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Malaysia

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Faculty of Architecture, Planning and Surveying (FSPU)
and,
Centre for Post Graduate Studies (CGS)
Universiti Teknologi MARA, Perak Branch, Seri Iskandar.
Malaysia

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RAINWATER HARVESTING SYSTEM FOR ACADEMIC BUILDING. IS IT WORTH IT?

Azirah Adnan[1,2], Asmalia Che Ahmad[3] and Suharto Teriman[3]
[1] Centre of Graduate Studies (CGS), Universiti Teknologi MARA, Perak Branch, Seri Iskandar Campus, 32610 Perak, Malaysia.
[2] Department of Civil Engineering, Politeknik Sultan Azlan Shah, Behrang, 35950 Perak, Malaysia.
[3] Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Perak Branch, Seri Iskandar Campus, 32610 Perak, Malaysia.

Abstract

Rainwater Harvesting System (RWHS) is proposed to address the water scarcity problem and as an alternative water supply for non-potable water usage. However, the economic benefit of the system depends on site-specific criteria such as rainfall availability, catchment area, storage, and water demand. This paper attempts to evaluate the economic benefits of RWHS for toilet flushing usage for one academic building at Politeknik Sultan Azlan Shah (PSAS) namely the Civil Engineering Department (CED) block. Daily rainfall data employed in this work were obtained from the nearest rainfall station at Felda Gedangsa and the water demand was obtained from the building's occupants through a questionnaire survey combined with data obtained from PSAS's documents. The daily water mass balance model was adopted as the simulation approach. The economic benefits of RWHS in terms of percentage of reliability (R) and payback period (PBP) were examined for the academic block. In addition, the effects of two types of rainwater tank sizes on PBP were also evaluated. The tanks are High-Density Polyethylene (HDPE) tank and Fibre-reinforced Plastic (FRP) sectional tanks. It was found that the percentage of reliability (R) for Civil Engineering Department block is between 82.22% to 100% by using a tank with a size ranging from 10 m3 to 150 m3. Interestingly, for tanks with a size range up to 60 m3, the cost of a HDPE tank is lower than FRP sectional tanks with the PBP ranging from 11 to 19 years and 13 to 20 years, respectively. However, for tanks with a size of 100 m3 onwards, the cost of HDPE tank becomes more expensive than the cost of FRP sectional tank with PBP ranging from 23 to 38 years and 23 to 29 years, respectively.

Keywords: *academic buildings; economic benefits; toilet flushing usage; reliability; payback period*

1.0 INTRODUCTION

Water is a vital necessity for the life of mankind. Humans can live without oil, but humans cannot survive without water to drink. The global water crisis is among the issues of concern in the present where freshwater sources around the world are getting scarcer since the release of carbon gas from fossil fuels has warmed the surface of the earth and has affected the rain. According to Mekonnen and Hoekstra (2016), at least in one month per year, more than half of the world's population is living in water scarcity areas. It is predicted that by 2025, almost two-thirds of the world's population will experience water shortage and almost 1.8 billion people are predicted to live in countries or regions that experience absolute water shortages (United Nation Educational, Scientific and Cultural Organization (UNESCO), 2012).

Based on the aforementiond water shortages problems, many researchers and policymakers have developed alternative water resource strategies in meeting the water demands (Rockström & Falkenmark, 2015). Rainwater Harvesting System (RWHS) is one of the solutions to overcome the shortage of water resources faced globally and helps to save water for non-potable uses (Silva et al., 2015). RWHS is a system that provides options in conserving water in buildings (Domènech et al., 2011). Belgium, France, Germany, Japan, New Zealand, Singapore and the United States have used this system mainly to complement conventional systems for non-potable uses such as for toilet flushing use (Schets et al., 2010). Among all, the toilet flushing consumes the highest water consumption that is around 63% of the domestic water consumption (Hamid & Nordin, 2011).

To ensure the efficiency of RWHS, an appropriate system design is needed. In order to design an effective RWHS installation method and stable harvested water supply, several parameters must be considered. It is well established that the performance of this system depends on the rainfall pattern, roof area, water demand, and the storage tank use (Guo & Baetz, 2007; Kim & Yoo, 2009; Imteaz et al., 2011; Mun & Han, 2012; Campisano et al., 2013, Morales-Pinzón et al., 2015; Temesgen et al., 2015; de Gois et al., 2015; Wallace et al., 2015). Guo & Guo (2018) has highlighted that the size of storage is the most important element to be considered in designing the RWHS. Morales-Pinzón et al. (2012), de Gois et al. (2015), Andrade et al. (2017), and Guo & Guo (2018) indicated that the performance of a RWHS mainly depends on the rainfall event characteristic. The catchment area will influence the reliability of the RWHS (Mun & Han, 2012; Nahrim, 2014; de Gois et al., 2015; Wallace et al., 2015; Lani et al., 2018a). Water demand is important for obtaining the ideal tank capacity and estimating potential potable water savings (Silva & Ghisi, 2016; Campisano & Lupia, 2017; Guo & Guo, 2018).

The last two decades have seen a growing trend towards studies on RWHS worldwide to verify the advantages of the RWHS. Lani et al. (2018b) in his study proved that RWHS can provide many useful benefits for the environment, economy, technology, and society. In terms of benefits to the environment, RWHS is capable in reducing the dependency on treated water sources (Coombes et al., 2002), helping minimize flash flood events (Kim & Yoo, 2009), and reducing emissions of greenhouse gas resulting from the use of pumps in distributing the treated water to the consumers (Coombes, 2007). RWHS also provides effective stormwater control as it can be considered as flood mitigation technology (Farahbaksh et al., 2009). On the economic aspect, RWHS can reduce the bill of treated water supply by the local water supply companies (Tam et al., 2010). Furthermore, RWHS can also reduce the government's burden of adding water supply infrastructure to meet the increasing water demand (Che-Ani et al., 2009; Coombes et al., 2002). In terms of the technology and social aspect, the advantages of installing RWHS include better water quality resulting from the filter features such as first flush technology that can reduce water-related health risk (Baguma et al., 2010).

Considering the aforementioned advantages, it is also possible to implement the RWHS for academic buildings. This is because the academic buildings generally offer large catchment areas and have high water consumption. Studies on RWHS show that the implementation of RWHS in educational buildings has encouraging results of its reliability and economic benefits. For example, Appan (2000) revealed that the implementation of RWHS at Nanyang Technological University (NTU) campus in Singapore has reduced the potable water consumption and saved up to S$18,500.00 per year for potable water expenditure, and reduced 12.4% of potable water consumption. Temesgen et al. (2015) has evaluated the performance of RHWS at a university building in Ethiopia, South Korea and found that RWHS has the possibility to be an alternative water source for the building. Similarly, Sarker et al.(2015) studied the potential of RWHS at the University of Asia Pacific in Bangladesh and found that RWHS can fulfill up to a maximum of 66% of their monthly water demand for drinking, washing, and sanitation with 9.5 years payback period. Therefore, it is timely to evaluate the potential of RWHS for academic building in Malaysia by considering its reliability and economic advantages since this country receives high average rainfall amount. The current data released by The World Bank (2018) revealed that the average rainfall historic data in Malaysia from 1991 to 2015 is around 3098.4 mm yearly.

Hence, this study aims to evaluate the economic benefits of RWHS for toilet flushing usage for one academic building at Politeknik Sultan Azlan Shah (PSAS) namely Civil Engineering Department (CED) block in terms of percentage of reliability (R) and payback period (PBP). In addition, the effects of two types of rainwater tanks with different sizes on PBP were also evaluated in order to find the most economical tank for the proposed RWHS. The tanks were High-Density Polyethylene (HDPE) tank and Fibre-reinforced Plastic (FRP) sectional tanks.

2.0 METHODOLOGY

2.1 Potential Rainwater Harvested

The potential harvested rainwater was calculated to get the Water Released (WR) by considering the area of the roof, the rainfall amount and the runoff coefficient (Silva et al., 2015). The potential rainwater that can be harvested in this study was estimated by using a formula adopted by Lani et al. (2018a) and can be mathematically expressed as below:

$$PRH = ART \ x \ RC \ x \ DR \tag{1}$$

a) *PRH* is the Potential Rainwater Harvested (m^3), *ART* is the area of rooftop (m^2), *RC* is the runoff coefficient (-) and *DR* is the daily rainfall (m).

The catchment area considered in this study was the CED block rooftop area at Politeknik Sultan Azlan Shah (PSAS). PSAS is situated at 03º77'00" N 101º45'01"E, Behrang Station , Perak which covers an area of 44.5 hectares. Generally, the temperature in the area is relatively high with average maximum temperature of 32.7ºC and average minimum temperature of 24ºC. The average humidity of the state is high at around 81.2%. The roof area of the Civil Engineering Department block which is concrete roof tiles pitch roof was measured by using following formula:

$$ART = (LRT \ x \ WRT) \ x \ PRT \tag{2}$$

ART is the rooftop area (m^2), *LRT* is the length of the rooftop (m), *WRT* is the width of the rooftop (m), and *PRT* is the pitch of the rooftop (º).

For this study, 10-year daily rainfall records from 2009 to 2018 recorded at the Felda Gedangsa rain station were used to obtain the average daily rainfall data. The rainfall records were obtained from the Department of Irrigation and Drainage Malaysia (DID). Felda Gedangsa's rain station was chosen because it is the closest to the case study area which is located about 13.8 km from PSAS.

In addition, the runoff coefficient (RC) or the water loss of the roof catchment area considered in this study is 0.90 which is referred to Nahrim Technical Guide No. 2 (2014).

2.2 Water Demand

In this study, only the water demand for toilet flushing use was considered andcalculated by considering the toilet usage frequency, number of building occupants, and the water closet cistern capacity. The data for toilet flushing frequency were obtained through a questionnaire survey which wasdistributed to students and staff in CED block, while the numbers of building occupants and cistern capacity were obtained from PSAS's documents. The water demand estimated in this study can be mathematically expressed as follows:

$$DT = B \ x \ F_T \ x \ F_W \tag{3}$$

DT is the daily demand for toilet flushing uses, *B* is the total number of building occupants, *FT* is the flushing time per day and *FW* is the water needed per flush.

2.3 Simulation Model

In the simulation model, the mass balance computation for the storage capacity was done using Microsoft Excel. The simulation was calculated with various ranges of possible storage tank sizes until the reliability of the system reaches 100%. The simulation model formula applied in this study was adopted from Rahman et al. (2012), Lani et al. (2018a) and Lani et al. (2018c) and can be mathematically expressed as below:

$$R_t = \begin{cases} D_t & \text{if } WI_t + WS_{t-1} \geq D_t \\ WI_t + WS_{t-1} & \text{if } WI_t + WS_{t-1} < D_t \end{cases} \tag{4}$$

Rt is the daily water released (m³), *Dt* is the daily water demand (m³), *WI* is the inflow (volume of rainfall captured from the roof) (m³), *WSt –1* is the tank storage at the end of the previous day (m³) and *t* is the time (day).

2.4 Economic Indicators

In this study, the economic benefits of the proposed RWHS were evaluated using two economic indicators which were the percentage of reliability (R) and the payback period (PBP). These two economic indicators were adopted from Lani et al. (2018a) and can be mathematically expressed as below:

$$R(\%) = \frac{WR}{D} \times 100\% \quad (5)$$

$$\sum_{t=0}^{s} StPt - It - Ot \quad (6)$$

R is the reliability of the RWHS use (%), WR is the annual water release (m³), D is the annual water demand (m³), *St* is the volume of public water saved over a period of time *t* (m³), *Pt* is the cost of the public water supply (RM), *It* is the installation cost required over a period of time (RM), *Ot* is the operational cost over a period of time (RM), *s* is the system lifespan (year) and *t* is the system operation period (year).

The isometric drawing for the proposed RWHS for CED block is shown in Figure 1. In the proposed system, seven components were considered to estimate the system's installation cost which are the catchment area (roof of the CED block), gutters, rainwater downpipes, first flush filter, storage tank, header tanks, and water pumps. In addition, the operational cost assumed for the proposed system was estimated using a formula adopted by Lani et al. (2018a) and can be mathematically expressed as below:

$$OC = \frac{Ws}{PFS} P_E E_t \quad (7)$$

OC is the annual operation cost (RM), *Ws* is public potable water saved (m³), *PFS* is the pump speed (m³/min), *PE* is the pump energy (w) and *Et* is the current electricity tariff (RM/w).

In addition, in estimating the PBP of the RWHS, two types of RWHS storage tank which were High Density Polyethylene (HDPE) tank and Fibre-reinforced Plastic (FRP) sectional tanks were proposed in order to provide an alternative to the selection of the tank and to find the most economical tank for the proposed RWHS.

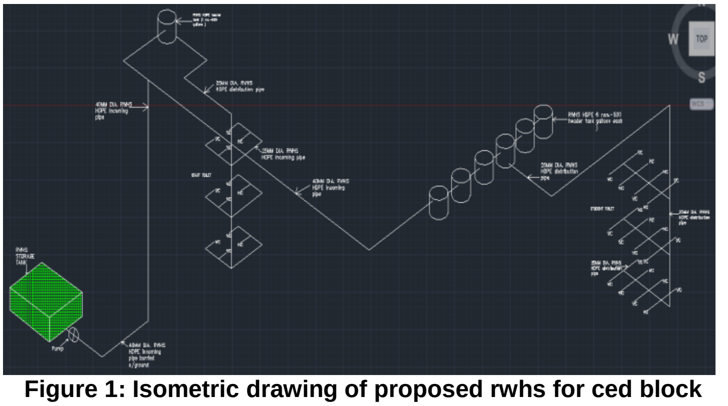

Figure 1: Isometric drawing of proposed rwhs for ced block

3.0 RESULT AND DISCUSSION

3.1 Potential Rainwater Harvested

The potential rainwater harvested (PRH) is calculated by considering the rooftop area, runoff coefficient and daily rainfall amount. Result shows that the PRH for CED block varies from month to month depending on the amount of rainfall received as shown in Figure 2. It can be seen that the highest PRH was in November (35.85 m3) and the lowest PRH was in September (20.85 m3).

Figure 2: Potential rainwater harvested (PRH) for CED block from January to December

3.2 Water Demand

Water demand was calculated by considering the number of CED occupants, the toilet flushing frequency, and the water closet cistern capacity. It was found that the total daily water demand for toilet flushing usage for CED block was 16.05 m3, a calculated result of 772 building occupants, 4 times average toilet flushing frequency per day, and 6 liters water closet cistern capacity.

3.3 RWHS Reliability

RWHS Reliability (R) is the ratio of the annual PRH which is Water Released (WR) and annual water demand (D) calculated from the daily mass simulation model using Formula 5. It was found that the annual WR was 6412 m3 and the annual D was 3672 m3 which means that the rainwater supply can fully meet the water demand with the use of a suitably-sized tank. Figure 3 shows the effects of rainwater tank size on the percentage of reliability for the proposed RWHS as the simulation was carried out with possible storage tank sizes until the maximum reliability was achieved. It can be seen that the maximum reliability (100%) of the proposed RWHS can be achieved with the use of 150 m3 tank size.

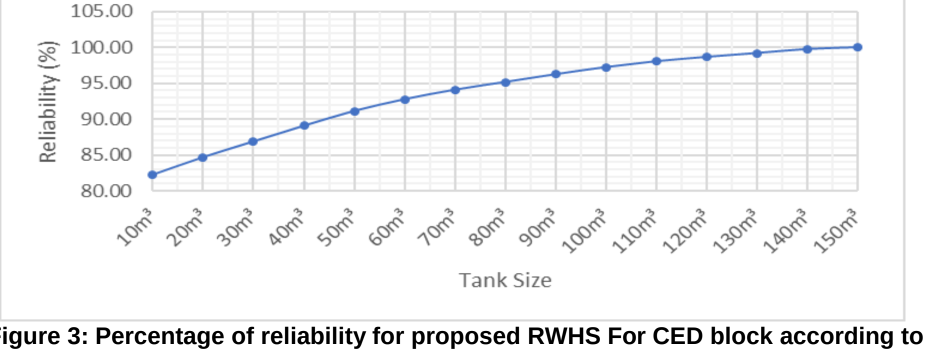

Figure 3: Percentage of reliability for proposed RWHS For CED block according to various tank sizes

3.4 Payback Period

In evaluating the PBP of the proposed RWHS, two types of RWHS storage tank which are HDPE tank and FRP sectional tanks were proposed in order to provide an alternative to the selection of the tank and to find the most economical tank. The potable water savings, installation cost and operational cost for both tanks were analyzed using a cash flow created in Microsoft Excel for 30 years duration which is the expected system lifespan. Figure 4 shows the PBP of the HDPE tank and FRP sectional tanks which plotted with the percentage of reliability. It can be seen that for tanks sized up to 60 m3, the cost of a HDPE tank is lower than FRP sectional tanks with the PBP ranging from 11 to 19 years and 13 to 20 years respectively. Interestingly, with a 90 m3 tank, the PBP for both types of tanks is the same which is 23 years. However, the cost of HDPE tank becomes more expensive than the cost of FRP sectional tank for tank size 100 m3 onwards with PBP ranging from 23 to 38 years and 23 to 29 years respectively. Hence, the maximum reliability of RWHS for this block which is with the 150 m3 tank size can be achieved with FRP sectional tank, but cannot be achieved with the HDPE tank. In addition, the reliability percentage for the proposed RWHS is between 82.22% to 100% by using the tank size from 10 m3 to 150 m3. However, within the system lifespan which is 30 years, the maximum reliability (100%) can only be achieved with the use of FRP tanks of which the PBP is 29 years.

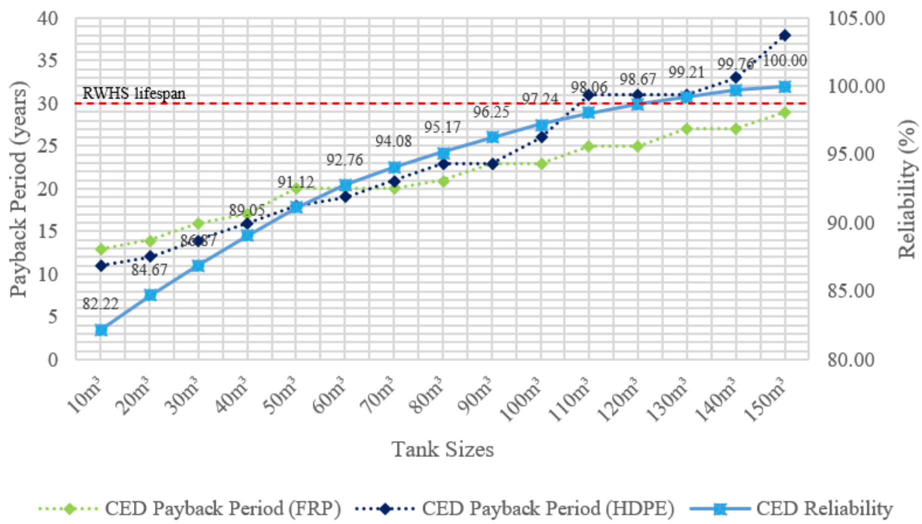

Figure 4: RWHS payback period for FRP and HDPE tank installation cost and percentage of reliability for CED block

The high percentage of reliability for the proposed RWHS is due to high potential rainwater harvested which is influenced by the rainfall characteristic within the area, size of the CED block's roof area, and also the combination of the suitable tank sizes. In addition, the higher amount of potential rainwater harvested than the water demand also has contributed to the high percentage of reliability of the system. This finding corresponds with the study done by Guo and Baetz (2007), Kim and Yoo, (2009), Imteaz et al. (2011), Mun and Han (2012), Campisano et al. (2013), Morales-Pinzón et al., (2015) and Temesgen et al., (2015) which claim that the performance of RWHS depends on the rainfall pattern, roof area, water demand, and the storage tank use.

4.0 CONCLUSION

The aim of the study was to evaluate the economic benefits of RWHS for toilet flushing usage at the academic building which was carried out at the Civil Engineering Department (CED) block at PSAS, Behrang. The site-specific RWHS important parameters which are rainfall availability, catchment area, storage, and water demand were evaluated in order to assess the percentage of reliability (R) and payback period (PBP) of the proposed system. In addition, two types of tank which are HDPE tank and FRP sectional tanks were proposed to provide an alternative to the selection of the tank.

It was found that the percentage of reliability (R) for CED block is between 82.22% to 100% by using the tank size from 10 m3 to 150 m3. For tank sizes up to 60 m3, the cost of a HDPE tank is lower than FRP sectional tanks with the PBP ranging from 11 to 19 years and 13 to 20 years, respectively. However, for tank size 100 m3 onwards, the cost of HDPE tank becomes more expensive than the cost of FRP sectional tank with PBP ranging from 23 to 38 years and 23 to 29 years, respectively. These findings prove that RWHS is economical to be implemented in academic buildings. If the maximum reliability is given priority, the larger tanks can be used. However, if a shorter PBP is required, the smaller tanks can be selected as the reliability of the system is still considered high. For future studies, it will be interesting to evaluate RWHS by diversifying the use of harvested rainwater such as for general cleaning and irrigating the landscape, which may offer more economic benefits.

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