Effect of Different Roof Materials on Energy Savings and Carbon Dioxide Reductions for Rainwater Harvesting Systems

by

Rozanna Roslan
14859

Dissertation submitted in partial fulfilment of
the requirements for the
Degree of Engineering (Hons)
(Mechanical)

JANUARY 2015

Universiti Teknologi PETRONAS,
Bandar Seri Iskandar,
31750 Tronoh,
Perak Darul Ridzuan

Effect of Different Roof Materials on Energy Savings and Carbon Dioxide Reductions for Rainwater Harvesting Systems

by

Rozanna Roslan
14859

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL)

Approved by,

____
(Dr Mohammad Shakir Nasif)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2015

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ROZANNA ROSLAN

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

CHAPTER 2: LITERATURE REVIEW

CHAPTER 3: METHODOLOGY

CHAPTER 4: RESULTS AND DISCUSSIONS

CHAPTER 5: CONCLUSION AND RECOMMENDATION

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The rapid requirement to reduce treated water consumption has necessitated action in finding alternate sources to be taken throughout the nation. One of the actions taken by the Malaysian government is the promotion of rainwater harvesting techniques. Rainwater harvesting systems not only provide water savings to users, but with proper implementation reduce the amount of energy consumed which is required to treat water to make suitable for consumption and its carbon dioxide emissions. Many developers intend to implement the system however lack of design tool that will help to identify the total amount of savings provided by the system with the effect of using different roofing materials across different tank sizes. The aim of this paper is to design a tool that analyses the effect of utilizing different roof materials on the total water and energy savings, and carbon dioxide emission reduction on hourly water demands and rainfall values via mass balance calculations. The scope will cover commercial buildings; offices, hospitals and hotels. Based on the findings, slate tiles with a run-off coefficient of 0.9 are found to be the best roof material which can provide energy savings and carbon dioxide emission reductions of 2870 MJ and 830 kg in offices, 9925 MJ and 2875 kg in hospitals and 5629 MJ and 1631 kg in hotels with a payback period of 20, 13 and 16 years respectively when using a large tank that accommodates 5 times the total demand of the specific building.

ACKNOWLEDGEMENT

"In the name of ALLAH, The Most Gracious and The Most Merciful"

All praise and thanks are to Almighty ALLAH, the creator of all worlds for providing me the courage and perseverance to complete this work sincerely. May there be every peace and blessings upon the holy prophet Muhammad (PBUH), his family and his companions.

I would like to express my profound gratitude to Universiti Teknologi PETRONAS for giving me an opportunity to complete my Bachelor Degree in Mechanical Engineering. My deepest appreciation is to my final year project supervisor, Dr. Mohammad Shakir Nasif for his continuous support, encouragement and guidance throughout this research work. I gained a lot of knowledge while working with him and have been benefitted with his innovative ideas and advices. He was very kind to me, helping me to pass through the difficult phase of my final year project.

Special thanks to my father and sister for their patience, moral support and abundant prayers for my success. I also owe thanks and recognition to my fellow course mates, colleagues and friends for their motivation and support. It would be difficult to name them all, but each one of them plays an important role in supporting me continuously from the beginning till the end.

CHAPTER 1

INTRODUCTION

Extensive effort has been adopted by the government of Malaysia to promote sustainable development via Green Buildings. Green Buildings are defined as energy saving premises, as the building may reduce its energy consumption and generate its own to produce a near zero energy usage. A Green Building focuses on increasing the efficiency of resource use while reducing building impact on human health and the environment during the building's lifecycle, through better design, construction, operation, maintenance, and removal. Green Buildings should be designed and operated to reduce the overall impact of the built environment to the surroundings. There are several criteria that are counted when designing a Green Building which is divided into energy efficiency, indoor environmental quality, sustainable site planning and management, material and resources, water efficiency and innovation. Any buildings that comply with the pre-mentioned criteria are worthy of applying a Green Building certificate, which may boost the property value. Among all the criteria, one has been given extra attention due to its rapid declination of its source, which is the water efficiency. Natural water resources such as spring water, rivers and underground sources have been depleting rapidly with the additions to population growth and water demands (Villatreal, 2004). Water is an essential element that is needed by every living being not only for consumption purposes, but for sanitation essentials as well. Even though man knows of the importance of water, its value is normally taken for granted as it is being used wastefully. Taking for example a national recurring incident where in several states mainly Selangor; faces critical water crisis each year due to excessive and wasteful use of water by residents in that area. According to reports by a local newspaper, the water supply in peninsular Malaysia in 2050 will decrease approximately by 3000 m^3 per year (Mak, 2014). This assumption is based on the study that showed Malaysians use 226 liters of water per person in daily basis which makes it among the highest among countries in Southeast Asia. The recommended daily limit for Malaysians is only 165 liters of water per person daily. From the findings, 70% of Malaysians used more water than required and 70% from that figure do not intend to change the current water usage habit (Choong, 2011). As the reduction of clean water sources is mainly becoming an issue, techniques on producing own supplies are researched.

Green Buildings are suggested to achieve water efficiency via rainwater harvesting systems. Rainwater harvesting system is seen as one of the cost effective alternative sources since rainwater does not require heavy treatment processes especially if it is to be used for non-potable uses such as irrigation and toilet flushing (Plappally, 2012). The system works by harvesting or collecting rainfall over a particular area normally the roof of a building, and storing the runoff for domestic use which will lead in the reduced demand for clean water supply and hence reduce water shortages. There are several basic components required for installing rainwater harvesting systems which are the catchment area, specific gutters or downspouts, storage tank and the water delivery system in which water is to be delivered to the required areas using pumps. In cases of costings, the rainwater tank is deemed as the largest impact to the matter and hence an optimal sizing should be done prior to building the system. Figure 1.1 demonstrates a setup of rainwater harvesting system tank incorporating the water balance model and all of its components.

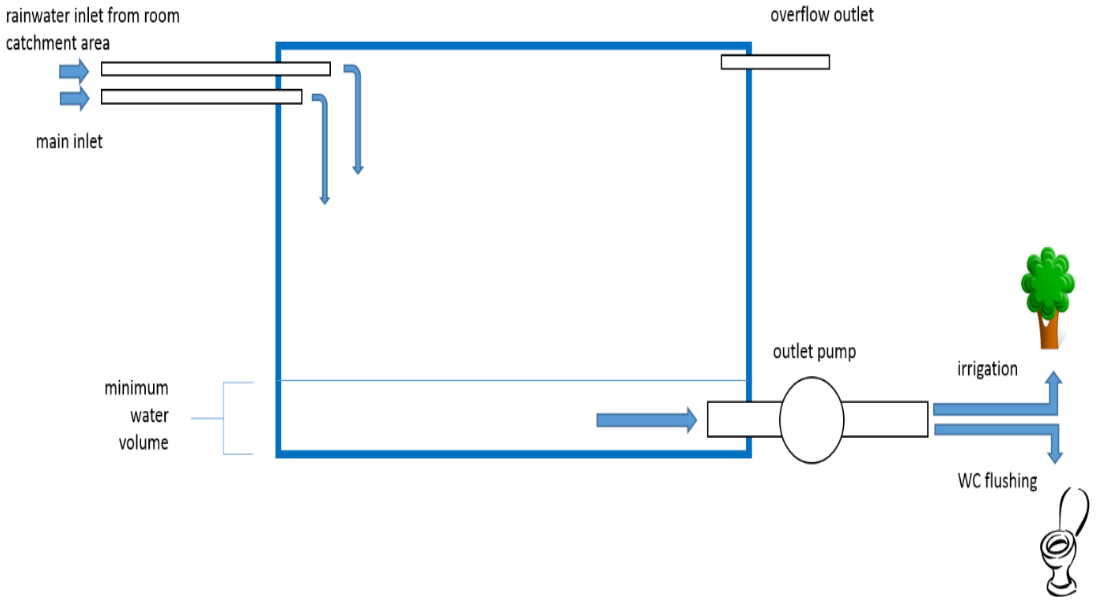


Figure 1.1: Components of rainwater harvesting system.

1.1 Problem Statement

The main water crisis are at this time arising in Malaysia is the shortage of clean water supply. Logically, increase in urbanization will cause a higher water demand from natural sources that are depleting drastically. Luckily, there has been a common solution to the problem; Rainwater Harvesting Systems (RWHS). The system is deemed to help reduce the amount of water demand from natural sources by harvesting of rainwater and using it for specific purposes such as irrigations, toilet flushing or washing of clothes. Since Malaysia has officially announced the importance of RWHS to society, the system has been gaining popularity especially among developers. There are many components to the system such as the catchment area size and material, and the tank size. In order to facilitate the design process, it is wise to have a tool that can help identify the effects of using several different roof materials on the total water savings, energy saving and carbon footprint reductions and the financial feasibility of installing RWHS. Current tools available in the market mostly display the financial feasibility of RWHS after the user inputs desired factors instead of displaying comparisons of different component possibilities.

1.2 Objectives and Scope of Study

The main objective of this project is to develop a tool that models a RWHS tank to analyse hourly water demand profiles in commercial buildings using mass balance calculations. The objectives are then segregated into smaller sub objectives where the tool developed will identify the following;

- Design, selection and sizing of the system;
- Effects of using different roof materials on the total savings by the system. There are three types of savings; volume of water from main supply, energy required to treat water from main supply, and carbon dioxide emission reduction; and
- Financial feasibility of utilizing the system across different tank sizes

The scope of study for RWHS must first consider the amount of water demand of a commercial building; given office, hospital and hotel premises in terms of toilet flushing, urinals and irrigation purposes per hour daily. Since the system is modelled in a building that is located in Shah Alam, rainfall data is obtained from the Metrological Department of Malaysia in terms of hourly values. The data is to cover for a whole year of 2013

Assumptions that are required are the reduced amount of total collected rainfall volume due to roof runoff coefficients, specifically for slate tiles, concrete tiles, concrete blocks and gravel roof material. The tank is also required to have a sensor that enables detection of total volume less than 20% of the tank which alerts the system to add water from main supply to at least 30% of the total tank size. In terms of energy and power requirement calculations, pump start-up and operations and energy used to treat the rainwater if required will be considered. At the end of the project, the total costing of the RWHS is also included but limited to the tank with different sizes, piping, pump and annual maintenance and treatment plant operating costs.

CHAPTER 2

LITERATURE REVIEW

2.1 Optimal Sizing of RWHS Tank

One of the most important components for the RWHS is tank and its size. This is because it may be the biggest contributor in the overall costing as the price varies with size. Hence, in order to determine the perfect amount of investment of the system, the tank size must be optimized to meet all requirements. Such requirements are meeting the daily total water demand, ability to store more than the requirement and reduced amount of overflow by tanks since this will cause wastage in harvested rainwater.

In the case of large roofs, Imteaz (2011) developed a spreadsheet that uses the basis of daily water demand by using rainfall data, roof area, rainfall loss factor and available storage volume for irrigation purposes in commercial buildings in Melbourne, Australia. They simulated two underground tanks of different sizes; 180 m^3 and 110 m^3 in which both of the effectiveness are analysed under different roof conditions. They concluded that the tanks were effective in wet and average years and less effective during dry years. A simple net present value pay back was also considered for estimating the cost of the overall system where they found the system requires 15 to 21 years of operation. They payback period relied on the tank size, climate and fluctuation in price of water. Some of the limitations in their paper was it needed a more detailed optimization in which the tank will be sized according to the demand and the way the demand was calculated, which is a daily basis.

In a study conducted by Matos (2013), they assessed the feasibility of RWHS tanks in commercial buildings using the simple method and Rippl method. The Rippl method is found to be more accurate however may compromise the results of the reservoir capacity due to the coarse time discretization. They concluded that RWHS are best of use in irrigation purposes, than of use indoors. The Rippl method was developed by Tomaz (2003), to help determine the necessary data required to size the rainwater storage tank. As concluded by Matos, larger time discretization of data will lead to inaccurate optimized tank sizing such as use of annual, monthly or even daily rainfall values. Similar studies regarding investigation of the tank sizing typically uses monthly values of rainfall data such as carried out by Imteaz, Matos, Farreny (2011), and Hashim (2013). This is the main limitation in most studies present as the results obtained may be compromised due to the time factor of data.

Most RWHS are modelled for residential use, such as those conducted by Fewkes (1999) and Hashim (2013) which give less attention to commercial buildings implementations. Fewkes (1999) managed to develop a model which provides size estmation of the desired rainwater storage tank to meet certain requirements of fixed roof areas and water use patterns. Investigations in spatial and temporal fluctuations in rainfall incorporation into behvioural models were conducted to identify the efficiency of the rainwater cathment area. He conducted the study on residential rainwater ahrvesting tanks in United Kingdom. One disadvantage to his findings was the coarse time discretezation of using daily and monthly values to obtain the curves.

Hashim (2013) on the other hand optimized the storage tank size by using water balance models that were paired with sensitivity analyses for usages with large scaled roofs of 20000 m^2. The water balance model comprises of a simple generation of a spreadsheet to analyse the total amount of water entering and leaving a tank with given parameters, in this case the water profile. The sensitivity analysis was used to identify the parameters that will bring large effect to the total amount of rainwater collected. Variables of the roof size and water demand were increased annually, to meet the demands of the residents. He found that a suitable storage tank size to meet a demand of 200 residential units was 160 m^3 with a 60% reliability. He also concluded that the system would require 25 years for a payback, and that a large roof cathment are will lead to a better overall rainwater harvesting efficiency.

In a different study conducted by Campisano (2012), an optimal design for the rainwater harvesting system via demensionless methodology was achieved. The study was carried out on 17 different areas in Italy, focusing on domestic purposes. The dimesnionless parameter allowed an improved description on the rainfall pattern which included ratios of storage fraction and demand fraction. They also demonstrated a payback period with application to the dimensionless model across daily time steps of rainfall. The demand usage was focused on non-potable use, specifically for toilet and urinal flushing.

The probablilistic approach on the other hand was carried out by Lee (2000), by adopting sequential peak analyses and failure probablity in their analytical procedure. The study was conducted in Taiwan, and the demands were focused on cistern usages for tea cultivation or irrigation. They optimized the tank size by considering the rainwater abstraction coefficient, ratio of cultivated area to rainwater collecting area and failure probability. The system was analysed based on rainfall data of 40 years. The major gap in this paper is the analysis used annual values of rainfall which may reduce the efficiency of the system.

2.1 Roof Materials and Run-off Coefficient

Materials of the catchment area, normally the roof of the building are one of the most important factor in determining the harvested quantity and quality. Based on CIBSE (2011), there are two factors to designing a good catchment area which are the material and angle at which it is placed. Larger inclinations smooth roofs will increase total quality and quantity of rainwater collected when compared to flat roofs. The smooth roofs that are found to have a runoff coefficient 0.9 are known to reduce the total amount of spillage, evaporation and better surface wetting (Singh, 1992). Some of the better materials for roofing are identified to be slate or concrete tiles due to their smoothness and ability to channel water into the tank based on CIBSE Reclaimed Water Knowledge Series Guide (2011).

In a study conducted by Zhang (2014), they analysed the quality of water using different roof materials of asphalt, ceramic tiles and green roofs in China. They found that the best quality of harvested rainwater came from ceramic roofs due to low leeching pollutants, which revealed the importance of proper roof material selection when applying the system, which also meant more rainwater capture. They also claimed that the total run-off was less in summer and autumn compared to winter and spring. This is due to larger amounts of rainfall during winter and spring, hence less roof pollution.

Farreny (2011) on the other hand analysed four types of roof which three of them were sloping; clay tiles, metal sheet and polycarbonate plastic and one flat gravel roof. He analysed the quality and quantity of the rainwater captured in Spain. He concluded large roof run-off coefficients are provided by smooth sloping roofs with values more than 0.9, and may harvest 50% more rainwater compared to coarse and flat roof of coefficients of only 0.62.

The roof run off coefficients of different roof shapes were carried out by Liaw (2004), with four roof types; inverted-V, level cement, parabolic and saw tooth shapes. Inverted-V roofs also known as sloping roofs were stated to have the highest run-off coefficent of 0.84 compared to the lowest shown in level cement and parabolic roofs with only 0.81. They found that using iron roofs provide more rainwater harvested compared to cement roofs due to high smoothness and low porosity levels.

Comparison of different roof materials on the quality of roof-harvested rainwater was also conducted by Lee (2012), in South Korea. They compared pilot-scale roofs that were constructed with wooden shingles, concrete and clay tiles and galvanized steel roofs. All of the roofs were at an angle of 20.5° from the horizontal and having a catchment area size of 2.55 m^2. They found that galvanized steel roofs provide the best run-off in terms of quantity and quality, as it met the Korean drinking water standards. The same conclusion was met by Mendez (2011), which compared asphalt fiberglass singles, metal, concrete tiles, cool and green roofs in Austin, Texas.

2.3 Energy Consumption and Carbon Emissions of RWHS

RWHS existed long time ago in Malaysia, especially in rural areas where a supply of sanitized water is scarce. The rainwater collected during that time is normally used for non-potable purposes such as washing clothes, dishes or even for watering of plants. However, with technological advancements today, the harvested rainwater can be treated up to a level that is safe for consumption. This process however raises a lot of disputes whether it is adding to the usage of energy and a higher carbon footprint due to carbon dioxide emissions (Parkes, 2010). However, total amounts of energy to treat water from main supplies are typically unaccounted for, in which a replacement of specific untreated rainwater volume with water from the main supply will provide users with energy savings. The sub-systems that mostly require energy are the treatment; depending on the quality of water needed the storage volume and location of the tank and the pump requirements and specifications (Vieira, 2014). Specific values of energy required to treat water from main supplies has been identified to be 0.8kWh/m^3 of water, and shall be accounted for in this paper (Plappally, 2012).

Vieira (2014) claimed that the median energy intensity for rainwater harvesting systems was 0.2 and 1.4 kWh/m^3, provided that the harvested rainwater requires treatment for potable use, and which are found to be much higher than that of centralised water treatment plants. The energy intensities rely on the pumps required for the system and the point to which requires treatment. The relation was established via the water-energy nexus, which has now been a main consideration in water planning. In cases where water is used for non-potable demands such as toilet flushing, the energy intensity is estimated to range between 0.14 and 0.57 kWh/m^3 daily, where 0.05 kWh/m^3 is used for active pumping, 0.01 to 0.03 kWh/m^3 for start-ups and 0.08 to 0.48 kWh/m^3 with standby power. He found that lower rainwater demand, the higher the energy intensity as rainwater can provide savings for the system.

Chiu (2009) estimated the total amount of energy savings in residential units after implementation of RWHS. He theorized energy intensity as 0.06 kWh/m3 for RWHS and 3.25 kWh/m^3 for the centralised town water supply in Taipei, Taiwan. However, the energy intensity of start-up consumption was underestimated which had compromised the concluded values. Even so, they managed to provide insight regarding achieving low energy intensity systems by using header tanks and optimized pump sizes and scheduling.

In another study conducted in the UK by Ward (2011) calculated the energy intensity of rainwater pumping systems by determining the relation of total energy consumption and total rainwater consumption in a period of time. She estimated that by considering start-up power of pumps, the intensity of RWHS will increase from 0.32 kWh/m^3 to 0.54 kWh/m^3. Carbon dioxide emissions on the other hand are found to be a factor of 1.04kg/kWh energy usages, where the energy focuses on the energy required to treat water from the main supply. In the study conducted by Ward (2011), estimated amounts of carbon dioxide emissions were calculated using assumed values of water demand, and not that of calculated values.

In these terms, this paper is assesses that gap by combining energy consumption and carbon emission calculations with a proper water demand tool by applying finer time discretization across hourly water demand profiles. In order for proper assessing of the total energy used by the system, all components that require energy consumptions are to be taken into account, which in this case is the energy required to treat centralized town water before channelling it to end use (Plappally, 2012).

CHAPTER 3

METHODOLOGY

3.1 Process Flow Chart

The process flow of work for the project started off with the selection of the title which is Rainwater Harvesting Systems and Energy Savings in Green Buildings. The topic selection was done based on the problem identification, which is the current depletion of clean water sources in Malaysia and inadequate tools to design the system. This includes literature review of the rainwater harvesting system and also some of the existing designs readily available. To ensure a reliable system design, a set of standards and design codes are to be followed. Such design guides applied to this project are the plumbing design system given by the Institute of Plumbing (2002) and the CIBSE Public Health Guide (2004). Once the standards have been analysed, an establishment of the project requirements is done. This is the requirements of the type of building, selection of size and also the energy requirements of the system. Once baseline requirements according to standards have been formed, the spreadsheet is to be developed in Microsoft Excel, as that given in the following chapter. As the project calls for a more specific data interpretation, hourly rainfall data is to be inserted in the spreadsheet and further analysed. This will give a more realistic version of existing tank optimization tools due to its smaller time discretization. To allow better analysis of the project, assumptions such as the amount of water demand per hour and the total amount of water runoff are to be included to be considered a detailed design of the spreadsheet.

The model is to be conducted using Excel once all data and assumptions have been included. This enables analysis of the water and energy savings given by the system. Any changes in the results once the input data such as catchment area, type of building and number of staff are to be recorded. All results are then concluded and a final recommendation is to be given for future improvement of the project.

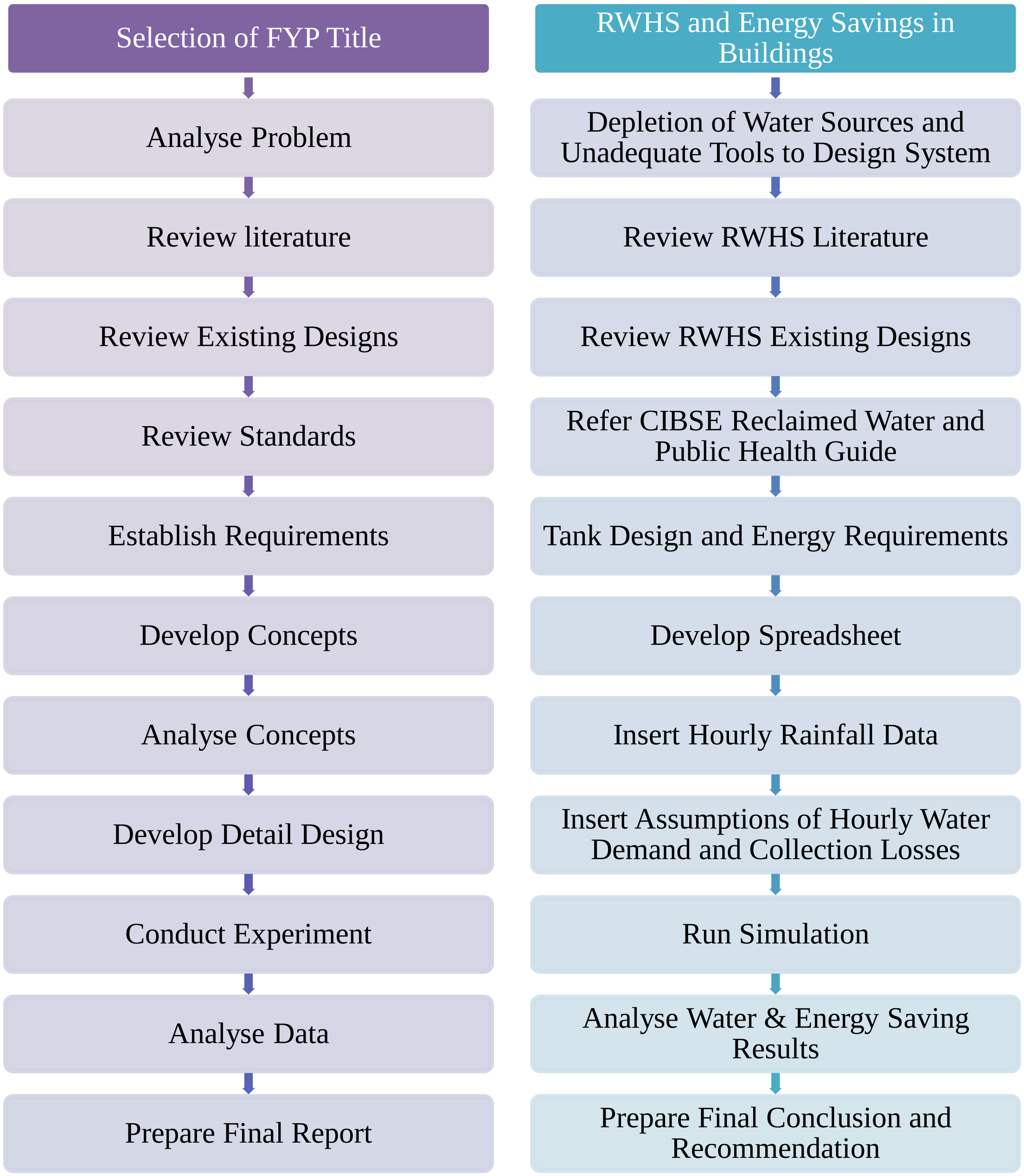


Figure 3.1: Process methodology flow chart.

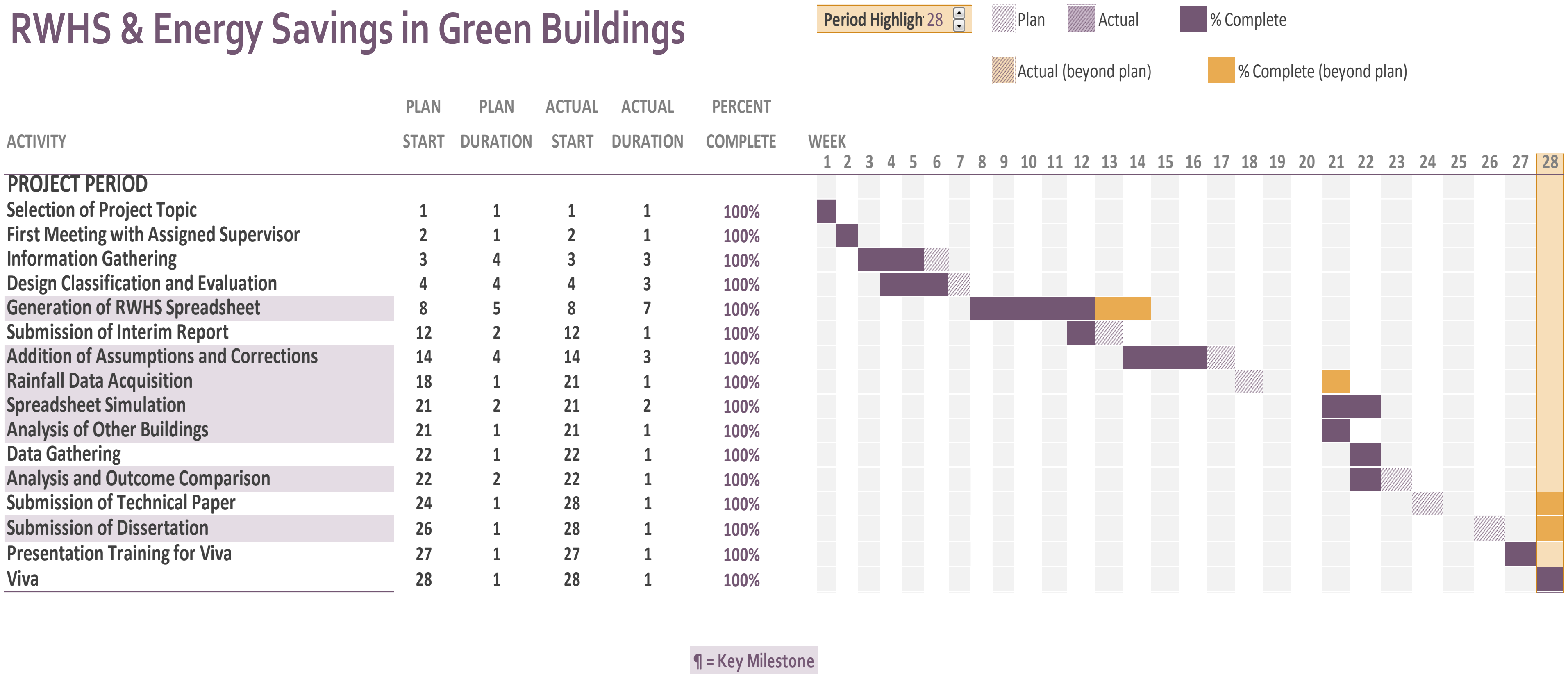
3.2 Key Milestones

Key Milestones	Generation of RWHS Spreadsheet
	Addition of Asumptions and other Corrections
	Rainfall Data Acquisition
	Spreadheet Simulation
	Analysis of other Buildings; Hospitals, Hotels
	Analyse and Compare Outcome
	Submission of Project Dissertation

Based on the Gantt chart in Figure 3.2, there have been several key milestones that are identified specifically for this project. Key milestones are important as they act as indicators to which the project may continue its progress. The main key milestones initially identified are generation of the spreadsheet via Excel and Visual Basic, addition of the assumptions and corrections such as water demand profile, spreadsheet simulation, analysis on other buildings such as hospitals and hotels, analysis and comparison of the outcome and finally the project dissertation submission.

Different from the initial final year project plan, another key milestone has been added which is the rainfall data acquisition. This is because without the data, the spreadsheet is unable to be completed and no simulation can be conducted to analyse such results, causing a halt in the project progress. Hence it has been identified as one of the key milestones for the project.

3.3 Gantt Chart



RWHS & Energy Savings in Green Buildings

Period Highlight: 28

▨ Plan ▨ Actual ■ % Complete

▨ Actual (beyond plan) ■ % Complete (beyond plan)

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
PROJECT PERIOD					
Selection of Project Topic	1	1	1	1	100%
First Meeting with Assigned Supervisor	2	1	2	1	100%
Information Gathering	3	4	3	3	100%
Design Classification and Evaluation	4	4	4	3	100%
Generation of RWHS Spreadsheet	8	5	8	7	100%
Submission of Interim Report	12	2	12	1	100%
Addition of Assumptions and Corrections	14	4	14	3	100%
Rainfall Data Acquisition	18	1	21	1	100%
Spreadsheet Simulation	21	2	21	2	100%
Analysis of Other Buildings	21	1	21	1	100%
Data Gathering	22	1	22	1	100%
Analysis and Outcome Comparison	22	2	22	1	100%
Submission of Technical Paper	24	1	28	1	100%
Submission of Dissertation	26	1	28	1	100%
Presentation Training for Viva	27	1	27	1	100%
Viva	28	1	28	1	100%

¶ = Key Milestone

Figure 3.2: Project Gantt chart.

3.4 Model Development

Proper spreadsheet execution requires crucial information that is to be obtained from the user such as those stated below:

Table 3.1: Input variables required from user.

Variable	Breakdown
Building Information	• Specific building type • Gross floor area • Number of floors • Number of occupants • Roof type
Irrigation Information	• Landscape areas o Trees o Shrubs o Grass
Rainwater Harvesting System	• Catchment area size • Storage tank capacity • Pump capacity

Based on the information provided by the user, the total amount of water demand will be paired with the hourly rainfall values to obtain the total amount of water savings given by the system. The Metrological Department of Malaysia has provided information such as the average temperatures, maximum temperatures, humidity, precipitation, and wind speed for each day of a year. For the purposes of this study, data of hourly rainfall values, the average temperature and humidity of the area is required. Hourly rainfall values is provided in millimetres of rainfall over a specific area, hence to obtain the volume of rainfall collected, the amount of rainfall in mm is to be multiplied with the rainfall catchment area, which is normally given in meters. It is important to note that the units of rainfall and catchment area are not similar; hence the value of rainfall is to be divided by 1000.

$$V_{collected} = V_{rainfall} * A_{catchment} * rc \quad m^3 \qquad (1)$$

Where

$V_{collected}$ = Water collected from the roof
$V_{rainfall}$ = Total amount of rainfall
$A_{catchment}$ = Area of catchment area
rc = Roof run off coefficient

The catchment area of the building will be user specified, where it the variable shall be used to identify if there are any effects on the catchment area size to the overall water savings. The roof coefficients are taken from CIBSE: Reclaimed Water guide study where they compared different roofing materials to obtain the different coefficients. The summarized values are given in the table below:

Table 3.2: Different roof types with different coefficients. (CIBSE, 2011)

Roof material	Run off coefficients, rc
Slate tiles	0.9
Concrete tiles	0.8
Concrete blocks	0.6
Gravel	0.25

Water demand for the purpose of this study can be further divided into two purposes, human usage and landscape irrigation. Human demand for water can be obtained specifically for offices, hospitals and hotels as given by the Institute of Plumbing Engineers adapted table below:

Table 3.3: Human demand for specific commercial buildings. (Institute of Plumbing, 2002)

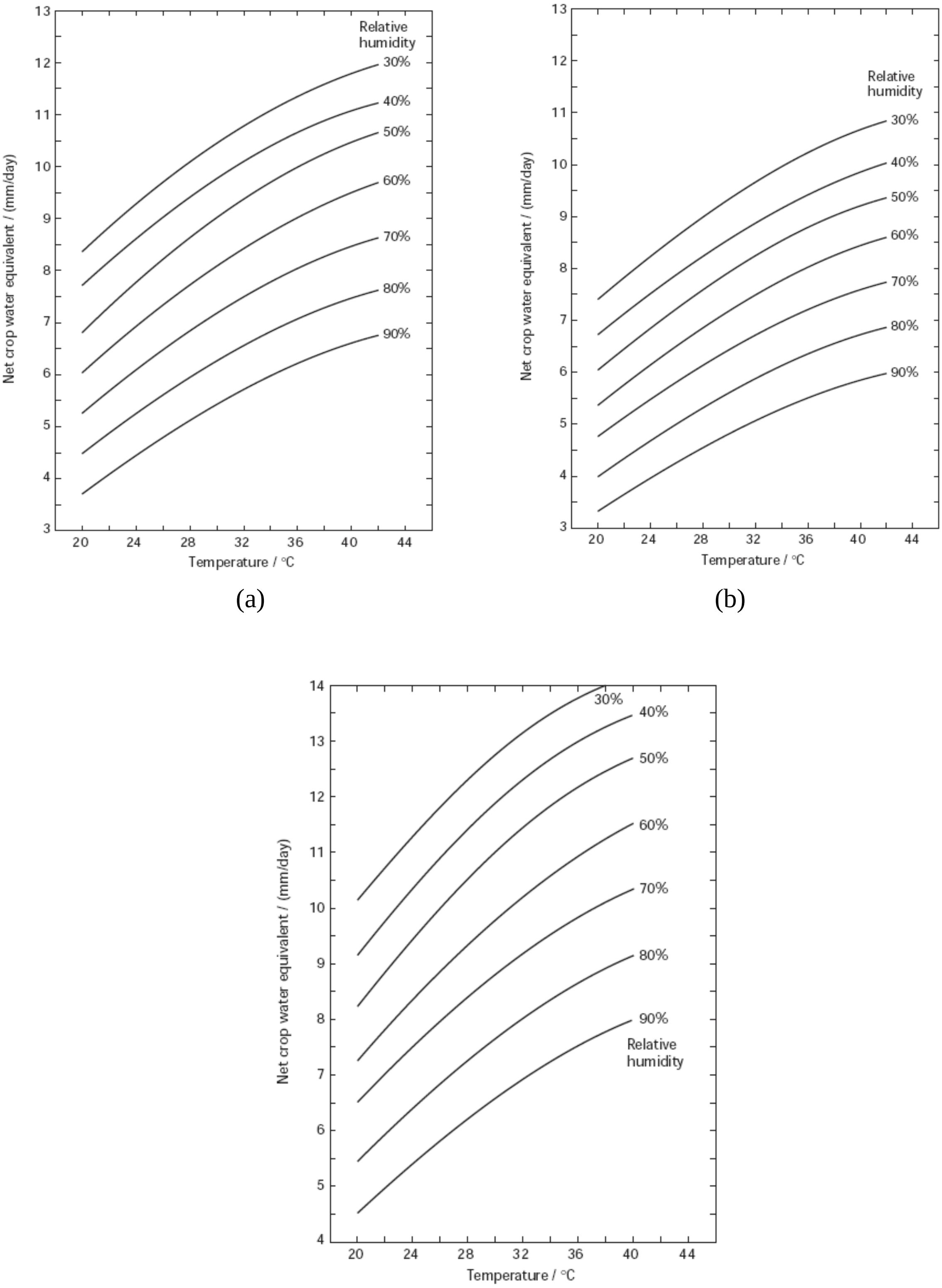
Type of Building	Litres	Criteria / Unit
Offices & General Work Places		
With canteen	45	Person (1)
Without canteen	40	Person (1)
Hospitals		
District General	600	Bed
Surgical Ward	250	Bed
Medical Ward	220	Bed
Paediatric Ward	300	Bed
Geriatric Ward	140	Bed
Hotel		
Budget	135	Bedroom
Travel Inn/Lodge	150	Bedroom
4/5 Star Luxury	200	Bedroom

The value given in the above table is the overall water demand. This includes for all types of use in a building such as toilet flushing, baths, sinks, outside supplies and others. In order to obtain specific values of human water demand such as those required in this project i.e. toilet flushing, a certain percentage is to be multiplied to the previous overall human water demand requirement. The percentage values for specific usages are given in the Table 4.4 below by CIBSE Public Health Guide (2004).

Water demand for irrigation on the other hand requires manipulation of charts for specific landscape elements such as trees, shrubs and grass. Water demand is determined by identifying and interpolating temperature and humidity of the specific area required onto the chart. In this analysis, the maximum temperature is taken to obtain maximum water demand for a given plant. The charts for water demand of trees, shrubs, and grass are also given in the CIBSE Public Health Guide G as seen below.

Table 3.4: Human water demand breakdown. (Institute of Plumbing, 2002)

Usage	Percentage (%)
WC Suite	32
Washing Machine	12
Kitchen Sink	15
Bath	15
Basin	9
Shower	5
Outside Supply	3
Miscellaneous	9



(a)

(b)

(c)

Figure 3.3: Daily water demand for (a) trees (b) shrubs (c) grass. (Institute of Plumbing, 2002)

Since the values of water demand given in the figures are of millimetres, the concept is still similar in terms of calculating the volume of rainfall whereby the values are to be multiplied with area of irrigation. The area of irrigation is obtained from analysing the layout given by the architect. Simple assumptions of the area is done and used. The volume of water demand for irrigation is given below:

$$V_{irrigation} = V_{irr\_req} * A_{irrigation} \quad m3 \qquad (2)$$

Where

$V_{irrigation}$ = Water required for irrigation
V_{irr_req} = Net crop water equivalent (from Figure 3.3)
$A_{irrigation}$ = Area for irrigation

To ensure a more accurate estimation of the water usage for both human demand and irrigation, an hourly water demand profiles will be factored to the overall water demand values (Aquacraft Inc., 2011). Each building specification has different profiles across time and can be shown in Figure 3.4.

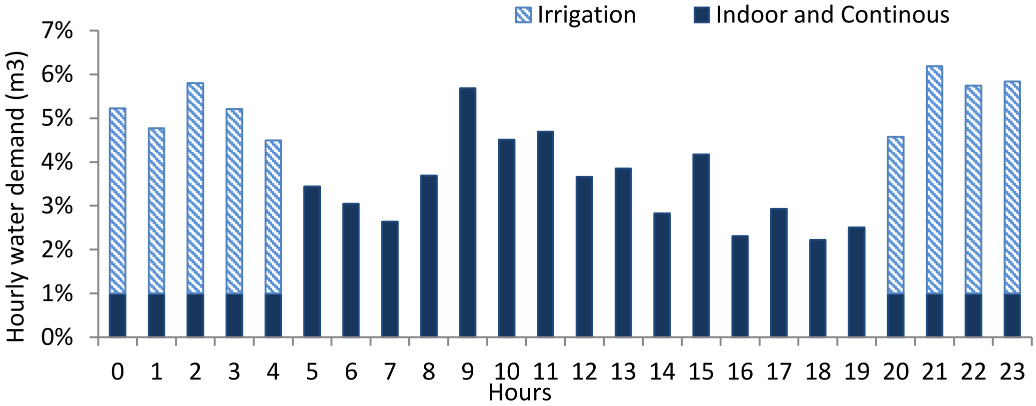
Water demand for both humans and irrigations are the core for the development of the spreadsheet. The volume of tank is the next element to be determined. The tank volume should be more than the total human and irrigation water demand to ensure that enough water can be supplied during crises. For initial purposes, the tank is assumed to be at full volume as this will ensure that there is a cumulative amount in the tank.

The required amount from the main supplied can be determined as follows:

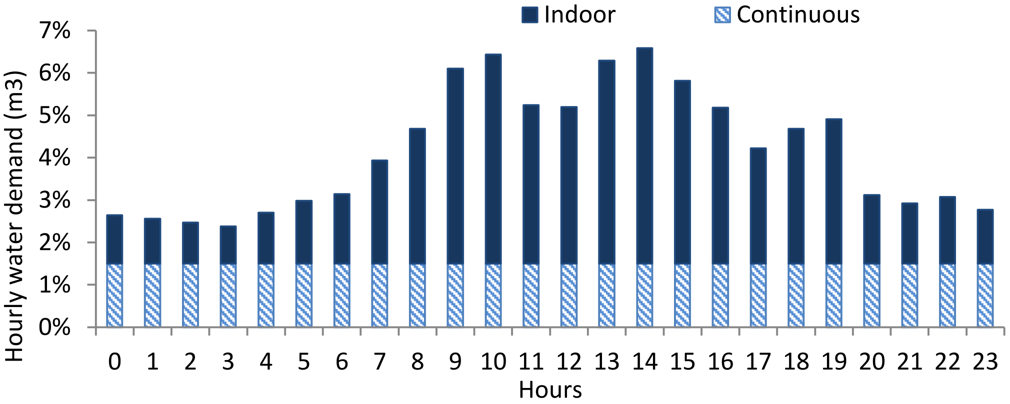
$$V_{req} = V_t - V_{const} - V_{collected} \quad m^3 \qquad (3)$$

Where

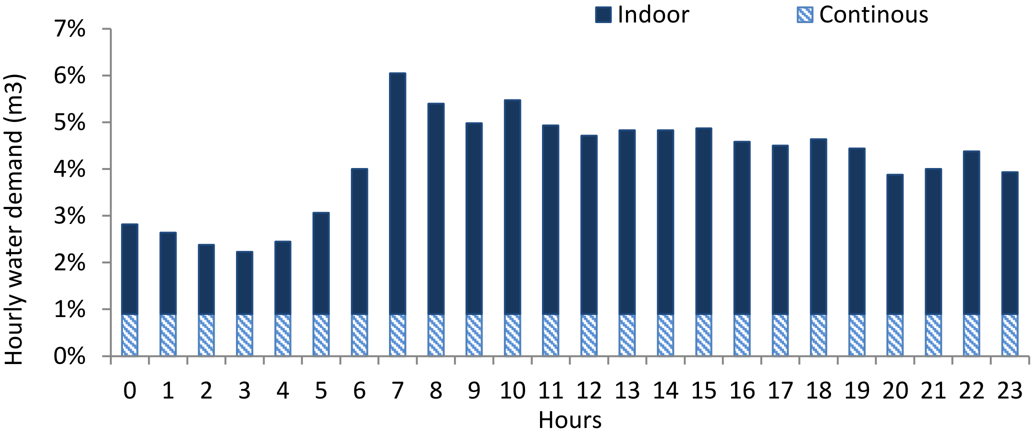
V_{req} = Water required from main supply
V_t = Total water demand
V_{const} = Constant current value in tank
$V_{collected}$ = Rainfall collected



(a)



(b)



(c)

Figure 3.4: Disaggregated hourly water demand profile for (a) offices (b) hospitals (c) hotels. (Aquacraft, 2011)

The constant amount of water in the tank is a minimum of 20% of the tank volume V_{tank}, which is given by the CIBSE: Public Health Guide G (2004). This is to ensure that a significant portion of the water demand can be met in case of water shortages, denoted by V_{const}. Another crucial reason is that a pump requires some volume of water in a specific region to avoid damage. If air is to enter the pump, it will cause damage and hence ruin the channelling of the system. This means that with conditions of tanks less than 20% its volume, water from main supply will top up or become V_{req_add} as shown in the equations below:

$$\text{If } V_{const} < 0.2V_{tank} \text{ after usage} \tag{4}$$

$$\text{Then } V_{req\_add} = V_{req} + V_{const} \tag{5}$$

The cumulative value of water in the tank V_{cum}, on the other hand is the addition of rainwater balance collected V_{bal} and the extra water from the main if the minimum volume of 20% is not met after the water demand is met. Hence we can compute that:

$$V_{cum} = V_{const} + V_{bal} \tag{6}$$

Overflow on the other hand can be denoted by V_{over} and can be computed using the following formula and logic:

$$\text{If } V_{cum} > V_{tank},\ V_{over} = V_{cum} - V_{tank} \tag{7}$$

whereas

$$\text{If } V_{cum} < V_{tank},\ V_{over} = 0 \tag{8}$$

Water overflow can help determine the amount of rainwater wasted and help adjust the volume of the tank, if it is desired.

Once the total hourly demand and tank size has been established, the basic programming of the spreadsheet can be initiated. The program flowchart based on the total water demand can be determined based on Figure 3.5 below:

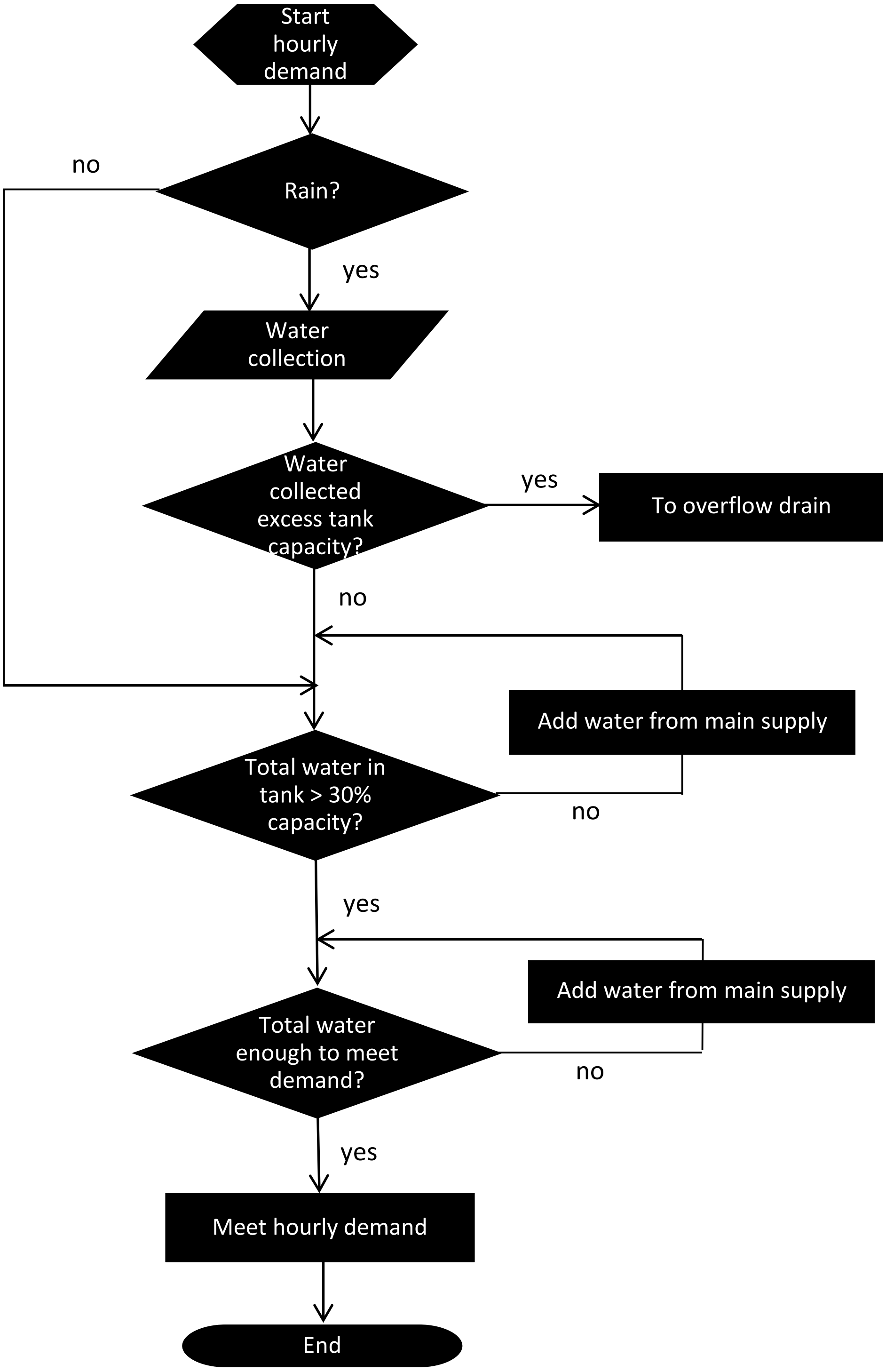


Figure 3.5: Program logic flow chart.

3.5 Cost Analysis

Annual water usage costs are to be determined by obtaining the value of yearly water from main supply needed after implementing the rainwater harvesting system and multiplying it with the water tariff. The water tariff is different for each building hence it is important to determine the owner and type of building that will be used. For example, government buildings have lower tariffs compared to commercial building rates due to subsidies. The lower tariffs also apply to electrical costings, which are used to calculate the amount of electricity used to treat the water from the main compared to no treatment of the harvested rainwater. This is done by multiplying the amount electricity required to treat the water from main with the electricity tariff. The amount of water compared is the total amount of water required for the building against the building having the rainwater harvesting system.

Costs of tanks and pumps on the other hand can be obtained from local stores in based on their sizing and capacity that was earlier determined in the spreadsheet. Once the specifications are determined, average costs of a concrete tank and indoor pump of the particular capacity is matched with a price given by a supplier.

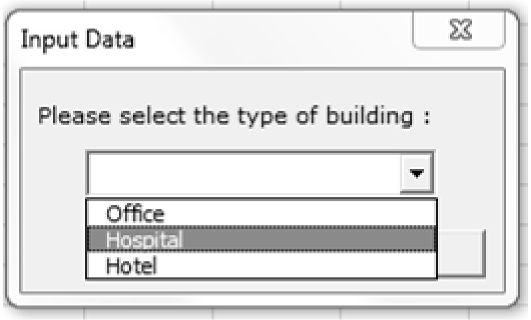
The final aspect of costing to be included is the piping, which is determined based on the size and type of the building, as given by the Rawlinson New Zealand Construction Handbook (2011). Buildings of different heights and requirements have different types of piping specifications. For example, hospitals have larger piping costs due to its need of different piping lines i.e. hot and cold water channels. The summarized costing of sanitary plumbing is as stated in Table 3.5.

Table 3.5: Estimated building piping cost. (Rawlinson, 2011)

Building Type	Breakdown	Pipe Costing, RM/m^2
Office	3-5 Storey with Air Conditioning	175
	6-15 Storey with Air Conditioning	288
Hospital	Private Multi-storey	633
	General Multi-storey	431
Hotel	3-4 Star	653
	4-5 Star High Rise Hotel	779
	Basic Motel	347

3.6 Microsoft Excel Visual Basic Addition

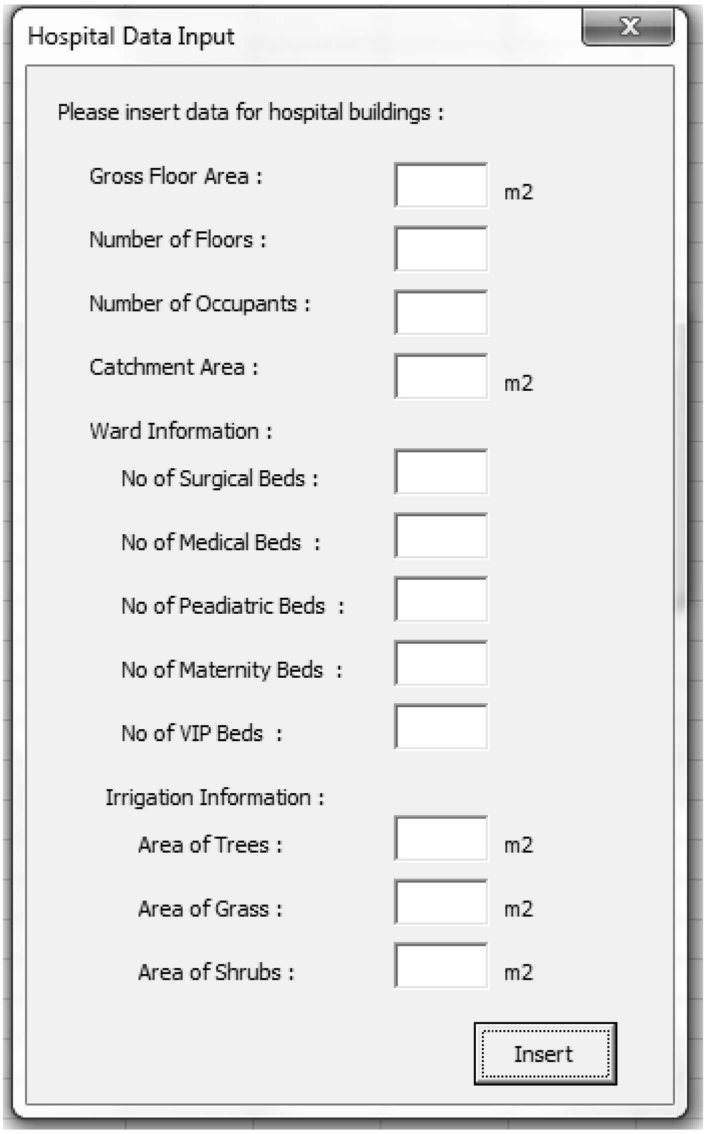
One of the most important elements in a tool is that it must be user compatible. In this sense, the spreadsheet is to be made accessible to the user and that it can be edited with ease. Microsoft Excel software by itself can be a very simple program to work with, however to ensure that users input the correct data to the correct columns, Visual Basic programming is used, where simple programming language of C++ is applied to make the program more comprehensive. For example, once a sheet is activated, a user form will prompt asking the type of building that the user will be modelling. Such example is seen in the Figure 3.6 below:



Please select the type of building :

Figure 3.6: Selection of building types in visual basic program.

Since each of the buildings have different water usage requirements, by selecting a particular building a specific input form will prompt afterward allowing the user to specify the water usage requirements for that particular building as shown in Figure 3.7. If such user form is not created, the user will be able to see all of the building types and their water usages which may cause confusion to unfamiliar users to the spreadsheet. The figure below shows a sample of the specific building, in this case for hospitals information input form. Once all required data has been inputted, the program will render the results across different roof materials and different tank sizes.



Hospital Data Input

Please insert data for hospital buildings :

Gross Floor Area : ☐ m2
Number of Floors : ☐
Number of Occupants : ☐
Catchment Area : ☐ m2

Ward Information :
No of Surgical Beds : ☐
No of Medical Beds : ☐
No of Peadiatric Beds : ☐
No of Maternity Beds : ☐
No of VIP Beds : ☐

Irrigation Information :
Area of Trees : ☐ m2
Area of Grass : ☐ m2
Area of Shrubs : ☐ m2

Figure 3.7: Example of hospital data input form.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Offices

An office building located in Subang Jaya was modelled with the following details:

Building type : Office
Total water demand : 6.48 m^3
Catchment area size : 400 m^2
Building size : 27500 m^2

The building was simulated with different roofing materials across different tank sizes. The types of roofing material selected are; slate tiles, concrete tiles, concrete blocks and gravel while the tank sizes are 16 m^3, 23 m3 and 32 m^3.

4.1.1 Water Savings

Different amounts of water savings can be observed annually by implementing different tank sizes across different roof materials. The summarized annual water savings are presented in Figure 4.1. Several constants that remained fixed are the number of occupants for the building, catchment area size and building gross floor area. An increase in the tank size also portrays an increase in the total amount of water saved by having the ability to store more than the required demand. Slate tiles show the most amounts of water savings while gravel type roofs show the least due to its porous and rough texture that reduces the total amount of rainwater harvested.

Slate and concrete tiles presents a significant difference in the water savings across different tank sizes while asphalt, concrete blocks and gravel roofs show relatively less volume difference per change in tank sizes. When paired with large tanks, slate tiles can provide water savings up to 995 m^3 which can be used to supply water to 9 houses for a whole year. Gravel roofs on the other hand will only provide 298 m^3 of water savings per year, which shows a 70% difference in slate tiles results.

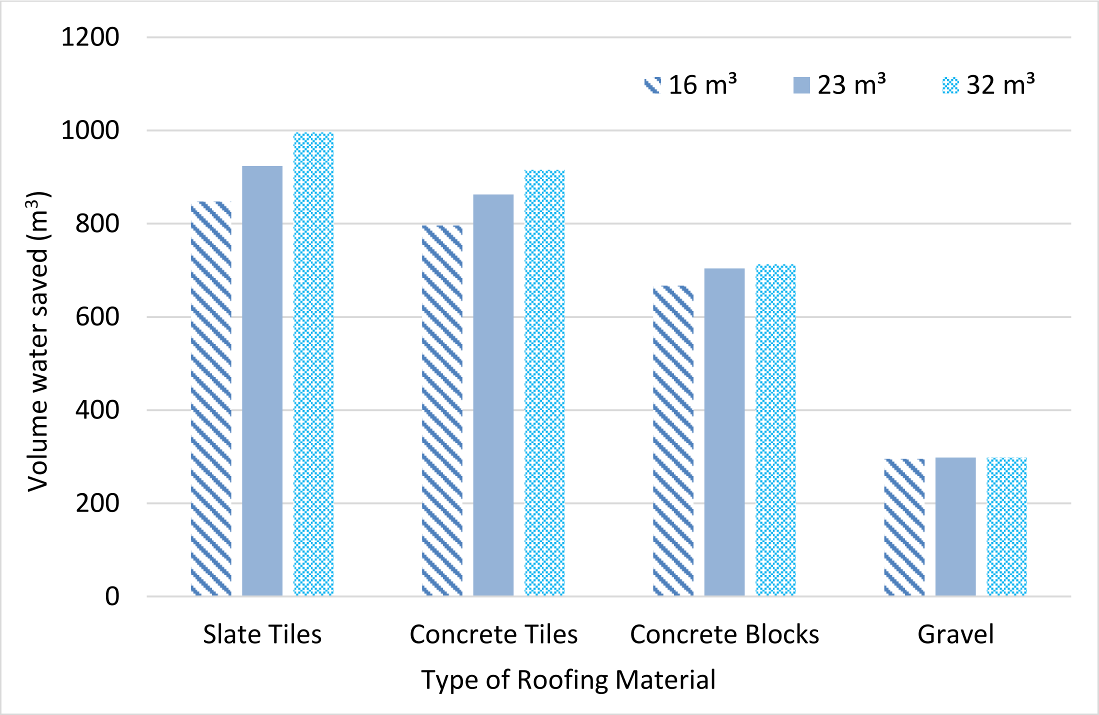
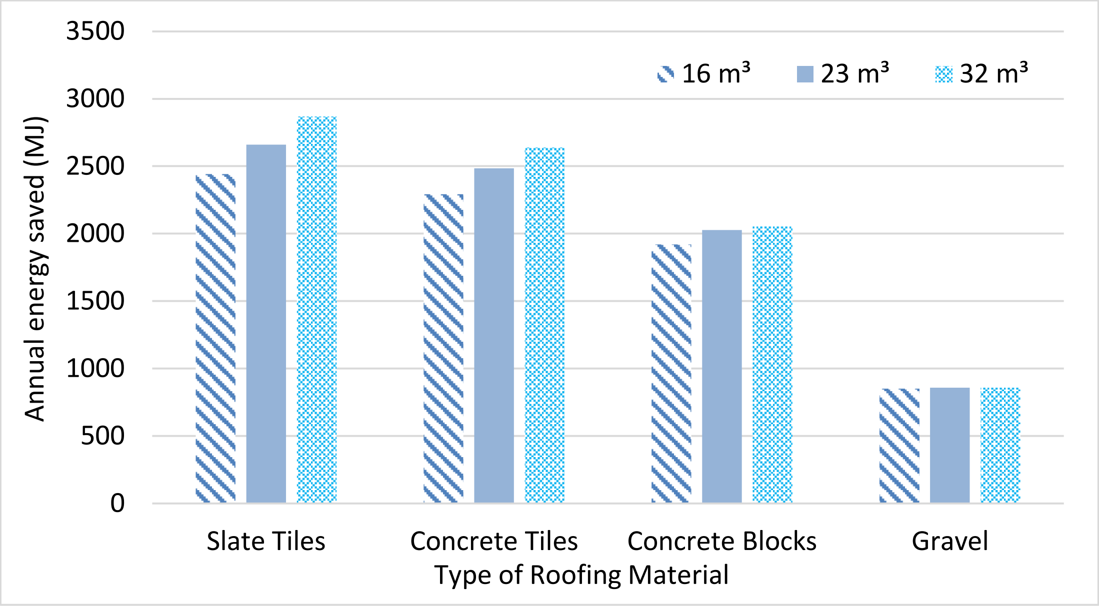


Figure 4.1: Water savings of different sized tanks and different roof materials – offices.

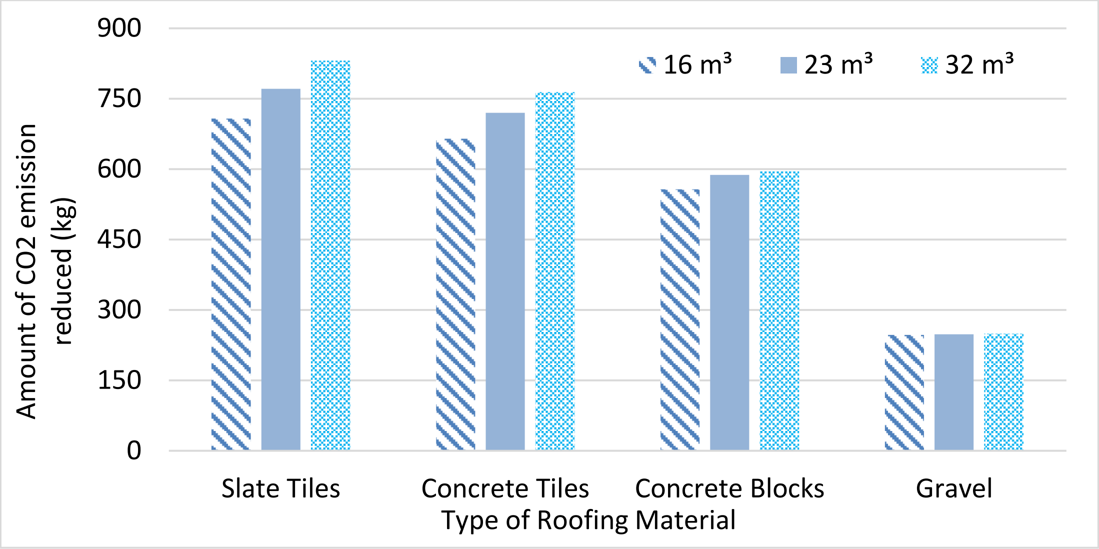
4.1.2 Energy savings and carbon dioxide emission reduction

Energy savings and carbon dioxide emission reductions are calculated based on the total amount of water savings earlier presented. It can be observed that the pattern of larger amounts of energy saving and carbon dioxide emission reductions are provided by slate tiled roofs when paired with large tanks while vice versa for gravel type roofs.

The annual energy savings for slate tiles and gravel roofs are 2870 MJ and 850 MJ respectively when large storage tanks are used while carbon dioxide reductions for the two roof materials are 830 kg and 250 kg respectively. The pattern is observed similar to the water savings due to the direct relations of the total energy savings and carbon dioxide emissions.



(a)



(b)

Figure 4.2: Annual savings of different sized tanks and roof materials in offices (a) energy (b) carbon dioxide emission reduction.

4.1.3 Cost analysis

Taking into account costs of larger tanks, pumps and piping for an office building, the capital costs of the rainwater harvesting system can be observed in Table 4.1. Copper pipes are selected for the system with a low speed pump for water channeling. Operational costs such as the maintenance fees and the total cost of water based on a fixed tariff of RM2.07/m^3 water usage are included in the analysis

Table 4.1: Costs of different tank sizes for offices.

Tank Size (m^3)	Price (RM)
16	21200
23	27200
32	35100

.

The payback period of the roofing materials are observed over a span of 30 years. Payback period can be estimated once the project returns a profit (in this study provides profits equal savings) over a cycle of operational years. The payback period of different roofing materials across different tank sizes are presented in Figure 4.3 below where the net present value is at a non-discounted rate. Based on Figure 4.3, it can be observed that for any tank size, gravel roofs will always have a payback period of more than 30 years. All other roof materials show that with an increase in tank size, the overall payback period increases. Slate tiles show the least amount of years for payback as its high efficiency in replacing the total water demand from the main supply with only 15, 18 and 20 years for small, medium and large tank sizes.

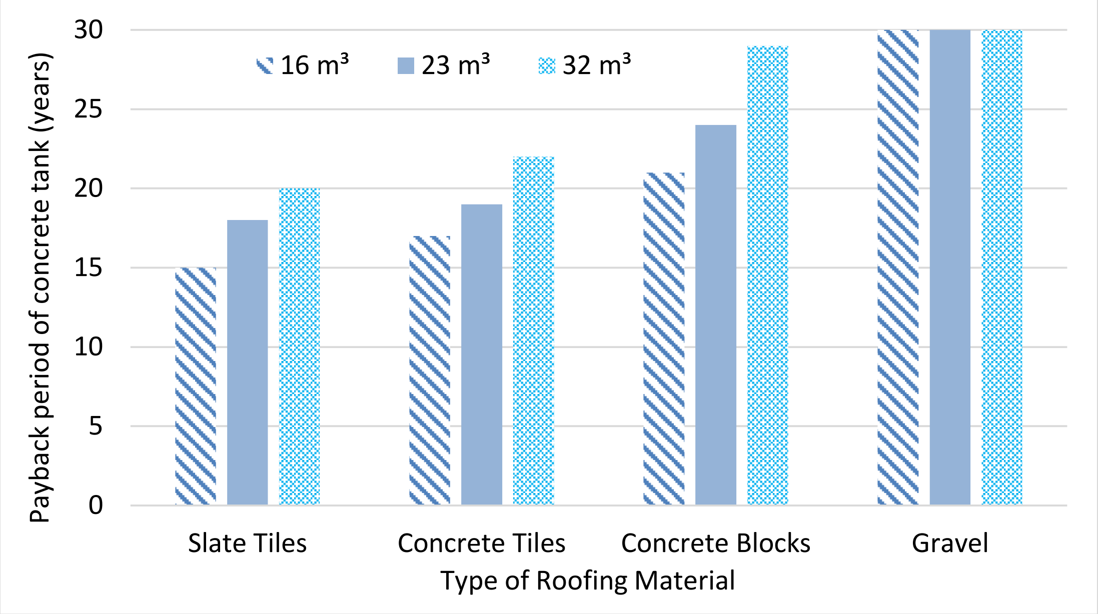


Figure 4.3: Payback period of different sized tanks and roof materials – offices.

4.2 Hospitals

A hospital building located in Subang Jaya was modelled with the following details:

Building type : Hospital
Total water demand : 18.12 m^3
Catchment area size : 1200 m^2
Building size : 41800 m^2

The building was simulated with similar roofing materials used in offices across different tank sizes of 36 m^3, 63 m3 and 90 m^3. A total of 350 staff is present at all times with 140 different beds i.e. medical, surgical, paediatric and maternity. Irrigation areas of trees, grasses and shrubs are also included to the have a total of 35m^3 in areas.

4.2.1 Water Savings

The pattern of water savings for hospitals can be analysed as similar to that of offices due to similar roof coefficients. The maximum amount of water saving can be obtained by using slate tiles with 3445 m^3 followed by concrete tiles with 3261 m^3 when paired with a tank of 36 m^3 in size. The least amount of savings is provided by gravel roofs paired with small tanks, in which they only provide 1268 m^3 of annual water savings, while concrete blocks provide 2824 m^3.

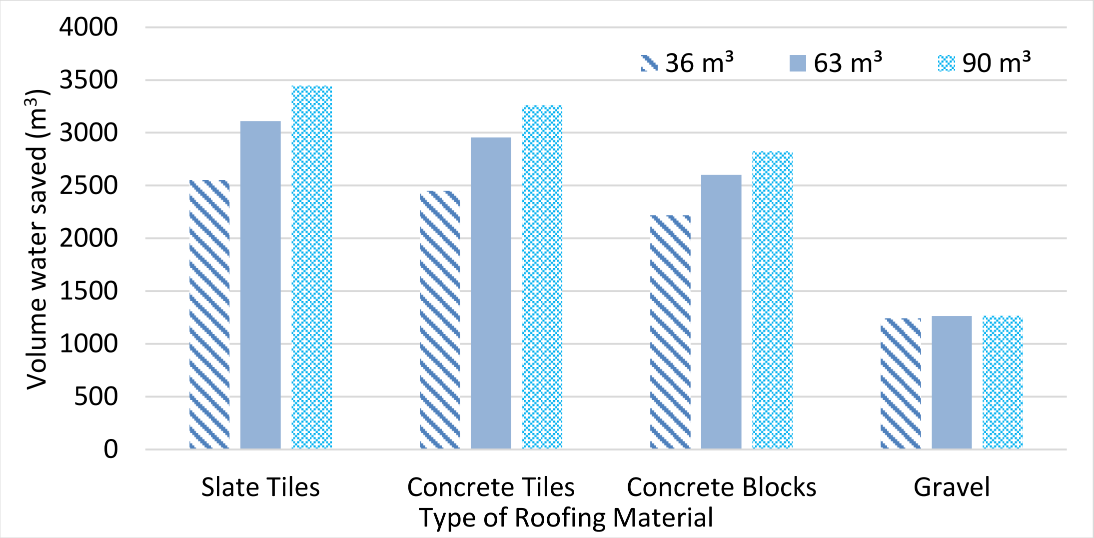
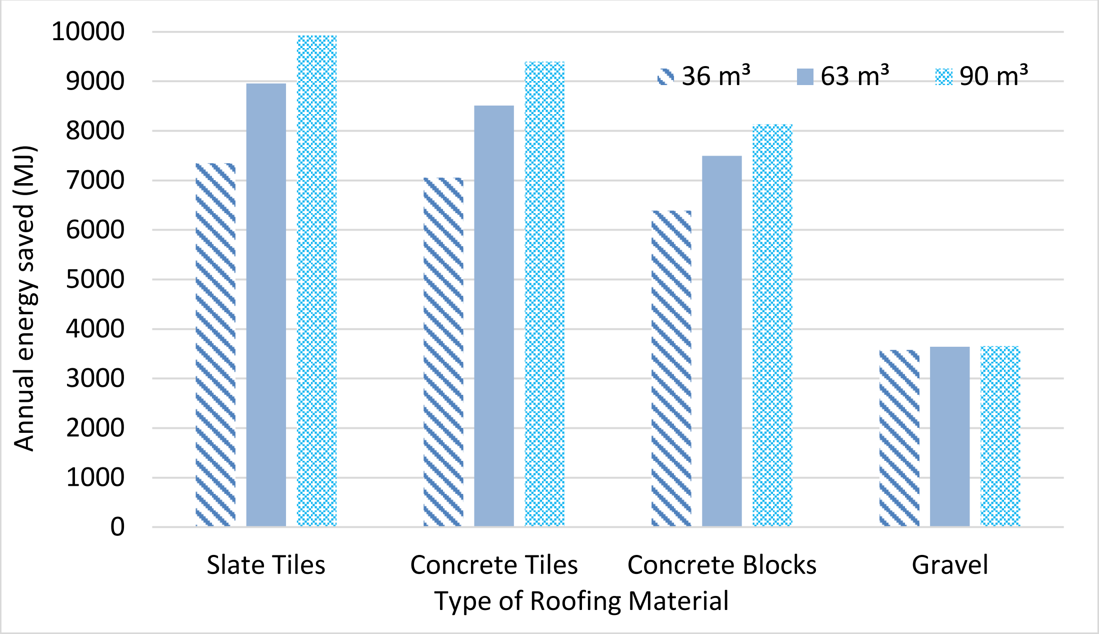


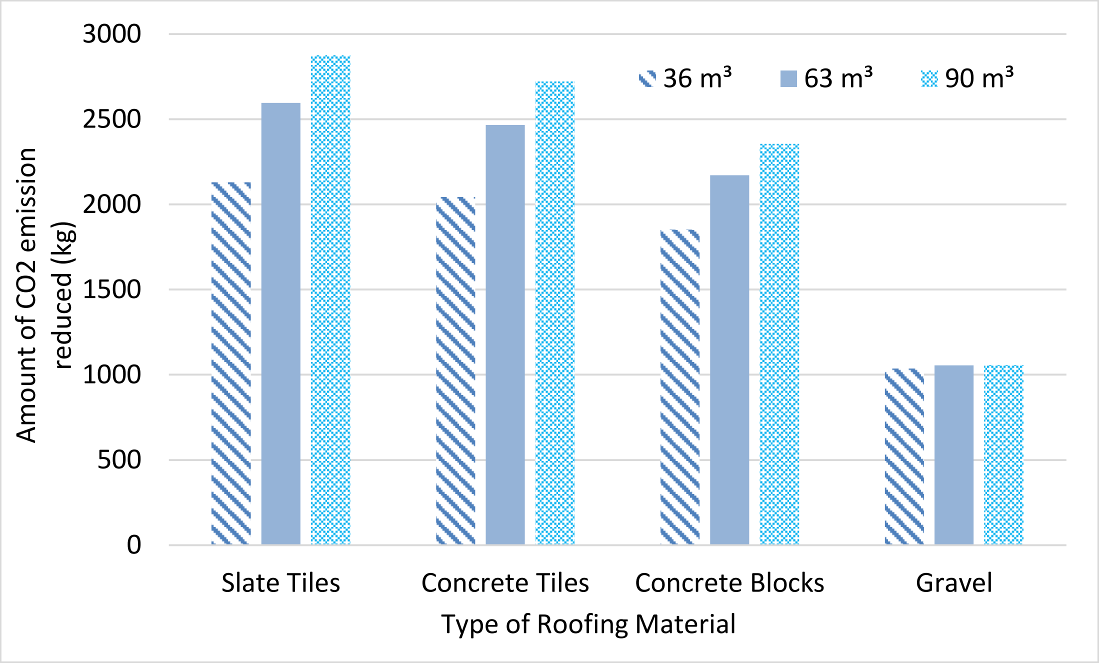
Figure 4.4: Water savings of different sized tanks and different roof materials – hospitals.

4.2.2 Energy savings and carbon dioxide emission reduction

Hospital buildings with given best specifications of the rainwater harvesting systems can provide energy savings up to 9925 MJ per year with a 2875 kg reduction in carbon dioxide emissions by using slate tiles, provided a large tank is used. Since concrete tiles were previously observed to have almost similar amounts in water savings to slate tiled roofs, a similar pattern follows for energy savings and carbon dioxide emission reduction. A difference of 5% is observed in the difference, where concrete tiled roofs provide 4394 MJ of energy savings and 2721 kg of carbon dioxide reductions. Gravel roofs on the other hand have a difference of 63% compared to slate tiles, with 3652 MJ energy savings and 1058 kg carbon dioxide reduction. Concrete blocks however also a slight difference of 18% when compared against slate tiles values of savings with values of 8133 MJ and 2356 kg.



(a)



(b)

Figure 4.5: Annual savings of different sized tanks and roof materials in hospitals (a) energy (b) carbon dioxide emission reduction.

4.2.3 Cost analysis

The capital costs of the project include the tank, piping and also the pump to be used where the piping and pump are assumed to be similar in the three different tank sizes. The costs of different tank sizes are tabulated in Table 4.2.

Table 4.2: Costs of different tank sizes for hospitals.

Tank Size (m^3)	Price (RM)
36	24310
63	50360
90	74410

The total costs of water savings for hospitals are seen to be higher compared to those of offices. By applying slate tiled roofs, total water savings that can be obtained are RM7234 annually, and RM2726 using gravel typed roofs. Due to the high savings, the large costs of the 90 m^3 tank can be returned about 13 years using slate or concrete tiles and concrete blocked roofs. Gravel roofs on the other hand require more than 30 years for a simple payback on 90 m^3 sized tanks. The shortest payback period is by slate tiled roofs paired with a 36 m^3 tank with 8 years of investment.

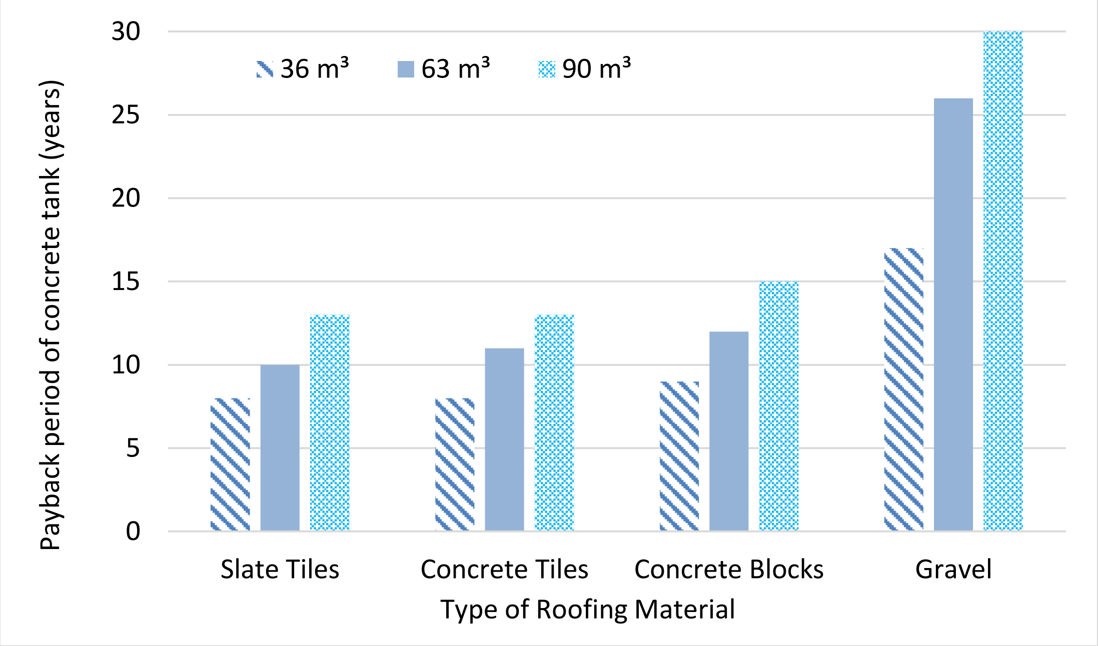


Figure 4.6: Payback period of different sized tanks and roof materials – hospitals.

4.3 Hotels

A hotel building located in Subang Jaya was modelled with the following details:

Building type : Hotel
Total water demand : 12.27 m^3
Catchment area size : 800 m^2
Building size : 31400 m^2

The building was simulated with similar roofing materials used in offices across different tank sizes of 25 m^3, 43 m3 and 60 m^3. A total of 180 staff is present at all times with 150 4-star rated rooms. Irrigation areas of grasses and shrubs are also included to the have a total of 11.85 m^3 in areas.

4.3.1 Water Savings

The pattern of water savings for hotels can be analysed as similar to that of offices and hospitals due to analogous roof coefficients. The maximum amount of water saving can be obtained by using slate tiles with 1954 m^3 and followed by concrete tiles and concrete blocks with 1816 m^3 and 1421 m^3 respectively when paired with a tank of 36 m^3. A large difference of 96% between slate tiles and gravel roofs can be observed, where they can only save 596 m^3 of water annually.

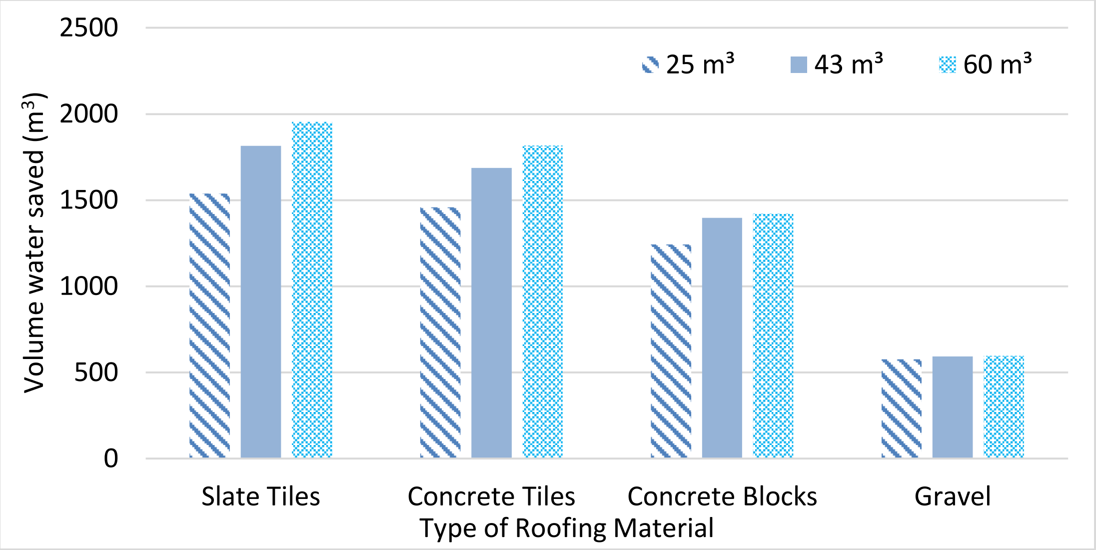
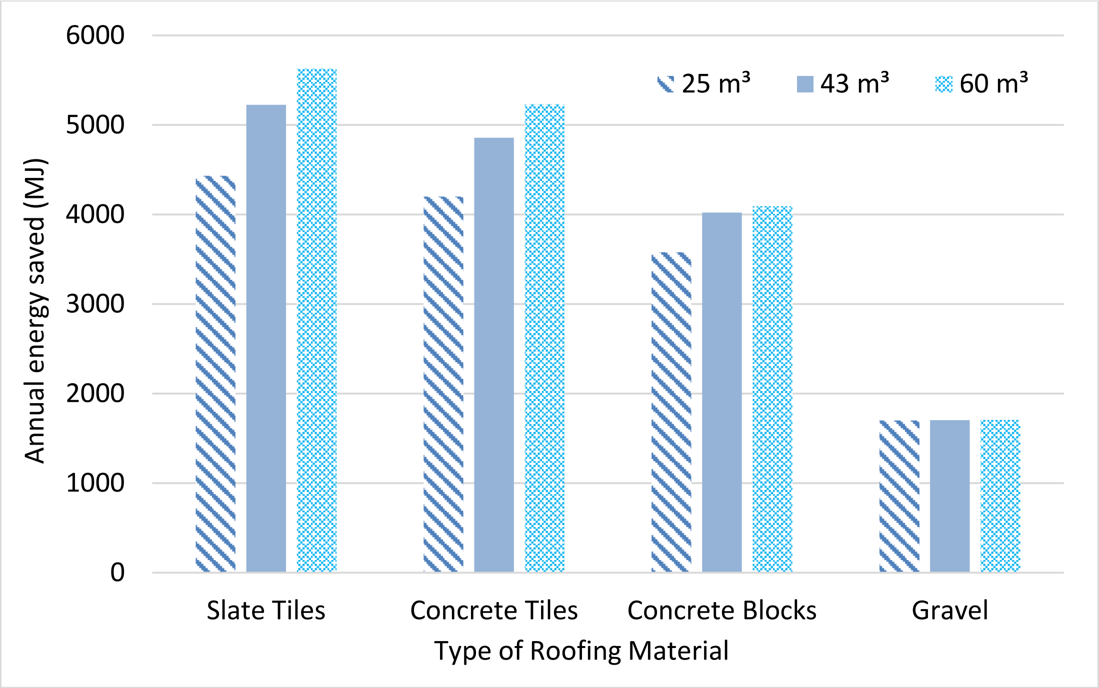


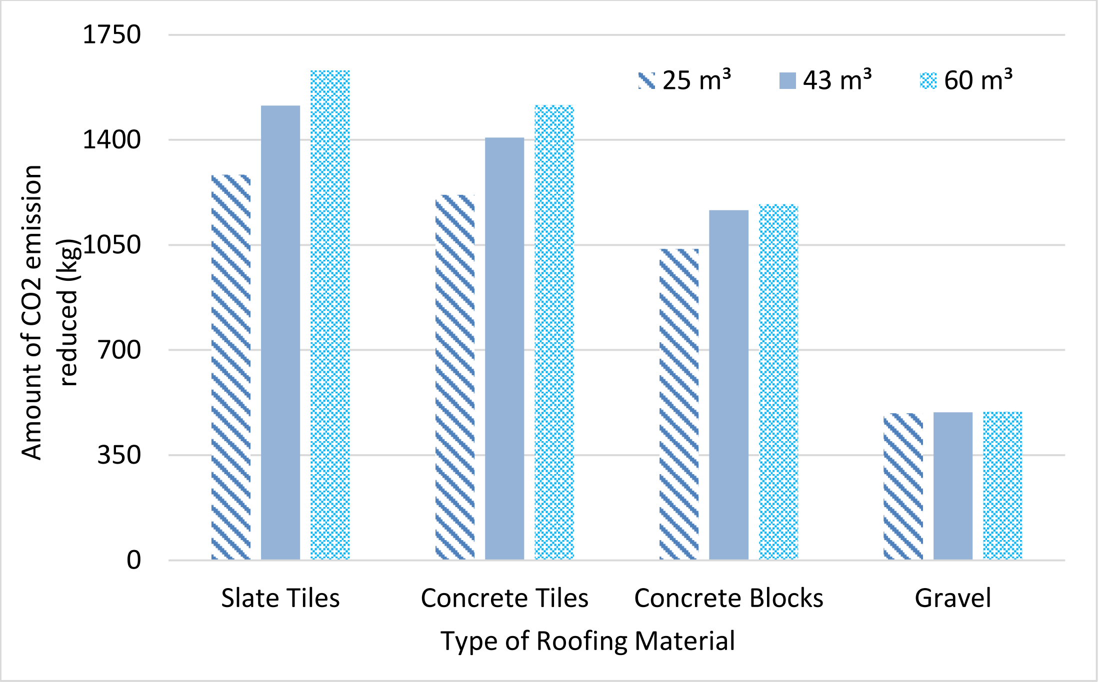
Figure 4.7: Water savings of different sized tanks and different roof materials – hotels.

4.3.2 Energy savings and carbon dioxide emission reduction

Based on Figure 4.8 (a) and (b) annual amount of energy savings and reductions of carbon dioxide emissions can be observed to have higher values of 5629 MJ and 1630 kg respectively using slate tiles, and 5232 MJ and 1515 kg using concrete tiles and a 60 m^3 tank. Concrete blocks have significant difference in the energy savings results compared to slate tiles with values of 4094 MJ and 1186 kg. Gravel roofs show little variation in energy savings across different tank sizes due to its maximum ability to harvest rainwater into the storage tanks. Gravel roofs can only provide 1708 MJ and 495 kg in energy and carbon dioxide emission reductions.



(a)



(b)

Figure 4.8: Annual savings of different sized tanks and roof materials in hotels (a) energy (b) carbon dioxide emission reduction.

4.3.3 Cost analysis

Similar to those of the offices and hospitals, the capital costs are inclusive of the piping and pumps. The costs of different tank sizes are tabulated in Table 4.3.

Table 4.3: Costs of different tank sizes for hotels.

Tank Size (m^3)	Price (RM)
25	58617
43	44184
60	58617

By using a large tank, the total cost savings from displacing water from the main are RM 4113, RM 3827, RM 3010 and RM 1294 the different types of roofs. As slate and concrete tiles have slightly different values, their payback period also seen as similar in which require 10 years for small tanks and 14 years for medium tanks and 16 years for large tanks. A gravel roof on the other hand requires more than 30 years for a payback to occur in almost all tank size cases and hence makes them economically inefficient. This is due to their inability to provide large water savings as a result of their low run off coefficient.

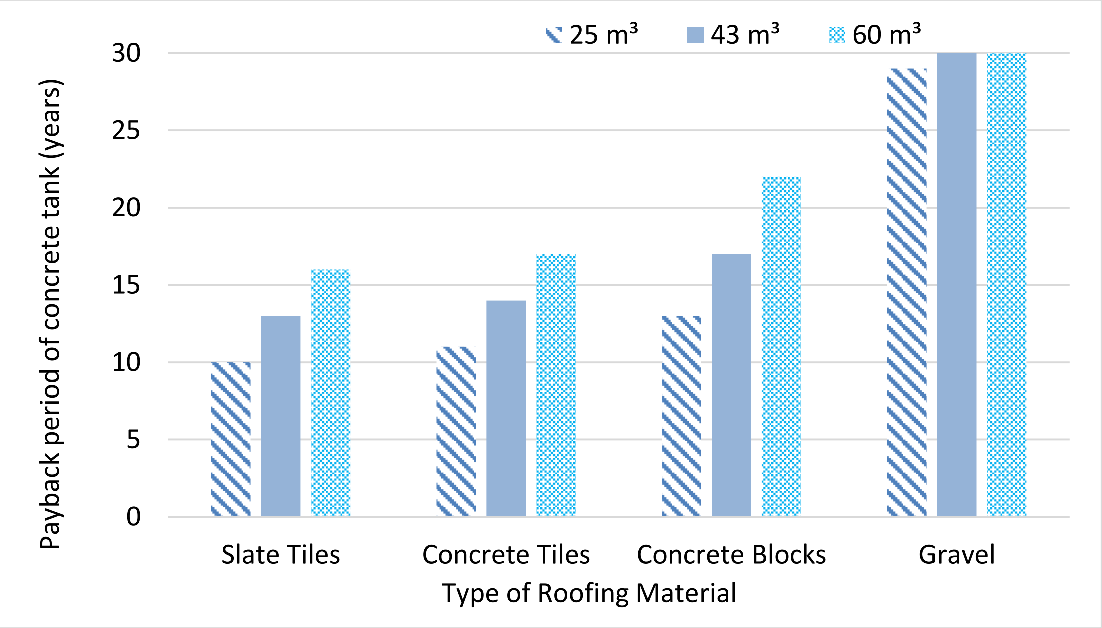


Figure 4.9: Payback period of different sized tanks and roof materials – hotels.

4.4 Overall Discussion

Based on the results obtained from the office, hospital and hotel buildings, it can be observed that a similar pattern of total amount of savings is generated; roof materials with better run off coefficients i.e. slate tiles and concrete tiles will provide a better overall savings then roofs with lower run off coefficients. The total amounts of savings will also increase with the tank size of the building. The best roof run off coefficient is bared by slate tiles, having a value of 0.9. The coefficient value tails to the amount of rainwater harvested that manages to flow into the tank by subtracting loses due to spillage, absorption, evaporation and surface wetting (Singh, 1992). This means that gravel roofs, with a run off coefficient of only 0.25 experiences large losses in water collection, primarily due to its porous and rough texture.

It can be seen that across the total amount of savings and carbon dioxide reductions, slate tiles show variation in the total values when paired with different tank sizes. Similarly, when concrete tiles were used, the water and energy saving, and CO2 emission reduction percentage difference were the same as for the slate tiles for different tank volumes. However, the variation in water and energy saving and reduction in CO2 emission for the three tank volumes became less when concrete blocks were used and almost no variation for the three different tank volumes were recorded when gravel roofing was used. Using slate and concrete tiles present a significant difference in the water and energy savings across different tank sizes while concrete blocks and gravel roofs show relatively less volume or almost no difference per change in tank sizes. This indicates that increasing the rain water harvesting tank volume will have minor or almost no effect on the amount of water saving and subsequent energy saving and reduction in CO2 emission when concrete blocks and gravel roofs were used.

Porous materials will act as sponges when water is supplied across its surface as the water will be absorbed into the pores, causing less rainwater to be harvested. During hot days, the absorbed rainwater will evaporate to surroundings and hence create a cycle in which rainwater harvesting would yield less. The rough texture also causes rainwater droplets to bounce off the roof due to dissimilar angles of the material. This causes the overall higher water main supply addition when using gravel roofs, and hence less amount of water savings. Since gravel roofs seem to cause retention of water, extra maintenance may be required to assist the effects such as cleaning mould and changing of parts that may have corroded due to long exposure of water. High levels of water retention may also cause the roof to support extra load which may lead to early fatigue of the building roof structure.

Another main factor that can be seen as affecting the total amount of rainwater collected is the size of the catchment area. In this study, different catchment area sizes are used across office, hospital and hotel buildings; 400 m^2, 1200 m^2 and 800 m^2 respectively. The larger catchment area will provide the building with larger amounts of rainwater harvested, and if paired with smaller tanks lead to higher amounts of overflow. Catchment areas sizes are also limited to the material run off coefficient and tank size. In order to have a clear representation of comparison, offices with a catchment area size of 400 m^2 and tank size of 32 m^3 is compared with a hospital which has a catchment area size of 1200 m^2 and tank size of 36 m^3; both using slate tiled roofs. The total amount of water saving provided for the offices and hospitals are found to be 995 m^3 and 3446 m^3. Even though the total water savings must be related to the total water demand, it can clearly be seen that larger catchment areas are capable of providing larger water harvesting and overflow amounts.

In the case of overflows, hospitals have a value of 1067 m^3 and offices only produce 65 m^3 of rainwater; both using slate tiles. Even if hospitals have higher overflow values, it must be kept in mind that the overflow seen is recorded values, in which we cannot see in office rainwater harvesting systems. The roof materials play an important role in determining how much water ends up being channelled to the drain. Slate tiled roofs provide more overflow than any other type of roof due to its high efficiency in channelling water into the tank. Across most buildings, gravel roofs will provide the user with a least overflow rainwater harvesting system. Most users would like to reduce the total amount of overflow since that it is seen as wastage of rainwater that could be used as meeting the water demands in the building. One method to mitigate this issue is by using larger sized tanks to meet the storable capacity of the catchment area size and material.

The payback period of the system is highly related to the total amount of water savings provided by the catchment area and tank. However, large investment costs translate to longer payback periods which include the tank sizes that differ according to the building demand. Longest payback periods are seen in offices due to their smaller catchment area size compared to their water demand, as the payback period is based on the highest amounts of savings using slate tiled roofs.

Capital costs of rainwater harvesting systems can be reduced by early planning of the system and implementation during the building construction rather than additions after the building construction has been completed. Costs to redirect piping in a building are potentially higher than implementation costs during early installations due to labor and material expenses. Problems may also occur as the main water supply must be turned off before redirecting the pipes and hence may affect productivity of the building staff. A project can be reckoned as viable by using a simple payback analysis.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Rainwater harvesting systems can be used to meet several demands of buildings; either potable or non-potable uses. The analysis obtained from the study shows that the system does not only provide savings for total water consumption, but for reducing greenhouse gas emissions to the environment. Non-potable uses such as toilet flushing and irrigation contribute less energy required due to reduced need for water treatment compared to potable uses. It is observed that over different roofing materials, slate tiles prove the highest performance in terms of energy saved and hence reduced carbon dioxide emission by 2870 MJ and 830 kg in offices, 9925 MJ and 2875 kg in hospitals and 5629 MJ and 1631 kg in hotels due to their smooth surface that promotes channeling of harvested rainwater into the tanks. On an annual basis, slate tiles provide almost 995 m^3, 3446 m^3 and 1954 m^3 of water saving form offices, hospitals and hotels respectively and reduces the total demand from the main supply. Gravel roofs are not recommended to be paired with rainwater harvesting systems due to its reduced efficiency as a roof catchment material and low overall savings of water, energy and carbon dioxide reductions. Although it can provide significant impact to the environment with reductions of 246 kg, 1058kg and 495 kg of carbon dioxide emissions in offices, hospitals and hotels respectively, the cost of investment does not pay back to its efficiency of 0.25 run off coefficient. The total amount of savings and carbon dioxide reductions for all types of roofs, tanks and buildings can be found in the appendices section. The paper also managed to prove that by using gravel roofs, the savings will not vary with an increase in tank size when compared to slate tiles.

The total project payback was very much affected by the total roof catchment area size paired with roof materials with good run off coefficients. It can be observed that larger roof catchment area sizes with better roof coefficients have lower payback periods. Offices, hospitals and hotels when modelled with largest tanks using slate tiles and their respective roof catchment area sizes of 400 m^2, 1200 m^2 and 800 m^2 return a payback of 20, 13 and 16 years respectively. Even though hospitals have larger investment costs compared to the others, the total amount of water savings are sufficient to provide a payback much less than the other buildings.

The project has been completed by the development of the spreadsheet in Microsoft Excel to analyse the correlation of rainfall and specific water demand by designing a selection and sizing tool of a RWHS. Secondly, the financial feasibility is also included by calculation of the payback period to identify the economic efficiency of the system using different tank sizes across different roof materials. Finally, the total savings given by the system which are savings of water from the main supply, energy usage to treat water from the main supply and finally the reduction of carbon dioxide gas emissions by not using the water from the main supply are determined and tested against the use of different roof materials. The objectives of the project have been met accordingly using the mass balance of water in the tank. The comprehensive RWHS design tool that analyses almost every aspect of a building will aid developers in determining the required system properties and to design the system accordingly to ensure better cost effectiveness. By using the developed spreadsheet, developers are able understand the necessity of saving the environment and the importance of construction styles that implement green initiatives for a better tomorrow.

5.2 Recommendation

One of the main recommendations that can be added to the developed spreadsheet is the type of buildings modelled. Currently, the developed tool only covers 3 types of buildings which are offices, hotels and hospitals in the area of Subang Jaya. In order to have a more comprehensive tool, it is recommended to add different types of buildings such as industries, residential, retail, etc. to ensure more universal use of the spreadsheet.

Another addition to the spreadsheet that should be included is the different roofing area selections. This is because there are some that are not modelled by Lee, Bak and Han (2012) such as glass or asphalt roofs which may be used by developers and have different roof coefficients with those as estimated by the unknown roof type. First flush reductions should also be modelled for future work as the total amount of water harvested may not meet the standard requirements due to animal droppings on the roof or other congesting materials such as algae, leafs and branches. First flush will provide the user with better quality water due to washing away of contaminants off the roof but however will affect the total amount of rainwater harvested.

Rainfall values are known to be one of the main factors that affect the total efficiency of the rainwater harvesting system. Increasing the scope of the rainfall areas should also be conducted as the only area covered in the design tool is Subang Jaya, which has average rainfall throughout the years. Addition of other rainfall prone or scarce areas should be done. For example Jelebu in Negeri Sembilan has the least amount of rainfall with higher temperatures compared to other regions in the country. By having such extreme values, all regions in and out of the country can be simulated and hence produce more accurate results.

Finally, the costing of the system is to be made more discrete compared to estimated values. Such costing that is to be made more inclusive is the piping cost and the tank cost. Currently, the piping cost is based on the size of the building per square meters and the tank is given per meter cube which may not render proper coting analysis results. The payback period should also be calculated using a discounted period rather than non-discounted values to ensure that risks such as deflation or increase in taxes, damages to the system and other factors are taken into consideration.

REFERENCES

Aquacraft Inc. (2011). *Embedded Energy in Water Studies, Study 3 : End-use Water Demand Profiles.* Aquacraft Inc.

Campisano, A., & Modica, C. (2012). Optimal sizing of storage tanks for domestic rainwater harvesting in Sicily. *Resources, Conservation and Recycling*, 9-16.

Chartered Institute of Building and Services Engineers. (2004). CIBSE Guide G. *Public Health Engineering*. London: CIBSE.

Chartered Institute of Building and Services Engineers. (n.d.). CIBSE Knowledge Series : Reclaimed water. London: CIBSE.

Chiu, Y.-R., Liaw, C.-H., & Chen, L.-C. (2009). Optimizing rainwater harvesting systems as an innovative approach to saving energy in hilly communities. *Renewable Energy*, 492-498.

Choong, M. Y. (22 March, 2011). *Malaysia faces looming water crisis*. (The Star) Retrieved 23 November, 2014, from http://www.thestar.com.my/story/?file=%2F2011%2F3%2F22%2Flifefocus%2F8192017

City of San Diego. (June, 2014). *Water, A Branch of Public Utiities*. Retrieved from The City of San Diego: http://www.sandiego.gov./water/conservation/rainwaer.shtml

Farreny, R., Morales-Pinzon, T., Guisasola, A., Taya, C., Rieradevall, J., & Gabarrell, X. (2011). Roof selection for rainwater harvesting: Quantity and quality assessments in Spain. *Water Researh*, 3745-3754.

Fewkes, A. (1999). The use of rainwater for WC flushing: the field testing of a collection system. *Building and Environment*, 765-772.

Hashim, H., Hudzori, A., Yusop, Z., & Ho, W. (2013). Simulation based programming for optimization of large-scale rainwater harvesting system: Malaysia case study. *Resources, Conservation and Recycling, 80*, 1-9.

Imteaz, M. A., Shanableh, A., Rahman, A., & Ahsan, A. (2011). Optimization of rainwater tank design from large roofs: A case study in Melbourne, Australia. *Resources, Conservation and Recycling*, 1022-1029.

Institue of Plumbing. (2002). *Plumbing Engineering Services Design Guide.*

Lee, J. Y., Bak, G., & Han, M. (2012). Quality of roof-harvested rainwater - Comparison of different roofing materials . *Environmental Pollution*, 422-429.

Lee, T. K., Lee, C.-D., Yang, M.-S., & Yu, C.-C. (2000). Probabilistic Design of Storage Capacity for Rainwater Cistern Systems. *Journal of Agricultural Engineering and Research*, 343-348.

Liaw, C.-H., & Tsai, Y.-L. (2004). Optimum storage volume of rooftop rainwater harvesting systems for domestic use. *Journal of the American Water Resources Association*, 901-912.

Mak, K. (19 March, 2014). *Current water crisis caused by over development and lack of planning*. (The Star) Retrieved 23 November, 2014, from http://www.thestar.com.my/News/Community/2014/03/19/Weather-not-to-blame-Current-water-crisis-caused-by-over-development-and-lack-of-planning/

Matos, C., Santos, C., Pereira, S., Bentes, I., & Imteaz, M. (2013). Rainwater storage tank sizing: Case study of a commercial building. *International Journal of Sustainable Built Environment*, 109-118.

Mendez, C. B., Klenzendorf, J. B., Afshar, B. R., Simmons, M. T., Barrett, M. E., Kinney, K. A., et al. (2011). The effect of roofing material on the quality of harvested. *Water Research*, 2049-2059.

Parkes, C., Kershaw, H., Hart, J., Sibille, R., & Grant, Z. (2010). *Energy and Carbon Implications of Rainwater Haarvesting and Greywater Recycling.* Bristol: Environmental Agency.

Plappally, A., & Lienhard V, J. (2012). Energy requirements for water production, treatment, end use, reclamation, and disposal. *Renewable and Sustainable Energy Reviews*, 4818–4848.

Proenca, L. C., & Ghisi, E. (2010). Water end-uses in Brazilian office buildings. *Resources, Conservation and Recycling*, 489-500.

Rawlinsons. (2011). *Rawlinsons New Zealand Construction Handbook.* Auckland: Rawlinsons Media Limited.

Roebuck, R. M. (2007). *An investigation into the whole life costing implications of using rainwater harvesting systems for non-potable applications in new-build developments in the UK.* University of Bradford.

Singh, V. (1992). *Elementary Hydrology.* New Jersey: Prentice Hall.

Tomaz, P. (2003). *Utilization of Rainwater in not drinkable purposes in Urban Areas.* Editora Navegar.

Vieira, A. S., Beal, C. D., Ghisi, E., & Stewart, R. A. (2014). Energy intensity of rainwater harvesting systems: A review. *Renewable and Sustainable Energy Reviews*, 225-242.

Villatrreal, E., Semadeni-Devies, A., & Bengtsson, L. (2004). Inner city stormwater control using a combination of best management practices. *Ecological Engineering*, 279-98.

Ward, S., Butler, D., & Memon, F. A. (2011). Benchmarking energy consumption and CO2 emissions form rainwater harvesting systems: an improved method by proxy. *Water and Environmen Journal*.

Water Environemnt Partnership Asia. (28 July, 2014). *WEPA*. Retrieved from National Water Quality Standards for Malaysia: www.wepa-db.net

Zhang, Q., Wang, X., Hou, P., Wan, W., Li, R., Ren, Y., et al. (2014). Quality and seasonal variation of rainwater harvested from concrete, asphalt, ceramic tile and green roofs in Chongqing, China. *Journal of Environmental Management*, 178-187.

APPENDICES

APPENDIX I

Table A1: Summarized results for offices.

Type of Saving	Tank Size (m^3)	Roof Type			
		Slate Tiles	Concrete Tiles	Concrete Blocks	Gravel
Water Saved (m^3)	16	847.70	796.28	666.95	295.32
	23	923.86	862.79	703.91	298.07
	32	995.87	915.92	712.88	298.24
Energy Saved (MJ)	16	2441.39	2293.29	1920.81	850.15
	23	2660.71	2484.84	2027.25	858.45
	32	2868.12	2637.86	2053.11	859.29
CO2 Reduced (kg)	16	707.32	664.42	556.50	246.91
	23	770.87	719.91	587.34	247.71
	32	830.96	764.25	594.83	249.35
Payback Period (years)	16	15	17	21	30
	23	18	19	24	30
	32	20	22	29	30

APPENDIX II

Table A2: Summarized results for hospitals.

Type of Saving	Tank Size (m^3)	Roof Type			
		Slate Tiles	Concrete Tiles	Concrete Blocks	Gravel
Water Saved (m^3)	36	2551.98	2450.35	2219.18	1242.45
	63	3110.83	2956.08	2601.65	1264.50
	90	3446.46	3261.86	2824.08	1268.11
Energy Saved (MJ)	36	7349.71	7057.01	6391.23	3578.25
	63	8959.20	8513.52	7492.75	3641.75
	90	9925.79	9394.16	8133.34	3652.16
CO2 Reduced (kg)	36	2129.37	2044.57	1851.68	1036.70
	63	2595.68	2466.56	2170.82	1055.10
	90	2875.72	2721.70	2356.41	1058.11
Payback Period (years)	36	8	8	9	17
	63	10	11	12	26
	90	13	13	15	30

APPENDIX III

Table A3: Summarized results for hotels.

Type of Saving	Tank Size (m^3)	Roof Type			
		Slate Tiles	Concrete Tiles	Concrete Blocks	Gravel
Water Saved (m^3)	25	1539.11	1458.90	1243.24	577.13
	43	1815.29	1686.67	1396.85	593.27
	60	1954.85	1816.68	1421.76	596.37
Energy Saved (MJ)	25	4432.65	4201.63	3580.52	1699.52
	43	5228.03	4857.62	4022.92	1704.63
	60	5629.98	5232.04	4094.68	1708.62
CO2 Reduced (kg)	25	1284.24	1217.31	1037.36	490.03
	43	1514.68	1407.36	1165.53	493.00
	60	1631.13	1515.84	1186.32	495.02
Payback Period (years)	25	10	11	13	29
	43	13	14	17	30
	60	16	17	22	30

PUBLICATION

1. Nasif, M. S., & Roslan, R. (2015). Effect of utilizing different buildings' roof material on cost and energy savings, and carbon dioxide emission reduction of rainwater harvesting systems. *Awam International Conference on Civil Engineering (AICCE'15).* Kuala Lumpur. (Submitted)