Evaluation of Greywater Reclamation and Reuse System in a Japanese University Building

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Abstract:

As part of an initiative to develop green university campuses, measures to reduce water consumption have been conducted in many universities. Water saving equipment and rainwater harvesting systems have been installed in many universities. On the other hand, cases of installing water reuse recycling systems in university campuses are few. In this study, an empirical experiment for greywater reuse was conducted in a university research building which did not have experimental facilities or dining halls. A long term monitoring survey was carried out to investigate the volumes of consumed water and drainage water, the quality of greywater, and the treatment performance by contact oxidation (biological treatment) using a Johkasou wastewater treatment tank. Furthermore, life cycle assessment (LCA) was conducted to evaluate the greywater reuse system combined with wastewater harvesting in the TRICEA building at Biwako Kusatsu Campus, Ritsumeikan University. The results demonstrated that it is feasible to introduce a greywater reuse system using Johkasou and microfiltration in terms of water quality. The LCA results showed that a 32% reduction of the life cycle greenhouse gas emissions related to water supply and treatment at the TRICEA building is possible by introducing both rainwater harvesting and water reuse systems.

Keywords: *greywater, water reuse, life cycle assessment, green building, Johkasou*

1. Introduction

Recently, maintaining a stable water supply has become difficult because the unfair spatial-temporal distribution of water resources in the world has expanded due to climate change. Therefore, water

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reclamation and reuse is becoming increasingly important to solve this issue. Greywater, which does not include excreta, usually contains low concentrations of pathogens. Thus, it is considered a suitable and acceptable recycling option for households (Hurlimann et al., 2010.; Jiawkok et al., 2013.; Oron et al., 2014).

University campuses use large amounts of water and also generate large amounts of wastewater. In recent years, the importance of environmental aspects in the construction and operation/ management of university campuses has been strongly recognized. As part of an action to develop green university campuses, measures to reduce water consumption have been conducted at many universities. Therefore, many universities have installed water saving equipment and rainwater usage systems, and some universities have installed water reuse systems.

University campuses have several buildings for many purposes such as experimental laboratories, lecture buildings, and office buildings. Although the amount and quality of greywater differ according to the intended use, the basic data of greywater reclamation and reuse is scarce. For feasible water reclamation and reuse in university buildings, it is important to consider the treated water quality and quantity.

Thus, an empirical experiment was conducted to investigate the potential greywater reuse in a university building which did not have experimental facilities or dining halls. Additionally, a long term monitoring survey was carried out to analyze the volumes of consumed water and drainage water, quality of greywater, and treatment performance by contact oxidation as a biological treatment, using a Johkasou[1]. The authors have reported the results of the long term monitoring (Shimizu and Nakajima, 2018, Shimizu et. al., 2018). This paper summarizes the previous reports and shows the characteristics of water consumption in detail.

It is important to evaluate water reclamation and reuse systems considering the life cycle cost and the greenhouse gases (GHG) emission. Water supply requires energy and materials for treatment and distribution, as well as wastewater treatment such as by Johkasou or centralized wastewater treatment plants. These processes cause GHG emissions through manufacturing and use of energy and materials, and non-CO_2 GHG emissions from biological treatment processes.

Only a few life cycle assessment (LCA) studies have considered decentralized water reclamation systems for businesses and households. Existing studies indicate that decentralized water reclamation systems can reduce environmental impacts compared to centralized water supply and treatment systems (Jeong et al., 2018; Opher and Friedler, 2016). However, there is no LCA study on water reclamation systems of university buildings. It is not clear if the amount and quality of greywater in university buildings can be utilized to conduce environmental benefits. Therefore, based on long term monitoring and empirical experiments, this study evaluates the life cycle GHG emissions of a wastewater reclamation system combined with wastewater harvesting in a university building.

2. Methodology

(1) Outline of the Water System and Johkasou in TRICEA

The target facility was the university building "TRICEA," which was completed in April 2014, and is located at the Biwako Kusatsu Campus, Ritsumeikan University (Photo 1). TRICEA comprises

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1 The Johkasou system was spreaded rapidly from 1960s as a kind of distributed wastewater treatment system to meet the high demand for clean water worldwide. The name has become synonymous with any small scale sewage treatment system that uses anaerobic, aerobic and disinfectant processes to render blackwater (that bears human excreta) and/or greywater (from kitchens and sinks) relatively harmless and clean.

TRICEA I, with 5 floors, and TRICEA II, with 3 floors. There are no experimental facilities, dining halls, or shower rooms in these buildings. Fig. 1 shows the architectural area, the approximate number of users, and the outline of the water system in TRICEA. Tap water from Kusatsu City is first supplied to the potable water tank and then to the non-potable water tank. Drinkable water is supplied to the sinks in rooms and toilets from the potable water tank. Water from the non-potable tank is mainly used to flush toilets, and the rest is supplied to the fire cisterns and the rainwater reservoir. Rainwater, collected from the roof of TRICEA, is stored in the rainwater reservoir. The collected rainwater is used

Photo 1. University Building "TRICEA"

*Treated water is designed to be able to connect to non-potable water tank, but actually treated water is not used.
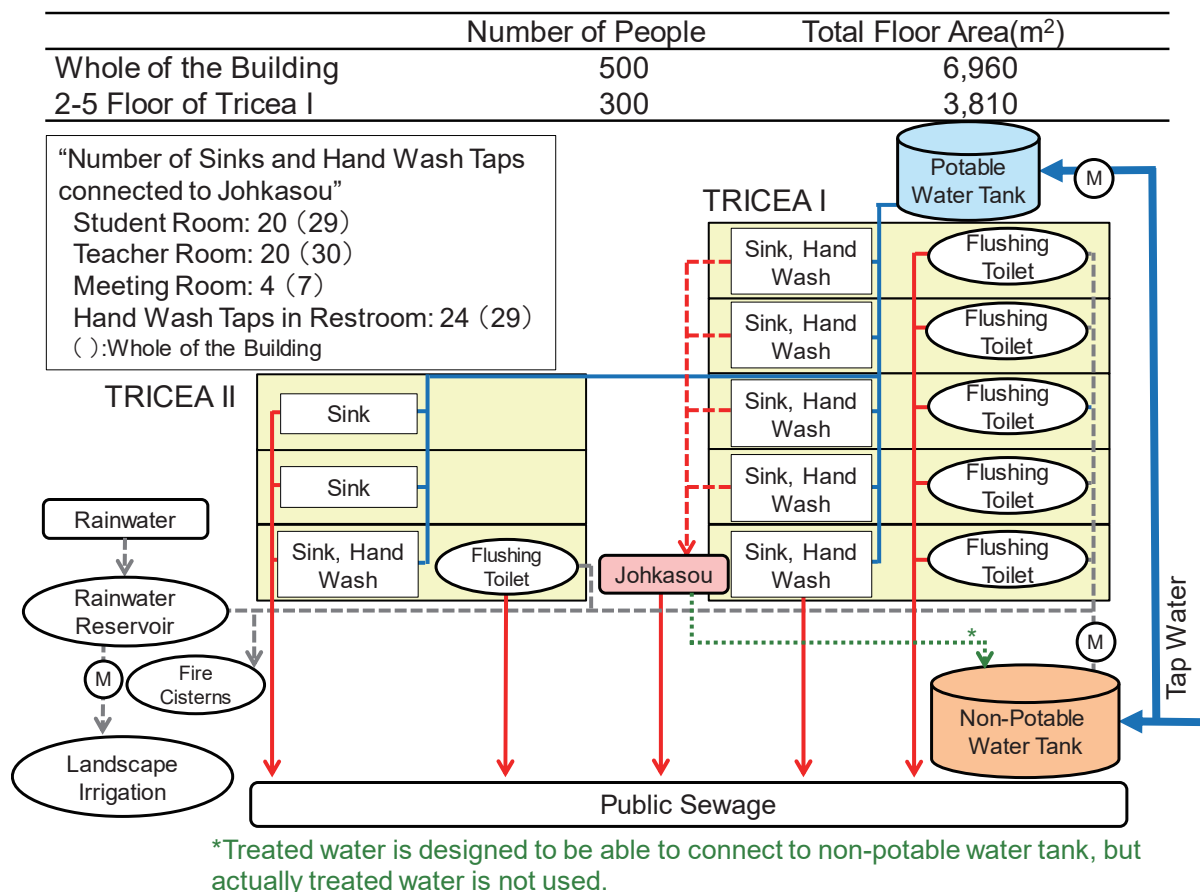
Fig. 1 Outline of Water System in TRICEA

for landscape irrigation. Water meters are installed at the front of the potable water tank, at the back of the non-potable water tank, and at the rainwater reservoir.

Experimental treatment of greywater, which is generated from the 2nd to 5th floor of TRICEA I, is conducted using the Johkasou system installed outside TRICEA. This greywater is first stored in a storage pit, and then pumped into the Johkasou. Wastewater from toilets and other sinks are connected to the public sewage pipeline. The treated greywater is designed to be connectable to the non-potable water tank. In actuality, greywater is not reused due to water quality management issues and the absence of a chlorination process.

Fig. 2 shows the outline of the greywater treatment using the Johkasou, which is a CEN-5 manufactured by Fuji Clean Co. Ltd. (Photo 2). The effective volume of the Johkasou is 2.8 m³. It consists of a sedimentation chamber, an anaerobic filtration chamber, an aerobic contact filtration chamber, and a treated water storage chamber. A part of the treated water is recirculated from the treated water storage chamber to the sedimentation chamber to remove nitrogen. A storage tank was installed in the rear stage of the Johkasou, and membrane filtration was carried out using a microfiltration membrane, manufactured by Toyobo Co. Ltd., with a pore diameter of 0.45 μm. The disinfection process was not performed because the system was connected to the public sewage pipeline.
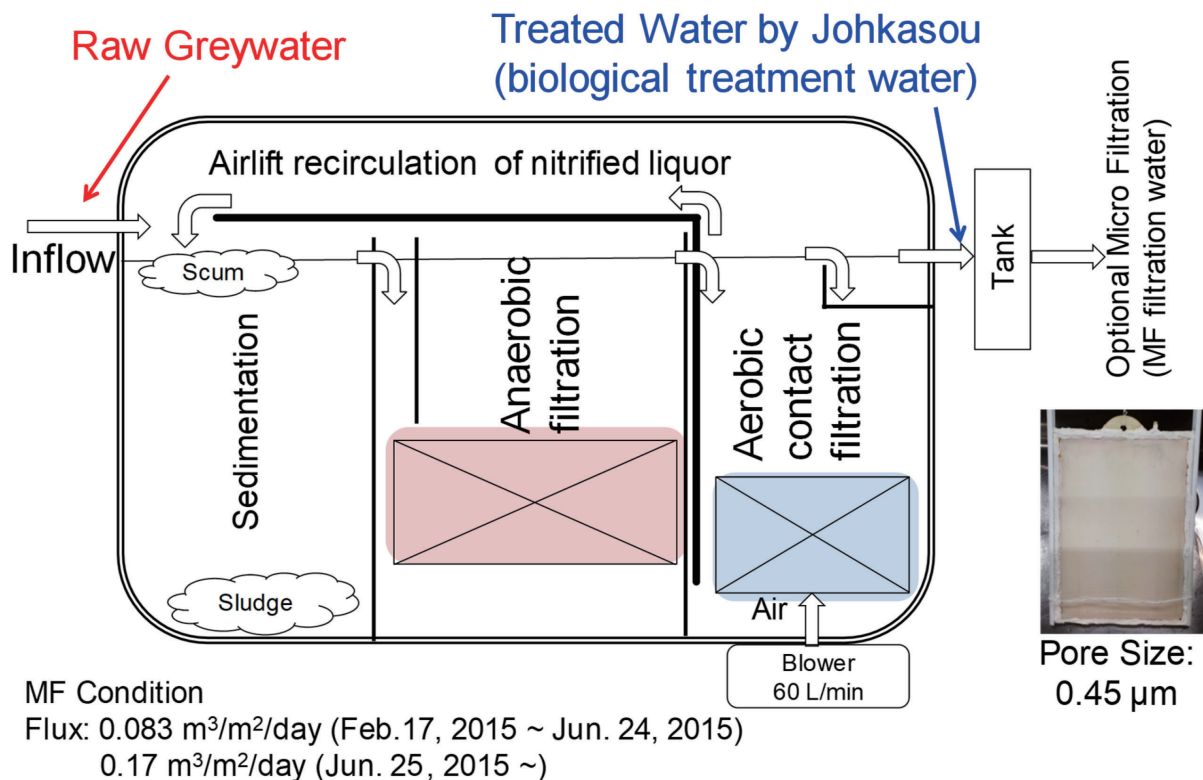

Photo 2. Installed Johkasou

Fig. 2 Outline of Greywater Treatment using Johkasou and Microfiltration

(2) Data Collection

1) Water Consumption

Daily water consumption data from the potable water tank and the non-potable water tank were provided by a contractor commissioned by the Ritsumeikan University. In this study, these data were handled on a monthly basis. Since a water meter was not installed in the Johkasou, the amount of greywater generated was estimated from the operation time of the inflow pump on a daily basis.

2) Water Quality Monitoring

The measured water quality parameters were temperature, dissolved oxygen (DO), electrical conductivity (EC), pH, suspended solids (SS), biochemical oxygen demand (BOD), total organic carbon (TOC), total nitrogen (T-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), total phosphorus (T-P), phosphate phosphorus (PO_4-P), n-hexane extract (n-Hex), methylene blue active substance (MBAS), turbidity, *E. coli*, and coliform group. Water quality was monitored for two years, from October 2014 to September 2016, and the monitoring frequency ranged from 4 to 12 times per month.

EC and pH were measured using an EC meter and pH meter, both manufactured by Horiba. A TOC analyzer, manufactured by Shimadzu, was used for TOC measurement. DO was measured using a DO meter, manufactured by Hack. T-N, NO_3-N, NO_2-N, T-P, and PO_4-P were measured by following the Standard Methods for Water Quality Examination of Wastewater (JSWA, 1997). Turbidity was measured using a turbidity meter, manufactured by Hack. Membrane filtration was performed to measure the number of *E. coli* and coliform group. Chromoagar, manufactured by CHROMagar, was used for *E. coli*, and X-MG agar, manufactured by Nissui Pharmaceutical, was used for the coliform group.

(3) Life Cycle Assessment

This study assumed available water supply/reuse scenarios in the TRICEA building. Fig. 3 shows the five scenarios developed. In the Reference Scenario, only centralized water supply and water treatment systems are utilized, and not rainwater and reused water. Scenario 1 reuses water for toilets. Scenario 2 harvests rainwater for landscape irrigation. Scenario 3 utilizes rainwater for toilets and landscape irrigation. Scenario 1+2+3 implements both water reuse and rainwater use, giving priority to the use of reclaimed water.

The functional unit is the tap water supply and wastewater treatment of Tricea building for one year. The system boundary includes operation of the Johkasou, rainwater harvesting system, tap water supply, and wastewater treatment. Thus, the material extraction, manufacturing, installation, maintenance and disposal processes of the Johkasou and rainwater harvesting facilities were not considered because this study mainly focuses on the operation of the existing facilities of the target building.

An inventory analysis was conducted based on the following steps. First, the water demand-supply balance for each scenario was simulated. Water balance was estimated daily for one year, considering the climatic conditions from 2011 to 2013, the catchment area of rainwater (1,180 m^2), and the capacity of the rainwater reservoir (162 m^3). Second, the amount of tap water and the amount of water produced by the centralized wastewater treatment were calculated. Finally, the life cycle GHG emissions related to tap water supply, water treatment by Johkasou, and centralized wastewater treatment were estimated. Primary energy and chemical data to calculate GHG emission from the tap water supply and wastewater treatment were obtained from the statistical data of water supply and sewage works in Kusatsu City. In Kusatsu, tap water supply undergoes both slow and rapid sand filtration as well as disinfection by chlorine. Centralized wastewater treatment introduces an active
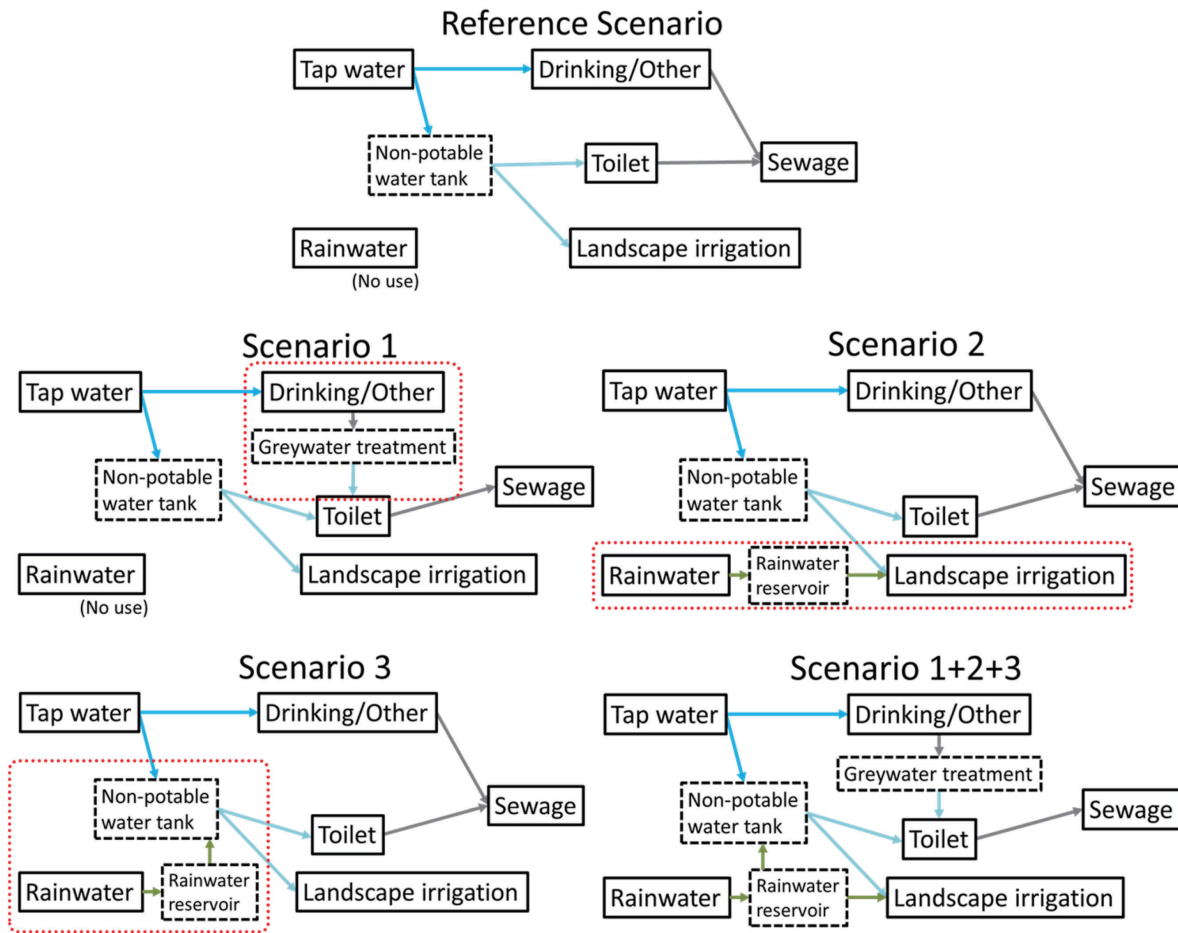
Fig. 3 Scenarios of Wastewater Reuse and Rainwater Utilization

sludge process with advanced treatment (N and P removal). The electricty consumption of the Johkasou is 33 W, or 0.792 kWh/day. GHG emissions were calculated by multiplying the amount of electricity/fuel/material consumption and GHG emission factors per unit of electricity (KEPCO, 2014, using data of The Kansai Electric Power Company in 2013), or unit fuels/material (MLIT, 2009). This study also considered methane (CH_4) and nitrogen monoxide (N_2O) emissions from the water treatment processes based on national governmental guideline (NIES, 2014).

3. Results and Discussion

(1) Water Consumption and Water Quality Monitoring
1) Water Consumption in TRICEA

Fig. 4 shows the monthly water consumption (measured in m^3/day) from the potable water tank and the non-potable water tank, and the greywater inflow to the Johkasou. The average water consumption in TRICEA was 1.4 m^3/day from the potable water tank, and 4.3 m^3/day from the non-potable water tank. Water consumption was high for both the potable and the non-potable water tank between December and February, which is the graduation and master thesis period. The average amount of greywater generated from the second to the fifth floor in TRICEA I was 0.3 m^3/day. Water consumption in August-September and March was less, which coincided with summer holiday and spring holiday, respectively. Generally, the distribution of water supply service tends to increase in summer. Thus, the characteristics of water consumption in the university building deviated from the

trend of general water consumption. Initially, the treated water was intended to be reused to flush toilets, etc., but the amount of greywater generated was less than expected and the toilets could not be supplied with the required amount of water. Reasons for less amount of greywater generation could be the absence of facilities like dining halls and poor water consumption in student laboratories.
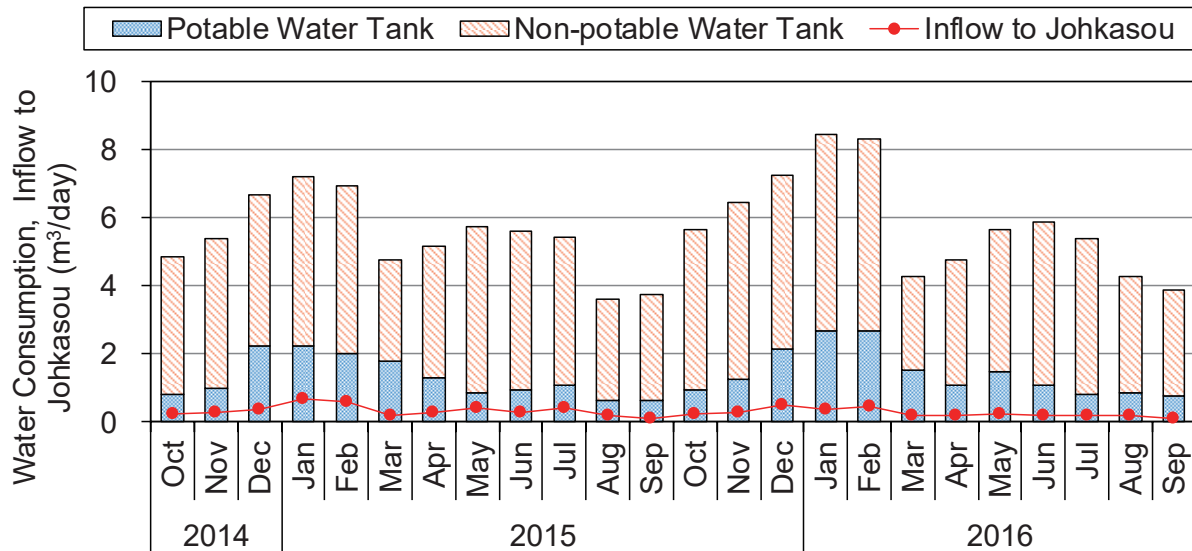

Fig. 4 Monthly Water Consumption and Inflow to Johkasou

Fig. 5 shows water consumption from the rainwater reservoir and the daily average precipitation in Otsu city, Shiga. Water consumption for landscape irrigation was high from May to September. Moreover, water consumption for landscape irrigation was less in autumn and winter, and it is possible to consider the use of rainwater for other applications. However, it is necessary to collect daily/hourly data for rainwater use and then consider operation and management methods. Fig. 6 shows the relationship between "the amount of water, after subtracting the consumption of landscape irrigation water from the consumption of the non-potable water tank" and "the consumption of the potable water tank". Assuming that the "consumption of the non-potable water tank excluding irrigation" is consumed to flush toilets, water consumption by sinks was less than half of that of the toilets (for flushing purposes) in most months.
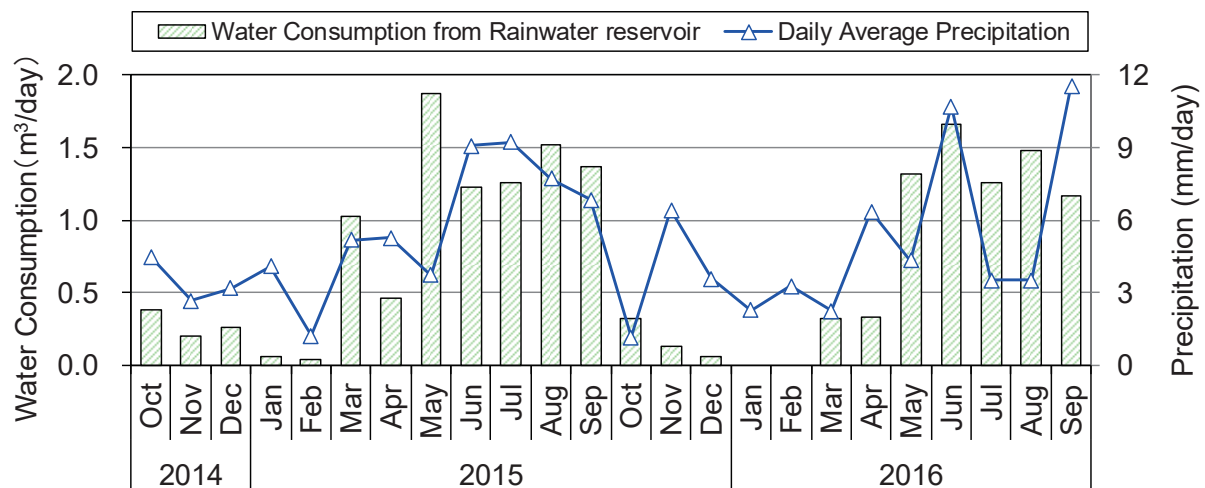

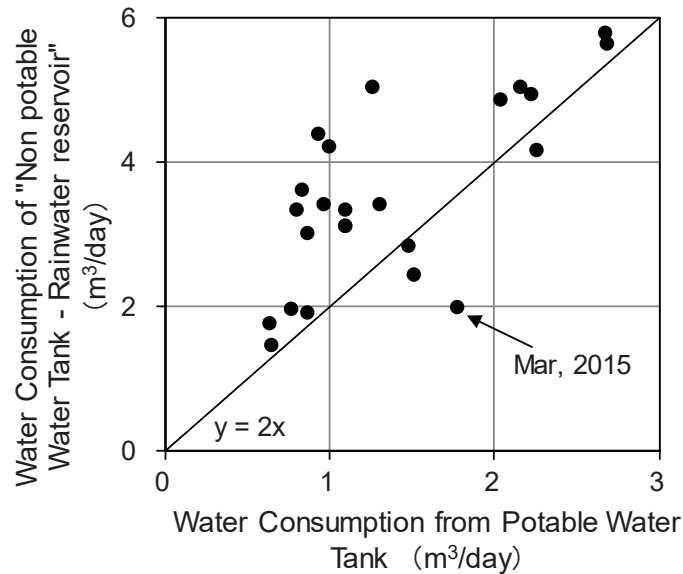**Fig. 5 Water Consumption from Rainwater Reservoir**

Fig. 6 Relationship between Potable Water Consumption and Other Use Consumption

2) Summary of Water Quality Monitoring

Table 1 shows a summary of the water quality measurement results during the monitoring period. Average EC was 390 µS/cm in raw greywater, 360 µS/cm after biological treatment, and 380 µS/cm after microfiltration. The removal rate of SS was higher than 90% in the biological treatment. The average BOD was 230 mg/L in raw greywater, 8.5 mg/L in biologically treated water, and 1.4 mg/L after microfiltration. The removal rate of BOD was 96% by the biological treatment, and 99% by the combined biological treatment and microfiltration. The average TOC was 100 mg/L in raw water, 15

Table 1. Summary of Water Quality Monitoring

Parameter	Raw Greywater			Treated Water by Johkasou			Filtration by Microfiltration*		
	Avg.	±	SD	Avg.	±	SD	Avg.	±	SD
pH (-)	5.9	±	0.58	7.3	±	0.53	7.5	±	0.38
EC (µs/cm)	394	±	133	360	±	63	381	±	52
SS (mg/L)	74	±	37	4.9	±	4.4	-		
BOD (mg/L)	227	±	128	8.5	±	7.6	1.4	±	1.4
TOC (mg/L)	100	±	57	15	±	8.4	7.0	±	3.5
T-N (mg/L)	13	±	5.3	4.2	±	3.0	2.6	±	2.7
NO_3-N (mg/L)	0.10	±	0.13	0.71	±	0.57	0.93	±	0.63
T-P (mg/L)	1.5	±	0.65	1.7	±	1.1	1.7	±	1.0
PO_4-P (mg/L)	0.37	±	0.42	1.3	±	1.1	1.6	±	1.0
MBAS (mg/L)	2.2	±	1.8	0.11	±	0.56	-		
n-Hex (mg/L)	17	±	12	0.73	±	0.99	-		
Turbidity (NTU)		-		2.9	±	2.4	0.24	±	0.26
coliform group (CFU/mL)	$1.4×10^6$	±	$3.5×10^6$	$4.4×10^3$	±	$1.5×10^4$		N.D.	
E. coli (CFU/mL)	$1.4×10^4$	±	$3.7×10^6$	$3.8×10^1$	±	$2.4×10^2$		N.D.	

*Microfiltration: Feb. 2015 ~ Sep. 2016

mg/L in biologically treated water, and 7.0 mg/L after microfiltration. The removal rate of TOC by the biological treatment was 85%, and by the combined biological treatment and microfiltration was 93%, slightly lower than BOD removal. The average T-N was 13 mg/L in raw water, 4.2 mg/L in biologically treated water, and 2.6 mg/L after microfiltration. The removal rate of T-N was 67% by biological treatment, and 79% by combined biological treatment & microfiltration. The average T-P was 1.6 mg/L in raw water. However, the installed Johkasou did not remove phosphorus. MBAS and n-Hex were satisfactorily treated by biological treatment. *E. coli* and the coliform group were detected in the biologically treated water but not after microfiltration.

3) Conformity to Water Quality Standards for Water Reuse

Table 2 shows the water quality standards and guideline values for reused water to flush toilets and irrigate landscapes, according to the Ministry of Health, Labor and Welfare (MHLW), Ministry of Land, Infrastructure, Transport and Tourism (MLIT, 2005), and the United States Environmental Protection Agency (US EPA). The comparison results (for *E. coli.*, pH, turbidity, and BOD) indicated that biological treatment was not enough to comply with the standards/guidelines, but microfiltration proved to be an adequate treatment. Although a disinfection process was not performed in this experiment, chlorine disinfection is required to control residual effects and viral contamination, for treated water to be used as reclaimed water.

Table 2. Water Quality Standards / Guideline Values for Water Reuse

Parameter	MHLW*		MLIT**		US EPA**
	Flushing Toilet	Landscape Irrigation	Flushing Toilet	Landscape Irrigation	Flushing Toilet, Landscape Irrigation
E. coli	N.D.	N.D.	N.D.	N.D.	-
Fecal coliform	-	-	-	-	N.D.
pH	5.8 – 8.6	5.8 – 8.6	5.8 – 8.6	5.8 – 8.6	6.0 - 9.0
Turbidity (NTU)	-	≤ 2	≤ 2	≤ 2	≤ 2
Residual chlorine (mg/L)	Free: ≥ 0.1 or Combined: ≥ 0.4	Free: ≥ 0.1 or Combined: ≥ 0.4	Free: ≥ 0.1 or Combined: ≥ 0.4	Free: ≥ 0.1 or Combined: ≥ 0.4***	≥ 1.0
BOD (mg/L)	-	-	-	-	≤ 10
Appearance	Almost clear and colorless	Not unpleasant	Almost clear and colorless	Not unpleasant	-
Oder	Not abnormal	Not unpleasant	Not abnormal	Not unpleasant	-

*Water quality standards, **Guideline values

*If residual effect of disinfection is unnecessary, it is not applied.

(2) Life Cycle Assessment

Fig. 7 shows the ratio of water use by source for each scenario. In this analysis, the average water use is 6.02 m³ for all scenarios. Water reclamation provides for 21% of the total water demand in Scenarios 1 and 3. Scenario 2 substitutes 14% of tap water by rainwater. Scenario 3 uses the highest amount of rainwater. The combination of Scenarios 1+2+3 can reduce tap water consumption.

Tap water use by purpose is shown in Fig. 8. The amount of tap water used for purposes other than toilet flushing and landscape irrigation is constant because the use of rainwater and treated water is avoided. No scenario substitutes 100% of toilet flushing by rainwater or treated water. Utilizing treated water for toilets is effective in reducing tap water consumption.

Fig. 9 compares the life cycle GHG emissions by scenario. Scenario 1 reduces 14% of GHG emissions compared to the Reference Scenario, by reducing 21% of tap water use and reducing 24% of required sewage treatment by reusing water. Rainwater harvesting contributes to tap water reduction but not to wastewater reduction. The GHG emission reduction ratio of Scenario 3 is 18%, although tap water use is 41% of that of the Reference Scenario. Scenario 1+2+3 reduces GHG emissions from wastewater treatment of public sewage by water reuse. Despite the life cycle GHG emission of 0.43 kg-CO_2 eq/day by the Johkasou, Scenario 1+2+3 can reduce 32% of GHG emissions.

The correlation between life cycle GHG emission per day and the capacity of the rainwater reservoir or the non-potable water tank is shown in Fig. 10 and Fig. 11. When the rainwater catchment area increases, GHG reduction potential also increases, but GHG reduction per unit area decreases. GHG emissions are constant where the catchment area is larger than required to fulfil all the rainwater demand of each scenario. The emissions are not completely constant within the range presented in Fig. 10 for S2 (>9400 m^2) and S1+2+3 (>7200 m^2). The non-potable water tank capacity follows the same trend. To optimize cost-benefit issues, life cycle GHG emissions per additional capacity (trend of the curve) should be considered.
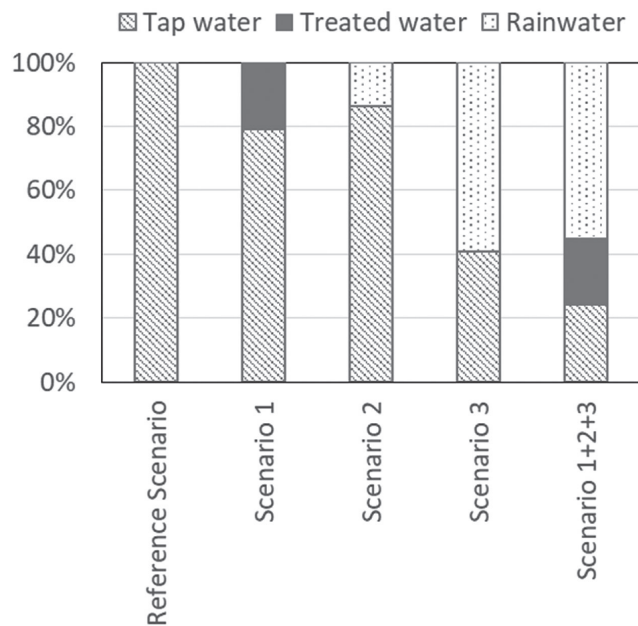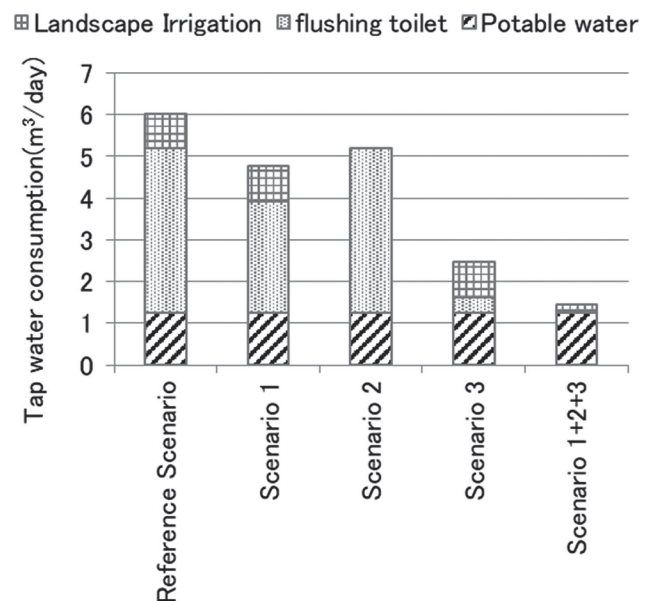

Fig. 7 Water Source in Each Scenario

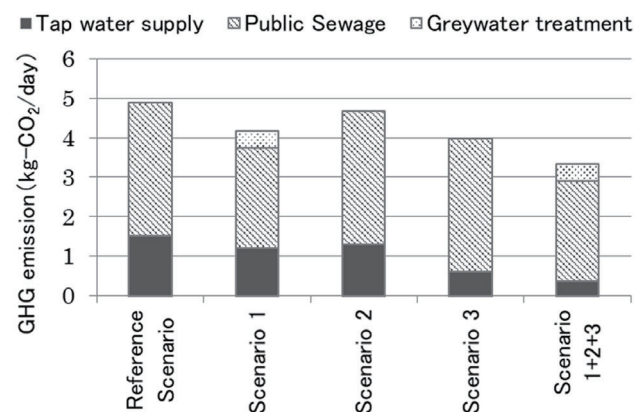**Fig. 8 Tap Water Consumption by Purpose**

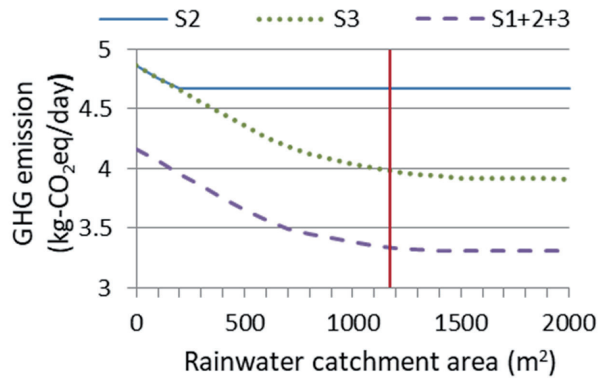**Fig. 9 Comparison of Life Cycle GHG Emissions**

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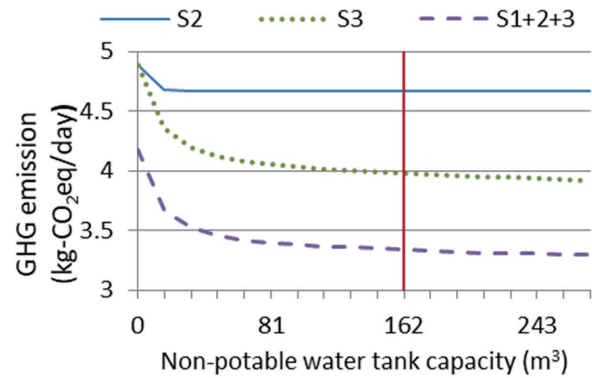**Fig. 10 Effect of Rainwater Catchment Area to Life Cycle GHG emission**

Fig. 11 Effect of Non-potable Water Tank Capacity to Life Cycle GHG Emission

4. Conclusion

In this study, long term monitoring of water quantity and quality was conducted using greywater generated from a university building and treating it with a Johkasou wastewater treatment tank. The greywater reclamation and reuse system in the university building was evaluated by the Life Cycle Assessment (LCA) method.

Water consumption during the summer holidays was less, which is typical of universities. It was not feasible to provide all the toilets with water for flushing purposes because the greywater generated from the university building was less than initially envisioned. Biological water treatment by the Johkasou alone was insufficient to meet water quality standards for reuse, but water from microfiltration adequately met the standards.

The LCA illustrated that greywater reclamation and reuse system can decrease the life cycle greenhouse gas (GHG) emissions, despite energy and materials requirements for on-site treatment. If combined with a rainwater harvesting system, it is possible to reduce 32% of GHG emissions related to water supply and treatment systems in the TRICEA building.

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