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Design a Rainwater Harvesting System for a Bungalow House Suitable for Malaysia Environment

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Abstract: Water is one of the most essential natural resources which maintains sustainability in life and environment. Humans, animals, plants, or other living creatures could not survive without water because water is one of the basic needs in life. Although Malaysia is blessing with plentiful of rainfall but water being wasted in unproductive way. Due to that, it affects the cost of utility bills which keep increasing in this country and this is the problem which needs to be solved. In consequence, the government has introduced the rainwater harvesting system as a preference to reduce the cost and the waste of water. This study was conducted to design a rainwater harvesting system for a bungalow house in Malaysia. Based on monthly rainfall, this RWHS is capable to store 4000 liter per month. In short, Rainwater Harvesting System for Bungalow House in Malaysia is successfully designed.

Keywords: Rainwater, Harvesting System, Design, Bungalow House

1. Introduction

Rainwater Harvesting System (RWHS) contains and stores rainwater for later use by humans. Rainwater collecting systems may range from simple rain buckets to more complex structures with pumps, tanks, and purification systems, all of which are instances of this. Besides irrigating gardens, flushing toilets, and even washing cars and clothes, non-potable water may `also be purified for human consumption and utilized for other purposes. Water scarcity is a severe concern in many densely populated places, and rainwater collection systems may be able to provide water to families and businesses during dry seasons, therefore decreasing the burden on the water distribution system.

The National Hydraulic Research Institute of Malaysia is one of the institutions involved in rainwater harvesting research (NAHRIM). According to NAHRIM (2014), in contrast to the

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conventional production of water sources in reservoirs, pipes, and pipelines, the extraction of rainwater would undoubtedly be a refreshing alternative path to a green and inclusive urban development plan for energy production and distribution The system also provided environmentally sound solutions (NAHRIM, 2014). Various techniques to build rainwater harvesting systems have been tried and tested over time.

Several types of rainwater harvesting system (RWHS) applied in Malaysia such as frontage system, backyard system and underground system. Yusop & Syafiuddin, (2018) mentioned that for frontage and backyard system, the storage tank could be constructed either on the ground or elevated.

The delivery of the rainwater was by gravity eradication and it was easier to manage and supervised the above ground tank (Neibaur, 2015). For the above ground tank, it contained of two types of tanks namely elevated and on the ground tank. Figure 1 shows separate indoor system and outdoor typical storey house.

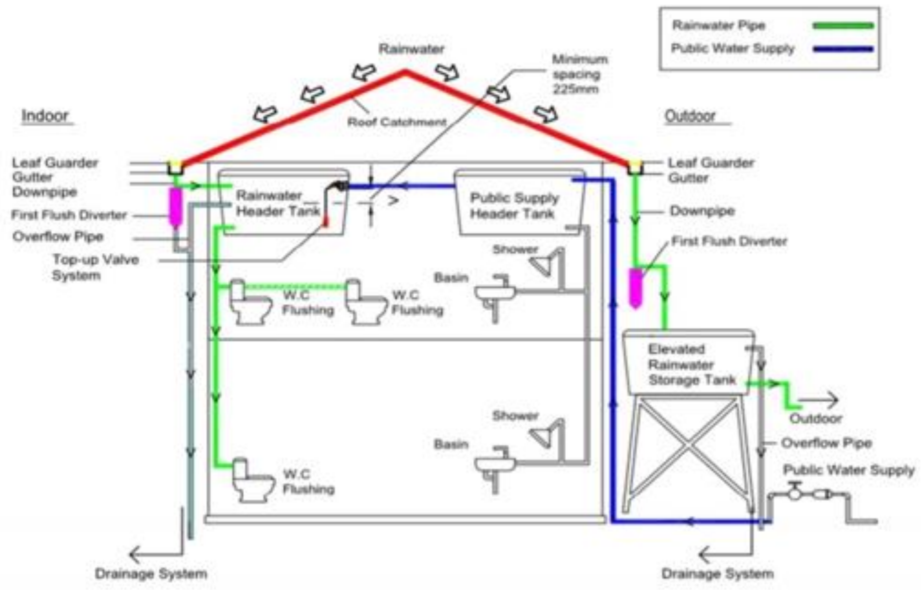

Figure 1: Separate indoor system and outdoor system for a typical storey house

(Nahrim, 2014)

Direct pumping system was one of the relevant systems to use the underground storage tank and the process was by pumping the rainwater straight from the storage tank to the appliances (NAHRIM, 2014). Figure 2 showed the combination of indoor and outdoor system using the underground rainwater storage tank for a typical 2-storey house.

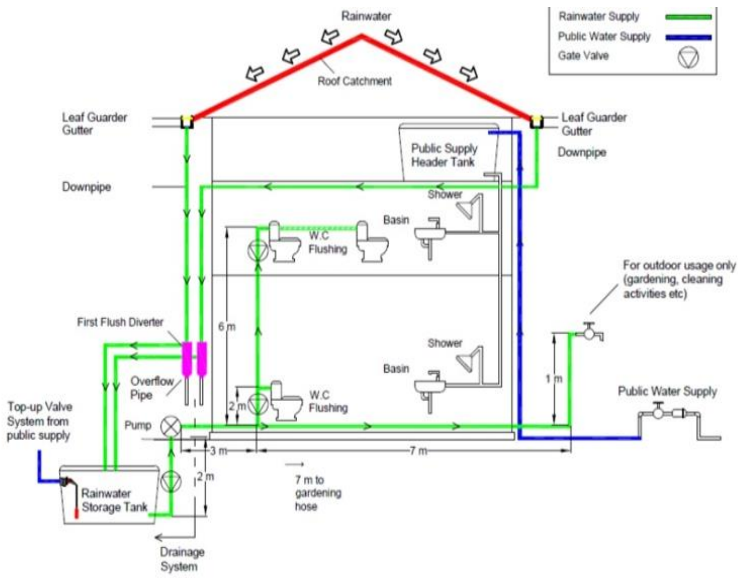

Figure 2: Combined Indoor-Outdoor System (on the ground rainwater storage tank) for a Typical 2-storey house (NAHRIM, 2014)

According to MSMA 2nd Edition, (2012) the aboveground tank needed to have sufficient protection facing the crack or leakage in storing the rainfall. This type of storage tank was more suitable to commercial and industrial buildings because these buildings commonly had flat roof which easy to locate this tank. Figure 3 shows details on rainwater harvesting system for multi-storey building. The system was including service well, recharge well and collection chamber.

Figure 3: Typical Rainwater Harvesting System for Multi- Storey (MSMA, 2012)

Catchment Efficiency, Water Runoff, Energy Equation, Major Losses, Minor Losses, and Reynold Number formula comprise the equations that will be used in this theory. Here is the equation that was fully described:

Equation 1 shows Catchment Efficiency. This formula is used to determine how much water can be collected from the specified roof catchment area. The efficiency can be calculated using the following formula:

$$\text{Catchment efficiency} = \text{efficiency} \times \text{rainfall data (mm)} \times \text{roof area}(\text{m}^2) \qquad \text{Eq. 1}$$

Equation 2 shows Water Runoff. Checking a tank size estimated to provide water throughout an average year is to use monthly rainfall data and to assume that at the start of the wetter months the tank is empty.

$$Vt\ Total = Vt_{-1} + (Runoff - Demand) \qquad \text{Eq. 2}$$

Where;

Vt = theoretical volume of water remaining in the tank at the end of the month.
V_{t-1} = volume of water left in the tank from the previous month

Equation 3 shows Energy Equation. On the basis of the standard pressure, the energy equation is utilised to calculate the theoretical flow rate. This equation is used once again to calculate the observed pressure based on the measured flow rate. Potential energy may be further differentiated in a fluid in motion into energy due to position or elevation above a particular datum and energy due to pressure in the fluid. Head represents the energy per Newton of fluid.

$$\frac{P_1}{\rho g} + \frac{v_1^2}{\rho g} + z_1 + h_P = \frac{P_2}{\rho g} + \frac{v_2^2}{\rho g} + z_2 + h_L \qquad \text{Eq. 3}$$

Where;

$\frac{V^2}{2g}$ = Kinetic head
$\frac{P}{\rho g}$ = Flow head
P = Pressure $\left(\frac{N}{m^2}\right)$
g = Acceleration due to gravity $\left(\frac{m}{s^2}\right)$
V = velocity $\left(\frac{m}{s}\right)$
z = elevation of the point (m) / Elevation head (measured from datum)
h_P = Head Pump (m)
h_L = Head Loss (m)

Equation 4 depicts Average Velocity. Average velocity will helps to complete the usage of Reynold Number, hence below calculation is made.

$$v = \frac{Q}{A} \qquad \text{Eq. 4}$$

Where:

Q = the volumetric flow rate
A = the cross sectional area of flow
V = the average velocity

Equation 5 displays the Reynold Number equation. Reynolds number is a ratio between the inertia effect and the viscosity effect within a circular pipe. When a fluid transitions from laminar flow to turbulent flow, it is due to the fluid's form, surface roughness, surface, surface temperature, and flow speed. Osborne Reynolds observed that the flow regime of a fluid changes when inertial forces are greater than viscous forces.

$$Re = \frac{\text{inertial forces}}{\text{viscous forces}} = \frac{\rho VD}{\mu} \qquad \text{Eq.5}$$

Where;

V = average flow velocity (m/s)
D = characteristic length of the geometry diameter (m)
ρ = Fluid density (kg/m^3)
μ = dynamic viscosity (Pa. s)

Equation 6 displays Total Head Loss. Friction in the pipe causes major losses. It depends on the Reynolds number, surface roughness, length and diameter of the pipe, and even the velocity within the pipe. The friction factor, f, depends on the Reynolds number and the roughness of the surface. Minor Losses are caused by pipe fittings, fluctuations in the flow direction, and modifications to the flow area. This formula is used to calculate total of major loss and minor loss in pipe system.

$$h_L \text{ total} = h_L \text{ major} + h_L \text{ minor} = \left(f \frac{L}{D} + \sum K_L \right) \frac{{v_2}^2}{2g} \quad \text{Eq. 6}$$

Where;

f = Pipe Length (m)
D = Diameter of Pipe
G = Gravitational acceleration constant (m/s^2)
V = Average velocity (m/s)
K = Coefficient K
$\frac{V^2}{2g}$ =Velocity head

The Colebrook–White Equation is represented as Equation 7. This equation is used to calculate the friction factor volume. The value of friction factor is dependent on the Reynolds number and the relative roughness, according to this equation.

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon}{3.7D_h} + \frac{2.51}{Re\sqrt{f}}\right) \quad \text{Eq. 7}$$

Where;

f = Friction factor
Re = Reynold number
ε = Roughness

2.2.8 Power of Pump

The Power of Pump is represented as Equation 8. When head pump, hp need to be determined, this formula will be the last step to obtain the pump power for the system.

$$w = \rho g Q h_p \quad \text{Eq. 8}$$

Where;

Q = Flow rate in pipe (m^3/s)
ρ = Density of water (kgm^3/s)
g = Gravitational Acceleration ($m/s^{2)}$
h_p= Head of Pump (m)

2. Methodology

Figure 4 shows the methodology chart for this project. In this project, it is focusing on designing rainwater harvesting system for bungalow house. Two process designs have to be done which is cconceptual design and embodiment design. For conceptual design, defining problem as for this project, water shortage can happen in some place in Malaysia, Rainwater Harvesting system can be one of alternative when scarcity of water happened. Gathering information is by doing study on all type of Rainwater Harvesting System available and one type has been choose which is Above ground Tank. As for concept generation, simple layout have been drawn for better visualize. Lastly, for evaluation of process, weighted rating method, decision making of each component has been thoroughly selected as it leads to component selection afterwards.

As for embodiment design, for product architecture rough sketching is being done with dimension as it gives the initial idea on how to detailing the project for the next process. As for configuration design type of pump, size of tanks, material of pipe, length of gutter needed have been decided based on usage and cost. Meanwhile, as for parametric design, in this analysis of water demand, water runoff, size of tanks and pump power is being calculated. Lastly, as for detail design, by using floor plan drawing of RWHS on the house is drawn by using AutoCAD with product specification that have been determined together.

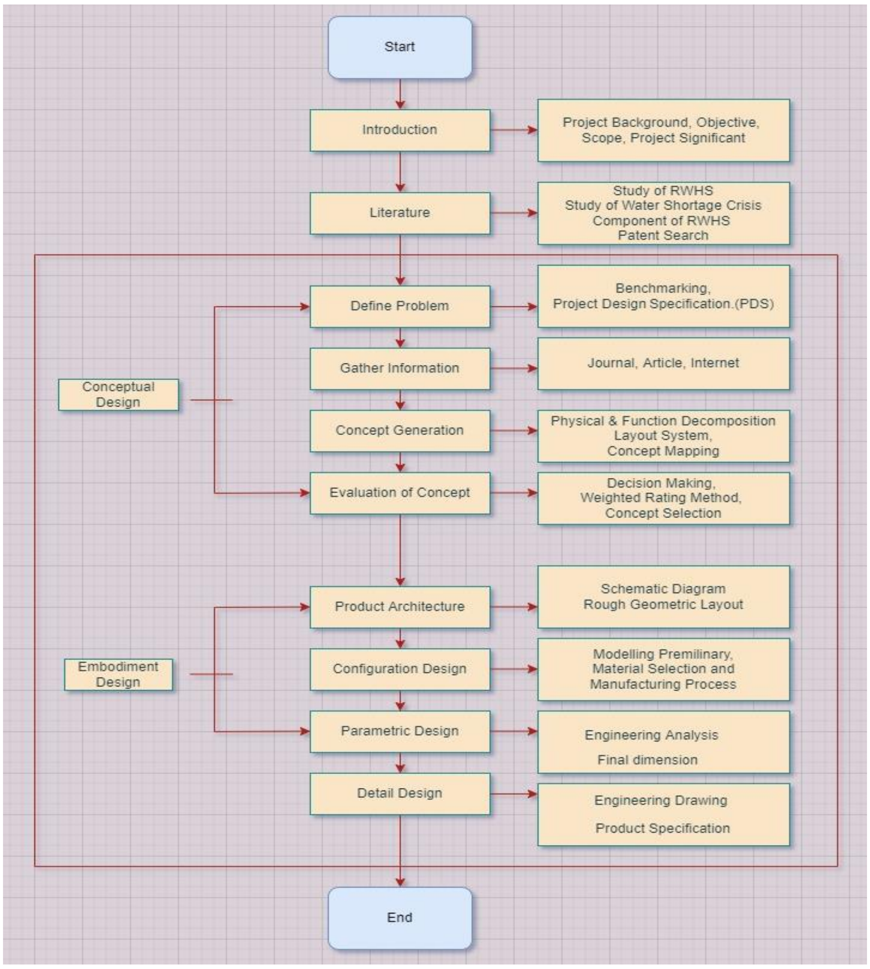

Figure 4: Methodology Chart

3. Results and Discussion

3.1 Monthly Rainfall Data

In this project, the scope of rainwater harvesting system all reference of the calculation is taken from the floor plan of bungalow house which is located in Melaka, Malaysia. As for that, Monthly Data Rainfall is based on Melaka. Below is the Table 1 for water runoff.

Table 1: Monthly Rainfall Depth and Water Runoff (Climate-Data.ORG, 2022)

Month	Monthly Rainfall Depth (mm)	Water Runoff (m^3)	Water Runoff (liter)
January	122	45.83	45830
February	83	31.18	31180
March	159	59.73	59730
April	217	81.52	81520
May	226	84.90	84900
June	188	70.63	70630
July	193	72.51	72510
August	203	76.26	76260
September	198	74.38	74380
October	234	87.91	87910
November	276	103.69	103690
December	227	85.28	85280

As for table above, it shows that there is numerous of excess rainwater can be collected, as for water demand is only 3902 liter. It shows that, it is relevant and wise choice to installed RWHS in the area.

3.2 Design Layout

Figure 5 illustrates the detail drawing of the RWHS. The detail drawing consists of the components in the system which include water storage tank, water pump, gutter, first flush, and water pipe. The configuration of the rainwater harvesting system with the housing application is also described in the drawing. Figure 6 shows that the Blue area which indicate Gutter of RWHS around the house.

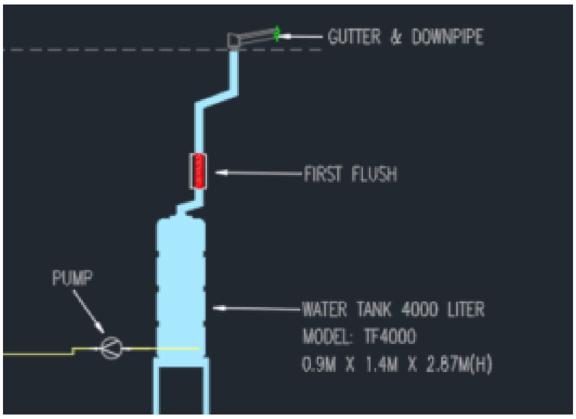

Figure 5: Plumbing System Installed RWHS

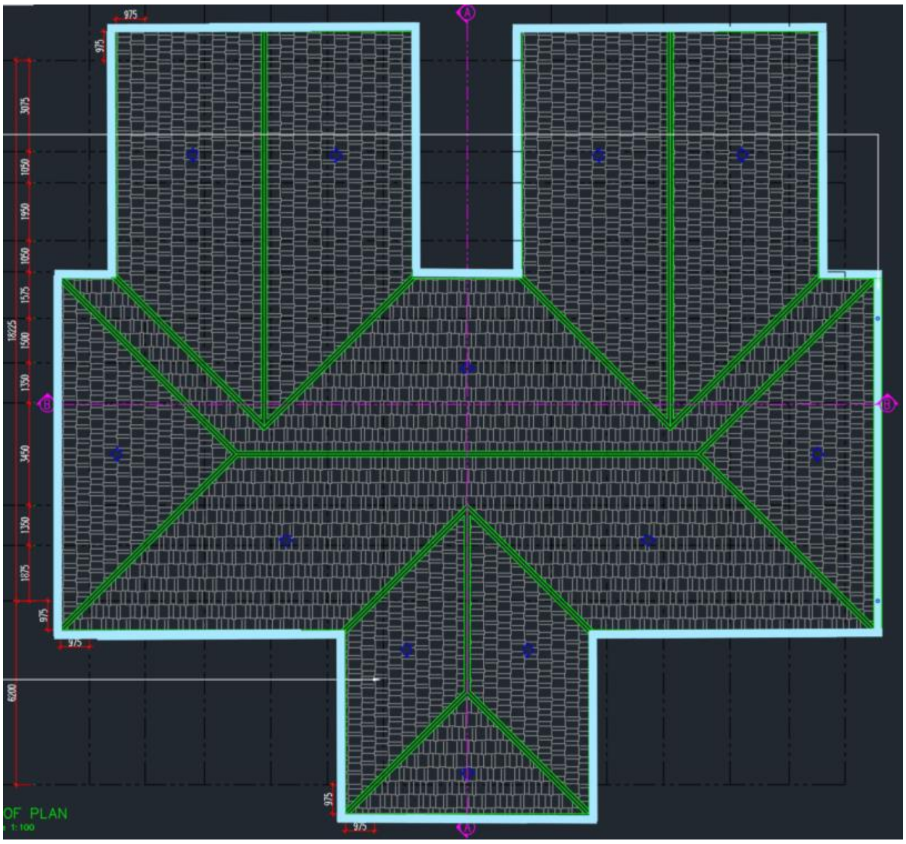

Figure 6: Blue Colour Indicate Gutter of RWHS and Roof That Involves In Catchment Areas.

3.3 Design Component

Rainwater harvesting systems collect, redirect, store and release the rain. Water that falls on a roof can be harvested, stored, and utilised for non-potable purposes, as well as for on-site storm water management disposal/infiltration. Toilet flushing and urinal flushing are examples of non-potable applications.

The design and implementation of a rainwater harvesting system must be coordinated with the end user of the building or structure. Whether it is large or small, a rainwater harvesting system (RWHS) has five basic components, which is catchment area where the surface area which catches the rainfall. It may be a roof or impervious pavement and may include landscaped areas. Then, gutter where its channels or pipes that transport the water from catchment area to a storage. Next, first flush in which the systems that filter and remove contaminants and debris using separation devices. Furthermore, storage tanks is where collected rainwater is stored and lastly is distribution in which where the system that delivers the rainwater to the point of use, either by gravity or pump. In certain case where collected rainwater is for potable usage, purification involving filtering, distillation and disinfection are the optional components in rainwater harvesting system.

3.3.1 Catchment Area

Catchment area is the first point of contact for rainfall. For the vast majority of tank-based rainwater harvesting systems, the catchment area is the roof surface. Figure 7 shows on the catchment area of the bungalow house from the floor plan.

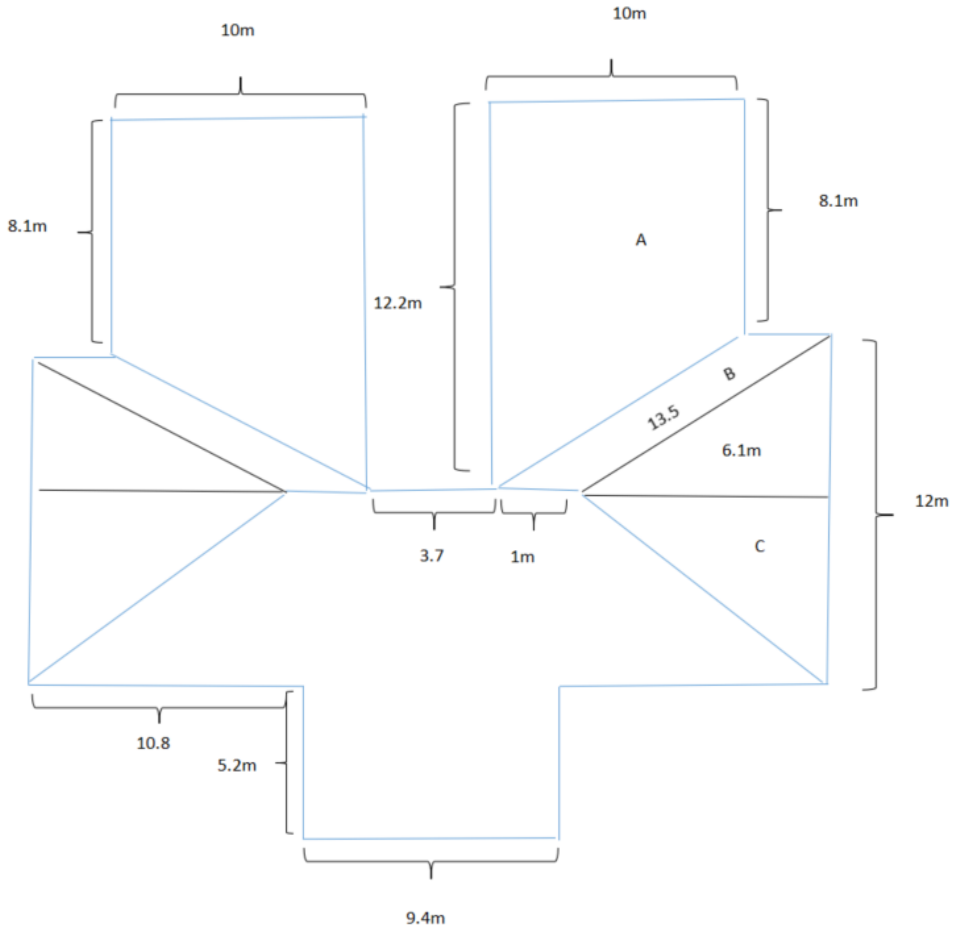

Figure 7: The Layout of Catchment Areas

3.3.2 Water Pump

The pump station collects water from the source and regulates the pressure so that it may be delivered into the pipe system. Figure 8 shows pump that is used for RWHS.

Figure 8: Pump Used For RWHS

3.3.3 Filter First Flush

Rainwater quality varies and is affected by environmental factors and commercial industrial activities in the area. The inclusion of the first flush device will improve the quality of the water. For this project, as Figure 9 is BACFREE FS First Flush that is chosen in the system as it have dual function which is filter & first flush.

Figure 9: Bacfree FS First Flush Rainwater Filter Collector

3.3.4 Water Storage

Water storage with pump-based system is a high-effective approach to harvest rainwater for bungalow house. Water tank for water supply must be able to hold enough water to last at least one month. Figure 10 shows the diagram of a tank above ground.

Figure 10: Water Tank That Have Been Selected

3.4 System Specification

System specifications are developed to explain detail about the pump used, roof catchment size, water storage, first flush & filter and piping. Specifications of the system are obtained from the previous analysis. Table 2 displays the system specifications for the RWHS.

Table 2 : System Specification

	Product Specification	Description
1.	Centrifugal Pump	**CM150/00** • Flow: 105 (l/min) • Max Head: 38 (meter) • Power: 1.1kW / 1Hp
2.	Roof Catchment Size	Cemented Tiles Roof In meter : 442 m^2
3.	Water Storage	TF4000 4000 LITERS
4.	First Flush & Filter	BACFREE FS First Flush Filter
5.	Total Pipe Length, PVC (m)	102 m

3.5 Total Cost

Cost for installing RWHS is RM6578.80, as it is covered the entire component which is Pump, Tank, Piping, First Flush, Downspout, Gutter and Installation Charge. Below is the table which depicts the total cost of installing RWHS. The cost of the rainwater harvesting system can be estimated based on the component used. Table 3 shows cost estimation for RWHS.

Table 3: Cost Estimation For Rainwater Harvesting System

No.	Item	Quantity	Price, (RM)	Cost (RM)
1	Centrifugal Water Pump	1	500.00	500.00
2	Tank (4000L)	1	3,600.00	3,600.00
3	PVC Pipe **x** 1 meter	102 m	7.00	714.0
4	Elbow Poly joint	3	7.00	21.00
5	First flush	1	739.00	739.00
6	Downspout	1	15.40	15.40
7	Gutter	20	25.00	500.00
8	Installation Process	1	500.00	500.00
	Total Cost			**6578.80**

3.6 Cost Saving

For better estimation, monthly bill of water from Melaka is used. The water demand is 3902 liters ≈ 4000 liters per monthly of water usage. By following charge rate from water bill, cost from 4000 liters is being calculated. Table 3 below is saving cost from RWHS based on water bill charge. RM 2.40 can be saved monthly if RWHS system installed in the house.

Table 3: Saving Cost from RWHS

Water Usage ($m^{3)}$	Charge	Amount (RM)
4	0.60	2.4
0	0.95	0
Total Cost		2.4

3.7 Breakeven Analysis

Breakeven analysis also is calculated, this is to ensure the profitable or return of investment is achievable within a logical time. Figure 11 illustrates years taken for break-even to intersect between fixed cost of RWHS and saving cost from RWHS.

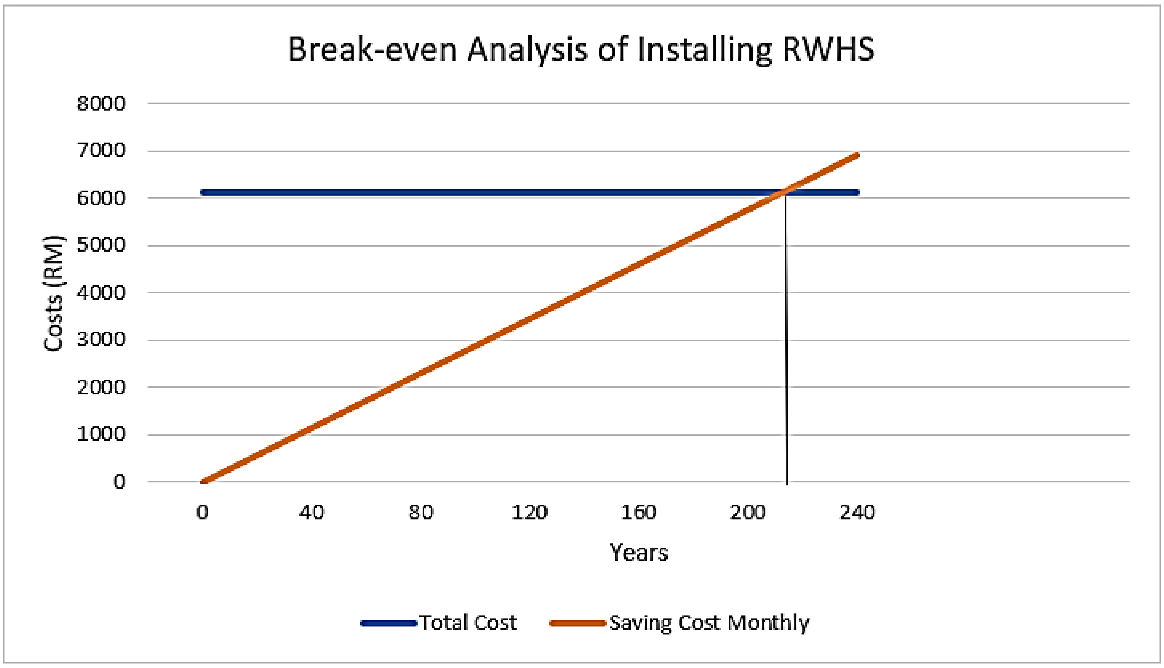

Figure 11: Graph of Break-even Analysis of Installing RWHS

After 228 years is where the return will be able to pay off the investment money to build this rainwater harvesting system. Apparently, RWHS is a good device to be installed with as it helps to utilize water bill, but in terms of investment it took a very long years to reach the intersection point of Break-even.

3.8 Discussion

In this project, the scope of rainwater harvesting system all reference of the calculation is taken from the floor plan of bungalow house which is located in Melaka, Malaysia. As for that, Monthly Data Rainfall is based on Melaka. From water runoff reading, it shows that there is excess rainwater can be collected, as for water demand is only 3902 liter. It shows that, it is relevant to installed RWHS in the area.

Pump for RWHS for this house is Centrifugal Pump CM150/00. As it passed the entire requirement needed for RWHS to operate properly. Flow rate, Head Loss, Head Pump is needed to required pump power which results in 0.12kW, with 32.57m of head loss, 33.9m of head pump. This pump is capable to provide 105 L/min @ 0.00175m^3/s and maximum head of 38m. As for estimation value of flow rate 0.000379 m^3/s it is suitable to operate the system.

Filter first flush also have been selected which is to use BACFREE Filter First Flush due to its dual function of first flush and filter. It is also suitable because it is ready to be worked on house of roof catchment area that is 150$m^{2.}$ Once in six months is also a low rate in terms of frequency of maintenance. Meanwhile, total cost for installing RWHS is RM6578.80, as it is covered all the component which is Pump, Tank, Piping, First Flush, Downspout, Gutter and Installation Charge.

Break-even analysis is also calculated, it is to determine when the profitable or return of investment can be achieved. After 228 years, then the return will only be able to pay off the investment money to build this rainwater harvesting system. Apparently, RWHS is a good device to be installed with as it helps to utilize water bill, but in terms of investment it took quite long years to reach the intersection point of Break-even and it is quite illogical to reach. Hence, installing profitable RWHS is not profitable.

4. Conclusion

At the end of this study, all of the objectives were achieved as concluded. RWHS is successfully designed with storage tank maximum of 4000 liter with water consumption of 3902 liters and power pump with 1100kW with maximum head of 38m, centrifugal pump is being chosen. Apart from that, total cost of RWHS is also having been determined which is RM6578.80 with saving cost RM2.40 per month. Return of Investment taken is 228 years.

Acknowledgement

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