size is 2 m^3 with water-saving and storage efficiency values of 51% and 63.2% respectively. Additionally, the performance of the optimum tank size of 2 m^3 was further examined under different water demand. It was found that a 2 m^3 tank was still able to save water up to 42.1% for a family of 10 persons. Meanwhile, the storage efficiency shows a little increment from 63.2% to 67.8%.

Keywords: Green technology; rainwater harvesting; yield-after-spillage; water-saving efficiency

INTRODUCTION

Climate change and togetherwith the rapid development of urban areas and growth of population, has affected the availability of water resource in many countries. Based on the statistics from the National Water Services Commission (SPAN) in 2020, Malaysia's current domestic water intake (201 liters per person) has exceeded the World Health Organization's (WHO) permissible limit. Moreover, according to NAHRIM, river pollution is the main issue of water security in Malaysia. Besides, the increasing cost of preparing and managing treated water, as well as the need to take corrective measures in the event of water disruptions has subsequently increased the water tariff in Malaysia.

Despite of all the problems associated with surface water, Malaysia is very lucky as it is a tropical country receiving rainfall with averages of 2400 mm per year and had experience no serious water shortagesin recent decades (Lani, Yusop, and Syafiuddin 2018). RWHS has been widely applied around the world, but its application is still considered low in Malaysia. It is proven that RWHS could offer various socio-economic and environmental benefits. The benefits include bill saving, flash flood reduction, and delaying the need for constructing new water supply infrastructure. Figure 1 shows the elements of a rainwater harvesting system for a household building.

Literature searches about Rainwater Harvesting System (RWHS) has found that the study and application of this system is still low for residential houses compared to government buildings. Research on the potential of RWHS for commercial buildings has gain more attention due to large rooftop catchment area, higher water tariff for commercial usage and bigger amount of water consumption(Lani et al. 2018). For instance, (Hashim et al. 2013) simulated a model for a large-scale RWHS and found that the optimal size storage tank is 160 m^3 of 60% reliability for a 20,000 m^2 roof area. (Hamid and Nordin 2011) found that for a student hostel roof area of 3000 m^2, a 40 m x 35 m storage tank with a 5-meter depth could result in a reduction of 6500 m^3 of treated water used each year. This results in an annual water bill savings of about RM10460. Another research on RWHS for institutional application was conducted by (Al-Saffar, Abood, and Haron 2016) where the study area is at the Infrastructure University Kuala Lumpur (IUKL) Bangi Campus using Tangki Nahrim 1.0 (TN). The selected tank sizes were 75 m^3 and they offer 81% and 93% water saving efficiency for two academic blocks. The potential application of RWHS for non-potable use for residential houses in Kuching, Sarawak using TN by (Kuok Kuok et al. 2020). They found that the optimal size of RWHS tank for double-story dwellings in Kuching is $2m^3$. A recent study by (Goh and Ideris 2021) found that the optimum RWHS tank size for a 100 m^2 roof size in Kuala Lumpur is 3 m^3 where 90% of the non-potable demand can be served by the rainwater. RWHS not only requires analysis of the weather, tank size, site, and utilization of conserved water but it also demands resources and interdisciplinary expertise(Maqsoom et al. 2021). Rainwater collection for use in a residential area, on the other hand, has rarely been studied. This paper aims to determine the optimum rainwater tank size for an average household size in Malaysia for a two-storey residential house using TN2.0 and to analyse its performance under varies rainwater demand.

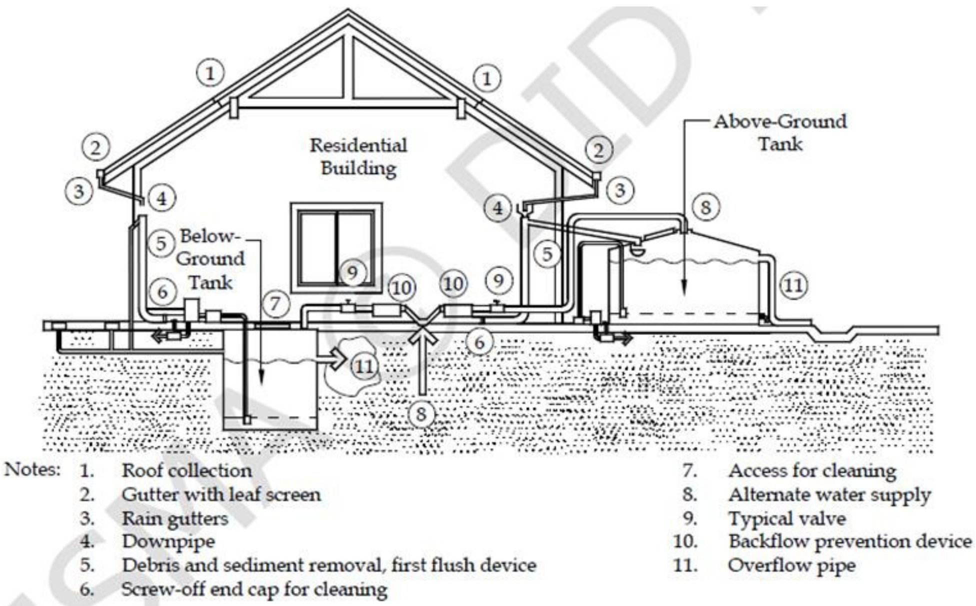

FIGURE 1. Elements of a Rainwater Harvesting System for a Household BuildingSource: MSMA 2nd Edition, Chapter 6 (Government of Malaysia Department of Irrigation and Drainage)

METHODOLOGY

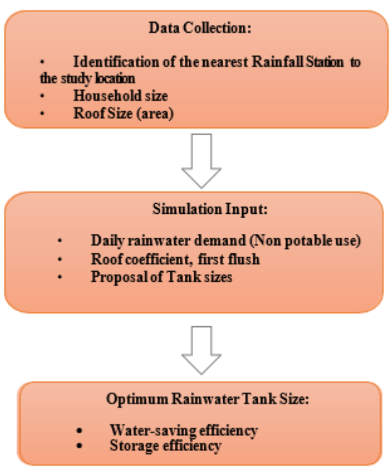

FIGURE 2. Estimation of Tank Size using TN2.0

SOFTWARE

TN2.0 is the upgraded version of a web application developed by the National Hydraulic Research Institute of Malaysia (NAHRIM). It is designed and developed to calculate the optimal tank size for RWHS with built-in rainfall data for Malaysia. TN2.0 applies an R-based water balance model. There are two types of water balance models which can be either Yield Before Storage (YBS) or Yield After Storage (YAS). The YBS model provides a strategic approach, with the rainwater harvested being used for everyday use and the balance being stored in a storage tank for use the next day. While the YAS model adopts a conservative approach in which rainwater is collected first and then channeled to the tank, with the excess rainwater being overflowed. The tank will be used to draw the daily consumption. TN2.0 adopts the YAS algorithm. YAS algorithm is further explained through Equation 1 and 2:

$$Y_i = \min\begin{cases} D_i \\ V_{i-1} + R_i \end{cases} \quad (1)$$

$$Y_i = \min\begin{cases} S - Y_i \\ V_{i-1} + R_i - Y_i \end{cases} \quad (2)$$

where Y is the rainfall volume yielded for the water demand, D is the water demand for the rainwater harvesting system, V is the volume of active storage in the tank and S is the tank storage capacity. The water demand is assumed to be constant daily.

Figure 2 shows the steps involved in TN2.0 to simulate the optimum tank size. Simulation for TN2.0 involves the subsequent data which are: i) daily rainfall, ii) roof area, iii) roof coefficient (depends on the type of roof material), iv) first flush (a basic device that diverts the first influx of water away from a rainwater catchment system) v) daily water demand, and vi) range of rainwater tank volume.

CASE STUDY

Taman Seri Akasia Kubang Semang, Penang has been selected for the study area. The nearest rainfall station is Pusat Kesihatan Bukit Berapit (station ID: 5304045). The average annual rainfall from year 2002 to 2017 is 2461 mm. This high annual rainfall intensity is suitable for the application of RWHS.

ROOF AREA, ROOF COEFFICIENT AND FIRST FLUSH

A rooftop serves as the study's catchment area. The size of the rooftop is assumed to be similar with the size of the double-storey residential terrace house. The roof area is 86.856 m^2 (12.952 m x 6.706m). A runoff coefficient is a measure of how much rainwater collects. A study by (Lai et al. 2018) shows that all roof runoff quality is not up to potable standard; though can be used for indoor non-potable use with minimal treatment. The roof coefficient selected in this study is concrete type of 0.8 (Siddiqui 2018). Meanwhile, a first flush diverter (also known as a roof washer) is a simple contraption that diverts the first flow of water away from a rainwater catchment system. The first flush was assumed to be 1 mm (Goh and Ideris 2021).

CALCULATION OF DAILY WATER DEMAND

The analysis of water demand is required to determine whether the rainwater delivered is sufficient to satisfy the household water demand. The demand for rainwater is determined by i) the number of individuals who consume, ii) the estimated per-person usage, and iii) the various uses of water. Daily water demand can be categorized to potable and non-potable use. Only non-potable demand was considered in this study which includes single flush toilet flushing, general cleaning, gardening, washing 2 cars, and pathways. The average water consumption rate was according to the guidelines established in the Urban Stormwater Management Manual 2nd edition (MSMA2). According to the Department of Statistics Malaysia, the household normal family size in Malaysia is 3.9 people. Nonetheless, for planning reasons, all family size was gathered to 4. For a family size of 4, the corresponding daily water demand is 542.29 litres per day.

Further in this study, the performance of the selected optimum tank size was tested under for the household size of 2, 4, 6, 8, and 10 persons. Table 1 shows the number of household and the corresponding non-potable water demand. The corresponding daily water demand for the mentioned family sizes are 488.29, 542.29, 596.29, 650.29, and 704.29 litres per day.

PERFORMANCE MEASUREMENT

Water-saving efficiency or also known as volumetric reliability is the main performance indicator of a RWHS. It refers to the amount of water demand satisfied by the system in comparison to the overall demand and it is the commonly used indicator for RWHS (Semaan et al. 2020). If the yield can meet the demand most of the time, it indicates that the water-saving efficiency is excellent, then the user can consider raising the water demand for other purposes. Equation 3 shows the formula for water-saving efficiency:

$$E_{WS} = \frac{\sum_{i=1}^{n} Y_i}{\sum_{i=1}^{n} D_i} \times 100 \quad (3)$$

where n is the entire time interval in the simulation.

Another less popular indicator is storage efficiency or well known as detention efficiency. Storage efficiency refers to the amount of runoff retained by the tank over the amount of tank rainfall intake. Storage efficiency is also described as the fraction of roof runoff that may be used and is not wasted due to leakage. Equation 4 shows the storage efficiency formula.

$$E_S = \left[1 - \frac{\sum_{i=1}^{n} Q_{Si}}{\sum_{i=1}^{n} R_i} \times 100\right] \quad (4)$$

where Q_S represents the spillage or overflow. Size of the tank is said to be efficient if the storage efficiency approaches unity or when the overflow loss is almost zero. A high volume of spillage implies a low storage efficiency. Storage efficiency can be improved by either increasing the tank size or the water demand (Goh and Ideris 2021).

TABE 1. Number of Household and The Corresponding Non-Potable Water Demand (litres per day)

Number of Household (person)	Total Water Use (litres per day)
2	488.29
4	542.29
6	596.29
8	650.29
10	704.29

RESULTS AND DISCUSSION

OPTIMUM TANK SIZE

According to NAHRIM, the percentage of water demand that can be fulfilled by the RWHS using the specified tank sizes is referred to as water saving efficiency and the quantity of rain that falls on a roof in percentages that is usedin a RWHS with the specified tank sizes is referred to as storage efficiency.

To determine the optimum tank size, tanks with capacities ranging from 1 to 10 m^3 were suggested for testing for the selected household of 4 (542.29 litres per day). Figure 3 shows the simulation result for the house where it illustrates the water-saving and storage efficiency curves versus the range of tank capacities under daily non-potable demand. According to Figure 3, the optimum tank size for the house was found to 2 m^3 with water-saving and storage efficiency value of 51% and 63.3% respectively. The graph grows linearly, it signifies that the larger the tank, the more water may be retrieved, depending on the desired water-saving efficiency. Judgment of the optimum tank size for each house was made mainly based on the shape of water-saving and storage-efficiency curves. Increment of tank sizes offers increment of both efficiencies until the percentage of efficiencies increased were not very significant with the increment of tank size (Goh and Ideris 2021). It can be seen when the graphs started to be flattened. A smaller roof area can only gather a small volume of rainwater. If the roof area is increased, the inflow will increase which will increase the reliability of the tank in terms of volume. For a particular tank size, the reliability increases as the catchment area increases (Khan et al. 2017).

PERFORMANCE OF OPTIMUM RAINWATER TANK UNDER VARYING DEMAND

The performance of the optimum rainwater tank was then examined under varied rainwater demand. The number of occupants were varied for 2, 4, 6, 8 and 10 persons in a house. The corresponding daily water consumptions for the mentioned number of households are 488.29, 542.29, 596.29, 650.29, and 704.29 litres per day respectively.

Figure 4 shows the water saving and storage efficiencies of the tank serving the mentioned number of occupants. It was found that the water saving efficiency has decreased from 54.7% to 42.1% as the water demand increased. Water-saving efficiency is decreasing corresponding to the increment of the occupants. As the roof area and the tank size is fixed, a smaller roof area can only gather a small volume of rainwater. With the increase in the demand, the inflow needs to fulfil higher demand, and this will subsequently reduce the saving efficiency.

However, storage efficiency shows an opposite trend to water-saving efficiency. The storage become more efficient when the demand is increased. The storage efficiency increased about from 61.2% to 67.8%. Storage efficiency is a combined function of spillage and roof runoff volume where decreasing spillage volume increases storage efficiency. High storage efficiency implies that a major percentage of the rainfall that the roof may gather is used. As the water demand is increased, the spillage will decrease and subsequently increase the storage efficiency (Goh and Ideris 2021).

According to a study conducted by (Khan et al. 2017) on a 10-member family with a 100-square-foot catchment area, variations in family/user size will cause a change in water demand. As a result of significant input, a particular water tank will be able to serve a family for a shorter period of time as the family grows. According to research (Londra et al. 2015), demand levels of nominal to intermediate (up to 40% of 4 individuals) necessitates smaller tanks, and exceedingly high demand (50% of 4 to 5 individuals) demands assembly spaces of beyond 300 m^2. As a result, in order to increase the tank's efficiency, the area should be increased so that rainwater can serve higher water demands.

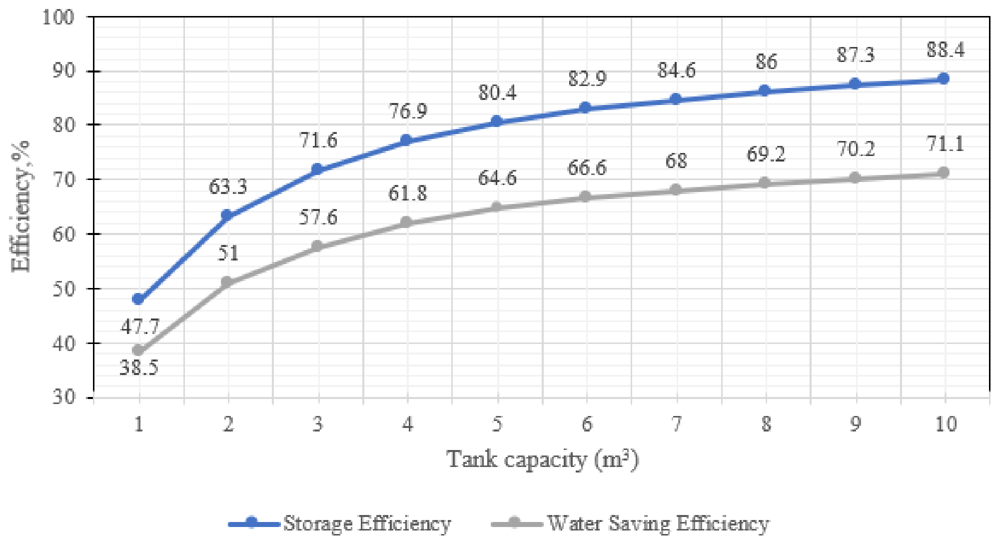

FIGURE 3. Efficiencies in Water Conservation and Storage vs. Proposed Tank Sizesfor 4 Persons

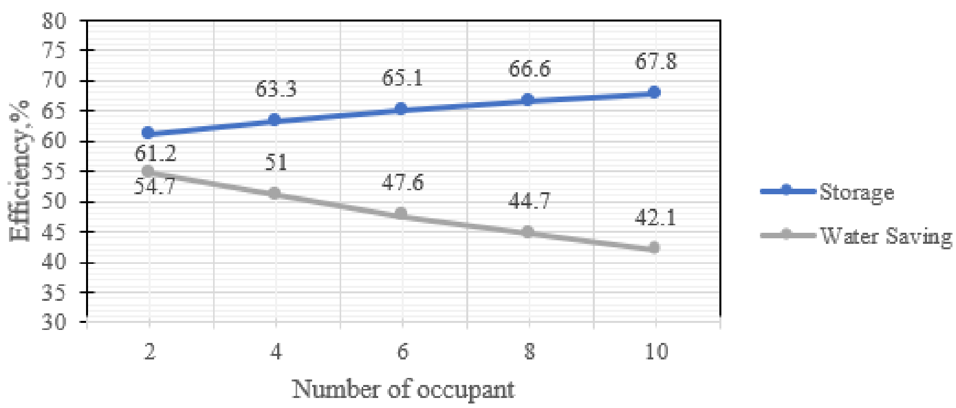

FIGURE 4. Efficiencies in Water Conservation and Storage vs. Proposed Tank Sizesfor 4 Persons

CONCLUSION

This study applies TN2.0 software to look for the potential of application of RWHS for non-potable usage for a double-storey residential terrace house at Taman Seri Akasia, Kubang Semang, Penang. The first objective of this study is to determine the optimum rainwater tank size for an average size household demand in Malaysia. It is found that for an 86.86 m^2 house, the optimum tank size is 2 m^3 with water-saving and storage efficiency values of 51% and 63.2% respectively. Furthermore, the optimum tank size of 2 m^3 was examined under different water demands to look at its performance. It was found that a 2 m^3 tank was still able to save about 42.1% of non-potable water for the family of 10 persons and the storage efficiency increased to 67.8%. The result provides a useful information in the selection of a suitable tank size for a RWHS in a residential house in Malaysia.

This study focuses on the performance of the RWHS serving for different number of occupants but limited to 10 number of occupants. Future study should explore on the performance of RWHS tank during weekdays and weekend water demand. Future study should also focus on the installation cost and maintenance cost over the benefits offers by the RWHS in long run.

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DECLARATION OF COMPETING INTEREST

None

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