Formosa Journal of Science and Technology (FJST)
Vol. 4, No. 12, 2025: 3851-3862

Performance and Efficiency Analysis of Rainwater and Greywater Management Systems in the Green Building of Cipta Karya, East Java Province

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A R T I C L E I N F O

Keywords: Value Engineering, Development Projects, Companies

Received : 27, October
Revised : 29, November
Accepted: 31, December

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A B S T R A C T

This study took place at the East Java Provincial Public Housing, Settlement Area, and Public Works Office. this information highlights a noticeable difference in both size and height between the two sections of the structure. On the other hand, a greywater management system is designed to process and recycle wastewater generated from domestic or building activities, including water from sinks, showers, and laundry machines, but excluding toilet waste (referred to as blackwater). Greywater typically contains low concentrations of soap, detergent, oil, fat, and organic matter, along with fewer pathogens compared to blackwater. As such, it can be repurposed following suitable treatment. Implementing greywater management in eco-friendly buildings can reduce potable water consumption by about 30 to 50%, depending on the building's size and usage.

ISSN-E: 2964-6804
DOI: https://doi.org/10.55927/fjst.v4i12.329
https://traformosapublisher.org/index.php/fjst

INTRODUCTION

Population growth and rapid urban infrastructure development in Indonesia have placed significant pressure on the availability of clean water resources and the environment's capacity to manage wastewater. The construction sector, particularly high-rise buildings, is a major contributor to water consumption and domestic waste generation. In response to these challenges, the Green Building (GWB) concept has been established as a strategic solution to minimize environmental impacts and optimize resource efficiency, in accordance with national regulations such as Minister of Public Works and Public Housing Regulation No. 21 of 2021, which targets water savings of at least 10% of raw water consumption.

One of the main pillars in achieving water efficiency at BGH is the implementation of alternative water management systems, particularly through rainwater harvesting (RWH) and greywater recycling (non-toilet wastewater). The RWH system utilizes Indonesia's high rainfall for non-potable needs (such as flushing and irrigation), while greywater recycling reduces the burden of waste disposal and dependence on PDAM water. The integration of these two systems (hybrid system) has been proven to contribute significantly to reducing clean water consumption, even achieving substantial levels of water conservation efficiency in case studies in several buildings (Farida & Aryuni, 2020; Mardiaman & Siahaan, 2024).

The Provincial Cipta Karya Green Building is one of the iconic government buildings promoted as a pilot project for BGH implementation at the regional level. As an entity under the Directorate General of Human Settlements, this building is expected to not only meet green certification standards but also optimally adopt sustainable technologies. However, despite normatively established water efficiency targets, the existing implementation of RWH and greywater recycling systems in government buildings often faces unique challenges, such as suboptimal technology adoption, lack of operational awareness, and management barriers to sustainable system maintenance (Jaya et al., 2024).

Therefore, an in-depth and detailed analysis of rainwater harvesting and greywater recycling at the Cipta Karya Provinsi Green Building is required. This research is crucial for identifying the existing conditions of the system, from installation design and operational capacity to construction and maintenance management constraints, which will ultimately determine the potential for broader and more integrated system implementation. This potential analysis will include an evaluation of the water balance, savings predictions, and technical recommendations tailored to the building's characteristics and local rainfall.

The primary focus in the review of water system implementation and efficiency in green buildings is water conservation, which includes the application of Rainwater Harvesting (RWH) technology and greywater recycling. The implementation of modern green building concepts demands significant water efficiency through the use of water-saving features and recycling installations. Research shows that, in various office buildings, the implementation of efficient water features can result in massive clean water savings, with some studies reporting a reduction in consumption of up to 28.74% of the total PDAM water demand (Mardiaman & Siahaan, 2024). Furthermore, these savings can be further enhanced through the integration of RWH systems, where the potential daily water savings can reach an average of 30.57% through the use of rainwater harvesting facilities, thereby directly reducing operational burdens and dependence on conventional water sources.

The implementation aspect of green buildings (BGH) is not only seen from the system design, but also from compliance with existing regulations and performance standards. The government's commitment to sustainable development is demonstrated through a minimum water savings target of 10% as an effort to achieve national climate targets (Info Republik, 2022). Assessment standards such as Greenship by GBCI also explicitly make stormwater management and water recycling mandatory criteria for improving water efficiency scores (Bobo et al., 2023). Therefore, construction management reviews must ensure that piping and recycling systems, including the selection of water-saving fixtures, are designed in accordance with hydraulic standards that can support the achievement of established water conservation targets.

To achieve optimal efficiency, much research during this period focused on combined or hybrid systems. The integration of rainwater harvesting with greywater recycling has proven to be a superior strategy for maximizing the fulfillment of non-potable water needs, such as for toilet flushing, irrigation, and cooling towers (Jaya et al., 2024). This is important considering that the proportion of greywater (non-toilet wastewater) in domestic and commercial buildings ranges from 60% to 80% of total wastewater, making it the most potential recycled water source (Bangka Belitung Public Works and Housing Agency, 2023). Through proper treatment, excess greywater from flushing needs can be utilized for groundwater conservation through infiltration wells, closing the domestic water cycle within buildings.

THEORETICAL REVIEW

The performance of the integrated recycling system shows promising results, especially when comparing system performance between the rainy and dry seasons. Case studies at several universities show that water conservation efficiency can increase significantly, reaching 69.0% in the rainy season thanks to the maximization of RWH, compared to only 30.1% in the dry season when relying solely on greywater recycling (Farida & Aryuni, 2020). This confirms that system performance is strongly influenced by seasonal variables, requiring careful water balance analysis to optimize rainwater retention capacity and greywater treatment system design for year-round operation.

The future of water system implementation is also moving toward digitalization. Recent innovations demonstrate a shift to smart water management systems utilizing IoT (Internet of Things) technology to monitor water quality and quantity in real time (Movva, 2023). The use of sensors in RWH and greywater recycling systems enables automatic leak detection and water usage optimization, which not only increases the effectiveness of non-potable water savings but also simplifies maintenance (IKN Authority, 2024). Therefore, the success of the water system implementation at the Provincial Cipta Karya Green Building must be assessed based on a combination of technical efficiency, construction management compliance, and the integration of the latest smart technologies.

The concept of green buildings emerged in response to increasing pressure on natural resources due to population growth, urbanization, and the impacts of climate change. Green buildings are defined as buildings that prioritize efficient use of resources (water, energy, materials), the health and comfort of occupants, and minimize negative impacts on the surrounding environment during their planning, construction, operation, and maintenance. This approach emphasizes not only energy efficiency but also water conservation, waste management, indoor air quality, and other sustainability aspects.

Extensive research has been conducted on the application of rainwater and greywater management systems in green buildings, both nationally and internationally. Reviewing previous research is crucial for understanding technological developments, performance evaluation methods, and factors influencing successful implementation.

The implementation of a rainwater harvesting system in the research area, which produces additional water sources, especially for domestic needs, is in line with research findings in other areas using the same method. Durensari Village, Bagelen District, Purworejo Regency, can save 214 m3 of water per year, or 4% of the total water needs in residential areas (Marwoto et al., 2021), and in Masohi City, Central Maluku Regency, a reservoir tank with dimensions per household was designed to accommodate rainwater. Research on rainwater utilization found that the volume of rainwater that can be harvested with a roof is 3 m3 (Tiwery et al., 2022). Several correlations with similar studies can certainly be confirmed that this method is effective in contributing additional water sources. (Hayatining Pamungkas et al., 2023)

Based on the analysis of alternative water sources in the form of grey water, condensate water, and rainwater can be used to meet the daily needs of the building, reducing water usage by 39,975.66 m3 in 10 years or 66.07%. For operational costs, there is a saving of Rp 391,761,636, which can reduce water usage costs by 60.74%. For the required capital expenditure of Rp 486,902,490. (Biyanto et al., 2016)

Among the effective filtration processes to reduce wastewater pollutants include, TSS 0.89%, BOD 69.11%, COD 87.24%, Ammonia 18.35%, Oil and Fat 95.16%, pH increase reaches 21.08%, an effective filtration process to reduce water pollutant levels, but can only make the pH from 5.64 to 6.87 so that it complies with the quality standards of the Minister of Environment and Forestry Regulation No. 68 of 2016 concerning domestic wastewater quality standards. Recommendations that can be conveyed in this study need to be developed in-depth studies and analysis related to the examination of domestic wastewater quality, further research to pay attention to and improve the effectiveness of filtration which includes the volume of the container and the thickness of each filter media, and the results of this study can be used as pretreatment for domestic wastewater treatment to the next stage of domestic wastewater treatment. (Faradila et al., 2023).

The reduction in wastewater levels after treatment using a filtration device was quite significant for several tested parameters, with the respective percentage reductions in BOD (77.33%), COD (79.78%), and sulfate (31.23%). Meanwhile, TSS (oil and grease) parameters did not decrease due to the absence of any contaminants from the initial application. (Afrhiani et al., 2020)

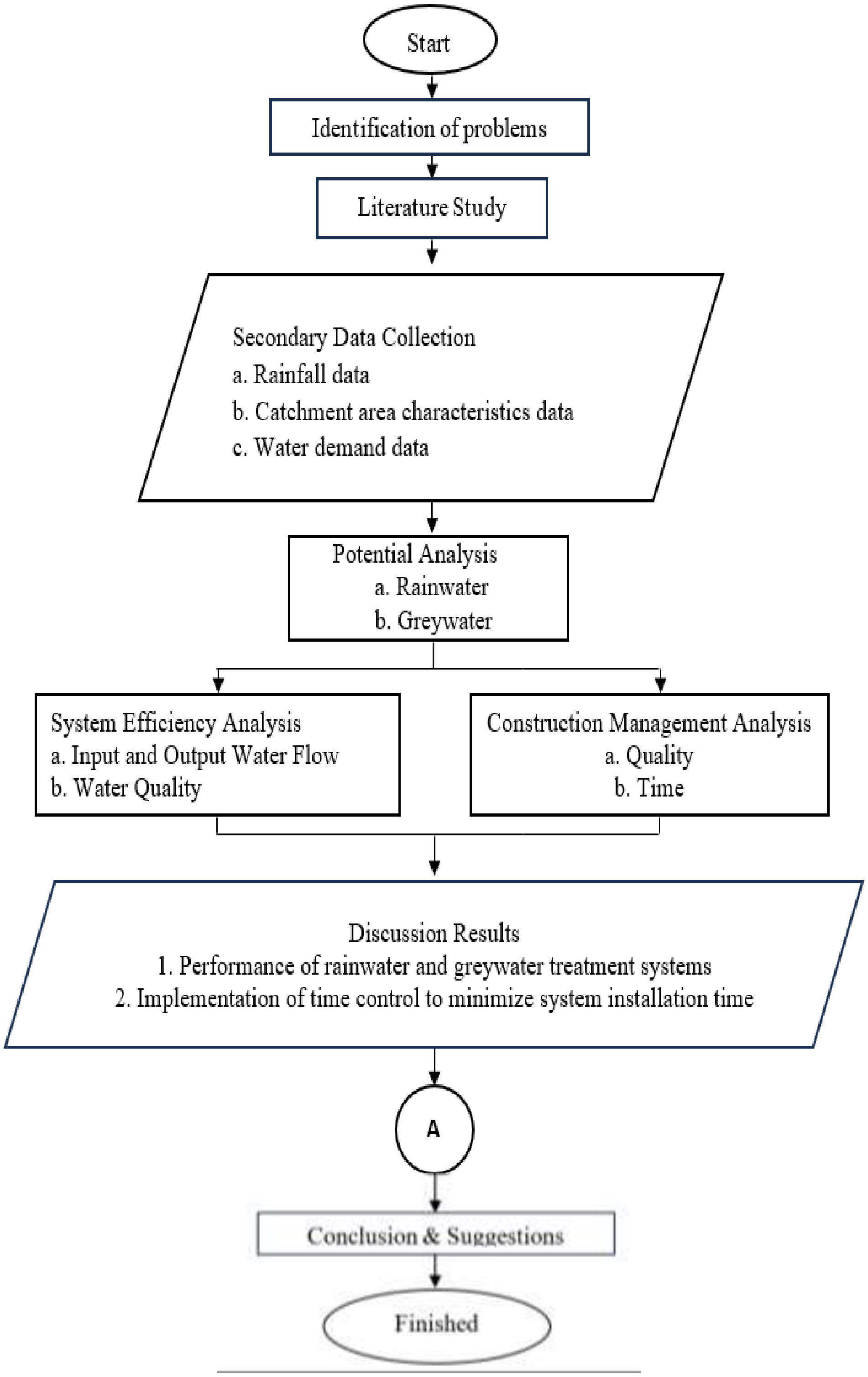
The appropriate and efficient technology for greywater wastewater treatment at the Taman Candiloka Housing Complex in Ngampelsari Village, Candi District, Sidoarjo Regency, is the use of Constructed Wetland technology with a Vertical Subsurface Flow System (Afrhiani et al., 2020).

Based on the redesign results, an equalization tank unit and a SRAB unit were added, resulting in a greywater storage volume and unit size in accordance with SNI 8455:2017. In addition, with the addition of the SRAB unit, there are changes to the wastewater distribution system, such as pipe slopes and differences in pipe elevation. Changes to the wastewater distribution system occur because the route and distance are different from the current conditions of the Gunung Anyar Surabaya Rusunawa. The redesign implementation in the field will be divided into 2 treatment unit zones, namely on the right and left of the Rusunawa. This is due to the limited empty land available at the Gunung Anyar Rusunawa. The planning of the WWTP should consider greywater waste so that the waste released meets the quality standards of the East Java Governor's Regulation No. 52 of 2014. (Afrhiani et al., 2020).

The results of the calculation of water needs in the UNDIP Campus area in 2014 were 5,920 lt/sec for average water needs, 6,808 lt/sec for maximum daily needs, and 9,955 lt/sec for needs during peak hours. The volume of groundwater use in the UNDIP Campus area in 2014 was 29541 m^3 or 2.23 lt/sec. The rainwater harvesting system used in the UNDIP Campus area is a Cistern Building and Infiltration Wells and is equipped with roads and infiltration gardens. The Cistern Building is planned to be made of concrete quality f'c 15 with a volume of 240 m^3, the use of gutters is used gutter size 15 x 20 cm, on the roof side is used splash guard from metal sheet with a width of 30 cm installed every 3 m, and used pipe with a diameter of 100 mm. The infiltration well planning is planned with a depth of 3 m and a diameter of 1.5 m. For the infiltration building, the total water that can be infiltrated is 1,429,569.4 m3, when compared to the total rainwater potential of the UNDIP campus area, the percentage of water that can be infiltrated by the infiltration building is 51% of the total rainwater potential of the UNDIP campus area. (Afrhiani et al., 2020).

METHODOLOGY

The flowchart for the research implementation stages can be seen in the following image:



The methods used include:

• Field observations to determine the existing condition of the rainwater and greywater management system.

• Technical document studies to obtain design data, capacity, and system specifications.

• Structured interviews with the management and construction implementers.

• Field measurements of storage volume, flow rate, and actual water usage. The first step is to collect and process the obtained primary and secondary data. The data collected includes a time schedule.

Data analysis was conducted through the following stages:

• Rainwater and Greywater Potential Analysis: Using a formula to calculate rainwater catchment volume and estimate greywater discharge based on the number of users and type of activity. Technical Document Studies: Obtaining design data, capacity, and system specifications.

• System Efficiency Analysis: Comparing potential and actual utilized volumes and analyzing system losses.

• Construction Management Analysis: Analyzing the planning, implementation, and monitoring processes of the system based on interviews and observations to assess implementation effectiveness.

This research will be conducted for 8 weeks from the research to the completion of the thesis report, namely in the first week of January 2026.

The main variables in this study consist of:

1. Technical Variables:

• Rainwater potential (capture volume)
• Rainwater harvesting system capacity and storage volume
• Discharge and volume of greywater produced
• System efficiency (comparison of potential and actual utilization)

2. Managerial Variables:

• System construction planning and implementation
• System monitoring and maintenance procedures
• Constraints and risks in system implementation

The parameters observed included local rainfall, roof area, runoff coefficient, greywater discharge, and data on the building's PDAM water usage.

The data used in this study includes:

• Primary Data: field observations, interviews with building managers, measurements of existing systems, and field photographic documentation.

• Secondary Data: rainfall data from the local BMKG (Meteorology, Climatology, and Geophysics Agency), building planning drawings, budget documents (RAB) and working drawings, as well as relevant literature and regulations.

RESULTS AND DISCUSSION

This research was conducted at the East Java Provincial Public Housing, Settlement Area, and Public Works Office building located at Jl. Gayung Kebonsari No. 169, Gayungan, Gayungan District, Surabaya, East Java. The building facility consists of three main roof structures, but in this case I only examined two of the three roof areas, namely the Main Building and the West Wing Building. The Main Building is the larger structure with dimensions of 37.30 meters in length and 22.00 meters in width. This building stands four stories tall, giving a total floor area of approximately 820.6 m². Meanwhile, the West Wing Building has dimensions of 24.57 meters in length and 9.28 meters in width. This structure is lower with only two stories, resulting in a total floor area of approximately 228.00 m². Overall, this data shows a significant difference in size and vertical capacity between the two parts of the building.

Meanwhile, a greywater management system is an effort to treat and reuse wastewater from household or building activities, such as from sinks, showers, and washing machines, but does not include water from toilets (blackwater). Greywater contains soap, detergent, oil, fat, and organic materials in low concentrations, and has fewer pathogens than blackwater, so it can be reused after treatment. Greywater management in green buildings can save clean water use by up to 30–50% depending on the size and activity of the building. The treatment process includes initial filtration to remove large impurities, sedimentation of solid particles, sand or multimedia filtration, biological treatment such as aerobic biofilters or membrane bioreactors (MBR), and a disinfection stage using chlorine, UV light, or ozone to reduce the number of pathogenic microorganisms.

Regulations related to greywater management in Indonesia are still under development, but have been accommodated in PUPR Ministerial Regulation No. 21 of 2021, the GBCI Greenship guidelines, and refer to Ministerial Regulation No. P.68/Menlhk/Setjen/Kum.1/8/2016 concerning domestic wastewater standards and WHO guidelines for the use of recycled water. Internationally, standards such as NSF/ANSI 350 (United States) and BS 8525 (United Kingdom) serve as references in system design, water quality parameters, and environmental health aspects. Commonly used technologies include aerobic biofilters for small-to-medium scale, membrane bioreactors (MBR) for large buildings, and constructed wetlands that utilize aquatic plants for natural filtration. The implementation of greywater treatment systems offers various benefits, including savings in clean water and operational costs, reduced domestic waste volume, increased water conservation points in green building assessments, and supporting the achievement of sustainable development principles through water resource efficiency and reduced environmental burdens.

Rainwater harvesting is a technology for collecting and utilizing rainwater from the surface of buildings or land for various purposes, particularly non-potable uses such as garden watering, toilet flushing, and washing areas. This system is one of the simplest and most effective water conservation methods because it utilizes naturally available water sources, reduces dependence on PDAM water, and reduces the burden on urban drainage systems.

The basic principle of a rainwater harvesting system is to capture, channel, filter, store, and distribute rainwater for reuse. Generally, this system consists of several main components:

- A catchment area, usually the roof of a building, where rainwater falls. The size and type of roof will affect the volume of rainwater that can be collected.
- Collection channels (gutters and downpipes), which function to channel rainwater from the roof to a storage system. These channels must be designed with adequate slope and capacity to prevent excessive runoff.

• A first-flush diverter, which removes the first rainwater, which typically contains dust and dirt, from the roof.
• A storage tank, which is used to store rainwater. Tanks can be located above ground (ground tank) or underground (underground tank), depending on the site conditions and building design.
• A filtration and distribution system, which functions to filter rainwater to meet quality standards for non-potable use, and distribute it to points of use.

In Indonesia, rainwater management is regulated by several regulations, including:

• Ministerial Regulation No. 12 of 2014 concerning the Implementation of Urban Drainage Systems, which encourages the implementation of rainwater harvesting systems to reduce runoff.
• SNI 8456:2017 concerning Procedures for Planning Urban Drainage Systems, which provides guidelines for calculating rainwater discharge and planning retention systems.
• Ministerial Regulation No. 21 of 2021 concerning Green Building Assessment, which requires rainwater utilization as part of water conservation efforts.

Internationally, standards such as AS/NZS 3500 (Australia) and BS 8515 (United Kingdom) also provide guidelines for planning rainwater harvesting systems, including calculations of tank capacity, water quality, and health aspects.

The benefits of implementing this system include:

• Reducing PDAM water consumption, thus lowering building operational costs.
• Controlling rainwater runoff and puddles around buildings.
• Contributing to the Water Conservation score in green building assessments.
• Increasing the building's water resilience to drought conditions or interruptions in clean water supply.

Therefore, rainwater harvesting systems are an important component in implementing green buildings, especially in government buildings with large roof areas and high non-potable water needs.

Greywater is wastewater from household or building activities, excluding toilets (blackwater). Primary sources of greywater include sinks, showers, bathtubs, washing machines, and kitchens. Greywater generally contains soap, detergent, oil, grease, organic particles, and traces of household chemicals in low concentrations. Greywater contains relatively lower levels of pathogens than blackwater, allowing it to be reused after undergoing a specific treatment process.

In the context of green buildings, greywater management is a crucial water conservation strategy. Greywater reuse can save up to 30–50% on clean water usage, depending on the building's size and number of occupants. Treated greywater is generally used for non-potable purposes, such as flushing toilets, watering gardens, or cleaning building areas.

Greywater treatment aims to remove suspended solids, organic matter, oil, and grease, and reduce the concentration of contaminants so the water can be safely reused. The treatment principle involves several stages, namely:

• Preliminary Screening

Greywater is filtered to remove large contaminants such as hair, food scraps, or rags. This stage prevents clogging in subsequent processes.

• Sedimentation: Heavier solid particles settle in the holding tank, reducing the burden on the filtration process.

Filtration and Biological Treatment consist of three types:

• Sand or multimedia filtration is used to remove fine particles and some organic matter.

• Aerobic biofilters or membrane bioreactors (MBR) are often used to significantly reduce BOD and COD levels.

• Disinfection

The final stage aims to reduce the number of pathogenic microorganisms, typically using chlorination, UV light, or ozonation, depending on the scale of the system and the established water quality standards.

The end result of this process is called treated greywater, whose quality meets the criteria for reuse, especially for non-potable purposes.

The implementation of green building concepts relies not only on technical planning and architectural design, but is also greatly influenced by effective construction management. Construction management is the process of planning, organizing, implementing, and controlling resources to achieve project objectives efficiently in terms of time, cost, quality, and safety. In the context of green buildings, the function of construction management is expanded to encompass aspects of sustainability and resource efficiency.

Early in the project, the construction management team must ensure that green building principles are integrated into the design documents and implementation plans. This includes selecting water- and energy-saving technologies, determining rainwater harvesting and greywater reuse strategies, and adjusting work schedules to support the implementation of these systems. Coordination across disciplines (architectural, civil, MEP, and environmental) is key to success.

One of the main challenges in implementing green technology is the initial investment costs, which tend to be higher than conventional systems. Construction management plays a role in optimizing the budget through life cycle cost analysis, selecting appropriate technology for scale, and controlling costs during implementation. Scheduling also needs to be adjusted to ensure that the integration of rainwater harvesting and greywater systems does not disrupt the main work sequence.

Installation of rainwater and greywater management systems must meet applicable technical standards. The construction management team is responsible for conducting regular inspections, ensuring materials and equipment meet specifications, and conducting system commissioning prior to handover.

The implementation of green building systems in government projects, such as the Provincial Cipta Karya Building, requires specific strategies to ensure sustainability. Some key strategies include:

- Integration of green concepts into contract documents, so that construction service providers have a legal obligation to implement these systems.
- Training and outreach to field workers, as rainwater harvesting and greywater reuse technologies are often new to some contractors.
- Intensive supervision by construction management, especially regarding the installation of pipes, storage tanks, and water treatment units.
- Involvement of building users from the outset, so that the systems can be operated sustainably after the project is completed.

The performance of rainwater and greywater management systems is significantly influenced by the quality of construction. Installation errors, inappropriate material selection, or inadequate testing can result in the system not functioning optimally. Therefore, construction management plays a strategic role in ensuring that green building technologies truly deliver the benefits intended.

CONCLUSION AND RECOMMENDATION

Based on the analysis conducted on the retrofitting of the East Java Provincial Public Works Agency Office Building into a Green Building, the following conclusions can be drawn. Analysis of the performance of the rainwater and greywater treatment system in the retrofitting project of the East Java Provincial Public Works Agency Office Building using a mixture of rainwater and PDAM water for clean water use. Analysis of the application of time control to minimize installation system usage in the retrofitting project of the East Java Provincial Public Works Agency Office Building.

FURTHER STUDY

Future research is recommended to further evaluate the long-term performance and efficiency of rainwater and greywater treatment systems implemented in green building retrofitting projects, particularly in government office buildings. Subsequent studies could analyze the consistency of water quality, operational costs, and maintenance requirements associated with the combined use of rainwater and PDAM water for clean water supply.

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