EFFECT OF ROOFTOP RAINWATER HARVESTING STORAGE ORIENTATION ON THE STABILITY OF A HIGH RISE BUILDING

BY

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ABSTRAK

Skop kajian ini adalah tertumpu kepada kesan daripada lokasi tangki simpanan air hujan ke atas kestabilan bangunan tinggi. Satu bangunan tinggi sedia ada di kawasan bandar telah dipilih. Bangunan tinggi tersebut adalah 77.0 m tinggi dan 59.35 m panjang dan 22.75 m lebar. Beban angin yang dikenakan pada bangunan tinggi tersebut dikira dengan merujuk kepada MS 1553:2002. *Supply Side Approach* telah digunakan untuk menentukan saiz tangki simpanan air hujan. Bangunan tinggi tersebut dimodelkan dan dianalisiskan dengan menggunakan perisian komputer – *EsteemPlus 6.2*.

Daripada projek ini, didapati pesongan maksimum untuk sebuah bangunan tinggi akan berubah dengan orientasi perletakan tangki simpanan air hujan. Keputusan menunjukkan bahawa impak perletakan tangki simpanan air hujan dapat dikurangkan jika ia diletakkan berhampiran dengan pusat tengah bangunan tersebut. Walau bagaimanapun, analisis perlu dilakukan ke atas sesuatu bangunan sebelum tangki simpanan air hujan dipasang.

ABSTRACT

The scope of this study is focussed on the effect of different rooftop rainwater harvesting storage orientations on the structural stability of a high rise building. An existing high rise building in urban area is selected. The high rise building is 77.0 m in height and 59.35 m x 22.75 m in plan. The wind load on the high rise building is calculated by referring to MS 1553:2002. Supply Side Approach is used to size the storage tanks. The high rise building is modelled and analysed by computer software – EsteemPlus 6.2.

From this project, it is found that the deflection of the high rise building varies with the orientation of the RRWH storage tank installation. The results also show that rainwater harvesting storage tank installation in high rise building is likely to reduce the impact of wind action if the storage tank is placed near to the centre of the building. However, it is essential to analyse the behaviour of a building before installing any rainwater harvesting storage tank.

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CHAPTER 1 INTRODUCTION

1.1 PREFACE

Water is one of the main requirements for living, without water one can not survive, no matter human, animals or plants. Since from the beginning, human obtained their water from river and also from rainwater for domestic uses. Collecting rainwater does not need specials skills, anyone can do it. The simplest method to collect rainwater is to put a container out side the house, under an open area when it rains, of course this method only collects a small scale of water.

The rainwater harvesting involves the collection of the water from surfaces on which rainfalls, and subsequently storing this water for later use. Normally water is collected from the roofs of building and stored in rainwater tanks.

1.2 STATUS & IMPORTANCE

The benefits of rainwater harvesting in water resources engineering include relief of strain on other water supply, increase independence and water security, lower water supply cost, reduce flood flows, greater sensitivity to and connection with natural cycles. In cities that are prone to earthquake, this captured rainwater functions as a back-up system for fire-fighting purpose.

Designers, engineers and general public still doubtful and argue on the application of extra hydraulic load on the building from rainwater harvesting especially on the roof and other related members nowadays. Generally, the entire building seems to have to be designed to cater for extra loading from rainwater harvesting storage. Subsequently, large scale structure is required and the project will become very costly. However, there is very limited published information describing the structural impact of this issue. Hence, the main objective of this project is to assess the effect of hydraulic loading on the stability of a high rise building for different storage orientation.

1.3 OBJECTIVES

The main objectives of this thesis are:

i. To evaluate the impact of rooftop rainwater storage in a high rise building on its structural stability.
ii. To study the wind impact on high rise building.

The scope of this study is focused on the effect of different rooftop rainwater harvesting storage orientations on the structural stability of a high rise building.

1.4 LAYOUT OF THESIS

The general introduction is given in Chapter 1 about the topic of this thesis. In Chapter 2, literature related to rooftop rainwater harvesting including urban storm water management and water reuse, and high rise building characteristic is reviewed. In Chapter 3, the method used which is finite element analysis using the software EsteemPlus 6.2 is described. This software is used to model and to analyse a 20-storey high rise building. The result and discussion are presented in Chapter 4. This is then followed by the conclusion in Chapter 5.

CHAPTER 2 LITERATURE REVIEW

2.1 ROOFTOP RAINWATER HARVESTING

Rooftop rainwater harvesting are mainly used in low and medium rise building, if there are high rise building, the storage tank normally located on the ground (basement) or underground. This is probably because there are still some doubts about whether the structure can or can not withstand the extra water load on top of the high rise building.

In some cultures, rainwater harvesting has been a traditional practice for centuries and many technologies are developed from the long evolutionary process. The techniques usually found in Asia and Africa arise from practices employed by ancient civilizations within these regions and still serve as a major source of drinking water supply in rural areas. As a result a number of technologies have become accepted in rainwater harvesting practice. Some of these are modifications of designs that go back into antiquity while others have been developed more recently. Rainwater harvesting systems can roughly be broken down into 4 primary processes and 3 treatment processes as shown in Figure 2.1.

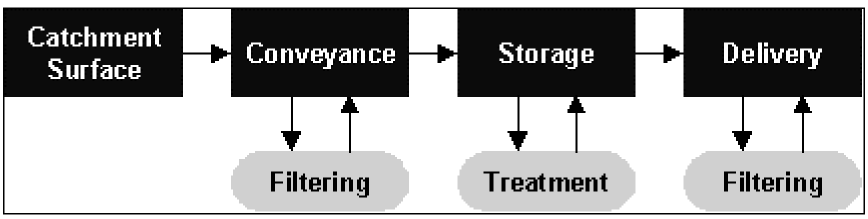

Figure 2.1: Process Diagram of Domestic Rainwater Harvesting Systems (University of Warwick, 2004)

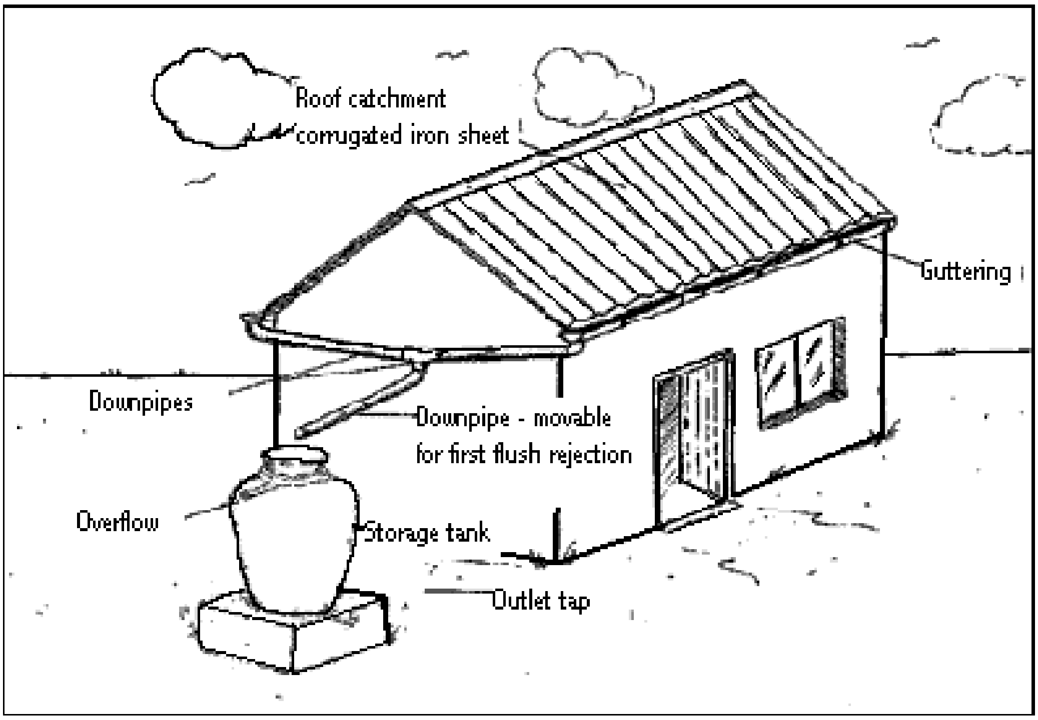

Figure 2.2: Typical Very Low Cost Roofwater Harvesting System In a Developing Country (University of Warwick, 2004)

In the most basic form of rainwater harvesting system, rainwater is collected in simple vessels at the edge of the roof, or collection of rainwater in gutters which drain to the collection vessel through down-pipes constructed for this purpose (Figure 2.2). The amount and quality of rainwater collected depends on the area and type of roofing material. Most losses are through infiltration, although some water will also bounce off the edge of the surface in heavy rain and usually some water will be lost in wetting the surface. The loss is usually represented by a "run-off coefficient" C_R which is a number between zero and one: (1- C_R) expresses the loss fraction averaged over a year (Warwick, 2004). This means that the higher the value of C_R the lesser water lost from the harvesting system.

Table 2.1 gives the characteristics of various types of roof and their associated runoff coefficients.

Table 2.1: Characteristics of Roof Types (University of Warwick, 2004)

TYPE	RUNOFF COEFFICIENT	NOTES
GI Sheets	>0.9	• Excellent quality water. Surface is smooth and high temperatures help to sterilise bacteria
Tile (glazed)	0.6 - 0.9	• Good quality water from glazed tiles. • Unglazed can harbour mould • Contamination can exist in tile joins
Asbestos Sheets	0.8 - 0.9	• New sheets give good quality water • No evidence of carcinogenic effects by ingestion • Slightly porous so reduced runoff coefficient and older roofs harbour moulds and even moss
Organic (Thatch, Cadjan)	0.2	• Poor quality water (>200 FC/100 ml) • Little first flush effect • High turbidity due to dissolved organic material which does not settle

Pure rainwater can be collected from roofs constructed with galvanized corrugated iron, aluminium or asbestos cement sheets, tiles and slates. Roofs with metallic paint or other coatings are not recommended as they may cause tastes or colour to the collected water. Roof catchments should also be cleaned regularly to remove dust, leaves and bird droppings so as to maintain the quality of the product water.

Usually, the main calculation when designing a RWH system will be to size the water tank correctly to give adequate storage capacity. The storage requirement will be determined by a number of interrelated factors. They include:

- local rainfall data and weather patterns
- roof (or other) collection area
- runoff coefficient (this varies between 0.5 and 0.9 depending on roof material and slope)
- user numbers and consumption rates

University of Warwick, UK (Warwick, 2004) has outlined 3 different methods with examples for sizing RWH system components; the methods are: Demand Side Approach, Supply Side Approach and Computer Model. However the best method to be used in this project is the second method that is Supply Side Approach because this method can size the storage properly in areas where the rainfall is of uneven distribution. The tank is sized in such the way that it can store water during the rainy season and supply it during the dry season.

Besides the advantage that rainwater harvested from this rainwater harvesting system can be reused (rainwater used for watering gardens, washing cars and flushing toilets), this system can also helps in urban stormwater management (control flash flood).

Reports on flash floods in urban areas are on the rise. This situation is caused by the total impervious areas is very high since the housing developers only have to obey to an open space of 10%. Surely the developers will go for the maximum built up areas to maximise land use and of course the maximum profits. The traditional approach of widening the rivers and drains to cater for increased discharges is not sustainable because the urban flooding problems will grow with time (Abdullah, Mohamed, 1998). It is a known fact that urbanisation increases urban runoff and makes urban areas highly prone to flash floods. This is due to the increase in paved surfaces resulting in rapid runoff and little infiltration.

Stormwater should be regarded as an asset and a resource to be valued, and not as an annoyance that need to be disposed of as quickly as possible. The local community can help to reduce the quantity of urban runoff by rainwater harvesting. The stored water can be used for watering gardens, washing cars and flushing toilets which do not required treated water. This can ease the water supply demand.

The new Urban Stormwater Management Manual for Malaysia 2000 (Manual Saliran Mesra Alam, MSMA), is based on the latest development in stormwater management that is known as control-at-source approach. This approach utilizes detention/retention, infiltration and purification processes. Hoping that the quality and quantity of the runoff from developing area can be maintained to be the same as predevelopment condition.

The benefits of using control-at-source method are:

i. Drain size needed in the urban area is smaller and comparable with the predevelopment condition;
ii. Stormwater runoff effect is reduced;
iii. There is an integration of environmental friendly drainage infrastructures and the landscape, developing natural harmony. As an example, if a swale (ground drainage which is covered with grasses) is constructed to replace concrete drain at the road side, it can function as stormwater discharge storage agent and filter pollutants from non-point source such as grease from vehicles. The swale also can be part of landscaped area that will be decorated with trees and flower plants.

Stormwater collection tank and retention pond, described in the Stormwater Collection Guidelines published by Housing and Local Government Ministry in 1998 and Guidelines for Retention Pond Area as Part of Open Space published by Department of Town and Rural Planning (*Piawaian Perancangan JPBD 4/97*), are among the suitable methods that can be used as control at source infrastructures.

The stormwater quantity control is done with two major concepts: detention and retention (MSMA, 2000). The detention concept is the most common concept used in urban stormwater drainage systems to limit the peak outflow rate. The primary function of detention facilities is to reduce peak discharge by the temporary storage and gradual release of stormwater runoff. While retention facilities reduce runoff volume, and peak discharge, by the temporary storage. Retention facilities, which provide for slow release of stormwater over an extended period of several days or more, are also referred to as extended detention facilities. Both detention and retention facilities are use to reduce the peak and volume of runoff from a given catchments. The difference between them is that the detention concept releases the water with a control structure or a release mechanism, while the retention concept release the water through evaporation and infiltration only. With the reduce of peak outflow, the probability of flash flood in urban area is hoped to be reduced.

Rainwater harvesting system is similar to these two methods which the rainwater is collected and release. In this system, the collected rainwater is utilised in useful manner rather than just releasing it to the drains or letting it to evaporate and infiltrate into the ground.

2.2 HIGH RISE BUILDING

2.2.1 CHARACTERISTICS

The main difference between low and high rise building is the influence of the wind forces on the behaviour of the structural elements. The horizontal loads are the main factor in the structural design of a high rise building. Lateral deflections of a high rise building happened when it exceeds the allowable sway due to applied lateral loads. The analysis of high rise building is to determine the influence of applied loads on forces and deformations in the individual structural elements such as beams, columns and walls.

Instability of a high rise building may occur by many reasons such as slenderness, excessive axial loads and deformations, cracks, creep, shrinkage, temperature changes and rotation of foundations (Hoenderkamp, 1990).

2.2.2 ASSUMPTIONS FOR ANALYSIS

The development of efficient methods of analysis for high rise buildings is possible only if the usual complex combination of many different types of structural members can be reduced or simplified whilst still representing accurately the overall behaviour of the structure (Hoenderkamp, 1990).

Simplifying assumptions are necessary to reduce the problem to a viable size. The ones adopted in forming a particular model will depend on the arrangement of the structure, its anticipated mode of behaviour, and the type of analysis (Coull and Smith, 1991).

2.2.3 STABILITY OF STRUCTURE

In its overall behaviour a high-rise building resembles a cantilever column of moderate slenderness ratio. The potential modes of overall buckling include flexural mode, shear mode and combined flexural-shear mode (Coull and Smith, 1991). Coull and Smith (1991) have shown the methods for determining the overall buckling load. According to BS 8110: Part 2: 1985 Section 3.2.1.1, structural members that are visible, the deflection should not exceed $l/250$, where l is the span or the length. The total gravity load on a high rise building is usually a small proportion of the load that would be required to cause overall buckling. The more serious stability consideration concerns the horizontal loading.

2.2.4 WIND LOAD

The lateral loading due to wind is the major factor that causes the design of high-rise building to differ from those of low- to medium-rise buildings. For buildings up to about 10 stories and of typical proportions, the design is rarely affected by wind loads. Above this height, however, the increase in size of the structural members, and the possible rearrangement of the structure to account for wind loading, incurs a cost premium that increases progressively with height.

MS 1553:2002 sets out procedures for determining wind speeds and resulting wind actions to be used in the structural design for structures subjected to wind action other than those caused by tornadoes and typhoons. MS 1553:2002 covers structures within the following criteria:

1. building less than 200 m high;
2. structures with roof spans less than 100 m;
3. structures other than off-shore structures, bridges and transmission towers.

BS 8110: Part 2: 1985 also stated that excessive accelerations under wind loads that may cause discomfort or alarm to occupant should be avoided in Section 3.2.2.1.

CHAPTER 3 METHODOLOGY

3.1 MODEL USED

An existing high rise building at Lot PT31431, Bukit Lanjan, Mukim Sungai Buloh, Daerah Petaling, Selangor Darul Ehsan is selected to be modelled and analysed. It is a 20 storey residential building, consists of 270 unit of service apartment. The building is 77.0 m height and 59.35 m x 22.75 m in plan. This building is selected because it is a common high rise building in urban area in Malaysia. The typical floor plan of the building is shown in Figure 3.1.

This model is constructed and assessed for the impact of rainwater harvesting storage tank load under wind action by using EsteemPlus 6.2.

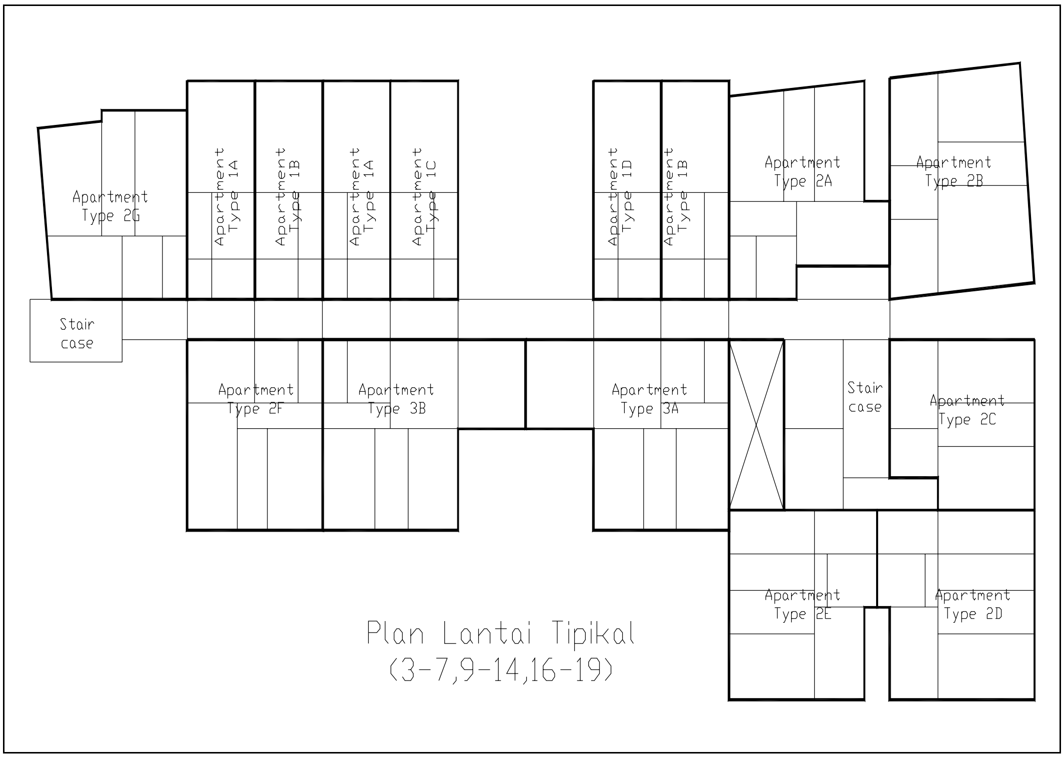

Figure 3.1: Typical Architectural Floor Plan

3.2 IMPOSED LOAD

The imposed loads used are referred to BS 6399: Part 1: 1996. The imposed loads used are the minimum values stated in Table 1: Minimum imposed floor loads, in the standard mentioned above. Table 3.1 below, summarises the values suggested from BS 6399: Part 1 (Table 1) that is adopted in this project.

Table 3.1 Minimum Imposed Floor Loads (BS 6399: Part 1: 1996, Table 1)

Type of activity/occupancy for part of the building or structure	Examples of specific use	Uniformity distributed load kN/m^2
A) Domestic and residential activities	Bedrooms in hotels and motels	2.0
	Toilet areas	2.0
	Balconies	1.5
E) Warehouse and storage areas. Areas subject to accumulation of goods. Areas for equipment and plant.	Cold storage	5.0
	Plant rooms, boiler rooms, fan rooms, etc., including weight of machinery.	7.5
F) Vehicle and traffic areas	Parking for cars, light vans, etc. not exceeding 2500 kg gross mass, including garages, driveways and ramps	2.5

3.3 WIND LOAD

The wind load applied is calculated by referring to MS 1553:2002 Code of Practice on Wind Loading for Building Structure. In the analysis, the wind action is assumed to be perpendicular to the 59.35 m face as shown in Figure 3.2.

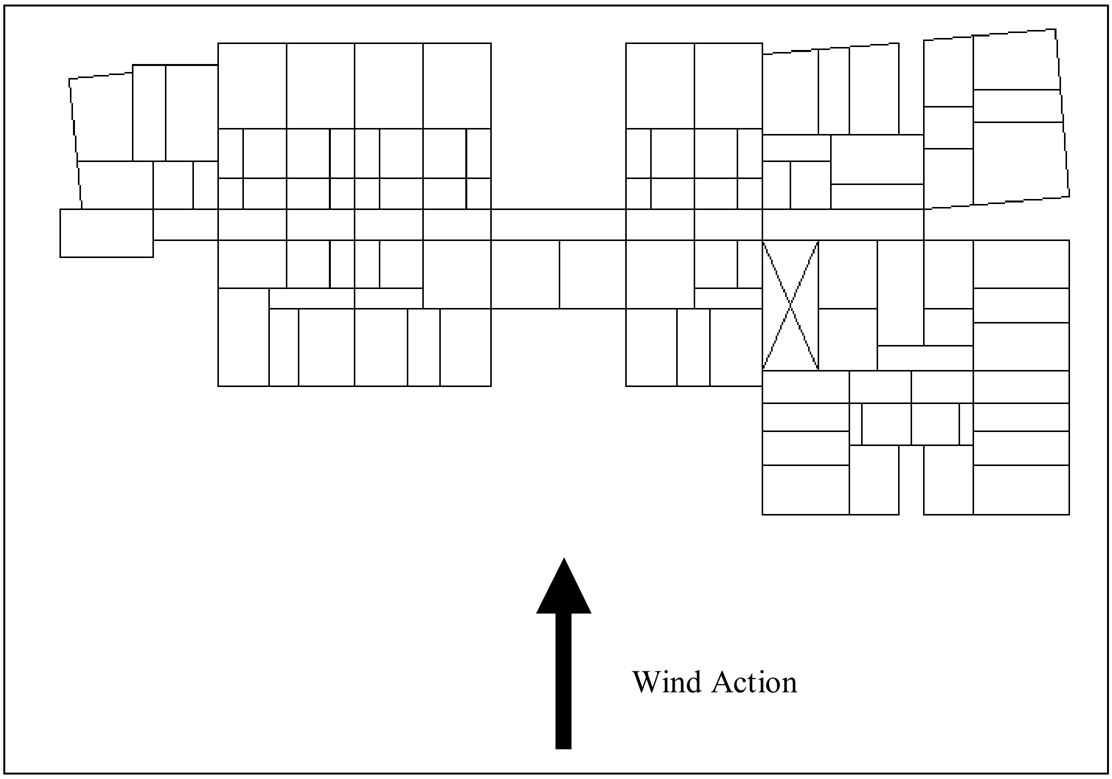

Figure 3.2: Direction of Wind Action

Some important site backgrounds of this project considered in calculating wind pressure are as follow:

Location : Petaling Jaya

Topography : Homogeneueous

Terrain : Urban

Dimensions : 77.0 m height, 59.35 m x 22.75 m in plan

(a) Site Wind speed

The site wind speeds, V_{sit} is defined at the level of the average roof height above ground by the expression:

$$V_{sit} = V_s(M_d)(M_{z,cat})(M_s)(M_h) \qquad (3.1)$$

Basic wind speed, V_s = 33.5 m/s (Zone I) (MS1553:Figure 3.1)

Wind directional multiplier, M_d = 1.0 (MS1553:Clause 2.2)

Shielding multiplier, M_s = 1.0 (MS1553:Clause 4.3.1)

Hill shape multiplier, M_h = 1.0 (MS1553:Clause 4.4)

Terrain/height multiplier, $M_{z,cat}$: vary with height, z (MS1553:Table 4.1)

$$\therefore V_{sit} = 33.5\ M_{z,cat}$$

(b) Design wind speeds

The building design wind speeds, V_{des} is taken as the maximum site wind speed, V_{sit} multiplied by the importance factor, I.

$$V_{des} = V_{sit} \times I \qquad (3.2)$$

Importance factor, I = 1.15 (Category of structures; III)

(MS1553:Table 3.2)

(c) Design wind pressure

The design wind pressures, in Pascal, is determined for structures and parts of structures using the following equation:

$$P = (0.5\rho_{air})(V_{des})^2\ C_{fig}\ C_{dyn} \quad N/m^2 \qquad (3.3)$$

ρ_{air} = density of air which can be taken as 1.225 kg/m^3

$0.5\rho_{air}$ = 0.613 (This value is based on standard air conditions and typical ground level atmospheric pressure).

C_{fig} = aerodynamic shape factor

Dynamic response factor, C_{dyn} = 1.0 (shall be taken as 1.0 unless the structure is wind sensitive)

(i) For external pressure

$$C_{fig} = C_{p,e} K_a K_c K_l K_p \quad (3.4)$$

(ii) For internal pressure

$$C_{fig} = C_{p,i} K_c \quad (3.5)$$

Internal pressure coefficient, $C_{p,i}$

$C_{p,i}$ = -0.3 or 0.0 whichever with the more severe for combined forces (MS 1553:Table 5.1(a)

External pressure coefficient, $C_{p,e}$ (MS 1553: Table 5.2)

$C_{p,e}$ = 0.8 (windward wall)

$C_{p,e}$ = -0.27 (Wind acting perpendicular to the 59.35 m face with d/b = 2.61) (leeward wall)

$C_{p,e}$ = -0.65 (side walls)

Area reduction factor, K_a (MS 1553: Table 5.4)

K_a = 1.0 (windward wall and leeward wall)

K_a = 0.8 (sidewalls)

Combination factor, K_c (MS 1553: Table 5.5)

K_c = 1.0

Local pressure factor, K_l (MS 1553: Table 5.6)

K_l = 1.0

Porous cladding reduction factor, K_p (MS 1553: Clause 5.4.5)

$K_p = 1.0$

(d) Summary of calculation

(i) External Pressure

The calculation for external wind pressure on windward walls and side walls are tabulated in Table 3.2 and Table 3.3 respectively. But, MS 1553 Clause 2.4.2 stated that the minimum design wind load = 0.65 kN/m^2. Therefore, $P_{e,ww}$ for Ground Floor to 13th Floor is taken as 0.65 kN/m^2.

Table 3.2: Calculation Sheet of External Wind Pressure on Windward Walls, $P_{e,ww}$.

Floor	Height (m)	$M_{z,cat}$	V_{des} (m/s)	windward wall	
				$C_{p,e}$	$P_{e,ww}$ (kN/m^2)
plant room	77.0	1.03	39.681	0.8	0.772
20	73.5	0.98	37.755	0.8	0.699
19	70.0	0.98	37.755	0.8	0.699
18	66.5	0.98	37.755	0.8	0.699
17	63.0	0.98	37.755	0.8	0.699
16	59.5	0.98	37.755	0.8	0.699
15	56.0	0.98	37.755	0.8	0.699
14	52.5	0.98	37.755	0.8	0.699
13	49.0	0.90	34.673	0.8	0.590
12	45.5	0.90	34.673	0.8	0.590
11	42.0	0.90	34.673	0.8	0.590
10	38.5	0.85	32.746	0.8	0.526
9	35.0	0.85	32.746	0.8	0.526
8	31.5	0.85	32.746	0.8	0.526
7	28.0	0.80	30.820	0.8	0.466
6	24.5	0.80	30.820	0.8	0.466
5	21.0	0.80	30.820	0.8	0.466
4	17.5	0.75	28.894	0.8	0.409
3	14.0	0.75	28.894	0.8	0.409
2	10.5	0.75	28.894	0.8	0.409
1	7.0	0.75	28.894	0.8	0.409
ground floor	3.5	0.75	28.894	0.8	0.409

Table 3.3: External Wind Pressure on Side Walls, $P_{e,sw}$.

Horizontal dist. from windward edge. (m)							
0 to 77.0		77.0 to 154.0		154.0 to 231.0		> 231.0	
$C_{p,e}$	$P_{e,sw}$ (kN/m^2)	$C_{p,e}$	$P_{e,sw}$ (kN/m^2)	$C_{p,e}$	$P_{e,sw}$ (kN/m^2)	$C_{p,e}$	$P_{e,sw}$ (kN/m^2)
-0.65	-0.502	-0.5	-0.386	-0.3	-0.232	-0.2	-0.154

The external wind pressure on leeward wall is given as

$$P_{e,lw} = -0.261 \text{ kN/m}^2$$

(ii) Internal Pressure

The internal pressure for all the walls is

$$P_i = -0.206 \text{ kN/m}^2$$

3.4 RAINWATER HARVESTING STORAGE TANK

3.4.1 RAINFALL

The total volume of rainwater collected is dependent on the roof collection areas, monthly average rainfall and the runoff coefficient of the roof materials. The rainfall data used in this project is sourced from Malaysian Meteorological Service record as given in Table 3.4.

Table 3.4: Average Rainfall for Petaling Jaya Area (MMS, 2005)

Month	Record Period	Monthly Total (mm)		
		Current	Past Average	Highest Recorded
January	1971-2004	292.0	195.8	530.4(2001)
February	1971-2004	128.6	210.5	498.1(1984)
March	1971-2004	263.3	271.5	513.8(1997)
April	1971-2004	245.6	275.8	507.3(1989)
May	1971-2004	305.4	235.1	565.9(1973)
Jun	1971-2004	24.0	138.9	262.3(1996)
July	1971-2004	386.0	145.9	297.2(2003)
August	1971-2004	53.8	167.0	454.2(1998)
September	1971-2004	409.8	202.0	363.9(1988)
October	1971-2004	125.0	281.9	602.3(1987)
November	1971-2004	600.8	334.3	661.4(1997)
December	1971-2004	370.5	264.9	455.0(1991)

The following is the calculation for estimating the rooftop rainwater that can be collected annually and monthly.

Average annual rainfall = 2.724 m

Roof size = 56.0 m * 27.27 m = 1527.12 m^2 of rainwater catchments area

Runoff Coefficient = 0.9 (for new corrugated GI roof)

Therefore,

Annual available water (assuming all is collected) = 1527.12*2.724*0.9

= 3743.9 m^3

Monthly available water = 3743.9/12

= 312 m^3

3.4.2 WATER DEMAND

For a household of six person, monthly usage for toilet flushing and general cleaning is 4650 litre (Shaaban, ec. al., 2002). Due to the size of household provided by the service apartment, the average of occupant for each dwelling unit is four persons. Therefore the monthly rainwater use by the Service Apartment for:

1 household with 4 occupants = 775 x 4

= 3,100 L

= 3.1 m^3

1 floor with 15 households = 3.1 x 15

= 46.5 m^3

The monthly collected rainwater serve approximately 100 households. This means that the RRWH system installed at the service apartment is only limited to 37 % households each month. However, the harvested rainwater will be distributed equally to all the households. The balance demand will be coped by piped water.

3.4.3 Storage Tank Sizing

As stated in Section 2.1, the method adapted to size storage tank is supply-side method recommended by University of Warwick, UK. The calculation is shown in Table 3.5, Figure 3.3 and 3.4.

Table 3.5: Spreadsheet Calculation For Sizing The Storage Tank

Month	Rainfall (mm)	Rainwater Harvested (m^3)	Cumulative Rainwater Harvested (m^3)	Demand (m^3)	Cumulative Demand (m^3)	Difference between Col 4 & 6 (m^3)
Oct	281.9	380.565	380.565	310	310	70.565
Nov	339.3	458.055	838.62	310	620	218.62
Dec	268.1	361.935	1200.555	310	930	270.555
Jan	195.8	264.33	1464.885	310	1240	224.885
Feb	208	280.8	1745.685	310	1550	195.685
Mar	271.5	366.525	2112.21	310	1860	252.21
Apr	305.6	412.56	2524.77	310	2170	354.77
May	235.1	317.385	2842.155	310	2480	**362.155**
June	138.9	187.515	3029.67	310	2790	239.67
July	145.9	196.965	3226.635	310	3100	126.635
Aug	167	225.45	3452.085	310	3410	42.085
Sept	202	272.7	3724.785	310	3720	4.785

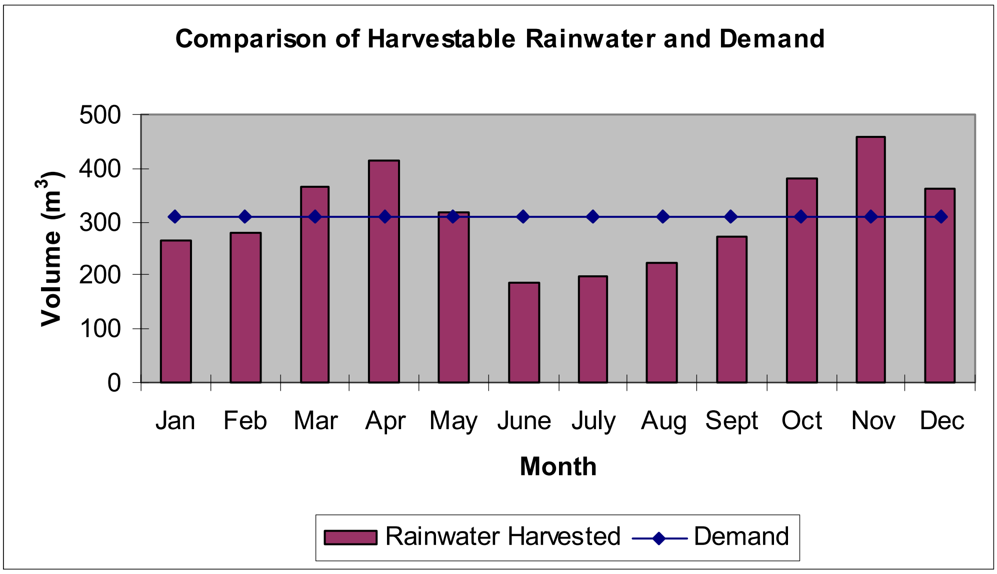

Figure 3.3: Comparison of Harvestable Rainwater and Demand

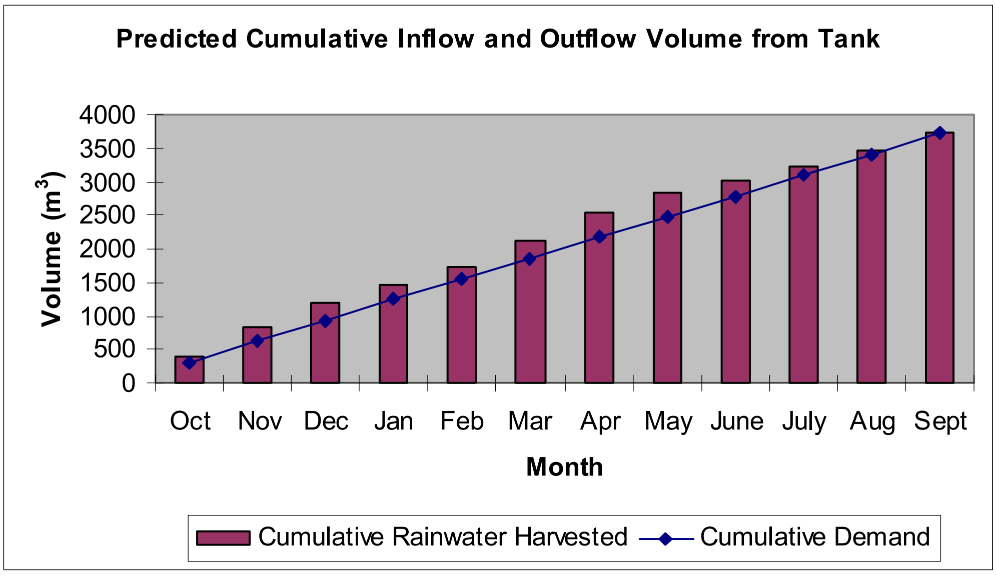

Figure 3.4: Predicted Cumulative Inflow and Outflow Volume from Tank

Five design of rainwater harvesting system storage tanks are proposed. The locations and sizes of tanks are shown in Chapter 4 for each case in Figure 4.2, Figure 4.4, Figure 4.6, Figure 4.8 and Figure 4.10.