

RAINWATER HARVESTING (RWH) INSTALLATION FOR BUILDINGS: A SYSTEMATIC REVIEW AND META-ANALYSIS APPROACH

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ABSTRACT

Rainwater that falls upon a roof surface which are collected and transferred to the storage facility for later use is a method known as Rainwater Harvesting (RWH). This method is a step towards conserving the public drinking water where the demand continues to grow worldwide. In Malaysia, there is a huge potential of rainwater harvesting based on the available rainfall amount. Even so, the existing RWH design guideline in Malaysia lacks the technical specification regarding congruousness of RWH installation method with the physical characteristic of the building. Therefore, systematic literature review and meta-analysis were done to identify and understand the suitability between the types of RWH installation system with the building's physical characteristic. The main objective of this study is to review the existing articles from year 2000 to the present on the installation systems used in RWH for non-potable purposes. The RWH installation system, types of building and building characteristics used in the previous studies will be evaluated in order to understand the suitability or regularity of the combinations. This review uses the Preferred

Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) as reviewing method. The systematic review process involved four stages which are identification, screening, eligibility and included. The sources of this review are Science Direct and Google Scholar. Results show there are three types of RWH installation system that were identified namely Gravity Fed System (GFS), Indirect Pumping System (IPS) and Direct Pumping System (DPS). DPS is commonly applied for non-potable purposes in residential, commercial and educational buildings. Small yard area, sloping site condition and types of soft landscape will affect the type of RWH installation system to be used. The result can be used to determine the suitability of the RWH installation system for different types and characteristics of a building.

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Keyword: *Systematic Review and Meta-Analysis, Rainwater Harvesting (RWH), Installation Systems, Building Characteristic, Non-Potable Use*

INTRODUCTION

Water conservation is an important issue in sustainable buildings and a basic strategy in facing current water shortages (Taleb et al., 2011). The main factor that hinders the development of society and has a negative impact on urban development and the basic life of the population is the lack of water resources (Hashim et al., 2013). Among several options for water conservation in buildings, rainwater harvesting (RWH) is very attractive (Özdemir et al., 2011; Domènech et al., 2013). The RWH system is a simple method that uses scientific techniques to store rainwater that falls on the roof surfaces into the storage for daily use such as bath, laundry, toilets and garden watering. This method is also called roof water harvesting which involves the collection, storage and distribution process of collected rainwater. Rainwater harvesting system could reduce the dependency on main water supply. (Che-Ani et al., 2009). The rediscovery of these systems was driven by the high water tariffs, the scarcity of this resource and the effort of national and international associations that helped to disseminate RWH system implementation (Gouvello et al., 2014). RWH systems are becoming increasingly common in several locations around the world such as Germany, Australia, United States, Japan, China, India, Sri Lanka, Japan and Singapore have implemented the RWH system (Jones & Hunt, 2010). RWH is not new in Malaysia. This was confirmed by the Sandakan Municipal Council in 2008 stating that Sandakan had been practicing rainwater harvesting since 1984 due to the problem of treated water supply in the area. This has proven that Malaysia has the potential to implement the RWH System. This is supported by Salmah, and K. Rafidah through their study in 1999 revealing that Malaysia receives almost 3,000 mm of rain a year, which is a huge amount of rainfall.

From this study, several guidelines on RWH system which are normally used in Malaysia were identified. The guidelines are Urban Stormwater Management Manual for Malaysia (MSMA 2nd Edition) developed by the Department of Irrigation and Drainage Malaysia in 2012, Garis Panduan Sistem Pengumpulan dan Penggunaan Semula Air Hujan developed by Ministry of Urban Wellbeing, Housing and Local Government in 2013, Manual Rekabentuk Sistem Pengumpulan dan Penggunaan Semula Air Hujan (SPAH) developed by Ministry of Works Malaysia and NAHRIM Technical Report No. 2 developed by National Hydraulic Research Institute

of Malaysia (NAHRIM) in 2014. However, these developed design guidelines lack the technical specification regarding congruousness of RWH installation method with the building physical characteristic which is important to understand before RWH is planned and implemented. Thus, the objective of this systematic review is to evaluate the RWH installation system with the types and characteristics of buildings used based on previous studies in order to understand the suitability or trend of the system.

METHODOLOGY

The systematic literature review and meta-analysis approach were performed to analyse the installation systems used in RWH for non-potable uses together with the characteristics of building selected. Systematic literature review is a method used to identify and evaluate the available research information on given research question. This method can provide an overview of the particular field of knowledge and can also confirm the existence of research on the topic. It also be used to detect gaps in knowledge and areas that can be studied for future studies (Petticrew and Roberts 2008; Kitchenham 2011). This study also used meta-analysis technique which is defined by DerSimonian et al. (1986) as a method to systematically combine the diversification of the similar qualitative and quantitative research data from selected studies to develop a single conclusion that has greater quality and statistical power. As this study is reviewing the heterogeneity of the RWHS installation method and buildings in an effort to understand the selection pattern, thus the approach is pertinent in achieving the objective of this study. A study done by Bouma et al. (2016) regarding RWHS technology also used meta-analysis as a technique to understand the impact of the system to crop yield. In this study, all RWHS installation system applied in the previous studies were assimilated to understand the selection criteria. The result obtained from this approach can lead to an understanding of the suitability of the type of RWHS installation system with the heterogeneity of building physical characteristic.

The procedure adopted to perform this review was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). This procedure consists of the stages shown in Figure 1. In the first stage of PRISMA that is identification, two sources of electronic

databases were used that are Science Direct and Google Scholar. Science Direct database provides full-text scientific data published by Elsevier that is a scientific and medical publication company (Tober, 2011). The web portal allows users to browse the world of scientific publications. The displayed search results in Science Direct database show the date of research published, the authors, the articles sources, the research title, the abstract of the research in systematic site design and quality writing style (Colepicolo, 2015). According to Tober (2011), the credible criteria for an electronic database include displaying the authors, published date, sources and high quality writing style and language.

Google Scholar is the academic version of Google that allow users to search scientific information such as books, journals and patents from multiple sources since the Google Scholar index includes various online academic books, journals, theses, conference papers, technical reports and other scientific information. Google Scholar also resembles subscription-based tools, such as Elsevier's Scopus and the Web of Science. (Falagas, 2008). The title, authors, source, subject area and date of publication will be displayed in the search results. All the details meet the credible criteria highlighted by Tober (2011). However, according to Falagas (2008), this database is not updated frequently. Thus, only reliable articles retrieved from trusted sources were used in this review.

Additional record that is Project Report and Case Study of Rainwater and Greywater in Buildings by Department of the Environment, Transport and the Regions (DETR) of United Kingdom was included in this review. The report consists information on the system used for RWH, installation guidelines and several related case studies. Common issues regarding design, installation, maintenance and management of RWH were also included in the report.

It is noteworthy that the classification of RWH system in this review are adapted from National Hydraulic Research Institute of Malaysia (NAHRIM) Technical Guide No. 2. National Hydraulic Research Institute of Malaysia (NAHRIM) has been aggressive in promoting rainwater harvesting in Malaysia. According to the NAHRIM official website, NAHRIM was established in September 1995 under the Ministry of Natural Resources and Environment (NRE). Through this study, among all the guidelines that have

been mentioned, only this guideline classified the types of RWH installation system clearly and in an orderly manner. Besides, this guideline is also the most recent of all the guidelines. The RWH system category stated in the NAHRIM Technical Guide No. 2. include Gravity Fed System (GFS), Indirect Pumping System (IPS) and Direct Pumping System (DPS).

The keyword search strategy or terms used in this review were 'rainwater harvesting installation system', 'rainwater harvest system for non-potable uses', 'roof-collected water system' to mention a few. Only English published articles from the year 2000 until April 2018 are considered in this review. All the identified articles were screened by their titles to remove the duplicate or similar articles found in the different database used. By reading the titles and abstracts, the irrelevant items for the defined issue such as RWH for irrigation purpose, RWH quality, RWH pollutants, RWH for potable uses, RWH potential for a city, RWH environmental impact, RWH life cycle cost, RWH material, RWH ancient technology, RWH energy intensity, RWH policy, RWH storage sizing, etc. are excluded from this review.

The next stage is eligibility screening where all articles that have been filtered will be evaluated in full text eligibility screening. After full-text assessment, 58 articles were excluded due to certain reasons and only 18 articles will be included for this review after considering several aspects. The exclusion and inclusion criteria are stated in Figure 1.

After the eligible articles are selected, the following data: authors, years of publication, countries where the studies were implemented, research strategy, research main objective, types of RWH systems used, harvested rainwater usage purpose, implementation status and their study results were extracted in each study. The building characteristic such as number of storey, yard area, site condition and landscape will affect the used of RWH installation system. Numbers of storey will affect the RWH system used (Zhang, 2009; Domènech, 2011). The criteria used for choosing the tank locations were based on the optimum ground area available, its conditions and surrounding vegetation (Angrill, 2012). The roots from surrounding trees can damage the underground structure (Biddle, 2012). Hence, those characteristics also will be extracted. The extracted data were analysed by using Microsoft Excel 2010 and presented in graphical techniques.

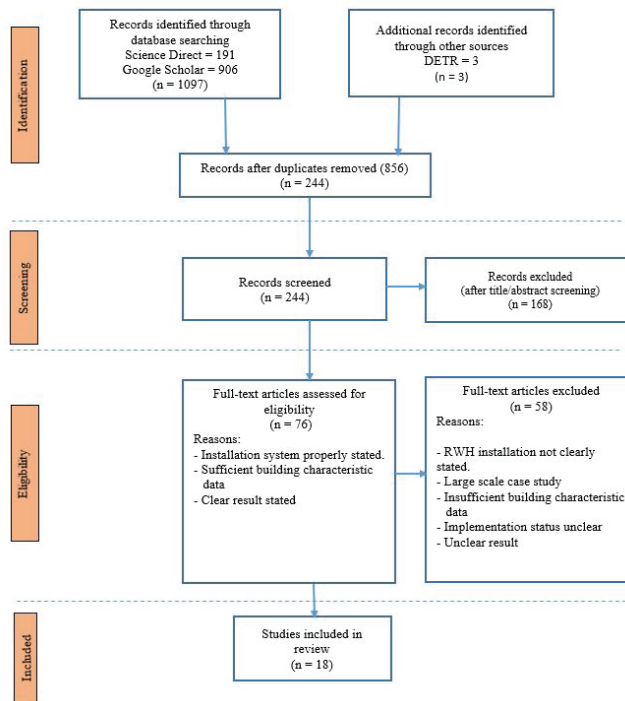


Figure 1: Data Collection and Screening Flow Diagram Adapted from PRISMA, 2009

RESULTS

Data Collection Countries and Types of Building Involved

A total of 18 publications and report were screened using PRISMA guideline and have been filtered according to the desired objectives to analyse suitable RWH installation system for non-potable use. The results of extracted data from previous studies are summarized in the tabulated form as shown in Table 1.

After the screening process, 18 publications and report have been reviewed from 10 countries from six continents around the world and three types of building have been identified. Through this review, three types

of buildings used as case study for the RWH research were identified as shown in Table 2 where residential and commercial buildings show the same number of buildings that is 6 numbers that represent 32% of the total numbers of building. Educational building is the most widely used building as case study for RWH study that is seven numbers of building (36%).

Table 2: Percentage of Types of Building Involved in Reviewed Studies

| Building Types | Percentage |
|----------------|------------|
| Educational | 36% |
| Residential | 32% |
| Commercial | 32% |

RWH Installation System

The types of RWH installation system specified by NAHRIM that are Gravity Fed System (GFS), Indirect Pumping System (IPS) and Direct Pumping System (DPS) were analysed along with the types of buildings mentioned above (Figure 2). The purpose of this analysis is to understand the selection of RWH installation system with the type of building used in the previous studies. Result shows that for educational building GFS and DPS are mostly used (43%) while IPS is seldom used (14%). For commercial building, IPS is the most widely used (50%) while GFS moderately uses (33%) and the less popular system used is DPS (17%). Residential building shows the most widely system used is DPS (50%) followed by IPS (33%) and GFS (17%).

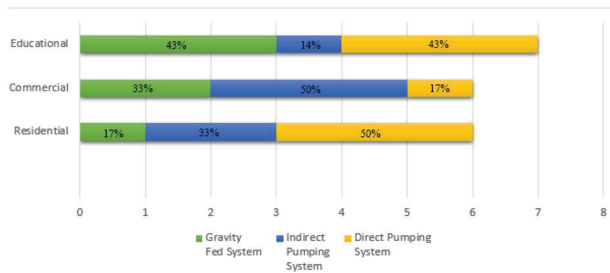


Figure 2: RWH Installation System Used in Different Types of Building

Table 1: Summary of Systematic Review on RWH Installation System Extracted from Previous Studies

| References | Countries | Research Strategy | Research Main Objective | Building Types & Characteristic | RWH System Applied | RWH Usage Purpose | Implementation Status | Study Results |
|--------------------------------|----------------|-------------------|--|---|--------------------|------------------------------------|----------------------------|---|
| Maguei et al. (2018) | Mexico | Case study | Reliability of RWH to cover potable water demand. | Commercial building (Transportation logistics company) • MS, LYA, FSC, SLS | IPS | Non-potable use | Feasibility Study | Current water demand can be totally covered (100%) by using rainwater. |
| Ward et al. (2010) | United Kingdom | Case study | Evaluate financial two different RWH. | Commercial building (Office) • MS, LYA, FSC, SLS Residential • MS, LYA, FSC, SLS | IPS IPS | Toilet Flushing Toilet Flushing | Implemented Implemented | RWH can fulfil 46% of WC water demand. RWH can fulfil 36% of WC water demand. |
| Li et al. (2010) | Ireland | Desktop Study | Utilize Potential of RWH | Residential • MS, LYA, FSC, SLS | DPS | Non-potable uses | Implemented | Current water demand can be 94% covered by using rainwater. |
| Chilton et al. (2000) | United Kingdom | Case Study | Potential of RWH in large roof building. | Commercial Building (Supermarket) • MS, SYA, FSC, NL | GFS | Toilet Flushing | Feasibility Study | Excellent reasons for installation. 70.7% possibility water saving. |
| Combess et al. (2000) | Australia | Case Study | Monitoring RWH efficiency. | Residential (27 units) • MS, LYA, FSC, SLS | DPS | Toilet Flushing | Implemented | Total water saving around 60%. |
| Pinón et al. (2012) | Spain | Case Study | Economic and environmental feasibility of RWH. | Residential (Apartment) • MS, LYA, FSC, SLS | DPS | Non-potable uses | Feasibility Study | Optimal scale for RWH can be achieved in large scale and high-density developments. |
| Ward et al. (2012) | United Kingdom | Case Study | Performance of RWHS in large building. | Commercial building (Office) • MS, LYA, FSC, SLS | GFS | Toilet Flushing | Feasibility Study | Office-scale RWH systems potentially offer significant water and cost savings. |
| Ghisi and Ferreira (2007) | Brazil | Case Study | Evaluate the potential for potable water savings by using rainwater. | Residential (Apartment) • MS, LYA, SSC, SLP | GFS | Non-potable uses | Feasibility Study | Potable water savings from 36.7% to 42.0%. |
| Temesgen et al. (2015) | Ethiopia | Case Study | Design and technical evaluation of improved RWH system. | Educational building (Adama Science and Technology University) • MS, LYA, FSC, SLS | IPS | Toilet Flushing | Implemented | Satisfying the non-potable water demand. |
| Islam et al. (2013) | Bangladesh | Case Study | Evaluate the potential of RWH. | Educational building (University of Information and Science). • MS, LYA, FSC, SLS | DPS | Non-potable uses | Feasibility Study | Potential of RWH will exceed the non-potable water demand. |
| Sarker et al. (2015) | Bangladesh | Case Study | Evaluate the potential of RWH. | Educational building (University of Asia Pacific) • MS, LYA, FSC, SLS | GFS | Non-potable uses | Feasibility Study | Potential 66% water saving. |
| Appan (2000) | Singapore | Case Study | Evaluate the feasibility of RWH. | Educational building (Nanyang Technological University) • MS, SYA, SSC, SLS | GFS | Toilet flushing | Feasibility Study | Saving 12.4% of monthly water potable consume (\$S 18,400/month) |
| Hamid and Norain (2011) | Malaysia | Case Study | Evaluate the reliability of RWH system. | Educational building (UiTM Residential College). • MS, SYA, FSC, NL | DPS | Toilet flushing | Feasibility Study | 90% reliability of RWH can be achieved. |
| Majizat et al. (2009) | Malaysia | Case Study | Evaluate the efficiency of RWH system. | Residential (Bungalow) • MS, LYA, FSC, SLS | IPS | Non-potable uses | Implemented | RWH reduced 37% of potable water consumption. |
| Mohammed et al. (2007) | Malaysia | Case Study | Evaluate the potential of RWH system. | Educational building (Universiti Putra Malaysia) • MS, SYA, FSC, NL | GFS | Toilet flushing | Feasibility Study | High potential, can meet the demand for toilet flushing uses. |
| Project Report by DETR. (2001) | United Kingdom | NA | NA | Commercial building (The new Linwave Technology facility) • MS, LYA, FSC, NL | DPS | Toilet flushing | Implemented | Water saving 260,000 litres per annum, 100% cover toilet flushing uses. |
| Project Report by DETR. (2001) | United Kingdom | NA | NA | Educational building (Bedfordshire East Schools Trust (BEST)) • MS, LYA, FSC, NL | DPS | Toilet flushing | Implemented | Saving the cost of 200,000 litres of mains water usage per annum. |
| Project Report by DETR. (2001) | United Kingdom | NA | NA | Commercial building (Stroud District Council) • MS, SYA, FSC, NL | IPS | Toilet flushing | Implemented | Saving the cost of 48,000 litres of mains water usage per annum. |

MS: Multistorey; LYA: Large Yard Area; SYA: Small Yard Area; FSC: Flatest Site Condition; SSC: Sloping Site Condition; SLS: Soft Landscape Shrubs; SLP: Soft Landscape Palms; NL: No Landscape; NA: Not Applicable; GFS: Gravity Feed System; IPS: Indirect Pumping System; DPS: Direct Pumping System

Building Characteristics

The building characteristics that have been determined in the methodology stage were analysed along with the types of RWH installation systems (Figure 3). This analysis is to understand the trend or pattern between the characteristic of the building with the installation system of RWH. The result shows that type of building storey does not affect the selection of RWH installation system where all the system (100%) are

multi-storey building. Large yard area does not really affect the IPS (83%) and DPS (86%) selection but it does affect the GFS selection (17%). Opposite with the small yard area factor where GFS was affected (83%) by this characteristic but did not affect the IPS (17%) and DPS (14%). Flattest site condition does not really affect the RHS installation system because it can be applied (100%) to IPS and DPS, and (67%) for GFS. In this review, sloping site condition is only applied for GFS (33%) but none (0%) for IPS and DPS. The types of soft landscape at the building affect the RWH installation where large trees such as palms exist, where only GFS is applied (17%) and none (0%) for IPS and DPS. In the shrub landscape existence, IPS shows the highest application (83%), where DPS (57%) and GFS (50%) are moderately applied. In no landscape condition, GFS (33%) and DPS (43%) are moderately used but only few (17%) on IPS.

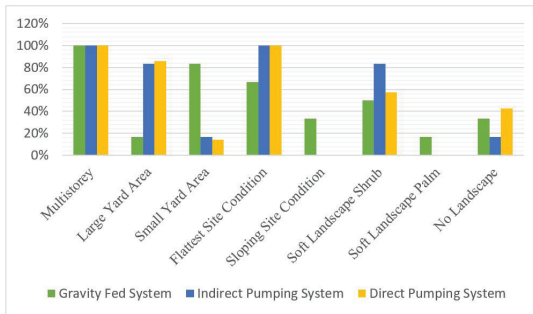


Figure 3: Building Characteristics Analysis

Implementation Status

The implementation status of the RWH installation system in the previous studies was also analysed to strengthen the results in terms of credibility factor of each installation system in RWH. Systems that have been implemented are practically proven while implementation status at feasibility study stage has not been practically proven yet. As shown in Figure 4, IPS shows the highest percentage (83%) on implemented status and followed by DPS (57%). Meanwhile, all (100%) previous studies that applied GFS are still in the feasibility study stage followed by DPS (43%) and IPS (17%). However, the findings from all the previous studies show positive results (100%) to get the benefit from harvested rainwater (Figure 5).

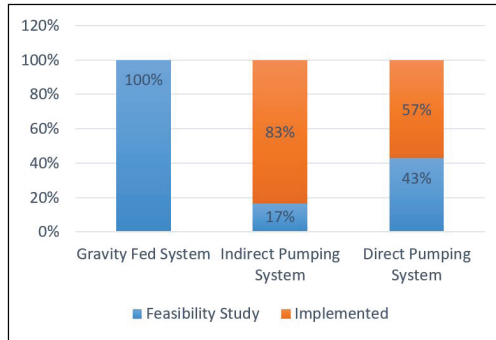


Figure 4: RWH Installation System Implementation Stages of Previous Studies

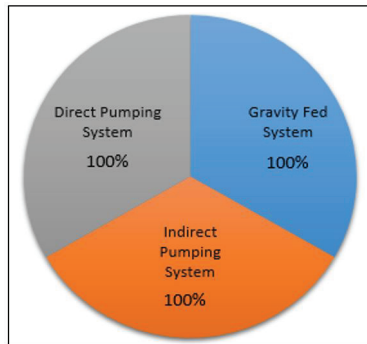


Figure 5: RWH Installation System Finding Result of Previous Studies

DISCUSSION

This review has revealed several RWS installation system used in various features and types of building together with the countries involved and the usage purpose of harvested rainwater cached. The results of this review have also discovered the attractive potential of RWH in saving the potable water consumption in a step towards a sustainable environment. There is restriction by year of publications in this review that will ensure only the latest installation system of RWH are included in this review which is one of the strengths of this articles. This study also includes the report from government regarding installed RWH in several locations which are the technical data taken from the actual situation of the building that has been

installed by the expert and the system effectiveness was proven. However, this review also has some limitations whereby only publications in English language were imposed and studies of RWH installation system from non-English-speaking countries may have been missed. This review also encountered some difficulties where only a few studies regarding RWH explained the installation system applied. There were a number of studies that focus on the economic feasibility of RWH, the quality of rainwater, the efficiency of RWH and the potential of RWH but none focus on the RWH installation system itself.

Firstly, this review revealed there are three types of building that are commonly used to study the feasibility, potential and the efficiency of RWH. They are residential building, commercial building and educational building. The types of building classification is based on Ekholm, (2000). Educational building was the most widely used type of building found in this review that is used as RWH case study site. As it is known, education campus is a large community that contains many buildings and many occupants and in such situation the use of water will be high. According to Anand and Apul (2011), the percentage of potable water used just for toilet flushing in office and educational buildings are higher since toilets and sinks are the primary uses of water in these buildings. Second, this review found that the GFS and DPS were the most common types of installation system used at educational building. This situation may be caused by the cost involved since GFS does not require pumps to distribute water to the distribution pipes because the header tank will distribute the water using the force of gravity. According to Tam et. al (2010), water pump is vital to provide adequate pressure to supply water for indoor use. Hence, this will reduce the operation cost and electricity consumption from using water pump (Cheng, 2002). Besides the selection factors of DPS are possibly caused by limited ceiling space and inadequate building structure strength since DPS only use underground rainwater tank. The size and location of water tank will affect the building structure and design. (Zhang, 2009).

In contrast with the commercial buildings, IPS is the most widely RWH installation system used for this kind of building. IPS require a rainwater tank installed underground and also placed on the ceiling as header tank. The underground water tank installation requires high cost. Sub-surface or underground tanks which are usually associated with purpose-built

ground catchment systems will increase the construction cost (Tam, 2010). According to Melbourne Water (2007), underground tanks will require additional protection against surface run-off or groundwater entry, animal or human faecal material and soils which will result in increased installation costs. Underground tank presented the largest impacts of installation cost due to its higher energy consumption (Angrill, 2012). However, this is not a problem since commercial buildings often have a lot of capital. Besides, this system is also suitable to be used in high water demand building. This is supported by a previous study by Lani et. al (2018) that suggests large building resulted better reliable of RWH and also in terms of economic assessment compared to small building. In addition, residential building commonly used DPS and it is possible because the ceiling space and the structure strength are not suitable for other types of RWH installation system like IPS and GFS.

Third, this review has identified the trend or relationship between the characteristic of the building with the installation system of RWH. Based on the characteristic analysed earlier, the most obvious features that can affect the types of RWH installation system are the size of yard area, site condition and soft landscape.

Large yard area is suitable for all types of system while small yard area is only suitable for GFS where the rainwater tank is installed on the ceiling space. Flattest site condition is suitable for all types of RWH installation system while sloping site condition is not suitable for system that need rainwater tank to be installed on-the-ground or underground such as IPS and DPS. Thus, only GFS can be used in the condition. Last but not least, underground rainwater tank is not suitable to be used when the site has large trees such as palm trees. The reason is, the root from the plant can affect or damage the tank.

Finally, this review analysed the implementation status of the studies in order to support or strengthen the credibility of the previous studies. From all the published articles, only two implementation stages found, feasibility studies and implemented. Research at the feasibility study are conducted mostly to evaluate the possibility and feasibility of potable water saving while at the implementation stage, the efficiency of the installed RWH system is studied. However, from all the studies reviewed, all results show

that RWH can successfully reduce the potable water consumption especially for non-potable purpose.

CONCLUSION

This systematic review has demonstrated considerable heterogeneity of RWH installation system used for toilet flushing purpose. The pattern of RWH installation system applied in the different types of building also has been identified together with the relation between the characteristics of the building with the suitability types of the RWH installation system used. As for the conclusion, Direct Pumping System (DPS) is the most common installation system chosen in the Rainwater Harvesting (RWH) implementation. The result can be used to determine the suitability of the RWH installation system in different types of building and different site or building characteristics. Still, in-depth studies such as conducting a case study in buildings that have applied the RWHS can be implemented to practically analyse the relationship and improve the robustness of this finding.

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