DESIGN/ENGINEERING OF LOW CO2 EMISSION OFFICE BUILDING USING HEAT PUMP AND THERMAL STORAGE

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Abstract: We verified with simulation that our challenging office building project, which we have been developing for CO2 emission saving, can achieve 55% CO2 emission reduction compared to conventional office buildings in Japan. In order to achieve such a drastic reduction, we are adopting passive as well as active methods of utilizing natural energy. The passive methods are utilizing natural energy sources and thermal performance of building. The active methods are combination of ground coupled heat pumps and air source heat pumps. The former is combined with well water cooling and produces medium chilled water, which is utilizing for latent heat thermal storage system. In addition, Building and Energy Management System and other management systems are adopted to manage to control building energy consumption. Furthermore, the building is rated as S rank of Comprehensive Assessment System for Built Environmental Efficiency (CASBEE®) and achieved 7.6 scores of BEE which was possible of adopting the overall reduction in environmental burdens. We are planning to accumulate and analyze the data, which must be fundamental to achieve Net Zero Energy Building in the future.

Key Words: Efficiency Low CO2 emission office building, Geothermal heat source heat pump, Air source heat pump, Thermal storage, Net Zero Energy Building,

1 INTRODUCTION

Obayashi Corporation opened Technical Research Institute in 1965. Previous research office was constructed in 1982 which adopted 98 technologies and then 410MJ/ (m2·year) energy consumption volume as the most energy consumption building in the world around that time. Previous research office and its laboratory were packaged in one building and scattered by department on site. Now those officers are concentrated in the main building: Techno-Station located in the middle of the site, connecting each laboratory with covered passages. It was built to establish a new R&D base that creates new technologies through integrated research functions and intellectual exchange, apply and demonstrate own technologies, and disseminates them to our clients and the society.

The Main Building: Techno-Station is the core facility of the Technical Research Institute and has three main concepts; the most advanced research environment, the most advanced environment-friendliness and the most advanced safety and security. We have adopted a lot of technologies in order to identify a goal for Net Zero Energy Building. For example “Heat source system by souped-up Air-cool Heat pump Chilling Unit, that improved part-load efficiency”, “Hybrid heat pump system of geothermal and well-water heat”, “Heating, Ventilation, Air-Conditioning (HVAC) System by medium chilled water, that improved COP”, “Water thermal storage tank and medium chilled water latent heat thermal storage system, aim to electric load leveling by using midnight power”, “Sensible/latent heat separated air-conditioning system”.

This project has obtained CASBEE S rank and BEE 7.6.

Picture 1 Building appearance

Picture 2 Workplace

2 BUILDING OUTLINE

2.1 Architectural Planning Outline

Location : 4-640 Shimo-kiyoto
Kiyose-city, Tokyo
Client : Obayashi Corporation
Designer's supervision : Obayashi Corporation
architect's office
District : Semi-industrial ,
Semi-fire proof area,
Site area : 69,401.30 m^2
Building area : 3,370.51 m^2
Total floor area : 5,535.38 m^2
Structure : Steel frame
(Super-active base isolation system)
Number of stories : +3, +1 penthouse
Principal use : Laboratory(Office)
General constructor : Obayashi Corporation
Construction period : November 2009
– September 2010

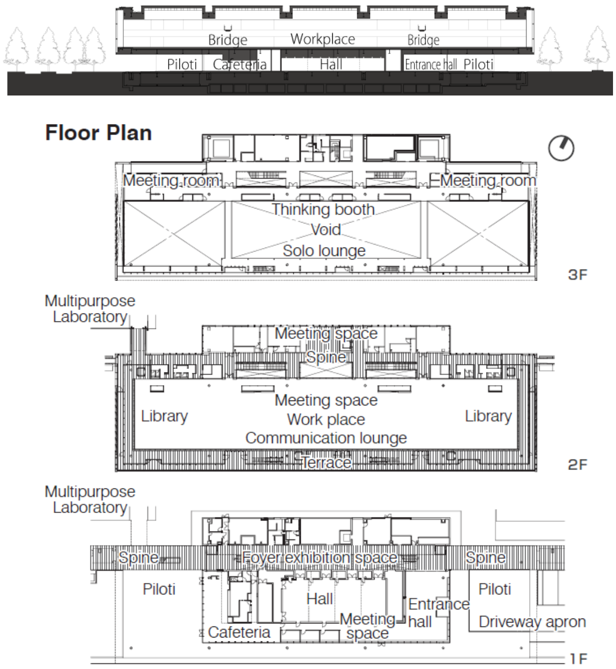

Figure 1 cross-sectional view, Floor plan

2.2 Facility Outline

【Electric System】
Incoming : 1 line, Indoor Cabinet,
1φ 300 kVA, 3φ 750 kVA
Generator : Generator 1 of 50 kVA ,
CGS 2 of 25 kW
Solar Cell 150 kW,
Wind Power 2 of 1 kW
Battery : Lithium – ion Battery 10 kWh
BAS : BEMS using BACnet, LONworks
Access Control : RFID tag and Card,

Sensing System using RFID tag

【M&E outline】

Heat Source : Air-cool Heat pump Chilling Unit
(9 of 30HP incl. Heat Machine 1)
Well water combined Ground Coupled Heat Pump Chilling Unit
(2 of 30 HP)
Water thermal Storage tank 430 m^3 (6 ºC)
Latent Heat Thermal Storage Tank 96 m^3 (15 ºC)

HVAC System : Latent and sensible heat separated air-conditioning system,
Task Ambient HVAC, Return air Desiccant OHU,
Personal Floor Diffusing、Task-Panel

【Sanitary System】

Water Source : City, Well Water for Irrigation and Rain Water for Flushing

2.3 Environment Friendliness

S rank of CASBEE and achieved 7.6 scores of BEE
36 % reduction in PAL value.
42 % reduction in ERR value, an integration of CEC values

3 TECHINOLOGIES FOR CO2 REDUCTION AND ENERGY CONSUMPTION

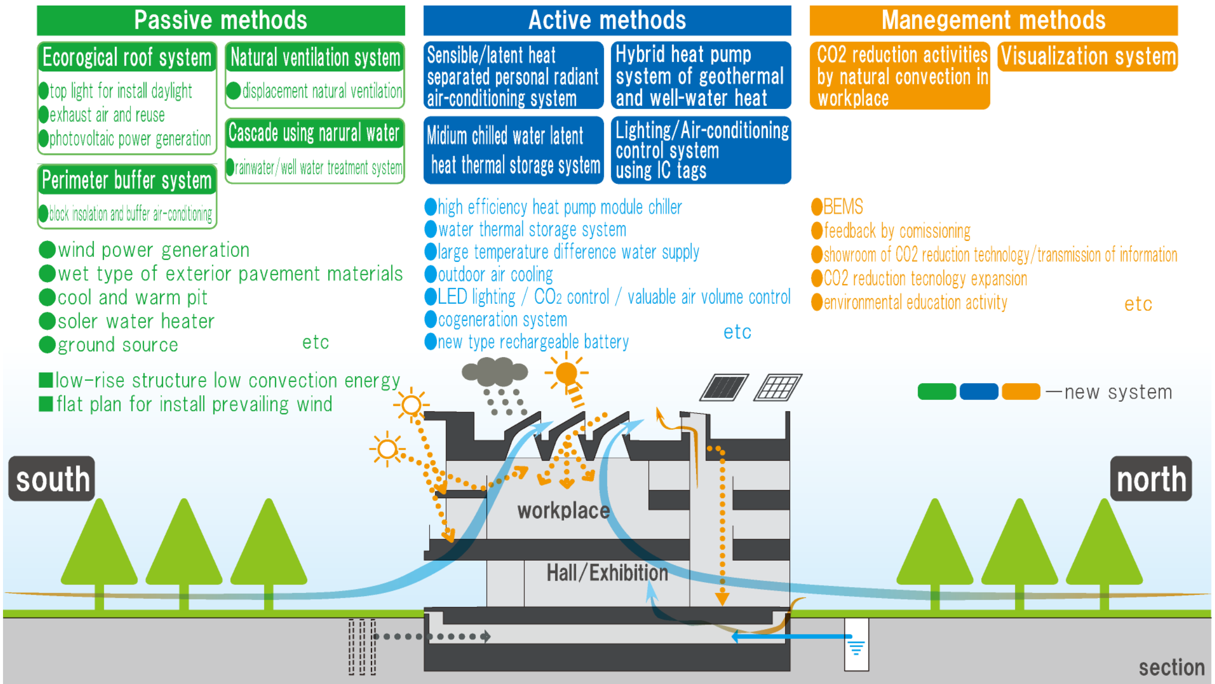

Figure 2 Map of Technologies for CO2 Reduction

We have aimed to achieve the substantial reduction of environmental load without reducing workplace productivity. Three systems are integrated to achieve the highest reduction rate of 55 percent of average kg-CO2/m2 emission in Tokyo. They are

(1) Passive system; Integrated passive natural energy use
(2) Active system; An active mechanical/ electrical system
(3) Management system; A new management system for support reduction CO2 and energy consumption in operation phase

These three systems allowed for 55 percent reduction in CO2 emissions during operation, that is the highest level in Japan.

Furthermore, we expect that the Techno-Station will be the Japan's first achievement of carbon neutral as a research facility, through purchase of carbon credits equivalent to 45%. The building was rated as S rank of CASBEE® and achieved 7.6 scores of BEE because of the overall reduction in environmental burdens.

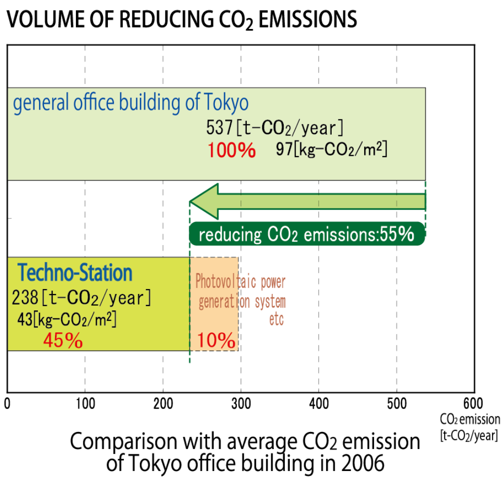

Figure 3 Estimation of CO2 reduction effect

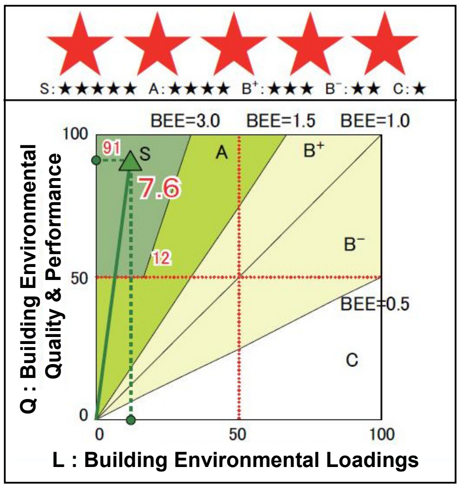

Figure 4 Certification of CO2 reduction effect（CASBEE v3.3）

3.1 Reduction Of CO2 By Architectural Planning

3.1.1 Ecological roof system

Techno-station is constructed as low-rise building with the top lights installed on a wide upper portion of the room to make full use of the characteristics of low-rise building. A system that takes in a skylight and eliminates the need of lighting during daytime promote energy consumption in office. Solar panels installed on the entire of the slanted roof generate power with high efficiently. The top lights are opened/closed remotely for natural ventilation.

3.1.2 Perimeter buffer system

Large eaves, vertical glass fins with ceramic print and low-e glasses are installed for the reduction of air-conditioning load while allowing for open space structure. In addition to the use of exterior that reduce energy requirement for air conditioning, this perimeter buffer zone is intended to control impact of air-conditioning loads on the inside working zone, and consists of aisles, meeting space and lounges that are located around the working area and adjacent to an outdoor deck. Floor mounted fun-coil unit is erected a barrier between interior and perimeter, Thereby minimize the thermal effect of perimeter zone.

This system owes work space to decreasing glare light. Automatic control blinds and inner light shelf bring the brightness.

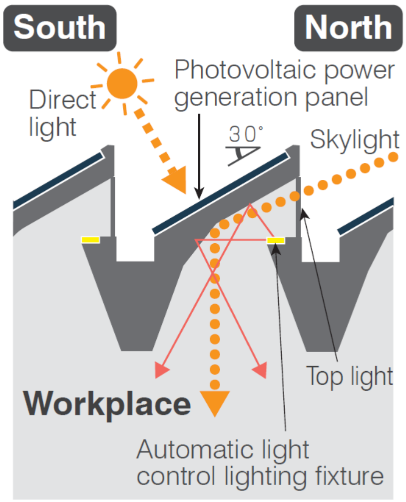

Figure 5 Ecological roof system

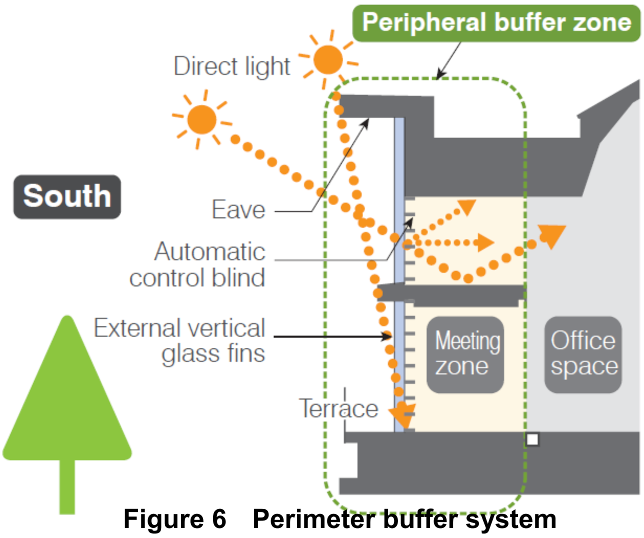

Figure 6 Perimeter buffer system

3.2 CO2 Reduction Planning Of Heat Sources

3.2.1 Heat source system

Heat sources have a combination of air-cool heat pump chilling unit and well water combined ground coupled heat pump chilling unit. Water thermal storage and latent heat thermal storage are adopted, and for that reason the electric load is leveled by using midnight power. Waste heat from micro-cogeneration is used by regeneration of desiccant roter in summer, and warm water in winter.

Heat source system is composed by the 5 temperature zone; cold water (6 ºC), medium chilled water (approximately 13 ºC to 19 ºC), warm water (46 ºC), medium heated warm water(approximately 40 ºC ~ 44 ºC), hot water for regeneration (85 ºC)}.

CO2 reduction system of heat source, we focused on follow technique. Part-load operation efficiency of air-cool heat pump, water-cooled heat pump system using natural energy such as geothermal heat and well water, HVAC system with medium chilled water for the improvement of the COP, Water thermal storage and latent heat thermal storage as a transition to lower CO2 emissions midnight power, and sensible/latent heat separated air-conditioning system.

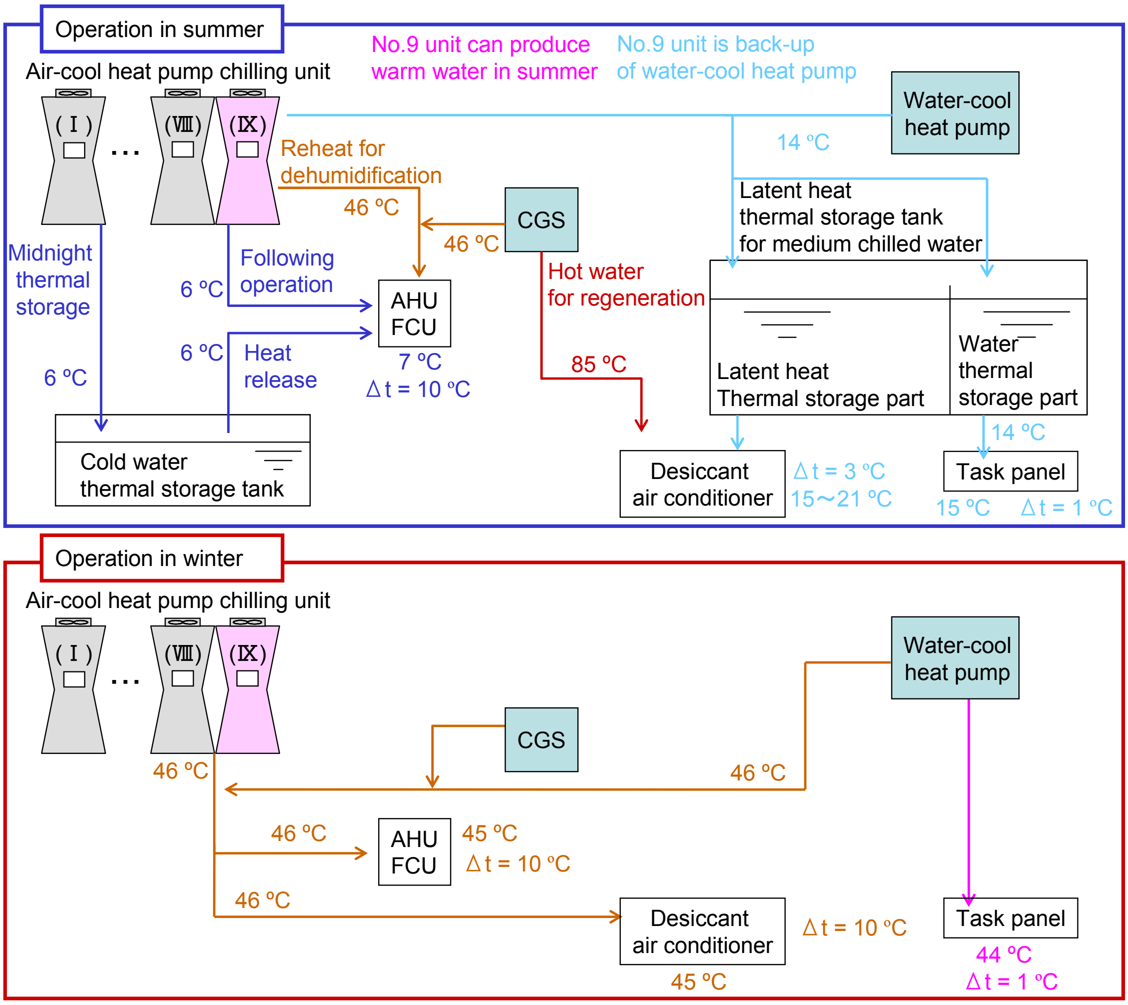

Figure 7 Outline of heat source system

3.2.2 Heat source system which is focusing on part-load operation efficiency of the air-cool heat pump chilling unit

Air-cool heat pump chilling unit operation is controlled according to the load by three. In general, if the unit operated full load and secondary load was excessive, unit is launched one after another. The large area of heat exchanger and evapolator improve efficiency due to the structure of the air-cool heat pump. COP of the machine while running two compressors is better than running three compressors. This effect increases the heat source efficiency about 10 %.

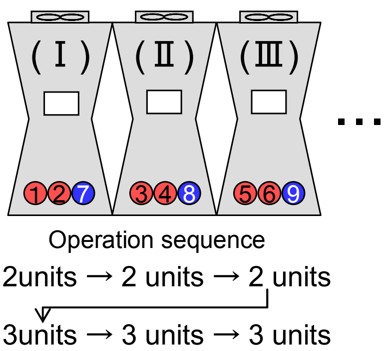

Figure 8 Cycle of air-cool heat pump system in part load operation

Table 1 The part-load operation efficiency of air heat pump(T inc)

Cold water temperature [ºC]	Operating capacity [%]	Elements	Outdoor temperature [ºC] 25	30	35	40	43
6	100 (Three compressor operating)	Cooling capacity (kW)	92.3	87.8	83.0	77.6	74.1
		Electric requirment (kW)	19.3	21.3	23.5	26.0	27.7
		COP (-)	4.78	4.12	3.53	2.98	2.68
	67 (Two compressor operating)	Cooling capacity (kW)	64.2	60.9	57.2	53.9	51.6
		Electric requirment (kW)	12.2	13.4	14.8	16.4	17.4
		COP (-)	5.26	4.54	3.86	3.29	2.97

3.2.3 Hybrid heat pump system of geothermal and well-water heat

The annual temuperature of the soil and outdoor level is almost the same, for example they are 17 degrees in Tokyo. Compared to outdoor temperature, soil temperature is cool in summer and warm in winter. This ground thermal energy is used by ground source heat pump system using boreholes (10 of 100 m) with a double U-tube.

In addition, there's a well in the site, and we can use the water from it under 20 m^3/day. Well water is used as heat source for the heat pump to improve the efficiency in heat source operation. The well water that is used for a heat exchanger is reused for flushing toilets and watering around the building (cascading).

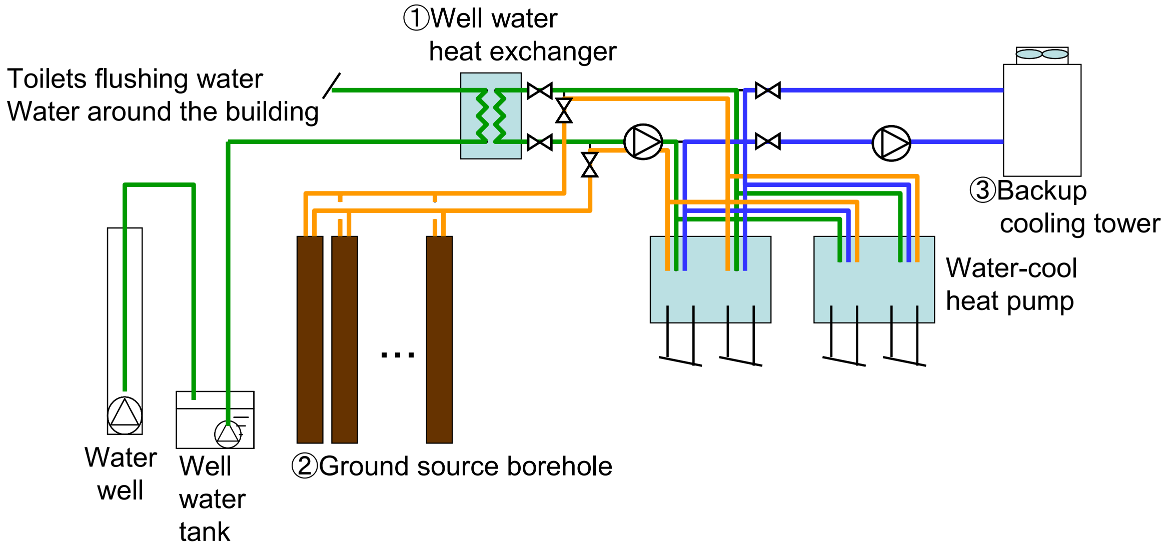

Figure 9 Geothermal heat pump system

3.2.4 HVAC system aim to improved COP by using middle chilled water

The air conditioning system in workspace is adopted sensible/latent heat separation air conditioning system.

For the air conditioning of the ambient area, a return-air desiccant air-conditioner treats latent heat of the outside air properly. The way of dehumidification technique is chemical dehumidification. For the air conditioning of the task area, a personal radiational and natural convectional panel is installed for sensible heat removal. Medium chilled water supply temperature to desiccant air conditioning system is 13 to 19 degrees, and medium chilled water supply temperature to the “task-panel” is also about 15 degrees. Therefore, the temperature of the chilled water can be higher than normal temperature about 6 to 7 degrees. Thus, that can be expected to improve the COP of heat pump.

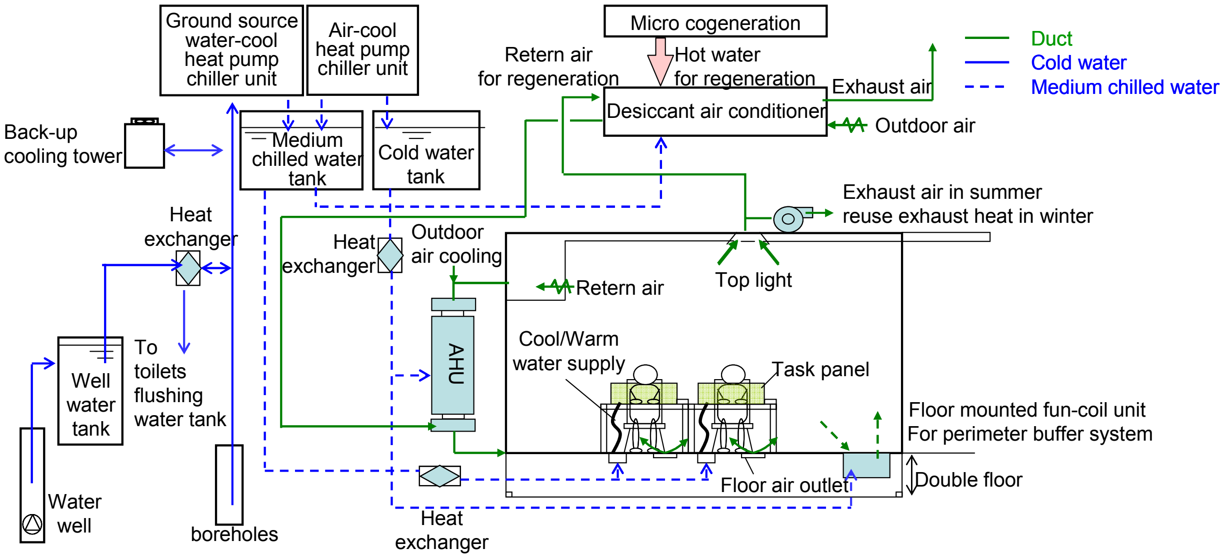

Figure 10 Outline of integrated medium chilled water air-conditioning system

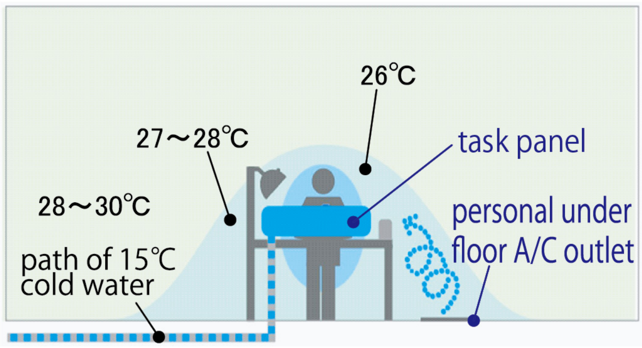

Figure 11 Outline of Task-ambient air-conditioning system in summer

Picture 3 Example of installation "Task panel"

3.2.5 Medium chilled water latent heat storage system

In order to achieve CO2 reduction system by using midnight power, latent heat storage material is necessary, which has non-traditional temperature zone. One of them is the paraffin-based latent heat storage material. The latent heat storage material that melts/freezes at a temperature of 15 ºC to 16 ºC is used for HVAC system.

Figure 13 shows the results of mock-up testing system. This testing system is a portion of actually adopted latent heat storage tank. Outlet temperature remains constant during thermal storage in freezing temperature of latent heat storage material, however it doesn't remains constant during thermal release. The melting is occurring in parts of the thermal storage material incousistentry due to differences in the thermal conductivity of liquid and solid. These characteristics are corrected by two-way valve controlling the secondary side.

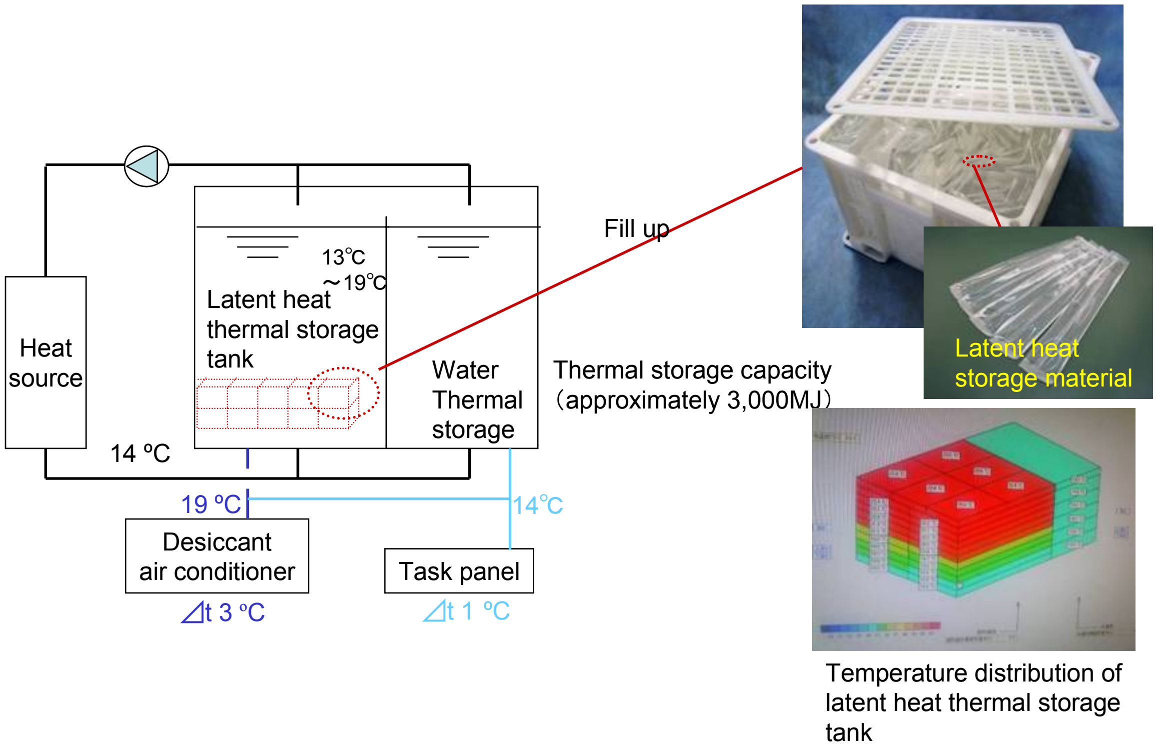

Figure 12 Medium chilled water latent heat storage system

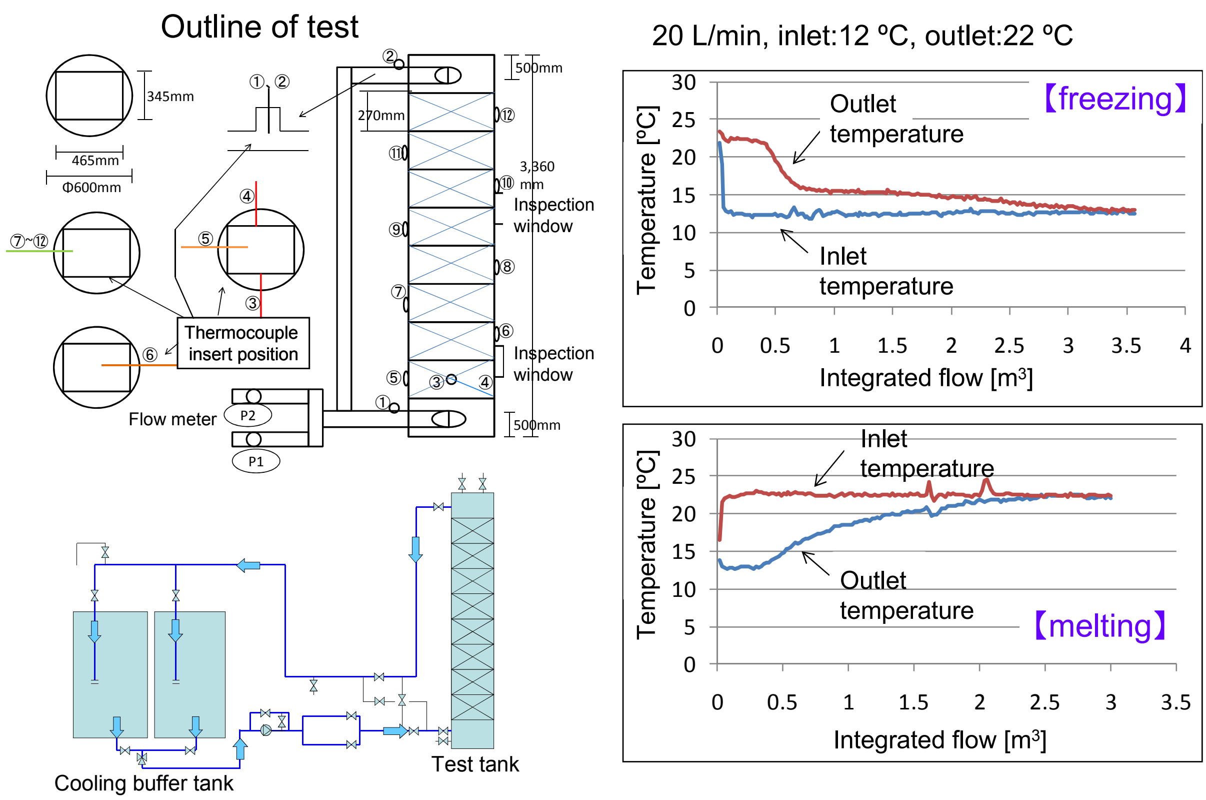

Figure 13 Mock-up experiments of latent heat storage system

4 CONCLUSIONS

We verified with simulation that our challenging office building (laboratory) project, we have been developing for CO_2 emission saving, achieves 55% CO_2 emission reduction compared to conventional office buildings in Japan. Three systems are integrated to achieve the highest reduction rate of 55% of average kg-CO_2/m2 emission in Tokyo.In order to achieve such a drastic reduction, we are adopting passive, active, and management methods of utilizing natural energy. We adopted following technique as an active system. Hybrid heat pump system of geothermal and well-water heat and air-cool heat pump system. The COP rises by producing medium chilled water about 13 to 19 degrees. The storage tank became reduced in size using latent heat storage material. Latent heat storage tank system is adopted in this building due to the experimental evaluation about behavior of the melting/freezing. We developed a new task-ambient air conditioning system and sensible/latent heat separated air conditioning system as suitable for medium chilled water air conditioning system.

These systems allowed for 55 % reduction in CO_2 emissions during operation, the highest level in Japan. In addition, purchase of carbon credit equivalent to 45 %, this building will achievement of carbon neutral.

Furthermore, the building was rated as S rank of CASBEE and achieved 7.6 scores of BEE because of the overall reduction in environmental burdens.

This building has completed in November 2010 and then begins operation. We are planning to accumulate and analyze the data.

The authors realized CO_2 reduction building design from collaborative research, so would like to appreciate the peoples as follows.

- Experimental evaluation of task ambient air-conditioning system with radiation and convection
  Tatsuo NOBE, Kogakuin University
- Creation of "task-panel" with radiation and convection
  Yoshihisa Hirayama, PS Company Ltd.
- Experimental evaluation of Latent heat storage tank system
  Motoi Yamaha, Chubu University
- Creation of latent heat storage material and storage containers
  Tadafumi Yokota, JX Nippon Oil & Energy Corp.

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