DESIGN OF A SUSTAINABLE RAINWATER HARVESTING SYSTEM

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UNIVERSITI TUNKU ABDUL RAHMAN

DESIGN OF A SUSTAINABLE RAINWATER HARVESTING SYSTEM

TAN KENG LIM

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Mechanical Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DESIGN OF A SUSTAINABLE RAINWATER HARVESTING SYSTEM"** was prepared by **TAN KENG LIM** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Mechanical Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Rainwater harvesting system (RWHS) is a system of collecting rainwater from impervious surfaces and storing it for future use. Although Malaysia has cheap water bills compared to other countries, Malaysia still experiences numerous water crises and water disruptions each year due to high water consumption or water pollution. This indirectly makes it difficult for stray animals to find water. Therefore, an animal-centric sustainable RWHS is a good solution for the problems mentioned above since Malaysia has a high average annual rainfall. The focus of this study was to design a RWHS for 10 stray cats and 25 kittens living in the Greater Gombak Animal Shelter (3°15'20.4"N, 101°43'53.3"E). In order to obtain the dimension of the office and select the appropriate sizes for the components, an on-site meeting was held with representatives of the animal shelter. Besides, Gombak Km16 was found to be the closest rainfall station to the animal shelter and its station number (3217001) was used in the following steps. First, the calculated roof catchment area on one of the longer sides of the hipped roof was 16.97 m^2. After applying the corresponding formula, the average rainfall intensity calculated for 20-year average recurrence interval and 5-minutes storm duration for this study area was 276.68 mm/hr. Taking the roof catchment area and average rainfall intensity as the reference indicators, the minimum effective cross-sectional area of the k-style gutter was 5000 m^2 and the minimum nominal size of the round downspout was 85 mm. Then, the minimum tank size required calculated by the Tangki Nahrim 2.0 software was 0.2 m^3 after considering the rainfall data from 1974 until 2016. A tank of this size had water 99.9% of the time and was capable of meeting the cats' total daily water consumption of 5.375 litres. A filter was also installed in this RWHS to filter the collected rainwater and provide the cats with clean drinking water. In addition, this RWHS was fitted with a special design that utilizes hydrostatic pressure to supply filtered rainwater to three cages at a time by opening the valve. Lastly, sipper water bottles were also installed on the cage so that the cat could drink by licking the nozzle ball without causing water accumulation. The collected rainwater was safe for animals to drink as it was classified as good quality water after water sampling and testing. Overall, this RWHS was a good long-term investment because it cost less than RM3000.

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LIST OF SYMBOLS / ABBREVIATIONS

ARI	Average recurrence interval
DID	Department of Irrigation and Drainage Malaysia
EC	Electrical conductivity
EPA	Environmental Protection Agency
IIUM	International Islamic University Malaysia
MCO	Movement Control Order
NAHRIM	National Water Research Institute of Malaysia
PPM	Parts per million
RWHS	Rainwater harvesting system
TDS	Total Dissolved Solids
VBA	Victorian Building Authority

CHAPTER 1

INTRODUCTION

1.1 General Introduction

In recent decades, many people are more aware of green environmental protection and this concept has become a hot topic for everyone. At the same time, the world population continues to increase, thereby indirectly increasing the demand for clean water. If there is not enough water supply, this can lead to problems or threats in real life. However, many people still waste water recklessly and do not cherish water due to their selfish attitudes and wasteful habits (Low, 2018). This further increases the water consumption and the possibility of water shortage, which in turn affects human life. Therefore, the rainwater harvesting system (RWHS) is a good solution for the problems mentioned above because the rainwater can be collected and utilized for different purposes.

First, the amount of rainwater collected by the RWHS depends on where it is implemented. As everyone knows, Malaysia is a tropical country which is located in the heart of Southeast Asia. Due to its strategic location, it is blessed with many natural resources such as rain, sunlight, tides and wind. For example, previous research has reported that the average annual rainfall in Peninsular Malaysia and Sabah is 2420 mm and 2630 mm respectively (Ahmad, Ushiyama and Sayama, 2017). Therefore, this congenital condition makes the RWHS very suitable for installation in Malaysia.

In fact, the Malaysian government starts working on the RWHS after experiencing the water crisis caused by severe thought in 1998 (Lani, Yusop and Syafiuddin, 2018). In order to promote the installation of RWHS, many government departments and agencies have issued various initiatives in the form of policies and guidelines. For example, the provided e-book includes the history of rainwater harvesting, detailed information on each system component, steps to calculate the optimal size, and others. Therefore, the Malaysian government plans to reduce its dependence on rivers and other surface waters by implementing this system.

However, RWHS are still unpopular in Malaysia due to many reasons. First, the installation and maintenance costs are not affordable for every social class, especially low-income people (Lani, Yusop and Syafiuddin, 2018). This problem has been exacerbated by the number of COVID-19 cases in Malaysia. This is because many companies have closed down and many people have lost their jobs. This makes more people unable to afford the cost of this system. Besides, NAHRIM (2021) stated that the water tariff in Malaysia is low compared to other countries. Naturally, people living in Malaysia will not spend money on this system because their water is cheap. Furthermore, the return on investment of the system is not fast, leading to fewer people implementing the system. Lastly, the community's awareness and interest in this system are low, so this system is currently limited to government buildings in Malaysia only.

1.2 Importance of the Study

This study focuses on animal-centric rainwater harvesting systems. It is important and different from the current one because it can be used as a guide in designing RWHS for animals. This study also shows the general idea from finding the best system implementation location until determining the RWHS with the optimal size for each component. For example, various design concepts, selection criteria and procedures have been provided in this study.

Besides, this study also foresees possible hidden threats and provides inspection standards or suggests solutions for each of them. For example, the water stored in the storage tank for a long time is not safe to drink due to the growth of bacteria, especially in a warm area (TNN, 2019). Thus, the tank storage must be sized properly because too much rainwater is stored in it if the water demand is not high.

In addition, this study also considered the problem of acid rain. This is because power plants and ground vehicles release sulphur dioxide and nitrogen oxides into the air every day (EPA, 2021). Sulfuric acid and nitric acid are formed when the water and oxygen in the air react with acidic gases such as sulphur dioxide or nitric oxide. Then, acid rain is formed when the sulfuric acid and nitric acid mix with the water. It will cause damage to the animals' brains if the animals directly drink this acid rain for a long time (Ecologic, Schwartz and Williamson, 2021). Therefore, this study also checks the quality of the collected rainwater and provides water treatment suggestions because the water is used for animal drinking.

Furthermore, the money that humans care most about is also discussed in this study. This is because humans are generally unwilling to implement a new system if they do not have a certain knowledge of it. For this reason, this study provides a list of components needed for the RWHS. In other words, this can help the user decide which alternative is the best decision for him.

In summary, the results may have a significant impact on providing rainwater as an alternative water source for animals and contributing to a better understanding of:

- The RWHS and their components suitable for animals
- The quantity of water stored for animal drinking purposes
- The size of the components used and the reasons behind them
- The total cost required for RWHS

1.3 Problem Statement

The problem statement for the current study of RWHS are In these past few years, several studies have shown that the RWHS is increasingly being valued by humid or developed countries such as Japan, Taiwan and Barcelona due to severe drought, water pollution, increased water demand and water scarcity (Cheng, Liao and Lee, 2006; Jones and Hunt, 2010; Domènech and Saurí, 2011; Furumai et al., 2012). However, all of these previous studies related to RWHS were closely related to humans rather than animals. In other words, these above-mentioned studies did not consider animals as their target consumer.

Next, Low (2018) stated that Malaysia is classified as a country with high domestic water consumption because the water consumption has exceeded the recommended level by World Health Organisation (WHO). For example, river resources in Selangor and Kuala Lumpur have been fully exploited because these areas are highly developed and densely populated (Shahabudin, 2014). In addition, the total water consumption in Malaysia has further increased and is expected to increase year by year. The reduction in the number of rivers in Malaysia from 519 in 2008 to 477 in 2017 proves this fact (New Straits Times, 2019). Then, similar water crises in the past may happen again in the future. In other words, it will be difficult for stray animals to find a source of water. As a result, stray animals may have health issues because they do not drink enough water.

Besides, water disruption has occurred several times a year, especially in Selangor. This may be caused by one of the following reasons, such as water pollution, pipe bursts, upgrading and replacement of water treatment plant assets, and others (Choong, 2020). For example, four water treatment plants in Selangor had shut down for three to five days because the Sungai Gong was contaminated by chemical effluents discharged by five people from a vehicle maintenance plant (The Straits Times, 2020). Besides, water pollution in Penang and Johor was caused by illegal granite mining and poultry farms respectively. As a result, the water quality proved to be declined year by year because only 219 of the remaining 477 rivers are clean (New Straits Times, 2019). In addition, water cuts may occur as planned or without notice, thereby further reducing the reliability of the water supply. As a result, drinking water for animals living in animal shelters needs to be purchased and transported from other places to prevent these animals from being poisoned or died after drinking polluted water.

Furthermore, human beings normally will use their money more carefully after losing their source of income. This may be caused by natural disasters or accidents that happen unexpectedly. For example, company closure rates and unemployment rates have risen because of the COVID-19 pandemic. This is because MCO implemented by the Malaysian government restricts the movement of people, most of the daily and economic activities for several months (Goi, 2020). This makes it impossible for animal lovers to provide financial support to animal shelters because they cannot even afford their own daily expenses. For those with financial means, they will choose to save humans first rather than animals during this MCO. Then, the financial burden on the head of the animal shelter will become heavier over time. Although the water tariff in Malaysia is low, the head of the animal shelter cannot pay the water fee once he has spent all his savings because there are many animals living in an animal shelter. As a result, the animal shelter is closed, and the number of stray animals increases.

1.4 Aim and Objectives

The main aim of this study was to propose a design of a sustainable RWHS to provide sufficient clean rainwater as an alternative water source for animals. To carry out the aim, three objectives had been identified that constitute the targets that need to be completed to achieve the aim, which are listed as the following:

- To study the different types of RWHS available in Malaysia
- To calculate the quantity of the rainwater collected and stored for an animal shelter.
- To design a suitable RWHS for the animal shelter.
- To evaluate the economic feasibility of the system.

1.5 Scope and Limitation of the Study

This study focuses on designing a suitable RWHS for animal drinking purposes in Malaysia. The design of the RWHS is proposed according to the available land area, the species, and the number of target animals in this study area. In addition, this study covers the calculation methods for three types of roofs at a specific rainfall slope. This study also provides complete computational steps for a gravity-fed system. Besides, the software developed by Malaysian departments and research institutions such as Tangki NAHRIM 2.0 is used to obtain rainfall data and calculate the storage size for this study. Furthermore, this study involves rainfall data from 1974 until 2016.

However, this study does not cover the RWHS for irrigation purposes in Malaysia. The results of this study may not be suitable for other places because the results depend on the conditions and circumstances of the location. In addition, many calculation methods for different types of roofs under different rainfall slopes are not covered in this study. This study also does not provide complete computational steps for pump-related systems, such as the direct-pumped system and indirect pumped system. Besides, Tangki NAHRIM 2.0 used in this study is not applicable to other countries because the databases of this software only store rainfall data for Malaysia. Furthermore, if there is a sudden climate change in Malaysia, the results may be inaccurate because this study assumes that future rainfall data will follow the same trend as before.

1.6 Contribution of the Study

To date, there has not been a single study on RWHS in the world that has animals as the target consumer. This study focuses on designing sustainable animal-centric rainwater harvesting system in Malaysia. This study is useful for any animal organization in Malaysia as it can be used as a guide in designing RWHS for animals. If the installation area or the target consumer change, the person from the animal organization just needs to do some research as most of the calculation steps are the same. For example, the amount of water per kilogram of body weight will be researched if the type of animals living in the animal shelter changes. Meanwhile, it reduces the workload of animal organizations to research while increasing their desire to build more animal shelters for stray animals. This is because the time needed to install RWHS is shortened. RWHS also helps animal shelter leaders solve drinking water shortages in times of water crisis or water pollution. It also indirectly saves the lives of many stray animals in Malaysia. Therefore, any animal organization can design the RWHS themselves by having this study as a guide.

In addition, stray animals also benefit from this study. RWHS uses Malaysia's free and renewable rainwater resources to provide clean drinking water to stray animals. Stray animals no need to travel around to find a source of water. This reduces the likelihood of stray animals drinking contaminated water or having an accident. As a result, the possibility of health problems and mortality in stray animals can be reduced. Furthermore, RWHS only requires a one-time payment. This eases the financial burden on animal shelter leaders during certain times, such as MCOs due to the COVID-19 pandemic. It also indirectly prevents the fate of the animal shelter from closing. Thus, the more the number of animal shelters installed with RWHS, the lower the number of stray animals in Malaysia.

1.7 Outline of the Report

First, a literature review was conducted in chapter 2. Then, the methodology and work plan required to complete this study were identified in chapter 3. The result and discussion were presented in chapter 4. Last, the conclusions and recommendations were delivered in chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A literature review of the RWHS was carried out in this chapter. Rainwater harvesting, components of RWHS, distribution system and simulation were further elaborated in the respective subsections under this chapter.

The rainwater harvesting practice was first studied in section 2.2. This was followed by different components of the RWHS in section 2.3. In addition, the distribution systems and simulations were introduced in sections 2.4 and 2.5 respectively. Lastly, all the decisions made were summarised in the last section of this chapter.

2.2 Rainwater Harvesting

The technique of collecting rainwater from impermeable surfaces and storing it for future use is known as rainwater harvesting. This method can prevent rainwater from being wasted as runoff. For example, the collected rainwater can for potable and non-potable purposes. In fact, Zhu et al. (2015) stated that rainwater harvesting has been implemented in arid and semi-arid places since ancient times. The different traditional rainwater harvesting methods and their benefits are further explained in their respective chapters.

2.2.1 Traditional Method

According to Mbua (2013), rainwater has been collected as their main water source in Sardinia since the 6th century. Sehgal (2006) also stated that rainwater harvesting has been practiced in Asia from the 9th or 10th century onwards. In addition, it is reported that many large reservoirs in Africa which can be dated back to about 2000 years ago are still in use today (Mbua, 2013). Therefore, this shows that rainwater harvesting has been existed for centuries in different parts of the world.

One of the traditional rainwater harvesting methods is jar. This is because Mbua (2013) stated that the rainwater flowing down from the roof can be transported through gutters and stored in the jar for domestic use. Besides, people living in the rural areas usually have the skills to make pots and jars from clay. Clay is used because it can be obtained easily and has low permeability (Tiab and Donaldson, 2016). This makes it a suitable material for the jars because the rainwater stored in it will not leak easily. For example, Thai jar as shown in Figure 2.1 has a curved shape because this design provides strength and cost efficiency (Zhu et al., 2015). Therefore, jar is a good choice for rural residents to collect and store rainwater from rooftop runoff because it is a cheap way to obtain high-quality drinking water for several months.

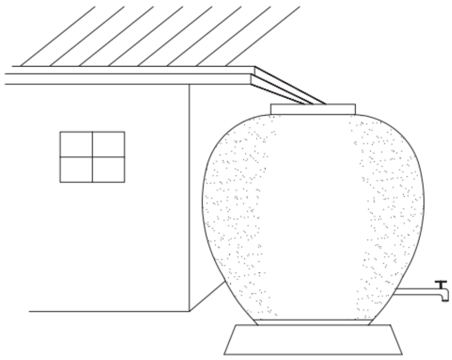


Figure 2.1: Thai Jar (Zhu et al., 2015).

Next, water cellar is a traditional rainwater harvesting method that can be found in China. It is also known as a “Shuijiao” in the local area. As shown in Figure 2.2, “Shuijiao” is an underground storage tank that is built for domestic water supply (Mbua, 2013). It was further mentioned that water cellar has the ability to store both roof runoff and surface runoff (Zhu et al., 2015). Besides, the quality of water stored is better because the temperature of water stored in the water cellar is lower compared with other traditional methods. It is also difficult for the collected rainwater to come into contact with contaminants because the water is stored underground. Furthermore, this method can reduce evaporation losses because the water stored in underground storage tank will not be affected by sunlight or wind. Thus, water cellars can provide additional water supply for rural residents and ensure crop production during dry seasons or water shortages (Qiang and Li, 2006).

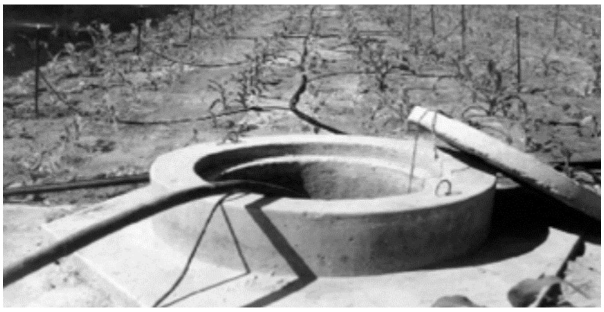


Figure 2.2: Water Cellar (Qiang and Li, 2006).

Besides, India has a traditional rainwater harvesting method called the Khadin system. It is also known as a “Dhora” in the local area. As shown in Figure 2.3, Khadin system uses crescent-shaped embankments (Khadin bund) to collect and store rainwater from surface runoff (Khadin bund) for agricultural purposes (Mbua, 2013; Raj, 2015). National Council of Educational Research and Training (2018) further explained that the main purpose of this system is to recharge groundwater rather than hold surface water. This is because the collected rainwater will diffuse into the soil to keep the soil moist for a long time and replenish the dug well. In addition, this method does not provide a breeding ground for mosquitoes because it does not cause water accumulation problems. This method can also prevent the collected rainwater from being polluted because the water will be converted into groundwater in the dug well. Therefore, clean water resources can be obtained from shallow-dug well and the production of crops can be guaranteed by using the Khadin system.

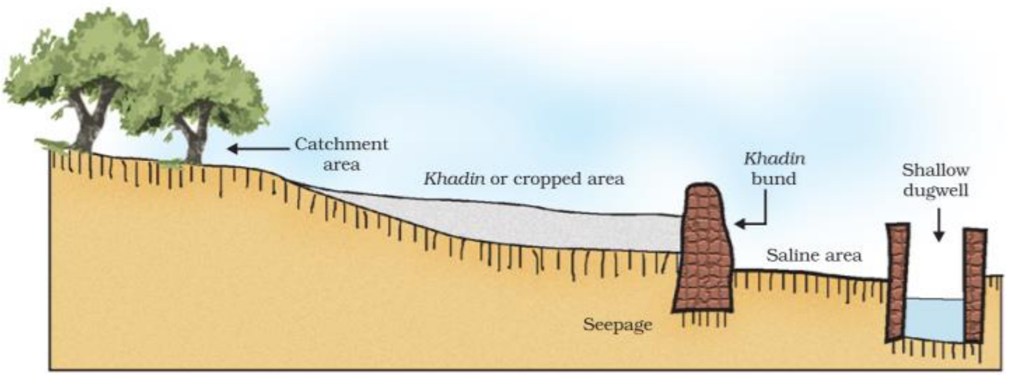


Figure 2.3: Khadin System (National Council of Educational Research and Training, 2018).

However, the emergence of these traditional rainwater harvesting methods is to meet the needs of humans rather than the needs of animals. In the past, humans would not purposely design a RWHS for animals. This was because they prioritized their lives over animals so they would not waste time and money on animals. In fact, these traditional methods can also be used as an alternative water supply for animals.

2.2.2 Benefits of Rainwater Harvesting

In recent years, various types of research related to rainwater harvesting have been carried out all over the world. Several studies have found that the advantages of rainwater harvesting greatly outweigh its disadvantages (Sehgal, 2006; Mbua, 2013; NAHRIM, 2014; Lani, Yusop and Syafiuddin, 2018).

From an economic point of view, rainwater harvesting can reduce the water bills for expensive and unreliable water purchased from the municipality. This is because the collected rainwater is free of charge and serves as an independent alternative water source. (Mbua, 2013) further pointed out that the ownership of rainwater cannot be claimed by any organization or individual. Although the construction cost of RWHS is relatively high, it can be regarded as a long-term investment. For example, Lani, Yusop and Syafiuddin (2018) stated that the annual cost savings for each house in the seven representative cities of Australia ranged from 0 to 240 Australian dollars if the collected rainwater was only used for outdoor activities. Due to rising water tariffs, RWHS is also getting popular in urban areas. For rural areas, rainwater harvesting not only provides a cheap alternative water source but also prevents the cost of installing a public water supply system (Sehgal, 2006). Therefore, this shows that rainwater harvesting will bring many economic advantages to urban and rural areas as long as these areas receive a moderate amount of precipitation.

From a social point of view, rainwater harvesting can provide a relatively clean water source. This is because Abdulla and Al-shareef (2009) stated that rainwater is less likely to be contaminated than groundwater and surface water. Rainwater is not in contact with the soil so the salts and minerals will not dissolve into water in the rainwater collection process. In other words, the collected rainwater is soft water because the hardness of the collected rainwater is close to zero (NAHRIM, 2014). As a result, the amount of detergent and soap required for cleaning are greatly reduced compared with tap water. Mineral deposits are also unlikely to be deposited in the pipeline, thereby reducing the chance of pipeline blockage. Furthermore, rainwater harvesting also can help developing countries solve water-borne diseases caused by water management issues (Baguma, Loiskandl and Jung, 2010; Mbua, 2013).

From an environmental point of view, rainwater harvesting can reduce soil erosion and floods caused by stormwater runoff from impervious surface (Sehgal, 2006; NAHRIM, 2014). This is because some rain will be captured and stored by the RWHS. For example, flooding was expected to be reduced by 10% if the entire urban area of Seoul was used as a rainwater collection surface (Kim and Yoo, 2009). Besides, rainwater harvesting also reduce human dependence on water storage dams by collecting rainwater directly (Coombes et al., 2002; Sehgal, 2006). Then, the development or expansion of new water storage facilities can be postponed due to the reduction in human demand for domestic water. Meanwhile, this method also reduces the chance of polluting water bodies by reducing the amount of stormwater runoff that picks up pollutants. Thus, rainwater harvesting can indirectly reduce human impacts on the environment and the risks of disaster.

2.3 Components of RWHS

RWHS typically consists of three main components, namely the catchment surface, the conveyance system and the storage system. These components could be further divided into smaller sub-components which are explained in their respective sections.

2.3.1 Catchment Surface

Catchment surface is the surface used to collect rainwater when it rains. The area of the catchment surface will determine the amount of rainwater collected when it is raining. According to the type of catchment surface, it could be further categorized into two systems which are roof RWHS and pond RWHS (Zabidi et al., 2020).

As shown in Figure 2.4, rainwater is collected from the impermeable roof and stored in a water tank by the roof RWHS. Zabidi et al (2020) stated that the rainwater collected by this system is usually used to meet potable water and non-potable water demand. This makes the roof harvesting system more well-known in different parts of the world. For example, people living in countries such as Italy, Ireland, and Malaysia prefer to install roof RWHS (Li, Boyle and Reynolds, 2010; Chan et al., 2016; Liuzzo, Notaro and Freni, 2016). Furthermore, the amount and quality of collected rainwater are greatly affected by roofing materials and conditions. The roofing material must be carefully selected and cannot be painted if the collected rainwater is used for drinking purposes. According to Mbua (2013), corrugated galvanized iron sheets are suitable for the above-mentioned purposes but these sheets are expensive. However, the roof can be painted and made of any materials if the collected rainwater is used for other household purposes because water quality is not one of the concerns.

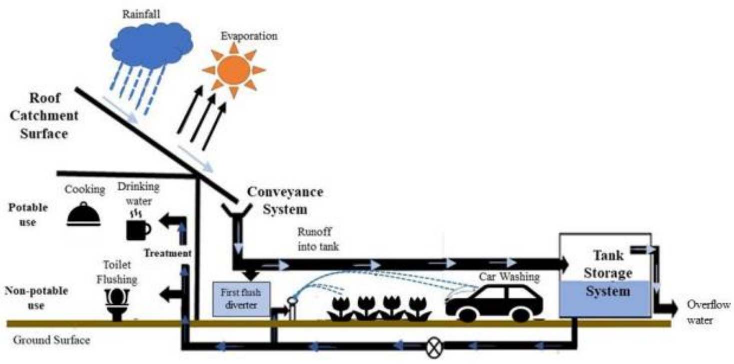


Figure 2.4: Roof RWHS (Zabidi et al., 2020).

As shown in Figure 2.5, the pond RWHS collects rainwater from the permeable land surface and stores it in the pond. The rainwater collected by this system is used to meet water demand in agriculture and animal husbandry (Nanekely and Scholz, 2017; Zabidi et al., 2020). This makes pond RWHS more popular in small-scale farming. For example, water stored can be used to enhance and supplement irrigation, thereby promoting crop growth and crop production (Hatibu et al., 2006; Amha, 2006). However, this system is not popular in households because it requires a specific land area.

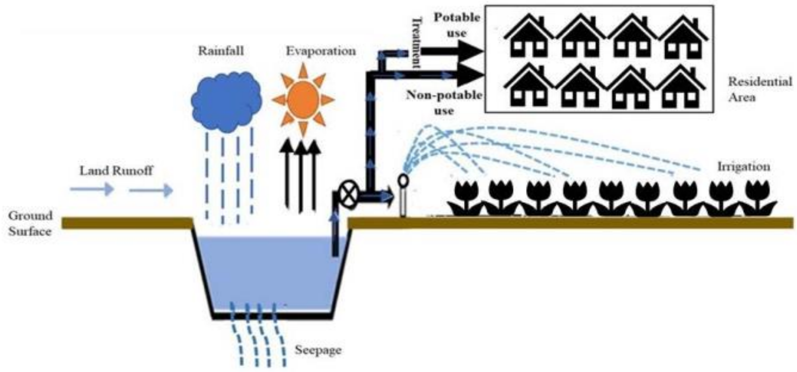
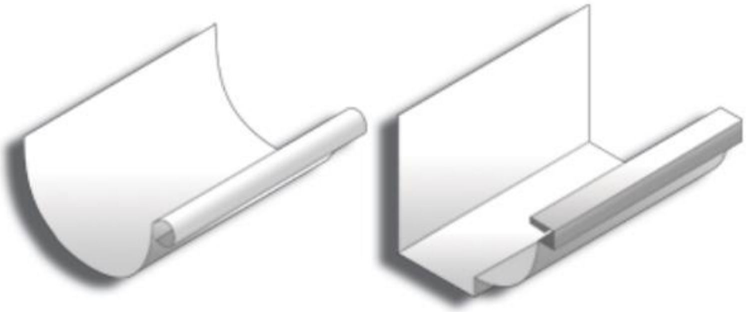


Figure 2.5: Pond RWHS (Zabidi et al., 2020).

2.3.2 Conveyance System

Conveyance system transports collected water from the catchment surface to the storage system. This system usually consists of two main components, namely the gutter and the downspout. NAHRIM (2016) stated that these components are either hidden in the walls of the building or installed on the exterior surface of the building. Besides, these components are only found in the roof RWHS instead of the pond RWHS. This is because stormwater runoff will flow to the pond under the action of gravity.

Gutters are the narrow ducts installed around the roof to receive rainwater runoff from the catchment surface and transfer it to the downspouts. As shown in Figure 2.6, k-style gutters and half-round gutters are the most typical two types of gutters. K-style gutter can provide optimum drainage and handle a large amount of stormwater runoff from the roof (Grant Hiatt, 2013). Under the same inch width, a k-style gutter is also more durable than a half-round gutter. However, the half-round gutter is easier to clean and can effectively catch water (Milliman, 2021). It also provides an aesthetic appearance to the building because it looks like a simple and clean line.

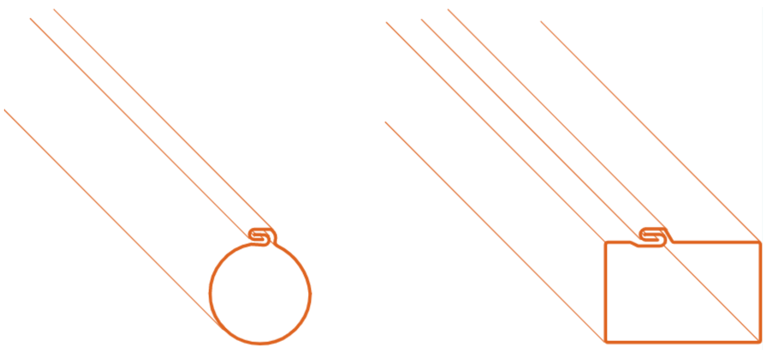


(a) Half-Round Gutter (b) K-Style Gutter

Figure 2.6: Common Types of Gutters (Lunney and Marasli, 2021).

Downspouts are upright pipes or inclined pipes installed on the side of the building to receive rainwater from the gutter and transfer it to the storage system. Downspouts usually extend from the gutter on the roof to the water storage tank on the floor. As shown in Figure 2.7, the two most typical downspouts are rectangular downspouts and round downspouts. Rectangular downspouts are usually installed with k-style gutters, while round downspouts are typically installed with half-round gutters.

Furthermore, Erika Cruz (2019) stated that the size of the gutter and downspout is related to the size of the roof, the volume of the gutter, and the rainfall in the rainy season. Properly sized gutters and downspouts can not only promote effective drainage, but also save costs such as material costs and maintenance costs. Then, properly sized brackets can be used to fix the gutters and downspouts to the building.



(a) Round Downspout (b) Rectangular Downspout

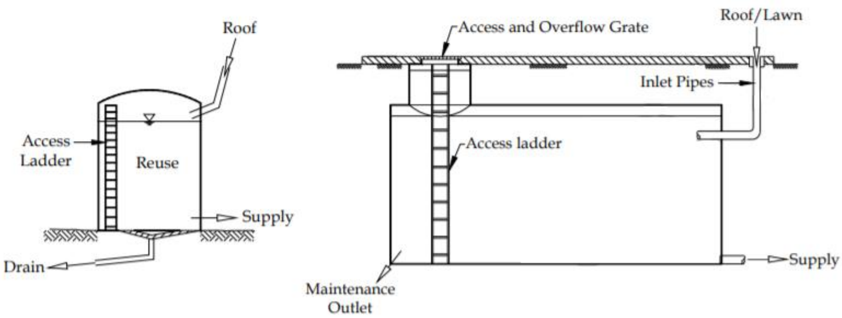
Figure 2.7: Common Types of Downspouts (Copper Development Association Inc., 2021).

In addition, the gutter and downspout can be made of different materials, such as copper, aluminium and vinyl. Jason (2018) stated that copper gutters and downspouts have high quality and long service life but they are heavy and expensive. Aluminium gutters and downspouts are rust-proof and lightweight, but they may be dented under certain situations. Vinyl gutters and downspouts are cheap and lightweight, but they are not suitable for use in cold weather (Jason, 2018). Zinc gutters and downspouts are rust-proof and durable, but they need welding. Therefore, the materials for the gutter and downspout are selected according to the purpose and budget of the project.

2.3.3 Storage System

Storage system stores the collected rainwater properly for future use. One of the common storage systems is a water storage tank which can be constructed in different ways, sizes, materials, and shapes. NAHRIM (2016) stated that the size of the storage tank is related to the rainfall demand, the expected length of the rain-free dry period, the catchment surface area, aesthetics, and budget. Then, the optimal size of the storage tank is determined to collect the maximum amount of available rainwater and provide sufficient storage capacity to meet the water demand between rainwater replenishment.

As shown in Figure 2.8, the two most typical water storage tank are above-ground water tank and underground water tank. The above-ground water tank can minimize costs because it is easy to install and maintain this storage tank. Besides, it is also easier to check and clean this storage tank periodically. This is because this storage tank is installed above the ground, and leaks or cracks are more likely to be found. Abdulla and Al-Shareef (2009) further pointed out that the collected rainwater is easily extracted from this storage tank under the action of gravity. However, the underground water tank can save above-ground space and keep the collected rainwater at a cool temperature (Zabidi et al., 2020). The aesthetic appearance of the building is also not affected because this storage tank is concealed below the ground. The installation of a pump is necessary because the pump is used to extract water from this storage tank. As a result, this further increases the installation costs. In addition, leaks or cracks due to soil shifting and settling are unlikely to be found because this storage tank is installed underground.



(a) Above-Ground Tank (b) Below-Ground Tank

Figure 2.8: Common Types of Water Storage Tank (DID, 2011).

Furthermore, the material of the water storage tank must be chosen wisely after thorough consideration. This is because the most expensive component of a RWHS is the water tank (Mbua, 2013). The water storage tank can be made of different materials. For example, the above-ground water storage tank is usually made of plastic or steel, while the underground water storage tank is typically made of concrete (Ezekiel Rochat, 2018). Plastic storage tanks are light in weight and highly flexible, but they slowly degrade in the sun and eventually cannot store water after a period of time (Lance Turner, 2018). Steel storage tanks have high durability and strength, but they are expensive. Concrete storage tanks are also strong and durable, but they are heavy.

In addition, the water storage tank can be made into different shapes such as round, rectangular, slimline, and others. DID (2011) stated that the shape of the storage tank is related to the height of the roof, the catchment surface area, the conveyance system, the space around the building, the alignment of the building with the boundary, and the local regulatory agency. Therefore, the water storage tank must be designed properly according to the purpose and budget of the project.

2.4 Distribution System

Distribution system conveys rainwater from the storage system to the end-users. The rainwater stored is usually distributed through a device such as a pipe, hose, or artificial channel (NAHRIM, 2016). Then, flow control valves such as water taps, or water spigots can be used to regulate the flow rate or pressure of the collected rainwater. There are many types of distribution systems in the different parts of the world, such as gravity-fed systems, direct-pumped systems, indirect pumped systems, and others. In some distribution systems, a water pump is used to deliver the collected rainwater to the end-user by increasing the pressure of the rainwater. The details of these systems are further explained in their respective sections.

2.4.1 Gravity-Fed System

As shown in Figure 2.9, gravity-fed system is a system that uses gravity to transport rainwater from an elevated water storage tank to the end-user. NAHRIM (2016) stated that this system is the most commonly used distribution system in the United Kingdom.

The system can minimize costs due to its low installation and maintenance costs. This is because there is no need to install a water pump in this system. Operating costs are also reduced since there is no need to supply electricity to the water pump. Hence, there is also no chance of a pump problem or power failure.

However, the collected rainwater is delivered at a low flow rate because the rainwater is provided at low pressure. In addition, the water storage tank used in this system must be an above-ground water storage tank because it needs to be installed at a high place. In other words, this system must be designed according to the available space above the land at that location. Therefore, this system will definitely affect the aesthetics of the building.

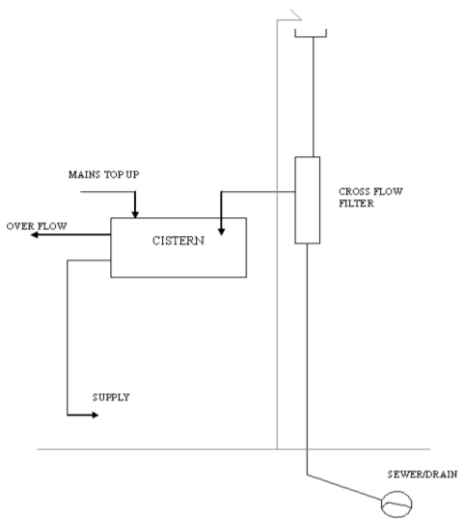


Figure 2.9: Gravity-Fed System Configuration (Ward, 2010).

2.4.2 Direct-Pumped System

As shown in Figure 2.10, direct-pumped system is a system that uses a pump to transport rainwater directly from the water storage tank to the end-user. Team GSB (2019) stated that this system is the easiest to install and is usually used for domestic purposes.

The rainwater in this system is provided at high pressure, so the collected rainwater is delivered at a high flow rate. This system can be used when the RWHS involves underground water storage tanks. This is because the pump in the system can provide energy to transport stored rainwater to the ground for use.

However, the number of maintenances required is higher due to the more frequent use of water pumps. Furthermore, there may be leakage problems in the pipeline due to the high pressure applied by the pump (Atul Purani, 2017a). In addition, the system is in a shutdown state when the pump is under maintenance. This will definitely lead to higher maintenance costs and more time wasted. Therefore, this system is only recommended for water appliances that are used the least frequently in a day (NAHRIM, 2016).

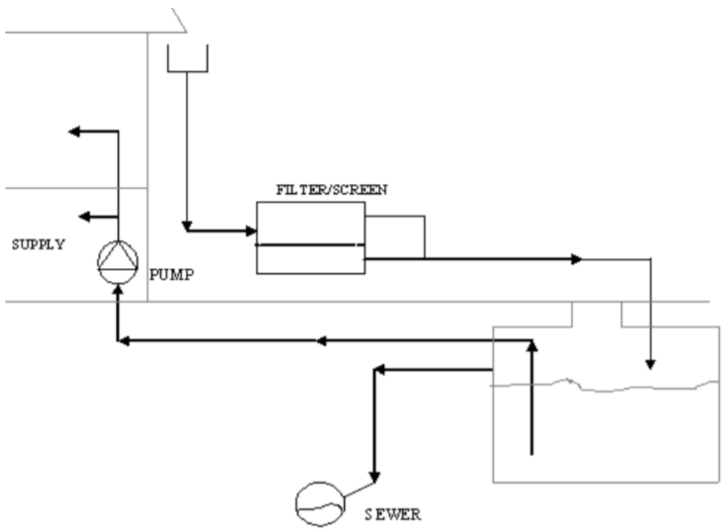


Figure 2.10: Direct-Pumped System Configuration (Ward, 2010).

2.4.3 Indirect Pumped System

As shown in Figure 2.11, indirect pumped system is a system that transfers rainwater from the water storage tank to the header tank by using a pump. The header tank is usually located higher than the main storage tank to keep a certain pressure level. Then, the rainwater stored in the header tank is delivered to the user only under the action of gravity when a water device is used. Atul Purani (2017b) stated that this system is the most commonly used distribution system in India and Pakistan.

When the water level in the header tank drops to a specified set level, the water pump will run to transfer rainwater from the water storage tank to the header tank (NAHRIM, 2016). In other words, the frequency of pump usage is reduced in this system. Thus, this can reduce the possibility of leakage problems in the pipeline due to the high pressure applied by the pump (Atul Purani, 2017b). Besides, the rainwater supply will not be interrupted even if the water pump has a mechanical or electrical failure. This is because there is still a lot of rainwater stored in the header tank, even if the pump cannot operate for a period of time.

However, the collected rainwater is delivered at a low flow rate because the rainwater is provided at low pressure. Furthermore, the space on the roof may be insufficient for the installation of a header tank. Even if there is enough space, this system still has high installation and maintenance costs. This is because an additional header tank is required to be installed and maintained in this system.

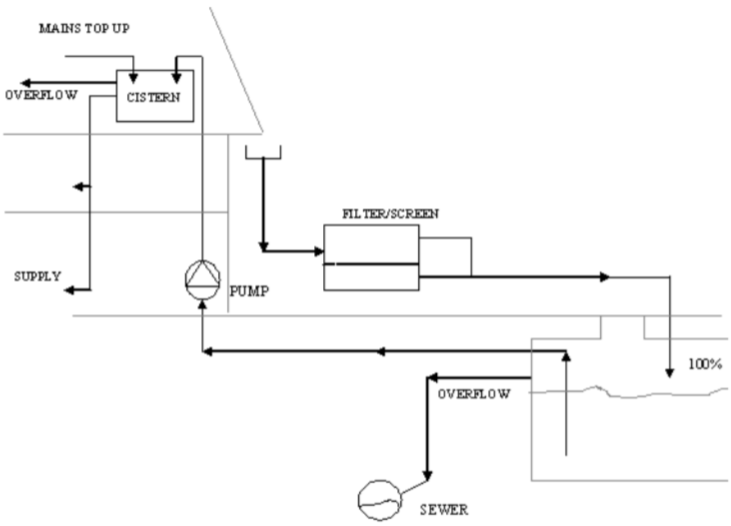


Figure 2.11: Indirect Pumped System Configuration (Ward, 2010).

2.5 Simulation

Simulation is the use of models to imitate real systems or processes over time. It can be used as an analysis tool to predict the results of different parameter changes. Nowadays, it is impossible to conduct any data collection across regions or states. Therefore, simulation is very useful, especially in the current severe pandemic situation (R. Hirschmann, 2021).

2.5.1 Rainwater Storage Tank Sizing

In 2008, NAHRIM developed a desktop software named Tangki NAHRIM by using Visual Basic (Goh and Ideris, 2021). Several studies have used this software to calculate and analyse the optimal tank size the optimal tank size for the RWHS in Malaysia (NAHRIM, 2014; Al-saffar, Abood and Haron, 2016; Effie, 2017). For example, this software can calculate the reliability ratio of the storage tank, rainwater usage coefficient, storage efficiency and percentage of tank empty time under user-defined conditions.

However, it was found that Tangki NAHRIM is already outdated in several aspects. First of all, Goh and Ideris (2021) stated that this software has an outdated interface and can only be used in a desktop environment. It is inconvenient for those who work outside to use this software. Besides, this software has only 24 rainfall stations to choose from, which is quite limited. The rainfall data collected from these stations is also outdated because it is from 1986 to 2006. In addition, the calculation and selection process for the tank size is opaque and tedious. Furthermore, the user guide published by NAHRIM is outdated and only has few descriptions (NAHRIM, 2014).

Nevertheless, Tangki NAHRIM 2.0 was still a new software released by NAHRIM in 2021 (NAHRIM, 2021a). In this software, a daily water balance model is generated to simulate the RWHS by using the built-in rainfall database. The model is designed based on the yield after the spill (YAS) convention, as it assumes the use of rainwater after the release of excess rainwater (Goh and Ideris, 2021). Then, the performance of the rainwater collection system can be reliably predicted.

The function of this software is similar to Tangki NAHRIM but updated with many new features. First, Chang et al. (2019) stated that it has a simplified and user-friendly user interface which is done by using the R Shiny framework. It can be accessed from any device, as long as there is a network. Besides, this software has hundreds of rain stations to choose from in Peninsular and East Malaysia. Moreover, simulation results can be downloaded from the website in Excel format for advanced analysis. Meanwhile, the development principle of this software and the method of using the software are also provided online. Therefore, Tangki NAHRIM 2.0 will be used to calculate the optimal tank size for the RWHS in this paper.

2.6 Summary

In summary, several decisions have been made on the design of the RWHS in this study. The decisions on these sub-components will remain the same regardless of the design.

First, the roof harvesting system is used in this study for several reasons. The roof is chosen as the rainwater catchment surface due to the limited land area. Besides, the roofing material must be resistant to corrosion, as this will prevent the water quality from degrading. The roof can be made of concrete but cannot be painted because the collected rainwater is used for drinking purposes. In addition, the cost of renting land for pond catchment surfaces is expensive and impractical for this study. Therefore, the roof catchment surface is more preferable, because it is more suitable for water demand purposes than for irrigation purposes.

Next, the design of the conveyance system has also been determined. All gutters and downspouts used in this study are k-style gutters and round downspouts made of unplasticized polyvinyl chloride (uPVC). uPVC gutters and downspouts are chosen because they save the cost significantly but provide the same level of protection against rainwater as cast iron and aluminium (Larry Bohan, 2018). Then, the k-style gutter bracket is used to support the weight of the gutters, while the round downspout bracket is used to fix the downspout on the wall. NAHRIM (2014) suggested that the maximum distance between two gutter brackets installed along the length of the gutter is 1 m. Therefore, this conveyance system may not be the cheapest means, but it is the most cost-effective for this purpose.

However, the design of the storage system still needs further investigation, depending on the collection time and location. This is because the storage system decision depends on the type of distribution system used. The gravity-fed system involves the use of an above-ground water storage tank. The direct-pumped system and the indirect pumped system involve the use of an underground water storage tank. Therefore, the storage system and the distribution system are selected according to the purpose and budget of the project.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

The design and evaluation methods of the RWHS was discussed in this chapter. Study area, data collection, component sizing, system modelling, estimated cost, water sampling and testing were further elaborated in the respective subsections under this chapter.

The study area was first chosen in section 3.2 before collecting data required in section 3.3. This was followed by the determination of the component specifications in section 3.4 and the modelling of the system in section 3.5. In addition, estimated cost in section 3.6 and water sampling and testing in section 3.7 were used to evaluate the RWHS. Lastly, the methodology and workplan were summarised in the last section of this chapter.

3.2 Study Area

An animal shelter was a prerequisite for the selected area, as this study focuses on RWHS for animals. The study area had to be selected first because other procedures required important data, such as the details of the buildings, the location of the water stations nearby, the type and number of animals.

In this paper, the IIUM Gombak campus in Selangor state was selected as the area under research. This was because an animal shelter called Greater Gombak Animal Shelter had been built by the Abu Hurairah Club IIUM in the Mahallah Aminah, as shown in Figure 3.1. Abu Hurairah Club IIUM did this because it is an animal lover club that focuses on improving the quality of life of all animals and saving abandoned animals in IIUM (Abu Hurairah Club IIUM, 2021). In addition, another building was built as an office next to this animal shelter as shown in Figure 3.2.

Figure 3.1: Greater Gombak Animal Shelter in the IIUM Gombak Campus.

Figure 3.2: Office next to the Greater Gombak Animal Shelter.

Meanwhile, the Mahallah Aminah mentioned above is one of the student hostels for female students. It consists of 8 undergraduate blocks, 1 graduate block and 1 central building (Abu Hurairah Club IIUM, 2021). As shown in Figure 3.3, the exact location of the Greater Gombak Animal Shelter was marked with a red pin. This animal shelter is located in front of the Mahallah Aminah Block F.

Figure 3.3: Mahallah Aminah Layout (Google, 2021).

3.3 Data Collection

After selecting the study area, the next step was the data collection process. The first data that needed to be collected was the details of the office and the Greater Gombak Animal Shelter. For example, the length, width, and height of walls and roofs are important parameters needed for modelling office and animal shelters in Solidworks software. Meanwhile, this data was collected because the design and dimensions of the office roof were essential for calculating the effective roof catchment area. Besides, the roofing material was essential in determining the roof runoff catchment rate and the optimal size of the rainwater storage tank (NAHRIM, 2016).

Next, the second data that needed to be collected was the species and number of animals living in that animal shelter. This was because these two parameters affected the water demand of this RWHS. For example, a dog and a cat should drink 65 ml and 50 ml of water per kilogram of their body weight every day, respectively (Dr. Sarah, 2020; Stefanie and Julia, 2018). In addition, Dr. Sarah (2020) stated that the water demand of each animal may vary, depending on their age, size, food type, health condition, the surrounding temperature, etc. For example, the water demand of a cat reduces if it eats wet food because the water content of wet food is higher than that of dry food. Thus, it was also important to know whether the food provided to the animals was dry food or wet food.

Furthermore, the third data that needed to be collected was the location of nearby rainfall station. As shown in Figure 3.4, three rainfall stations were built near the animal shelter, namely Gombak Km16, Empangan Genting Klang and Gombak Km11. The station ID of the Gombak Km16 is 3217001, while the station ID of the Empangan Genting Klang is 3217002. Then, the station ID of the Gombak Km11 is 3217003. After deciding the desired rainfall station, the rainfall data could be extracted from Tangki NAHRIM 2.0 by entering the corresponding station ID. This data was collected because this rainfall data was crucial for calculating the roof catchment runoff and sizing the storage tank.

Last, the remaining data that needed to be collected was the rainwater running off the office roof. This was because the quality of rainwater must be checked through water testing to ensure that it was safe for animals to drink. If rainwater is polluted, necessary measures should be taken, such as installing suitable filters or finding the source of the problem and solving it.

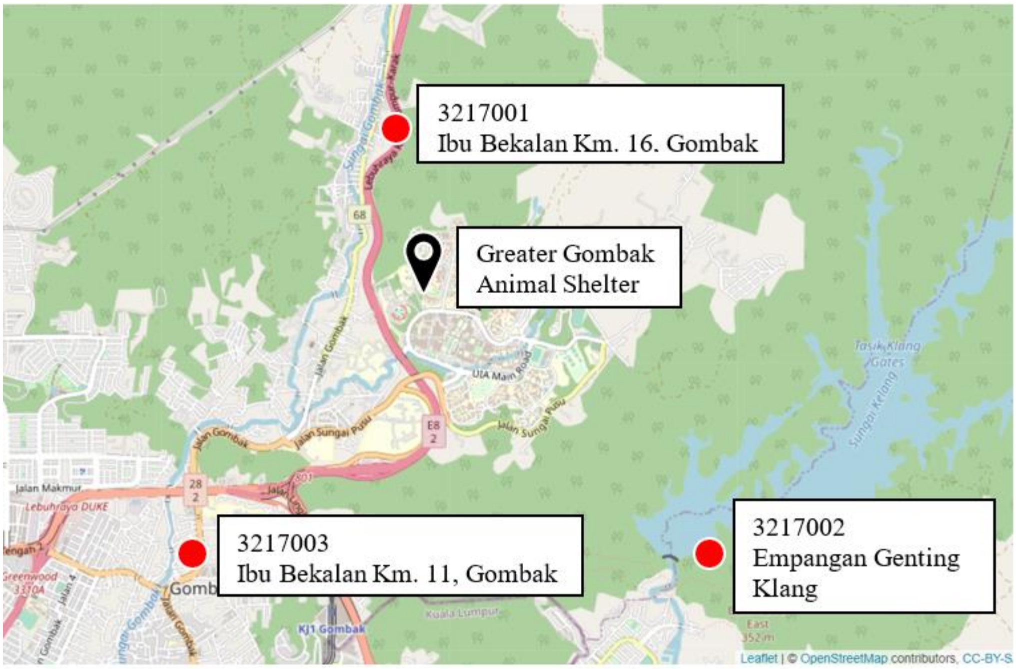


Figure 3.4: Location of the Animal Shelter and the Rainfall Station Nearby (NAHRIM, 2021b).

3.4 Component Sizing

AS/NZS 3500.3 is the Australian/ New Zealand Standard for rainwater drainage. This Standard provides the design and installation requirements of rainwater drainage systems, including roofs, gutters, downspouts, and others (VBA, 2018). In Malaysia, the Department of Irrigation and Drainage Malaysia (DID) has decided to adopt this standard in the RWHS.

The roof catchment area was first calculated in section 3.4.1 before calculating the average rainfall intensity in section 3.4.2. This was followed by the gutter and downspout sizing in section 3.4.3 and the estimation of the daily water demand in section 3.4.4. In addition, the optimal storage tank size was determined in section 3.4.5.

3.4.1 Roof Catchment Area

As mentioned in the AS/NZS 3500.3, the calculation of the roof catchment area had to take the wind effects on rainfall into account (Joint Technical Committee WS-014, 2003). This was because the wind tilted the rain and produced a horizontal component of rainfall, thereby affecting the effectiveness of the roof catchment area. Therefore, the wind direction leading to the largest roof catchment area should be selected.

In this study, it was assumed that the maximum rainfall slope ratio was -2:1. According to the design of the roof, the roof can be divided into three types: a single-slope roof, a single-slope roof sheltered by a wall, and two adjacent sloping roofs (DID, 2012). The calculation methods for these three types of roofs were different because the formulas used were different. However, two parameters were first calculated by using the same formula regardless of the roof type. These two parameters were horizontal area of the roof (A_{rh}), and vertical area of the roof (A_{rv}), which were calculated by using Equations 3.1, and 3.2, respectively.

$$A_{rh} = l_r \times w_r \tag{3.1}$$

Where

A_{rh} = Horizontal area of the roof (m^2)

l_r = Length of roof (m)

w_r = Width of roof (m)

$$A_{rv} = w_r \times h_r \tag{3.2}$$

Where

A_{rv} = Vertical area of the roof (m^2)

w_r = Width of roof (m)

h_r = Height of roof (m)

After that, the corresponding formula was used to calculate the roof catchment area of each roof design. Figure 3.5 showed the single-slope roof and the angle of descent of the rain. Equation 3.3 was used to calculate the roof catchment area of a single-slope roof.

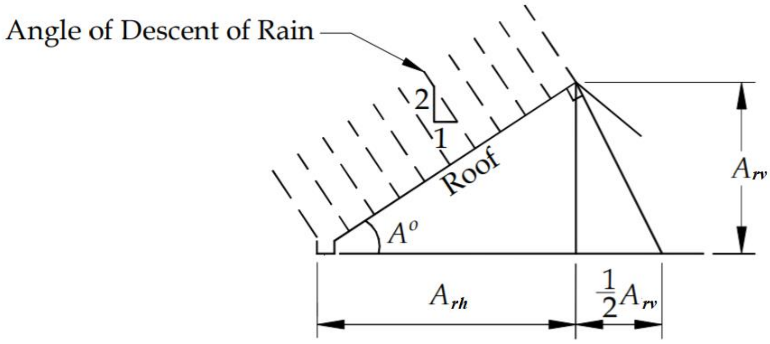


Figure 3.5: Single-slope Roof (DID, 2012).

$$A_{rc} = A_{rh} + \frac{A_{rv}}{2} \tag{3.3}$$

Where

A_{rc} = Roof catchment area (m^2)

A_{rh} = Horizontal area of the roof (m^2)

A_{rv} = Vertical area of the roof (m^2)

Figure 3.6 showed the single-slope roof sheltered by a wall and the angle of descent of the rain. Equation 3.4 was used to calculate the roof catchment area of a single-slope roof sheltered by a wall.

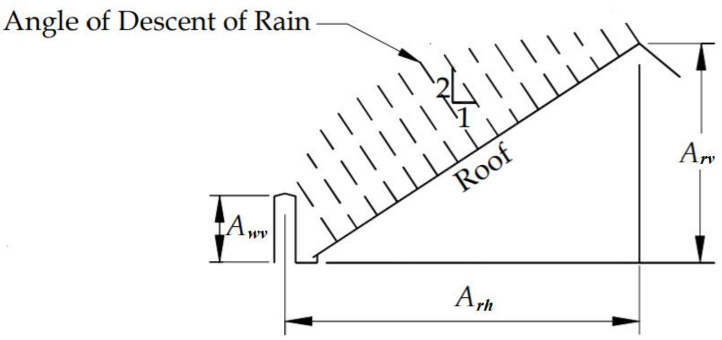


Figure 3.6: Single-slope Roof Sheltered by A Wall (DID, 2012).

$$A_{rc} = A_{rh} + \frac{1}{2}(A_{rv} - A_{rw}) \tag{3.4}$$

Where

A_{rc} = Roof catchment area (m^2)

A_{rh} = Horizontal area of the roof (m^2)

A_{rv} = Vertical area of the roof (m^2)

A_{rw} = Vertical area of the wall (m^2)

Figure 3.7 showed the two adjacent sloping roofs and the angle of descent of the rain. Equation 3.5 was used to calculate the roof catchment area of two adjacent sloping roofs.

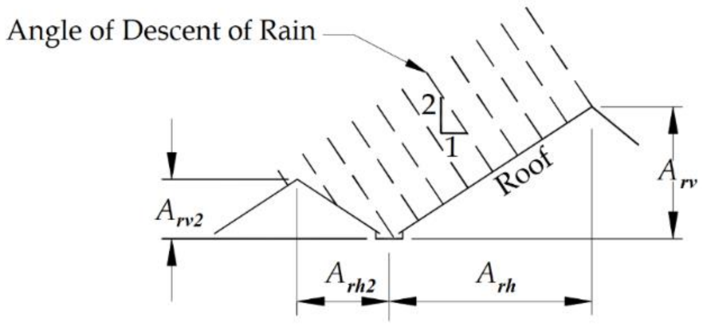


Figure 3.7: Two Adjacent Sloping Roofs (DID, 2012).

$$A_{rc} = A_{rh} + A_{rh2} + \frac{1}{2}(A_{rv} - A_{rv2}) \tag{3.5}$$

Where

A_{rc} = Roof catchment area (m^2)

A_{rh} = Horizontal area of the roof (m^2)

A_{rv} = Vertical area of the roof (m^2)

A_{rh2} = Horizontal area of the adjacent roof (m^2)

A_{rv2} = Vertical area of the adjacent roof (m^2)

3.4.2 Average Rainfall Intensity

The average rainfall intensity is defined as the average rainfall rate for a particular rainfall duration, in millimetres/hour or millimetres/minute (Ramke, 2018). Average rainfall intensity was affected by the average recurrence interval (ARI), storm duration and fitting constants dependent on the rainfall location (DID, 2012).

First, ARI is the average measurement of time between rainfall events that exceed the same magnitude, amount, or duration (DID, 2012). The type of gutters was first determined to find the suitable design ARI for RWHS from Table 3.1.

Table 3.1: Design ARIs for Different Types of Gutters (DID, 2012).

Type of Gutter	**ARI (year)**
K-Style Gutters	20
Valley and Box Gutters	100

In order to obtain the average storm duration and fitting constants, the desired rainfall station was first determined after measuring the distance between the animal shelter and the rainfall station. This was because the shorter the distance between the animal shelter and the rainfall station, the higher the similarity of hyetograph. After that, the fitting constants required to calculate the average rainfall intensity were determined from Table 3.2 according to the rainfall station selected.

Next, a 5-minute storm duration should be adopted for all roofs unless exceptional circumstances require a longer duration (DID, 2012). In the end, the average rainfall intensity was calculated by using Equation 3.6 after obtaining parameters.

Table 3.2: Fitting Constants for 20-Year ARI and 5-Minutes Storm Duration at Different Locations in Kuala Lumpur (DID, 2012).

Station ID	Station Name	Constants			
		λ	k	θ	η
3015001	Puchong Drop, K Lumpur	69.650	0.151	0.223	0.880
3116003	Ibu Pejabat JPS	61.976	0.145	0.122	0.818
3116004	Ibu Pejabat JPS1	64.689	0.149	0.174	0.837
3116005	SK Taman Maluri	62.765	0.132	0.147	0.820
3116006	Ladang Edinburgh	63.483	0.146	0.210	0.830
3216001	Kg. Sungai Tua	64.203	0.152	0.250	0.844
3216004	SK Jenis Keb. Kepong	73.602	0.164	0.330	0.874
3217001	Ibu Bek. KM16, Gombak	66.328	0.144	0.230	0.859
3217002	Emp. Genting Kelang	70.200	0.165	0.290	0.854
3217003	Ibu Bek. KM11, Gombak	62.609	0.152	0.221	0.804
3217004	Kg. Kuala Seleh, H. Klg	61.516	0.139	0.183	0.837
3217005	Kg. Kerdas, Gombak	63.241	0.162	0.137	0.856
3317001	Air Terjun Sg. Batu	72.992	0.162	0.171	0.871
3317004	Genting Sempah	61.335	0.157	0.292	0.868

$$I = \frac{\lambda T^k}{(d_a + \theta)^\eta} \tag{3.6}$$

Where

I = Average rainfall intensity (mm/hr)

T = Average recurrence interval (year)

d_a = Average storm duration (hr)

λ, k, θ and η = Fitting constants dependent on rainfall location

3.4.3 Gutter and Downspout Sizing

In this study, all gutters and downspouts used were k-style gutters and rectangular downspouts made of unplasticized polyvinyl chloride (uPVC). Before sizing the gutter, DID (2012) recommended a gutter fall of 1 in 500 because this design provided adequate drop and minimise the risk of standing water.

Since the gutters used were k-style gutters, the roof catchment area and the average rainfall intensity calculated in sections 3.4.1 and 3.4.2 respectively were required as a guide in Figure 3.8 to determine the minimum cross-sectional size required for these gutters. Besides, the catchment area per vertical downpipe in Figure 3.8 was the same as the roof catchment area calculated because all rainwater collected from the roof flew into one downspout.

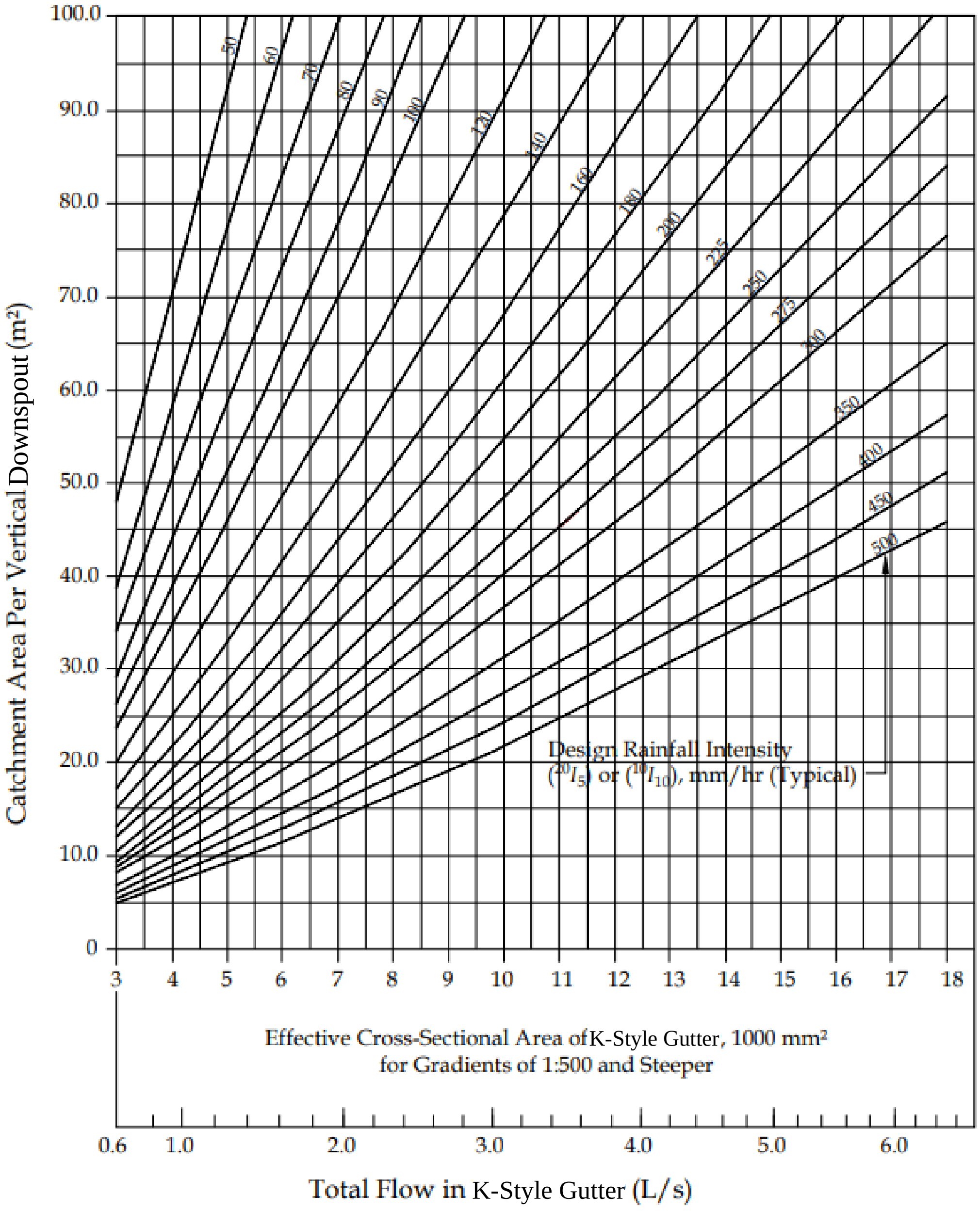


Figure 3.8: Sizing K-Style Gutters for Gradients 1:500 and Steeper (DID, 2012).

Then, the minimum size of downspout required to match the minimum size of the k-style gutter was determined from Table 3.3. The downspout could be circular or rectangular as shown in Table 3.3. Furthermore, DID (2012) stated that the size of the downspout was still the same irrespective of the slope of the k-style gutter for a given roof catchment area.

Table 3.3: Required Size of Downspout for K-Style Gutter (DID, 2012).

<table>
<tr><th rowspan="2">Minimum Cross-Sectional Size of K-Style Gutter (mm^2)</th><th colspan="2">Minimum Nominal Size of Downspout (mm)</th></tr>
<tr><th>Circular</th><th>Rectangular</th></tr>
<tr><td>4000</td><td rowspan="3">75</td><td rowspan="2">65 × 50</td></tr>
<tr><td>4200</td></tr>
<tr><td>4600</td><td rowspan="2">75 × 50</td></tr>
<tr><td>4800</td><td rowspan="2">85</td></tr>
<tr><td>5900</td><td rowspan="2">100 × 50</td></tr>
<tr><td>6400</td><td rowspan="2">90</td></tr>
<tr><td>6600</td><td rowspan="2">75 × 70</td></tr>
<tr><td>6700</td><td rowspan="2">100</td></tr>
<tr><td>8200</td><td rowspan="2">100 × 75</td></tr>
<tr><td>9600</td><td rowspan="2">125</td></tr>
<tr><td>12800</td><td>100 × 100</td></tr>
<tr><td>16000</td><td rowspan="2">150</td><td>125 × 100</td></tr>
<tr><td>18400</td><td rowspan="2">150 × 100</td></tr>
<tr><td>19200</td><td rowspan="3">Not applicable</td></tr>
<tr><td>20000</td><td>125 × 125</td></tr>
<tr><td>22000</td><td>150 × 125</td></tr>
</table>

3.4.4 Daily Water Demand

First, water demand depended on the species and number of animals living in the Greater Gombak Animal Shelter. These two parameters were obtained during the data collection process mentioned in section 3.3. Then, Equation 3.7 was used to calculate the daily water consumption of an animal. After that, the daily water demand was calculated by substituting the daily water consumption of each animal and the total number of animals into Equation 3.8.

$$V_h = W_h \times v_h \tag{3.7}$$

Where

V_h = Daily water consumption of an animal (ℓ/day)

W_h = Body weight (kg)

v_h = Daily water consumption per kilogram of body weight of an animal (ℓ/(kg day))

$$V_d = \sum_{h=1}^{h}(N_h \times V_h) \tag{3.8}$$

Where

V_d = Daily water demand (ℓ/day)

h = Total number of animal species (unitless)

N_h = Total number of animals in species h^{th} (unitless)

V_h = Daily water consumption of each animal in species h^{th} (ℓ/day)

3.4.5 Storage Tank Sizing

Tangki NAHRIM 2.0 was used in this section to help predict the optimal size of storage tank for the RWHS. As shown in Figure 3.9, the input information required by Tangki NAHRIM 2.0 were rainfall station ID, roof length, roof width, water demand, roof runoff coefficient, first flush volume, tank capacity range.

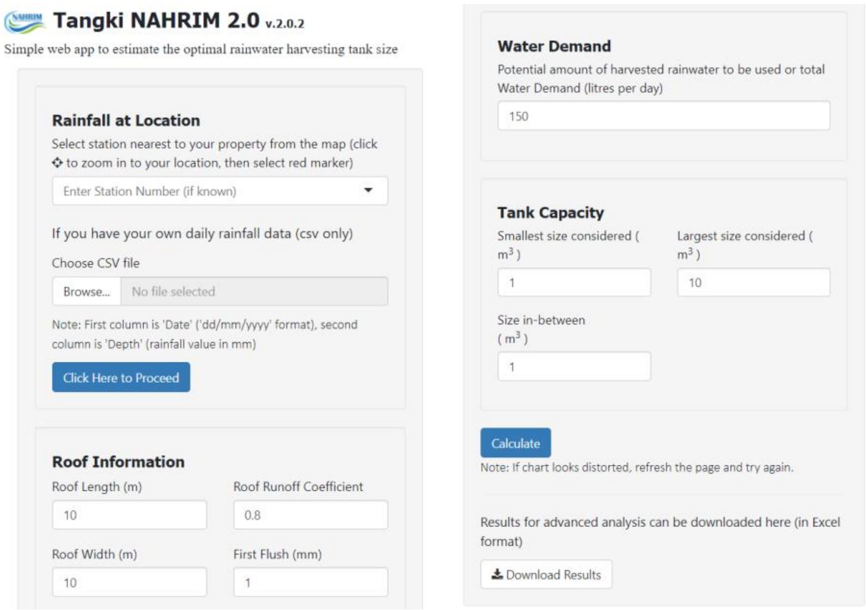


Figure 3.9: Tangki NAHRIM 2.0 Interface (NAHRIM, 2021b).

First, rainfall station ID, roof length, and roof width were obtained during the data collection process mentioned in section 3.3. Then, the calculated water demand could be obtained from section 3.4.4. After that, the runoff coefficient is the percentage of precipitation that appears as runoff (NAHRIM, 2016) which is the ratio of rainwater runoff to rainwater falling on the roof. The higher the runoff efficient, the greater the amount of collected rainwater. As shown in Table 3.4, Biswas and Mandal (2014) stated that the runoff coefficient changes depending on the roof type used. Then, the runoff coefficient was determined based on the type of roof used in the animal shelter known during the data collection process.

Table 3.4: Runoff Coefficients for Different Types of Roof (Biswas and Mandal, 2014).

Type of Roof	**Runoff Coefficient Range**
Concrete	0.60 - 0.80
Tiles	0.80 - 0.90
Corrugated metal sheets	0.70 - 0.90
Galvanized iron sheets	> 0.90

Since the RWHS in this study did not involve a first flush diverter, the first flush volume was set to 0 mm. In order to test the performance of different tank capacities, three parameters were entered by the user, namely smallest size considered, size in-between, and largest size considered. Furthermore, these three parameters could be adjusted regardless of the number of trials to obtain the desired storage tank size.

After clicking the calculate button in Figure 3.9, two graphs were generated by Tangki NAHRIM 2.0. The relationship between storage efficiency and water-saving efficiency against a series of tank capacities was plotted as shown in Figure 3.10. Goh and Ideris (2021) defined storage efficiency as the ratio of the runoff stored in a storage tank to the rainwater flowing into the storage tank. Meanwhile, Goh and Ideris (2021) also defined water efficiency as the ratio of the amount of water demand met to the total demand. In this study, storage efficiency and water-saving efficiency were used as the measurement indicators of retention efficiency and volumetric efficiency respectively. Besides, the relationship between the percentage time the tank was at each class of volumes against a series of tank capacities was plotted as shown in Figure 3.11. Finally, these two graphs were used as a guide for finding the optimal size of the tank.

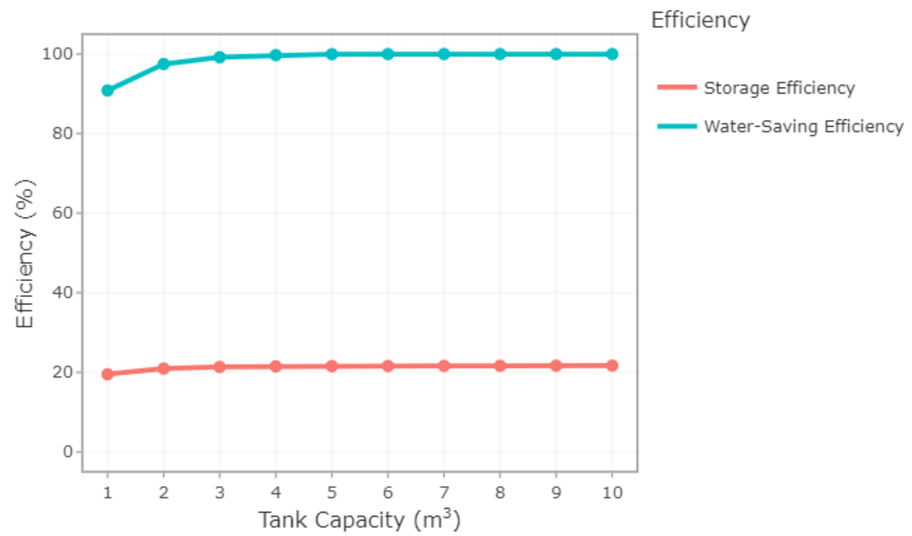


Figure 3.10: Graph of Efficiency against Tank Capacity (NAHRIM, 2021b).

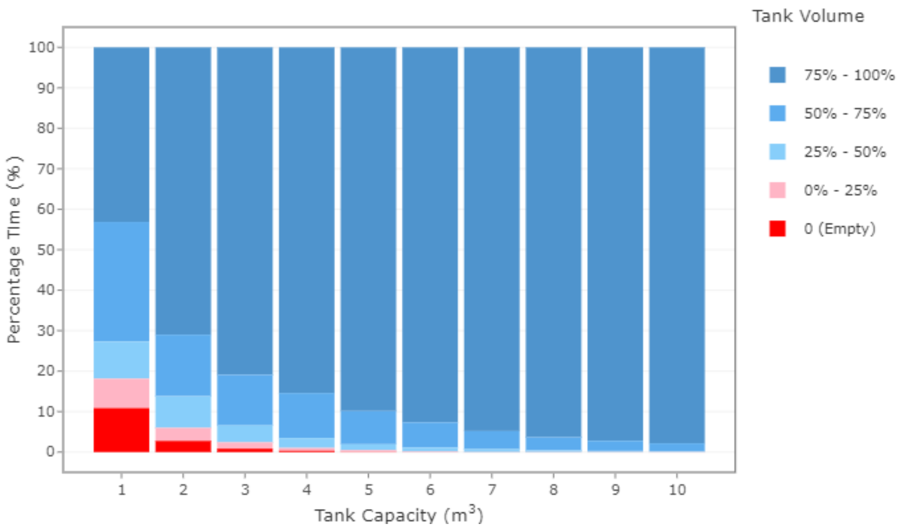


Figure 3.11: Graph of Percentage Time against Tank Capacity (NAHRIM, 2021b).

3.5 System Modelling

First, three types of RWHS were proposed in this study. After considering the type of the building, these three systems were modelled separately in Solidworks for demonstration. The design of the gravity-fed system was first shown in section 3.5.1. This was followed by the design of the direct-pumped system in section 3.5.2 and the design of the indirect pumped system in section 3.5.3.

3.5.1 Gravity-Fed System

The 3-D solid model of the gravity-fed system was shown in Figure 3.12. In this system, the user received the collected rainwater through the tap in the lowest rain barrel as shown in Figure 3.13. The 3-D solid model of a building after implementing the gravity-fed system was shown in Figure 3.14.

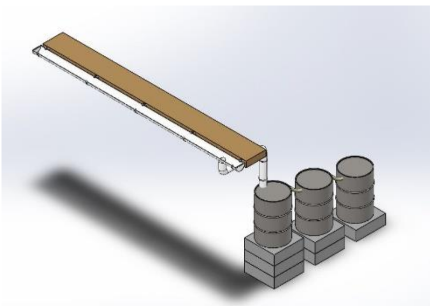


Figure 3.12: Components of a Gravity-Fed System.

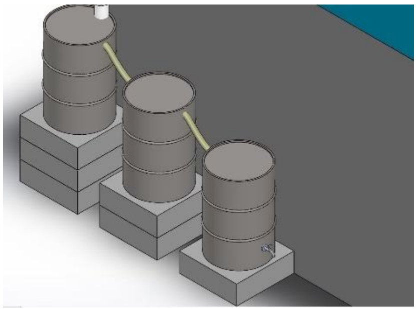


Figure 3.13: Rain Barrel System.

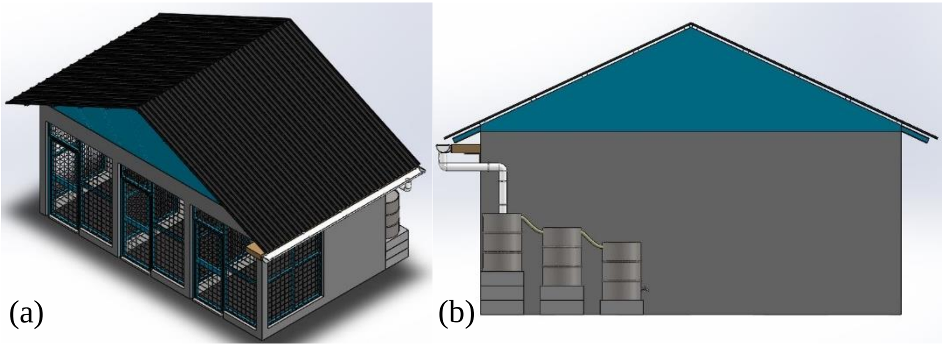


Figure 3.14: (a) Isometric View and (b) Rear View of a Building after Implementing Gravity-Fed System.

3.5.2 Direct-Pumped System

The 3-D solid model of the direct-pumped system was shown in Figure 3.15. In this system, the user received the collected rainwater through the tap and pump as shown in Figure 3.16. The 3-D solid model of a building after implementing the direct-pumped system was shown in Figure 3.17.

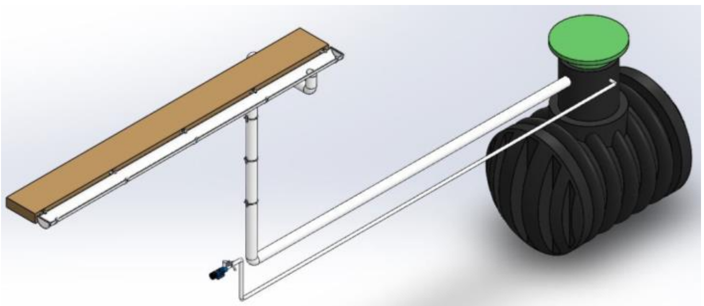


Figure 3.15: Components of a Direct-Pumped System.

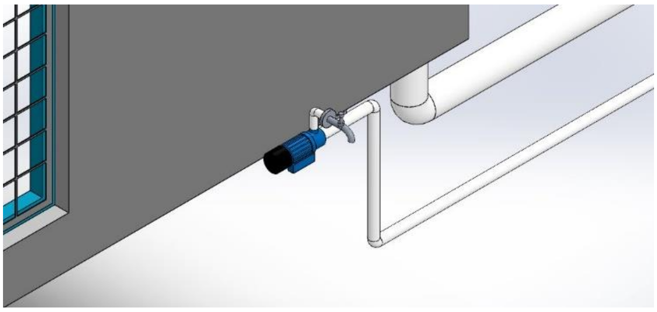


Figure 3.16: Pump and Tap.

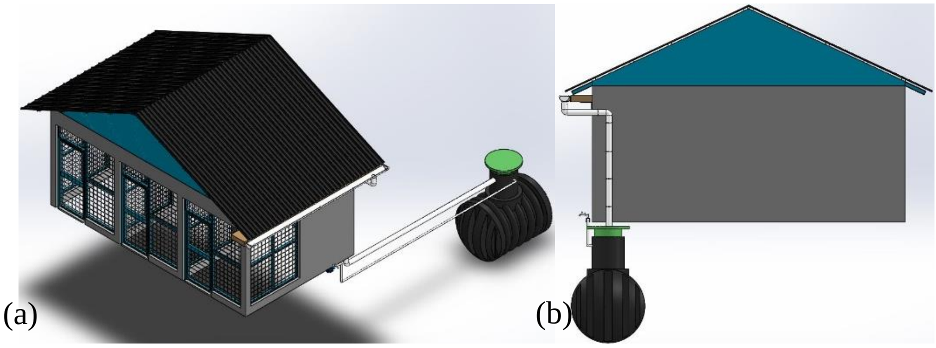


Figure 3.17: (a) Isometric View and (b) Rear View of a Building after Implementing the Direct-Pumped System.

3.5.3 Indirect Pumped System

The 3-D solid model of the indirect pumped system was shown in Figure 3.18. However, due to the design of the roof shown in Figure 3.19, the header tank was not allowed to be placed above the wall of a building. Therefore, another concrete table shown in Figure 3.20 was built to support the weight of the header tank and the rainwater stored in it.

In this system, the user received the collected rainwater stored in the header tank through the tap in each room as shown in Figure 3.21. The 3-D solid model of a building after implementing the indirect pumped system was shown in Figure 3.22.

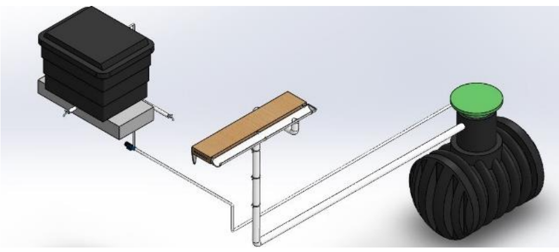


Figure 3.18: Components of an Indirect Pumped System.

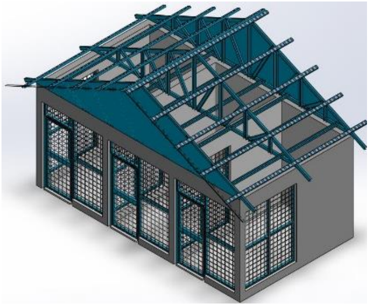


Figure 3.19: Section View of a Building before Implementing the Indirect Pumped System.

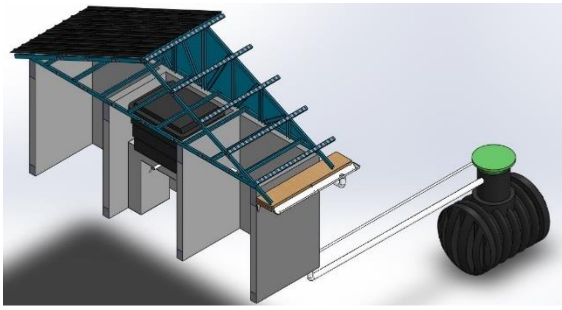


Figure 3.20: Section View of a Building after Implementing the Indirect Pumped System.

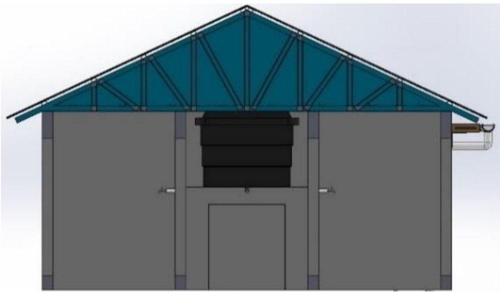


Figure 3.21: Location of Header Tank and Taps.

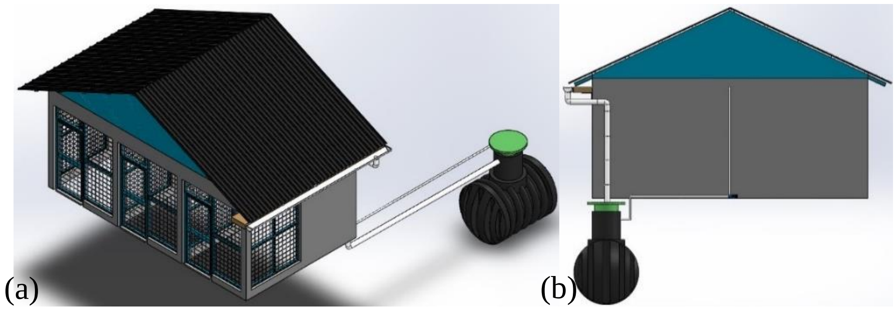


Figure 3.22: (a) Isometric View and (b) Rear View of a Building after Implementing the Indirect Pumped System.

3.6 Estimated Cost

Cost estimating is the process of forecasting the financial and other resources required to complete a project (Wrike, 2022). This section calculated the total amount required for the RWHS in this study. The initial cost estimation could determine whether the organization approved the project. If the project was approved and in progress, this estimate was used to manage all of its ancillary costs to keep the project within budget. If a project was not approved because the cost estimation was too high, the organization could scale down the project to fit within what they could afford.

In this study, a total of 24 parts were required for the construction of the RWHS. The first key component in the RWHS was the gutter. The length of the gutter to be purchased needed to be longer than the width of the roof. Then, the gutter joiner and spout head were required to connect the gutters and guide the collected rainwater to the downspout. The number of gutter joiners purchased was two less than the number of gutters purchased because the spout head could also be used as a joiner. A spout head was sufficient because there was only one water outlet in this design. An adjustable gutter bracket was also needed every 1 meter to secure the gutter to the fascia board at a specific slope. Furthermore, a debris trap was bought to put in the gutter spout head and prevent blockage.

Next, the second key component in the RWHS was the downspout. The length of the downspout to be purchased needed to be sufficient to connect from the gutter spout head to the storage tank. 2 45-degree elbow connectors were required to get the downspout close to the wall, and 1 90-degree elbow connector was required to connect the downspout to the storage tank. A downspout bracket was also needed every 1 meter to secure the downspout to the wall.

After that, the third key component in the RWHS was the storage tank. An appropriately sized storage tank must be purchased to store sufficient rainwater. Considering that the water storage tank might be full during heavy rain days, water might accumulate inside the downspout causing the downspout to carry extra weight. As a result, a tube, acrylic plate, and solid round stick were needed to build an overflow port on the storage tank. Then, a water pipe with a smaller diameter was bought and installed on the bottom of the tank to let the collected rainwater flow out.

Since this design used the two long sides of the roof as the catchment surface, the number of parts to be purchased above must be doubled. After that, the remaining key component in the RWHS for this study was the distribution system. A tee connector was purchased to combine fluid flowing in the water pipes mentioned above from both storage tanks. Then, a feed water adapter ball valve was required to restrict, stop or control the flow of the collected rainwater. It was also used to change the diameter of the white hoses that came out of the valve. In addition, a filter was bought to ensure that the collected rainwater was safe to drink. Concrete blocks were also required to allow the filter to be placed higher and easier to handle.

Next, long white hoses were purchased to direct the collected rainwater from a water valve near the office to a filter near an animal shelter far away. Besides, these hoses were also used to direct the filtered rainwater from the filter to the sipper water bottles. During the process, two tee connectors were needed to divert the fluid flowing in the aforementioned white hoses as there were three cages in the animal shelter. Then, an elbow connector was required for each cage to change the flow of the filtered rainwater in the direction of sipper water bottles. Sockets were also bought to join two white hoses if the length of the white hoses was not long enough to reach a specific location. Furthermore, end plugs were purchased to seal the end run of the white hose in each cage and the last tee connector in the furthest cage. As a result, water was prevented from flowing out of these components.

In addition, the number of sipper water bottles needed depended on the size of the bottle and the water demand of the cats and kittens. The 1-day labour cost of 2 workers also needed to be paid because they helped us build the RWHS. Finally, the total cost required for this RWHS could be calculated after including the shipping fee for each component. This total cost could then be used as a reference when getting quotations from outside contractors.

3.7 Water Sampling and Testing

Total Dissolved Solids (TDS) refers to the inorganic salts (such as calcium, magnesium, potassium and sodium chloride) and small amounts of organic matter that are dissolved in water (Centre for Affordable Water and Sanitation Technology, 2009). TDS in untreated tap water can come from natural sources, sewage, urban runoff and industrial wastewater. Animals' health may be affected by the contaminants lurking in untreated tap water. Holistic veterinarians believe cats should also not drink treated tap water due to chemicals such as chlorine and fluoride used in the water treatment process (EcoWater Systems, 2018). A low level of certain contaminants can cause significant health issues from exposure since a cat has a small body mass compared to a human. Therefore, TDS concentrations must be measured to ensure that the collected rainwater was free of any contaminants.

The equipment needed for this water quality test was a TDS & EC meter. This equipment determined TDS by detecting the presence of ions in water and measuring the electrical conductivity (EC) of water (Westlab, 2018). Once the EC level was determined, the meter ran a conversion factor between 0.4 and 1.0 to determine the TDS. Then, the result was in, and the TDS was expressed in parts per million (ppm). TDS for good quality water fell between 0 and 600 ppm while TDS over 1200 ppm was generally considered an unsatisfactory level (Westlab, 2018). However, this meter was only a quick way to estimate TDS.

In this study, the rainwater sample was first obtained during the data collection process mentioned in section 3.3. The sample was collected in a clean glass container. Then, the container was rinsed several times by using the water to be sampled. Next, the container was filled and the water from the depth and the surface were collected. Last, this water was tested by using the TDS & EC meter mentioned above. If the TDS was equal to or greater than 4500 ppm, the sample was submitted for laboratory test (Scherer and Meehan, 2019). After that, the sources of the problems were identified and solutions were provided.

3.8 Summary

The methodology and work plan were graphically summarized in Figure 3.23 and Figure 3.24.

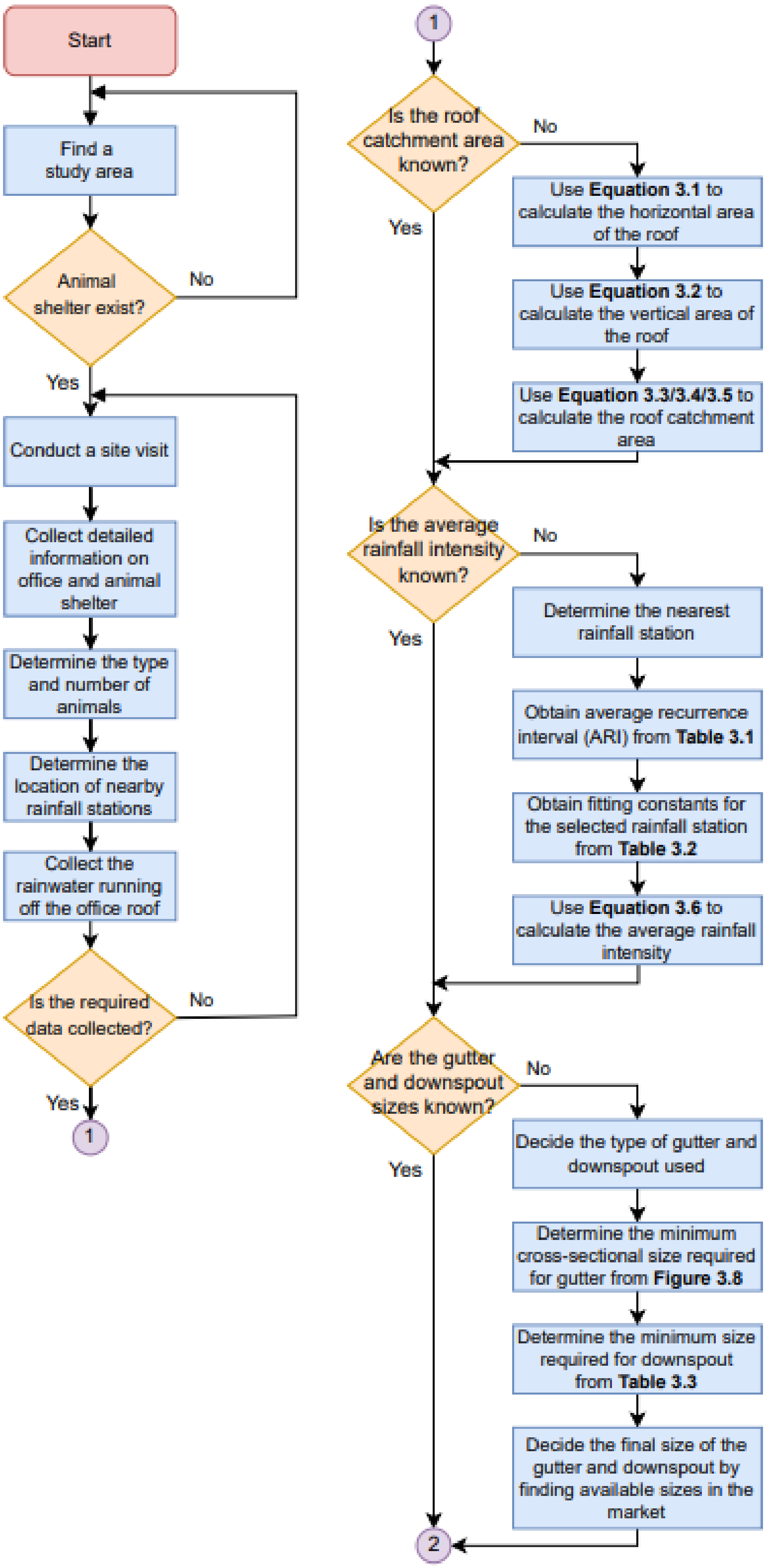


Figure 3.23: Working Flow Chart (Part 1).

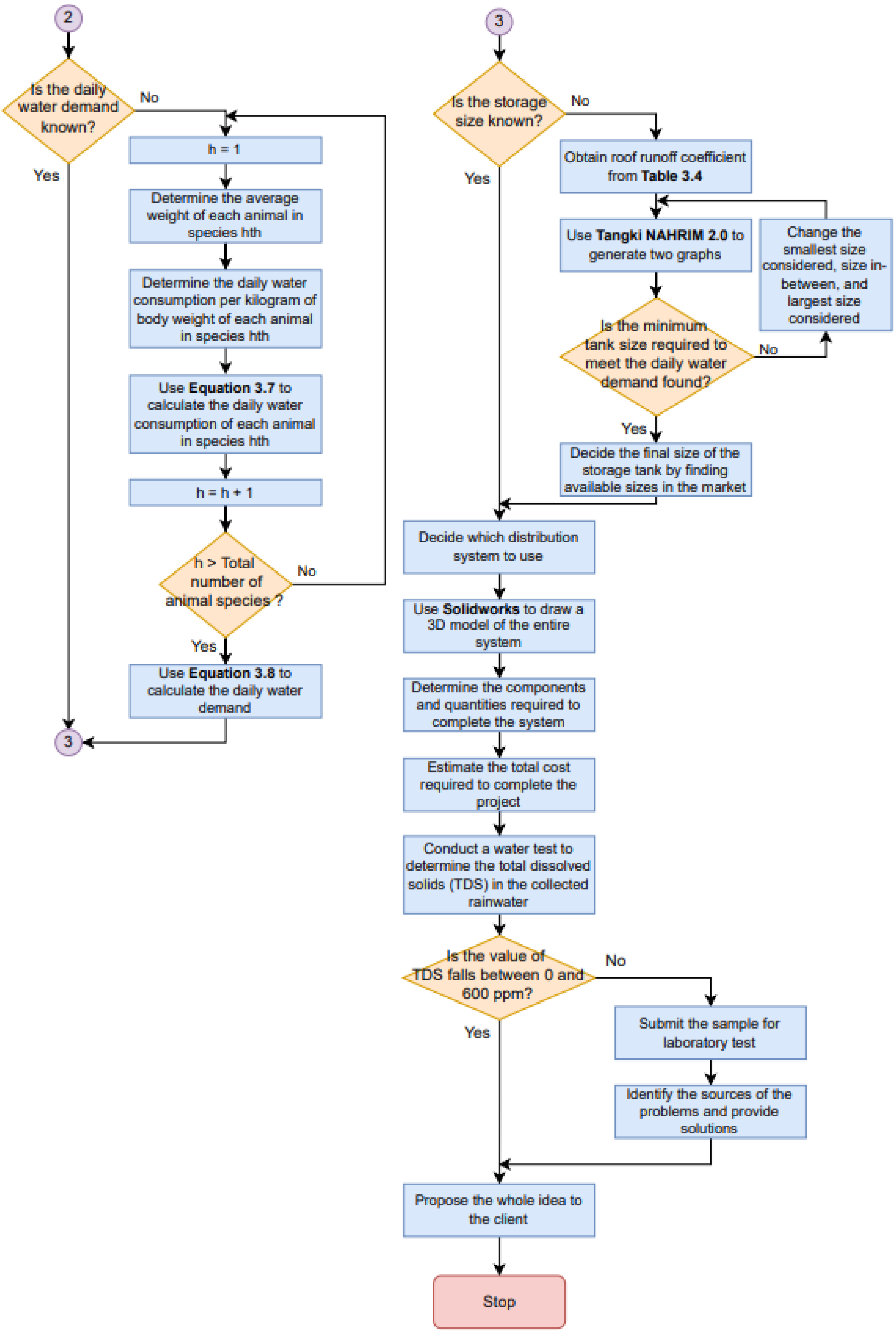


Figure 3.24: Working Flow Chart (Part 2).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The entire process required to complete the system was discussed in this chapter. The calculation, decision made, system modelling, design concept, estimated cost, water sampling and testing were further elaborated in the respective subsections under this chapter.

The calculation of the various components of the RWHS and the decisions made based on the calculation results were shown in section 4.2. This was followed by the 3D modelling of the system and the design concept behind it in section 4.3. After that, the estimated cost for the system was computed and listed in detail in section 4.4. In addition, water sampling and testing were conducted in section 4.5. Lastly, the results obtained were summarised in the last section of this chapter.

4.2 Calculation and Decision Made

The roof catchment area was first calculated in section 4.2.1 before calculating the average rainfall intensity in section 4.2.2. The final sizes of gutters and downspouts were then determined in section 4.2.3, while the daily water demand was estimated in section 4.2.4. Finally, the final storage tank size was determined in section 4.2.5.

4.2.1 Roof Catchment Area

It was assumed that the hip roof of the office was composed of four single-slope roofs. For this RWHS, two longer sides of the office roof were used to capture rainwater. Therefore, the first step was to calculate the roof catchment area on one of the longer sides of the office roof as shown in Figure 4.1.

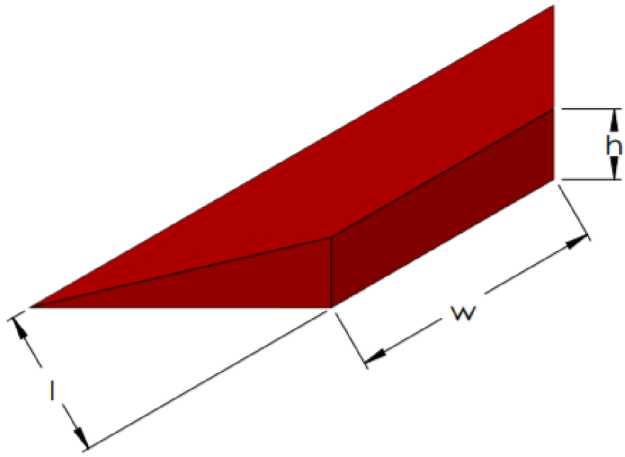


Figure 4.1: Simplified Longer Side of the Office Roof.

As shown in Figure 4.2, the bottom area of the office roof consisted of 1 rectangle and 2 triangles.

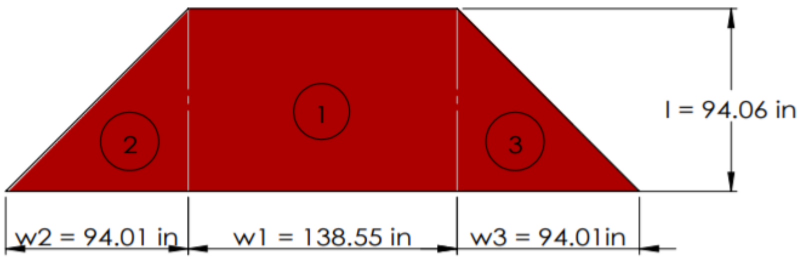


Figure 4.2: Horizontal Area of the Long Side of the Office Roof.

For horizontal area of the office roof,

$$A_{rh} = A_{rh,1} + A_{rh,2} + A_{rh,3}$$

$$= l_{r,1} \times w_{r,1} + \frac{1}{2} \times l_{r,2} \times w_{r,2} + \frac{1}{2} \times l_{r,3} \times w_{r,3}$$

$$= \left(94.06 \times 138.55 + \frac{1}{2} \times 94.06 \times 94.01 + \frac{1}{2} \times 94.06 \times 94.01\right) \text{ in}^2$$

$$= 21874.59 \text{ in}^2$$

As shown in Figure 4.3, the vertical area of the office roof consisted of 1 rectangle and 2 triangles.

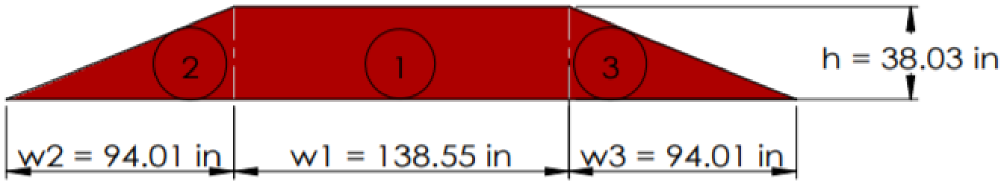


Figure 4.3: Vertical Area of the Long Side of the Office Roof.

For vertical area of the Office roof,

$$\begin{aligned} A_{rv} &= A_{rv,1} + A_{rv,2} + A_{rv,3} \\ &= w_{r,1} \times h_{r,1} + \frac{1}{2} \times w_{r,2} \times h_{r,2} + \frac{1}{2} \times w_{r,3} \times h_{r,3} \\ &= \left(138.55 \times 38.03 + \frac{1}{2} \times 94.01 \times 38.03 + \frac{1}{2} \times 94.01 \times 38.03\right) \text{ in}^2 \\ &= 8844.26 \text{ in}^2 \end{aligned}$$

Roof catchment area,

$$\begin{aligned} A_{rc,one} &= A_{rh} + \frac{A_{rv}}{2} \\ &= 21874.59 \text{ in}^2 + \frac{8844.26 \text{ in}^2}{2} \\ &= 26296.72 \text{ in}^2 \\ &= 26296.72 \text{ in}^2 \times \frac{0.0254^2 \text{ m}^2}{1 \text{ in}^2} \\ &= 16.97 \text{ m}^2 \end{aligned}$$

4.2.2 Average Rainfall Intensity

First, displacements between different rain stations and animal shelters were first measured using Google Maps. Then, according to Table 4.1, Gombak Km16 was found to be the closest rainfall station to the animal shelter because the displacement between them was 1.39 km. Therefore, the selected rainfall station in this study area was Gombak Km16, and its station number was used in the following steps.

Table 4.1: Displacements between different rain stations and animal shelters (Google, 2022).

Station ID	Rainfall Station	Displacement between Station and Animal Shelter (km)
3217001	Gombak Km16	1.39
3217002	Empangan Genting Klang	3.24
3217003	Gombak Km11	2.87

Based on Table 3.1, the ARI for the k-style gutter was $T = 20$ year

Based on Table 3.2, the fitting constants for the Gombak Km16 were

$\lambda = 66.328$, $k = 0.144$, $\theta = 0.230$ and $\eta = 0.859$

Storm duration,

$$d = 5 \text{ min}$$
$$= 5 \text{ min} \times \frac{1 \text{ hr}}{60 \text{ min}}$$
$$= 0.0833 \text{ hr}$$

Average rainfall intensity,

$$I = \frac{\lambda T^k}{(d_a+\theta)^\eta}$$
$$= \frac{(66.328)(20)^{0.144}}{(0.0833+0.230)^{0.859}}$$
$$= 276.68 \text{ mm/hr}$$

4.2.3 Gutter and Downspout Sizing

The gutter fall was assumed to be 1 in 500 to provide adequate drop and minimize the risk of standing water. The catchment area per vertical downspout and the average rainfall intensity calculated earlier were used as guides to determine the minimum cross-sectional size of the k-style gutter.

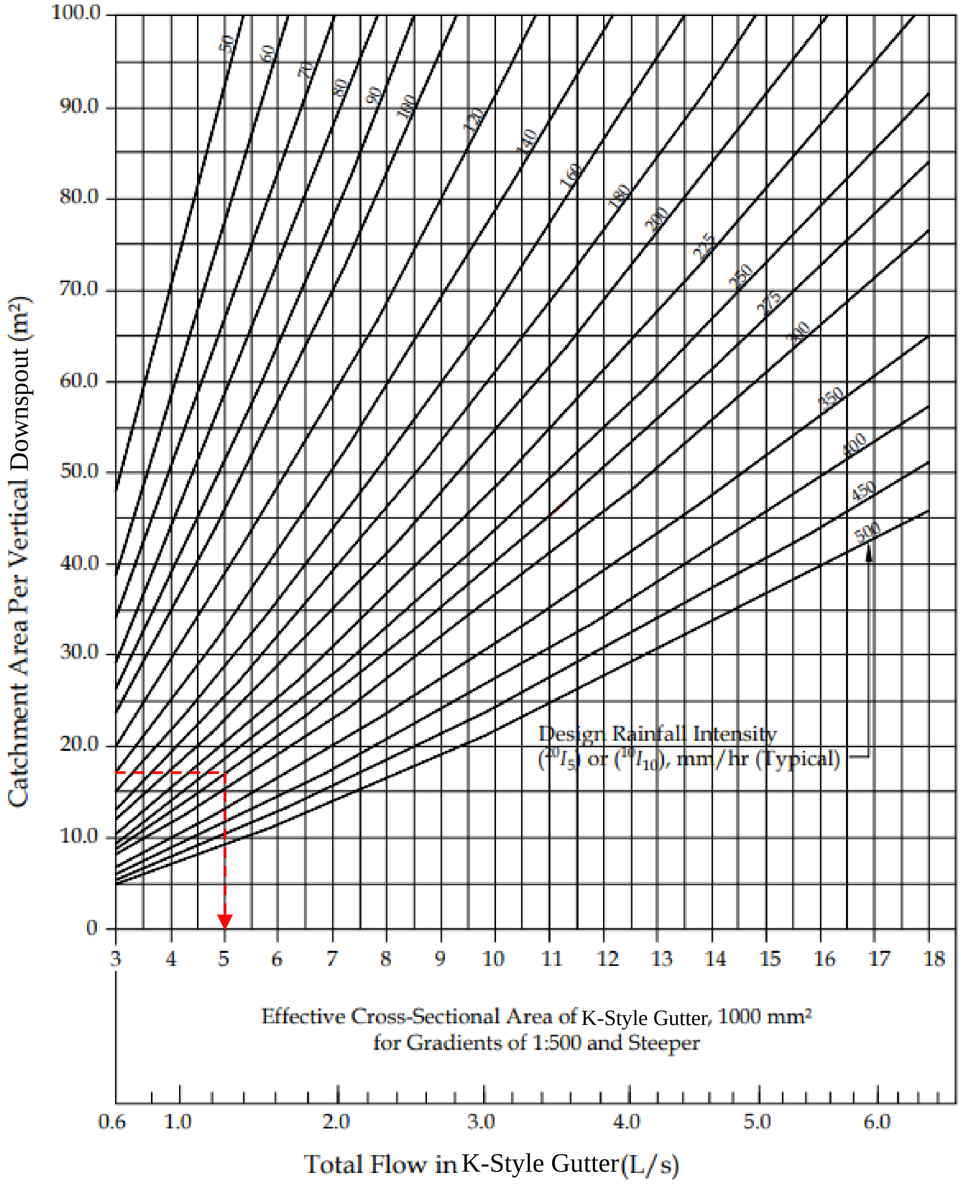
Slope of the gutters, $m = \frac{1}{500}$

Catchment area per vertical downspout, $A =$ Roof catchment area

$= 16.97\ \mathrm{m}^2$

The average rainfall intensity, $I = 276.68\ \mathrm{mm/hr}$

For $A = 16.97\ m^2$ and $I = 276.68\ \mathrm{mm/hr}$,



Based on figure above, the minimum effective cross-sectional area of the k-style gutter was 5000 m^2. 5000 m^2 was between 4800 m^2 and 5900 m^2. Based on Table 3.3, the minimum nominal size of downspout required to match the minimum size of the k-style gutter was 85 mm because the downspout used in this study was round.

Therefore, F300 gutters were used in this study because they met a minimum effective cross-sectional area of $5000\ m^2$. Besides, round downspouts with a 4-inch diameter were used in this study as they met a minimum diameter of 85 mm.

4.2.4 Daily Water Demand

According to the director of Abu Hurairah Club IIUM, the type of animals living in the Greater Gombak Animal Shelter were cats. The person in charge also mentioned that the animal shelter can accommodate up to 10 adult cats and 25 kittens at a time. Next, Stefanie and Julia (2018) stated that a cat should drink 50 ml of water per kilogram of their body weight every day. Furthermore, Sarah (2016) noted that the average weight of a medium cat and a six-month-old kitten was 4 kg and 2.7 kg respectively.

Daily water consumption of a medium cat,

$$\begin{aligned} V_{medium\ cat} &= W_{medium\ cat} \times v_{medium\ cat} \\ &= 4\text{ kg} \times 50\ m\ell/(\text{kg day}) \times \frac{1\ \ell}{1000\ m\ell} \\ &= 0.2\ \ell/\text{day} \end{aligned}$$

Daily water consumption of a six-month-old kitten,

$$\begin{aligned} V_{kitten} &= W_{kitten} \times v_{kitten} \\ &= 2.7\text{ kg} \times 50\ m\ell/(\text{kg day}) \times \frac{1\ \ell}{1000\ m\ell} \\ &= 0.135\ \ell/\text{day} \end{aligned}$$

Daily water demand,

$$\begin{aligned} V_d &= \sum_{h=1}^{2}(N_h \times V_h) \\ &= N_{medium\ cat} \times V_{medium\ cat} + N_{kitten} \times V_{kitten} \\ &= 10 \times 0.2\ \ell/\text{day} + 25 \times 0.135\ \ell/\text{day} \\ &= 10 \times 0.2\ \ell/\text{day} + 25 \times 0.135\ \ell/\text{day} \\ &= 5.375\ \ell/\text{day} \end{aligned}$$

4.2.5 Storage Tank Sizing

The rainfall station ID, roof length, roof width, and water demand determined earlier were needed in the Tangki NAHRIM 2.0 to predict the optimal size of the storage tank for the RWHS.

Rainfall station ID $= 3217001$

Roof length, $l = 94.06 \text{ in} \times \frac{0.0254 \text{ m}}{1 \text{ in}}$

$= 2.3891 \text{ m}$

Roof width, $w = 138.55 \text{ in} + 94.01 \text{ in} + 94.01 \text{ in}$

$= 326.57 \text{ in} \times \frac{0.0254 \text{ m}}{1 \text{ in}}$

$= 8.2949 \text{ m}$

Water demand $V_d =$ Daily water demand

$= 5.375\ \ell/\text{day}$

Based on Table 3.4, the runoff coefficient was assumed to be 0.80 since the type of roof used in the office was the concrete roof. Since the RWHS in this study had a filter, the first flush volume was assumed to be 0.

Roof runoff coefficient, $C = 0.80$

First flush volume $= 0$ mm

Smallest size considered $= 0 \text{ m}^3$

Largest size considered $= 1 \text{ m}^3$

Size in-between $= 0.05 \text{ m}^3$

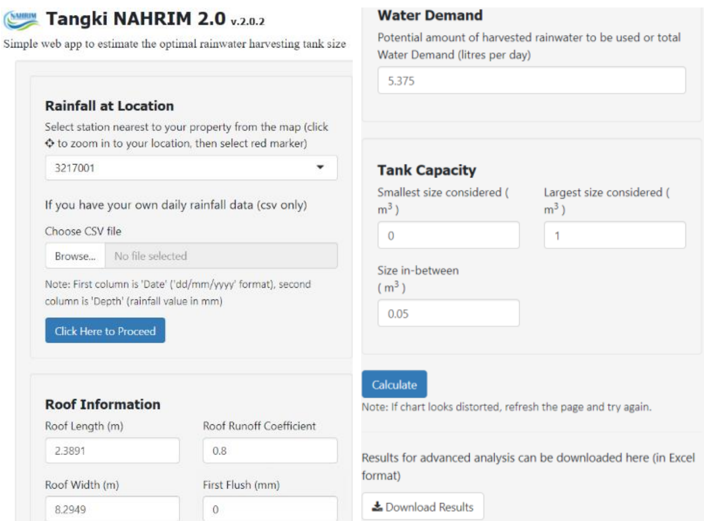


Figure 4.4: Tangki NAHRIM 2.0 Interface (NAHRIM, 2021b).

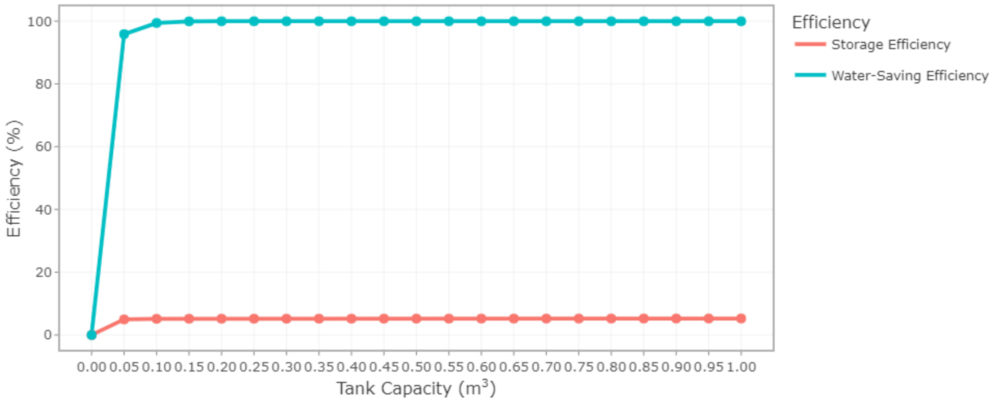


Figure 4.5: Graph of Efficiency against Tank Capacity (NAHRIM, 2021b).

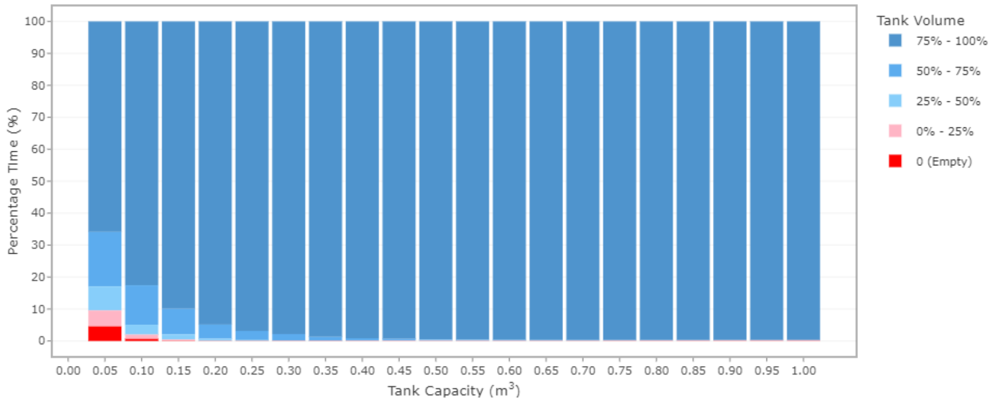


Figure 4.6: Graph of Percentage Time against Tank Capacity (NAHRIM, 2021b).

Based on Figure 4.5, 100.0% of water demand can be met for tank size 0.2 m^3 and 2 m^3 of water can be saved per year. Based on Figure 4.6, the water volume in the 0.2 m^3 tank was at 75% to 100% of the total volume for 94.9% of the time. Besides, the water volume in the 0.2 m^3 tank was at 50% to 75% of the total volume for 4.4% of the time. Next, the water volume in the 0.2 m^3 tank was at 25% to 50% of the total volume for 0.6% of the time. Therefore, the minimum tank size required for this study was 0.2 m^3 as this tank size had water in it 99.9% of the time.

Minimum tank size,

$$V_{minimum} = 0.2\ \text{m}^3 \times \frac{1000\ \ell}{1\ \text{m}^3}$$
$$= 200\ \ell$$
$$= 200\ \ell \times \frac{1\ \text{gal}}{4.546\ \ell}$$
$$= 43.99\ \text{gal}$$

Thus, Deluxe polyethylene tanks with a volume of 318 litres or 70 gallons were used in this study because they met the minimum tank size of 0.2 m^3.

4.3 System Modelling and Design Concept

Gravity-fed system was used as the distribution system in this study because it was the cheapest and most environmentally friendly system. A 3D model of the entire system, including the office and animal shelter, was then drawn using Solidworks as shown in Figure 4.7. This section also explained how the system operated when this study area rained.

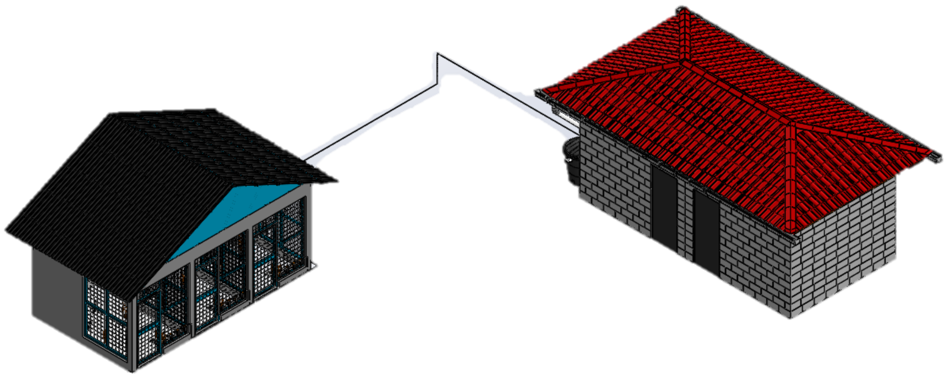


Figure 4.7: Overall View of RWHS.

First, rainwater fell on the concrete roof of the office and flew down the roof on rainy days, as shown in Figure 4.8. Most of the rainwater continued to flow along the roof, while some stopped on the roof.

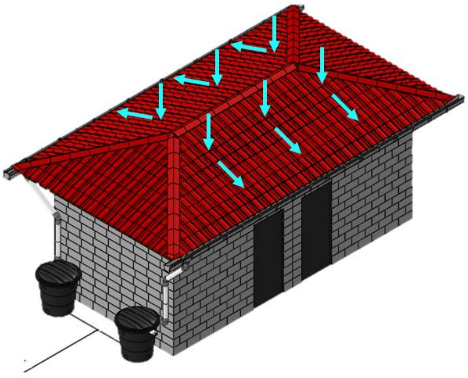


Figure 4.8: Office on a Rainy Day.

Then, the flowing rainwater fell into the k-style gutter which was connected by the gutter joiners and spout head as shown in Figure 4.9. The rainwater flowed toward the spout head because the gutter was fixed on the fascia board with a gradient of 1:500 by using the adjustable gutter brackets. Left and right gutter ends as shown in Figure 4.9 were also installed to prevent water from flowing out of the gutter. In addition, a debris trap was installed to prevent blockage and keep rainwater running freely through the spout head as shown in Figure 4.10. The component also acted as a simple filter to keep unwanted stuff like leaves from going into the downspout.

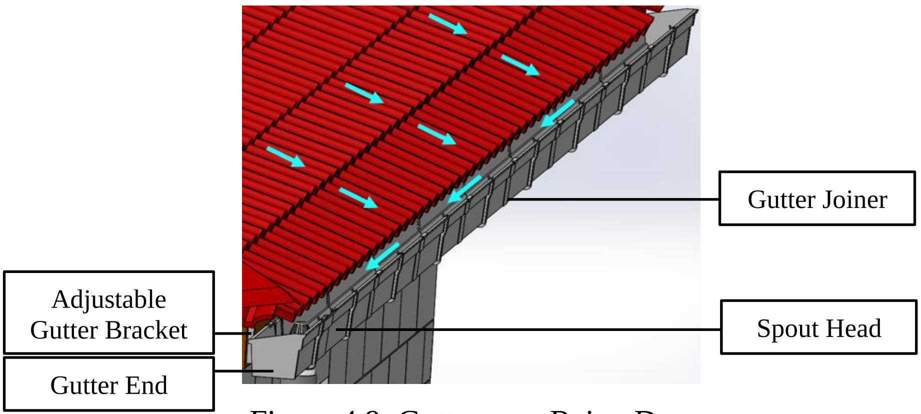


Figure 4.9: Gutter on a Rainy Day.

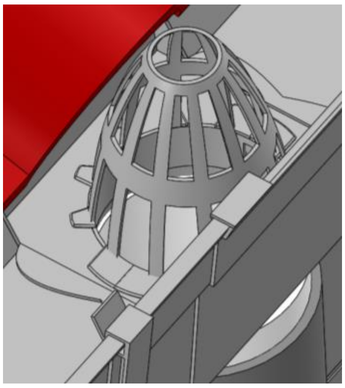


Figure 4.10: Debris Trap Installed in the Spout Head.

After passing through the debris trap and spout head, the rainwater flowed within the pipeline constructed by using downspouts, 45-degree and 90-degree elbow connectors as shown in Figure 4.11. A downspout bracket was also installed every 1 meter to secure the downspout to the wall and provide support for the RWHS.

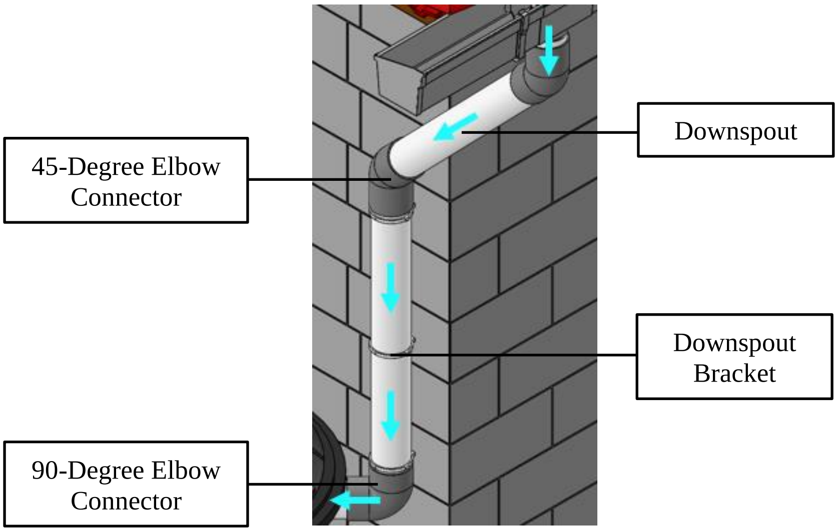


Figure 4.11: Downspout on a Rainy Day.

Next, the collected rainwater flowed into the water storage tank and was stored within it as shown in Figure 4.12. This design allowed the storage tank to be easily dismantled and washed by removing the downspout and water hose below. In other words, this reduced damage to the system during maintenance. During the dry season, rainwater also could be used to water surrounding plants by removing the tank cover and scooping the water out.

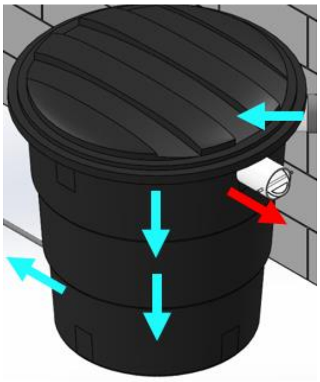


Figure 4.12: Storage Tank on a Rainy Day.

Furthermore, an overflow port made of a tube, acrylic plates, and solid round sticks was installed on the tank as shown in Figure 4.13. This port was used to drain excess rainwater when the collected water exceeded the capacity of the storage tank. This prevented rainwater from accumulating in the downspout and putting extra weight on the downspout. In other words, this increased the product life of the system and reduced the number of maintenances required. On the other hand, the overflow port allowed the opening to automatically close when there was no need to drain excess rainwater because of the extra weight on the bottom of the acrylic plate. Since there were many mosquitoes in that area and mosquitoes liked to breed in stagnant water, this design prevented mosquitoes from flying into the tank. In other words, it also guaranteed the quality of the collected rainwater.

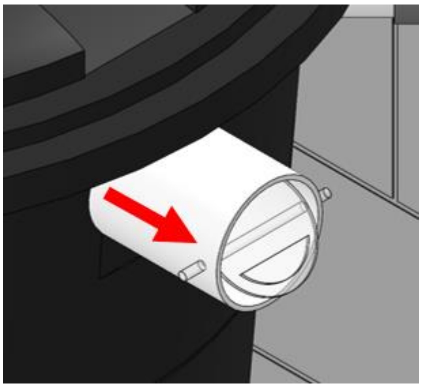


Figure 4.13: Overflow Port Installed on the Storage Tank.

After that, the collected rainwater flowed into the water pipe and was ready for use. Since the RWHS used two long sides of the office roof as the catchment surface, a tee connector was used to combine the water flowing in the water pipe which came from both directions as shown in Figure 4.14. Once the feed water adapter ball valve was opened, water flowed through the white hose to the animal shelter for use.

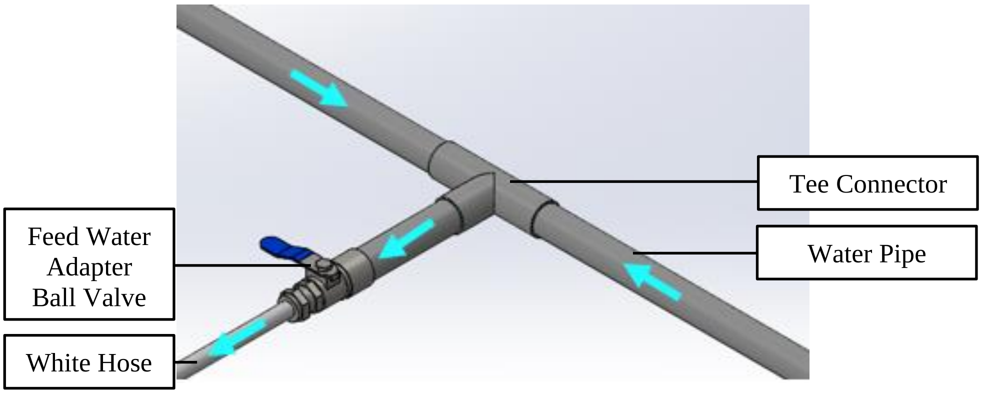


Figure 4.14: Beginning of Distribution System.

As shown in Figure 4.15, the white hose mentioned earlier was connected to the 7-stage filter outside the animal shelter. The filter was installed as a safety measure to ensure that the collected rainwater was as safe as possible for cats to drink. It was set on concrete blocks as shown in Figure 4.16 to create a height difference from the ground, making it easier for users to operate. Once the faucet was turned on, the filtered rainwater was sent to the water bottle through another white hose. Meanwhile, this design also prevented the filter from being kicked or damaged by stray animals. On the other hand, the white hose attached to the water faucet could be removed at any time if the user wanted to use the filtered rainwater for other purposes such as hand washing or drinking.

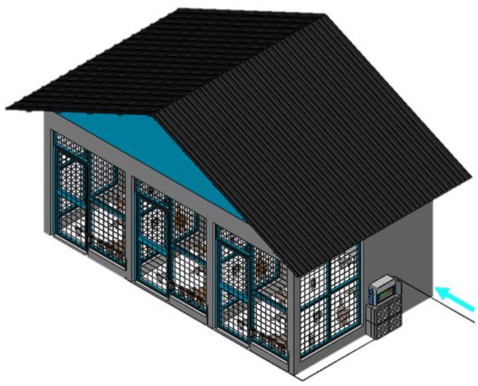


Figure 4.15: Greater Gombak Animal Shelter on a Rainy Day.

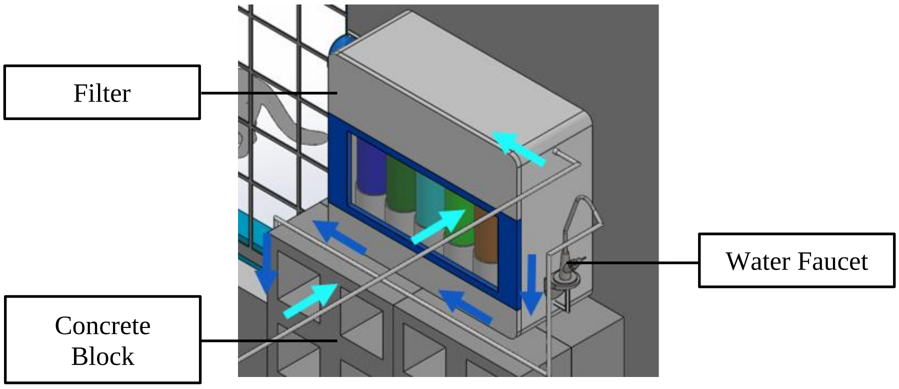


Figure 4.16: 7-Stages Filter outside the Animal Shelter.

Afterward, the filtered rainwater flowing in the white hoses was shunted into the three cages using three tee and 90-degree elbow connectors as shown in Figure 4.17. As shown in Figure 4.18, the filtered rainwater then flowed simultaneously into vertical water pipes in each cage under the action of hydrostatic pressure. This was because the pressure inside the filtered rainwater depended on the depth rather than the shape of the water. Next, the filtered rainwater flowed into the white hose connected with the sipper water bottles as shown in Figure 4.19. Furthermore, end plugs were installed on the end run of the white hose in each cage and the last tee connector in the furthest cage as shown in Figure 4.20 and Figure 4.21 respectively. As a result, this prevented water from flowing out of the other outlets.

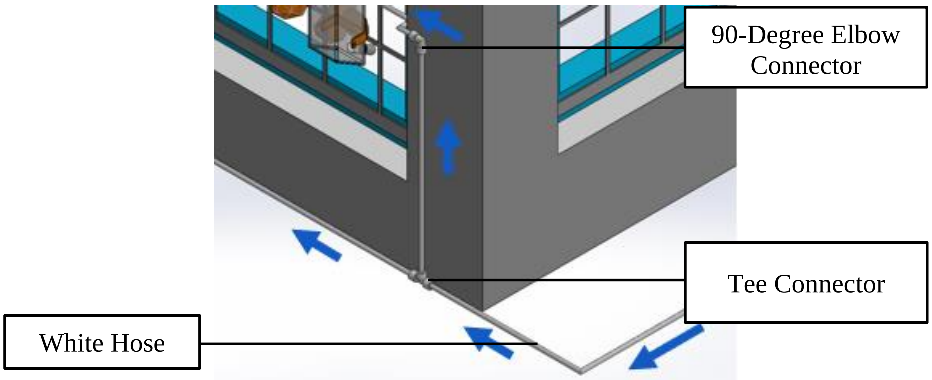


Figure 4.17: White Hose Coming out of the Filter.

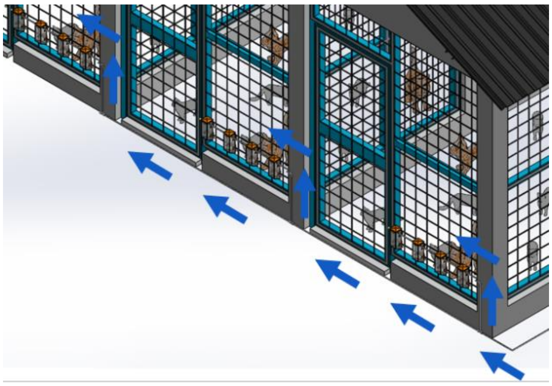


Figure 4.18: Distribution System after Filter.

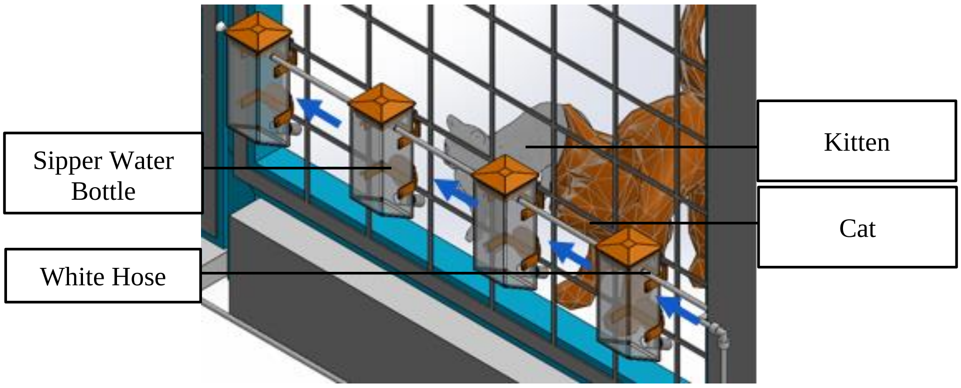


Figure 4.19: Last Part of Distribution System.

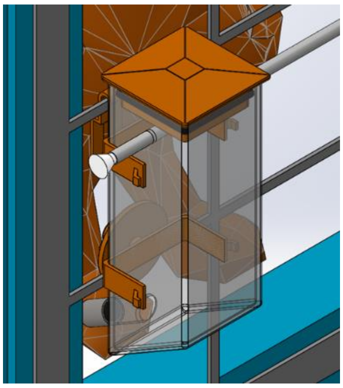


Figure 4.20: End Plug Installed on the End Run of the White Hose.

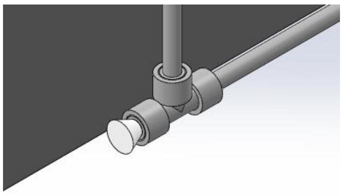


Figure 4.21: End Plug Installed on the Last Tee Connector.

Finally, filtered rainwater flowed out of the white hose using the same principle described above, as shown in Figure 4.22. In other words, the sipper water bottles were filled with water by turning on the water faucet installed on the filter. Last, the cats and kittens drank the water by licking the nozzle ball of the water bottle as shown in Figure 4.22. This was because the spring inside the nozzle pushed the nozzle ball to prevent water from flowing out of the water bottle. As a result, the collected rainwater definitely would not be wasted. This design also prevented mosquitoes from flying into the water bottle and contaminating the filtered rainwater.

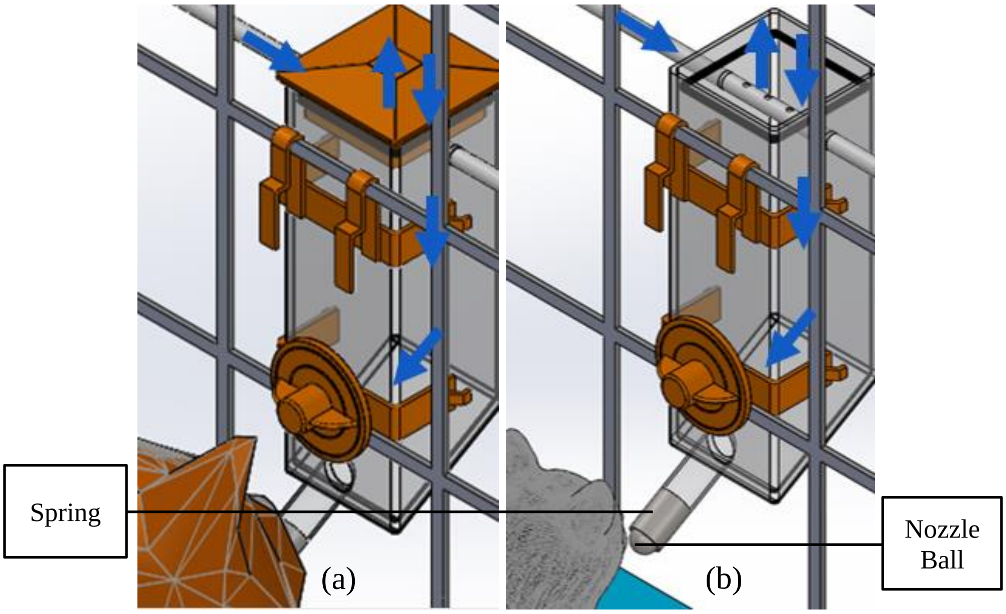


Figure 4.22: Sipper Water Bottle (a) Before and (b) After Removing the Top Cover.

4.4 Estimated Cost (Based on Available Quotation)

In Table 4.2, the part list was shown along with their respective shipping fees, materials, and suppliers. Table 4.2 also showed the unit price of each part and the number of parts required to complete the RWHS. In short, the total cost estimated for this RWHS was RM2900.

Table 4.2: Quotation from Shopee without the Use of Free Shipping Coupons.

No	Description	Quantity	Price/ Unit (RM)	Shipping Fee (RM)	Total Amount (RM)	Material	Supplier/ Procurement Website
1	Arensi-Marley F300 Gutter (1 m)	18	27.88	136.60	638.44	uPVC	**Shopee** Website: https://shopee.com.my/1-METER-ARENSI-MARLEY-F300-F370-UPVC-Rainwater-Gutter-Rain-Gutter-Grey-Brown-Salur-Air-i.72482968.10412935744
2	Arensi-Marley F300 Gutter End Stopper (Left+Right)	2	7.50	6.60	21.60	uPVC	**Shopee** Website: https://shopee.com.my/F300-(GREY)-UPVC-Rainwater-Gutter-System-Accessories-Gutter-Mitre-Filling-Salur-Air-Kelabu-i.72482968.8568823786
3	Arensi-Marley F300 Gutter Joiner	14	4.50	39.80	102.80	uPVC	
4	Arensi-Marley F300 Gutter Spout Head (4 ")	2	14.00	6.60	34.60	uPVC	
5	Arensi-Marley F300 Adjustable Gutter Bracket	18	5.00	49.80	139.80	uPVC	
6	Arensi-Marley F300 Debris Trap (4 ")	2	20.00	4.50	44.50	uPVC	**Shopee** Website: https://shopee.com.my/4-UPVC-DEBRIS-TRAP-WHITE-FOR-F300-i.85266340.4439386343?sp_atk=4360c6b8-d32d-478b-a7ca-099bceeaa1d5

7	Downspout (4 " × 3 ft)	6	10.00	13.60	73.60	uPVC	**Shopee** Website: https://shopee.com.my/-3FEET-KAKI-36MM-43MM-56MM-82MM-110MM-3-FEET-UPVC-SWV-DRAINAGE-PIPE-PAIP-AIR-PVC-PUTIH-WHITE-UPVC-NO-SIRIM-i.143237163.11216101885
8	Elbow × 45 Degree (4 ")	4	10.50	24.30	66.30	uPVC	**Shopee** Website: https://shopee.com.my/uPVC-Fitting-4-100mm-Tee-Elbow-X-45-90-Degree-Socket-Class-SWV-Thin-Nipis-Grey-Pipe-Kelabu-uPVC-i.143237163.5732362654?sp_atk=b0901079-255c-458a-af94-c36be9b61679
9	Elbow × 90 Degree (4 ")	2	7.50	12.60	27.60	uPVC	**Shopee** Website: https://shopee.com.my/uPVC-Fitting-4-100mm-Tee-Elbow-X-45-90-Degree-Socket-Class-SWV-Thin-Nipis-Grey-Pipe-Kelabu-uPVC-i.143237163.5732362654?sp_atk=b0901079-255c-458a-af94-c36be9b61679
10	Arensi-Marley Downspout Bracket (4 ")	6	10.00	5.20	65.20	uPVC	**Shopee** Website: https://shopee.com.my/ARENSI-MARLEY-DN110MM-UPVC-DOWN-PIPE-BRACKET-HOLDER-(MALAYSIA-PRODUCTS)-i.143237163.5701424587
11	Circle Acrylic Plate (90 mm x 90 mm)	3	4.33	4.50	17.50	PMMA	**Shopee** Website: https://shopee.com.my/%E2%9A%A0Custom-Cut%E2%9A%A0-RM-1-200-Acrylic-Sheet-Papan-Perspek-%E4%BA%9A%E5%85%8B%E5%8A%9B%E6%9D%BF-Laser-cut-i.15583796.204096274

12	Solid White Round Stick (8 mm × 50 cm)	1	6.00	4.50	10.50	ABS	**Shopee** Website: https://shopee.com.my/ABS-Plastic-Solid-White-Round-Stick-Diameter-0.5-1-1.5-2-3-4-5-6-8-10mm-x-50cm-(length)-i.156706123.12238269472
13	Deluxe Polyethylene PeTank Round Type Water Tank Slim & Tall (318 ℓ)	2	146.00	100.00	392.00	Polyethylene	**Shopee** Website: https://shopee.com.my/Deluxe-Polyethylene-PeTank-Round-Type-Water-Tank-Slim-Tall--70-100-300-400-Gallon-Tangki-Air-Polietilena-Warranty-5-Year-i.10953511.9105669622?gclid=CjwKCAjwopWSBhB6EiwAjxmqDeXmUWMB1UOqnHcRhvExi6TBUGWWQFLFFGGpS1rdj9gGfXtdLSE3SRoC7bIQAvD_BwE
14	Ultrafiltration Membrane Flush System Water Filter With Faucet FULL SET (S-Ceramic + 7 Stage)	1	260.00	0.00	260.00	Plastic	**Shopee** Website: https://shopee.com.my/2021-NEW-MODEL-3-7Stage-7-in-1-Water-Dispenser-Ultrafiltration-Membrane-Flush-System-Water-Filter-With-Faucet-FULL-SET-i.341700963.6484352045?sp_atk=7c16dac5-38bc-41d8-b81a-a09b417000ea&xptdk=7c16dac5-38bc-41d8-b81a-a09b417000ea
15	Water Pipe (1/2 " × 1 ft)	6	1.20	4.50	11.70	uPVC	**Shopee** Website: https://shopee.com.my/YLK-%F0%9D%90%92%F0%9D%90%84%F0%9D%90%8B%F0%9D%90%8B-%F0%9D%90%81%F0%9D%90%98-%F0%9D%90%85%F0%9D%90%93-PVC-Pipe-Air-PVC-Kelabu-PVC-Water-Pipe-1-2-15MM-3-4-20MM-1-25MM-Class-D-Class-6-Class-7-i.93107041.9772598725?sp_atk=7714250e-b872-4f09-b31e-48ef9f43e82f

16	Tee Connector (1/2 ")	1	0.80	0.00	0.80	PVC	**Shopee** Website: https://shopee.com.my/YLK-PVC-PIPE-Fitting-15mm-20MM-25MM-Connector-Socket-Elbow-Tee-PT-Socket-Valve-Socket-End-Cap-Tank-Connector-etc.-i.93107041.9272809173?sp_atk=0e6fbce0-53ec-42d6-ab28-be570d0311b9
17	Feed Water Adapter 1/2 " to 1/4 " Ball Valve	1	9.90	4.50	14.40	Copper	**Shopee** Website: https://shopee.com.my/1-2-NPT-Male-to-1-4-OD-Tube-Feed-Water-Diverter-Valve-Adaptor-for-RO-water-filter-water-dispenser-Cuckoo-Coway-i.28162410.4279455469
18	White Hose (1/4 " × 10 m)	2	9.80	4.50	24.10	Low Density Polyethylene	**Shopee** Website: https://shopee.com.my/Water-Filter-(Taiwan-)1-4-RO-Tube-White-Tube-Hose-for-Water-Dispenser-i.34447039.5159595250
19	Tee Connector (1/4 ")	3	2.70	4.50	12.60	Plastic	**Shopee** Website: https://shopee.com.my/(VARIOUS-TYPE)-1-4-6MM-WATER-FILTER-ELBOW-SOCKET-TEE-VALVE-FITTING-JOINT-FILTER-CONNECTOR-FILTER-JOINT-CUCKOO-COWEY-PE-i.5053579.7647628059
20	Elbow × 90 Degree (1/4 ")	3	1.70	0.00	5.10	Plastic	**Shopee** Website: https://shopee.com.my/(VARIOUS-TYPE)-1-4-6MM-WATER-FILTER-ELBOW-SOCKET-TEE-VALVE-FITTING-JOINT-FILTER-CONNECTOR-FILTER-JOINT-CUCKOO-COWEY-PE-i.5053579.7647628059

21	Socket (1/4 ")	2	1.70	0.00	3.40	Plastic	**Shopee** Website: https://shopee.com.my/(VARIOUS-TYPE)-1-4-6MM-WATER-FILTER-ELBOW-SOCKET-TEE-VALVE-FITTING-JOINT-FILTER-CONNECTOR-FILTER-JOINT-CUCKOO-COWEY-PE-i.5053579.7647628059
22	End Plug (1/4 " × 5 pcs)	1	0.79	4.50	5.29	Plastic	**Shopee** Website: https://shopee.com.my/5-Pcs-1-4-Inside-diameter-Slip-Lock-connector-6mm-Reverse-Osmosis-Aquarium-Quick-Connector-End-Plug-i.154832782.4912956741
23	Water Bottle	16	13.90	9.60	232.00	Plastic + Stainless Steel	**Shopee** Website: https://shopee.com.my/%F0%9F%92%A7READY-STOCK-%F0%9F%92%A7350ml-500ml-Pet-CAT-DOG-HANGING-WATER-BOTTLE-No-Drip-Cage-Dispenser-Waterer-Feeder-Botol-Minum-Air-Kucing-i.11421388.7540962959
24	Concrete Block (300 mm × 300 mm × 125 mm)	8	9.00	80.00	152.00	Cement	**Shopee** Website: https://shopee.com.my/MR.-BUILDER-Times-Square-Ventilation-Block-Concrete-Block-Cement-Block-Breeze-Block-Batu-Blok-Garden-Deco-Blok-Simen-i.339707071.9312163917
25	Labour Cost and Others	2	250.00	44.17	544.17		
				Total	**2900.00**		

4.5 Water Sampling and Testing

The rainwater running off the office roof as shown in Figure 4.23 was collected in a clean glass container. Water quality tests were conducted for the collected rainwater and tap water separately by using the TDS & EC meter.

After that, the TDS for the collected rainwater and the tap water were obtained as shown in Figure 4.24. TDS for the collected rainwater was 1008 ppm while TDS for the tap water was 1044 ppm. Since the base reading started at 1000 ppm, the actual TDS for the collected rainwater and the tap water should be 8 ppm and 44 ppm respectively. Therefore, both of these waters were classified as good quality water because their TDS were less than 600 ppm.

However, the collected rainwater was a better option than tap water in this study. This was because the lower the TDS, the less minerals and salts in the water. In other words, the collected rainwater was almost pure distillate water. Due to its low mineral content, this water greatly reduced the possibility of causing corrosion to plumbing fixtures, pipes, and appliances. Most importantly, this showed that the collected rainwater did not contain any pollutants or chemicals that are harmful to cats. Therefore, it was safe for animals to drink the collected rainwater.

Figure 4.23: Office Roof.

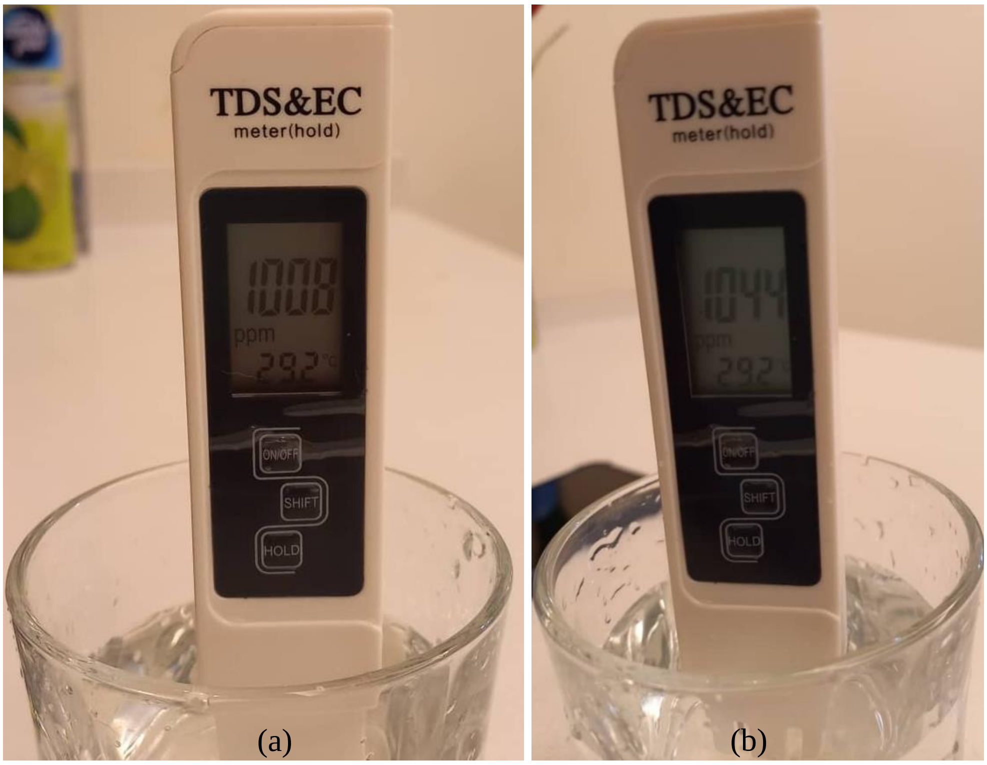


Figure 4.24: TDS for (a) the Collected Rainwater and (b) the Tap Water.

4.6 Summary

The incorporation of the RWHS in the IIUM Gombak campus had the potential to provide stray animals with sufficient drinking water throughout the year. This RWHS was highly reliable due to a series of detailed calculations, 3D modelling, price studies, water sampling and testing.

First, the calculated roof catchment area on one of the longer sides of the hipped roof was 16.97 m^2. The average rainfall intensity calculated for 20-year average recurrence interval and 5-minutes storm duration for this study area was 276.68 mm/hr. Based on these two calculated results, F300 k-style gutters were used in this RWHS because they met a minimum effective cross-sectional area of 5000 m^2. On the other hand, 4-inch round downspouts were used because they matched the size of the aforementioned gutters and met a minimum diameter of 85 mm. Then, Deluxe polyethylene tanks with a volume of 318 litres or 70 gallons were used in this study because they met the minimum tank size of 0.2 m^3. Therefore, this tank had water 99.9% of the time and was capable of meeting the cats' total daily water demand of 5.375 litres.

Next, this study chose to use a gravity-fed system because it was the cheapest and most environmentally friendly system. The entire RWHS was successfully installed on the office and the Greater Gombak Animal Shelter at a 1:1 scale in Solidworks. Then, this RWHS also included a 7-stages filter to ensure that the collected rainwater was safe for cats and kittens to drink. Overflow ports were also built to reduce the burden on this system. Meanwhile, mosquito breeding problems were prevented by designing a self-closing opening in the overflow port and using a sipper water bottle. This further secured the quality of the collected rainwater in this study. In addition, this RWHS was fitted with a special design that utilized hydrostatic pressure to supply filtered rainwater to three cages at a time by turning on the water faucet. Thus, this system was easy to use as it allowed any user to fill all sipper water bottles simply by turning the water faucet.

Furthermore, this RWHS also adapted to other situations. If the user wanted to use the filtered rainwater for other purposes such as hand washing or drinking, the white hose attached to the water faucet could be removed at any time. Rainwater also could be used to water surrounding plants during the dry season by removing the tank cover and scooping the water out. Moreover, this system was designed to be easily assembled and disassembled for easy cleaning and maintenance.

Last, the total cost estimated for this RWHS was RM2900 after including the labour cost and the shipping fee for each component. This total cost could then be used as a reference when obtaining quotes from outside contractors. Finally, the TDS for the collected rainwater and the tap water were obtained by using the TDS & EC meter. The actual TDS for the collected rainwater and the tap water were 8 ppm and 44 ppm respectively. This showed that the collected rainwater was a better option than tap water in this study. This collected rainwater not only reduced the possibility of causing corrosion but also contained no pollutants and harmful chemicals. Therefore, it was safe for animals to drink the collected rainwater.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Different types of RWHS available in the world have been studied in this paper. Up till now, there is still no study related to RWHS considering animals as their target consumer. Therefore, the design proposed in this study is pioneering in the world and is helpful to the animal organization's future planning.

The first objective in this study was to study different types of RWHS available in Malaysia. Different components of RWHS available in Malaysia, such as the catchment surface, the conveyance system and the storage system have been well-studied. There were two types of catchment surface, namely roof catchment surface and pond catchment surface. The conveyance system consisted of the gutter and the downspout. The gutter could be further divided into the k-style gutter and half-round gutter while the downspout could be further divided into the rectangular downspout and round downspout. According to the installation location, storage systems were divided into two categories: above-ground water tanks and underground water tanks. Therefore, these components were usually chosen according to the purpose and budget of the project since each of them had its pros and cons.

Then, the second objective was to calculate the quantity of the rainwater collected and stored for an animal shelter. In order to calculate the quantity of the rainwater stored, the minimum tank size required for this study was first determined. This was because the chosen tank size must collect enough rainwater on rainy days and meet 100.0% of the cats' daily water demand even when it was not raining. Thus, it was found that the quantity of the rainwater collected and stored for this animal shelter was 200 litres because the minimum tank size required was 0.2 m^3.

Next, the third objective in this study was to design a suitable RWHS for the animal shelter. The hip roof of the office adjacent to the animal shelter served as the roof catchment surface. After considering availability and cost-effectiveness, this study selected k-type gutters, round downspouts, and above-ground water storage tanks as components of the RWHS. Since the collected rainwater was used for animal drinking purposes, the cheapest and most environmentally friendly gravity-fed system was needed as a distribution system. A 7-stages filter was also installed to ensure that the collected rainwater was safe for cats and kittens to drink. Since there were many mosquito breeding problems in the study area, the overflow port was designed to have a self-closing opening. Meanwhile, sipper water bottles that were refilled using hydrostatic pressure also prevented the filtered rainwater from getting polluted. Finally, a 3D model of the entire RWHS system, including the office and animal shelter, was then drawn successfully at a 1:1 scale in Solidworks.

Last, the fourth objective was to evaluate the economic feasibility of the system. The total cost estimated for this RWHS was RM2900 after including the labour cost and the shipping fee for each component. This price was within a reasonable price range, so this system could be considered a long-term investment.

In conclusion, it was found that this study has reached all its aim and objectives. An animal-centric sustainable RWHS was successfully designed in this study.

5.2 Recommendations for future work

RWHS in this study mainly focused on the components it uses, such as k-style gutters, round downspouts, above-ground water storage tanks, and the gravity-fed system. The sizing methods for half-round gutters, rectangular downspouts, and underground water storage tanks can be further studied if needed for the design of RWHS. If the collected rainwater needs to be transported to the animals at a higher position, a direct-pumped system or an indirect pumped system will be chosen instead of the gravity-fed system. Then, another research has to be conducted on the design of the pumping system to determine the flow rate and horsepower required by the pump. In addition, the friction head losses for different pipes and fittings have to be studied because they will affect the pump head.

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