【*Technical Paper*】

ZERO WATER BUILDING EVALUATION AND CONSIDERATION AT TAKASAGO THERMAL ENGINEERING INNOVATION CENTER

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ABSTRACT

To achieve carbon neutrality by 2050, Japan's Basic Energy Plan positions renewable energy sources, such as solar power, woody biomass, and geothermal energy, as important domestic energy sources. Although energy and resource self-sufficiency has been touted as part of this transition, concrete examples are lacking. The Takasago Thermal Engineering Innovation Center, which was completed in January 2020, has achieved an energy-self-sufficient system by combining renewable energy sources such as woody biomass gasification power generation, solar power generation, and geothermal water utilization with storage batteries. This report presents an overview of the equipment, water use, electricity, and thermal energy performances of the facility throughout the year. In addition, owing to the increasing interest in water resource conservation and reuse, this report proposes evaluation methods for zero-water building (ZWB) in relation to geothermal water and water utilization.

1. INTRODUCTION

The importance of building facilities to achieve carbon neutrality by 2050 is increasing, as buildings must be environmentally friendly with a focus on energy conservation and use of renewable energy while maintaining a comfortable environment inside the building. In the areas of water supply, drainage, and sanitary facilities, zero-water buildings (ZWBs) are attracting attention as buildings that not only save water and recycle water, but also recycle water resources to reduce the burden on the water supply and sewerage infrastructure. Under these circumstances, the Takasago Thermal Engineering Innovation Center (Fig. 1) was constructed in conjunction with the relocation of the former Technical Research Institute, based on the design concept of "a sustainable building that both reduces global environmental impact and improves intellectual productivity," and was completed in January 2020. This report provides an overview of the facilities and achievements of the groundwater heat utilization systems. The ZWB of the facility was estimated based on the definition provided by the U.S. Department of Energy. In addition, interpretations of the use of groundwater heat are discussed.

Location	Tsukubamirai City, Ibaraki Prefecture, Japan
Site area	Research Facilities
Building area	22,746.18㎡
Extended bed area	7,129.74 ㎡
Total floor area	11,763.97 ㎡
Number of stairs	2 above ground, 1 in tower
Building Height	15.455 m
Structure	steel construction, RC construction in part
Construction period	February 2019 - January 2020

Fig.1 Takasago Thermal Engineering Innovation Center

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2. BUILDING OVERVIEW

2.1 Building and Facilities Overview

The facility consists of two main buildings: an office building (area of approximately 4,750 m^2) with an exhibition area, café/restaurant, office space, and a laboratory building (area of approximately 6,050 m^2) for experiments and analysis. The office building was arranged around a four-axis layout, and the façade was designed to match the heat and light environment in each direction to effectively take in the prevailing wind from the northeast and create a façade that is in line with the environment. Changing rooms, toilets, conference rooms, etc., which do not require natural ventilation or views, are located in corner areas, and high windows are used to reduce the solar load to the maximum extent possible. The interior and exterior surfaces of the roof slab were insulated to reduce the heat load. Fig. 2 presents an overview of the facilities installed to achieve ZEB. The building has achieved a significant reduction in energy consumption through the use of natural energy to reduce the air-conditioning load in the building plan and the introduction of advanced facilities, such as latent-sensible air conditioning. Photovoltaic power generation, combined biomass heat and power generation, and storage batteries have been introduced as renewable energy sources, while groundwater heat and water have been effectively used to reduce CO_2 emissions.

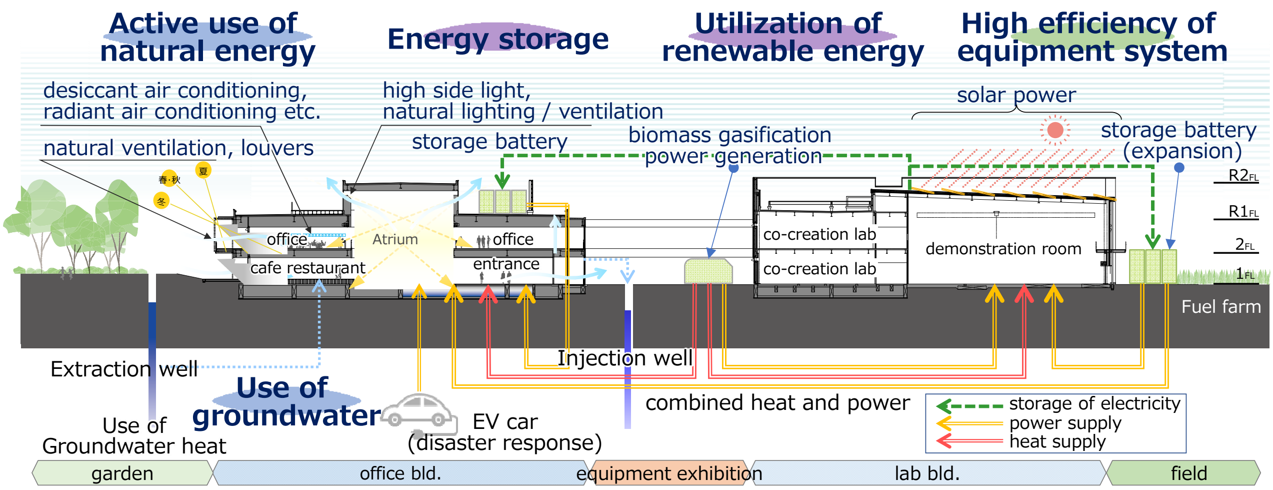

Fig. 2 Overview of equipment installed for ZEB

2.2 Certification

In acquiring certification under various evaluation systems, the company achieved a BEI of 0.09 and a BELS rating of *5 Nearly-ZEB (BEI = 0.33 if energy creation is excluded). In the CASBEE-Wellness Office (WO) evaluation, the building received an S-rank certification with an overall rating of 86.6 points, and in LEED v4, the building's comprehensive environmental performance evaluation received a gold certification of 72 points.

2.3 Evaluation of Energy and CO_2 Emissions

Simulations of the office building based on ASHRAE90.1_2010 for the former R&D center yielded a design value of -130 MJ/sqm/year compared to the baseline value of 421 MJ/sqm/year, with 131 % energy savings. The actual 2021 records show a further 14.3 % reduction in the proposed value through continuous operational improvements. Furthermore, the power generated by the PV panels and biomass CHP units would reduce the primary energy consumption to -263 MJ/sqm/year, or 162 % savings compared to the baseline, achieving the status of net ZEB (Fig. 3).

An aggressive use of renewable energy sources and a highly efficient system set-up and operation yielded an operational carbon emission of -159 t - CO_2/year (-33.4 kg - CO_2/sqm/year), conferring the status of “Zero Emission” to this building (Fig. 4). (The CO_2 emission baseline unit is 0.457 kg - CO_2/kWh according to the Tokyo Electric Power Co.).

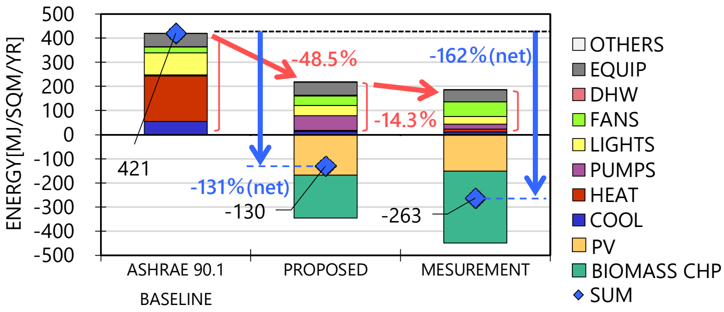

Fig. 3 Primary energy consumption

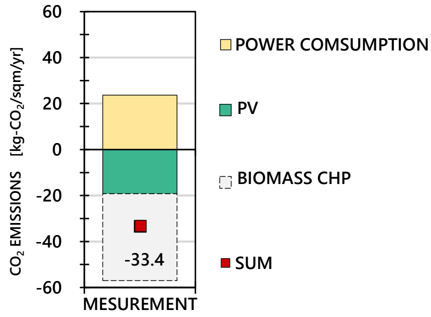

Fig. 4 Operational CO_2 emissions.

As a result of the above operational achievements, the center has been recognized as the leading facility for a carbon-neutral society in Japan and has received the Academic Award from the Society of Heating, Air-Conditioning, and Sanitary Engineers of Japan (SHASE) and the Carbon Neutrality Award from the Japanese Association of Building Mechanical and Electrical Engineers (JABMEE).

3. GROUNDWATER HEAT UTILIZATION SYSTEM

This section discusses the groundwater heat utilization system of the installed facilities. This system effectively utilizes groundwater heat and water, which contributes to energy and water conservation and carbon neutrality.

3.1 Overview of the groundwater heat utilization system

This facility uses groundwater heat and water effectively. Fig. 5 shows a schematic of the groundwater utilization. The system has two wells–a pumping well and a return well–both of which are approximately 150 m deep. The pumping and return wells are almost identical; however, the return well has a backwash pump to prevent blockage. Fig. 6 shows a schematic of the water-return process. Groundwater pumped from the pumping well is used for floor radiation at the entrance, daytime outdoor air conditioning, radiant air conditioning, etc., and is subsequently used as the heat source water for the water-source heat pump unit in a three-stage heat cascade. A portion of the heat-utilized groundwater is used for miscellaneous purposes, and the remainder is returned to the ground through a water return well.

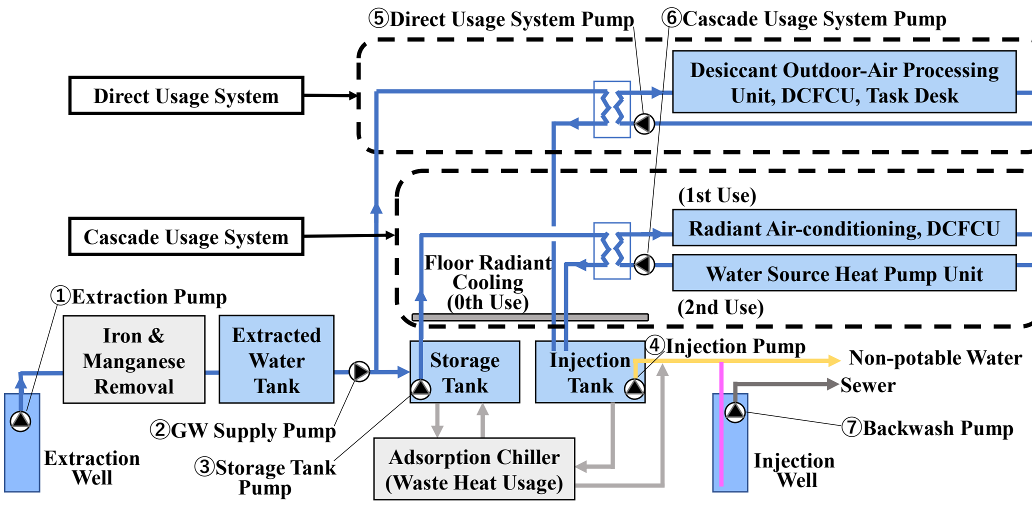

Fig. 5 Overview of the groundwater heat utilization system

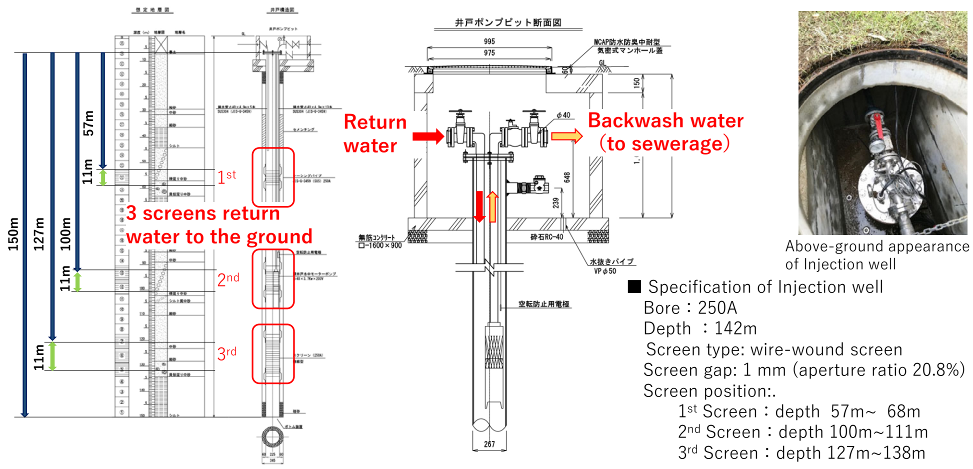

Fig. 6 Overview of injection well

Fig. 7 shows the actual groundwater heat use in FY2022. The amount of cold heat is the sum of cold heat from the direct groundwater heat utilization system, cascade utilization system, and cold heat from heat pumps. "Groundwater Heat" in Fig. 7 is the amount of cold heat used by exterior air conditioners, radiant panels, personal air conditioners, and individual air conditioners with water heat sources. "Heat pump" is the amount of cold heat produced by air-source heat pumps. Groundwater heat accounts for approximately 65 % of the total annual cold heat. Groundwater heat was used for cooling from April to October, and the system COP during this period was 7.5 for the groundwater heat and 3.9 for the heat pump, confirming the energy efficiency of the groundwater heat use (Fig. 8).

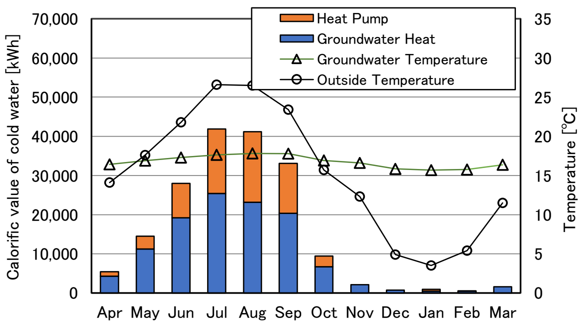

Fig. 7 Quantity of cold heat

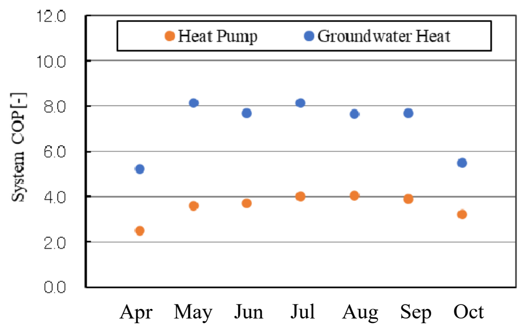

Fig. 8 SCOP value

3.2 Groundwater Use and Water Balance

In this building, tap water is stored in a receiving tank and supplied to the building; groundwater is pumped and used as heat for air conditioning; and a portion of the groundwater is used for miscellaneous purposes, such as toilet flushing water. As shown in Fig. 9, the volume of drinking water was 600 m^3/year. The percentage of essential drinking and kitchen water was 53 % (320/600), and the remainder could be reclaimed from groundwater. The well backup contained 20 m^3/year of tap water. The groundwater used for air conditioning was reused along with water for the experiments, hand washing and flushing of toilets, backwashing of iron and manganese removal equipment, and irrigation, among other uses. The well water used for the experiments, hand washing, toilet flushing, etc. amounts to 1,490 m^3/year, which implies an increase over the previous year. This was because of the increase in the number of experiments conducted in the laboratory building. The volumes of tap water, groundwater, and sewage were approximately 600 m^3/year, 25,430 m^3/year, and 7,240 m^3/year, respectively, making the discharge rate to sewage to approximately 28 %, with the remainder 72 % recycled. The amount of water used for backwashing the iron and manganese removal equipment accounted for approximately 60 % of the total sewage volume, which could be reduced by changing the backwashing conditions.

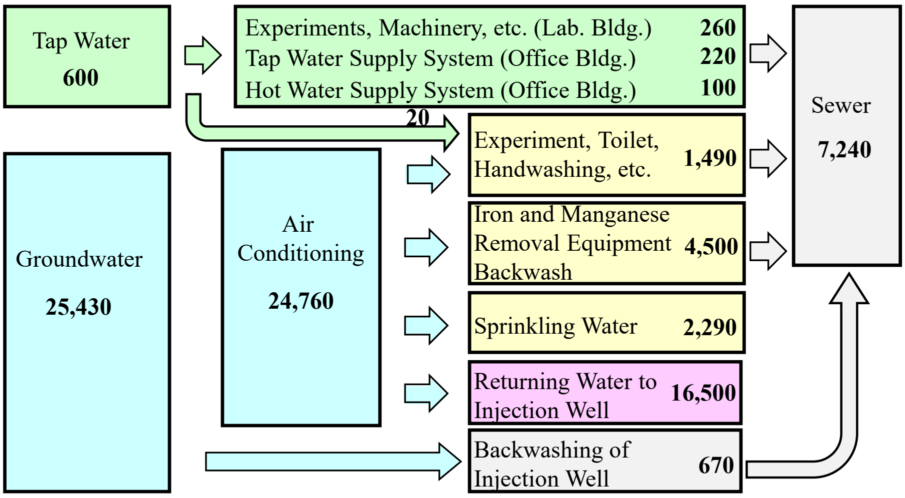

Fig. 9 Diagram of the Flow of Water Usage in the Facility［m^3/year］

3.3 Relationship between Groundwater Pumping and Water Use

Fig. 10 shows the amount of tap water and groundwater used each month. From April to October, when the cooling demand is high, the amount of pumped groundwater ranges from approximately 1,200 m^3/month to 4,600 m^3/month (an average of approximately 3,100 m^3/month). However, from November to March, when the cooling demand is low, groundwater is pumped for miscellaneous water usage, averaging approximately 640 m^3/month.

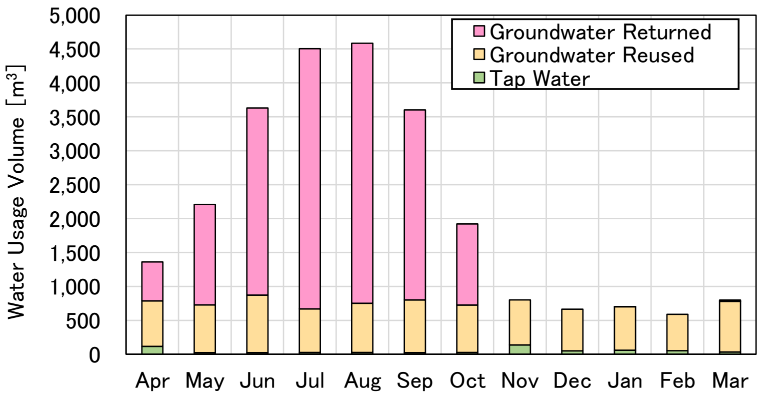

Fig. 10 Monthly quantity of tap water and groundwater

From the above, the groundwater heat utilization system at this facility was shown to not only utilize groundwater heat, which is renewable, but also to effectively use groundwater by reusing part of it after heat utilization for miscellaneous water usage.

4. ZWB EVALUATION

While various ZWB evaluation formulas have been reported, this study focuses on analyzing and discussing them in accordance with the ZEB evaluation method proposed by the U.S. Department of Energy (DOE).

4.1 Method for Evaluating ZWB

The definition of ZWB as stated on the U.S. Department of Energy's website is shown in Table 1. ZWB is defined as a building where the sum of the alternative water use (AW) and return to groundwater (WR) equals the total water use (WU). The ZWB attainment percentage calculation is simple: WU is divided by the sum of AW and WR. The ZWB attainment rate is calculated by dividing WU by the sum of AW and WR. If the ZWB formula in Table 1 yields a value greater than 100 %, then ZWB is achieved. In this study, underground stormwater infiltration was not considered given that no facilities contributing to stormwater infiltration were installed. In addition, some water uses could not be clearly sorted based on the ZWB definition. Some interpretations of the various uses of groundwater are difficult and should be examined in the future.

Table 1 Definition of ZWB by the U.S. Department of Energy

TERM		DEFINITION
AW	Alternative water use	A sustainable water source not derived from fresh-, surface-, or groundwater sources. Alternative water includes: ・Harvested rainwater, stormwater, sump-pump (foundation) water ・Graywater ・Air-cooling condensate ・Rejected water from water purification systems ・Reclaimed wastewater ・Water derived from other water reuse strategies. A net zero water building (or campus) uses alternative water sources to offset the use of freshwater.
WR	Water returned	The amount of water collected from the building systems, such as green infrastructure and on-site treated wastewater, and returned back to the original water source over the course of a year.
WU	Total water use	Total water use is the amount of water consumed within the boundaries of a building from all sources (potable and non-potable including freshwater※ and alternative water) over the course of a year.
ZWB	Zero Water Building	ZWB = (AW+WR)/WU×100

※：Freshwater is water sourced from surface or groundwater such as lakes and rivers.

4.2 Results and Discussion of ZWB Evaluation

Each water volume in Fig. 9 is shown in Fig. 11, and Table 2 lists the calculated results of the ZWB evaluation (Case-1).

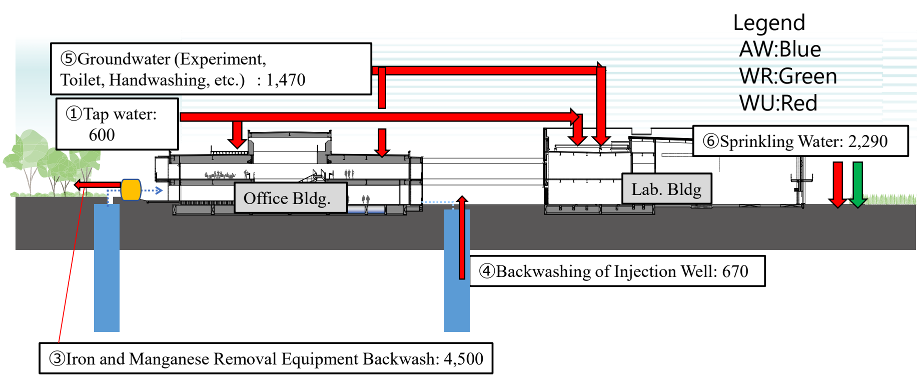

Fig. 11 Water and Groundwater Consumption in FY2022 (Case-1)

Table 2 Calculated results of ZWB based on DOE (Case-1)

Term	Unit	Value	Remarks
AW	m^3/year	0	
WR	m^3/year	2,290	⑥
WU	m^3/year	9,530	①+③+④+⑤+⑥
ZWB	%	24	

None of the alternative waters defined in Table 1 are applicable for water use at the facility. Groundwater plant irrigation and stormwater groundwater infiltration were considered applicable to the amount of water returned. Total water use was the sum of the groundwater used for miscellaneous purposes, including drinking water, backwash water from the iron and manganese removal equipment and injection wells, and sprinkling water. This resulted in a ZWB rating of 24 %. Given that no examples of ZWB evaluations for facilities that use groundwater for heat and water, such as the facility considered in this study, have been reported, and the definitions in Table 1 are not applicable, groundwater heat use was not included in water consumption in this ZWB evaluation estimation. However, it is incongruous that groundwater pumped up from underground and returned to the ground after heat use is not included in water usage. It is expected that an increasing number of facilities, such as the aforementioned facility, will have diverse water use methods, such as heat use of water. Therefore, it is necessary to discuss how to define ZWB for diverse water use methods as soon as possible.

Consider the case in which groundwater used as heat in this facility is included in the calculation of water consumption (Case-2). Fig. 12 shows the respective water volumes. Under the present conditions, the groundwater used for backwashing of the iron and manganese removal equipment, and the groundwater used for miscellaneous purposes were considered as alternative water volume, given that the water after air conditioning used as groundwater heat is considered to be reused water. In addition, the amount of groundwater returned to the ground through the injection wells after heat utilization is added to the amount of water to be returned to the ground. The total water consumption is defined as the sum of drinking water, groundwater used for heat utilization, and groundwater used for miscellaneous purposes, including sprinkling water after heat utilization. As a result, the ZWB evaluation value was 72 %, as shown in Table 3.

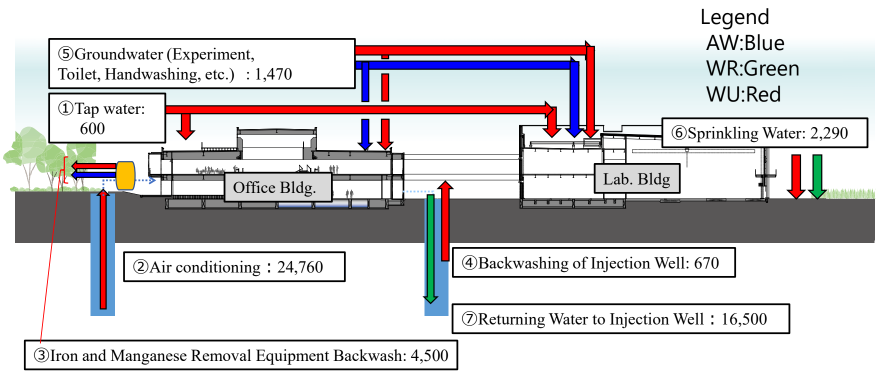

Fig. 12 Water and Groundwater Consumption in FY2022 (Case-2)

Table 3 Calculated results of ZWB based on DOE (Case-2)

Term	Unit	Value	Remarks
AW	m^3/year	5,970	③+⑤
WR	m^3/year	18,790	⑥+⑦
WU	m^3/year	34,290	①+②+③+④+⑤+⑥
ZWB※	%	72	

※: ZWB approaches 100 % if underground infiltration water from rainfall on the site is included in the WR.

In Case-2, both groundwater pumping and return water are taken into account, resulting in a 48 % improvement in the ZWB value compared to Case-1. This is considered to be a calculation in line with actual water use. With the increasing focus on efficient water resource utilization in the pursuit of carbon neutrality, there is a growing consensus that evaluations should encompass not only water usage but also heat usage, and should be more accurate for diverse water resources. In addition, because this facility does not currently have rainwater infiltration facilities, this study estimates the rainwater infiltration water as WR as zero. However, we believe that incorporating the underground infiltration of rainwater and rainwater utilization will bring us closer to achieving a ZWB. By including the underground infiltration water of rainfall at the site as WR, it is estimated that it will approach ZWB. As a specific improvement proposal for ZWB, we are considering the utilization of rainwater storage tanks and the reuse of groundwater used for water usage.

5. CONCLUSIONS

This study introduces a research facility in Japan constructed as a sustainable building considering the global environment. We propose a new ZWB that can be applied to various systems, including factors such as water heat utilization, rather than simply evaluating the ZWB from the viewpoint of water consumption alone. We propose a new ZWB that can be applied to various systems.

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[2] U.S. Office of Energy Efficiency & Renewable Energy, Federal Energy Management Program "Net-zero Water Building Strategies",
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要　約

2020 年 1 月に竣工した高砂熱学イノベーションセンターは、主力電源として採用した木質バイオマスガス化発電と太陽光発電、及び地下水熱利用からなる再生可能エネルギーの活用と蓄電池を組み合わせることで、自立運転が可能なエネルギーシステムを実現した。本施設は、我が国のカーボンニュートラル社会を先導する施設として、SHASE の学会賞、JABMEE のカーボンニュートラル大賞などのアワードを受賞した。本報では、本センターの設備概要と年間を通しての水利用、電力、熱エネルギー実績を報告する。さらに、水資源の保全や水の再利用への関心の高まりから近年注目されている Zero Water Building(ZWB)について、地下水熱・水利用における評価および考察した。ZWB に向けた具体的な改善案として、雨水貯留槽の活用や水使用した地下水の再利用などを考えている。今後は、単に水使用量だけの観点から ZWB を評価するのではなく、水の熱利用なども含めた様々なシステムに適用可能な新たな ZWB を考えていきたい。