The Cutting-edge Environmental Design and Performance Verification at HD Hyundai Global R&D Center (GRC)

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Abstract. This is an example of a large-scale office building built by HD Hyundai in Seongnam city, South Korea. The young population in South Korea is expected to decline, and there is a need for an attractive work environment to secure human resources (Wellness). Energy consumption per person is increasing (Energy). There was a need to consolidate 17 companies dispersed across various regions (Communication). The concept of "Geometric Design" is shown, which creates various synergistic effects by integrated design concept of CUBE/VOID/GRID. This report explains the cutting-edge environmentally friendly design through integration of architecture and building services, and its actual performance in regard to IEQ and energy savings proven by post completion commissioning. The purpose is to spread the message not only in South Korea but also widely by showing best practices by fact data.

1 Introduction

The target building is the HD Hyundai Global R&D Center (GRC) located in Seongnam, South Korea. (Figure 1) It is a large-scale office building with a total floor area of approximately 180,000 m^2, 20 floors above ground and 5 floors underground, where 17 affiliated companies, that were previously dispersed in various places, work together. This report explains the cutting-edge environmentally friendly design through integration of architecture and building services, and its actual performance in regard to IEQ and energy savings proven by post completion commissioning. The purpose is to spread the message not only in South Korea but also widely by showing best practices that lead to carbon neutrality and SDGs by fact data.

2 Overview: Building and Environmental planning

2.1 Concept and Building design

The overall concept of the plan is to create opportunities for communication between companies and individuals (Communication), create a comfortable space that supports various activities (Wellness), and be considerate of the global environment (Energy). Figure 1 shows the façade view of the building. Three clear design concepts were proposed to resolve these issues: CUBE/ GRID/VOID. The building shape is a 90m square CUBE shape. The exterior is made of a GRID-shaped steel frame that serves as a structural frame but also blocks sunlight. Figures 2, 3 and 4 show the VOID view, the typical floor plan, and the building section. A large-scale VOID is placed in the center of the building, connected to multiple office floors, and contributes to the creation of communication and environmental adjustment.

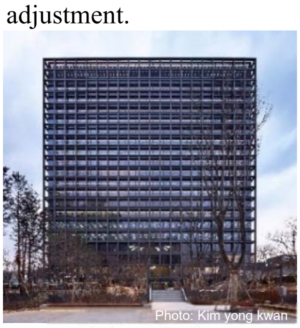

Figure 1. Façade view

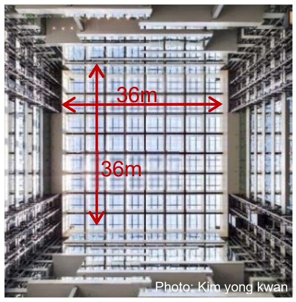

Figure 2. VOID view

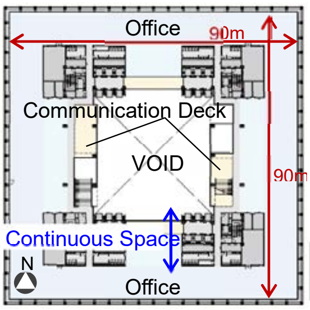

Figure 3. Typical floor plan

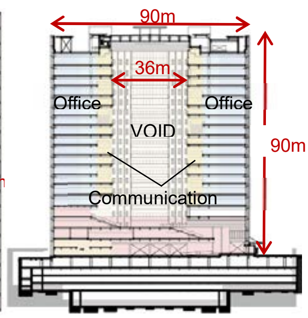

Figure 4. Building section

The GRID-shaped ceiling is equipped with radiant heating/cooling system, allowing the building to flexibly respond to the changing external environment, from humid summers to harsh winters. Figures 5 and 6 show the typical office interior and the psychrometric chart of outdoor air.

Figure 5. Typical office space

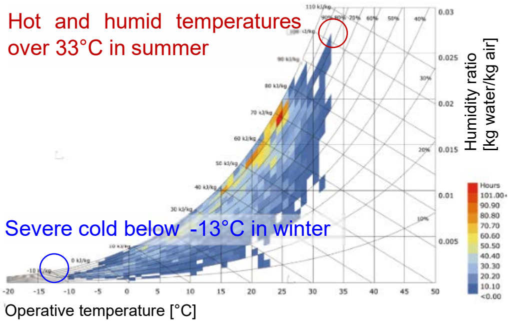

Figure 6. Psychrometric chart of outdoor air

The main innovation point of this project is the implementation of a "Geometric Design". The MEP systems are integrated functionally with the geometric architectural design of CUBE/VOID/GRID as an integrated environmental control system. Various synergistic effects are produced, such as improved comfort and energy savings. Figure 7 shows the diverse values generated by the design.

2.2 Radiant heating/cooling, and facade systems that adapt to the external environment

The facade and radiant heating/cooling system work together to adapt to the fluctuating external climate, creating a comfortable thermal environment for the office space. Figure 8 shows the diagram for the integrated facade and radiant heating/cooling system. The heat load through the outer skin is reduced by solar shading from the outer frame and the high thermal performance triple glazing (1.06W/m^{2}K).

Chilled beams on the perimeter and radiant heating/cooling panels on the interior create a comfortable environment with a calm draft while reducing air conveying energy. In the summer, the ceiling surface is cooled to 21°C, lower than the air temperature of the room (26°C) and the skin temperature of occupants (35°C). The radiation makes the room and human body cooler. This adjustable thermal environment using radiation was inspired by the Korean traditional "Ondol" (underfloor heating system).

The maximum cooling capacity per radiant panel area is 75W/m^2, and the maximum cooling capacity per floor area is approximately 52W/m^2 (installation rate 70%). The radiant heating/cooling panels and chilled beams use the same water piping to streamline installation costs. In winter, when the perimeter is under heating load and the interior is under cooling load, the chilled beam operates for heating, and the interior can be cooled by outside air cooling from the Dedicated Outdoor Air System (DOAS).

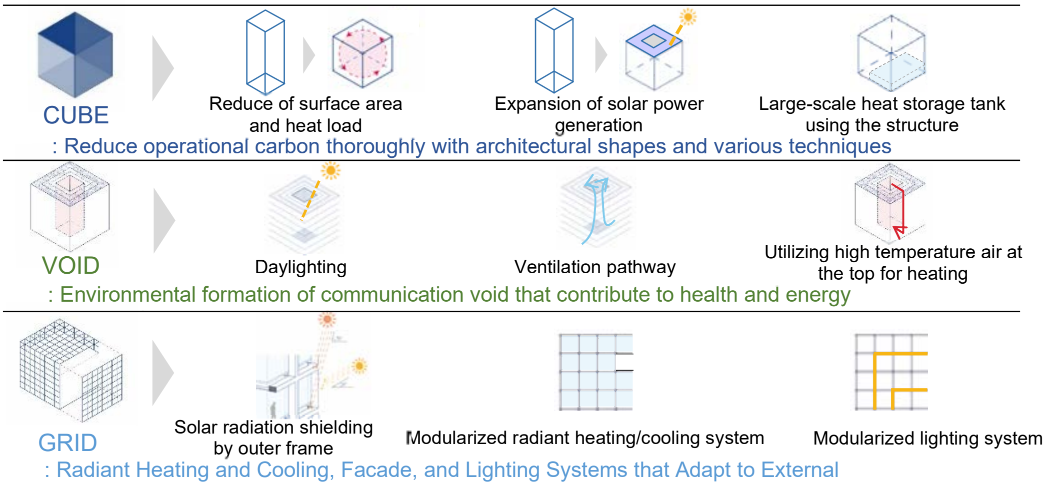

Figure 7. Diverse values generated by "Geometric Design"

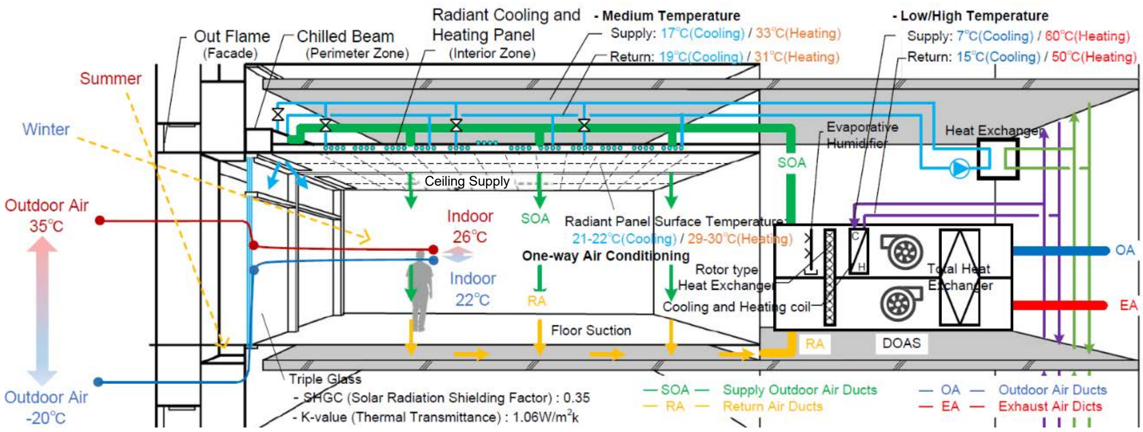

Figure 8. Integrated facade and radiant heating/cooling system

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2.3 Medium and Low temperature hybrid heat source system

Indoor sensible heat load is managed by radiant heating/cooling and a chilled beam (medium temperature chilled water 17°C) system, and outdoor air treatment including latent heat treatment is treated by a DOAS (low temperature chilled water 7°C) system. Figure 9 shows the diagram for latent/sensible heat separation air-conditioning system. The system concept is to separate the treatment of latent and sensible load.

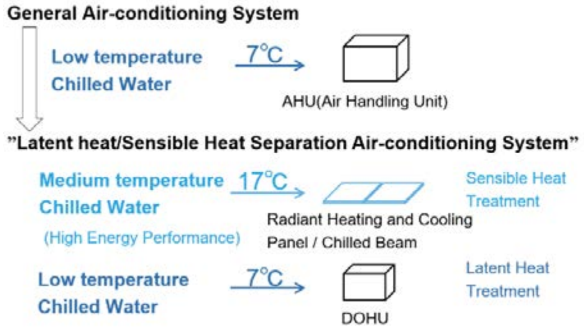


Figure 9. Latent/Sensible heat separation air-conditioning system

Figure 10 shows the heat source system diagram. Using medium temperature chilled water improves the efficiency of the centrifugal chiller (COP5.6 → 7.3). Despite the humid climate and the open office conditions connected to the VOID, proper dehumidification, air balance adjustment, and management of the chilled water temperature to the radiant panels prevents condensation on the panels. In the low temperature chilled water system, a large-scale heat storage tank (7,500 m^3) was installed to store heat late at night and use it during the day. It reduces power demand significantly. The amount of heat storage was 153,000 MJ/day (the actual transfer rate: 78%). The hot water system uses heat received from district heating.

3 CUBE: Reduce operational carbon with architectural shapes and various techniques

3.1 Reduce building surface area and heat load

For the same building volume, the surface area becomes smaller with a CUBE shape. Figure 11 shows the diagram of reducing surface area. The smaller surface area reduces the AC load caused by the temperature difference between the indoors and the outdoors through the exterior walls (12% reduction).

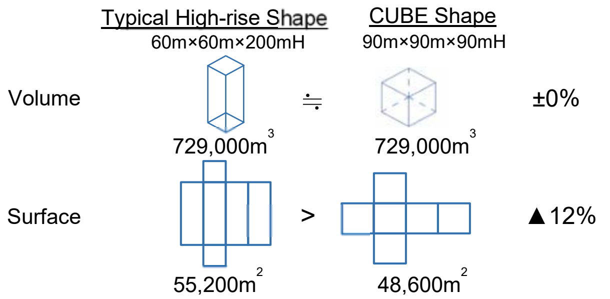


Figure 11. Reducing surface area

3.2 Expansion of roof top area and solar power generation

The roof area of the CUBE is also increased compared with a typical high-rise building, and more solar panels can be installed on the rooftop. Figure 12 shows the expansion of photovoltaic power generation. the Photovoltaic power generation is 481.5 kWp. Annual power generation is assumed to be 2-3% of the total energy consumption.

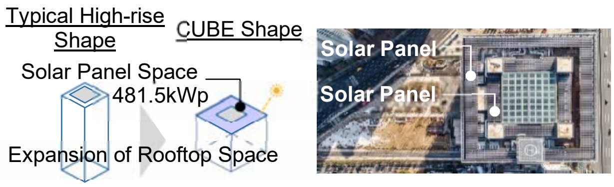


Figure 12. Expansion of photovoltaic power generation Space

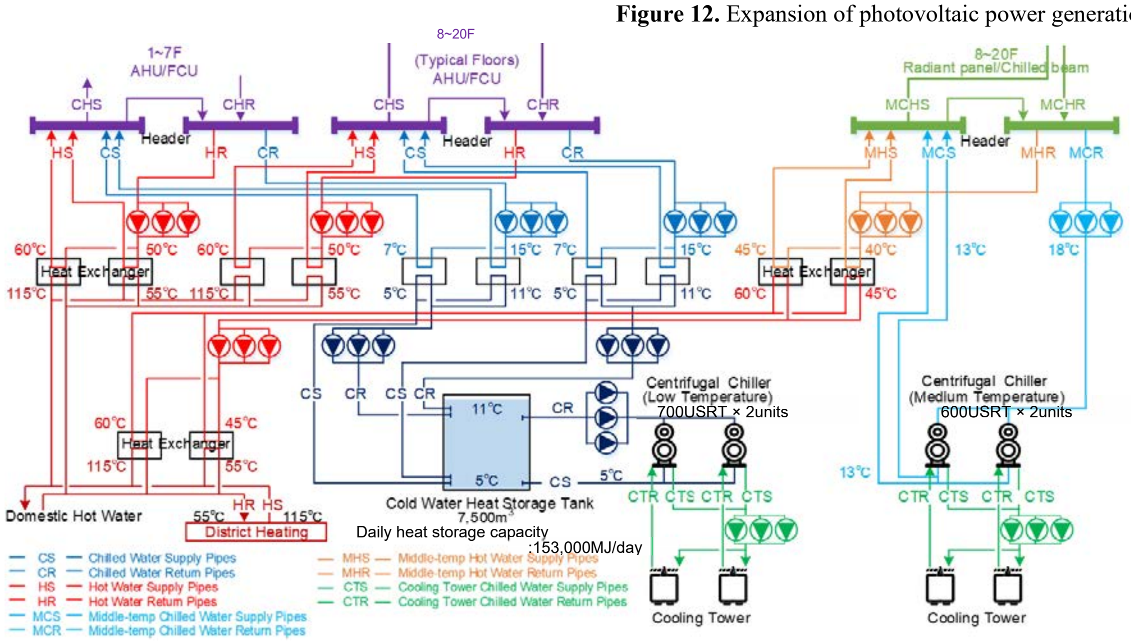


Figure 10. Heat source system diagram

4 VOID: Environmental Formation of Communication Void that Contribute to Health and Energy Conservation

4.1 Leveraging the thermal environment for energy saving

Figure 13 shows the diagram for heat removal and utilization from VOID space. When the VOID temperature at the top is over 35°C, the ventilation windows will open and exhaust the air to remove heat naturally. Figure 14 shows the heat distribution image in the VOID top in summer. Since the temperature can be high on the upper floors, the VOID space is separated from the office with glass on the 16th to 20th floors to protect the thermal environment in the office space. In winter, the hot air of the top is used for heating the bottom area.

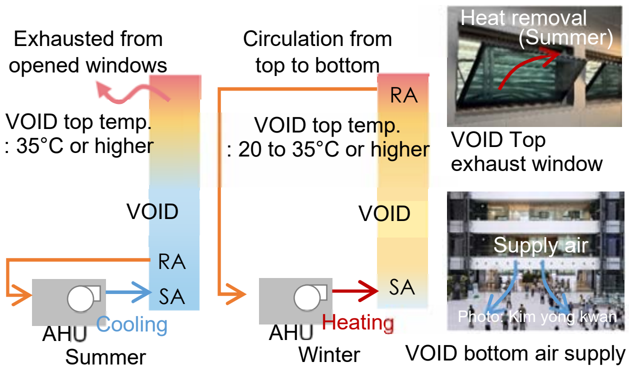


Figure 13. Heat removal and utilization from VOID space

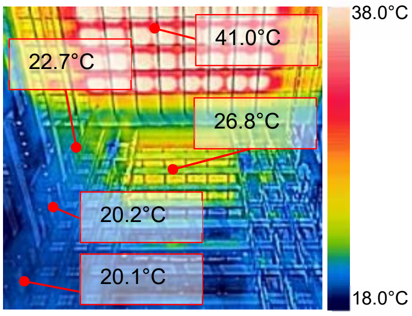


Figure 14. Heat distribution image in VOID top (summer)

4.2 Valuable light environment by daylighting

The creation of a comfortable and healthy light environment through daylighting in the VOID has been verified through actual measurements. Figure 15 shows the appearance of daylighting through the VOID. The illuminance of the communication deck is not greatly attenuated by the depth, and stable brightness is ensured on each floor. Figure 16 shows the measured spectral distribution. The light on the window-side area and the communication deck has a spectrum equivalent to natural light wave shape, and a high-quality light environment has been achieved.

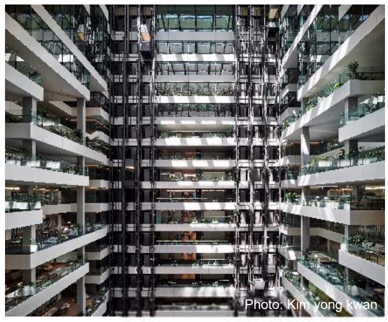


Figure 15. Daylighting through the VOID

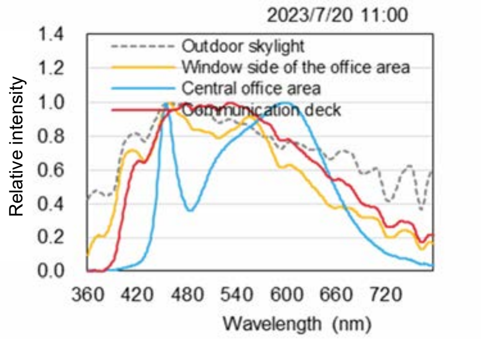


Figure 16. Spectral distribution

It is effective for the optimization of circadian rhythm by receiving sufficient "Equivalent Melanopic Illuminance (EML)" in the daytime. Figure 17 shows the measured EML. The measured EML was sufficient at over 275 EML at the communication deck and window-side area [1]. Since the occupants can access high EML areas easily, they can select the best place for working according to the desired scene.

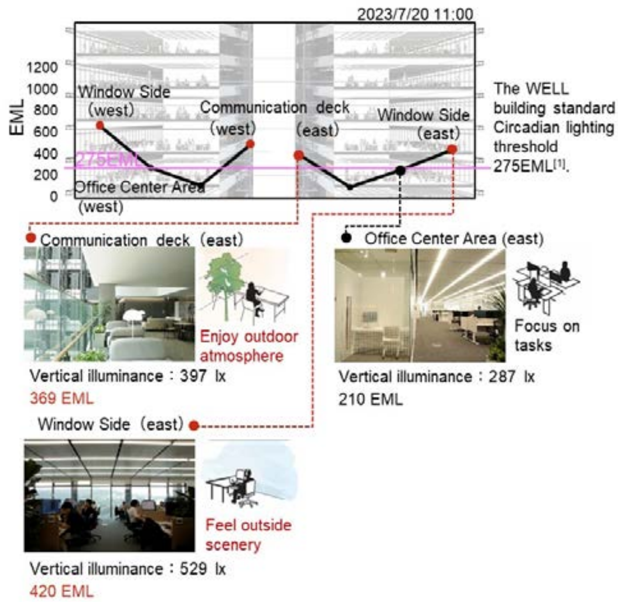


Figure 17. Equivalent melanopic illuminance (EML): A unit used in 2014 to express the amount of light. The sensitivity of new photoreceptors (endogenous light-sensitive retinal neural node cells, ipRGC) discovered in 2002 can be considered, and the brightness that affects internal rhythm (circadian rhythm) can be quantitatively captured.

4.3 Comfortable sound environment for communication

A field survey was conducted, and the measured noise levels were 45-50 dB in office space, and 51-56 dB on the communication deck along the VOID. Figure 18 shows the measured noise level [2]. It was confirmed that a sound environment suitable for each application such as a normal office area and a comfortable communication deck could be realized.

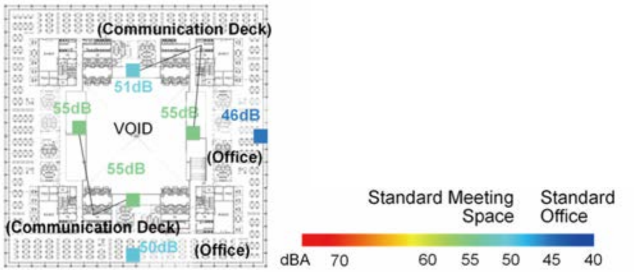
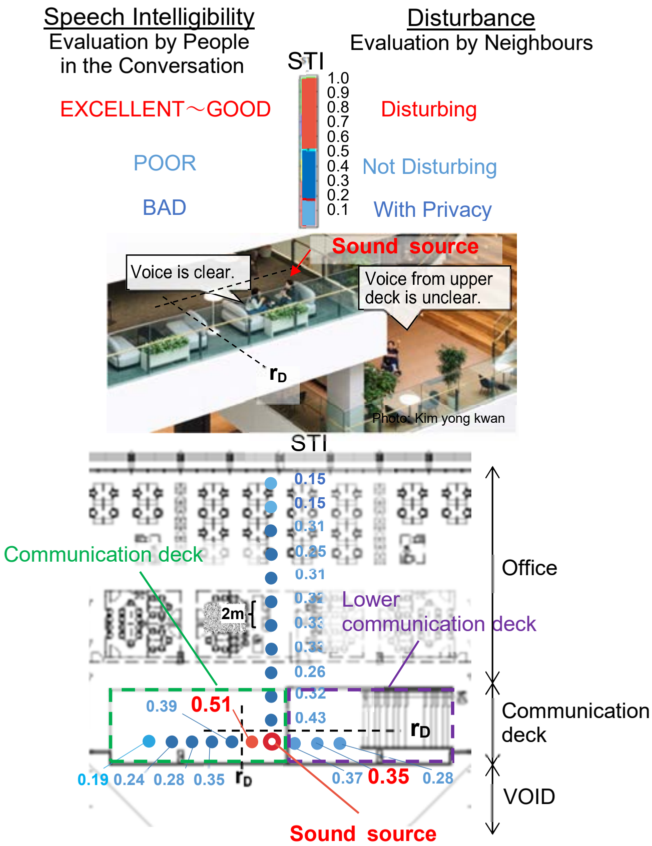


Figure 18. Noise level

By measuring the distribution of "STI (Speech Transmission Index)", the intelligibility and interference of conversations on the communication deck were verified. Figure 19 shows the measured STI. The STI was 0.51 near the sound source, indicating high conversation intelligibility, while on the deck one floor below, interference was low at 0.35. It was confirmed that the sound environment allowed clear communication without affecting the surrounding environment.



※rD **(Distraction distance)**: Shortest distance from the sound source where the STI is lower than 0.50 distance (ISO 3382-3) [3]

Figure 19. STI (Speech Transmission Index): Quantity describing the transmission quality of speech from speaker to listener

5 GRID: Façade and Ceiling GRID that adapt to external and internal conditions

5.1 Solar radiation shielding by GRID outer frame

The GRID-shaped outer frame blocks solar radiation from high altitudes. Figure 20 shows the southward solar radiation heat. The reduction of solar radiation in the summer and mid-term (cooling season) is large, exceeding the reduction in the winter season (heating season). It was confirmed energy conservation will be achieved throughout the year (64% reduction southward).

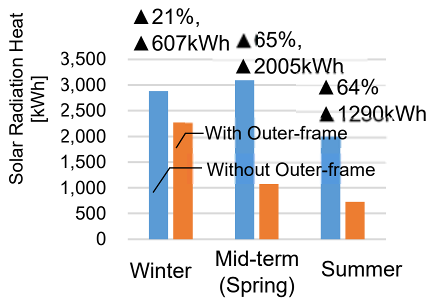
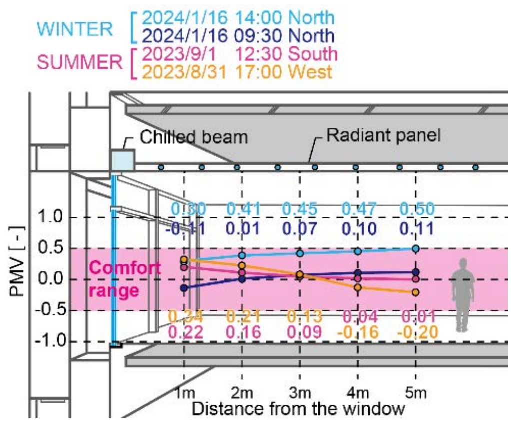


Figure 20. Southward solar radiation heat

5.2 Thermal environment

The thermal environment is compliant with ASHRAE 55_2017 [4]. Post occupancy measurements have proved that PMV is within a comfortable range of ±0.5 in Summer and Winter. Figure 21 shows the measured PMV in office space. It was also confirmed that the vertical temperature differences were within 3°C at every hour at the 0.1~1.7 m level and satisfied comfort requirements. During the measurement period, the radiant heating/cooling panels operated in cooling mode during the summer and the ceiling surface temperature was approximately 20°C (4°C below room temperature). In the winter, the panels were turned off and the surface temperature was similar to the room air temperature, ranging from 22°C to 24°C.



*Measurements were conducted using a PMV sensor.
- Measurement height: 1.1m
- Clothing insulation: 0.7clo (Summer), 1.2clo (Winter)
- Metabolic rate: 1.0 met

Figure 21. Measured PMV

5.3 Air quality environment

The ventilation system was designed based on ASHRAE 62.1_2013 [5], with sufficient fresh air introduced by the DOAS. The ventilation rate for the office is 6.0 m3/hr-m^2 (30 m^3/h per person), and it can be increased up to 9.0 m^3/hr-m^2 when cooling with outside air in the middle season. Figure 22 shows the air flow for "One-way air conditioning". Using the distribution concept, the fresh air delivered from the ceiling can be exhausted to the raised floor plenum, while removing the droplets and particles around occupants.

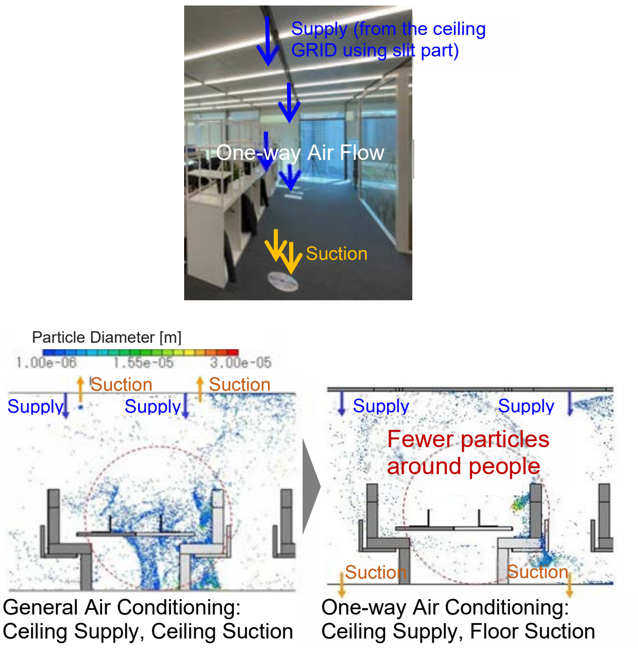


Figure 22. Air flow for "One-way air conditioning"

5.4 Enhanced feeling of human sense of brightness through lighting design

Radiant heating/cooling panels were placed on a 0.6 m×0.6 m ceiling GRID. Almost all radiation panels could be applied using the same size through the modularization. Figure 23 shows the Lighting plan enhancing the feeling of brightness. LED lighting fixtures with DC supply are arranged continuously in a line between the panels. Continuous passage through the space increases the amount of light in the field of view and enhances the feeling of human sense of brightness.

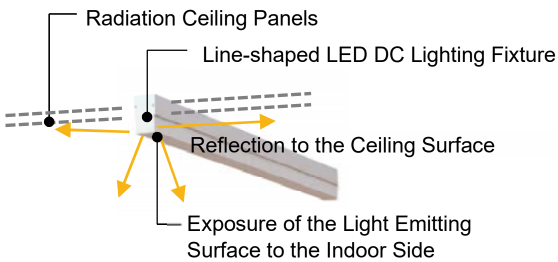


Figure 23. Lighting plan that enhances the feeling of brightness

The actual light environment was evaluated using "Feu", an index related to people's sense of brightness [6]. Figure 24 shows the Brightness distribution and Feu value. In Feu, the perceived brightness by the human eye, an evaluation of "18.6 (bright)" was obtained. At present, the current illuminance is 600 lx on a desk and the brightness of the space is sufficient. There is a possibility that it can be reduced to 400 lx while maintaining the brightness of the space in the future, and further energy savings can be realized. Approximately 48% reduction in lighting energy consumption can be expected compared to general office lighting.

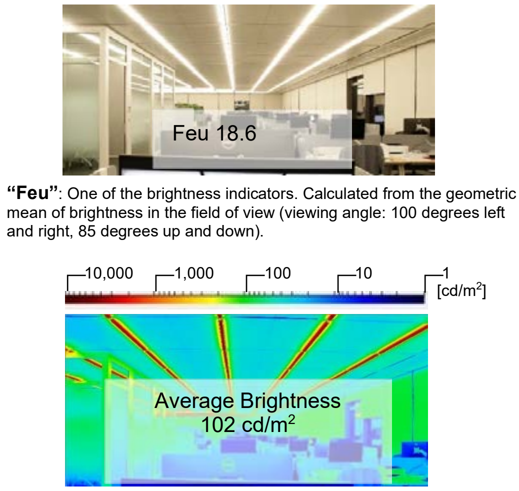


Figure 24. Brightness distribution and Feu value

6 Optimization: Equipment operation and energy reduction performance

6.1 Operation and Maintainance

Due to the application of various advanced technologies in this building, the architects and MEP system designers are involved in post occupant commissioning process in collaboration with facility managers for the optimization of system operation. Table 1 shows the examples of optimization of system operation. These items were derived through the verification of actural operational conditions and equivalent to 7% energy reduction (-7kWh/m^{2}yr.), and the adjustments are being made to feed back into actual operations.

As an example of operational improvements, there were the adjustments of the water supply temperature for radiant heating/cooling system. This equipment was unfamiliar to the facility managers, who had no prior operational experience. Initially, the water supply temperature for cooling was set to 15°C during the summer to enhance cooling efficiency by the facility manager. Consequently, the condensation prevention control was activated, causing the radiant cooling operation to stop, which led to a rise in room temperature. The design intent was to ensure sufficient cooling capacity with a 17°C water supply, so the operation was changed to a 17°C setting after communicating about the intent of this system. This allowed stable radiant cooling operation while preventing condensation on the ceiling panels.

Additionally, the system controlling the exhaust and supply fans based on CO concentration in the parking area, was not utilized due to a lack of understanding by the facility operators. After explaining the purpose and benefits for the control system, it was implemented, resulting in significant energy savings.
It was considered essential for designers to be involved and effectively communicate their intentions, even in overseas operations.

6.2 Energy performance

The energy performance of the entire building was simulated based on ASHRAE 90.1-2016. Figure 25 shows the energy-saving effect based on simulation and actual performance. The entire building is modeled using IESVE (IES Virtual Environment) software [7]. The proposed building (106 kWh/m^{2}yr.) was expected to be reduced by 29% compared to the ASHRAE 90.1 baseline (148 kWh/m^{2}yr.) [8].
The actual energy consumption of the entire building was 92 kWh/m^{2}yr., including power outlets, (Feb. 2023-Jan. 2024) is a 45% reduction compared to the average building in South Korea (167 kWh/m^{2}yr.) [9]. The reduction rate is higher than that by the energy simulation.
When converted to CO_2 emissions, this corresponds to a reduction of -17,400 t-CO_2/yr. (-99 kg/CO2/m^{2}yr.) . These reductions were calculated based on South Korea's domestic emission coefficient of 0.4781 t-CO_2/MWh, 2022. The result shows that the various CO_{2vv} reduction efforts in large-scale offices greatly contributed to the global environment.

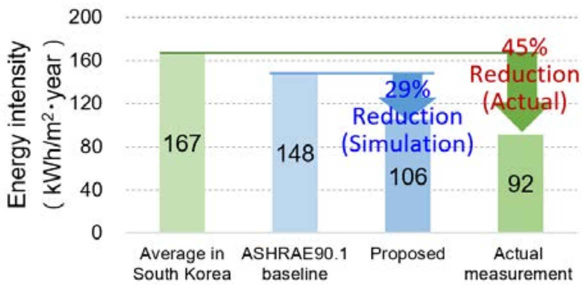


Figure 25. Energy-saving effect

7 Conclusion

The approach of Geometric Design are described, which integrates the design concepts of CUBE/VOID/GRID and the cutting-edge environmental technologies to create various values, such as communication, wellness, and energy. The achievements include the realization of a comfortable indoor environment and significant energy savings. The implementation achievements and effect verification results demonstrated in this report are expected to be widely referenced in the future, not only in South Korea but also more broadly.

Table 1. Examples of optimization of system operation

Column heading	Energy-saving items	Energy-saving effect (kWh/yr.)
Heat source	1. Reduction of transport power by lowering the temperature of low-temperature heat sources	-130,000
	2. Variable flow rate control with secondary pump drive	-26,000
	3. Fully closing the secondary side bypass valve	-76,000
	4. Chiller condenser water temperature-lowering (Optimization of secondary temperature design temperature difference)	-76,000
Secondary side	5. Air conditioner airflow rate optimization	-44,000
	6. Supply/exhaust fan CO control of parking lot	-637,000
	7. Changing the lower limit of the inverter frequency for tertiary pump (Change of the minimum opening of the bypass valve)	-31,000
	8. Adjustments of supply water temperature for radiant cooling	-
Operation	9. Adjustments at room temperature	-
	10. Alleviation of illumination intensity of lighting	-117,000
	Total	-1,137,000 (-7kWh/m^{2}yr.)

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