SMALL SCALE INTEGRATED SUSTAINABLE ROOF DESIGN

Submitted in partial fulfillment of the requirements for Bachelor of Engineering in Civil Engineering

Submitted by:

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APPROVAL SHEET

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SMALL SCALE INTEGRATED SUSTAINABLE ROOF DESIGN

Abstrak

Kota Solo merupakan salah satu kota padat penduduk di Indonesia. Setiap tahun populasi kota ini terus bertambah. Dari Biro Pusat Statistik Surakarta, Kepadatan Penduduk Kota Solo mencapai 12.000 jiwa per satu kilometer perseginya. Hal tersebut tentu berpengaruh terhadap besarnya kebutuhan sumber daya air bersih yang semakin meningkat serta berkurangnya daerah resapan air hujan yang dapat mengakibatkan bencana alam seperti banjir dan tanah longsor. Sehingga diperlukan inovasi desain atap berkelanjutan khususnya pada rumah tinggal sederhana agar mudah diaplikasikan. Rumah sederhana tersebut di desain dengan tipe 70/120 dan berisikan 4 orang. Adapun komponen atap berkelanjutan tersebut adalah atap hijau ekstensif berukuran panjang 5.1 meter dan lebar 2.3 meter menggunakan rumput sedum, aplikasi penanaman air hujan dengan kapasitas 22.000 liter yang digunakan untuk memenuhi kebutuhan air bersih penghuni rumah, serta listrik untuk sebuah pompa yang menggunakan tenaga panel surya bertenaga 100 wp.

Kata kunci: Atap Berkelanjutan, Atap Hijau, Panel Surya, Penanaman Air Hujan

Abstract

The city of Solo is one of the densest cities in Indonesia. Every year the city's population continues to grow. From the Surakarta Central Bureau of Statistics, the population density of Solo City reaches 12.000 people per one square kilometer. This certainly affects the magnitude of the increasing demand for clean water resources and the reduction of rainwater catchment areas which can lead to disasters such as floods and landslides. So, we need a sustainable roof design innovation, especially in residences is simple to be easily applied. This simple house is designed with type 70/120 and contains 4 people. The sustainable roof component is an extensive green roof measuring 5.1 meters long and 2.3 meters wide using sedum grass, an application of rainwater harvesting with a capacity of 22,000 liters that is used to fill the needs of clean water for residents, as well as electricity for a pump that uses powered solar panel 100 wp.

Keywords: Sustainable Roof, Green Roof, Solar Panel, Rainwater Harvesting

1. INTRODUCTION

وَلَا تُفۡسِدُواْ فِي ٱلۡأَرۡضِ بَعۡدَ إِصۡلَٰحِهَا وَٱدۡعُوهُ خَوۡفٗا وَطَمَعًاۚ إِنَّ
رَحۡمَتَ ٱللَّهِ قَرِيبٞ مِّنَ ٱلۡمُحۡسِنِينَ ٥٦

“And do not cause damage on the earth, after (Allah) repairs it and pray to Him with fear (will not be accepted) and hope (will be granted). Surely the mercy of Allah is very near to those who do good.” (Al-A’raf/7:56).

Every year the population of this city continues to grow. According to data taken from the Surakarta Central Bureau of Statistics the Population Density of Solo City reaches 12,000 inhabitants per one square kilometer. That is certainly a big influence on natural resource needs that are increasing every day. Besides that global warming is one of the biggest impacts of the destruction of this earth. So that awareness of environmental hazards and scarcity is needed. Only wise plans will allow humans to enjoy progress. Therefore we need a simple design that can change the environment. With a sustainable roof theme, an important component of an eco-friendly house is obtained. The green roof is the roof of a building partially or completely covered with vegetation and growing media, planted on a waterproof membrane. It also includes additional layers such as root barriers and drainage as an irrigation system. In general, the benefits of green roofs are to reduce the level of air pollution, reduce air temperature, conserve water, reduce noise / noise pollution, display the beauty of aspects of the building (aesthetics), and increase the biodiversity of the city. Equipped with rainwater harvesting which is expected to be able to overcome two problems at once, namely preventing the risk of flooding and meeting clean water needs. Also solar panels are devices that consist of solar cells that convert light into electricity. They are called solar over the Sun because the Sun is the strongest light source that can be utilized Solar cells on photovoltaic effects to absorb solar energy and cause currents to flow between two opposite charged layers. The installation of solar cells is effective because the territory of Indonesia is in the tropics.

2. METHOD

2.1 **Site of Research**

The location of the study reviewed is shown in Figure 1. The location under study is Surakarta, Pabelan, Central Java. Show some watersheds in Surakarta for research in Figure 2 and Figure 3.

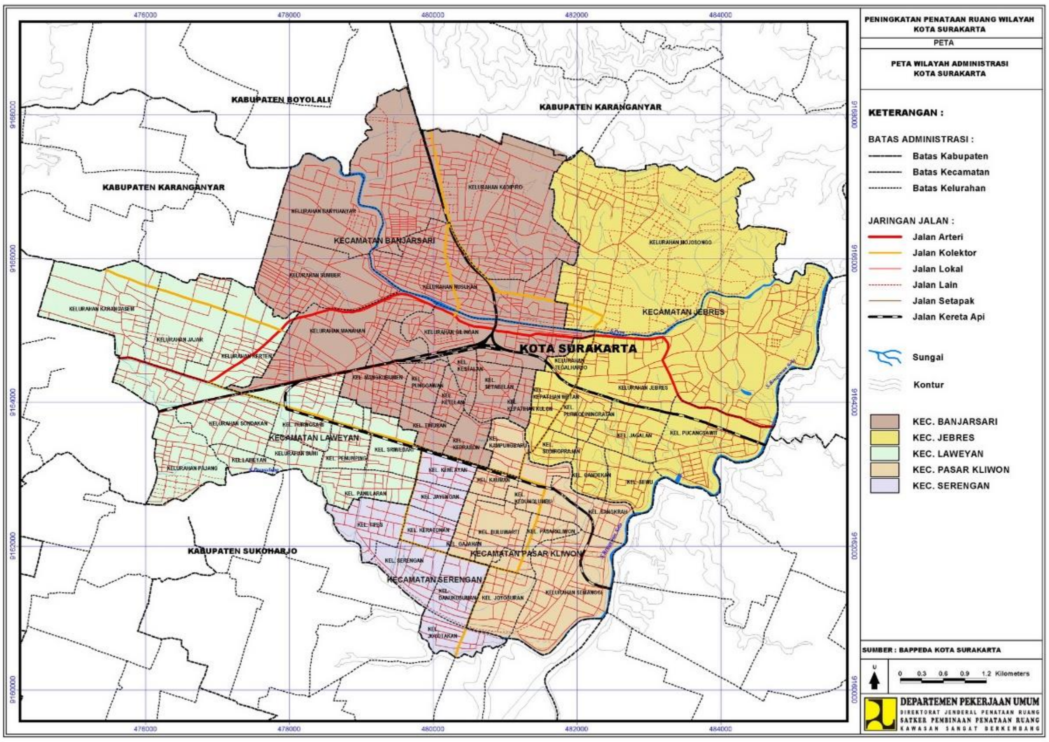


Figure 1. Map of research location

(Source: https://www.google.co.id)

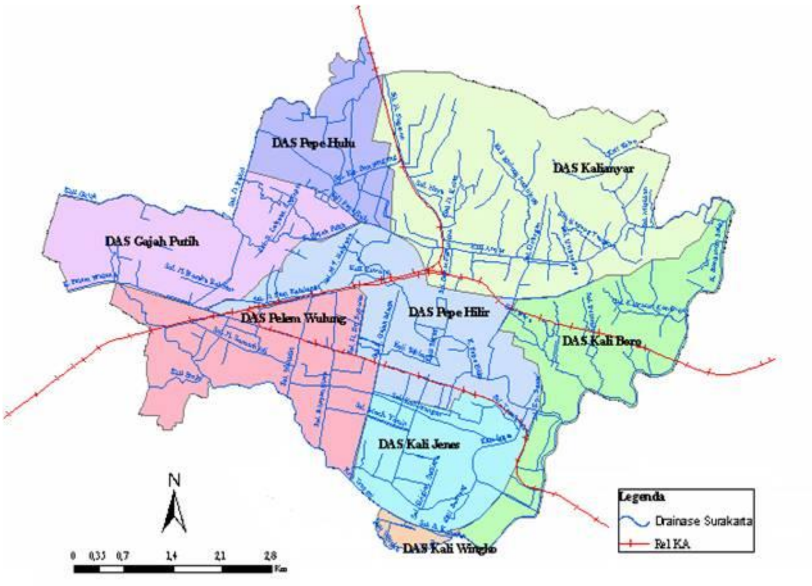


Figure 2. Map of watersheeds

(Source: https://www.google.co.id)

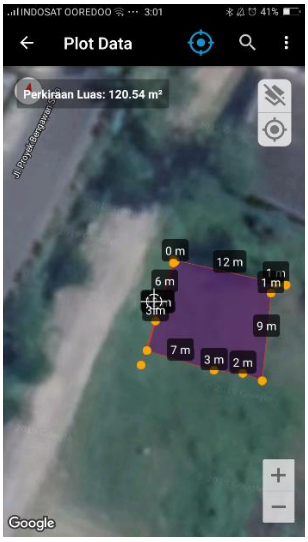


Figure 3. Map of detail location of study area

(Source : Badan Pertanahan Nasional)

2.2 Method of collecting data

In this study, data collection to collect rainfall data by request to the BBWS (Balai Besar Wilayah Sungai) on Area of watershed of Bengawan Solo. Rainfall data obtained is rainfall data at Sta Pabelan, Sta. Munggur, Sta. Palur and Sta. Masaran. Where each rainfall post has 15 years of rainfall data from 2004 to 2018.

For data in the form of area studies obtained through the touch application of land owned by BPN (National Land Agency). So that we get the right size and location.

3. RESULT AND DISCUSSION

3.1 Consistency Test

One series of rain data for one particular station, it is possible that it is not inconsistent. This kind of data cannot be analyzed directly because actually the data in it comes from different data populations. There are four rain gauge stations around / on the same watershed with a rainfall station in the Pabelan area. But in this study using two rain gauge stations with the closest distance and the most complete data balanced with the Pabelan rain post data, namely, Munggur, Palur, and Masaran.

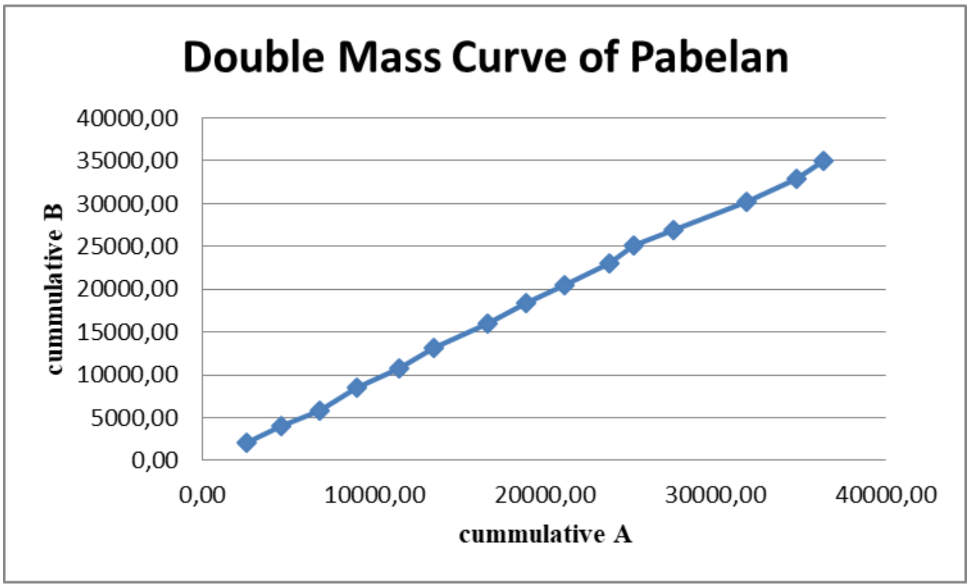
A. Double Mass Curve Method

Rainfall Data of Sta Pabelan and Sta. Index

Table 1 Commulative data Sta. Tested and Sta. Index

Year	Sta.Pabelan (A) (mm)	Sta.Index (C)	Cumulative	
			(A)	(C)
2004	2526	2037,00	2526,00	2037,00
2005	2087	1923,33	4613,00	3960,33
2006	2240	1845,67	6853,00	5806,00
2007	2199	2683,67	9052,00	8489,67
2008	2426	2288,33	11478,00	10778,00
2009	2045	2324,67	13523,00	13102,67
2010	3136	2903,67	16659,00	16006,33
2011	2243	2327,00	18902,00	18333,33
2012	2241	2119,67	21143,00	20453,00
2013	2646	2568,67	23789,00	23021,67
2014	1475	2023,67	25264,00	25045,33
2015	2317	1927,67	27581,00	26973,00
2016	4259	3286,00	31840,00	30259,00
2017	2929	2619,00	34769,00	32878,00
2018	1560,6	2144,33	36329,60	35022,33

(Source : BBWS Bengawan Solo)



Graph 1 : Linear regression chart for Sta. Pabelan towards Sta. Index

$$r = \frac{n.\sum xy - \sum x \sum y}{\sqrt{\left\{n.\sum x^2 - \left(\sum x\right)^2\right\}}\sqrt{\left\{n.\sum y^2 - \left(\sum y\right)^2\right\}}}$$

r = 0.998

From the results of the linear regression analysis above it can be concluded that the rainfall data of Pabelan, Munggur, Palur, and Masaran on rainfall observation stations can be said consistently with other observation post data as a comparison, because the correlation coefficient (r) has a value near 1 (one).

B. RAPS (Rescaled Adjusted Partial Sums) Method)

Table 2 Commulative data of Sta. Pabelan

Year	Rainfall Data	SK	Cummulative SK	StandardDeviation	SK**	|sk**cummulative|
2004	632,00	8,70	8,70	144,91	0,06	0,060
2005	573,00	-50,30	-41,60	144,91	-0,29	0,287
2006	569,00	-54,30	-95,90	144,91	-0,66	0,662
2007	491,00	-132,30	-228,20	144,91	-1,57	1,575
2008	644,00	20,70	-207,50	144,91	-1,43	1,432
2009	598,00	-25,30	-232,80	144,91	-1,61	1,607
2010	732,00	108,70	-124,10	144,91	-0,86	0,856
2011	630,00	6,70	-117,40	144,91	-0,81	0,810
2012	559,00	-64,30	-181,70	144,91	-1,25	1,254
2013	511,00	-112,30	-294,00	144,91	-2,03	2,029
2014	511,00	-112,30	-406,30	144,91	-2,80	2,804
2015	691,00	67,70	-338,60	144,91	-2,34	2,337
2016	1013,00	389,70	51,10	144,91	0,35	0,353
2017	786,00	162,70	213,80	144,91	1,48	1,475
2018	409,50	-213,80	0,00	144,91	0,00	0,000

Table 3 values of R$\sqrt{n}$ and Q$\sqrt{n}$

N	Q/√n			R/√n		
	90%	95%	99%	90%	95%	99%
10	1.05	1.14	1.29	1.21	1.28	1.38
20	1.1	1.22	1.42	1.34	1.43	1.6
30.00	1.12	1.24	1.46	1.40	1.50	1.70
40.00	1.13	1.26	1.50	1.42	1.53	1.74
50.00	1.14	1.27	1.52	1.44	1.55	1.78
100.00	1.17	1.29	1.55	1.50	1.62	1.86
~	1.22	1.36	1.63	1.62	1.75	2.00

(Source : Analisis Hidrologi, Sri Hartono Br, 1993)

R_{table} = R (90%) $\sqrt{n}$ = 1.21 + $(\frac{15-10}{20-10})$ (1.34-1.21) $\sqrt{15}$ = 19.125

$R_{calculation}$ = SK**max – SK**min = 2.804-0.000 = 2.804

Q_{table} = Q (90%) $\sqrt{n}$ =1.05 + $(\frac{15-10}{20-10})$ (1.1-1.05) $\sqrt{15}$ = 4.16

$Q_{calculation}$ = max (SK**) = 2.804

The results of the count of R and Q are calculated to be smaller than Q and R tables of values of R$\sqrt{n}$and Q$\sqrt{n}$, it can be concluded that the data at Sta. Pabelan is inconsistent data. But it can still be used because the data originates from the same data population.

3.2 Green Roof

A. Type of Green Roof

Because the theme of this research is environmentally friendly conventional house, so an extensive type of green roof is considered the most suitable for this research.

Figure 4 : Structure of extensive type of green roof

B. Selected Plants

Sedum is the most appropriate type of plant to use on an extensive type of green roof. It has the necessary compressive strength, a low profile height (for thickness of planting media), and little weight. Besides sedum does not require intense treatment, it can grow in the dry season but can absorb water well during the rainy season. In addition sedum has a wide range of colors, such as red, green, and yellow, it certainly can add to the aesthetic value of a building

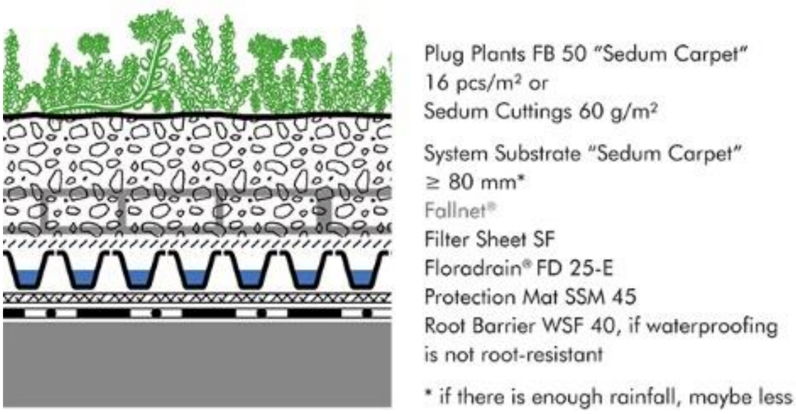


Figure 5 : Sedum system build-up

C. Design of Green Roof

1) Layer vapor barrier: is a layer that keeps the steam from the roof sub-structure not damaging the layers above it. Made of polyethylene plastic
2) Heat insulation layer: a layer that keeps the heat from the green roof from entering the building. The material used is polyurethane foam sheet which has good heat insulation character
3) The waterproofing and root barrier layer: is a waterproof coating to protect the roof sub-structure
4) Layer of draincomposite and filtration: draincomposite serves to provide space for water to drop from the ground. This space is important so that excessive water can be directly channeled to drainage or drain pipes. Meanwhile filtration serves to hold so that the wet soil exposed to water does not experience erosion and dissolves into the drainage channel
5) Substrate / soil layer: is the layer where vegetation grows
6) Vegetation / plants: types of plants used (Sedum)

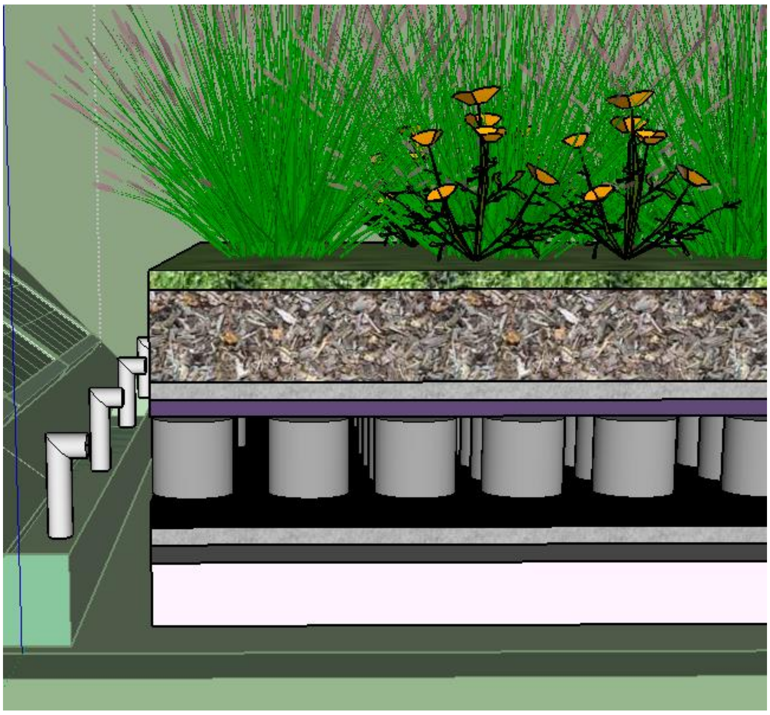


Figure 6 : Layer of green roof

Figure 7 : Design of green roof

3.3 Clean Water Needed

Table 4 Clean water needed per person

No.	Kind of Building	Daily Water Needs (Liter)	The average period of use of water a day (Hour)	Notes
1.	Real estate	250	8-100	Every Occupant
2.	Conventional Houses	120-250	8-10	Every Occupant
3.	Primary school	40	5	Teacher : 100 Lt
4.	Shophouse	100-200	8	Occupants : 120L
5.	Office building	100	8	Every worker
6.	Department Store	3	7	Just for washroom
7.	Restaurant	30	5	restaurant guests

Source (SNI 03-7065-2005)

Clean Water Neede for 4 (four) person = 120 lt x 4 = 480 lt / day

3.4 Rainwater Harvesting

A. Rainwater Harvesting System

In this study, rain water fell on the roof tiles of the house which later flowed into the gutters. From gutters, water will be channeled to rainwater harvesting using pipes. After that the water will go to the filtration process using fibers, sand and gravel with a mixture of bricks. Then water can be pumped and reused for household needs. To get rid of excess water in the rainwater harvesting, there is a drain pipe, which functions to drain excess water in the rainwater harvesting towards the drainage canal around the house.

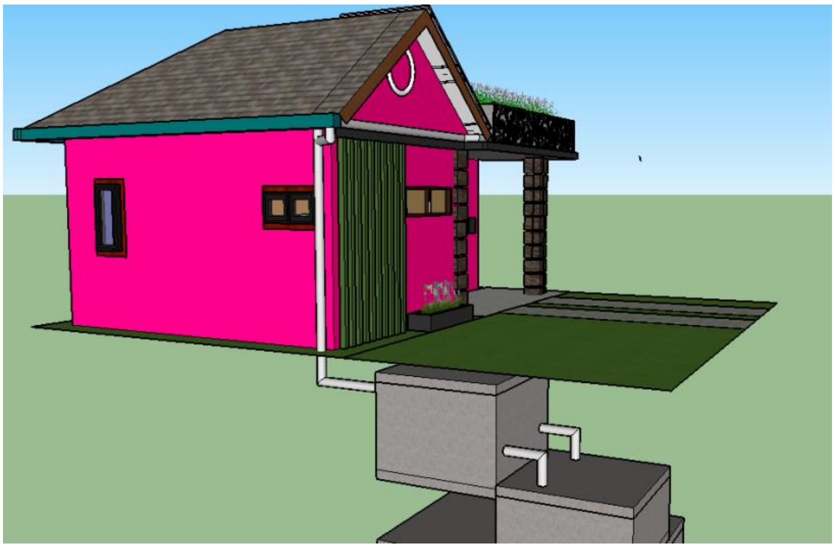


Figure 8 : Rainwater harvesting system

B. Dimention of Rainwater Harvesting

Roof Area (A) = 76.61 m^2

Runoff Coefficient (C) = 0.75 (Using Tiles Roof)

Table 5 Calculation of Rainwater Harvesting

Mounth	Rain (mm)	Rain Volume(Lt)	Total of Rain Volume (Lt)	Water Needs (Lt)	Total of Water Needsr (Lt)	Water Volume on Collecting (Lt)	Surplus or Deficit (Lt)
January	367,60	21121,38	21121,38	14880,00	14880,00	6241,38	6241,38
February	367,70	21127,12	42248,50	13920,00	28800,00	13448,50	7207,12
Mart	310,60	17846,30	60094,80	14880,00	43680,00	16414,80	2966,30
April	257,33	14785,73	74880,53	14400,00	58080,00	16800,53	385,73
May	155,23	8919,32	83799,85	14880,00	72960,00	10839,85	-5960,68
June	92,60	5320,56	89120,41	14400,00	87360,00	1760,41	-9079,44
July	50,87	2922,67	92043,08	14880,00	102240,00	0,00	-11957,33
August	11,47	658,85	92701,93	14880,00	117120,00	0,00	-14221,15
September	58,40	3355,52	96057,45	14400,00	131520,00	0,00	-11044,48
October	131,37	7548,00	103605,45	14880,00	146400,00	0,00	-7332,00
November	247,40	14214,99	117820,43	14400,00	160800,00	0,00	-185,01
December	368,77	21188,41	139008,85	14880,00	175680,00	0,00	6308,41

a. Using Maximum Value of Water Volume on Collecting

Vr = 16,800.53 liters = 16.81 m^3

Assume Height= 1 m

Maximal Width (Residual Area) = 5m

Maximal Length (Residual Area) = 10m

Width = Length = Y

16.81 m^3 = Y x Y x 1m

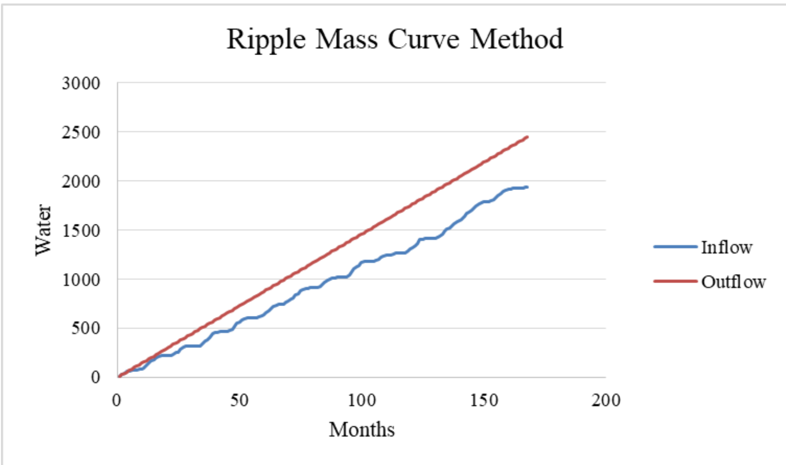
$Y^2 = \frac{16.81}{1} = 16.81$

Y = 4.1 m (it is still on the residual area)

V = 4.1 x 4.1 x 1 = 16.81 m^3 so its save for rain water harvesting.

So the size of water harvesting is 1m height, 4.1m width and 4.1m length.

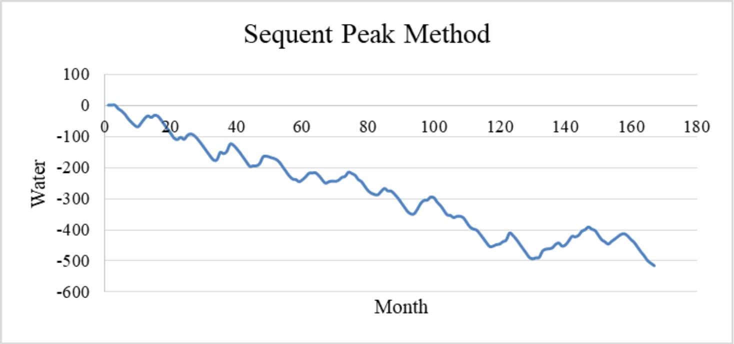
b. Using Ripple Mass Curve Method



Graph 2 Rainwater Harvesting Needed

From this graph the difference in height between the cummulative water demand and the cumulative rain line is 551.816 m^3, but the size is too large and exceeds the total area of the planned house. Retry using the sequent peak method

c. Using Sequent Peak Method



Graph 3 Rainwater Harvesting Neede on Sequent Peak

From the graph of sequent peak method the maximum differences of sequent is 516.226 m^3, but the size is too large and exceeds the total area of the planned house. So for the dimention of the rainwater harvesting we choose from maximal value of inflow, and the value of inflow is 38.32 m^3

Vr = 38,324 litters = 38.32 m^3

Assume Height= 1 m

Maximal Width (Residual Area) = 5m

Maximal Length (Residual Area) = 10m

Width = Length = Y

38.32 m^3 = Y x Y x 1 m

$Y^2 = \frac{38.32}{1} = 38.32$

Y = 6.19 m = 6.2 (it is still on the length residual area)

V = 5 x 7.7 x 1 = 38.5 m^3 so its save for rain water harvesting. But the most efficient is the first size, so the size of water harvesting is 1m height, 5 m width and 5.26 m length because is more efficient. Rainwater harvesting also has a large effect on the reduced amount of runoff water. This is because the rain water which is usually thrown away it is collected and reused. This is certainly useful to prevent floods.

3.5 The Energy Needed

Figure 9 : Detail of pump (Source : https://www.shimizu.co.id)

The criteria for pumps commonly used in residential homes are shallow well pumps. The value of the pump's criteria capacity is in the range of 28 liters per minutes if the head is 5 meters and 10 liters per minutes if the head is 20 meters. So we can conclude the capacity for 1 meter head is 56 liters / minutes

Table 6 Capacity of the pump

Head	Capacity (Litters / min)	Capacity (Litters / sec)
1	56	0.000933
5	28	0.000467
20	10	0.000167

Using the matrics from the table V.7 we can get the equation is

$0.00933\ Q^2 - 0.000467\ Q + 0.000167$

For looking the total head losses on pump, on Figure V.19 we can get the equation for every turn, so the equation is

$$H_{pump} = 1.4 + (0.5+1.27+1.27+1.27+0.32)\,\frac{V2}{2g}$$

$$H_{pump} = 1,4 + 4.63\,\frac{Q2/A2}{2g}$$

$H_{pump} = 1.4 + ((5.282 \text{ x } 10^6)\text{-}7)\ Q^2$

And then input the first qution into the second eqution

H = H

$0.00933\ Q^2 – 0.000467\ Q + 0.000167 = ((5.282 \text{ x } 10^6)\text{-}7)\ Q^2$

And got Q = 0.000955 m^3

So the total head loss is = 2.80

And for total energy

$$\frac{Q\ x\ Htotal\ x\ \delta w}{\tau}$$

$$\frac{0.000955\ x\ 2.80\ x\ 9810}{0.7} = 37.278\ watt$$

So the energy needed per day for a pump is 37.278 watt

3.6 The Solar Panel Needed

WP Solar Cell 100 WP module provides increased efficiency through the use of the latest Polycrystalline cells, making it ideal for battery charging applications. This has proven performance at high temperatures and a strong design that makes the product durable in the field and easy for installation. Solar cell 100 WP means that the solar cell has 100 watt peaks (during the maximum hot sun) Peak one day for four hours so the will produce 100 x 4 = 400 watt hour / day is the maximum capacity for one day usage. Because of energy the pump need just 37.278 watts so we just use one unit of Polycrystalline.

Spesifikasi	Keterangan
Max. Power (Pmax)	100W
Max. Power Voltage (Vmp)	17.5V
Max. Power Current (Imp)	5.71A
Open Circuit Voltage (Voc)	21V
Short Circuit Current (Isc)	6.4A
Nominal Operating Cell Temp (NOCT)	45±2°C
Max. System Voltage	1000V
Max. Series Fuse	16A
Weight	7.55Kg
Dimension	1085 x 675 x 25 mm

Figure 10 : Detail of solar panel (Source : http://panelsuryajakarta.com)

4. CONCLUSIONS

the results of the analysis it can be concluded as follows:

4.1 The type of roof is 70 / 120 with 4 people inside with the area of roof is 76.61 m^2 and the water neede for one day is 480 liters.

4.2 The type of green roof chosen is extensive by choosing the type of plant namely sedum grass. The simple green roof plate measuring 2.3m x 5.1m

4.3 The selected rainwater harvesting capacity is 22,000 litters with the size is 4.10 m long, 4.10 m wide and 1m high.

4.4 The pump using one unit shallow well Shimizu PL – 138 BIT and the energy needed for the pump per is 37.278 watt. The selected solar panel is one unit Solar Panel 100 WP Shinyoku Polycrystalline. Solar cell 100 wp means that the solar cell has 100 watt peaks (during the maximum hot sun) Peak 1 day for 4 hours so that 100 x 4 = 400 watt hour / day is the maximum capacity for 1 day usage.

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