YKK80 High Efficiency Building - Radiant Control both Outside and Inside

Kitaro MIZUIDE[a]

[a] *M&E Design Department of NIKKEN SEKKEI, Japan*

1. INTRODUCTION

Located in the metropolitan city of Tokyo, Japan, the new YKK headquarters building is named "YKK 80" because it was completed in 2015, which marked the 80th year since the company was founded. Tragically, in March 2011, just one month after design began, the Great East Japan Earthquake and disaster occurred. Japan rapidly shut down all of its nuclear power plants (nearly 30% of Japan's total energy supply) and reassessed their energy supply and demand as well as their seismic vulnerability. This allowed the owner and design team to reassess the energy, comfort, sustainability, and seismic design requirements for this project—ultimately leading to much more innovative, integrated, comfortable, healthy, and aseismic design solution.

The project site is a 5-minute walk from Akihabara station, and the longer axis of the site is 70 meters (230 feet) in length, faces westward, and overlooks a metropolitan expressway. These constraints immediately established several energy, daylight, noise and view design challenges for the hot and humid summer climate of Tokyo.

2. ENERGY EFFICIENCY

Using a passive first approach, an exterior “sudare screen”, or Japanese traditional blind, was used over the entire west facing façade to block and filter direct solar gain while maintaining daylight and views. This sudare screen is positioned 1.5 meters (~5 ft.) in front of the glazed façade utilizing the cantilevered floor structure as overhangs. The screen is made of "Y" shaped aluminium bars making a delicate filtering of light. Clear double glazing with automatically controlled bottom-up or “climbing” blinds also provides solar shading while still allowing exterior views. The sudare screen also helps filter outdoor noise, creates a safe service space for maintenance of exterior installed mechanical systems, and even provides lightning protection—ultimately providing 6 functions for a single cost (shading, reflecting daylight, noise filter, deck enclosure, maintaining views, and lightning protection)

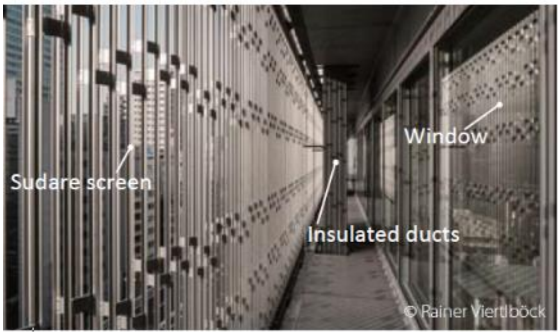

Photo 1: Sudare screen/ maintenance deck

Figure 1: Details of sudare screen/ perimeter image

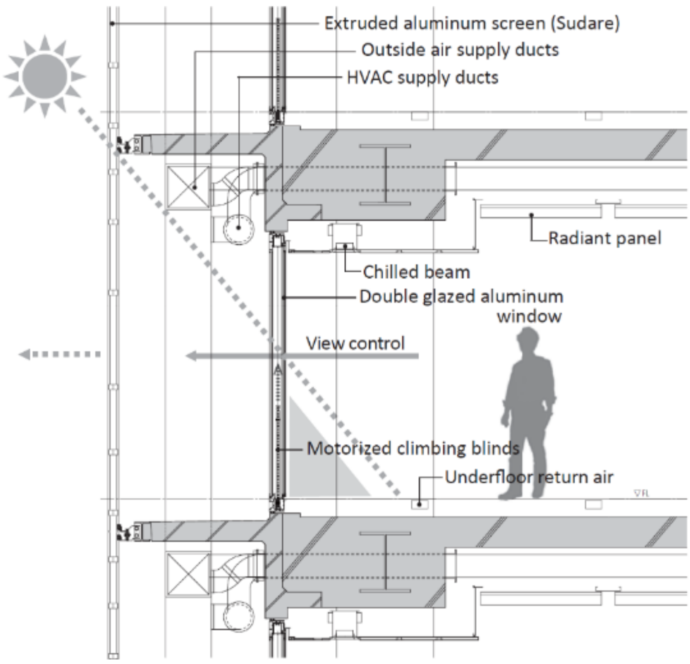

Figure 2: Multi-functional facade system

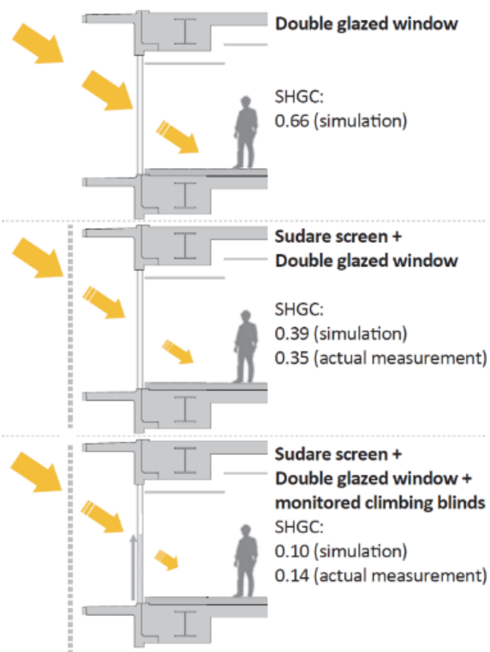

Figure 3: SHGC diagram

Daylighting is maximized by controlling the light coming through the windows with automatic solar adjustment of the angle of the blind slats every 10 minutes. Through post-occupancy evaluation, which was completed in February 2016, more than 80% of the occupants were satisfied with the indoor lighting conditions noting that it was "bright enough" and "not too bright" (no presence of glare). Ceiling integrated LED lighting and controls for dimming or turning off lighting in vacant areas using daylight and motion sensors, extends the value of the energy saving façade design to the indoor environment.

With direct solar heat gains mitigated and daylight and lighting optimized, a properly sized, high-efficiency HVAC system could be designed. A custom, radiant ceiling panel cooling/heating system was designed to facilitate integration of hot/cold water piping with lighting and low-velocity (slight) air flow. This slight air-flow concept came from the memory of experiencing a natural breeze under the shade of a tree. Small fans, functioning as diffusers, provide the slight air flow behind the inclined radiant panels and allow greater variation in temperature set points.

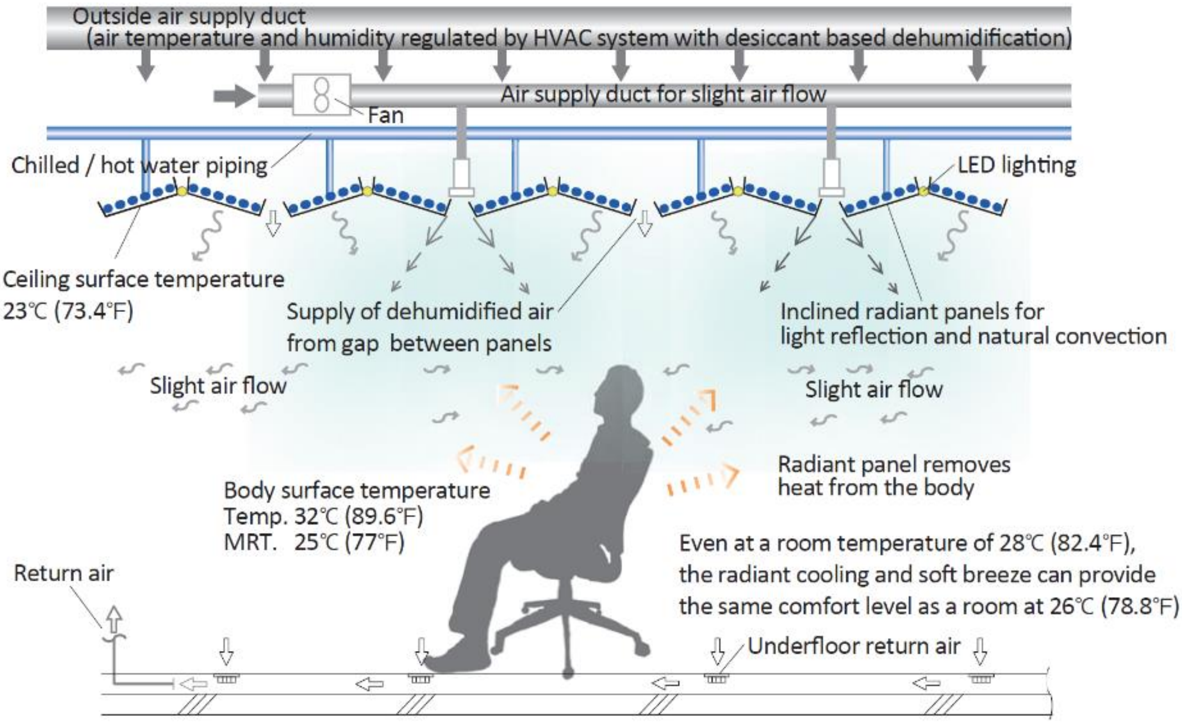

Figure 4: Conceptual drawing of HVAC system

Figure 5 shows the quantity of energy consumption for control of the sensible heat load on the vertical axis and the difference between outside temperatures and an average of all room air temperatures on the horizontal axis. This proved that if room temperature is increased by 1K (kelvin) in cooling mode, energy savings is 8.6MJ/h (source energy 23.3MJ/h). Similarly, lowering the room temperature by 1K while in heating mode, saves 12.0MJ/h (source energy 32.4MJ/h). The chilled water temperature is relatively high which contributes to the high performance operation of the chillers.

Thermal loads in the interior zone, where the temperature does not significantly change, are met by the radiant ceiling panel system. However, the variable thermal load near the exterior windows is met using an Active Chilled Beam. Together, this zoned approach provides for a very efficient distribution of both energy and comfort.

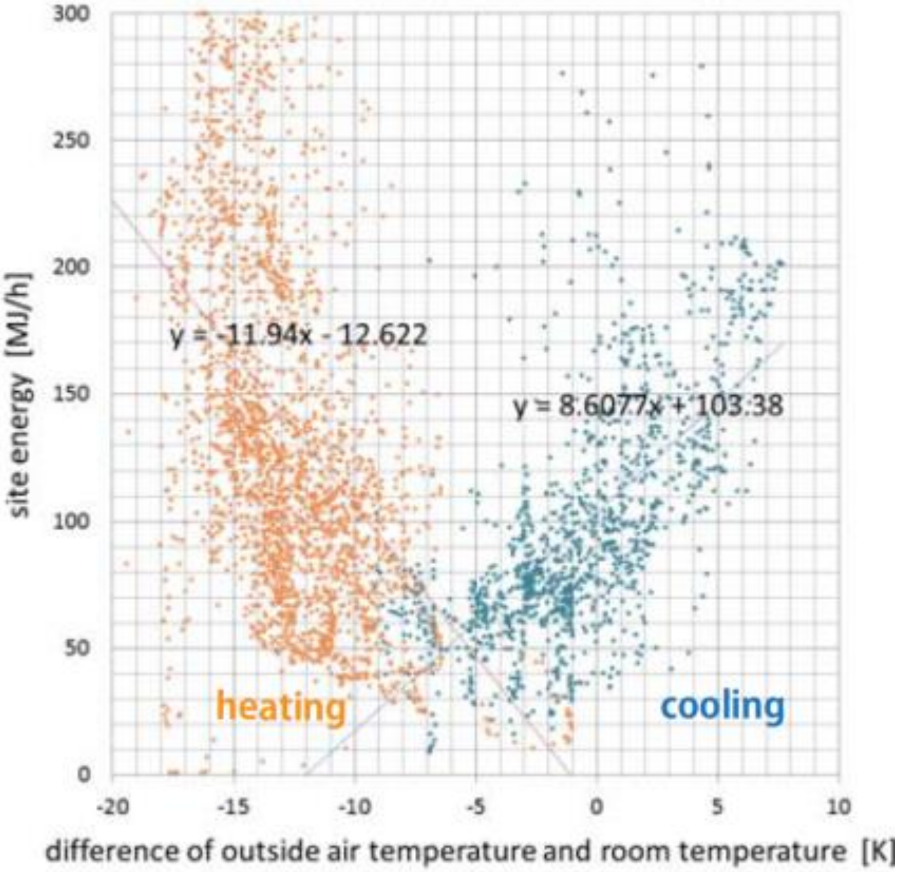

Figure 5: Energy savings from YKK actual temperature set point mitigation

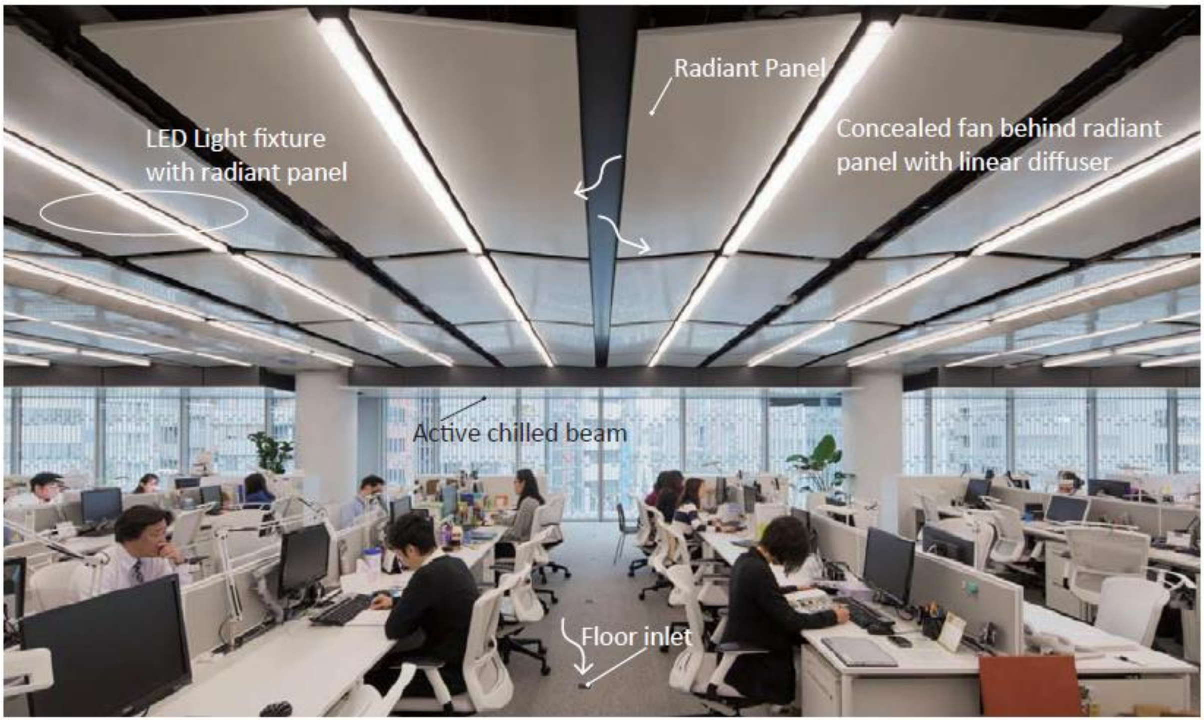

Photo 2: Interior image

Other energy reduction strategies include active plug-load management and geo-exchange. Each desk is equipped with an electric outlet or receptacle which is capable of showing electricity consumption for that desk. It is also equipped with a sensor which detects an occupant's presence and the power is automatically turned off when nobody is present.

Earth-to-air energy exchange occurs using a trench in the seismic isolation layer to preheat or precool outdoor air through an underground tunnel. In addition, well water for direct thermal exchange is used as an untapped natural resource in the lower level air handlers.

The final energy results are shown in both Table 1 and Figure 6. These results, when modeled using Energy Plus against an ASHRAE 90.1 baseline, demonstrate a 27.5% savings (site energy) and, when comparing actual results to the baseline, they indicate a 32.5% savings (site energy) and indicate a 53 % (source energy) savings compared to an average Tokyo regional office building.

	Site	Source
ASHRAE Baseline	153.65 kWh/㎡-yr (48.71 kBtu/ft²-yr)	1,371 MJ/㎡-yr (120.74 kBtu/ft²-yr)
Proposed (modeled)	111.40 kWh/㎡-yr (35.31 kBtu/ft²-yr)	1,034 MJ/㎡-yr (91.06 kBtu/ ft²-yr)
Actual	103.69 kWh/㎡-yr (32.87 kBtu/ft²-yr)	932 MJ/㎡-yr (82.08 kBtu/ft²-yr)

※Source-Site Ratios in Tokyo Japan
Electricity:2.711 ; Natural Gas:1.005

Table 1: Annual energy performance summary

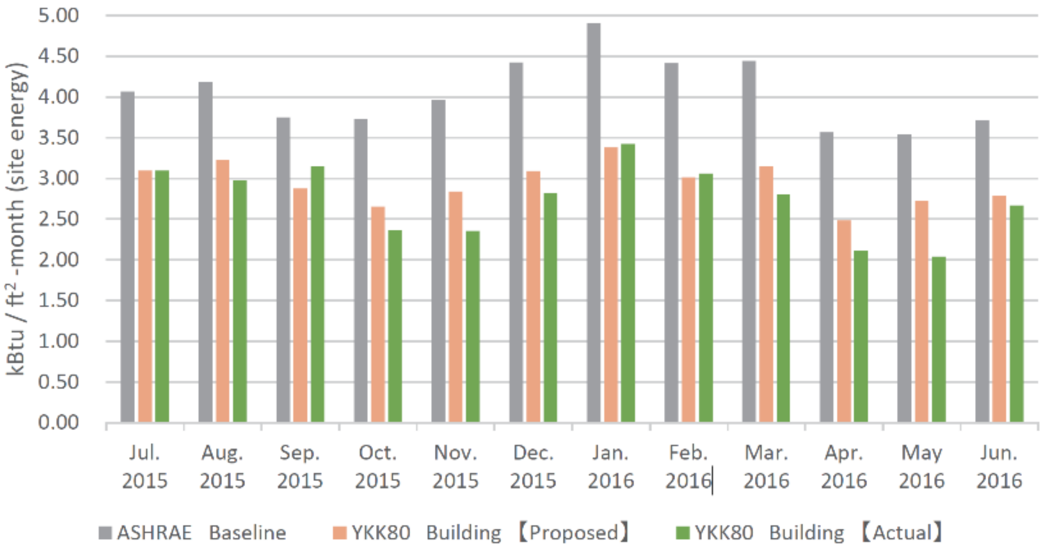

Figure 6: One year monthly operating data of building energy performance

3. INDOOR AIR QUALITY AND THERMAL COMFORT

Excellent indoor air quality is maintained throughout the year by utilizing air handling units with desiccant-based dehumidification, a Dedicated Outdoor Air System (DOAS) and proper control of the quantity of outdoor air based on CO_2 concentration. The minimum quantity of outside air, which is taken through the air handlers, is supplied to the space above the radiant ceiling panels. This air is continuously returned at the floor level and is then returned to the rooftop air handlers. Figure 7 shows indoor CO_2 concentration data on the vertical axis, which was measured by floor and time of day when the air handlers were in operation, and the average temperatures of each season (summer, shoulder seasons, and winter) on the horizontal axis. CO_2 concentration has been maintained around

707 ppm throughout the year, indicating very good air quality. Additionally, MERV 13 filtration of supply air was used to control respirable particulate matter, pollen and dust.

Figure 7: Relationship of CO_2 concentration and room temperature

Using a detailed 3-dimensional Building Information Model (BIM) and Computational Fluid Dynamics (CFD) comfort verification of the radiant cooling assisted by the slight air flow system was confirmed during the design phase. Additionally, experiments were conducted with subjects in a mock-up research laboratory to verify comfort in areas using the slight air flow (Figures 8, 9). Figure 10 shows the relationship between the room temperature, Predicted Mean Vote (PMV=0), Mean Radiant Temperature (MRT), and air speed-- referencing Thermal Comfort from the 2013 ASHRAE Fundamentals Handbook. It was determined that when the average radiant temperature is lower than the air temperature of the room, the room temperature could be increased by around 2ºC--from 26ºC to 28ºC (78.8ºF to 82.4 ºF)--keeping the PMV the same if the air is supplied with a slight air flow of 0.2 or 0.3m/s (0.66 or 0.98 ft/s) with a MRT of 25ºC (77 ºF). The mock-up research and lab experiment, with over 150 participants, confirmed comfort in over 75% of the participants using higher temperature set points with a slight air flow--demonstrating compliance with ASHRAE Standard 55-2010 (Figure 11).

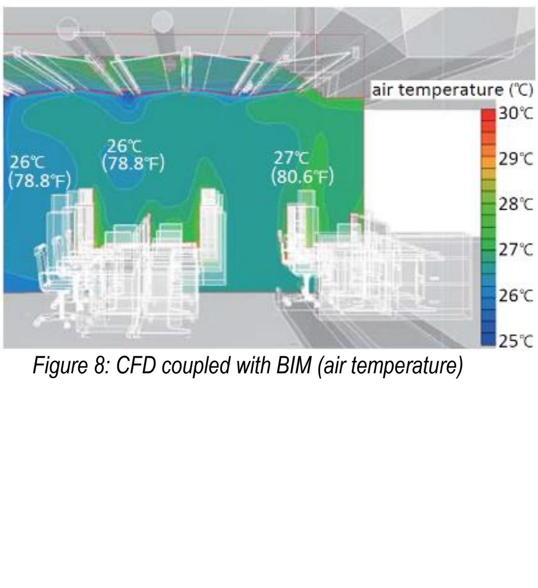

Figure 8: CFD coupled with BIM (air temperature)

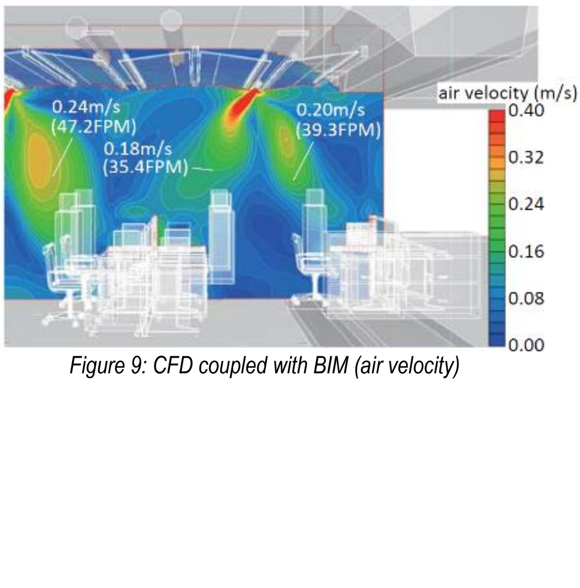

Figure 9: CFD coupled with BIM (air velocity)

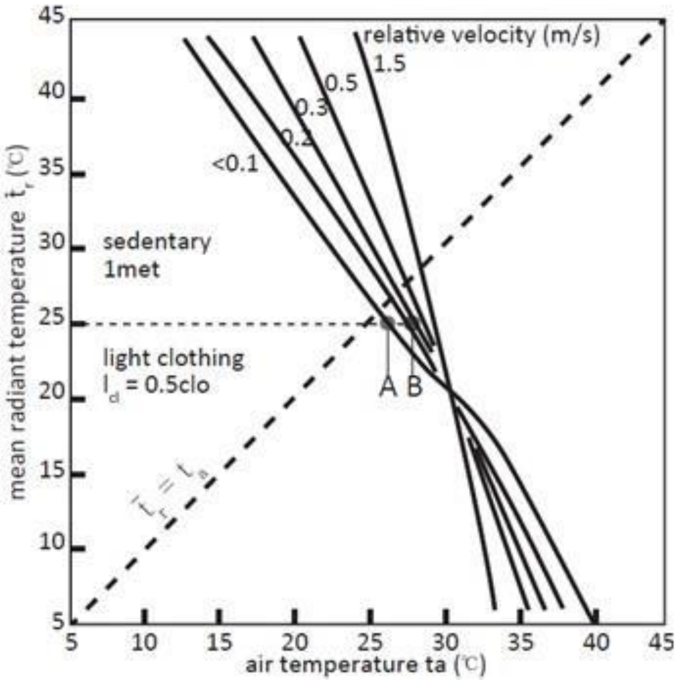

Figure 10: Air temperature and MRT necessary for comfort (PMV=0) of sedentary persons in summer clothing at 50% RH

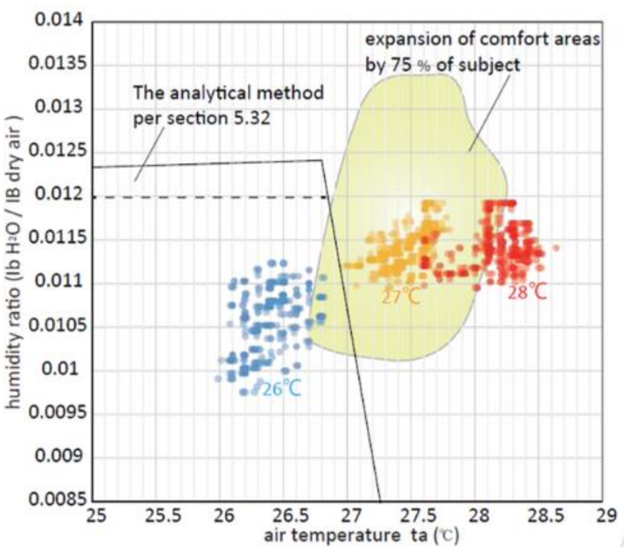

Figure 11: Expansion of comfort zone

4. INNOVATION

The real innovation of the YKK80 building was in meeting the challenges brought forth by the 3/11 disaster and the entire owner, design and construction teams commitment to utilize an integrated design process in response to that. The key innovations include: the multi-functional façade design, the “under-the-tree” breeze radiant cooling system, the design, mock-up and lab comfort verification process, and the enhanced commissioning and ongoing measurement and verification. Today, YKK80 is one of the lowest energy consuming offices in Japan with verified occupant comfort (Figure 12). Beyond energy savings and comfort, YKK invites visitors on regular facility tours and utilizes graphic-based data from their Building Energy Management System (BEMS) to communicate the value of energy and water reduction strategies. Another innovation feature is a state-of-the-art, real-time earthquake detection system designed to provide immediate response and safety information for occupants. The entire building rests on seismic isolation pads.

5. OPERATION AND MAINTENANCE

Two years of performance verification was included in each team members contract and uses sophisticated BEMS data to support operation and maintenance. The entire team (owner, designer, contractor, manufacturers, and operators) will participate in this ongoing performance verification until two years after occupancy. Detailed real time monitoring of energy and environmental systems (cooling/heating, plumbing systems, water use, electricity, and lighting) is provided by the Building Automation System (BAS). This information is reported monthly at a commissioning meeting and contributes to ongoing energy-savings and improved occupant comfort. Figure 6 on page 5 shows one year of actual monthly operating data as compared to the ASHRAE baseline and energy simulation.

6. COST EFFECTIVENESS

YKK80 utilized an integrated design process to optimize the whole building as a system and to utilize single elements, such as the sudare screen or the sloped radiant ceiling panels, for multiple functions. Still, the initial investment was greater than a conventional similar office building. The increase in the initial (2013) investment was JPY720 million (~$7.2 million USD) or JPY34,418/m^2 (~$32 USD/$ft^2$). The present day utility cost savings are JPY66 million (~$630,000 USD) per year, or JPY 3,155/m^2 ($2.8/$ft^2$), which is 52% less than a similar sized Tokyo office building. Using a simple payback analysis, this will require just under 11 years to pay back the additional investment—assuming utility costs do not increase. It should be noted that even with a modest productivity gain of 5% (much higher increases have been documented in other green office buildings) this 11 year payback period would be less than 2 years.

7. ENVIRONMENT IMPACT

The actual reduction in CO_2 emissions is 22.6kg-CO_2/m^2 (4.64 lbs/ft^2) or 32% below the baseline (CO_2 emission factor in Tokyo, Japan, Electricity: 0.496kg-CO_2/kWh ; Natural Gas: 2.23kg-CO_2/kWh ; Tap Water: 3.129kg-CO_2/m^3).This building also incorporated high-efficiency water-saving equipment (water closets: 3.8L (1 gallon US) water per flush, faucets with 14 second shut-off timer), and currently consumes 65% less tap water than that of an ordinary office building in Japan. In addition, 100% of the non-tap water necessary for a bio-film process is provided using treated wastewater and reclaimed rain water.

8. SOCIAL ENGAGEMENT/ CONCLUSION

YKK understands the importance of being a good corporate citizen and integrating themselves with the local community. Examples of their community engagement include: utilizing outdoor plants (with signage) on their site that have been present in their neighbourhood since the Edo period; promoting farm-to-table food utilizing their rooftop garden; and offering local handicraft manufacturer's opportunities to hold workshops and exhibition events using the area around the building entrance. YKK staff also participate in the local traditional festival and allow their lobby to be used for displaying the "Mikoshi" or sacred portable shrine.

Based on the latest data from Tokyo Metropolitan Government, YKK80 energy performance is in the top 1% of the 465 buildings sampled.

Focusing on the initial project goals of energy-savings, comfort, health, seismic safety and cost-effectiveness in the life cycle design, the YKK80 building has clearly met, and even exceeded these goals—providing a new benchmark for green office buildings in Japan.

Photo 3: Rooftop garden

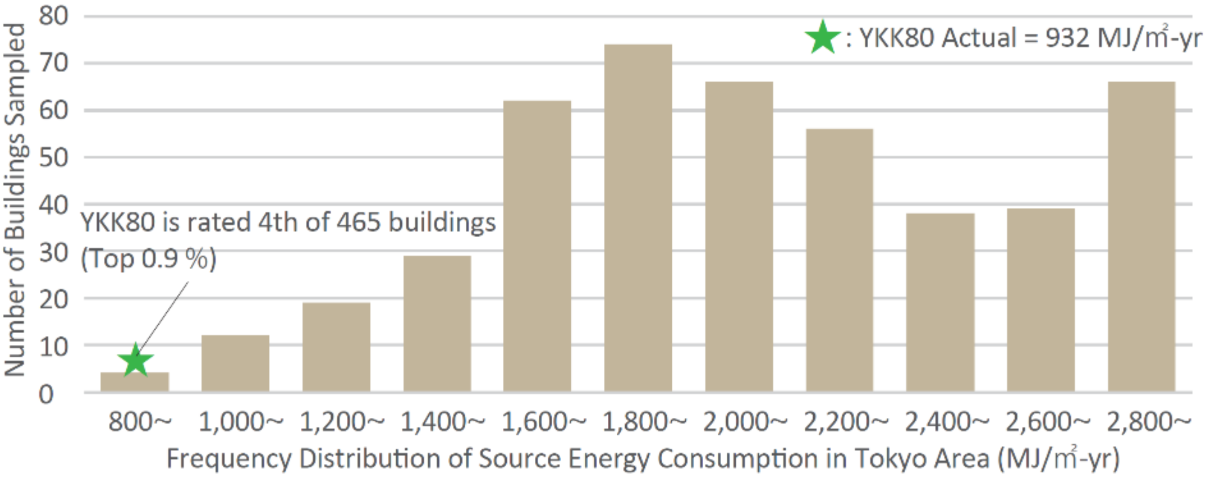

Figure 12: Source energy of office buildings over 10,000m² in Tokyo (2009)