PLANNING MALAYSIA:
Journal of the Malaysian Institute of Planners
VOLUME 21 ISSUE 5 (2023), Page 253 – 266

INTEGRATING RAINWATER HARVESTING AND GREYWATER RECYCLING TO INCREASE WATER EFFICIENCY IN OFFICE BUILDINGS

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Abstract

Water is an essential component of existence. It is one of the primary resources for maintaining a daily presence. Due to high demand, freshwater becomes limited; therefore, rainwater harvesting and greywater recycling should be implemented as an alternative to substituting freshwater consumption for non-potable activities. This study discusses the implementation of rainwater harvesting and greywater recycling and the contribution to water efficiency and the environment. The main objectives of this paper are to explicate the potential benefits of integrating rainwater harvesting and greywater recycling in office buildings and to elucidate the impact of water conservation from office buildings on the environment. The result shows that implementing both systems in buildings can reduce freshwater consumption, water saving, and the discharge of wastewater to the environment, which is an essential point for water efficiency. The findings can serve as a reference for stakeholders, as they can reduce the freshwater consumption for non-potable activities and increase the water efficiency of buildings, thereby alleviating freshwater scarcity in the future.

Keywords: Rainwater Harvesting, Greywater Recycling, Potable Water, Non-Potable Water, Water Efficiency

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INTRODUCTION

Water is one of the precious elements on earth that is essential to human life. Consequently, the availability of clean water is decreasing, leading to its scarcity. The rapid development and population growth have led to an increasing demand for water consumption and increased water pollution levels in Malaysia. As a developing country Malaysia adopts green programmes (green buildings and green technologies), where the government implements them and focuses on the improvement of living standards, promoting a sustainable development system, preserving and conserving the environment and green supply management (Shaharudin et al., 2022). According to Chi et al. (2020), green buildings can be defined as buildings that go beyond conventional codes, have higher sustainability goals in energy saving, carbon emission reduction, and indoor air quality improvement besides emphasising the efficient use of water and materials, as well as reduced impacts on human health and the environment throughout the building's life cycle.

Water efficiency is one of the criteria of the green building concept that has been implemented in the building operation by conserving water consumption, substituting freshwater with rainwater harvesting and greywater for domestic use. With rainwater harvesting, water saving is from 12% to 100% depending on the amount of precipitation, water consumption per person, household economic self-sufficiency, roof type, number of occupants, and the life cycle of the technology that is used (Şahin & Manioğlu, 2019). Therefore, rainwater harvesting should be essential to augment urban and rural water supply (Al-Batsh et al., 2019). Meanwhile, greywater from lightly polluted yet more significant volume streams, such as hand-basins and laundry, requires significantly less treatment if they are separated from streams with high organic loads originating from the kitchen and toilet (Pradhan et al., 2019). Rainwater harvesting and greywater can be recycled to minimise freshwater consumption and increase efficiency.

As Malaysia is blessed with tropical rainforests, it is one of the countries that receives a high volume of monthly and yearly rainwater (Lani et al., 2018). Therefore, implementing rainwater harvesting is feasible for all types of structures, particularly office buildings. Besides, office buildings have a high occupancy rate during the daytime, when the generation level of greywater is at its peak, thus it is the perfect time to collect greywater from human activities from the use of wash basins and ablution water. This circumstance will lead to the effectiveness of using rainwater and greywater for domestic purposes due to the continuity of the sources.

LITERATURE REVIEW

Rainwater harvesting

Harvesting rainwater as an alternative source of raw water supply has been practised for centuries in various countries to cope with water shortages in the community (Murdiana et al., 2019). It can also be used as an alternative water source in conjunction with the conventional water supply in buildings due to the demand for potable water (Diehl de Souza & Ghisi, 2020). With rainwater harvesting, there are three water networks- potable, stormwater, and wastewater. These three networks can reduce the demand for potable water and reduce the stormwater runoff and the quantity of wastewater when they are combined with the greywater recycling systems (Semaan et al., 2020). One of the advantages of water demand reduction is the assurance of sufficient water supply for the population and economic growth (Nanle et al., 2022; Wijayanti et al., 2020). Having a rainwater harvesting infrastructure in the building could decrease the water stress on the groundwater due to stored rainwater that had been collected during rainy days.

However, the quality of rainwater arises because the water supply for rainwater harvesting is obtained through the accumulation of surface runoff from the roof. The quality of rainwater is influenced by several factors, i.e., the type of catchment area, conditions of topographic, climate, the air pollution level of the catchment area, the storage tank material, and the management of rainwater collection before it is used (Azis et al., 2021; Mukaromah, 2020). Nevertheless, the potential concern is mitigated because rainwater collecting is exclusively employed for domestic purposes, such as toilet flushing, household cleaning, and landscape irrigation, and so does not necessitate adherence to drinking water quality standards.

Greywater recycling

Besides rainwater harvesting, greywater recycling is the best solution for water scarcity and conservation (Radingoana et al., 2020). Greywater contributes to the largest water-saving in domestic residences as it promotes the preservation of high-quality freshwater, reduces environmental pollutants, and decreases the overall supply cost (Knutsson & Knutsson, 2021). Greywater can be defined as household wastewater that comes from both kitchen and bathroom sinks, showers, or baths and is the discharge from laundry activities where it can be reused, replacing the freshwater for non-potable activities such as toilet flushing and the irrigation of plants (Oh et al., 2018). According to Pradhan et al. (2019), greywater is lightly polluted and requires significantly less treatment for separating the organic loads in the wastewater and decreasing public health risks. Through greywater recycling, it can manage urban wastewater up to 10% to 50% of household water-saving.

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In urban water scarcity, rainwater harvesting and greywater recycling are significant as they can be the alternative water source that can be collected, treated, and channelled for domestic usage (Zaharuddin I. S. & Ahmad N. A., 2022). In Malaysia, rainwater harvesting and greywater recycling are not commonly practised due to the limited resources and knowledge on their implementation and management, even though there is an extensive amount of both resources (Oh et al., 2018). However, both rainwater harvesting and greywater recycling have the potential to reduce the dependency of using freshwater for domestic usage. Hence this study is conducted to provide some positive views and references on the rainwater harvesting and greywater recycling system that can be implemented in office buildings and other buildings which give more benefits to the stakeholders, the occupants, the environment, and many other fields. As office buildings have more capacity usage during the day where activities such as washing, cleaning and praying are held more compared to the houses, the office buildings are perfect places for conducting the study. In addition, the volume of rainwater and greywater collected is higher than houses, as the roof area of the buildings is bigger and the number of occupants contributing to the greywater discharge from the office buildings during daytime.

RESEARCH METHODOLOGY

This study adopted a quantitative research design, focusing on the primary data that are collected from the building's control system (water collection and water consumption) and secondary data from the Monthly Green Building Reports that are provided by the contractor. The analysis is expected to explicate the potential benefits of integrating rainwater harvesting and greywater recycling in office buildings, as it can contribute to water conservation and give advantages to the environment.

Rainwater collection and consumption

The rainwater surface runoff from the roof is the primary source of rainwater harvesting. The amount of water that is collected depends on the size of the roof, whereby the larger the area, the more rainwater can be collected. In this study, the rainwater collection and consumption are monitored using the Building Control System of the building. All the surface runoff will be caught through the rainwater harvesting system using a siphon system where the maximum volume of water will be drawn into a trap and channelled to the rainwater harvesting tank. The rainwater harvesting tank is equipped with a water meter which is connected to the Building Control System. This water meter will record the water flow in and out of the rainwater harvesting tank, the volume of the water that is collected, and the volume of water that is pumped out for reuse for non-potable activities such as irrigation and toilet flush. The water movement is recorded every 15 minutes, 24 hours a day. The system will record the data automatically as it was

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set for every 15 minutes recording. Figure 1 illustrates how the rainwater harvesting system is applied and how the system works in the building.

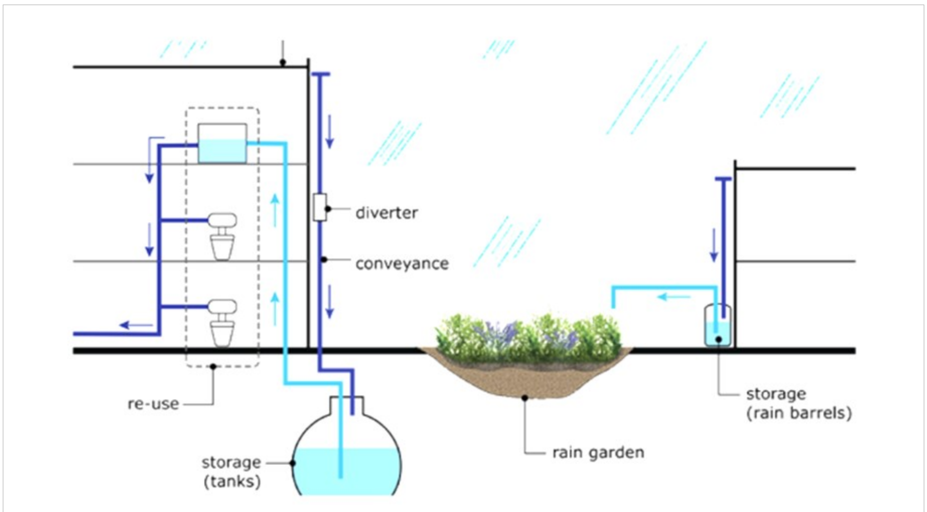

Figure 1: Rainwater Harvesting System in a Building
Source: Annual Technical Volume The Institution of Engineers (India) (2020)

Besides relying on the readings from the Building Control System, the collected rainwater can be calculated manually using a simple calculation. Table 1 shows the items that are needed for the manual calculation.

Table 1: Rainwater collection item needed for manual calculation

Item	**Unit**
Catchment area	m^2
Runoff coefficient	0.85
Duration	min

Table 1 illustrates the manual calculation of rainwater collection, which is expressed below as an equation:

$$\text{Rain water collection} = \frac{\text{Roof catchment area} \times (\text{runoff coefficient}) \times \text{duration}}{1000}$$

$$= \frac{Xm^2 \times 0.85 \times X\,\text{min}}{1000}$$

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Greywater collection

Greywater also contributes to the reduction of freshwater usage for non-potable purposes. To mitigate potable water usage within the building, the greywater originating from the wash basin and ablution taps is gathered, subjected to treatment, and then stored for irrigation. In this study, greywater will be the main contributor. This is because the building has eleven stories of occupants in which the percentage of wash basin and ablution use is higher. All the greywater collected will be stored in a greywater tank in the building and treated before it is used for non-potable activities. Greywater collection can be calculated manually using a simple calculation. The items that are involved in the calculation are illustrated in Table 2.

Table 2: Rainwater collection item needed for manual calculation

Item	Unit
Daily consumption	m^3/day
Flow rate	L/min
Duration	m
Occupants	n
Water usage	L

From the items in Table 2, the manual greywater collection calculation can be expressed as an equation below:

$$\text{Greywater collection} = \frac{\text{Daily consumption x flow rate x duration x occupants x water used}}{1000}$$

$$= \frac{\text{day x L/min x min x n x L}}{1000}$$

Building Control System (BCS)

The Building Control System is a computerised, computer-based system that has been installed in a building that controls and monitors the mechanical and electrical equipment (Murdiana et al., 2019). In this study, the systems that have been controlled and monitored by the BCS are the rainwater harvesting system and greywater recycling system for irrigation and toilet flushing. According to Muna (2019), a water meter is installed in both the rainwater harvesting and greywater tanks to monitor the volume of water that is collected and reused. This water meter is mechanical and connected to the BCS, where it is computer-based. The data on the water flow will be recorded in the system. Using the BCS is helpful for the engineer for easy monitoring. This study's rainwater harvesting and greywater recycling data are downloaded from the BCS as the primary data.

Green Building Monthly Report
The building for this case study is one of the green buildings that implement both the rainwater harvesting system and greywater recycling concurrently. As a green building, the contractor that manages the building maintenance needs to produce a monthly report as a record for green building points. The monthly report is used as the secondary data to support the primary data.

RESULT AND DISCUSSION

Volume of water collection

Rainwater harvesting capacity

The study on the rainwater harvesting system was conducted for two months to observe the effectiveness of rainwater collection and its reuse for non-potable activities. The data are from the Building Control System, which monitors every fifteen (15) minutes and twenty-four (24) hours daily. Figure 2 shows the volume of collected rainwater in two months.

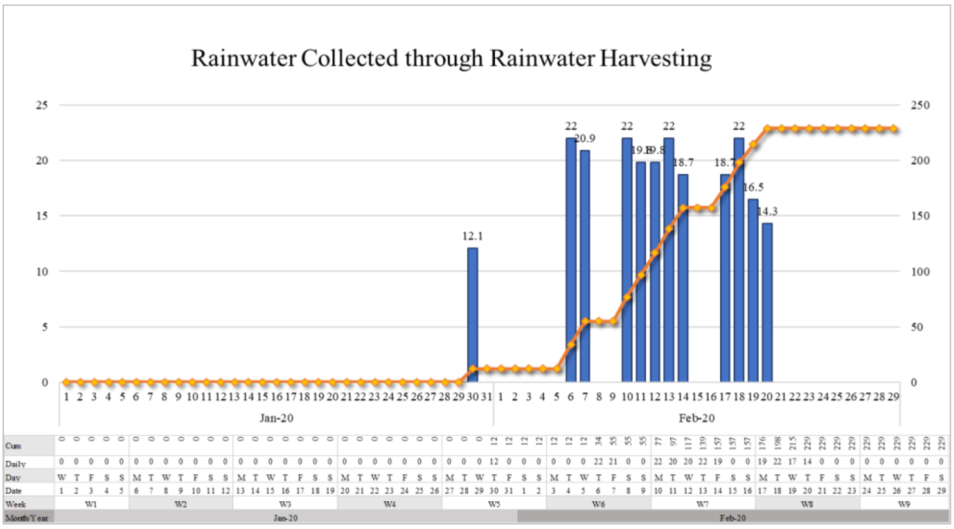

Figure 2: The volume of rainwater collected in Jan 2020 and Feb 2020

From the figure, the total rainwater that has been collected through the rainwater harvesting system in January 2020 was only 12.1m^3. This is due to the dry and sunny weather. In February 2020, the rainwater that is collected through the rainwater harvesting system has increased to 216.7m^3. The total volume of rainwater collected is 228.8m^3.

Greywater capacity

There are a few numbers of sources for greywater collection. This study's main sources for greywater collection are the wash basins and ablution. The Building

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Control System also records all the greywater that has been collected. The capacity of greywater is collected daily. Figure 3 illustrates the total volume of collected greywater from both sources, i.e., wash basins and ablution, for January 2020 and February 2020.

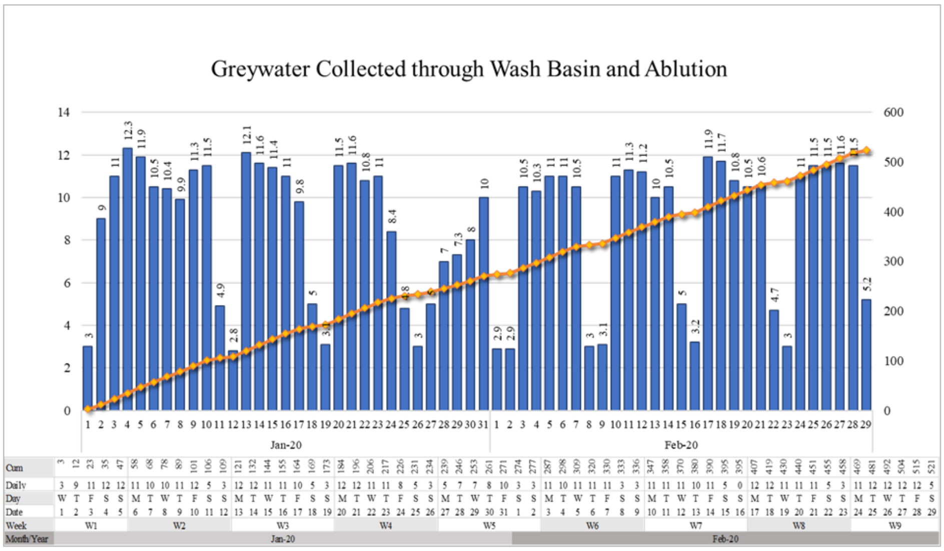

Figure 3: The volume of greywater collected in Jan 2020 and Feb 2020

In January 2020, 270.9m^3 of greywater was collected from the wash basin and ablution. The greywater was collected on a daily basis, including Saturdays, Sundays, and public holidays. For February 2020, the total greywater collected is 249.7m^3. This total water collected has brought to the cumulative volume of greywater collected in two months, which is 520.6m^3.

Volume of water consumption

SYABAS water supply

The potable water or freshwater supply to the building is mainly from Syarikat Bekalan Air Selangor or SYABAS. Every day, the water supply to the building's water tank will be recorded by the Building Control System (BCS). Figure 4 illustrates the volume of freshwater supply into the water tank for January 2020 and February 2020. There was 1568.5m^3 of freshwater supplied in January 2020 and 1571.3m^3 in February 2020. This totals 3139.8m^3 of freshwater that has been supplied for the building in both months. This freshwater is mainly used for potable drinking, cleaning, and other activities. But from the 3139.8m^3 of freshwater, only 1924.3m^3 is used. The rest has remained in the building's water tank. Figure 5 illustrates the domestic use of freshwater in January 2020 and February 2020.

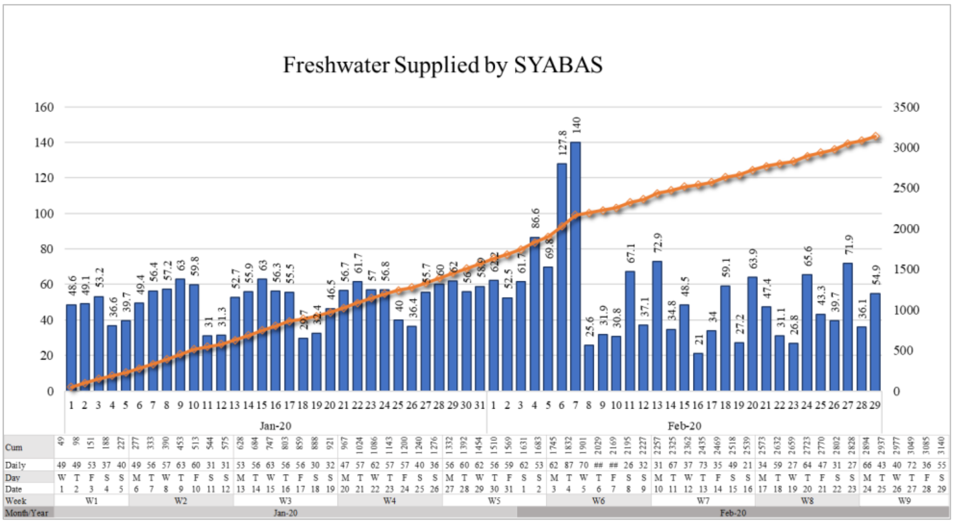

Figure 4: The volume of freshwater supplied by SYABAS in Jan 2020 and Feb 2020

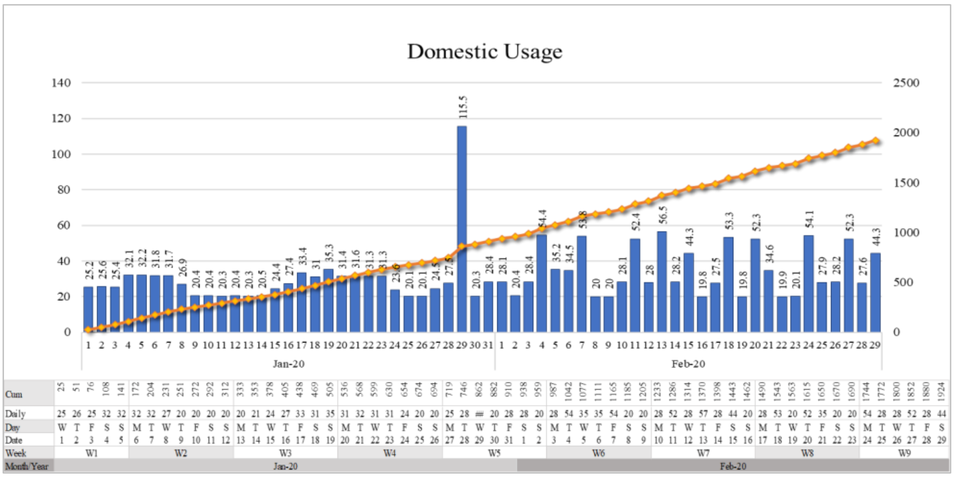

Figure 5: The volume of freshwater usage for domestic purposes in Jan 2020 and Feb 2020

Rainwater and greywater are reused and recycling

The collected rainwater and greywater were used for purposes of irrigation and toilet flushing. Greywater will be treated first before it is reused, mainly for irrigation; this is to reduce the chemicals in the greywater source that is from wash basins and ablutions where the tendency of using chemicals during cleaning is high. It is also to avoid any harm to the plants and soil. Table 3 shows the weekly water collection and consumption in the building for January 2020 and February 2020.

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Table 3: Weekly water collection and consumption

Month	Week	SYABAS supply (m^3)	Domestic Usage (m^3)	Rainwater and greywater for non-potable usage (m^3)
Jan 20	W1	227.2	140.5	53.7
	W2	348.1	171.9	109.1
	W3	345.5	192.3	94.9
	W4	355.1	189.4	102.6
	W5	407.3	264.7	88.3
Feb 20	W1	543.4	246.3	184.0
	W2	312.2	257.3	34.0
	W3	289.5	227.5	38.4
	W4	311.5	234.4	47.7
Total		3139.8	1924.3	752.6

Table 3 shows the decreasing volume of potable water consumption for domestic use compared to the freshwater supply from SYABAS. Rainwater and greywater recycling have contributed 28.11% of the total water consumption for potable and non-potable activities. It has reduced freshwater consumption and automatically saved building expenses in the long term. Even though rainwater and greywater recycling are at the initial stage of building operation, the effectiveness of using rainwater and greywater as substitutes for freshwater for non-potable activities is evident.

Freshwater saving and water efficiency

Figure 6 shows the patterns of collected rainwater and greywater, freshwater that is supplied by SYABAS, the volume of recycled rainwater and greywater, and how much freshwater can be saved when rainwater harvesting and greywater recycling is being implemented in office buildings. The graph indicated that 752.6m^3 of freshwater can be saved in these two months. This result might give a positive outcome where more freshwater can be saved for months or through the years, and will indirectly overcome the shortage of freshwater sources when more buildings implement these systems on their premises. As Malaysia is a country with a tropical climate, rainwater can be collected throughout the year, hence, rainwater availability is not an issue for the implementation of the system. Besides, Malaysia has at least five working days every week, thus, greywater would not become an issue for the system either.

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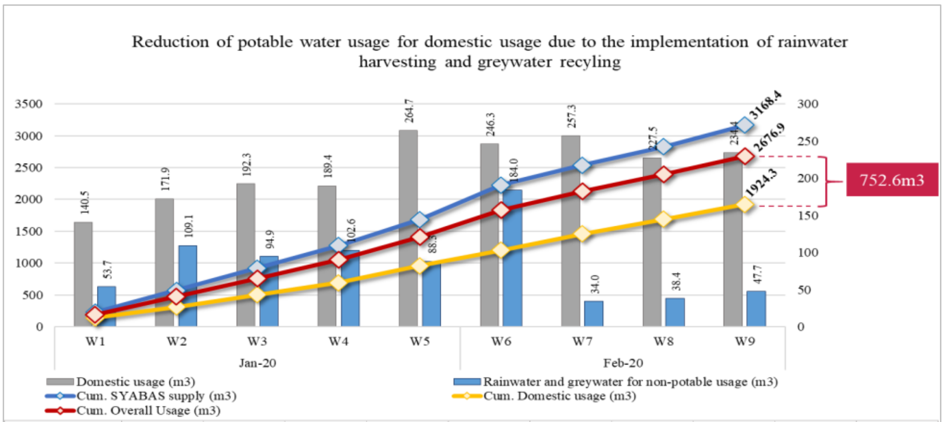

	W1	W2	W3	W4	W5	W6	W7	W8	W9	Total
Total usage (m3)	194.2	281.0	287.2	292.0	353.0	430.3	291.3	265.9	282.1	2676.9
Rainwater & greywater for non-portable usage (m3)	53.7	109.1	94.9	102.6	88.3	184.0	34.0	38.4	47.7	752.6
Domestic usage (m3)	140.5	171.9	192.3	189.4	264.7	246.3	257.3	227.5	234.4	1924.3
SYABAS supply	227.2	348.1	345.5	355.1	407.3	543.4	312.2	289.5	311.5	3139.8
Week	W1	W2	W3	W4	W5	W6	W7	W8	W9	Total
Month/Year	Jan-20					Feb-20				

Figure 6: The volume of freshwater usage for domestic purposes in Jan 2020 and Feb 2020

The office buildings' rainwater harvesting, and greywater recycling are functioning by collection of the rain by a siphonage system that is installed on the roof of the buildings. All the rainwater will be going a full-blast suction, which will then be channelled by siphonage piping into the rainwater harvesting tank. Meanwhile, in the buildings, all the buildings, all the greywater discharge from the wash basin and ablution will be collected and stored in the greywater tank that is located at the bottom of the buildings. The greywater will then be treated until it can safely be used for toilet flushing and irrigation purposes.

It has been estimated that more than 3000m^3 of freshwater can be saved in a year when the systems run smoothly in the buildings. The amount is enough to grant the whole buildings of green building points underwater efficiency. Water efficiency can be described as reducing water usage and minimising wastewater discharge. Water efficiency emphasises the responsibility of using freshwater cautiously and conserving it for future generations. In this scenario, it means that freshwater can only be consumed for the most reasonable purposes, such as cooking, drinking, and other activities that really need freshwater to avoid any harm and to replace freshwater consumption for non-potable activities with other alternatives whereby in this study is the substitution through reusing and recycling rainwater and greywater for non-potable activities.

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Furthermore, rainwater harvesting, and greywater recycling can reduce the amount of wastewater that is discharged to the environment. This is because some of the wastewater, which is greywater from wash basins and ablution, will be collected in order to be reused for toilet flushing and irrigation. The lesser the amount of wastewater that is being discharged into the environment, the cleaner the environment, and this will contribute to the reduction of water source pollution, which are the rivers. This circumstance aligns with Sustainable Goal Development 6: clean water and sanitation. In the long term, if the systems are well-implemented and well-maintained, the goal can be achieved quickly, the earth will have a sufficient freshwater supply for future generations, and we can have more water at the drinking level. The systems can be seen as an environmentally friendly method where, as we know, rainwater is safe to be used for irrigation due to lesser chemicals that are contained in the molecules. As such, rainwater can conserve energy compared to the regular potable water that is needed. In addition, lesser energy usage to power the water will make it a tremendous appreciation of nature.

CONCLUSION

Rainwater harvesting and greywater recycling are considerably new in Malaysia. Most buildings' management only considers either rainwater harvesting systems or greywater recycling, and not both systems. This is believed to be due to the high initial cost of installation and maintenance of mechanical equipment. But for the long term, implementing both systems will benefit and profit the stakeholders of the building because of the high returns in potable water consumption and water savings. It can be concluded that when both systems are implemented together in a building, the potable water consumption for non-potable activities is reduced, and besides reducing freshwater usage, it increases the water efficiency due to the recycling of rainwater and greywater, conserve the freshwater and reduce the volume of wastewater discharge to the environment. These are crucial elements as freshwater is becoming scarce. Thus, prompt implementation of the systems, especially in office buildings, will contribute to a better future. As suggested, the systems can be required for newly constructed buildings, especially those with large roof areas and high occupant capacity. The systems can be one of the potential alternatives to overcome water wastage and indirectly avoid more untreated wastewater discharge to the environment. In the future, the stakeholders can consider applying both systems in their premises for a better lifestyle, especially in controlling freshwater consumption and eventually solving the freshwater crisis.

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Received: 26th June 2023. Accepted: 15th August 2023

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