Approachable ZEB (Zero Energy Building) (Part.2)
- ZEB for Everyone -

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Abstract. In addition to policy target in Japan (ZEB (Zero Energy Building) is scheduled for new buildings on the average by 2030), the efforts to decarbonize corporate activities are accelerated and private needs of ZEB is growing after Paris Agreement. On the other hand, most of owners tend to be careful to invest in ZEB due to high cost to realize ZEB in general. With above background, we’re promoting ZEBs at the same cost as general buildings and have designed and built “Office-TS and Office-AI” as model projects of ZEB to meet such private needs of ZEB. Based on our policy to provide ZEB with a lot of owners by reasonable cost, economically ZEBs are realized with design of both comfort and ecology by optimum combination of general technologies with excellent cost–performance. Currently in general, most of other existing ZEBs are the demonstration projects implemented by Design or Construction Companies, therefore, it is very advanced examples to provide ZEBs with general private clients. “Approachable ZEB” which can be realized economically will contribute sustainable corporate activities of many owners and sustainable social foundation. In below actual two “Approachable ZEB” projects are introduce; Office-TS has set an energy-saving target of <Nearly ZEB > (more than 75% energy saving) and Office-AI <ZEB Ready> (more than 50% energy saving). Both are realized with the general technologies also with the same cost level as other general non-ZEB projects.

1. Office-TS

1.0 First project and client overview
This client is the manufacturing industry of the automobile interior parts, mainly car seats. It is the worldwide company and actively promoting efforts for decarbonizing. This is the project to rebuild the headquarters office building on the same site. The high reduction rate of energy consumption is required for construction of the new head office building, compared to the former head office. The high interest for the energy saving of both the client’s and ours has been matched, then this ZEB project has been realized. (Figure.1-0,1-1)

This project consists of the below four concepts.
• Comfort: Enhancing comfort while reduction of energy consumption compared to former head building.
Economy efficiency: Realized by almost the same cost as the other general office building (similar size) of our company. (No extra-cost for ZEB)

- General-purpose technology: Built with the popular energy-saving technologies (Easily applicable for other buildings)
- User friendly: While workers can unconsciously save energy, they also induce eco consciousness and can continuously use the building eco-friendlily. Moreover, it is possible to maintain and manage the building without special engineers.

As a result, the primary energy consumption has been reduced by 78% compared with general office buildings (design values) and acquired Nearly ZEB (Nearly Zero Energy Building) at Building Energy Saving Performance Indication System (BELS) (Figure 1-2). The summary of Contribution of each energy saving category is shown on Figure 1-4. Also, in CASBEE Saitama the highest rank, S-rank has been certified.

Also, this building has been completed with the almost same cost as the other buildings of our company’s which are the similar size of the office buildings (cf. 3. Cost Result).

The details of main efforts for ZEB is described from the next chapters.

1.1 Minimizing air conditioning load and equipment capacity (the highest impact for ZEB)

A large amount of energy saving is realized by thoroughly reducing factors of air conditioning loads from inside and outside of building, and minimizing air conditioner capacity (104 W/m²) for the actual load.

1.1.1 Reducing internal lead.

1.1.1.a. Load from lighting. All of lighting fixtures are LED in the whole building, and the office area adopts the highly efficient line type LED (149 lm/W) as the design illuminance 500 Lux. As a result, the air conditioning load by illumination is about 5 W/m², and the air conditioning capacity is calculated as 8 W/m².

1.1.1.b. Load from power socket. Air conditioning capacity is calculated based on the actual socket load. It was calculated as 10 W/m² based on the socket load data of various performance surveys of buildings. By the way, the owners of the rented offices often requires the high socket load (ex. 50W/m², 60W/m²...), however, it is possible to rationalize the capacity of air conditioner by separating system of air conditioner; the capacity for corresponding actual performance load and corresponding owner’s requirement as back-up. (Applicable for both individual heat source and central heat source).

1.1.2 Reduction of the load from façade and outdoor-air. In recent, the internal loads of buildings tend to be reduced due to the spread of LED lighting and high efficiency OA equipment. Therefore the load ratio of façade and outdoor air is increasing. The reasonable reduction of these loads is required.
1.1.2.a Reducing façade load. The façade consists of the high-performance insulation panels and the lateral-multiple mounting glazing. The heat insulating panel adopts high heat insulation specification with thermal conductivity of 0.017 W/(mK). The opening (glazing) is almost only northside and southside, and the height and size of glazing area is designed minimum but the comfortable view and sufficient daylighting can be obtained, also Low-E glasses are adopted on southside. By above, both comfortable view, daylighting and minimization of façade load have been realized simultaneously and the BPI\(^2\) value of 0.7 has been achieved (Figure.1-5).

1.1.2.b Minimizing outdoor-air volume setting. According to the requirement of the client, the number of occupants in the office area is 150 as actual use and maximum 200 for the space. Since the occupancy rate will be almost never 100% as even maximum use, the outdoor-air volume for ventilation is designed to be fulfilled for both 30m\(^3\)/h per a person for 150 and 25m\(^3\)/h per a person for 200. Herewith, the amount of outdoor-air intake is not to be large and the air conditioning load and air conditioner capacity are reduced.

1.2 Minimizing energy for building operation

1.2.1 Air conditioning and illumination control by presence/absence detection by the thermopile sensor. In the office, thermopile sensors are installed, and both air conditioning and lighting are turned off in the absence area, also the controlled zone is subdivided to improve the energy saving effect (Figure.1-6).

1.2.2 Lighting control (control system will be described later on 1.4.4). Since daylight is taken in, in the office area the brightness sensors perform finer output control according to the daylight utilization.
The controlled zone is subdivided from perimeter to interior to improve the energy saving effect (Figure.1-6). For the area without daylight, the initial illumination output is controlled by BEMS (building energy management system). All the lighting fixtures are connected to BEMS and controlled by the schedule.

In the office area task and ambient LED lighting system is operated, and the ambient illuminance is dimmed to 300 lux (desktop height level) including daylight use. As a result, the energy consumption (lighting load) is 3W/m² at 300 Lux (5W/m² at 500 Lux). Since the conference rooms are assumed to be paperless operation, illuminance level not for the room average but for the average of the table surface is set to 400 Lux.

1.2.3 High efficiency VRV system and latent heat utilization of rainwater. All air conditioning consists of highly efficient VRVs (COP 3.3 to 3.9). Outdoor units are sprayed (using manufacturer accessories) with recycled rainwater (filtered and chlorinated), and aiming at highly efficient cooling by latent heat utilization. It was actually measured this summer that the temperature of the outdoor unit surface is decreasing by nearly 10 °C at the outside temperature of 37 °C in sunny. Also air conditioning has been working effectively even on hot summer days beyond the outside temperature of design condition, and outdoor unit spraying has been confirmed to be effective for serious hot summer.

![Figure 1-7. Effect of water spraying (thermos camera)](image)

1.2.4 Control of outdoor-air intake volume. The outdoor-air volume for ventilation in each room is controlled by the CO₂ concentration which is the accessory function of the total heat exchanger (ventilator).

The fresh air intake in the entrance and the atrium are supplied with outdoor-air conditioners and are balanced with the exhaust of the 2nd floor toilet. The exhaust of the toilet starts and stops by infrared sensors in order for energy saving, and atrium and entrance are pressurized (positive pressure kept) at the time of stopping the toilet exhaust. Herewith, outdoor-air induction from the entrance doorway is aimed to be prevented.

When precooling/preheating before start of working time, ventilation operation is automatically stopped and the load from outdoor-air is reduced (schedule control).

The kitchen is ventilated by the air supply fan and the exhaust fan installed with the inverter to reduce the amount of ventilation air by half when no fire such as preparation or tidying is used, and the load from outdoor-air is quite reduced in addition to ventilation power load.

1.2.5 Reducing Power load of domestic hot water supply and elevator. The high efficiency gas water heater, latent heat recovery type, is installed for domestic hot water supply to kitchen. The automatic faucet and the small electric water heater are for hand washing in toilets, equipped with the yearly timer and hot water supply is stopped from May to September.

The open-staircases in the atrium in the center of the building encourage the use of stairs and greatly reduce the use of an elevator. The elevator is gearless and has a power regeneration function that returns the generated electricity to the circuit when braking.
1.2.6 Maximizing photovoltaic power generation. A high efficiency photovoltaic panels (total 87kW) are installed on the rooftop and a power generation of about 84,000 kWh per year is expected (including loss due to shadow, AC conversion and aging). The panel layout is examined by power generation simulation including the influence of the shadow between the panels, and it is installed at an angle that can maximize the power generation amount toward the limited roof area.

The roof is made of a heat insulating panel + waterproof sheet and it is set as a stand without any steel structures for panel installation but on a special disk which is welded integrally with the waterproof sheet (Figure 1-8). Herewith, while minimizing the initial cost, the amount of power generation is maximized on the limited roof area. Also, by reducing the height of the panel the line of sight from the outside is cut and the safety against strong winds is much enhanced.

1.3 Energy saving operation support: Real time monitoring of energy saving achievement degree. Generally, signage displays the amount of electricity generation and consumption only, but it is hard to connect with energy saving behavior by building users. Therefore, in this project, it is the system that displays the “degree of energy saving achievement” in real time (calculated from the actual value for the set the target value of electricity consumption), and bellows are installed; “ECO LAMPS” in the office area (lamps turn on when beyond the target) (Figure 1-9) / a large monitor in the 1st floor cafeteria (Figure 1-10). This system encourages energy saving behavior so that workers can be conscious of the relation between work style and energy use regularly. The measurement of power consumption is segmented by each floor and each use category (air conditioning / ventilation / lighting / power socket / domestic hot water supply / elevator / kitchen machine / network server) and displayed on the signage, so that building users can grasp finely what amount they are using for what kind of purpose. Grasp of annual electricity consumption and target value setting are carried out by energy simulation by BEST [3] Program.

1.4 Others: Enhanced comfort and energy saving

1.4.1 Outside comfort display (Applying SOTO-COMI® technology). Indicating outdoor comfort to indoor workers, they can go out and take refreshes and breaks. The external area of building are positively greened with existing green leaved. The comfort indication system is based on measured weather data with a commercially available multi-meteorological meter outside (measurement of air temperature, humidity, quantity of solar radiation, wind speed and rain) applying SOTO-COMI® (press release August 2, 2016) which is our technology (Figure 1-11).
1.4.2 Brightness evaluation design at the atrium.
As the lighting standards of brightness values in space have been published by the Architectural Institute Japan recently, the lightness of the space has been focused to be optimized based on the brightness evaluation and sense of brightness and feeling of brightness. In this project, the lightness of the atrium which does not need exact Lux level at all is designed based on the brightness evaluation. After the brightness simulation of the atrium with the BIM (Building Information Model) (Figure 1-12), by measuring the brightness in several real spaces, collecting the sample data, feeling the lightness of the spaces and comparing them with the simulation result, the brightness feeling at the atrium is predicted. After construction completion, the atrium was photographed with a brightness camera and compared with the simulation result (Figure 1-13). As a result, it seems to be possible to realize the space where it is perceived as bright enough though the ambient light at the center of the atrium is 200Lux under daylight + lighting fixtures. Incidentally, the atrium is made up of sufficient daylighting and minimum lighting fixtures, and the change of the lightness at the atrium is acceptable on design; the brightening in the daytime and the darkening in the evening and the night according to the change of the outside lightness.

1.4.3 Pneumatic radiation air conditioning and dimming/toning lighting.
The executive meeting room which conducts a communication conference with overseas offices etc. adopts pneumatic radiant air conditioning where the airflow seeps at a low wind speed (average 0.2 m/s) from the ceiling radiation panel, considering reducing tiredness due to long-term conference continuity (Figure 1-14). Also, in this room, the lighting system can perform dimming and toning so that the mode can be changed according to the time zone or content of the meeting.

1.4.4 Wireless lighting control by open network standard. All lighting control is made wireless with the self-generating lighting switch, infrared sensor and brightness sensor (Figure 1-15). It is the open network system as EnOcean standard, therefore any manufacturer's fixtures can be connected in the future, and it is easy to modify the layout of sensors because of wireless. Also, the manpower saving as 18% of labor man-hours for electrical work of lighting and socket in construction has been confirmed due to wireless system, and it can be expected as the solution for recent lack of manpower for construction site in Japan.
1.5 Tuning process
It is one of the most important process to tune each building system after occupancy. Between designer, builder and client, the monthly meeting for energy management has been continuing after occupancy; monitoring/analyzing the daily record of each energy consumption and discussing what and how to tune the several set points and optimize operation. For example, the half-air-volume mode installed for kitchen ventilation was not utilized just after starting occupation because kitchen staff didn’t know well, but now they’ve habituated to use it, and the daily electrical consumption of kitchen fans is apt to decrease (Figure.1-16).

1.6 Measured energy
The result of one year energy measurement (April.2018 – March.2019) as BELS evaluation target base is below (Figure 1-17-1,2). BEI=0.148 (85.2% energy reduction from base building) as energy consumption and power generation, and BEI=0.395 (60.5% reduction) as only energy consumption. Both are under BELS evaluation as design. Data collection, analysis and communication with client to be continued.

[1] BEI = designed primary energy consumption / standard primary energy consumption
[2] BPI = designed PAL* / standard PAL*
[3] BEST Program: One of the most popular simulation tool for energy consumption in Japan
2. Office-AI

2.1 Second Project Overview

Figure 2-1 shows a building overview, and Figure 2-2 shows the adopted technologies and a system outline. This project was planned to rebuild the existing Aichi Steel Head Office (built 56 years ago) in Tokai City, Aichi as a cutting-edge energy-saving building that improves the comfort and intellectual productivity of workers.

2.2 LIGHT ENVIRONMENT PLAN

(1) Illumination and color control lighting

Standard floors (4F-7F) introduced a lighting control system that adjusts illuminance and lighting color temperature according to the human biorhythm (circadian rhythm). The system helps promote the good health of workers by aligning their biorhythms from wake-up in the morning, consciousness during the daytime to sound sleep during the nighttime. It also provides energy savings by controlling lighting energy depending on time (Figure. 2-3).

In this project, the combined use of direct light from lighting fixtures and indirect light on the ceilings provides more apparent changes in color temperature, offering greater effects. In addition, lights are designed to go out at a scheduled time during a lunch break to encourage workers to have a rest, and at the closing time and every hour after that, illumination is controlled to reduce overtime work. Furthermore, attempts are being made to improve the cool/warm sensation via lighting by using different cooling/warming modes depending on the season (changes from 4000 to 5000K in summer and from 3000 to 4000K in winter).

Furthermore, meeting rooms on the standard floors (4F-7F) and the Board Meeting Room on the 8th floor introduced a system for selecting scenes in which light color and illumiance are controlled. This allows different scenes to be selected according to the meeting in order to improve the efficiency of discussions. Three patterns are available for the meeting rooms and six patterns for the Board Meeting Room (Figure. 2-4).

(2) Gradation louver on the west site
The head office building was provided with louvers that provide an extensive view to monitor the plant on the west side of the building while shielding sunlight. Small holes are opened in the louvers. The holes at eye level are larger than the more narrowly spaced holes at other heights, in order to provide a sufficient view (Figure 2-5).

As a result of optical simulation, solar radiation shielding performance has been estimated to reduce the peak solar radiation load on the west side by about 55% throughout the year.

(3) Light shelf on the south side
On the south side of the building, a louver-integrated light shelf was introduced to let in more light into the room for saving energy. In addition, the automated bottom-up blinds perform automatic control according to the position of the sun and the outdoor solar radiation (Figure 2-6).

(4) High side-light with light shelf
A light shelf with a daylight redirecting film is provided on a high side-light on the top of the Eco-void to admit direct and indirect light into rooms efficiently. The incoming light is diffused by a finishing material of high reflectivity and provided for the lower void space, allowing for a reduction in lighting energy consumption (Figure 2-7).

2.3 AIR CONDITIONING/VENTILATION PLAN
(1) Total radiant air conditioning system
Standard floors (4F-7F) introduced a total radiant air conditioning system using ceilings, floors and windows, consisting of ceiling radiation panels, floor radiant air conditioning, and air flow windows around the perimeter of the building. The system was designed to improve comfort of workers, eliminate draft, and create an office environment that allows workers to focus on their tasks with improved intellectual productivity (Figure 2-8). In addition, we adopted environmental-friendly and lightweight cardboard ducts in the chamber of the ceiling radiating panel.

(2) Desiccant air conditioning system using exhaust heat from Eco-void, outdoor air cooling
A new, building-integrated air conditioning system was developed in this project. The system uses exhaust heat accumulated above Eco-void as a desiccant rotor regenerative heat source in summer, while in winter reusing it through a total heat exchanger, providing energy savings throughout the year. The air conditioning system is also designed to blow air (15000 m3/h) when outdoor air cooling is
suggests a great effect of lighting control on productivity. Approximately 40% answered that the lighting control helps improve productivity and this respondents realized that closing time had passed because of the lighting control every one hour after closing time, rather than the wake-up effect in the morning. In particular, more than half of the shutting off lighting during lunch break and lighting color/illuminant control in the evening and after lighting control was not so obtrusive to workers. Therefore, approximately 20% of respondents did not notice the change throughout the day and effects of lighting control during lunch break and lighting color/illuminant control in the evening and after lighting control were shown in Figure. 2-12. The color of the lighting is controlled gradually over 60 seconds.

2.4 PERFORMANCE VERIFICATION AND QUESTIONNAIRE SURVEY

The verification overviews before and after construction are shown in Figure. 2-10 and Figure. 2-11, respectively. Performance verification and questionnaire surveys were conducted once before construction and three times after construction (in summer, autumn and winter). The same areas including the General Affairs Department and Sales Department were subject to verification before and after construction. The office building before construction was a structure of reinforced concrete with medium-height windows, fluorescent lamps on the 4th floor and LED lamps on the 2nd floor that had been renovated. They had a typical air conditioning system using ceiling cassette air conditioners. As for

a seating plan, the General Affairs Department on the 2nd floor had a relatively high-density environment.

2.5 RESULTS OF VERIFICATION OF LIGHT ENVIRONMENT

(1) Illumination and color control lighting

Results of the questionnaire survey on lighting control are shown in Figure. 2-12. The color of the lighting is controlled gradually over 60 seconds. Therefore, approximately 20% of respondents did not notice the change throughout the day and lighting control was not so obtrusive to workers. In addition, more respondents felt the effects of shutting off lighting during lunch break and lighting color/illuminant control in the evening and after closing time, rather than the wake-up effect in the morning. In particular, more than half of the respondents realized that closing time had passed because of the lighting control every one hour after closing time. Approximately 40% answered that the lighting control helps improve productivity and this suggests a great effect of lighting control on productivity.
(2) Light shelf on the south side and gradation louver on the west side
Results of the questionnaire survey are shown in Figure. 2-13. 30% of the respondents felt that the light shelf helps increase illuminance inside a room. 8% of the respondents felt the glare to some degree, but almost none of them were uncomfortable with it. As for the gradation louver, 40% had a clearer view of the outside and 50% felt the sunlight shielding effect. The data suggests that the gradation louver can shield sunlight without interrupting sightlines. Approximately 40% had a positive impression on the gradation louver and the light shelf as a whole.

2.6 RESULTS OF VERIFICATION OF AIR CONDITIONING AND VENTILATION
(1) Performance verification and evaluation
Thermal camera images are shown in Figure. 2-14. As shown in the image taken in winter before construction, the temperature on the window, the perimeter pillar and wall was low and it caused a cold draft. After construction, on the other hand, the temperature was higher at around 18°C to 20°C on the window and 23°C on the floor, and a uniform environment was maintained in the entire room. As shown in the image taken in summer after construction, the temperature was around 23°C to 26°C on the radiation panel and around 27°C on the air flow window (around 29°C on the upper side). The temperature of the window (not an air flow window) of the east side elevator hall reached 30°C at the same time, which suggests that the air flow window increased the window temperature close to the room temperature. The floor surface remained around 26°C and a uniform environment of 24°C to 27°C was created in the entire room. Such a uniform thermal environment in the entire room both in summer and in winter facilitates the use of meeting space on the perimeter side throughout the year.
(2) Warm-Cold assessment
Questionnaire surveys on temperature, humidity and air flow were conducted before and after construction (Figure. 2-15). As shown in the results, many respondents answered that both cooling and heating was provided at an appropriate temperature after construction and the warm-cold sensation shifted to neutral. As for humidity, the installation of an exterior desiccant air conditioning system helped improve comfort from humid to neutral in summer, and from dry to neutral in winter. More respondents felt less air flow after construction in which ceiling radiation and floor radiant air conditioning systems had been introduced. Approximately 60% of the respondents answered that these air conditioning systems improved productivity. The data suggests that the newly-introduced total radiant air conditioning system improves efficiency in the workplace.
2.7 EVALUATION OF ENERGY-SAVING AND INTELLECTUAL PRODUCTIVITY

Estimated energy saving effects are shown in Figure 2-16. Primary energy consumption was estimated with reference to the pre-renovation building. Energy consumption was reduced by approximately 50.5% in the first year after construction compared to that before construction, and met the ZEB-Ready standard of at least a 50-percent reduction in energy consumption.

Some of the results of the intellectual productivity survey (SAP) are shown in Figure 2-17. Before construction of the office, more respondents had felt a decline in intellectual productivity, while after construction, many of them answered they experienced improvement. Before construction, many respondents pointed out a decline in productivity (by 3% to 10%), but after construction, they felt improvements (by 3% to 20%), suggesting a significant increase in intellectual productivity. Satisfaction with environmental factors is shown in Figure 2-18. The rating shifted from dissatisfaction to satisfaction and the overall satisfaction improved uniformly. By department, the staff of the General Affairs Department who work in the office felt greater improvements compared with their cohorts in the Sales Department.

3. Cost Result

The cost of above two projects Office-TS, Office-AI is compared with other projects which are for offices and similar size of total floor areas (Figure 3-1, 3-2). Both are almost on the average and they, ZEB projects, have been realized with the equivalent cost level to general buildings (non-ZEB projects).
4. Conclusion
All the technologies adopted in above projects are general ones used for general building project recently. ZEB can be realized at reasonable cost by maximizing energy saving performance by design with proper coordination of these technologies. In addition, in order to realize ZEB, it is very important that the process of firmly realizing usability and operation method with the client (building user) through the design stage and incorporating it.

Buildings in Japan of less than 10,000 square meters occupy 97% as the number of buildings, and 60% as the area of buildings, therefore it is much expected and needed to realize ZEB in medium-sized buildings. It is significant and impactful that we could realize widely spreadable ZEB in these projects of the medium-sized buildings, and we would like to make it a momentum for popularization of ZEB for the future.