



FINANCIAL BENEFITS OF POTENTIAL RAINWATER HARVESTING SYSTEM INITIATIVE FOR HOSTEL

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Abstract

Higher Education Institutions (HEI) have been considered ‘small cities’ with various buildings, services, and activities. Proposing a Rainwater Harvesting System (RWHS) in the HEI environment is an initiative towards greening the campus as well as action toward achieving global targets of Sustainable Development Goal (SDG) and UI GreenMetric World University Rankings. Thus, a study on the potential RWHS is required to obtain the financial benefits of RWHS installation and investment. This research focuses on the potential of RWHS for hostel buildings at one of the HEIs in Malaysia, i.e., Politeknik Sultan Azlan Shah (PSAS). PSAS was selected to promote polytechnics as a sustainable, superior, and excellent way to implement green elements at the site and across the curriculum in the Polygreen Blueprint. This research objective is to evaluate the financial benefits of potential RWHS as a sustainable initiative for hostel buildings in terms of Reliability (R) and Payback Period (PBP). Data collected from related documents are used to simulate calculation for R and PBP. The daily water mass balance model was adopted in the simulation process to obtain the financial benefits of RWHS. For hostel buildings, the RWHS initiative could potentially benefit in terms of finances with PBP from 23 to 26 years if 10 m³ to 30 m³ capacity High-Density Polyethylene (HDPE) water storage is installed. The R of the RWHS is between 63.14% to 74.52% with 30 years of lifespan. This study focuses on PBP, which considers local conditions that limit result generalizability.

Keywords: financial benefits, Higher Education Institution (HEI), hostel, sustainable initiative, Rainwater Harvesting System (RWHS).

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INTRODUCTION

Higher Education Institutions (HEI) are considered small cities, namely campuses with various buildings, services, and activities. Notably, initiatives toward sustainable and green campuses are planned and developed to combat global warming and foster sustainable campus growth (Muhiddin et al., 2023). The initiatives align with the global agenda of the Sustainable Development Goal (SDG) (UN, 2015) and green campus assessment of UI GreenMetric World University Rankings (UI, 2023). As such, the Rainwater Harvesting System (RWHS) in the HEI environment is one of the sustainable initiatives for greening the campus.

RWHS provides numerous useful values for the environment, economy, technology, and society (Lani et al., 2018). In terms of environmental returns and technology, the implementation of RWHS helps save water, reduces demand on public supply, and lowers runoff, which helps prevent erosion and floods (DID, 2017). Financially, RWHS can lower the cost of water treatment and lessen the government burden of constructing new water distribution infrastructure to fulfill the water demand from society (Che-Ani et al., 2009). Thus, rainwater harvesting could be adopted as an alternative to reduce freshwater use for non-potable purposes (Habibullah et al., 2023).

Even though RWHS offers tons of benefits, its application is relatively at a minimum level. Implementation of green initiatives at HEI, such as RWHS, encounters some challenges, such as financial, awareness, and knowledge (Mohd Isa, 2021). Domènech and Saurí (2011) described that the long Payback Period (PBP) is the main drawback of RWHS implementation. However, installing RWHS requires high capital costs (Sakson, 2018) and a longer period of return on investment (Lani et al., 2018). Silva et al. (2015) claimed that the economic viability of the RWHS is uncertain, thus limiting the decision on its application. Other challenges to social acceptance of RWHS are risk perception, health risk, and the water quality harvested (Campisano et al., 2017).

This study focuses on Politeknik Sultan Azlan Shah (PSAS), a HEI in Malaysia selected as a case study due to its designation to promote the integration of green practices across campus operations and curriculum under the Blueprint Polygreen (JPP, 2015). While prior Malaysian research has primarily emphasized on general issues and barriers, this study offers a novel contribution by assessing RWHS feasibility specifically within the operational and sustainability priorities of HEI hostel buildings. This provides specific financial insights for sustainable campus strategies and decision making. Therefore, the objective of this study is to evaluate the financial benefits of implementing a potential RWHS for hostel buildings at PSAS.

LITERATURE REVIEW

Guidelines on RWHS

In Malaysia, guidelines regarding RWHS have been developed by various government agencies to support and enhance RWHS as a sustainable initiative. Table 1 summarizes the list of agencies and guidelines developed for RWHS in Malaysia.

Table 1: Guidelines for RWHS in Malaysia

No	Ministry/Department/Agency	Guidelines	Year
1	Ministry of Housing and Local Government	Guideline for Installing a Rainwater Collection and Utilization System	1999
2	Department of Irrigation and Drainage Malaysia	Rainwater Harvesting: Guidebook on Planning and Design	2009
3	National Hydraulic Research Institute of Malaysia	Guideline on Eco-Efficiency in Water Infrastructure for Public Buildings in Malaysia	2011
4	Department of Irrigation and Drainage Malaysia	Urban Storm Water Management Manual for Malaysia, MSMA 2 nd Edition	2012
5	Federal Town and Country Planning Department	Panduan Pelaksanaan Inisiatif Pembangunan Kejiranan Hijau – Sistem Pengumpulan dan Penggunaan Semula Air Hujan	2012
6	Federal Town and Country Planning Department	Garis Panduan Perancangan Kejiranan Hijau	2012
7	Federal Town and Country Planning Department, Ministry of Urban Wellbeing, Housing and Local Government	Garis Panduan Sistem Pengumpulan dan Penggunaan Air Hujan	2013
8	National Hydraulic Research Institute of Malaysia	NAHRIM Technical Guide No. 2	2014
9	Malaysian Public Works Department	Rekabentuk Sistem Penuaian Air Hujan (Panduan 06)	2014
10	Department of Standards Malaysia	Urban Storm Water Management – Part 6: Rainwater Harvesting, MS2526-6:2014	2014

Source: Adopted from Lee et al. (2016)

Storage tank

A storage tank is a component where the collected rainwater is stored or harvested for later use to reduce the main water consumption in terms of economic or environmental reasons (NAHRIM, 2014). According to DID (2017), the storage tank can be installed whether above-ground or below-ground. Alternatively,

Standards Malaysia (2014) and NAHRIM (2014) stated that the tank can be installed on the ground, underground, or roof.

Previous studies have paid particular attention to storage tanks since they are the most expensive component in RWHS installation. Temesgen et al. (2015) dictated that the largest investment of RWHS is the storage tank, which ranges from 50% to 85% of the overall installation cost. Meanwhile, Nasif and Roslan (2016) highlighted that the major investment in RWHS is the storage tank, and the increasing size will increase the cost. The oversizing of the tank can lead to the excessive initial cost of the RWHS. Hence, the optimum tank size must be determined to provide the optimal value for the money. The material and tank capacity of the tank are significant design parameters in RWHS installation (Mun and Han, 2011). In other words, the higher cost of the tank will affect the longer PBP (Nasif and Roslan, 2016).

Financial Assessment

Financial assessment is essential in evaluating the value for money of RWHS. Previous studies commonly use Payback Period (PBP) as the primary economic indicator because it is simple and widely applicable (Imteaz et al., 2021). A shorter PBP indicates better financial performance and has been used effectively to assess RWHS viability (Silva et al., 2015; Pacheco & Campos, 2017). However, findings from international contexts do not always align with Malaysian conditions. Countries with higher water tariffs often report shorter PBPs, while longer PBPs described in Malaysian studies due to lower water tariff and higher installation costs (Che-Ani et al., 2009; Habibullah et al., 2023). These differences highlight the importance of localized financial assessment because PBP outcomes are influenced by rainfall patterns, construction costs, and building specific conditions.

RESEARCH METHODOLOGY

Case Study

PSAS was selected as the case study to evaluate the potential of RWHS for sustainable campus development as identified in the Blueprint Polygreen (JPP, 2015). PSAS is located in Behrang, Perak (03°77'00" N, 101°45'01"E), covering 44.5 hectares of hilly terrain. The campus consists of administration buildings, academic blocks, and six hostel blocks accommodating the largest student population (3,082 students). Given their high water demand for non-potable uses, the six hostel blocks were selected for RWHS financial evaluation.

Daily rainfall data for a ten-year period (2008 – 2018) were obtained from the nearest meteorological station i.e. Felda Gedangsa, located 13.8 km from PSAS. The dataset meets the minimum recommended duration for RWHS analysis (Ward et al., 2014) and aligns with findings that 10-year records are sufficiently reliable for evaluating RWHS performance (Mitchell, 2007). As

RWHS efficiency is highly dependent on local rainfall patterns, these long-term records provide a meaningful evaluation basis (Su et al., 2009; Rahman, 2014).

Limitations

The methodology has several limitations that may affect the generalizability of the findings. First, the reliance on historical rainfall data from a single nearby station may not fully capture micro-climatic variations across the PSAS campus, potentially influencing reliability estimates. Second, the use of document analysis as the primary data source depends on the accuracy and completeness of available institutional records. This may present vagueness in installation and operation cost data. These limitations indicate that the results are most applicable to PSAS and similar HEIs with comparable climatic and operational conditions.

Document Analysis

Document analysis is a systematic data collection procedure for evaluating or reviewing various forms of documents to obtain accurate and detailed information (Bowen, 2009). Document analysis methods produce detailed descriptions of a single program, events, and phenomena such as case studies (Yin, 1994). The document analysis method was employed in this study to gather data needed to calculate Reliability (R) and PBP. For this study, the required documents for R and PBP calculation for RWHS simulation and financial assessment are summarized in Tables 2 and 3, respectively.

Table 2: Documents for reliability (R) analysis

Documents	Organization/ Publisher	Data Obtained	Purpose
Study site's plans	PSAS	- Roof area - Roof covering material	Used in potential rainwater harvested calculation.
		Cistern capacity	Used in water demand calculation.
		Plumbing layout and header tank location	Reference in designing the proposed RWHS.
<i>Sistem Pengurusan Maklumat Politeknik (SPMP)</i>	PSAS	Number of building occupants	Used in water demand calculation.
Historic Rainfall Data	DID	Rainfall amount	Used in potential rainwater harvested calculation.
NAHRIM Technical Guide No.2	NAHRIM	Runoff coefficient	Used in potential rainwater harvested calculation.

Table 3: Documents for Payback Period (PBP) analysis

Documents	Organization/ Publisher	Data Obtained	Purpose
Storage Tank Catalogue	G-FRP Industries Sdn. Bhd.	▪ Tank sizes	Used in installation cost estimation.
Water Pump Catalogue	Nanfang Pump Industries Co., Ltd	▪ Water pump capacity	Used in installation cost and operational cost estimation.
RWHS Bills of Quantities	Aura-Lite Sdn. Bhd.	▪ Price of tanks, first flush filter, piping, water pump, and plinth	Used in installation cost estimation.
Water Tariff	<i>Lembaga Air Perak (LAP)</i>	▪ Water tariff	Used in water savings estimation.

Daily Mass Balance Simulation Model

The daily mass balance simulation model is applied to calculate the R of RWHS by considering the design parameter (Su et al., 2009). This model is the most preferred tool to calculate R and the size of the storage tank (Devkota et al., 2015). In addition, the simulation model could evaluate the ideal alternatives of RWHS in terms of storage capacity for decent decision-making on the RWHS initiative (Mun and Han, 2012). Previous researchers on RWHS, such as Su et al. (2009), Rahman et al. (2014), and Lani et al. (2018), used this model in their study. The daily mass balance simulation model formula is as follows:

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

where the R_t is the daily water released (m^3), D_t is the daily water demand (m^3), WI is the inflow (volume of rainfall captured from the roof) (m^3), WS_{t-1} is the tank storage at the end of the previous day (m^3), and t is the time (day).

A spreadsheet of daily mass balance simulation models is created using Microsoft Excel. Related data from the document are inserted into the simulation model to ease the calculation of R.

Reliability (R)

As the output of the daily mass simulation model is the water released (WR) and water demand (D), the R of the RWHS for all building categories is identified using the formula as follows:

$$R(\%) = \frac{WR}{D} \times 100\% \quad (2)$$

where R is the reliability of the RWHS use (%), WR is the annual water release (m³), and D is the annual water demand (m³). The R is calculated for the six hostel blocks in a year duration (Lani et al., 2018).

Payback Period (PBP)

The financial benefit of the RWHS depends on investment, operation cost and the public water supply saving. Additionally, the system, installation cost, operational cost, and the amount of savings are calculated to obtain PBP (Silva et al., 2015). The flow chart on the financial benefit assessment of RWHS using PBP is displayed in Figure 1.

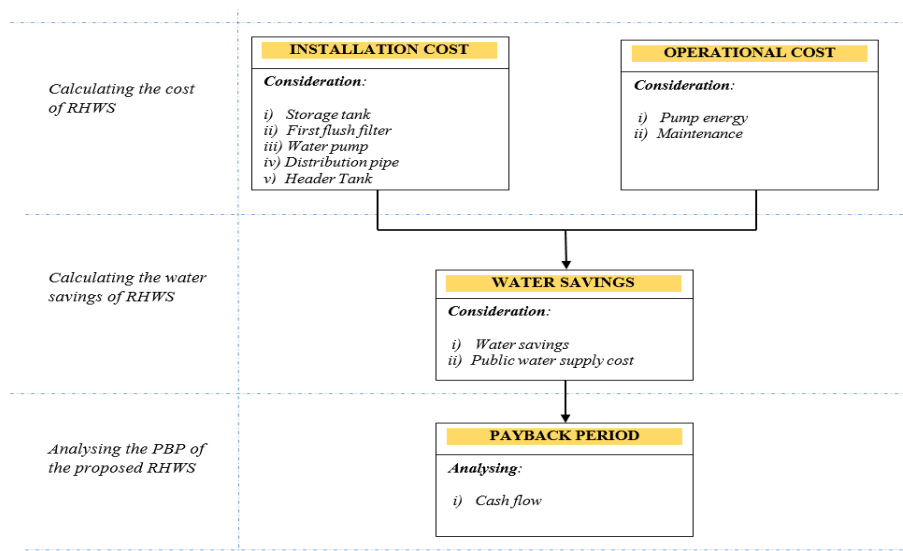


Figure 1: Flow chart of financial benefit assessment of RWHS using PBP

Financial Benefit RWHS Assessment

The financial benefit of RWHS for hostel blocks was determined based on R and the PBP. The R and the PBP were plotted in the graph along with the various sizes of storage tanks simulated in the water mass simulation model.

Two approaches have been employed to determine the optimal RWHS application for each block. The first approach is to select an optimum storage tank since the cost of RWHS is influenced by the storage tank (Temesgen et al., 2015; Mun and Han, 2012; and Zavala et al., 2018). The second approach is to consider if the optimum tank size has exceeded the system's life span. The most economic

RWHS is determined by selecting the tank size range where the PBP is still within the expected system's lifespan (Silva et al., 2015). Simultaneously, the RWHS is determined through the PBP estimation where the shorter PBP is the better financial benefit.

FINDINGS AND DISCUSSION

The financial benefits of the potential RWHS initiative for the hostel in PSAS are based on the simulation calculation for PBP and R.

Payback Period (PBP)

For PBP simulation on the potential RWHS, two types of water storage tanks, namely Fiber-Reinforced Plastic (FRP) sectional tanks and High-Density Polyethylene (HDPE) tanks, are considered due to the availability of these products in the market. Figures 2.1, 2.2, 2.3, 2.4, 2.5, and 2.6 illustrate the impact of different sizes of tanks on FRP sectional tanks and HDPE tank cost installation on the PBP of the RWHS.

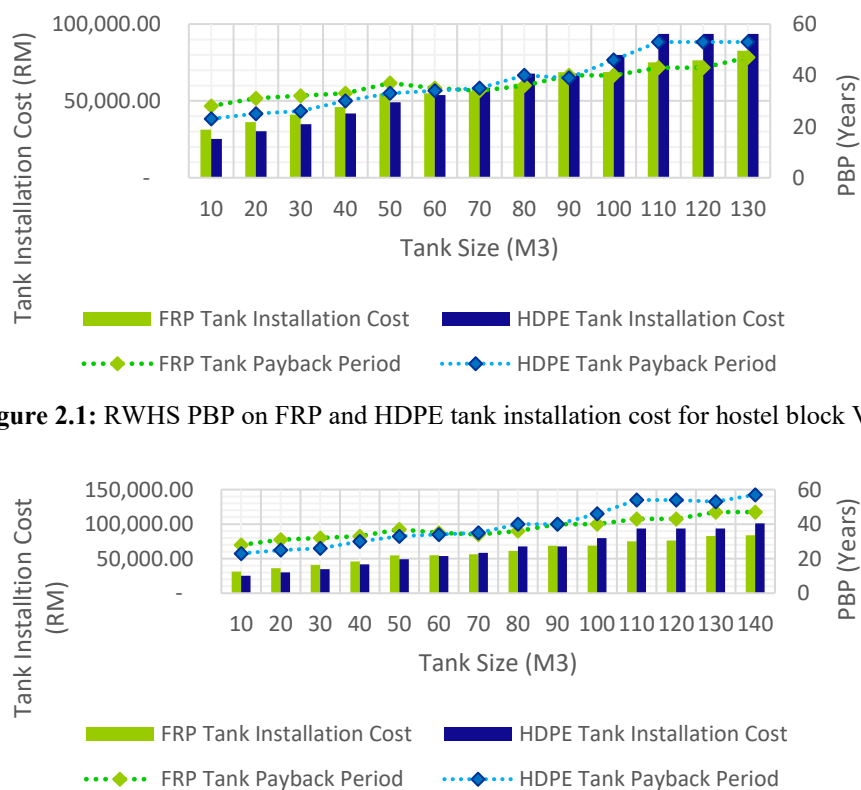


Figure 2.1: RWHS PBP on FRP and HDPE tank installation cost for hostel block V1

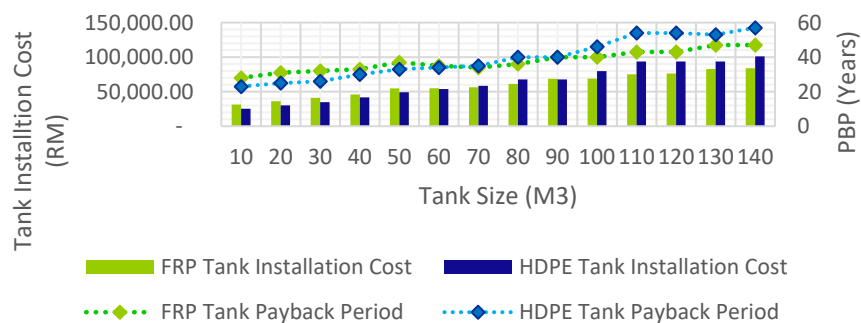


Figure 2.2: RWHS PBP on FRP and HDPE tank installation cost for hostel block V2

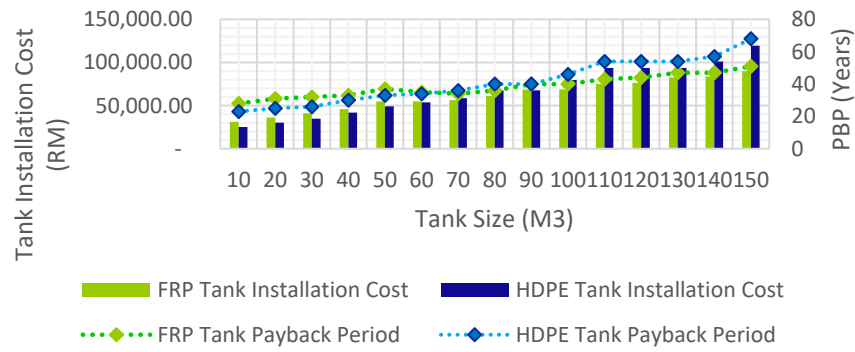


Figure 2.3: RWHS PBP on FRP and HDPE tank installation cost for hostel block V3

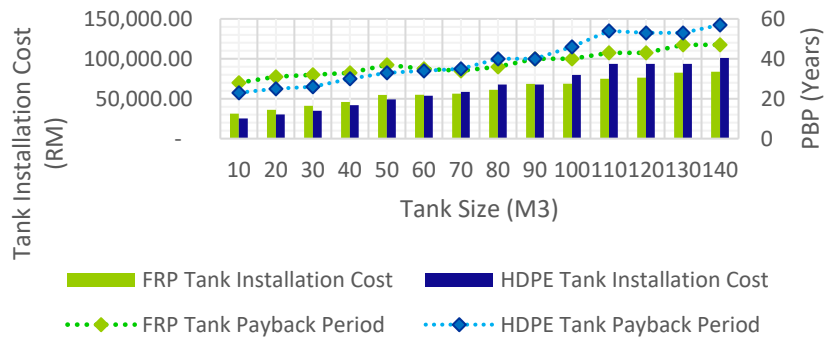


Figure 2.4: RWHS PBP on FRP and HDPE tank installation cost for hostel block V4

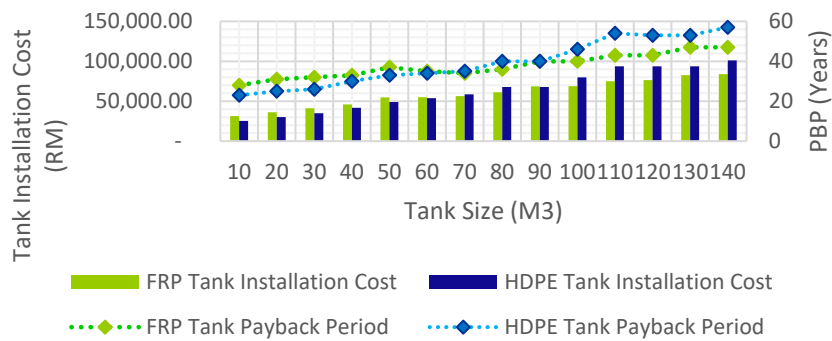


Figure 2.5: RWHS PBP on FRP and HDPE tank installation cost for hostel block V5

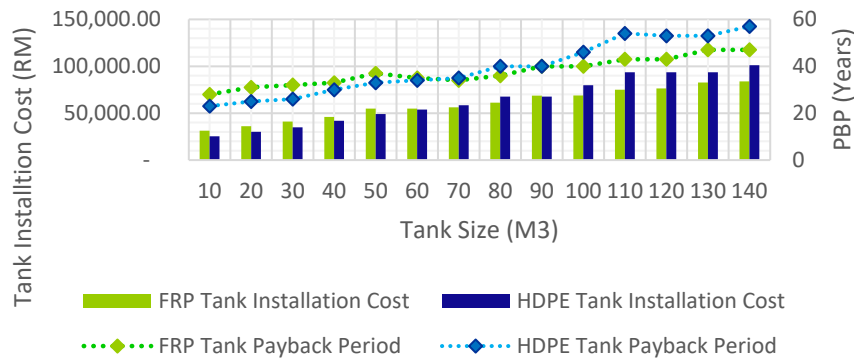


Figure 2.6: RWHS PBP on FRP and HDPE tank installation cost for hostel block V6

Figures 2.1, 2.2, 2.3, 2.4, 2.5, and 2.6 illustrate the RWHS PBP for FRP and HDPE tank installation cost for hostel blocks of V1, V2, V3, V4, V5, and V6, respectively with various tank sizes proposed. The result reveals that from the tank size of 10 m³ to 60 m³, the installation cost of the HDPE tank is lower than the FRP sectional tank. However, the cost of installing an HDPE tank becomes pricier than the cost of an FRP sectional tank for tank size 70 m³ onwards. Meanwhile, for the tank size of 10 m³ to 60 m³, the PBP for the HDPE tank is shorter, ranging from 23 to 34 years, compared to the FRP sectional tank with 28 to 35 years. For the tank size of 70 m³ onwards, the PBP for the HDPE tank is longer, ranging from 35 to 57 years, compared to the FRP sectional tank with 34 to 47 years.

In terms of financial benefits based on the cost of tank installation and PBP, the HDPE tank with smaller sizes, between 10 m³ and 60 m³, is optimum for implementation with PBP ranging from 23 to 34 years.

Reliability (R)

R simulation on the potential RWHS on the two types of water storage tanks, namely FRP sectional tank and HDPE tank, is conducted until the size of the water tanks achieves the highest target of R of RWHS, which is 100%.

The financial benefits evaluation is based on graphs plotted by combining the type of tanks, sizes of tanks, percentage of R, PBP, and lifespan of the RWHS. Figures 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6 display the evaluation of different sizes of FRP and HDPE tanks to R and PBP within the potential RWHS lifespan of 30 years.

The percentages of R for the RWHS for HDPE tanks are between 63.14% and 74.52%, which is acceptable to implement when considering the system's lifespan and PBP. The 100% maximum R of RWHS with larger tank sizes for the hostel blocks is also simulated. Inappropriately, larger sizes of FRP

and HDPE tanks, for example, 100 m³ onwards, are not significant due to longer PBP and exceed the system's lifespan.

Financial benefits

The analysis of the six (V1, V2, V3, V4, V5, and V6) hostel blocks in PSAS demonstrates similar findings for each hostel block that the PBP of RWHS was affected by the types of storage tanks and tank sizes. In other words, tank selection in RWHS design contributes significantly to the cost implication of RWHS. These findings align with previous research by Zavala et al. (2018) and Lani et al. (2018).

Based on the Malaysia market price of water storage tanks, the cost of an HDPE tank is cheaper than FRP sectional tanks for installation of water storage tank sizes 10 m³ to 60 m³. However, the cost of the HDPE tank becomes more expensive than FRP sectional tanks for tank size 70 m³ onwards.

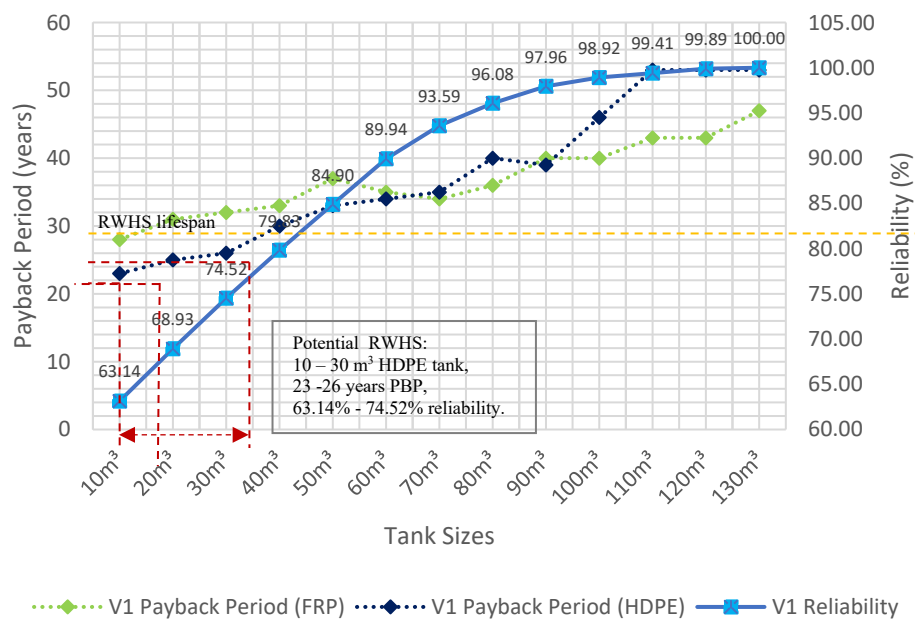


Figure 3.1: Financial benefit evaluation of potential RWHS for hostel block V1

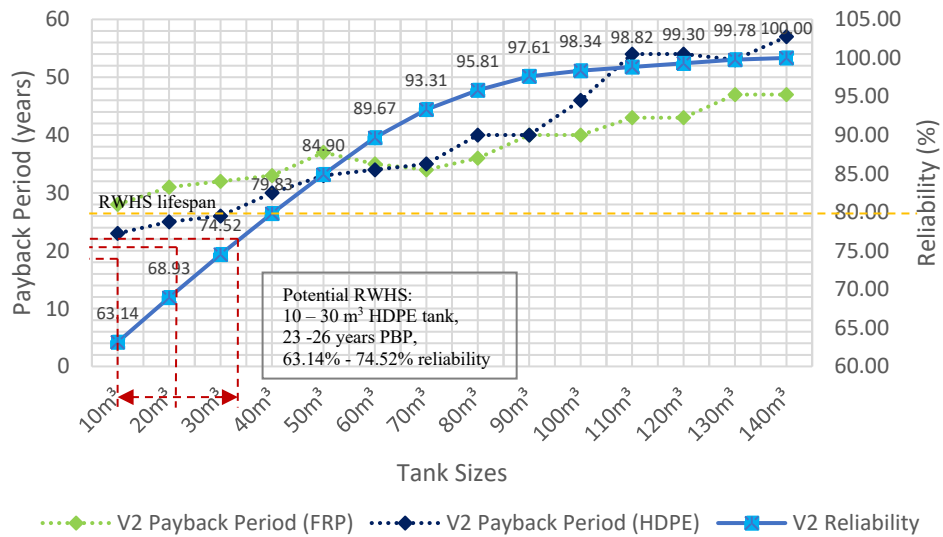


Figure 3.2: Financial benefit evaluation of potential RWHS for hostel block V2

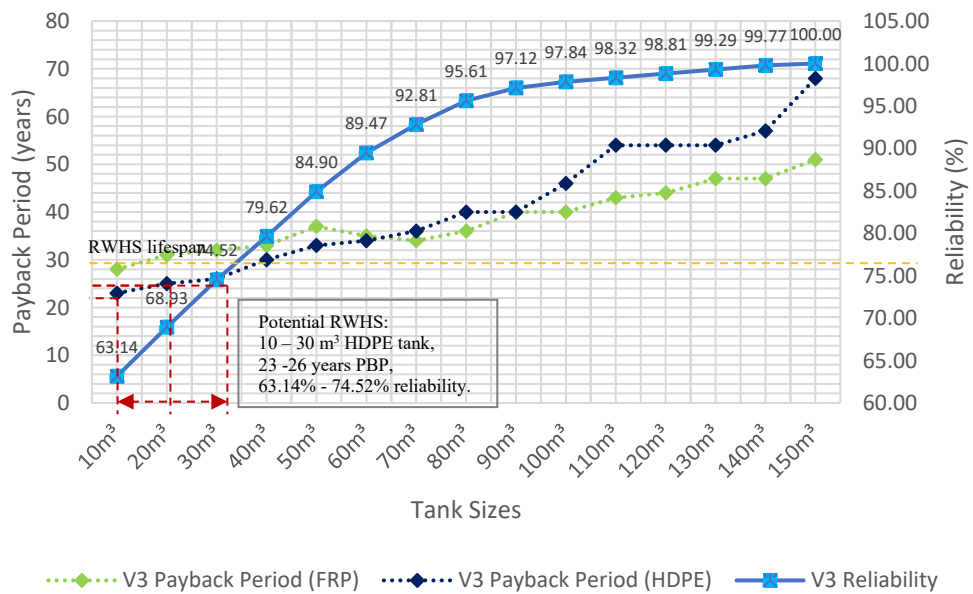


Figure 3.3: Financial benefit evaluation of potential RWHS for hostel block V3

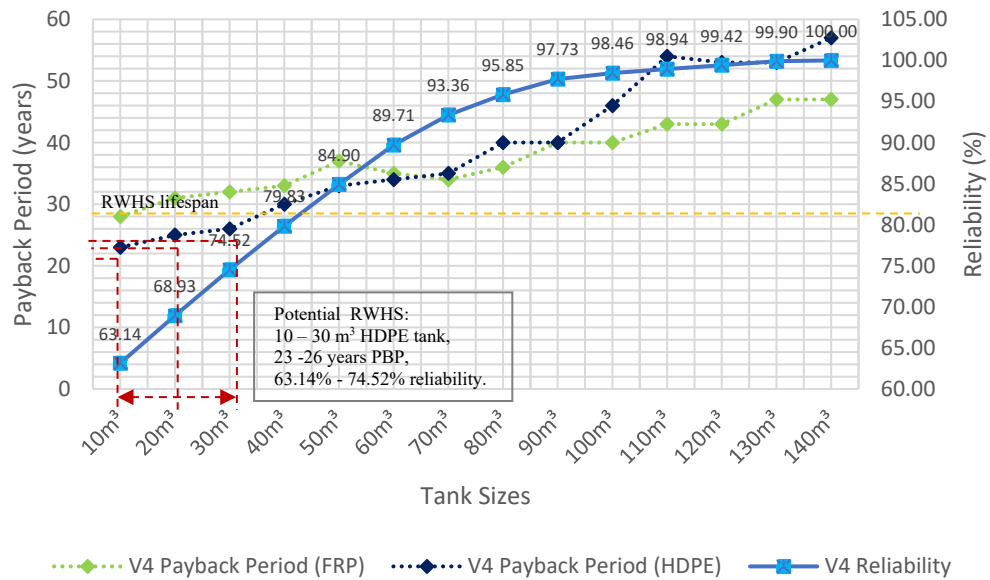


Figure 3.4: Financial benefit evaluation of potential RWHS for hostel block V4

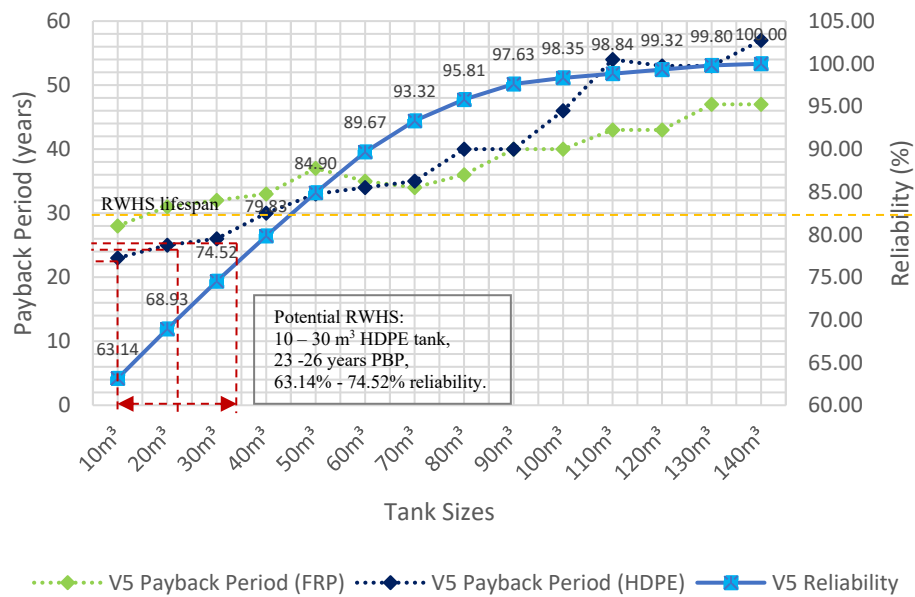


Figure 3.5: Financial benefit evaluation of potential RWHS for hostel block V5

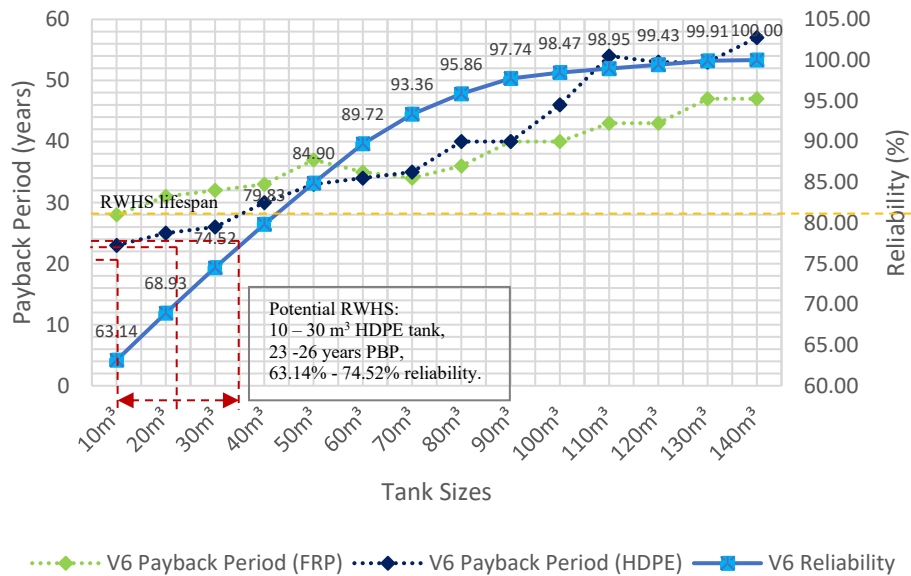


Figure 3.6: Financial benefit evaluation of potential RWHS for hostel block V6

For optimal financial benefits, the potential RWHS design must consider the R and lifespan of RWHS for 30 years. The smaller HDPE tank sizes range from 10 m³ to 30 m³ with 23 to 26 years of PBP, which are considered the most appropriate financial benefits of RWHS for all the hostel blocks. This is due to the acceptable R ranging between 63.14% and 74.52%, and PBP is within the RWHS expected lifespan. The maximum R of 100% on the tank sizes will result in high PBP, which exceeds the RWHS expected lifespan, which is a disadvantage in terms of finances. Silva et al. (2015) suggested that the most financial benefits of potential RWHS should be based on shorter PBP.

CONCLUSION

In conclusion, the study shows that selecting the appropriate HDPE tank size is essential for ensuring the financial feasibility of RWHS in PSAS hostel buildings. Small to medium sized tanks offer the best balance between cost and performance, particularly for institutions seeking shorter payback periods. These findings provide practical guidance for HEIs considering RWHS as part of their sustainability policies and strategies, supporting progress toward SDGs and strengthening performance in the UI GreenMetric ranking.

Even though the payback period is relatively long under current tariff rates, the financial viability of RWHS is likely to improve as water tariffs rise in the future. RWHS can serve as a strategic long-term resource management

measure for HEIs. Future research should therefore examine how potential tariff increases could further enhance the economic value of RWHS in Malaysian HEIs.

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REFERENCES

- Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, 9(2), 27–40.
- Campisano, A., Butler, D., Ward, S., Burns, M., Friedler, E., DeBusk, K., Fisher-Jeffes, L., Ghisi, E., Rahman, A., Furumai, H., & Han, M. (2017). Urban rainwater harvesting systems: Research, implementation and future perspectives. *Water Research*, 115, 195–209. <https://doi.org/10.1016/j.watres.2017.02.056>
- Che-Ani, A. I., Shaari, N., Sairi, A., Zain, M. F. M., & Tahir, M. M. (2009). Rainwater harvesting as an alternative water supply in the future. *European Journal of Scientific Research*, 34(1), 132–140.
- Department of Irrigation and Drainage (DID). (2017). *Rainwater harvesting guidebook*. <https://www.water.gov.my/index.php/pages/view/585>
- Devkota, J., Schlachter, H., & Apul, D. (2015). Life cycle-based evaluation of harvested rainwater in toilets and for irrigation. *Journal of Cleaner Production*, 95, 311–321.
- Domènech, L., & Saurí, D. (2011). A comparative appraisal of the use of rainwater harvesting in single and multi-family buildings of the Metropolitan Area of Barcelona (Spain): Social experience, drinking water savings and economic costs. *Journal of Cleaner Production*, 19(6–7), 598–608.
- Habibullah, N., Sahrir, S., & Ponrahono, Z. (2023). Integrating rainwater harvesting and greywater recycling to increase water efficiency in office buildings. *Planning Malaysia*, 21(29). <https://doi.org/10.21837/pm.v21i29.1369>
- Imteaz, M. A., Bayatvarkeshi, M., & Karim, M. R. (2021). Developing generalised equation for the calculation of payback period for rainwater harvesting systems. *Sustainability*, 13(8), Article 4266. <https://doi.org/10.3390/su13084266>
- Jabatan Pengajian Politeknik (JPP). (2015). *Blueprint polygreen*. Kementerian Pendidikan Malaysia. <https://www.mypolycc.edu.my/index.php/muat-turun/poly-green/send/3-polygreen/12-blueprint-polygreen-politeknik-malaysia>
- Lani, N. H. M., Yusop, Z., & Syafiuddin, A. (2018). A review of rainwater harvesting in Malaysia: Prospects and challenges. *Water*, 10(4), 1–21.
- Lee, K. E., Mokhtar, M., Hanafiah, M. M., Halim, A. A., & Badusah, J. (2016). Rainwater harvesting as an alternative water resource in Malaysia: Potential, policies and development. *Journal of Cleaner Production*, 126, 218–222.
- Mitchell, V. G. (2007). How important is the selection of computational analysis method to the accuracy of rainwater tank behaviour modelling? *Hydrological Processes*, 21(21), 2850–2861.
- Mohd Isa, H., Sedhu, D. S., Lop, N. S., Rashid, K., Mohd Nor, O., & Iffahd, M. (2021). Strategies, challenges and solutions towards the implementation of green campus in

- UiTM Perak. *Planning Malaysia*, 19(2), 60–71.
<https://www.planningmalaysia.org/index.php/pmj/article/view/952>
- Muhiddin, A. A. M., Isa, H. M., Sakip, S. R. M., Nor, O. M., & Sedhu, D. S. (2023). Green campus implementation in the Malaysian public universities: Challenges and solutions. *Planning Malaysia*, 21(1), 274–298.
<https://www.planningmalaysia.org/index.php/pmj/article/view/1239>
- Mun, J. S., & Han, M. Y. (2012). Design and operational parameters of a rooftop rainwater harvesting system: Definition, sensitivity and verification. *Journal of Environmental Management*, 93(1), 147–153.
- NAHRIM. (2014). *NAHRIM Technical Guide No. 2: The design guide for rainwater harvesting*. Ministry of Natural Resources and Environment.
https://jkt.kpkt.gov.my/jkt/resources/user_30/2016_OKU/NAHRIM_Tech_Guide_No_2.pdf
- Nasif, M. S., & Roslan, R. (2016). Effect of varying roof run-off coefficient values and tank size on rainwater harvesting system's water savings in Malaysia. *ARPN Journal of Engineering and Applied Sciences*, 11, 12937–12941.
- Pacheco, G. C., & Campos, M. A. (2017). Economic feasibility of rainwater harvesting systems: A systematic literature review. *Journal of Water Supply: Research and Technology—Aqua*, 66(1), 1–14.
- Rahman, S., Khan, M. T. R., Akib, S., Din, N. B. C., Biswas, S. K., & Shirazi, S. M. (2014). Sustainability of rainwater harvesting system in terms of water quality. *The Scientific World Journal*.
- Sakson, G. (2018). Cost analysis of a rainwater harvesting system in Poland. *E3S Web of Conferences*, 45, Article 00078.
- Silva, C. M., Sousa, V., & Carvalho, N. V. (2015). Evaluation of rainwater harvesting in Portugal: Application to single-family residences. *Resources, Conservation and Recycling*, 94, 21–34. <https://doi.org/10.1016/j.resconrec.2014.11.004>
- Standards Malaysia. (2014). *Urban stormwater management—Part 6: Rainwater harvesting*. Department of Malaysian Standards.
- Su, M. D., Lin, C. H., Chang, L. F., Kang, J. L., & Lin, M. C. (2009). A probabilistic approach to rainwater harvesting systems design and evaluation. *Resources, Conservation and Recycling*, 53(7), 393–399.
- Temesgen, T., Han, M., Park, H., & Kim, T. I. (2015). Design and technical evaluation of improved rainwater harvesting system on a university building in Ethiopia. *Water Science and Technology: Water Supply*, 15(6), 1220–1227.
- Universitas Indonesia (UI). (2023). *Guideline of UI GreenMetric World University Ranking*. <https://greenmetric.ui.ac.id/publications/guidelines/2023/english>
- United Nations (UN). (2015). *Transforming our world: The 2030 agenda for sustainable development*. <https://sdgs.un.org/publications/transforming-our-world-2030-agenda-sustainable-development-17981>
- Yin, R. (1994). *Case study research: Design and methods* (2nd ed.). Sage Publishing.
- Zavala, M. Á. L., Prieto, M. J. C., & Rojas, C. A. R. (2018). Rainwater harvesting as an alternative for water supply in regions with high water stress. *Water Science and Technology: Water Supply*, 18(6), 1946–1955.

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