© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

E-SPAH: Aesthetic Innovation in UTHM's Small-scale Rainwater Harvesting System

Muhamad Faizal Mostaffa[1], Sharifah Meryam Shareh Musa[1]*, Rozlin Zainal[1], Narimah Kasim[1], Hamidun Mohd Noh[1] , Azlina Md Yassin[2]

[1]Department of Construction Management, Faculty of Technology and Management
Universiti Tun Hussein Onn Malaysia, Johor, MALAYSIA

[2]Department of Real Estate Management, Faculty of Technology and Management
Universiti Tun Hussein Onn Malaysia, Johor, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2021.13.05.025
Received 23 June 2021; Accepted 23 August 2021; Available online 24 November 2021

Abstract: A rainwater harvesting (RWH) system is a method of storing rainwater for future purposes. Universiti Tun Hussein Onn Malaysia (UTHM) has implemented this effort on some of the buildings in Main Campus, Parit Raja. However, this system has the weakness that caused the RWH system to stop from appropriately operated. Some of the RWH components are damaged because the design is not thought of thoroughly in the long term. Furthermore, the Main Campus is highly dependent on the treated water supply that caused a high amount of utility bills. Therefore, this study has highlighted the need to analyse the existing small scale RWH system in UTHM's Main Campus, identify the suitable tank form for UTHM's Main Campus' small scale RWH system, and suggest a small scale RWH system's design for outdoor purposes in Main Campus UTHM. This study has been carried out by using literature review, interview session and observation. The result shows that the small scale RWH system in UTHM Main Campus has a few strengths, weaknesses, opportunities, and threats. Cylindrical tank form is chosen to design the university's small scale RWH system. A modular RWH system with the number of tanks installed based on rainwater catchment area is suggested and named E-SPAH, a concept of RWH system that emphasises efficiency and outdoor usage. Perhaps this study would help future researchers, universities, and contractors guide future small-scale rainwater harvesting systems for outdoor purposes in UTHM's Main Campus.

Keyword: Rainwater harvesting (RWH), small scale, outdoor, design

1. Introduction

RWH system collected rainwater from the catchment area and channelled it to a storage tank before being reused for domestic purposes. For example, irrigations, washing garments, lavatories and others. Society has a high readiness to use rainwater for non-body contact rather than an activity that involved body contact [1]. However, there are different human perceptions of the utilization of rainwater for domestic purposes. In brief, rainwater has many potential advantages if the designed system works correctly and efficiently as intended.

RWH's designer in Malaysia thought that the system needs less maintenance and can be operated by itself [2]. The existing RWH system in UTHM failed to work correctly as the initial intention of the design. Because of mistakenly chosen pipe, the material eventually corroded, and pipe blockade happened. The system designed to pump stored water to lavatories required electricity and considered inefficient. The location of the tanks, which is underground, worsens the situation as it made the maintenance works difficult and accessibility is limited [3].

*Corresponding author: meryam@uthm.edu.my

The water utility bill in UTHM recorded RM 2,550,448 with water usage of 729,246m³ in 2017. While in 2018, the bill recorded is RM 2,579,895.24 with water usage of 766,237m³. In 2019 until May, the utility bill recorded is RM 1,172,756.02 with 355,434.00m3 water usage [4]. Therefore, initiatives should be done to lessen the dependency on treated water in UTHM, and one of them is to suggest an RWH system that is efficient to use.

Therefore, the study's objective is to analyse the existing small scale RWH system in UTHM's Main Campus, identify the suitable tank form for UTHM's Main Campus' small scale RWH system and suggest a small scale RWH system's design for outdoor purposes in Main Campus UTHM.

2. Literature Review

Rainwater consists of dissolved oxygen and carbon dioxide from the atmosphere, nitrogen oxide from lightning and thunder and sulphur dioxide from combustion-rainwater used for general cleaning, for example, bath and washing dishes and garments. In general, it can be used as alternative treated water usage [5].

RWH can be defined as collecting and storing rainwater to prevent it from hydrate from hydrological activity [6]. Besides, RWH refers to collecting and storing harvested rainwater either above the ground or underground and preventing it from condensation from hydrological activity [7]. Besides, it aims to reuse the water efficiently because of limited physiography.

2.1 Basic Concept of RWH

RWH can be classified into three categories, small, medium, and large scale [8]. The water from RWH can be utilised for different purposes, drinking, non-drinking with body contact and non-drinking without body contact [9]. There are six elements in RWH which are catchment area, gutter, downpipe, first flush, storage tank, and distribution and treatment system [10]. Figure 1 shows the basic component of RWH.

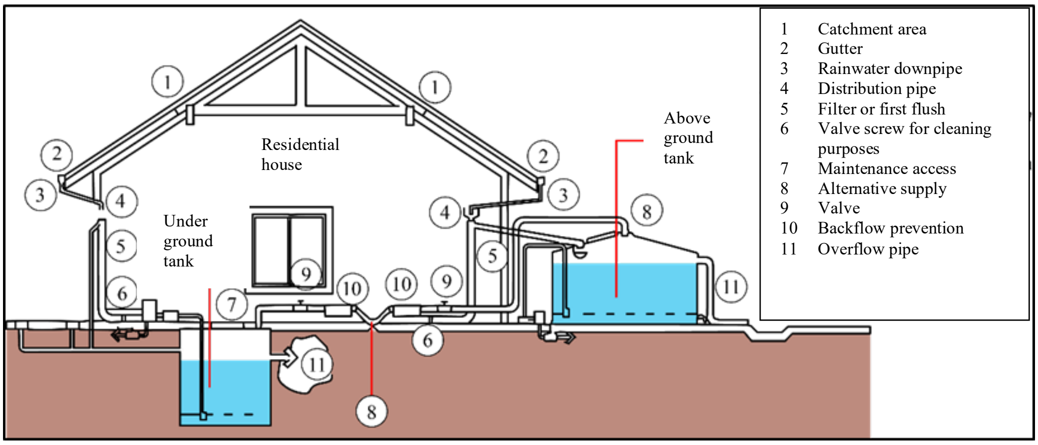
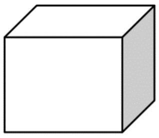
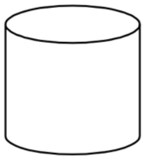
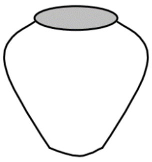


Fig. 1 - Basic RWH component (DID, 2010)

2.2 RWH Tank Form

There are three shapes of a rainwater tank, cuboid, cylinder and doubly curve [11]. These shapes affected by the volume to surface ratio and the acting force to the tank. The suitable material for the tank is crucial to ensure the tank can withstand an extended usage period. The cuboid form is the least recommended to use as a water tank. The shape fares relatively severely in terms of material used compared to storage capacity, and it is also associated with high peak stresses. The cylindrical shape deals quite well with stresses in contrast, and it has a lower ratio of walling material to the storage volume. The cylindrical shape is still easy to manufacture, a technique well suited to circular or irregular forms. The doubly curve tank is ideal for a rainwater tank since it can cope with induced stress. However, this shape needs specific skill and tool to create. Table 1 shows the comparison of different RWH tank form [11].

Table 1 - Tank form comparison

Tank shape	Pressure	Material usage	Construction
Cuboid 	It has unevenly distributed stress around the structure—high bending stress near the edges.	It has a higher ratio between material use and storage capacity than a cylindrical and doubly curves tank.	Simple construction using most of materials.
Cylindrical 	Uniformly distributed stresses with bending stress only near the bottom.	Material usage to storage capacity ratio improved. A similarly proportion cuboid has a 7.5% higher ratio.	Difficult construction with some materials such as bricks. But the shape is fit to construction with materials that bendable. For example, galvanized iron sheet.
Doubly curve 	Well distributed stress. The base of the tank is smaller diameter, both hoop stresses and bending stresses reduced.	It has good material usage to capacity ratio. Potentially savings up to 20% material usage over a cuboid.	Complicated construction as it requires custom mould. Pliable and able to curve materials in two directions is highly suggested—Ferro-cement and clay.

2.3 Steps in Designing and Implementing RWH

Rainwater harvesting systems require detailed planning, the strategic design of the tank, water treatment and distribution systems, adherence to all applicable local building codes and regulations, expert installation, and appropriate landscaping. Construction should all be completed in a precise sequence to ensure the project's success, efficiency, and cost-effectiveness, design, and permits. Active system installation, particularly the placement of large tanks and the installation of sophisticated plumbing, irrigation, and electrical components, should be handled by an experienced contractor. These are the steps in designing and implementing RWH [12]:

- Create a map of your site
- Evaluate site's watering needs
- Evaluate site's resources and challenges
- Determine whether to use passive water harvesting, active water harvesting or both
- Determine who will be installing the RWH
- Determine irrigation contractor
- Determine the aboveground tank or belowground tank
- Determine possible tank location and tank overflow location
- Determine the type, size, and composition of components
- Prepare and submit an application for tank permit
- Installation and maintenance of the tank

3. Methodology

The instrument conducted from this study is through semi-structured interview, literature review and observation [13] on the site location, which is in UTHM. The 2020 UTHM's UI Greenmetric report used as a reference to conduct this research. This report consists of green technology that existed on the campus and information on energy saved from sustainable implementation in the university.

An observation has been made on the site to analyse the existing small scale RWH system in UTHM's Main Campus. A few possible factors have been considered when an observation has been completed. Furthermore, several individuals from various background have been interviewed to give perspective on the existing RWH system and consultation on designing the new RWH system. These individuals are PPP UTHM's assistant engineer, SCO UTHM's director and the contractor involved in installing existing UTHM's small scale RWH system. The recorded information is analysed using SWOT analysis and arranged as strengths, weakness, opportunities and threat.

The tank volume needs to be calculated using Batu Pahat rainfall data to identify the suitable tank form for UTHM's Main Campus' small scale RWH system. The average rainfall volume previous three years, which are in

2017, 2018, and 2019, is taken from Meteorological Department of Malaysia. Literature review assisted in identifying various RWH tank shape.

All the information gathered from the first and second objective of the study used as guidance to create a new form of RWH system in UTHM to fulfil this study's last objective: to suggest a small-scale RWH system's design for outdoor purposes in Main Campus UTHM. Then, it translated to three-dimensional illustration that created through SketchUp software.

4. Analysis and Discussion

The observation indicated a small scale RWH system located within the UTHM's Main Campus. The installed system situated in between of D9 building and the UTHM Fleet Unit. This structure near a 1m height slope and close to the vehicle wash area. Figure 2 shows the installed system.

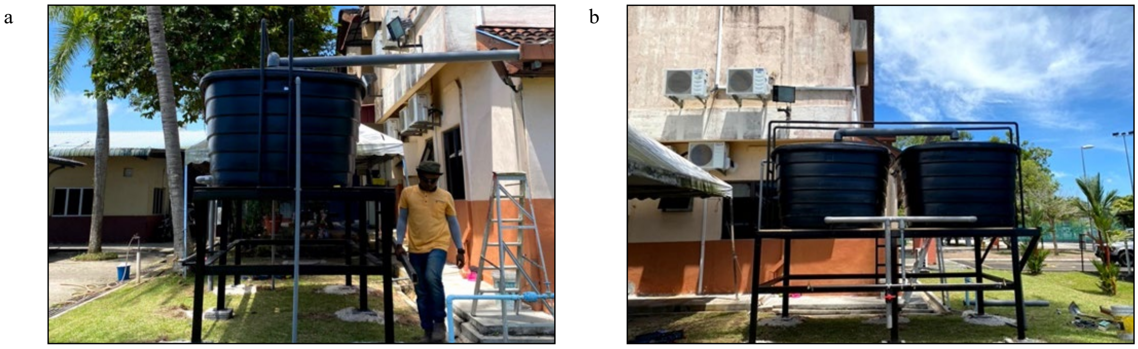


Fig. 2 - a) front elevation; b) side elevation

4.1 SWOT Analysis

Interview with respondents showed a few strengths, weaknesses, opportunities, and threats observed from the existing UTHM's small scale RWH system. This analysis conducted to improvise the installed system and used as guidance to design a new method for future purposes. Table 2 showed the SWOT analysis.

Table 2 - UTHM's small scale RWH system SWOT analysis

Strengths	Weaknesses	Opportunities	Threats
i. Elevated tank placement, sufficient pressure to channel stored water. ii. The system's location near to the activity that required additional water consumption. iii. Neat design. iv. Sturdy built material.	i. Low aesthetic value. ii. The fixed structure could potentially prone to hazard and a minor accident. iii. Area consuming.	i. Gravity is the source of pressure. ii. It has the potential to integrate with intelligent features. iii. Small scale RWH system has the potential to educate society.	i. Negative stigma and perception from public and surrounding. ii. Low rainwater quality might damage the system. iii. Dried leaves from the surrounding trees could get tucked on the pipe. iv. Unexpected weather conditions might cause the tank not to fill up to its maximum capacity.

4.2 Selection of Small Scale RWH Tank Form

There are few perspectives on the suitable tank form to be installed on the campus. Most of the respondents agreed that a cylindrical and doubly curve tank is the most convenient tank form. Several elements such as mobility, modularity, and upgradability are concerned during the design stage of the system.

The tank capacity that is suited to be installed is around 300-350ℓ. The height of the tank is based on the minimum maintenance reachability, 1220-920mm [12]. The volume formula can calculate the radius of the tank. The tank measured as 600mmø x 1200mm is selected according to the lean and tall shape. The base of this form is compact and has less area consumption. The diameter of the tank is suitable for an adult to lift, carry and move the tank to another location [13]. If there is a necessity to move the tank, a consumer can move it without special equipment. Therefore, the suggested RWH system is upgradeable, modular, mobile, repairable, and movable after a while [2].

4.3 E-SPAH: Proposed RWH Design for UTHM

E-SPAH is a concept of a small-scale RWH system that emphasis on efficiency and outdoor usage. The harvested water is not intended to use for any activity that involved bodily contact. On the contrary, the stored water is meant for outdoor usages such as washing vehicles and watering plants. The existing small-scale RWH is derived from this concept. However, this design has a few issues that need to be fixed. Low aesthetic value, extensive space consumption, and safety concern need to be discussed when designing the new system.

The newly introduced E-SPAH concept showcase different design language. The proposed E-SPAH is versatile, modular, flexible, mobile, and has aesthetic value without losing the RWH system characteristic to store water from the catchment area. Some of the features of the existing system are preserved, such as the twin tank. However, this design takes a similar approach by expanding its capability by adding modular characteristics. The tank could be attached and joined together if the consumer wished to add its capacity. Besides, the E-SPAH tank has a compact size that can be lifted easily. If the system is required to locate to another place, it can be moved easily. Figure 3 dan Figure 4 illustrated the suggested system. Besides, the proposed E-SPAH has another practical usage as an added element to the building's landscape as it can make use as a planting box. Simultaneously, it gave an aesthetic touch to the building façade.

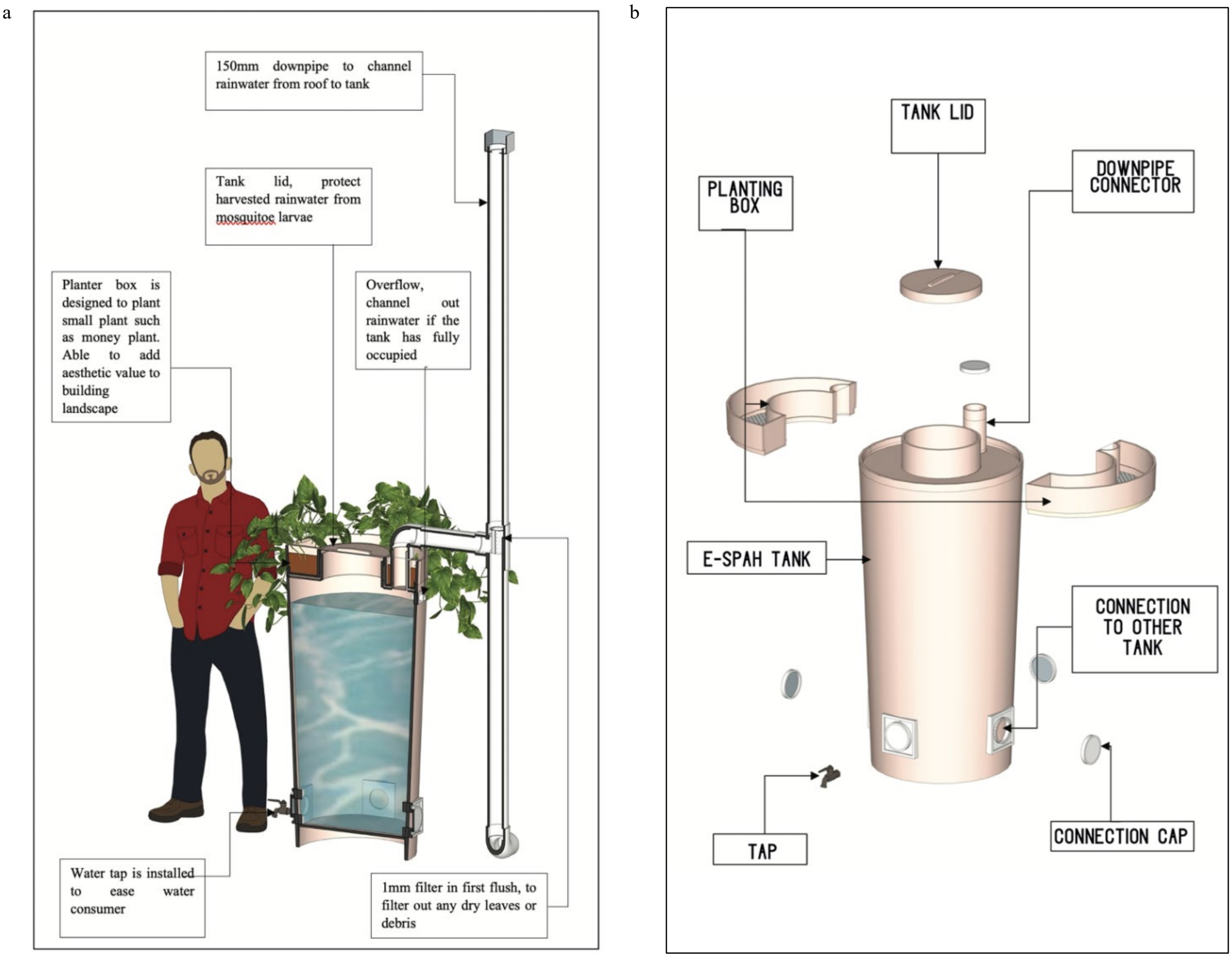


Fig. 3 - a) Sectional cut; b) axonometric projection

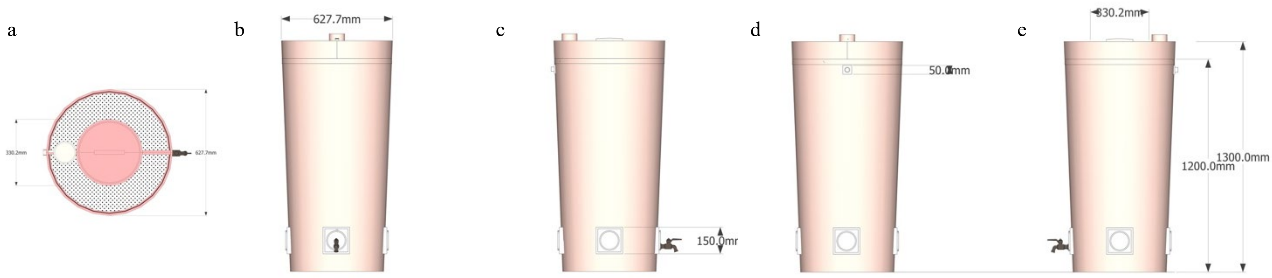


Fig. 4 - a) Plan; b) front elevation; c) right elevation; d) rear elevation; e) left elevation

4.4 Rainfall Data

The suitable tank capacity is calculated by using average rainfall data of the area and size of the catchment area. Rainfall data collection has been done by MetMalaysia. Batu Pahat Meteorology Station is the nearest station which is about 6 kilometers from the location of the study. In 2017, 2018 and 2019, the recorded annual rainfall data recorded for each year is 2118mm, 2253mm and 1949mm respectively [14]. If the data for these three years combined, the average rainfall data is 2107mm. Table 3 below shows the rainfall data for Batu Pahat district.

Table 3 - Batu Pahat rainfall data (MetMalaysia, 2020)

Year	Rainwater volume (mm)												
	January	February	March	April	May	June	July	August	September	October	November	December	Total
2017	194	114	153	286	159	73	82	292	204	202	181	177	2118
2018	212	46	154	436	214	207	146	129	206	192	152	158	2253
2019	30	50	61	254	140	209	104	83	136	373	258	251	1949
Total	436	210	368	976	513	489	332	504	546	767	591	586	6320
Average													2107

4.5 Storage Tank Calculation

The capability of the RWH system depended on local weather, the size of the catchment area and the capacity tank. Thus, the number of the tank has to be selected to optimise the RWH system. The selection of tank capacity can be calculated using DID (2012) formula:

i. Average daily runoff (ADR),
   a. Given,

Catchment area (m^2), x Average annual rainfall/430

ii. Determine the rainfall area, Batu Pahat.
iii. N value equal to number of days. Tank sizes can be calculated by using

ADR x N (ℓ) formula.

Calculation of suitable tank capacity:

Variable catchment area *(x)* = $20m^2$, $40m^2$, $60m^2$, $80m^2$, $100m^2$
Average annual rainfall = 2107mm

Thus,

ADR = x x 2107mm/430= 2107x mm/430ℓ /day

Therefore, the number of tanks need to be chosen based on the size of the catchment area to optimise the harvested rainwater. N value is based on seven days per week. Thus, the calculation for tank capacity;

$$\text{ADR x N} \quad = \quad 2107x \text{ mm/430 x 7 days}$$

The designed E-SPAH has 300ℓ capacity. The number of tanks can be proposed by dividing the weekly potential harvested rainwater. Table 4 shows the bigger the catchment area, the more tank can be installed. Table 4 shows the suggested number of tanks. Figure 5 shows the tank arrangement, and Figure 6 illustrates the E-SPAH application on the building.

Table 4 - Proposed number of tanks based on catchment area size

Catchment area (m^2)	Water capacity/week (ℓ)	Proposed number of tanks
20	686	2-3
40	1372	4-5
60	2058	6-7
80	2744	9-10

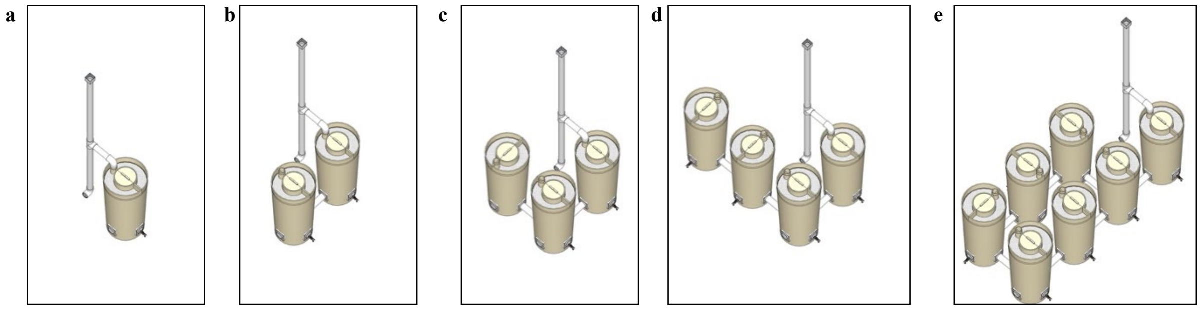


Fig. 5 - a) Single tank; b) twin tank; c) triplet tank; d) quadruplet tank; e) septuplet tank

Fig. 6 - Application of E-SPAH on building

5. Conclusion

As a result, an improved RWH system named E-SPAH could have been implemented. A few factors such as rainfall data, size of the catchment area, and suggestion from respondents have considered designing a better system that adapts to the specific location.

The existing small scale RWH system has several strengths, weakness, opportunities and threats. Those subjects utilized as guidelines to design a new form of system. The strengths and opportunities of the system have taken advantage of and preserved the characteristic. In comparison, the weakness and threats have been avoided and minimized the impact that could probably threaten the new design in the future. Therefore, the previous problem of the existing small scale RWH system in UTHM can be solved.

A cylindrical form has been chosen as guidance to design a new form of the RWH system. This form can uniformly distribute stresses with bending stress only near the bottom. Besides, the materials to construct this form can be saved up to 7.5% to a similarly proportioned cuboid [11]. The proposed E-SPAH has the dimension of 600mmø x 1200mm, which has a compact size and consumed less space at the base area. The tank size is proportioned to human size and designed according to anthropometry factor [14] [15].

The proposed system has a dual function, an RWH system and a planter box. Besides harvesting rainwater, the tank has added a landscape element on the building façade. Moreover, the number of E-SPAH tank can be multiplied according to the potential rainwater can be harvested on the catchment area. Thus, growing the possibilities of upgrading the RWH system in the future.

Acknowledgement

The authors would like to extend our appreciation to the Construction Management Department, Faculty of Technology Management and Business of University Tun Hussein Onn Malaysia for their generous support for this study.

References

[1] Man, S., & Hashim, N. M. (2015). Sistem Penuaian Air Hujan: Kajian Kes Kesediaan Masyarakat di Bandar Baru Bangi. GEOGRAFIA Online Malaysia Journal of Society and Space 11 Issue 11. 2015, ISSM 2180-2491, 53-62

[2] Che-Ani, A.I., Shaari, A., Zain, M.F.M. & tahir, M.M (2009). Rainwater Harvesting as an Alternative Water Supply in the Future. European Journal of Scientific Resesarch. 34(1) Jul 09, 132-140

[3] Mostaffa, M., F., (2019). Reka bentuk sistem penuaian air hujan (SPAH) bagi skala kecil untuk kegunaan aktiviti luar bangunan di UTHM. Bachelor’s degree report

[4] Sustainable Campus Office UTHM (SCO)(2020), Kategori 4: Pelaksanaan Program Penjimatan Air Universiti, UI Greenmetric UTHM 2020 Report

[5] Institut Penyelidikan Hidraulik Kebangsaan Malaysia (NAHRIM) (2014), Rainwater Harvesting System [electronic version] Retrieved on September 29, 2018 from Institut Penyelidikan Hidraulik Kebangsaan Malaysia:http://www.nahrim.gov.my/en/products/59-sistem-penuaian-air-hujan/201introduction.html#water-usage

[6] Athavale, R.N. (2003), Water Harvesting and Sustainable Supply in India Environment & Development Series, India: Centre for Environment Education. 2003

[7] Agarwal, A., Narain, S. and Khurana, I., (2003). Making Water Everybody’s Business: Practice and Policy of Water Harvesting. Centre for Science and Environment, New Delhi

[8] Gould, J. (1999). Contributions Relating to Rainwater Harvesting. The World Comission on Dams Secretariat (WCD) Thematic Review IV.3

[9] Burgess, B (2012), Rainwater Harvesting Best Practices Guidebook. Retrieved on October 29, 2018 from Regional District of Nanaimo: https://www.rdn.bc.ca/

[10] Department of Irrigation and Drainage (DID) (2010), Rainwater Harvesting Guidebook, Jabatan Pengairan dan Saliran, Selangor, Malaysia

[11] Rees, D., & Whitehead, V (2001). Optimal Tank Shape. Recommendations for Designing Rainwater Harvesting System Tanks, DTU, UK

[12] Accetturo A. (2012), Steps in designing and implementing active rainwater harvesting. Rainwater Harvesting Guidance Toward A Sustainable Water Future, (pp. 18-30); Washington, USA: City of Bellingham PWD

[13] Chua, Y. P. (2006). Kaedah dan statistik penyelidikan. Kuala Lumpur: McGraw-Hill

[14] Littlefield, D. (2015). Body Clearance. Metric handbook: Planning and design data. Hampshire: Routledge

[15] Smardzewski, J. (2016). Anthropotechnical Measures of the Human. Anthropotechnical designing. In Furniture Design (pp 118-128). Poznan, Poland: SPRINGER INTERNATIONAL PU

[16] Malaysian Meteorological Department (MetMalaysia) (2019), Batu Pahat rainfall data 2017-2019, Ministry of Environment and Water, Petaling Jaya, Selangor, Malaysia