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## Renovation of “Earth Port” for Net-Zero Energy Building

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### ABSTRACT

A middle-sized office building (floor area : 5,645 m<sup>2</sup>), nicknamed “Earth Port,” was renovated with the intention of making it a ZEB (“net-zero energy building”) by 2030. As a first step, the following technologies were introduced.

- (1) Thermal network utilizing both solar heat and waste heat from gas cogeneration system (CGS) and gas engine driven heat pump (GHP)
- (2) Bright-feeling lighting system and other measures to utilize natural sunlight
- (3) Integrated power management system

The thermal and lighting environments were measured and analyzed to investigate the indoor environment as well as detailed energy consumption data. Questionnaires for occupants were also conducted to know self-estimated productivity.

The renovation resulted in a 37% reduction of primary energy consumption and a 45% reduction of CO<sub>2</sub> emissions compared with the average for tenant-occupied office buildings (baseline)..

### 1. INTRODUCTION

In moving to realize a low-carbon society, there are strong demands for energy conservation and CO<sub>2</sub> emissions reduction in the commercial and residential sector, which accounts for about 30% of Japan’s final energy consumption and has rising CO<sub>2</sub> emissions. In particular, measures for the huge stock of existing middle sized buildings are urgently needed.

To address this, we renovated the Tokyo Gas Kohoku New Town Building, nicknamed “Earth Port”, toward making this into a Net-Zero Energy Building (ZEB). Specifically, we used renewable energies and state-of-the-art technologies to verify energy conservation and CO<sub>2</sub> emissions reductions measures, identified the issues, and examined solutions in an effort toward making this existing middle sized building into a ZEB.

This project was aimed at utilizing renewable energies, decreasing electric power consumption for lighting and otherwise thoroughly, reducing energy consumption on an individual-building basis as the first step toward making the Earth Port a ZEB by 2030. We took on the challenge of realizing additional reductions at this building, which had already achieved top-level energy conservation and CO<sub>2</sub> emissions due to installation of a gas engine cogeneration system (CGS) and the use of natural sunlight and ventilation (Shibata, 1999). After confirming and

analyzing the effects from renovating the Earth Port under this project, the next step will be to aim at even greater efficiencies through an area energy network.

It is difficult to achieve ZEB on an individual-building basis for Japanese commercial buildings, which are generally located on small plots, so networking with neighboring buildings (area energy networks) is considered necessary. ZEB is defined as “a building that consumes zero or nearly zero energy on an annual net basis by reducing primary energy consumption in the building through enhanced energy efficiency performance of the building envelope and facilities, networking of neighboring buildings, on-site utilization of renewable energy, and so on” in Japan (Agency for Natural Resources and Energy Japan, 2009). However, the detail of the definition hasn't been standardized. Marszal et al. (2011) reviewed existing ZEB definitions and the various approaches towards possible ZEB calculation methodologies and Kurnitski et al. (2011) proposed an uniformed national implementation of EPBD recast. But it is still challenging to do ZEB calculation for networked buildings, some of them generating energy and sharing it each other. The next step of this project will include definition and methodology of ZEB calculation for networked and energy sharing buildings.

This project was selected as a “Demonstration Project for Next-generation Buildings Using Energy Efficiency Technologies” and subsidized by Japan's New Energy and Industrial Technology Development Organization (NEDO).

## 2. OUTLINE OF THE RENOVATION WORKS

Photograph 1 shows the Earth Port, when it was completed in 1966, and Table 1 shows the overview.

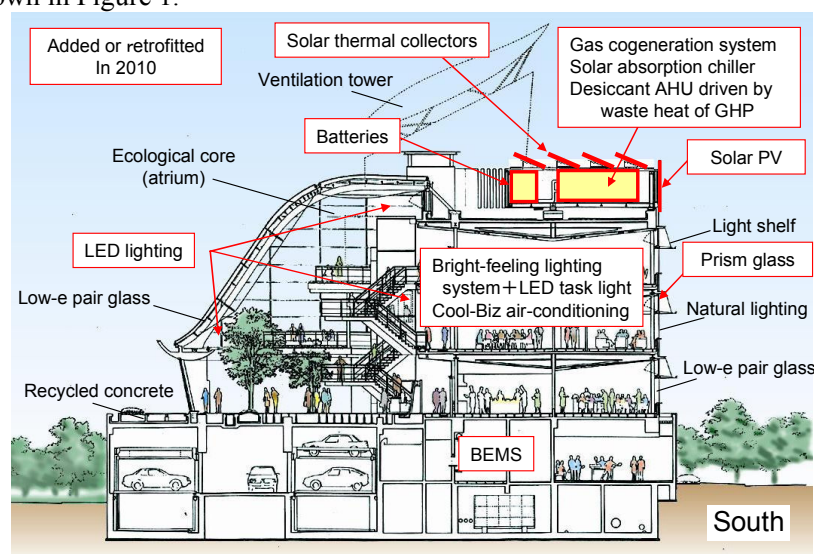
**Table1:** Overview of the Earth Port

Location	Yokohama City, Kanagawa Pref.
Completed	March 1996
Floor area	5,645m <sup>2</sup>
Structure	SRC, RC, S, wood
No. of floors	4 stories above ground + 1 penthouse
Use	Offices, showroom



**Photograph 1:** Earth Port (1996)

The goal of the renovation was to reduce primary energy consumption by around 40% compared with a regular tenant building, and to verify the effectiveness of the following technologies. An overview of the renovation is shown in Figure 1.



**Figure 1:** Overview of the renovation

## 2.1 Energy Conservation and CO<sub>2</sub> Reduction Air Conditioning System with Optimal Use of Solar Heat, CGS Waste Heat and GHP Chiller Waste Heat

The use of renewable energies is essential to improve air conditioning system efficiency toward realizing ZEBs. Among these, solar heat, which can efficiently utilize solar energy, is effective for air conditioning and other heat applications. It is important to develop heat utilization equipment that can use solar heat, as well as control technologies. This project formed a thermal network utilizing solar heat together with CGS waste heat and GHP chiller waste heat in an absorption chiller heater and in desiccant Air Handling Units (AHUs), constructing a high-efficiency air conditioning system. The system flow is summarized in Figure 2.

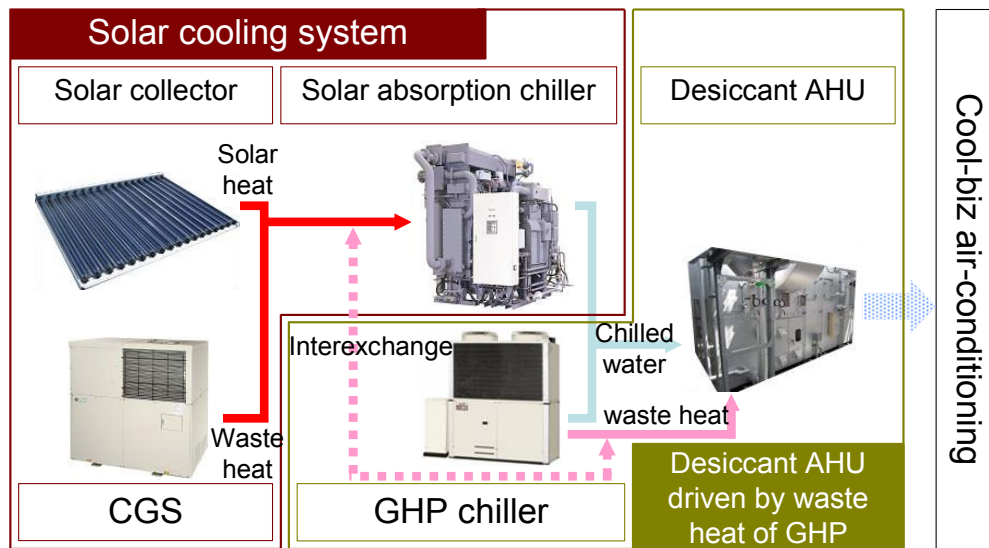


Figure 2: Air conditioning system flow

Solar thermal collectors with a rated heat output of around 100kW were installed on the roof. The system uses heat from these collectors, which varies depending on the weather, on a preferential basis. It is supported by CGS waste heat to provide stable air conditioning using a solar absorption chiller heater (a gas absorption chiller that can utilize solar heat). In this design, the system uses the solar absorption chiller heater and desiccant AHUs in a cascade flow, depending on the temperature of the hot water from the solar thermal collectors, to achieve greater efficiency through the maximum use of heat.

The solar thermal collectors use doubled-walled concentric glass tubes, which have a vacuum between their two layers. Together with the reflectors, glass tubes make high-efficiency heat collection possible because of its high insulation performance.

Desiccant AHUs are used as air conditioning equipment, with the goals of conserving energy and reducing CO<sub>2</sub> emissions while also providing comfortable air conditioning by controlling humidity and maintaining a relatively high indoor temperature. By using the GHP chiller waste heat as the heat source for regenerating the desiccant rotor, comfortable air conditioning is achieved without using any additional energy. This project is the first example of effectively using GHP waste heat during cooling.

The project also adopted “Cool chairs” on an experimental basis to make the desiccant “Cool Biz” air conditioning more effective. The Ministry of Environment Cool Biz campaign aims at reducing energy consumption by limiting air conditioning use. “Cool chairs” are chairs with battery-driven fans. The ventilation fan at the front of the chair dissipates the heat from the chair seat, and the fans on the armrests blow air directly on to the body (the airflow amount and direction can be adjusted). In offices where different types of people work, those who are more sensitive to heat could use cool chairs to minimize discomfort even in rooms where the temperature is set relatively high. The cool chair electric power consumption at maximum fan speed is only about 5W, and the fans are turned on and off by sitting down and standing up, so they cannot be left running accidentally. The increased energy use from using “Cool

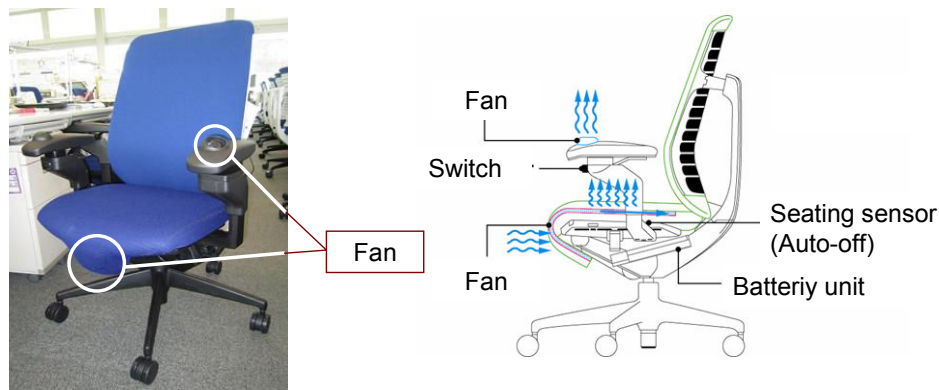


Figure 3: Cool chair

chairs” is minimal compared with the energy saved by reduced air conditioning use by setting the thermostat at a higher temperature.

Figure 4 summarizes the relation of rate of using “Cool chair” and mean room and outside temperature of each month. The rate of using “Cool chair” seems to have correlation with outside temperature. This is because occupants tend to use “Cool chair” just after returning from outside. This result derives that “Cool chair” is effective for mitigating warm situation for the occupant.

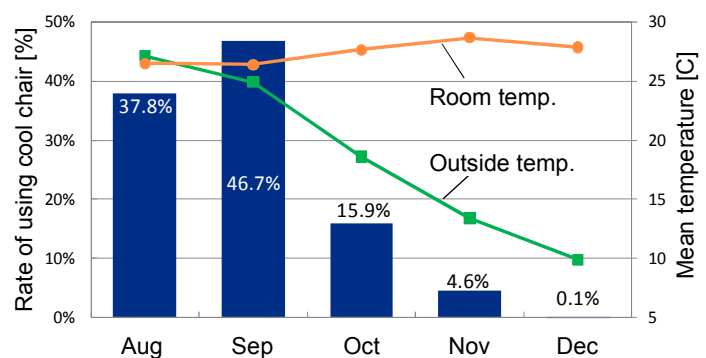


Figure 4: Rate of using cool chair and mean room and outside temperature of each month

## 2.2 Bright-feeling lighting system and other measures to utilize natural sunlight

The measures to conserve energy use in lighting system have more universal applications compared with the other measures. To horizontally roll out these measures to other existing middle sized buildings, beyond just introducing high-efficiency lighting, responding to changes in applications, layouts and other usage conditions are also important to continuously maintain the effects.

In this project we expanded the use of natural sunlight, which had already been adopted, introduced “bright-feeling” lighting that emphasizes a feeling of brightness in ambient areas along with high-efficiency LED lighting for task lighting. Lightings were replaced to LED lighting in common areas. We also installed optimal control system through motion sensors on-off control and illuminance control by area, in order to verify technologies that conserve energy, respond flexibly to layout and other changes and maintain continuous effects.

Figure 5 presents an image and a cross-section of the bright-feeling lighting, as well as the luminance distribution and photos before and after the improvements. The bright-feeling lighting installed reflectors to the existing lighting features to illuminate the ceiling and impart a feeling of brightness throughout the room. Figure 5 shows that users perceived a similar sensation-of-room-brightness-index (Iwai and Iguchi, 2008), Feu was about 14, on their desks at 435Lux with the reflectors as they did at 684Lux without the reflectors, meaning significant amount of electricity for lighting was saved. While the desk-top illuminance in ambient areas was set as 300Lux during the summer of 2011 as an electricity conservation measure, during the daytime natural sunlight almost always provided sufficient light and users almost never used the task lights provided for lighting at hand. This system is deemed extremely effective to reduce electric power consumption for lighting at existing buildings.

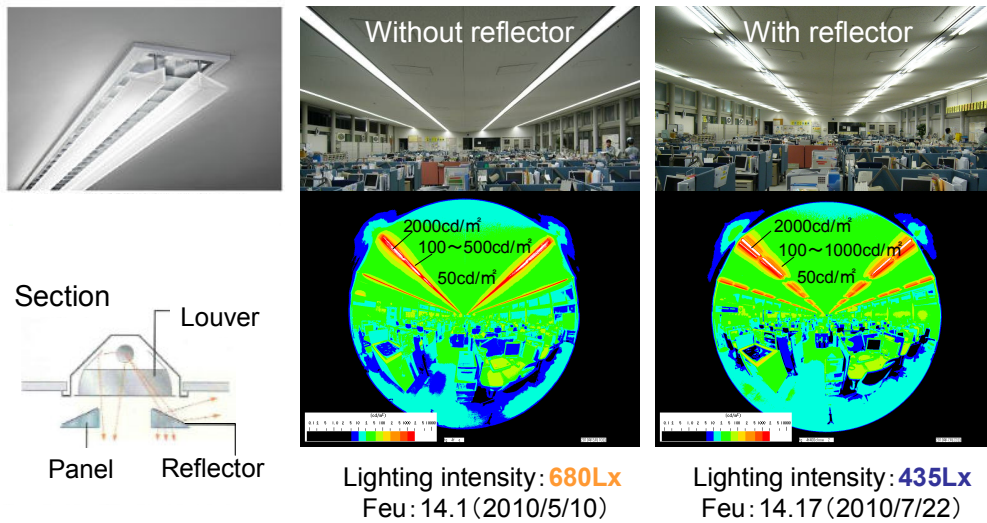


Figure 5: Bright-feeling lighting system

### 2.3 Integrated Power Management System Combining Photovoltaic Power Generation with High-efficiency CGS, etc.

Improving the economics of photovoltaic power generation and stabilizing electric power supply when introduced on a large scale are important issues for spreading photovoltaic power and turning buildings into ZEBs. To address these issues, while the normal approach is to combine photovoltaic power generation with storage batteries, this project makes the further addition of CGS and introduces an integrated power management system to build a stable energy conservation type electricity supply system which compensates for the demerits of battery function deterioration, and charge and discharge loss. This works at (1)improving the economics through the effect of reducing demand, and (2) stabilizing the photovoltaic power output via cooperative control of the CGS and the batteries. The evaluation results of this demonstration will lead to component technologies important for building a smart area energy network that conserves energy and reduces CO<sub>2</sub> emissions throughout the area.

A total of 21.5kW of photovoltaic panels were installed on the southern and western sides of the rooftop sound barrier wall. The system works to secure the demand reduction effect and stabilize overall electric power output by compensating for the relatively short-term fluctuations of photovoltaic electric power generation with the batteries and for the relatively long-term fluctuations with the CGS. Figure 6 presents an outline of the integrated power management system.

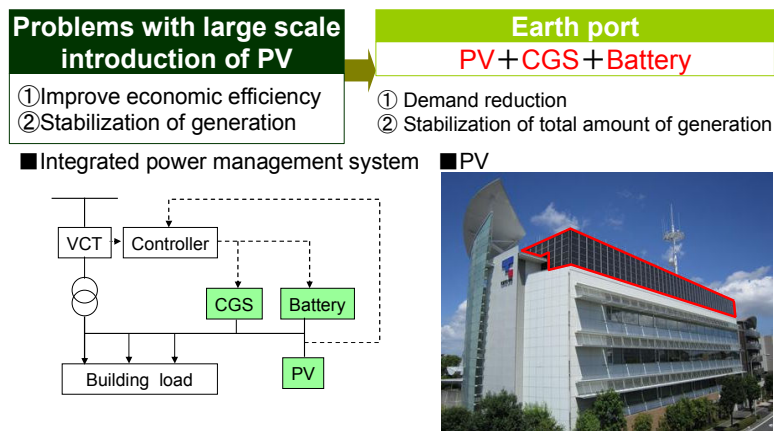


Figure 6: Integrated power management system



### 3. ENERGY CONSUMPTION

Figure 7 presents the primary energy consumption per unit floor area over the 12 months from October 2010, when the new system began regular operation through September 2011 compared with the fiscal 2004 level prior to the renovation and with a baseline level. The baseline shows the actual fiscal 2005 figures for tenant buildings published by the Tokyo Energy-Saving Program, Tokyo Metropolitan Government.

The primary energy consumption per floor area at the Earth Port after the renovation was 1,585MJ/m<sup>2</sup>, which is a 17% reduction compared with before the renovation and a 37% reduction from the baseline.

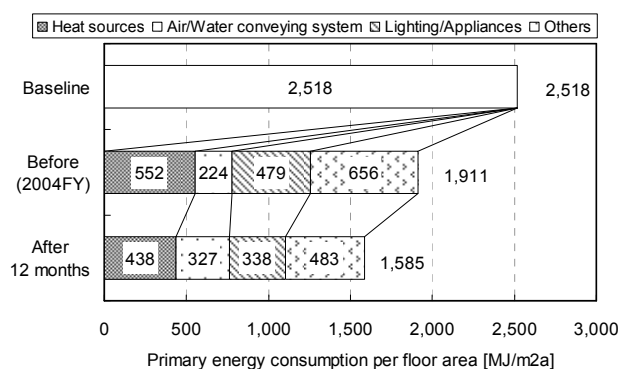


Figure 7: Primary energy consumption per floor area

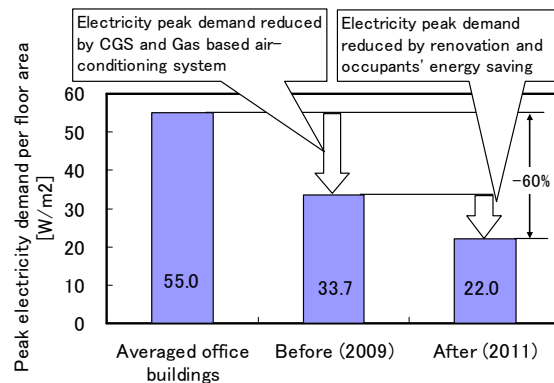


Figure 8: Peak electricity demand per floor area

Comparing the energy consumption details before and after the renovation works, the energy consumption for air and water conveying systems increased. The increase for the solar cooling system's hot water cycling system was about 4%, and we investigated the causes. We determined that the air volume output by the Variable Air Volume (VAV) system always ran near the maximum, and that the energy used by the air conditioning fans had greatly increased. The cause was that in this building, which uses the ceiling chamber system, seal leaks had appeared along with the passage of time. If there were no seal leaks and the energy consumption for the air and water conveying systems had remained the same before and after the renovation, the reduction in primary energy consumption from the baseline figure would have been around 41%. A problem mentioned above will be fixed in May 2012.

Figure 8 presents the peak electricity demand per floor area in 2009 before the renovations and in 2011 after the renovations compared with that at a regular office building. Because the Earth Port had already introduced CGS and gas air conditioning before the renovation, the peak electricity demand was already a reduction of about 39% from a regular office building. In 2011, adding the effects from the higher overall systems efficiencies under the renovation and tenant energy conservation efforts, the peak electricity demand was reduced by nearly an additional 35%, for a total reduction of about 60% compared with a regular office building. This shows that the CGS and gas air conditioning greatly contributed to reducing the peak electricity demand in summer and to demand leveling.

### 4. INDOOR ENVIRONMENT

We measured the indoor temperature and illuminance distribution to confirm the indoor environment formed by the air conditioning and lighting changes due to the renovation. The measurements were conducted on a room being used as an office with dimensions of 32m (east-west) by 13.5m (north-south). The measurements were conducted with the systems set for a desk-top illuminance of 300Lux in ambient areas and a room temperature of 26°C.

Figure 9 presents the desktop illuminance distribution on cloudy and sunny days. The figure indicates that natural sunlight from the south windows and the north-side atrium is being effectively used on both cloudy and sunny days. The northeast corner does not effectively use natural sunlight, and shows less than 300Lux illuminance. This is because, there was no occupant during daytime at the part and lighting switch was off.

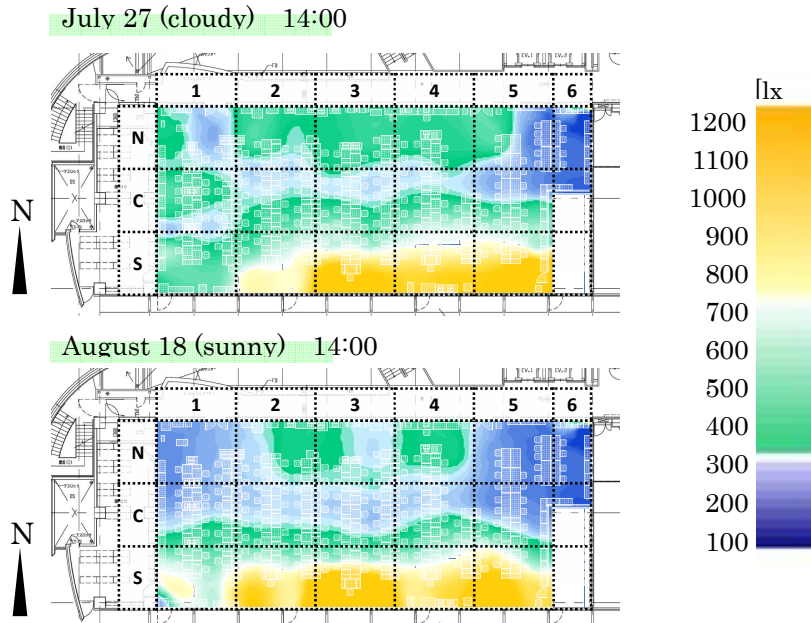


Figure 9: Desktop illuminance distribution

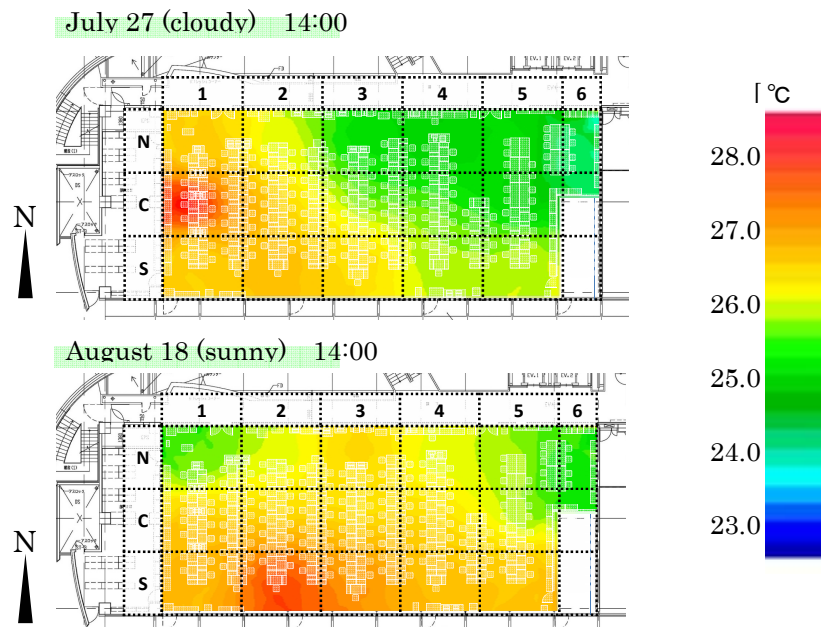


Figure 10: Temperature distribution



Figure 10 shows the temperature distribution 1.1 meters above the floor on both cloudy and sunny days. On cloudy days, the temperature increases in areas on the west side of the room where there are many people. On sunny days, the temperature increases in areas on the south side because of the effect of the sunlight. In both cases, the indoor temperature is uneven and the temperature control insufficient because of the leaks in the seals in the ceiling chamber system air conditioning mentioned in section 3. As explained above, while the indoor environment is within the acceptable range, further improvements are expected to provide an even more comfortable environment.

## 5. PRODUCTIVITY CHANGE

To check the effect of renovation to the work productivity, questionnaires were conducted. Figure 11 shows one of the results. The question was “How much your productivity has been changed after the renovation?” and 119 occupants answered. The most occupants answered that there had been no-change, but some answered positive change. The averaged value was 4.0%. This result suggests that the renovation might provide favorable environment for the improvement of productivity. More analysis will be done concerning relations of room (thermal) environment and productivity.

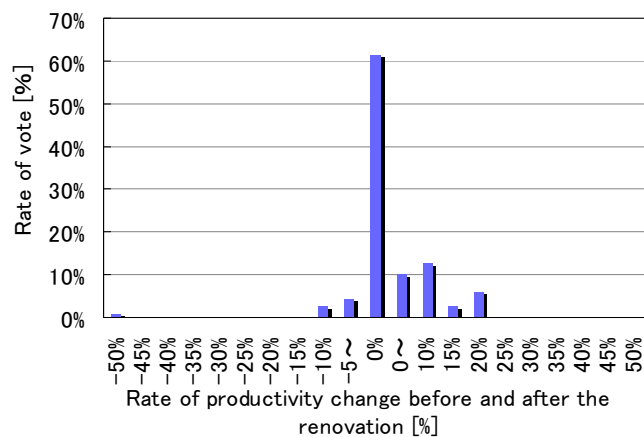


Figure 11: Rate of self-estimated productivity change

## 6. CONCLUSION AND FUTURE OUTLOOK

These renovation works reduced primary energy consumption by around 37% from the baseline level, as the first step toward making the Earth Port a ZEB. Additional reductions should be possible by repairing the above-mentioned seal leaks and further optimization of operations. The technologies verified as effective through this renovation will be considered for application to existing middle-sized buildings without advanced energy conservation measures.

As the next stage for the Earth Port, we will introduce even more high-efficiency equipment and examine energy reductions from an area energy network. If the Earth Port and neighboring buildings with a different demand pattern could share larger scale solar thermal collection, photovoltaic and cogeneration systems and give each other heat and electricity, the combined demand would level out, and it would be possible to introduce large-scale high-efficiency equipment and operate them near rated capacity to achieve further high efficiencies. Also, when the sky is clear on a Sunday and the Earth Port—which is used mainly as office—generates more energy than it needs, that energy could be effectively used in neighboring buildings. We will work toward achieving ZEB by 2030 in this manner, not for the Earth Port on a stand-alone basis but rather through energy sharing among a group of buildings in an area energy network while reducing energy consumption..

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