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Towards Safe Cities & Resilient Communities

13 & 14 SEPTEMBER 2018
IMPIANA HOTEL, IPOH, PERAK

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A SYSTEMATIC REVIEW ON RAINWATER HARVESTING (RWH) INSTALLATION SYSTEM FOR NON-POTABLE USE

Azirah Binti Adnan[1]*, Asmalia Binti Che Ahmad[2], Suharto Bin Teriman[3]
[1]Institute of Graduate Studies (IPSis), Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Seri Iskandar Campus, Seri Iskandar, 32610 Perak, Malaysia.
[2]Department of Quantity Surveying, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Seri Iskandar Campus, Seri Iskandar, 32610 Perak, Malaysia.
[3]Department of Town and Regional Planning, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Seri Iskandar Campus, Seri Iskandar, 32610 Perak, Malaysia.
Email of corresponding author *: azirahadnan@gmail.com, asmalia.qs@gmail.com, suhar429@perak.uitm.edu.my

***Abstract* -** Rainwater that falls upon a roof surfaces 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 is lacking on the technical specification regarding congruousness of RWH installation method with the building physical characteristic. Therefore, systematic literature review is one of the ways to identify and understand the suitability between the type of RWH installation system with the building 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. The result shows there are three types of RWH installation system 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.
***Keyword* –** Systematic review**,** Rainwater Harvesting (RWH), installation systems, building characteristic, non-potable use.

1 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) are 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. Collected rainwater harvesting system could reduce the dependency on main water supply (Che-Ani et al., 2009).

RWH systems are becoming increasingly common in several locations around the world (Jones and Hunt, 2010). 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). Many countries such as Germany, Australia, United States, Japan, China, India, Sri Lanka, Japan and Singapore have implemented the RWH system.

Malaysia receives a lot of rainfall throughout the year. The average rainfall is estimated to be around 3000 mm a year calculated based on the average rainfall of 2420 mm in Peninsular Malaysia, 2630 mm in Sabah and 3830 mm in Sarawak (Z. Salmah, and K. Rafidah, 1999). Obviously, there is a huge potential in rainwater harvesting in Malaysia based on the available rainfall. In fact, rainwater harvesting is not new in Malaysia especially in the rural areas such as in Sandakan, Sabah. RWHS was implemented since 1984 to supply the rural community there for all their non-portable uses due to the limited treated water supply from the State Water Board (Sandakan Municipal Council, 2008).

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) that was developed by Department of Irrigation and Drainage Malaysia in 2012, *Garis Panduan Sistem Pengumpulan dan Penggunaan Semula Air Hujan* was developed by Ministry of Urban Wellbeing, Housing and Local Government in 2013, *Manual Rekabentuk Sistem Pengumpulan dan Penggunaan Semula Air Hujan (SPAH)* was developed by Ministry of Works Malaysia and NAHRIM Technical Report No. 2 was developed by National Hydraulic Research Institute of Malaysia (NAHRIM) in 2014. However, these developed design guidelines are lacking on 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.

2 METHODOLOGY

This systematic literature review was performed to analyse the installation systems used in RWH for toilet flushing and was used together with the characteristics of building selected. Systematic literature review was 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 used to detect gaps in knowledge and areas that can be studied for future studies (Petticrew & Roberts 2008; Kitchenham 2011).

Systematic review increases the methodological rigour, as its process of implementation must be replicable and transparent (Transfield et al., 2003). 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 were Science Direct and Google Scholar. Science Direct is a full-text scientific database which is provided by the medical and scientific publishing company Elsevier (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 must display the authors, published date, sources and high quality writing style and language. Science Direct follows the progress of science and technology with the immediate publication of diverse documents (Colepicolo, 2015). University libraries and institutions offer Science Direct access to their communities of researchers. In addition, professionals such as researchers, educators and students to use the Science Direct also find the required information as well as sharing their scientific research (Tober, 2011).

Google Scholar is the academic version of Google launched on 20th November 2004. Users can search scientific information such as books, journals and patents from multiple sources because 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). In the advanced search the results are displayed by title words, authors, source, date of publication, and subject areas. Each retrieved article is represented by title, date, authors, sources and abstract which are considered as a credible online database highlighted by Tober (2011). The number of cited articles is shown under each retrieved articles and it also can be accessed by clicking on the relevant link usually on the journal's site. According to Falagas (2008), even though Google Scholar can help in the retrieval of even the most obscure information, its use is marred by inadequate and less often updated. 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 of 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. The report can be referred by those who are responsible for the installation or monitoring of rainwater systems and those who wish to get the underlying data and information captured from the rainwater systems monitored.

It is noteworthy that the classification of RWH system in this review was adapted from National Hydraulic Research Institute of Malaysia (NAHRIM) Technical Guide No. 2. The National Hydraulic Research Institute of Malaysia (NAHRIM) has been aggressived in promoting rainwater harvesting in Malaysia. Refer to the NAHRIM official website NAHRIM which 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 has 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, includes Gravity Fed System (GFS), Indirect Pumping System (IPS) and Direct Pumping System (DPS).

The keyword search strategy or terms used in this review were like ‘rainwater harvest installation system for toilet flushing’, ‘rainwater harvest system for non-potable uses ‘harvested rainwater system, ‘roof-collected water system’ to mention a few. Only English published articles range from 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 for some reasons and only 18 articles were included for this review after considering few aspects. The exclusion and inclusion criteria are stated in Figure 1.

After selecting the eligible articles, 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 availability, its conditions and surrounding vegetation

(Angrill, 2012). The roots from surrounding trees can damage the underground structure (Biddle, 2012). Hence, those characteristics also were extracted. The extracted data were analysed by using Microsoft Excel 2010 and presented in graphical techniques.

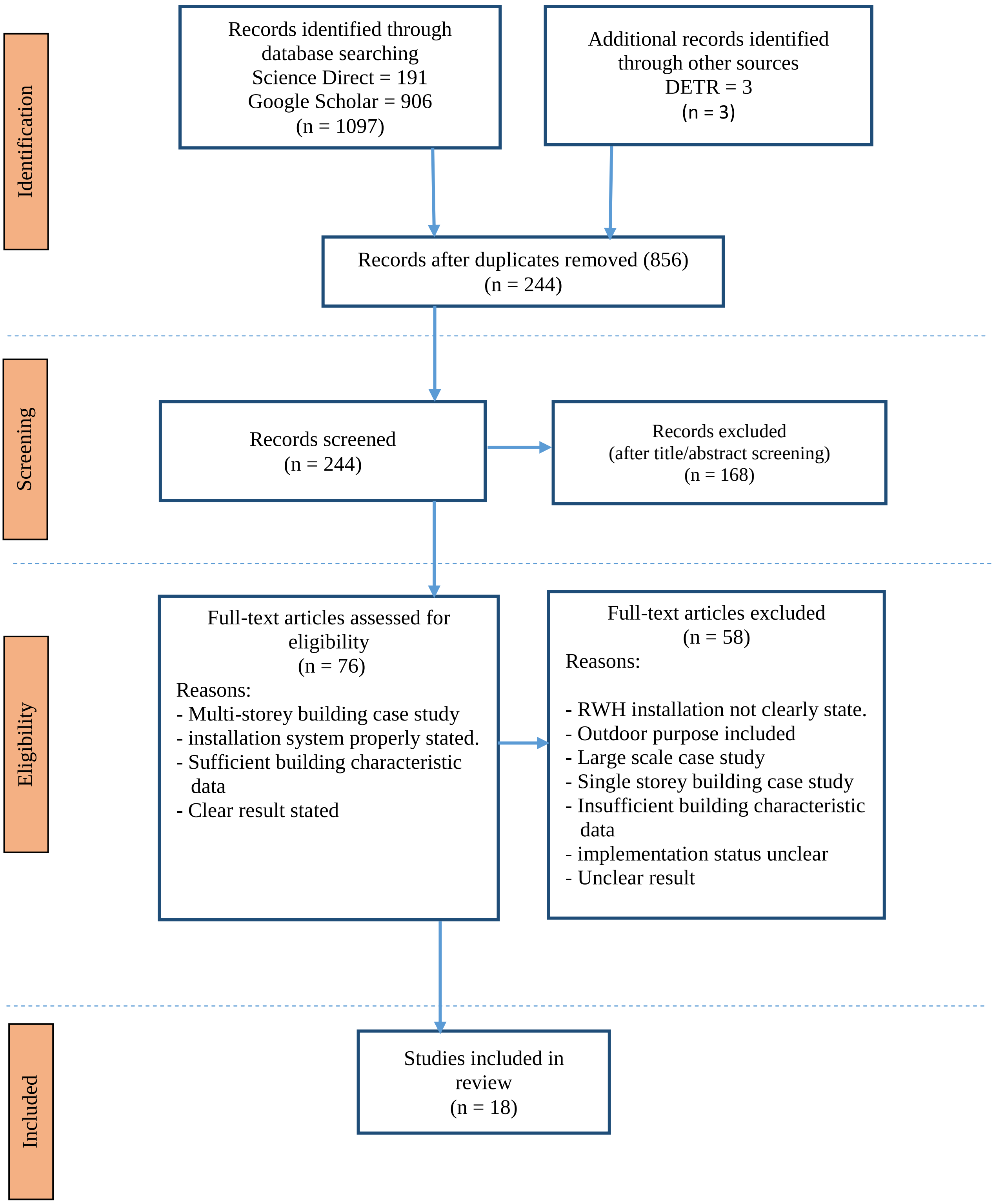

Figure 1 Data collection and screening flow diagram adapted from PRISMA, 2009.

3 RESULTS

3.1 Data Collection Countries and Types of Building Involved

A total of 18 publications and report were screened using PRISMA guideline and has been filtered according to the desired objectives to analyse suitable RWH installation system for toilet flushing use. The results of extracted data from previous studies were 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 6 continents around the world and 3 types of building have been identified. As illustrated in Figure 2, European (44%) and Asia (33%) stand out as continents with the largest number of researcher in this subject that contributed to this review. North and South America, Australasia and Africa showed the same amount of researcher (6%) regarding RWH system. The breakdown according to the countries is shown in Figure 3.

Through this review, three types of buildings used as case study for the RWH research were identified as shown in Figure 4, 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 a total of 7 numbers of buildings (36%).

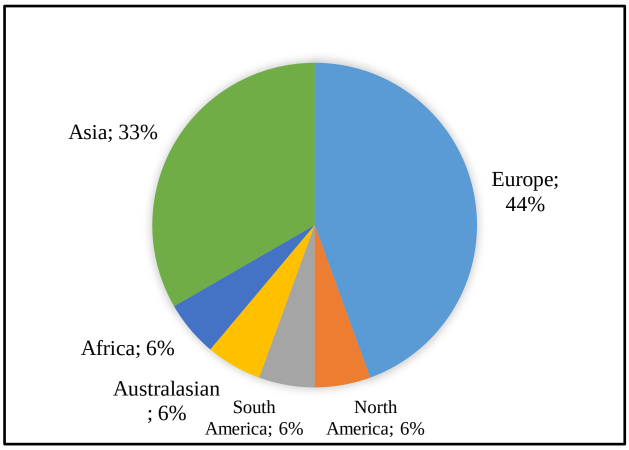

Figure 2 Percentage of continents involved in reviewed studies.

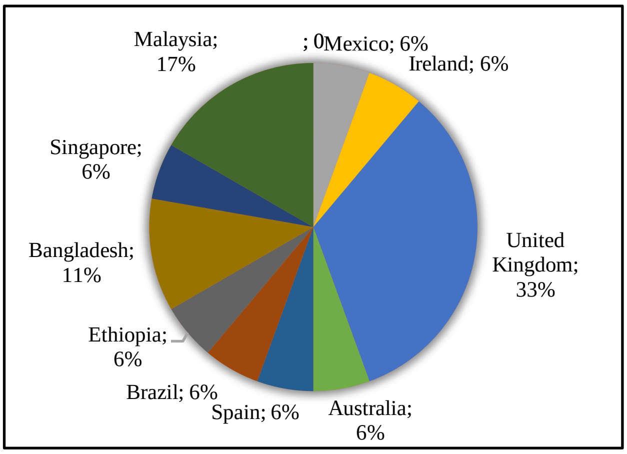

Figure 3 Percentage of countries involved in reviewed studies.

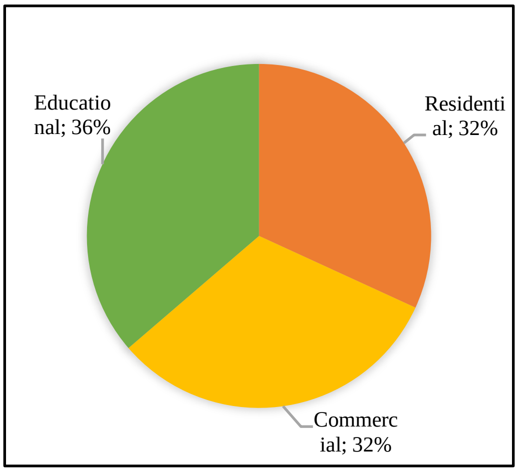

Figure 4 Percentage of types of building involved in reviewed studies.

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*
Miguel 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	IPS	Toilet Flushing	Implemented	RWH can fulfil 46% of WC water demand.
				Residential • MS, LYA, FSC, SLS	IPS	Toilet Flushing	Implemented	RWH can fulfil 36% of WC water demand.
Li et al. (2010)	Ireland	Desktop Study	Utilise 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%.
Pinzón 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 (Namyang 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 Nordin (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**: Flattest Site Condition; **SSC**: Sloping Site Condition; **SLS**: Soft Landscape Shrubs; **SLP**: Soft Landscape Palms; **NL**: No Landscape; **NA**: Not Applicable; **GFS**: Gravity Fed System; **IPS**: Indirect Pumping System; **DPS**: Direct Pumping System

3.2 RWH Installation System

The types of RWH installation system as specified by NAHRIM are Gravity Fed System (GFS), Indirect Pumping System (IPS) and Direct pumping system (DPS) and were analysed along with the types of buildings mentioned above to (Figure 5). 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 was moderately used (33%) and the less popular system used was DPS (17%),while, for residential building the most widely system used was DPS (50%), followed by IPS (33%) and GFS (17%).

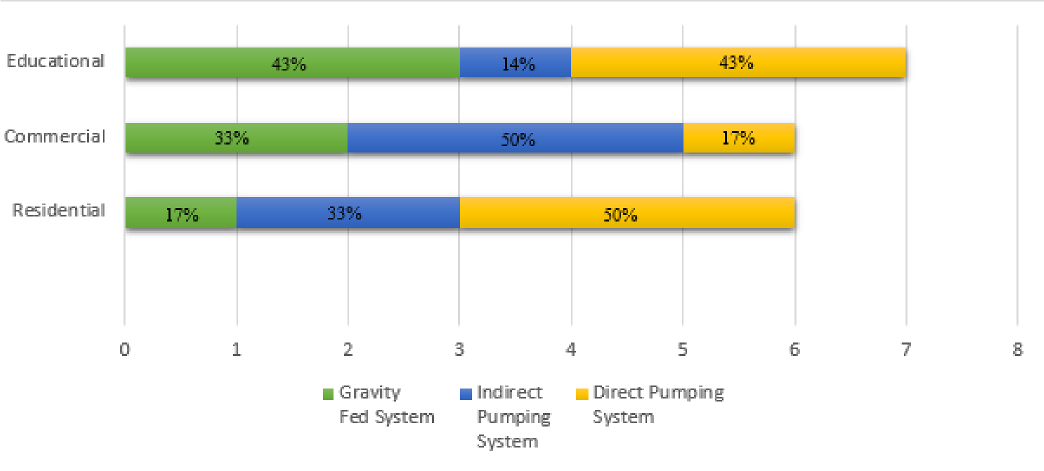

Figure 5 RWH installation system used in different types of building.

3.3 Building Characteristics

The building characteristics that have been determined in the methodology stage were analysed along with the types of RWH installation systems (Figure 6). 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 systems (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%). However, with the small yard area factor where GFS was affected (83%) by this characteristic, it does 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 tree 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%) were moderately used but only a few (17%) on IPS.

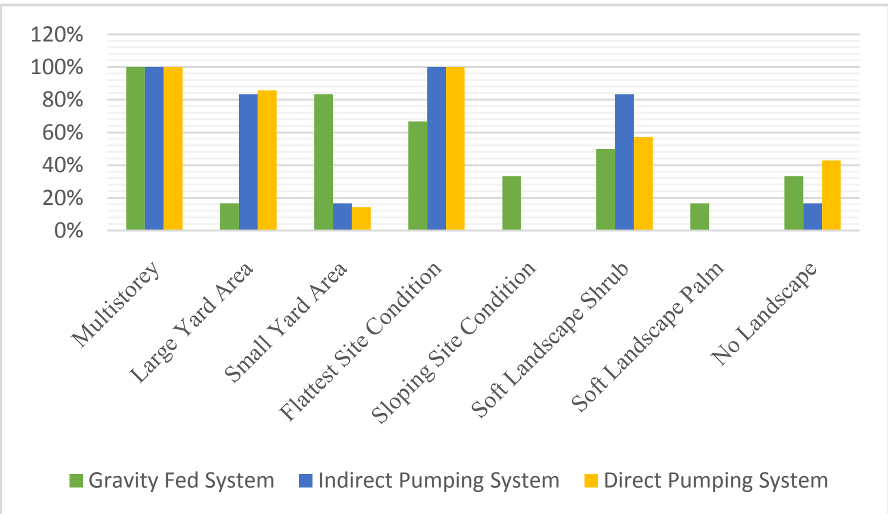

Figure 6 Building characteristics analysis

3.4 Implementation Status

The implementation status of the RWH installation system in the previous studies also was analysed in this review. This analysis was done to strengthen the previous research results in term 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 7, 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 feasibility study stage followed by DPS (43%) and IPS (17%). However, the findings from all the previous studies shows positive results (100%) on the benefits of harvested rainwater (Figure 8).

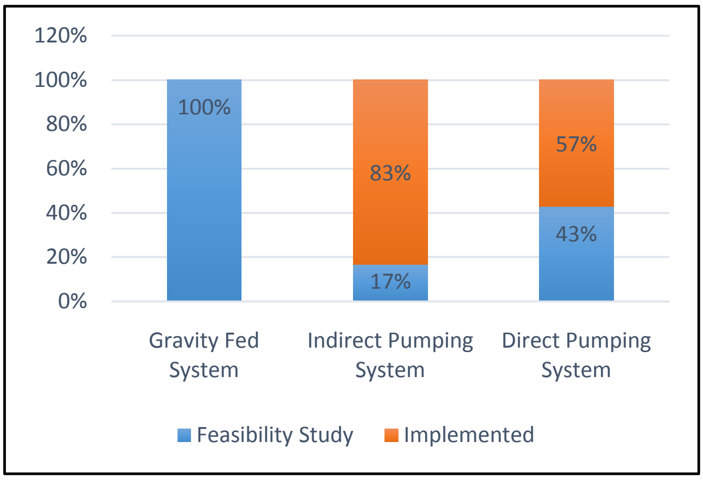

Figure 7: RWH installation system implementation stages of previous studies

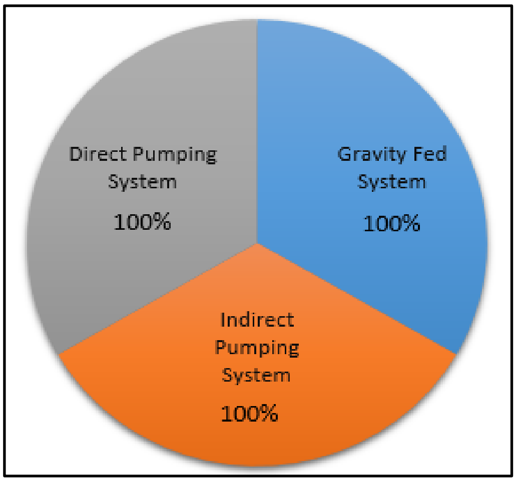

Figure 8: RWH installation system finding result of previous studies

4 DISCUSSION

This review has revealed several RWS installation systems 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 as a step towards the sustainable environment. This review has several strengths. In the literature search, there were restrictions by year of publications which will ensure that only the latest installation systems of RWH are included in the review. 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, there are also limitations. English language restriction was imposed and it is possible that 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 have explained the installation system applied. There were a lot 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 that United Kingdom is the most involved country that has conducted research regarding RWH installation system. There are three types of building that 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 are based on Ekholm, (2000). Educational building was the most widely used type of building found in this review that can be 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 or potable water used just for toilet flushing used in educational and office buildings is likely 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 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. A water pump is typically required to provide adequate pressure if the tank supplies water for indoor use (Tam, 2010). 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 is only used as underground rainwater tank. The size and location of water tank will affect the building structure and design (Zhang, 2009).

Contrast with the commercial buildings, IPS is the most widely RWH installation system used for this kind of building. IPS requires 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 that 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. In densely populated areas where more water is consumed, an important consideration would be whether a part of the urban water requirement can be covered by rainwater harvesting (Nolde, 2007). Residential building commonly used DPS and it is possible because the ceiling space and the structure strength are not suitable to use 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 tree such as trees and palms. 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 implementation. 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 studied reviewed, all results show that RWH can successfully reduce the potable water consumption especially for non-potable purpose.

5 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 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.

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