**Challenge to Implement Zero Net Energy Building by thorough Commissioning Process**

## 1. Introduction

[redacted] Environmental Research Center & [redacted] Institute of Public Health, located in [redacted], scientifically and technically supports [redacted]'s environmental and sanitary administration. The [redacted] city is located in [redacted] at the central of [redacted] and its monthly average outdoor temperature is approximate from 5℃ to 28℃ (41ºF to 82.4ºF) shown in **figure 1**. A new building, four-story, with a total area of 8,147.46 m$^2$ (87,698.53 ft$^2$) was built on the site of the existing building to replace the old one and completed in March 2019.

The [redacted] environmental conservation strategy required the new building to achieve "Nearly Zero Energy Building (Nealy ZEB)", described in **section 2.4** on page 4. To ensure the achievement of "Nearly ZEB", commissioning process (Cx) was introduced and conducted during design stage and construction stage. Postoccupancy Cx from April 2019 to March 2021 was conducted so that the new building achieved "Nearly ZEB" in FY2020[*1]. (*1: FY means from April to March in [redacted].) However, since there was room for improvement in HVAC system, existing building Cx (EBCx) has been conducted since April 2021 so that the new building achieved zero net energy building, defined by [redacted] standard, in FY 2022 and FY 2023.

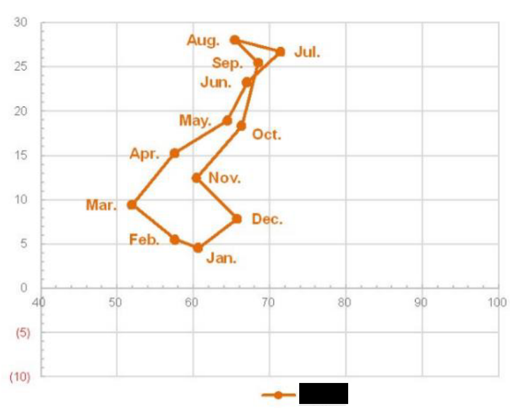
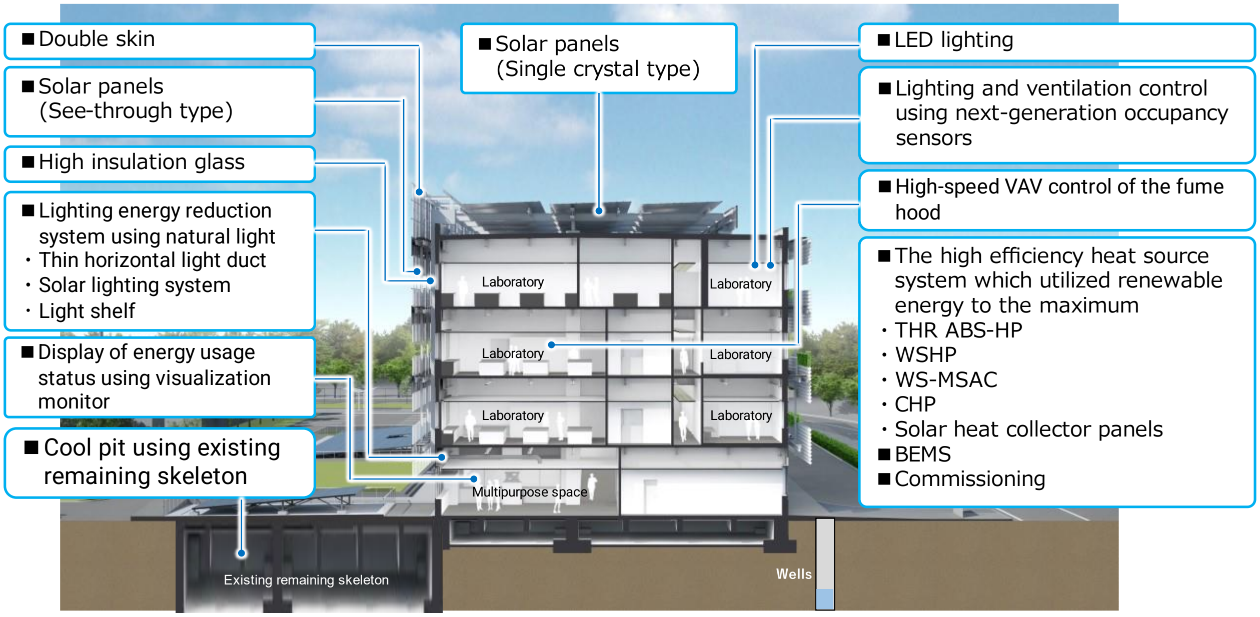



**Figure 1 Climate Data for [redacted] City**

**Photo 1 Ground View from South-West**

## 2. Energy Efficiency

The new building is equipped with a variety of innovated energy saving and generating systems shown in **figure 2** to achieve “Nearly ZEB” required by the OPR (Owner’s Project Requirements).




**THR ABS-HP ： Two-source hot water recovery absorption heat pump/chiller**
**WSHP ： Water-source heat pump**
**WS-MSAC ： Water-source multi-split type air conditioner**
**CHP ： Combined heat and power**

**Figure 2 Conceptual Section of Innovated Energy Saving and Generating Systems**

### 2.1 Energy Generation Facade and Solar Shading Using Two Types of PV Panels

Single crystal type PV panels were installed on the roof, the ground level, and the south facade. See-through type PV panels, same as transparent type, were also installed outside the south-facing balcony shown in **photo 1 and 2**. The south facade panels have two functions of generating energy and sun shading improving indoor comfort by reducing solar radiation load shown in **figure 3**.

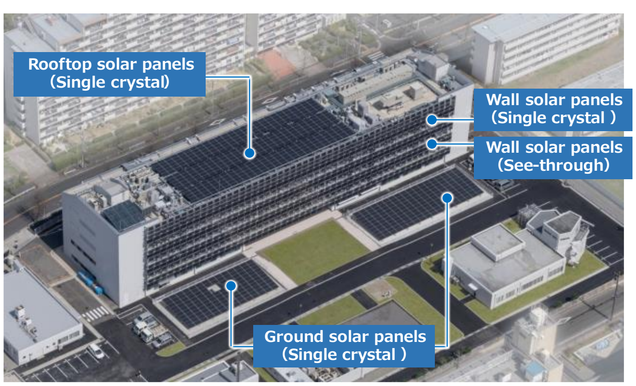



**Photo 2 Sky View from South-West and Locations of Two Types of PV Panels**

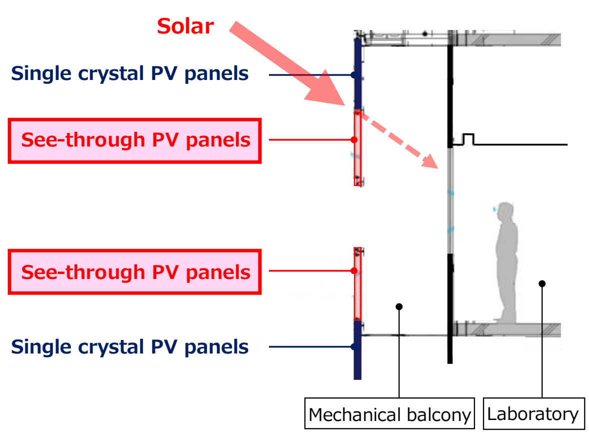



**Figure 3 Section of the South Façade with PV Panels**

### 2.2 Lighting and Ventilation Control Using Next-generation Occupancy Sensors

High-precision next-generation occupancy sensor (New Type Sensor) that can distinguish heat from computers, sunlight, and the human body was employed. It controls lighting system and demand control ventilation (DCV) system in laboratories, offices, conference rooms, etc. based on the presence of people in the room. The DCV system successfully reduced the peak of outdoor air load to 241kW (822kBtu/h) for cooling and 250kW (853kBtu/h) for heating in FY2023. These values were 88% for the cooling and 87% for heating compared to the design value.

### 2.3 Best Combination of Heat Source System Using Renewable Energy and CHP

Instead of a conventional heat source system like an air source heat pump, designers tried innovative approaches. **Figure 4** shows the heat source system using renewable energy such as solar heat, well water heat, and heating energy from CHP to reduce energy consumption and CO2 emissions . The heat source system for outdoor air handlers (OHUs) and hydraulic fan-coil units (FCUs) consists of water-source heat pump (WSHP) and two-source hot water recovery absorption heat pump/chiller (THR ABS-HP).

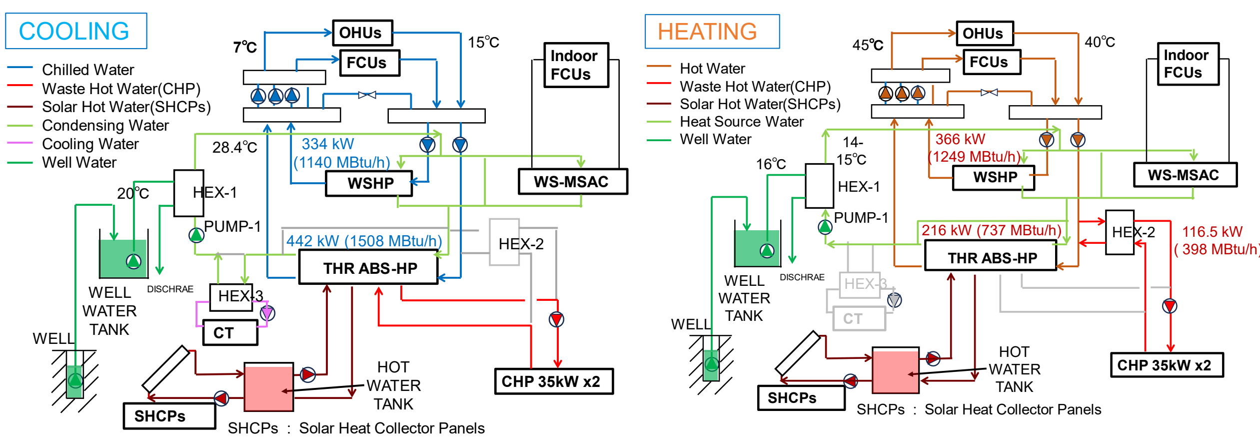



**Figure 4 Diagram of Innovative Energy Heat Source System**

**For cooling operation** shown in **figure 4**, the WSHP and the THR ABS-HP supply chilled water. Condensing water through the WSHP, the THR ABS-HP, and water-source multi-split type air conditioner using VRF (WS-MSAC) is cooled by well water through a heat exchanger (HEX-1) or using a cooling tower through a heat exchanger (HEX-3).

**For heating operation** shown in **figure 4**, the WSHP and the THR ABS-HP supply hot water with using heat source water loop through the HEX-1. Waste hot water from the CHPs also provides hot water for the heating system through a heat exchanger (HEX-2). During the heating operation, the well water temperature (WWT) in the tank shown in **figure 4** gradually drops through the heat exchange with the heat source water. When the WWT has dropped to its lowest point, new well water is replenished. There is a limit to the amount of well water that can be pumped in a day, and replenishment during the daytime is not anticipated. The capacity of the tank was based on the amount needed for heating operation from 8:00 to 18:00.

The innovative THR ABS-HP was developed to achieve the following purposes.

- Improvement in COP for heat source by using natural energy like solar and well water
- Prevention of increase electric power demand due to using only electric driven heat pump
- Up to around 40% capacity of it can supply chilled water by only receiving waste hot water
- Decreasing exchanged energy through well water compared to electric water source heat pump

**In summer,** the THR ABS-HP shown in **figure 5** supplies chilled water as absorption chiller by using gas fuel with using hot water from the solar panels and the waste hot water from the CHPs.

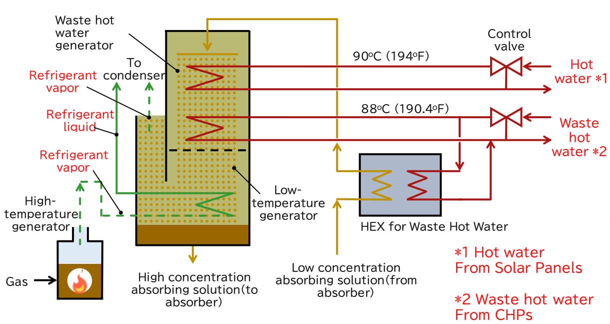



**Figure 5 Diagram of Two-source Hot Water Recovery Absorption Chiller (THR ABS-HP)**

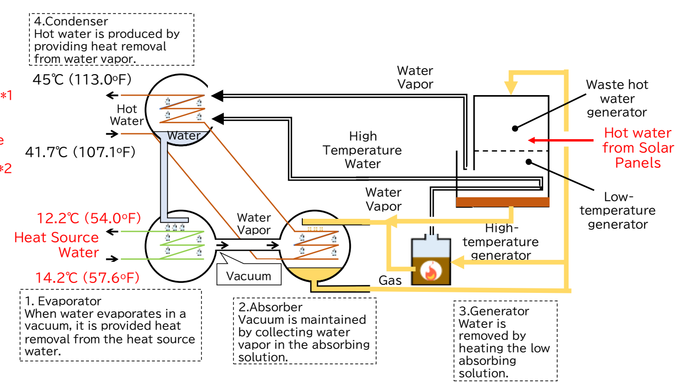



**Figure 6 Diagram of Absorption Heat Pump**

**In winter,** the THR ABS-HP shown in **figure 6** supplies hot water as absorption heat pump by using gas fuel with using solar heat and the heat source water around 14ºC (57.2ºF) to achieve maximum COP of 2.0. Strong points of the THR ABS-HP are also described in **section 4.**

**2.4 Continuous Commissioning Process from the Design Stage to the Operational Stage**

Continuous Cx has been conducted by the Cx team from the design stage to the operational stage to meet OPR which requires the new building achieve "Nearly ZEB", defined by SHASE, that net source energy of the new building shall be reduced to 25% or less of that of the baseline building through energy saving and on-site renewable energy supply by PV panels.

[redacted]

During the design stage from October 2016, the Cx team supported the designers to select the heat source system and the capacity of heat source system and PV panels to achieve “Nearly ZEB”.

During the construction stage from November 2017, simulation models were developed by the Cx team to evaluate the performance of the heat source system, and operational patterns of the heat source system were created and executed how to reduce energy consumption.

From April 2019, postoccupancy Cx started. Energy analysts joined the Cx team, and all of the building system performance data have been evaluated to reduce energy consumption and improve the performance of HVAC system and lighting system.

### 2.5 Existing Building Cx (EBCx): Continuous Cx after Two Years Operation and Occupancy

After two years operation from April 2019, since tuning items of HVAC system and room for improvement in the COP of the heat source were found, the continuous Cx started as the EBCx from April 2021 to mainly solve the following three issues.

#### 2.5.1 Solutions for the Three Issues

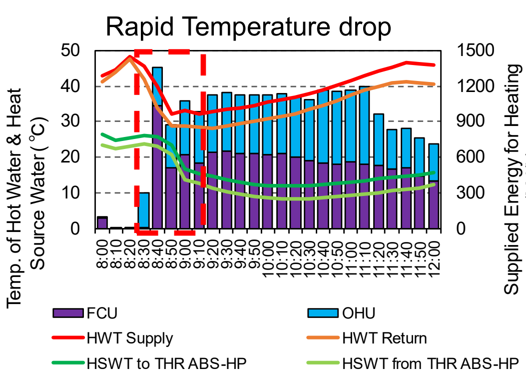



**Figure 10 HWT & HSWT and Heating Energy Supply on Feb.27 2023**

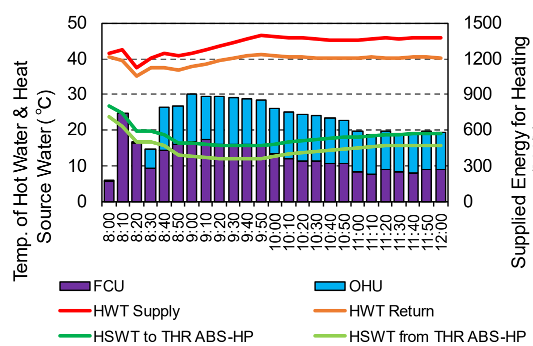



**Figure 11 HWT & HSWT and Heating Energy Supply on Mar. 3 2023**

- **Issue One: Improvement in Instability of Temperature of Hot Water and Heat Source Water in Winter**

As shown in **figure 10**, there was a rapid drop in the hot water temperature (HWT) and the heat source water temperature (HSWT) at heating system startup because the start of FCU operation was concentrated at around 8:45 shown in **figure 10**. In order to solve this issue, FCU start time was modified from 8:45 to around 8:00 am, and the successful peak shifting resulted in reduction of the peak load at the time of start-up. As shown in **figure 11,** the temperature drops of the HWT and the HSWT also became slower than before the improvement, and the HWT and the HSWT stabilized after 10:00 am.

- **Issue Two: Improvement in COP of the THR ABS-HP as Heat Pump**

The result of the performance testing at the construction stage showed that COP of THR ABS-HP as heat pump was around 1.5 to 1.8 shown in **figure 12**. Temperature difference between outlet and inlet of the HSWT in shown **figure 12** means that heat exchange was conducted in the THR ABS-HP. However, as shown in **figure 12**, the HSWT and the WWT rapidly dropped at around 3 p.m. This is because the WWT reached its lowest point around 3 p.m. because the actual WWT was 16ºC-17ºC (60.8ºF-62.6ºF), which was lower than the design value of 18ºC-20ºC (64.4ºF-68ºF). This phenomenon caused a shortage of well water and colder tap water had to be used to replenish the well water tank. The rapid drop of the WWT caused rapid drop of the HSWT. In order to avoid unstable operation of the heating system, heat pump operation of the THR ABS-HP was canceled and forced to be operated with its COP under 1.0 such as a boiler from April 2019 to Dec 2021.

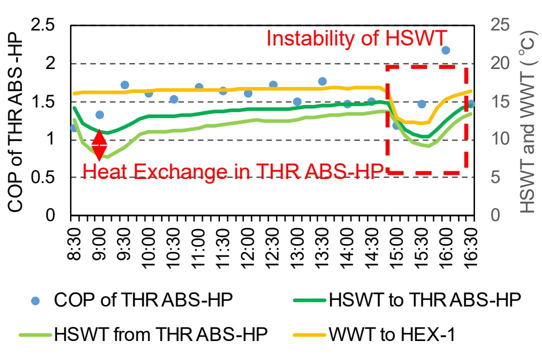



**Figure 12 COP of THR ABS-HP and HSWT on Feb 13 2019**

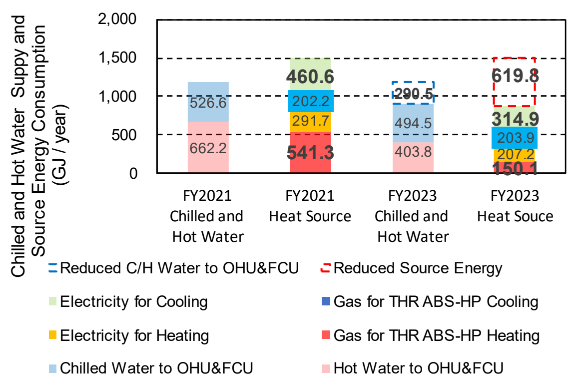



**Figure 13 Comparion of Chilled/Hot Water Supply and Source Energy Consumption in FY2021 and FY2023**

During the EBCx, in order to improve the COP, simulations was conducted to check the relationship among the WWT, the HSWT, and the performance of the THR ABS-HP so that the optimized method of heat pump operation was found. Heat pump operation restarted in 2023 January. The improvement in the COP enabled the annual gas fuel consumption to reduce from 541.3 GJ (513.1MMBtu) in FY 2021 to 150.1GJ (142.3MBtu) in FY2023 shown in **figure 13**.

- **Issue Three: Optimization of Condensing Water Circulation**

For the first two years operation, energy consumption of the condensing water circulation pump, **Pump-1** shown in **figure 4,** was larger than the designed value. To reduce the energy consumption, water flow was reviewed and found that 1672L/min (441.7 gallon/min) was sufficient according to the two years operation although the original water flow rate was 2000 L/min (528.34 gallon/min). Therefore, on August 24 in 2021, the water flow rate of the pump-1 was changed to 1672L/min (441.7 gallon/min). Energy simulations, conducted by the EBCx team, found that this optimization of water flow can reduce by around 50% of electric consumption in cooling system operation.

Setting heat source water temperature in summer was also changed from 28.4ºC (83.12ºF) to 22ºC (71.6ºF) to improve the COP of the WSHP and the THR ABS-HP. These improvements resulted in the reduction of electric consumption for cooling system from 460.6 GJ/yr. (436.6 MBtu/yr.) in FY2021 to 314.9 GJ/yr. (298.5 MBtu/yr.) in FY2023 shown in **figure 13**.

### 2.5.2 Result of the EBCx from FY2021 to FY2023

**Figure 13** shows the amount of chilled and hot water supplied energy (CHWSE) to OHUs and FCUs decreased by 290.5 GJ/yr. (275.3 MBtu/yr.) from FY2021 to FY2023. This is partly due to the fact that overtime hours, which were high during the Covid-19 pandemic, decreased in FY2023.

Meanwhile, the energy consumption of the heat source system decreased by 619.8 GJ/yr. (587.5 MBtu/yr.) more than 290.5 GJ/yr. (275.3 MBtu/yr.) of the CHWSE, which is the result of the EBCx including the three main points mentioned as above.

### 2.5.3 Implementation of Nearly ZEB and Close to Zero Net Energy Building by the EBCx

**Figure 14** shows the history of source energy consumption and generated energy by PV panels of the baseline building, designed value of the new building, and actual values in five years operation.

The energy consumption in lighting system is reduced by 60% compared to the design value. This is an effect of the New Type Sensor described in **section 2.2** on page 3.

The net source energy in FY2020 was less than 25% of the baseline building's net source energy. It means the new building achieved "Nealy ZEB" required by the OPR.

After the EBCx in FY2022, the source energy consumption except plug load was 2,924 GJ/yr. (2,771.4 MBtu/yr.) and the generated energy by PV panels was 3,088 GJ/yr. (2,926.9 MBtu/yr.) shown in **figure 14** in green. It means the new building achieved net zero energy building defined by [redacted] standard method that dosed not include plug load to evaluate zero net energy.

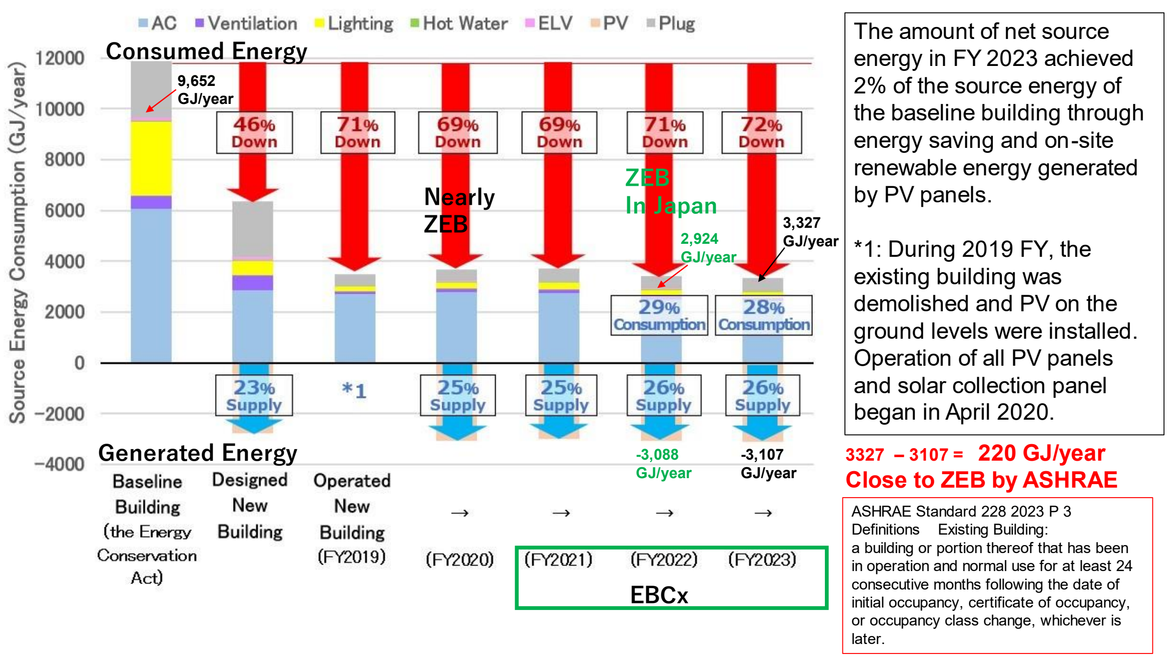



**Figure 14 History of Source Energy Consumption and Generated Energy by PV Panels**

### 2.5.4 Strategies for More Decreasing the Source Energy Consumption

ASHRAE standard requires plug load to be included to evaluate zero net energy so that, as shown in **figure 14**, the source energy consumption was 3,327 GJ/yr. (3,153.4 MBtu/yr.) in FY2023. Since the generated energy was 3,107 GJ/yr. (2,944.9 MBtu/yr.), the net source energy is 220 GJ/yr. (208.5 MBtu/yr.). The EBCx team has proposed the following two methods to reduce the source energy consumption so that the consumed energy will be almost equal to the generated energy.

- **Method One: More Improvement in the COP of the THR ABS-HP**

Although the heat pump operation of the THR ABS-HP restarted, its COP has not perfectly reached the COP of 2.0. If more than 30% of reduction of the gas fuel consumption, which was

150.1 GJ/yr. (142.3 MBtu/yr.) in FY2023, is succeeded in FY2024 or future by increasing the COP, its more than around 45 GJ/yr. (42.7 MBtu/yr.) may be reduced.

- **Method Two: Improvement in Efficiency of the CHP System**

Efficiency of generating electricity by the CHP has been around 28% that is inferior to original efficiency, which is 32 % according to the supplier, due to long time partial load. The lower efficiency operation increased the gas fuel consumption. The optimized number of two sets CHP operation will enable the gas fuel consumption to decrease 74 GJ/yr. (70.1 MBtu/yr.).

The total reduction of the source energy by using the two methods as above is 119 GJ/yr. (112.8 MBtu/yr.) that is not sufficient for 220 GJ/yr. (208.5 MBtu/yr.). However, continuous challenge for reducing source energy consumption by Cx will contribute to the building decarbonization.

## 3. Indoor Air Quality

Ventilation requirements and indoor temperature conditions were designed according to the prefectural standards with reference to ASHRAE Standard 55. HVAC system is using dedicated outdoor air systems (DOASs) using OHUs. Humidification system is using vaporization type to meet indoor humidity requirement. The air filter was selected according to [redacted] standards with reference to ASHRAE standard 62. Two types of FCUs, the hydraulic FCUs and the VRF FCUs, are used for individual room temperature control system shown in **figure 4** on page 3.

## 4. Innovation

In the innovated systems shown in **figure 2**, the THR ABS-HP is the first machine in [redacted] that combined two-source hot water recovery absorption chiller and heat pump system in one unit.

A heating system using an absorption heat pump is effective for reducing the source energy and $CO_2$ emissions. **Table 1** on page 10 shows that value of $CO_2$ emissions of the THR ABS-HP as heat pump is superior to its of air source heat pump when the outdoor air temperature is below 0°C (32°F). Since THR ABS-HP has no problem about defrost under cold weather condition, it has the potential to replace a conventional boiler system as the main heat source in cold climate regions.

The Cx team has been supporting the THR ABS-HP and the entire heat source system to ensure that they perform to their full potential, and Cx will have been done until the COP of the THR

ABS-HP as heat pump achieve the expected value.

**Table 1 Comparison of Performance about THR ABS-HP, WSHP and Air Source Heat Pump**

| Heat Sources *1 Dry bulb temperature 7°C (44.6 oF) *2 Dry bulb temperature 0°C (32 oF) | Heating Capacity (Supplied hot water temp. is 45°C) | | Energy Consumption for Heating (Gas Nm3/h) ( Electricty kW) | Energy Consumption of Heat Source Water pump& well water pumps | Source Energy Consumption | Source Energy Consumption per 1 kWh (1 Btu) of heating capacity | | $CO_2$ Emmisions per 1 kWh (1Btu) of heating capacity | |
|---|---|---|---|---|---|---|---|---|---|
| | kW | Btu/h | | | | MJ/kW | MJ/Btu | kg-CO2/kW | kg-CO2/Btu |
| THR ABS-HP | 216.0 | 737.0 | 8.7 Nm3/h | 17.1 kW | 558 MJ/h | 2.59 | 0.76 | 0.129 | 0.038 |
| WSHP | 365.8 | 1,248.2 | 70.8 kW | 10.2 kW | 791 MJ/h | 2.16 | 0.63 | 0.102 | 0.030 |
| Air Source Heat Pump *1 | 85.0 | 290.0 | 21.8 kW | None | 213 MJ/h | 2.50 | 0.73 | 0.118 | 0.035 |
| Air Source Heat Pump *2 | 102.0 | 348.0 | 31.3 kW | None | 305 MJ/h | 2.99 | 0.88 | 0.141 | 0.041 |
| Greenhouse Gas Emission (GHG) Factors | | | 0.0509 kg-CO2/MJ by TOHO GAS | | 0.459 kg-CO2/kWh by CHUBU ELECTRIC | | | | |
| Source Energy Conversion Factor | | | GAS 45 MJ/Nm$^3$ | | Electric 9.76 MJ/kWh | | | | |

## 5. Maintenance & Operation

The remote management tool for HVAC using internet has been used to coordinate between the new building in [redacted] and Cx team in [redacted]. Monthly energy report has been provided since April 2019 by energy analysts in the Cx team to evaluate the performance of the new building.

## 6. Cost Effectiveness

The source energy consumption except plug loads of the baseline building is 9,652 GJ/yr. (9,148.4 MBtu/yr.) and the operational energy consumption except plug loads in FY2022 was 2,924 GJ/yr. (2,771.4 MBtu/yr.) shown in **figure 14**. The reduced energy of 6,728 GJ/yr. (6,377.0 MBtu/yr.) in FY2022 during the EBCx is equivalent to operational cost around 84,000 US$ per /yr. The increased first cost to employ the energy saving systems can be recovered in around six years.

## 7. Environment Impact

The $CO_2$ emissions in the latest FY2023 during the EBCx was 167.3 t-$CO_2$/yr. (=20.5 kg-$CO_2$/m$^2$) calculated by the source energy consumption of 3,327 GJ/yr. (3,153.4 MBtu/yr.) shown in **figure 14.** The net $CO_2$ emissions after deducting the amount of energy generated by the PV panels is 10.4 t-$CO_2$/yr. (=1.3 kg-$CO_2$/m$^2$), and it is close to zero net carbon building.

## 8. Conclusion

The thorough Cx enabled the new building to implement "Nearly ZEB" required by the OPR and achieve net zero energy building by [redacted] standard and significantly reduce $CO_2$ emissions.

Cx is essential for an innovative system to perform at its best and contribute to the building decarbonization, and this essay makes the case.