Modeling Study of "Zero Water Building"

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Abstract

Based on the research results of the "Subcommittee on Evaluation Method of Zero Water Building", which ended its four-year activities from 2019 to 2022 at the Architectural Institute of Japan, the two years of 2023 and 2024 "Subcommittee on modeling of Zero Water Building" has started its activities. This paper presents an overview of the research results of the "Subcommittee on Evaluation Method of Zero Water Building." It also summarizes information as a starting point for reaching consensus on the concept of "Zero Water Building", which is the activity goal of the "Subcommittee on modeling of Zero Water Building." Various conditions for building owners and designers to plan and design "Zero Water Building" (site area, green infrastructure, building area, roof area, building usage, total floor area, building personnel, potable water consumption, alternative water consumption, alternative water treatment amount, alternative water storage amount, rainfall amount, flood response, potable water outage response, etc.) and consider a method of displaying the results. Specifically, evaluation based on differences in building coverage ratios in buildings with the same total floor area, evaluation based on the infiltration coefficient of green infrastructure, evaluation based on building personnel, evaluation as "Zero Water Building" based on expanded use of alternative water, and evaluation of energy consumption. relationship, evaluation of water consumption by application in an emergency, and evaluation based on a combination of these evaluations.

Keywords

"Zero Water Building", trial evaluation, rainwater infiltration, potable water consumption, alternative water consumption.

1 Introduction

The U.S. Department of Energy's "Net Zero Water Strategy" [1] and the USGBC's LEED Zero project [2] started in 2018, with "water" positioned as one of the four zeros (Zero Carbon, Zero Energy, Zero Water, Zero Waste). As a result, interest in "Zero Water" is increasing in Japan as well. In Japan, the government and others are strongly promoting ZEB and ZEH, and the Energy Conservation Law for Buildings promulgated in 2015 has strengthened energy conservation standards for buildings [3]. On the other hand, about water, the water supply penetration rate will reach 98.2% [4] in 2021, and the sewage treatment population penetration rate will reach 92.6% [5]. regulations are not strict. Under these circumstances, in 2014, Water Cycle Basic Act [6] was promulgated and enforced as a basic law for the comprehensive implementation of measures by the government with the goal of maintaining or restoring a sound water cycle. In the same year, Act to Advance the Utilization of Rainwater [7] was enacted to promote the effective use of water resources and to contribute to the control of concentrated rainwater runoff into sewers and rivers.

Japan has much more rainfall than the world average of 880mm [8], with Tokyo's annual average rainfall of 1598.2mm from 1991 to 2020. However, there is a large monthly variation of 56.5mm in February and 234.8mm in October [9]. Water-related risks are higher in floods than in droughts. This is what I introduced in my 2019 paper [10]. On the other hand, due to the use of groundwater due to urbanization, the decline of groundwater level, ground subsidence, depletion of spring water, etc. became prominent in the 1960s in central Tokyo. As a result, in central Tokyo, there is currently a problem of floating underground structures due to rising groundwater levels.

Goal 6 of the SDGs (Sustainable Development Goals) is to "Ensure availability and sustainable management of water and sanitation for all." Target 6.4 states: "By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity." Target 6.6 states, "By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes." [11] Interest in zero water is gradually increasing as the desire to contribute to the achievement of the SDGs in organizations such as regions and companies is increasing.

Therefore, in this paper, I will report the outline of the research results of the "Subcommittee on Evaluation Method of Zero Water Building" from FY2019 to FY2022 at the Architectural Institute of Japan. In addition, the "Subcommittee on modeling of Zero Water Building" established from FY2023 to FY2024 aims to reach a consensus on the concept of "Zero Water Building". As a starting point, in this paper, I consider the conditions for achieving "Zero Water Building" by changing various conditions for building owners and designers to plan and design "Zero Water Building".

2 Methodology

In March 2023, the "Subcommittee on Evaluation Method of Zero Water Building" held the 46th Water Environment Symposium "Thinking about 'Zero Water Building' in Sustainable Community Development." At this symposium, five committee members prepared materials and gave presentations [12]. In this paper, I will introduce an overview and discuss matters to be considered in future "Zero Water".

Regarding the consideration of various conditions for achieving “zero water”, I modified the Excel spreadsheet program in reference [13] presented at CIB W062 (Haarlem) in 2017. Using this, a case study of a small-scale apartment house and an office is conducted, and the results are presented and discussed.

3 Overview of the research results of the “Subcommittee on Evaluation Method of Zero Water Building”

Presentations at the symposium were based on the following five materials. Titles and their outlines are shown below.

3.1 Hiroyuki Kose (Toyo University): Explanation of purpose (issues surrounding the water environment of buildings in Japan)

This article introduced the current state of the water environment in Japan, where disaster and ecosystem risks are on the rise while pollution risks are on the decline. I also proposed a framework and evaluation of Japan's “Net Zero Water Building” considering disaster risk, based on research results at the 2017 CIB W062 International Symposium. Based on these results, future issues concerning the water environment of buildings in Japan were presented.

3.2 Tamio Nakano (Shizuoka University of Art and Culture): Overseas trends such as “Net Zero Water Strategy” and “LEED Zero Water”

He described the differences between the US “Zero Water Building Strategy” and Japan's “Zero Water Building” concept. In addition, he proposed a new scenario of zero water building that matches the actual situation in Japan, considering the contribution to disaster countermeasures (BCP, LCP) and energy reduction. He also introduced examples of overseas LEED Zero Water certification acquisition.

3.3 Toyohiro Nishikawa (Kogakuin University): Calculation of “Zero Water Building”

The water balance in the evaluation area was modeled in three parts, the amount of alternative water (AW), the amount of returned water (WR), and the amount of water used (WU). Using this model, he calculated a “Zero Water Building” using the management records and meteorological data of three buildings or campuses and presented the results of plotting the water balance.

3.4 Takeshi Aoi (Nikken Sekkei): Concept of “Zero Water Building” Design

From the perspective of a design company, six water issues (dependence on infrastructure, high domestic water consumption, low awareness of water conservation, deficit management of infrastructure, marine pollution, and BCP (flood damage)) were presented. He also explained the necessity of evaluating “Zero Water Building” from the three perspectives of water resources, BCP, and energy balance evaluation. In addition, he introduced two examples of planning, a research facility and a distribution warehouse, and introduced planning matters that considered “zero water building” and matters related to energy conservation and BCP.

3.5 Michitaro Maki (LIXIL): “Zero Water” Product Trends

As a product that produces water, he introduced domestic and foreign products of water generators that generate drinking water from air. In addition, as a product that reuses water, he introduced examples of a portable water reclamation plant that can repeatedly use water without supplementary water, and a house based on the concept of self-sufficiency in water and electricity.

4 Examination of various conditions for achieving zero water building

4.1 Purpose

Quantitatively evaluate water use, energy consumption (in this study, evaluated by CO_2 emissions), regional precipitation, and water availability in the event of a disaster. Based on this result, the purpose is to clarify the considerations for the establishment of “Zero Water”.

4.2 Calculation targets and conditions

I set two conditions, an apartment house (or detached housing complexes) and a small office building, and set conditions that facilitate comparison and study, and calculated annual water consumption and CO_2 emissions by use. In addition, the “Zero Water Index” was calculated based on the calculation conditions of “LEED Zero Water”. Table 1 shows the building conditions, Table 2 shows the CO_2 emissions and water consumption per unit or rate, and Table 3 shows the trial calculation conditions for water consumption and water sources, water supply, hot water supply, wastewater, and water treatment by application.

This program is adapted from the one used in reference [13]. However, since the program at that time targeted detached houses and did not add rainwater infiltration to the site, it was added in this study. In addition, I added the condition of potable water supply water in the alternative water use. In addition, the use of water supply pumps was added for buildings with four or more floors. A direct connection booster water supply system was adopted for potable water supply, and an elevated water tank system was adopted for alternative water supply.

Regarding the basic housing conditions, the amount of water used for sanitary fixtures, hot water supply, and bathing is based on reference [14], and the facility conditions are based on case 4 of reference [13]. The amount of water used in the office was assumed for each use based on the unit water supply amount proposal in Reference [15] (10 to 20 L/person/day for potable water, 20 to 40 L/person/day for alternative water). Considering holidays, the number of working days for the office is set at 250 days.

In this program, priority is given to reused wastewater, and rainwater usage is calculated by overflowing and infiltrating surplus water collected from the roof. In addition, the trial calculations for rainwater utilization and rainwater infiltration are based on annual rainfall, and do not consider changes in rainfall or water storage. Taking these factors into account, the rainwater utilization rate is set at 0.6.

As for Case 5, which assumes an emergency, it is not suitable for annual calculations, but based on Reference [16], we calculated using the average water consumption for three weeks from the time of the disaster. From this, the effect of alternative water was grasped.

Table 1 - Building conditions

System	CO_2 Emission [kg-CO_2/m^3]	Basis for calculation
Potable Water	0.251	[17]
Non-Potable Water	0.063	[18]
Hot Water Supply	2.4 (Combined with solar water heater)	[19]
Sewage System	0.439	[20]
Septic System	1	[21]
Water Treatment	0.6	[22]
Potable Water Booster Pump	0.327 (Booster direct water supply system)	[23][24]
Non-Potable Water Pump	0.092 (Elevated tank water supply system)	[23][24]
Others		
Rainfall [mm/year]	1300 (Average rainfall in Kumagaya)	[25]
Hot Water Use Ratio	0.5	
Rate of Water Collection (Roof)	0.6 (or conditions to satisfy zero water)	
Rate of Water Filtration (Non-building area)	0.5 (or conditions to satisfy zero water)	

Table 2 - CO_2 emissions and water consumption per unit or rate

System	CO_2 Emission [kg-CO_2/m^3]	Basis for calculation
Potable Water	0.251	[16]
Non-Potable Water	0.063	[17]
Hot Water Supply	2.4 (Combined with solar water heater)	[18]
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Others		
Rainfall [mm/year]	1300 (Average rainfall in Kumagaya)	[24]
Hot Water Use Ratio	0.5	
Rate of Water Collection (Roof)	0.6 (or conditions to satisfy zero water)	
Rate of Water Filtration (Non-building area)	0.5 (or conditions to satisfy zero water)	

Table 3 - Trial calculation conditions for water consumption and water sources, water supply, hot water supply, wastewater, and water treatment by application

Apartment House		Case 1,2,3,5-2				Case 4 (Emergency)				Case 5-1 (Use of All Collected Rainwater)			
No.	Water Use	Unit of Water Consumption [L/times]	Times [times/day]	Person(s) or Times	Number of Days Used	Unit of Water Consumption [L/times]	Times [times/day]	Person(s) or Times	Number of Days Used	Unit of Water Consumption [L/times]	Times [times/day]	Person(s) or Times	Number of Days Used
1	Kitchen Cooking & Washing	13	3	3	365					13	3	3	365
2	Hand & Face Washing	1.5	7	3	365					1.5	7	3	365
3	Bathtub	200	1	1	250					200	1	1	250
4	Bathroom Shower	25	1	3	365	25	1	3	365	25	1	3	365
5	Bidet	0.2	3	3	365					0.2	3	3	365
6	Washing Machine	40	1	3	300	20	1	3	300	40	1	3	300
8	Humidifying	1	1	1	100					1	1	1	100
11	Cleaning	5	1	3	180	5	1	3	180	5	1	3	180
12	Plumbing Fixtures	6	5	3	365	5	5	3	365	6	5	3	365
16	Irrigation	20	1	1	100					20	1	1	100
17	Landscape									118.3	1	1	365
Total [L/day,person] or Zero Water Index [(Altenative Water Use + Water Returned) /		188.0				68.9				227.4			

Apartment House		Case 1 (Base Model)					Case 2,5 (Rainwater Harvesting)					Case 3 (Rainwater Harvesting and Greywater Reuse)					Case 4 (Emergency)				
No.	Water Use	Water Source	Water Supply	Water Heating	Water Discharge or Returned	Water Treatment	Water Source	Water Supply	Water Heating	Water Discharge or Returned	Water Treatment	Water Source	Water Supply	Water Heating	Water Discharge or Returned	Water Treatment	Water Source	Water Supply	Water Heating or Cooling	Water Discharge or Recharge	Water Treatment
1	Kitchen Cooking & Washing	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System					
2	Hand & Face Washing	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Grey Water	Water Treatment					
3	Bathtub	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Grey Water	Water Treatment					
4	Bathroom Shower	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Grey Water	Water Treatment	Rainwater+Grey Water	Non-Potable Water	Hot Water Supply	Grey Water	Water Treatment
5	Bidet	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System					
6	Washing Machine	City Potable Water	Potable Water		Black Water	Sewage System	City Potable Water	Potable Water		Black Water	Sewage System	City Potable Water	Potable Water		Grey Water	Water Treatment	Rainwater+Grey Water	Non-Potable Water		Grey Water	Water Treatment
8	Humidifying	City Potable Water	Potable Water				City Potable Water	Potable Water				City Potable Water	Potable Water								
11	Cleaning	City Potable Water	Potable Water		Black Water	Sewage System	City Potable Water	Potable Water		Black Water	Sewage System	City Potable Water	Potable Water		Grey Water	Water Treatment	Rainwater+Grey Water	Non-Potable Water		Grey Water	Water Treatment
12	Plumbing Fixtures	City Potable Water	Potable Water		Black Water	Sewage System	Rainwater+Grey Water	Non-Potable Water		Black Water	Sewage System	Rainwater+Grey Water	Non-Potable Water		Black Water	Sewage System	Rainwater+Grey Water	Non-Potable Water		Water Returned	Septic System
16	Irrigation	City Potable Water	Potable Water				Rainwater+Grey Water	Non-Potable Water				Rainwater+Grey Water	Non-Potable Water								
17	Landscape						Rainwater+Grey Water	Non-Potable Water													
Total [L/day,person] or Zero Water Index [(Altenative Water Use + Water Returned) /		0.00					Case 2-1: 0.69, Case 2-2: 0.66 Case 2-3: 0.65, Case 2-4: 0.65 Case 2-6: 0.64, Case 2-8: 0.64 Case 5-1: 0.57, Case 5-2: 1.00					0.86					1.90				

Office		Case 1,2,3,5				Case 4 (Emergency)			
No.	Water Use	Unit of Water Consumption [L/times]	Times [times/day]	Person(s) or Times	Number of Days Used	Unit of Water Consumption [L/times]	Times [times/day]	Person(s) or Times	Number of Days Used
1	Kitchen Cooking & Washing	5	2	120	250				
2	Hand & Face Washing	1.5	4	120	250				
5	Bidet	0.2	3	120	250				
8	Humidifying	1	1	120	250				
11	Cleaning	5	1	120	250	5	1	120	250
12	Plumbing Fixtures	6	4	120	250	5	4	120	250
16	Irrigation	100	1	1	365				
Total [L/day,person] or Zero Water Index [(Altenative Water Use + Water Returned) /		47.8				25.0			

Office		Case 1 (Base Model)					Case 2,5 (Rainwater Harvesting)					Case 3 (Rainwater Harvesting and Greywater Reuse)					Case 4 (Emergency)				
No.	Water Use	Water Source	Water Supply	Water Heating or Cooling	Water Discharge or Recharge	Water Treatment	Water Source	Water Supply	Water Heating or Cooling	Water Discharge or Recharge	Water Treatment	Water Source	Water Supply	Water Heating or Cooling	Water Discharge or Recharge	Water Treatment	Water Source	Water Supply	Water Heating or Cooling	Water Discharge or Recharge	Water Treatment
1	Kitchen Cooking & Washing	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System					
2	Hand & Face Washing	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Grey Water	Water Treatment					
5	Bidet	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System					
8	Humidifying	City Potable Water	Potable Water				City Potable Water	Potable Water				City Potable Water	Potable Water								
11	Cleaning	City Potable Water	Potable Water		Black Water	Sewage System	City Potable Water	Potable Water		Black Water	Sewage System	City Potable Water	Potable Water		Grey Water	Water Treatment	Rainwater+Grey Water	Non-Potable Water		Grey Water	Water Treatment
12	Plumbing Fixtures	City Potable Water	Potable Water		Black Water	Sewage System	Rainwater+Grey Water	Non-Potable Water		Black Water	Sewage System	Rainwater+Grey Water	Non-Potable Water		Black Water	Sewage System	Rainwater+Grey Water	Non-Potable Water		Water Returned	Septic System
16	Irrigation	City Potable Water	Potable Water				Rainwater+Grey Water	Non-Potable Water				Rainwater+Grey Water	Non-Potable Water								
Total [L/day,person] or Zero Water Index [(Altenative Water Use + Water Returned) /		0.00					Case 2-1: 0.79, Case 2-2: 0.73 Case 2-3: 0.72 ,Case 2-4: 0.71 Case 2-6: 0.70 ,Case 2-8: 0.69 Case 5: 1.01					1.02					1.71				

4.3 Trial calculation results for apartment house

Figure 1 shows the results of trial calculations for each case. Here, I used the following four graphs. “Pie chart showing the ratio of potable water and non-portable water in total water usage”, “Bar graph showing the balance between water sources and alternative water usage”, “Bar graph calculated showing CO_2 emissions related to water use for infrastructure and buildings”, “Bar graph calculated for the balance between the total amount of water used and the amount of alternative water used + the amount of water returned for the evaluation of ‘zero water’”.

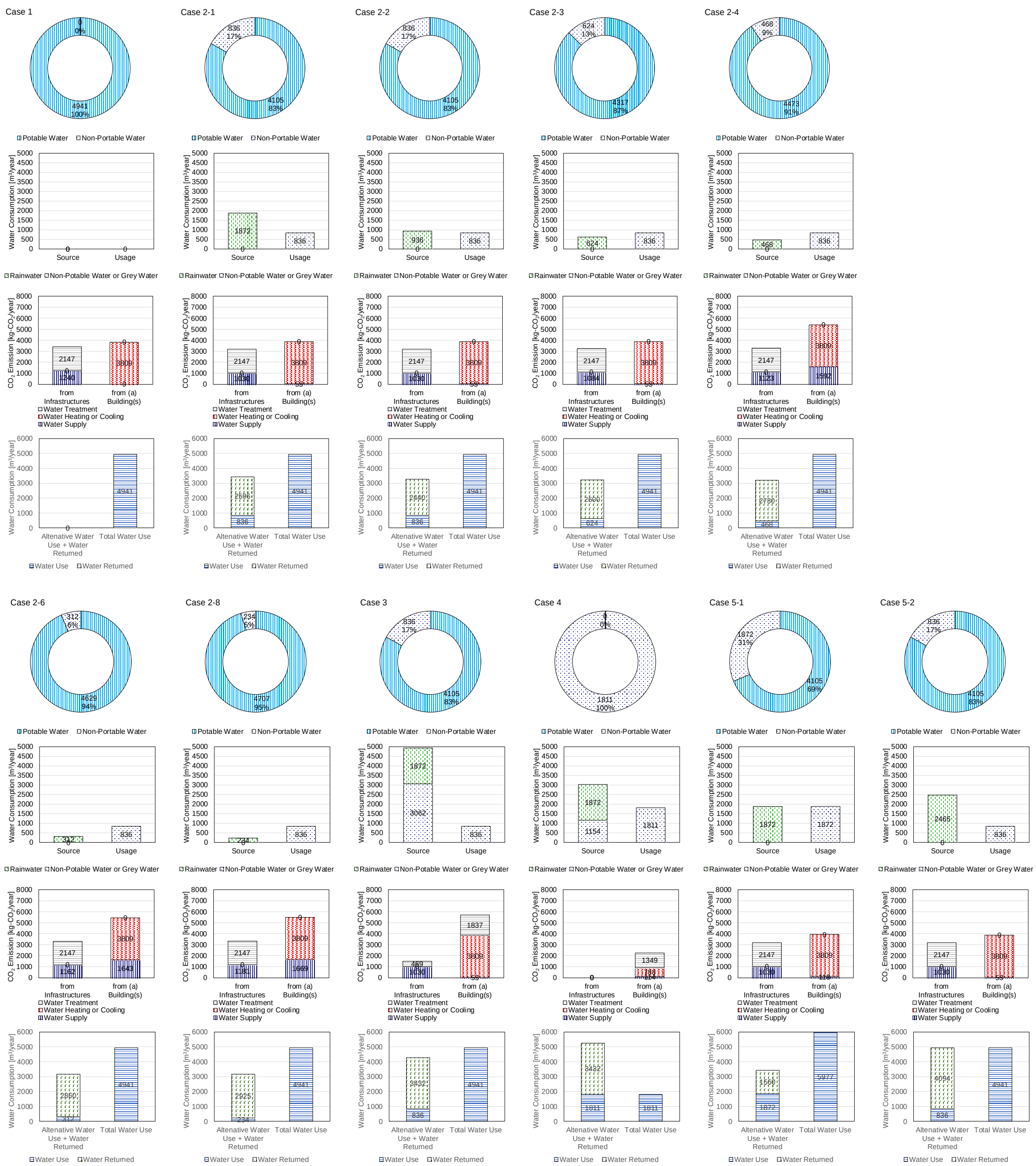

Figure 1 - Trial calculation results for apartment house

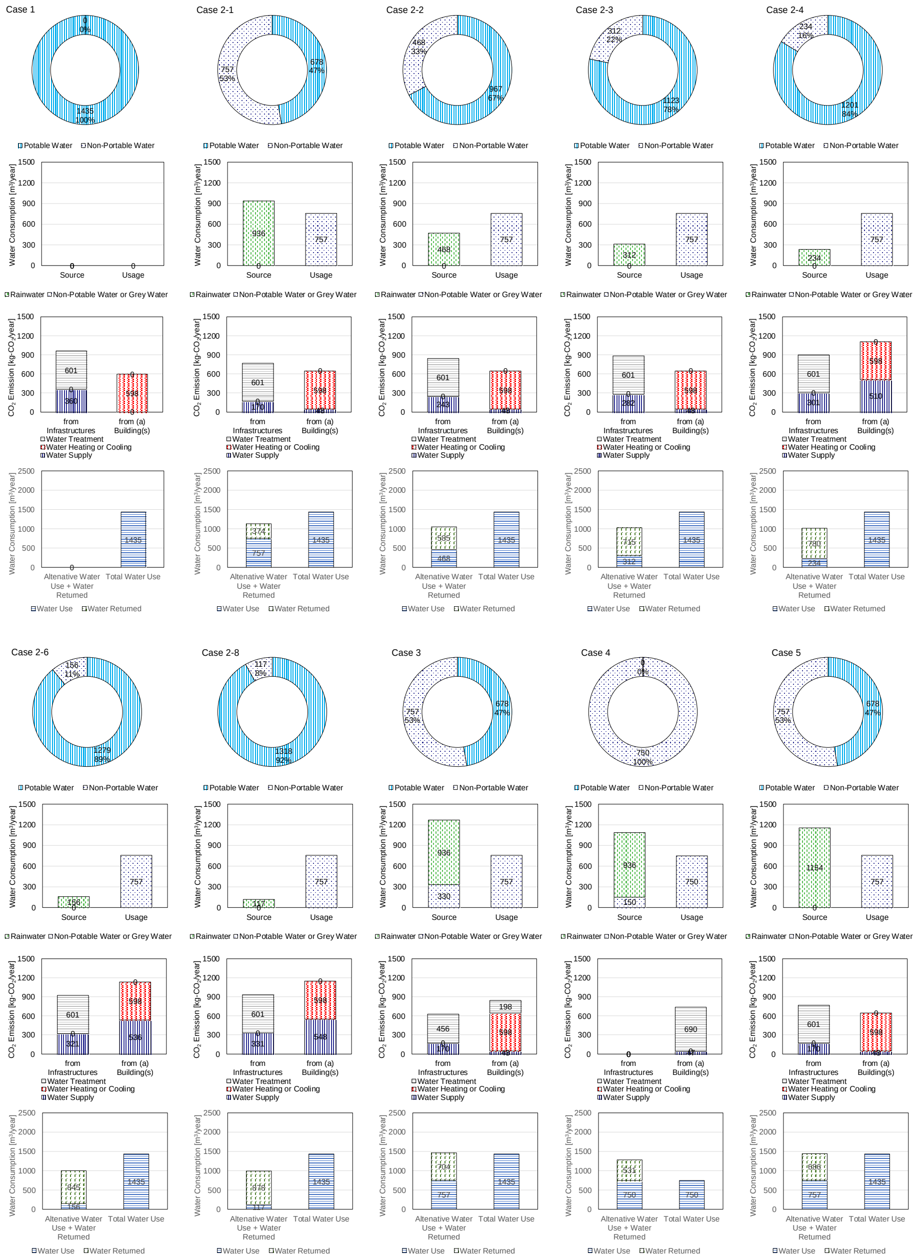

Figure 2 - Trial calculation results at the office

If alternative water use is limited to flushing toilets, alternative water use accounts for up to 17% of total water use. The branch number in Case 2 represents the number of floors. In the case of the third floor and above, it is not possible to secure alternative water use only by using rainwater, so it is supplemented with potable water. On the 4th floor and above, the amount of CO_2 emitted from the water supply in the building has increased significantly, but this is due to the assumption that a direct booster water supply system will be used. On the other hand, rainwater is a big difference because it is assumed to be an elevated water tank system. From the perspective of decarbonization, low-rise buildings are advantageous in various ways.

Case 3 is calculated on the assumption that wastewater from washing hands, bathrooms, laundry, and cleaning is reused. In this case, grey water is sufficient as a water source, so rainwater can infiltrate the whole amount. Case 4 assumes that the water supply is cut off during a disaster. If the system in the building can be operated normally, it is possible to secure alternative water. However, since rainfall is calculated based on annual rainfall here, a detailed study is required. Case 5-1 is a calculation of the conditions for using all the collected rainwater in the rainwater utilization conditions (Case 2). In this case, 118.3 L of water per household per day can be used for landscape use, or 138.3 L of water when combined with watering. If landscape water is used for microclimate and thermal mitigation, such as rain ponds and wall watering, it can contribute to the overall reduction of CO_2 emissions from the site and building. Case 5-2 is a trial calculation of the rainwater infiltration rate to satisfy “Zero Water” under the conditions of Case 2. In case 2, the roof rainwater utilization rate (excess water is infiltrated) is set at 0.6, and the site rainwater infiltration rate is set at 0.5. If these are set to 0.79, the condition of “Zero Water” is satisfied. To achieve “Zero Water”, it is necessary to increase the rainwater infiltration rate as much as possible.

4.4 Trial calculation results at the office

Figure 2 shows the results of comparative calculations in the same way as for the apartment house. In the case of the office, the ratio of potable water to alternative water is 1:2, so effective use of rainwater is desirable. However, in Case 2, replenishment water from potable water is required on the second floor and above, and its effectiveness is limited. Case 3, which introduces a wastewater reuse system, is an effective means from the viewpoint of effective use of water. Under the calculation conditions of this time, the condition of “Zero Water” is satisfied. In Case 4, which assumes an emergency, if enough rainwater can be stored, water can be secured to meet the demand for alternative water. In case 2, as in the apartment house, the roof rainwater utilization rate (excess water is infiltrated) is set at 0.6, and the site rainwater infiltration rate is set at 0.5. Setting these to 0.74 satisfies the condition of “Zero Water” (Case 5).

5 Discussion

A low-rise building with a large roof area is desirable from the viewpoint of rainwater utilization and CO2 emissions. However, it is difficult to achieve "zero water" without increasing the rainwater infiltration rate in houses where water consumption per person is high. It is required that most of the site be used as a rainwater infiltration surface, and surplus water from roof rainwater can also permeate. On the other hand, in offices where water demand is low and the ratio of miscellaneous water is high, it is easier to satisfy the condition of "zero water" than in collective housing. Under the conditions of this trial calculation, it is possible to achieve zero water if the building coverage ratio is 60% (site area of 2,000m2). If a wastewater reuse system is introduced, it will be easier to achieve the condition of "zero water", but it is not realistic to introduce it in houses. However, from the viewpoint of securing water in an emergency, the introduction of a wastewater reuse system in collective housing is effective.

6 Conclusion

In this study, for the purpose of dissemination and enlightenment of “Zero Water Building”, I reported the outline of the research results of “Subcommittee on Evaluation Method of Zero Water Building” of Architectural Institute of Japan. In addition, trial calculations were made using various conditions for building owners and designers to plan and design the “Zero Water Building” as parameters, and various conditions for achieving “Zero Water” were considered.

As a future task, I will continue trial calculations and case studies for the purpose of obtaining consensus on the concept of “Zero Water”, which is the activity goal of the “Subcommittee on modeling of Zero Water Building.” In addition, I will consider the possibility of introducing the concept of “Zero Water” such as water generators and systems that repeatedly use water, which were mentioned in previous committee results. Furthermore, I would like to examine the role that water should play in architecture, such as resilience and wellness, which are required for architecture, from a broad perspective.

7 Acknowledgments

In advancing this study, I cooperated with the members of the Architectural Institute of Japan “Subcommittee on Evaluation Method of Zero Water Building” from FY2019 to FY2022 and “Subcommittee on modeling of Zero Water Building”, which has been active since FY2023.

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Former members: Satoshi Ueda, Yoshihisa Nagao, Yoshiki Higuchi, Yoshiyuki Funayama, Shunsuke Reisui.

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9 Presentation of Author

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