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From “Comparing Convection vs. Radiant Air-Conditioning Systems in Office”

Indoor Air Quality

The design was based on ASHRAE Standards 55 and 62 to provide a comfortable and healthful indoor environment. The versions referred to at the time of design were 55-2017 and 62.1-2013, respectively.

Ventilation Scheme. The internal ventilation supplies fresh outside air to occupied spaces, and odoriferous spaces like toilet rooms are provided with a localized exhaust system. This keeps occupied spaces in positive pressure, and spaces with odor are in negative pressure, which prevents unpleasant smell or contaminants from entering the occupied spaces. The ventilation volume for an occupied space is calculated according to the required fresh air volume per person. For example, a general office space expects to have 25 m^3/h per person, and the density of 0.2 person/m^2, or 5.0 $m^3/h{\cdot}m^2$ in total for ventilation volume. This is much more than the office ventilation volume per Standard 62 (1.53 $m^3/hr{\cdot}m^2$), and should be of an adequate capacity. For the study of ventilation efficiency of floors with the VAV Coanda AC, the set of reference data of Standard 62 did not have any that suits the purpose. Therefore, the mock-up experiment was implemented to study the return positions, the results of which were reflected in the actual building. For the toilet, the CFD analysis was used to simulate the return locations most effective for capturing odoriferous particles. As a result, returns were installed near the floor level to realize an efficient exhaust system.

Thermal Environment Scheme. The Graphic Comfort Zone Method specified in Standard 55 was the basis of the design of the AC system and methodology for its control for both the VAV Coanda AC and the dynamic range radiant AC systems. The design temperatures for AC were set at 25°C for cooling and 22°C for heating. The indoor air velocity around people was designed to be at 0.15 m/s or less. Since this limit was expected to exceed the VAV Coanda AC, mock-up experiments and CFD analyses were used for verification, and then the system adjustment was very carefully implemented with a measurement of air velocity distribution. In terms of humidity, desiccant outside air handlers were introduced to prevent condensation on radiant panel surfaces in the radiant AC floors, where the indoor dew-point temperature was approximately 16°C to 18°C or lower depending on the temperature of water pumped into the panels. On convective AC floors, depending on the dew-point temperature of the space, the control adjusts the cooler chilled water volume to regulate the dehumidification level, which was capable of keeping the relative humidity between 50% to 60% when the dry-bulb temperature was at 25°C. As to the radiant temperature, to avoid an uncomfortable situation due to uneven radiant activities caused by the weather, architectural design considerations were well incorporated, such as the thermal insulation performance of the outer skin and windows and prevention of direct sunlight entering the indoor space. The scheme called for 0.30 $W/m^2{\cdot}K$ of exterior wall heat transfer coefficient and that for windows is 1.3 $W/m^2{\cdot}K$, which was an adequate thermal insulation property to prevent unpleasant cold radiation in the interior against a winter outdoor temperature. The solar transmittance rate was 0.23, and the stairwell in the front of the building acts as canopies preventing office space from direct sunlight.

Actual Measurements in a Mock-Up and System Adjustments

A full-scale mock up of one bay of office space was built before construction began to conduct full-scale experiments in the process of developing the two ductless AC systems. Air diffusers blowing air from the wall on one side and returns located near the floor level on the ACR wall and column cover on the opposite side were designed to improve the AC and ventilation efficiency of the entire space. Using the mock-up, subject-based experiments were conducted in addition to investigation of the thermal environment and airflow pattern characteristics. Questionnaires taken by subjects at both Point A and Point B, with a distance of 3 m and 9 m from the diffuser, respectively, came back with high scores for comfort level, indicating comfortable environment throughout the space.

Comparison of Real-Life Measurements and Mock-Up

After the completion and before move-in, the AC system was turned on to provide data with hypothetical load values, in a fashion similar to the experiment using the mock-up. The full-scale experiments, CFD analyses and real-life survey do not show an identical temperature distribution pattern as the measurements and analytical conditions were somewhat different. However, the location in which the conditioned airflow peels off the ceiling plane, which is an important factor in the design of Coanda AC, tended to be basically the same, demonstrating the high level of precision in the advance estimates.

Additionally, after the tenants moved in, thermal environment data were taken and user experience surveys were conducted in summer as well as winter. Regarding the perception of drafts, 0.15 m/s was observed. Actual measurements and questionnaire responses indicated that for both AC systems, comfortable environments were established in terms of how occupants felt about the temperature. As to the natural ventilation through the stairwell, during the period when it was effective, measurements were recorded indicating that approximately twice per hour air exchange was achieved. Questionnaires of office workers before and after the move-in to this building indicated that compared to the office environment before the move using a conventional VRV system, more positive responses were given in terms of air quality as well as the thermal environment under both systems.

Operation and Maintenance

Environmental Visualization

A variety of indoor and outdoor climactic measurements are continually taken. The data service of the cloud-managed building energy management system allows office workers to retrieve, on their computer monitor the current ventilation rate and CO_2 concentration of the room, and, in addition, view the real-time plan distribution of temperature, humidity, luminance, VOC concentration, etc. This service enables office occupants to issue an AC adjustment request—and for the operation manager to get a quick picture of the indoor environmental conditions in response to their control adjustments. As a result, it is conducive to continually good indoor environment conditions.

The Maintainability of the Two Systems Developed

The Coanda diffuser developed for the convective system is, as mentioned above, an autonomous mechanical system without power connection, which adjusts the air velocity without becoming another item requiring maintenance. The non-chemical injection anti-corrosion system developed for the radiant system prolongs the service life of piping. The corrosion speed measured with a corrosion sensor was only 28 μm/yr. The expected service life of steel pipe thread with corrosion allowance of 1.4 mm comes out to be 50 years, which is 2.5 times the typical life of 20 years.

Energy Operation Evaluation of VAV Coanda AC System

For one year since the beginning of practical operation, power consumption data for the convective AC were taken and analyzed to calculate how much the set of systems incorporated contributed to energy savings compared with the typical constant air volume Coanda AC system. Especially the juxtaposition of the newly developed Coanda AC system and the VAV control did quite well, achieving an 83% reduction for the air conveyance power use according to our calculation. The outdoor air utilization rate for the warmer chilled water, which we wanted to improve, was at 68% in the actual measurement. The annual system COP of the chilled water heat source was looked at with the one-year operation data. High COPs of pre-cooling and free-cooling pushed the numbers up, ending up with COP = 8.1 in total for the warmer chilled water.

Cost Effectiveness

The cost effectiveness of the HVAC system introduction was estimated using the energy simulation, the actual construction cost of the actual building and its actual measurements of energy consumption between October 2020 and September 2021. Of the annual power consumption in the simulation, the energy used for the HVAC system was 229,845 kWh/yr. The actual measurement after the start of building operation came out to be 67,320 kWh/yr. The reduced power consumption translates to JPY4,063,000 savings on the electricity bill per year. On the other hand, the increase of the construction cost (initial investment) was calculated to be JPY54,230,000. The initial cost payback period was calculated to be 13.4 years. In addition, introduction of this system helped realize lower floor heights leading to reduction of architectural elements, such as the building envelope, structural steel and interior finishes. The estimated reduction of architectural costs was calculated to be JPY36,000,000 if the floor height of each floor was reduced by 550 mm from the typical, which would make the payback period approximately 4.5 years.

Environmental Impact

To reduce the operational carbon, this building incorporated a set of energy saving measures described in this document. As a result, the energy consumption was rated 48.0 $kWh/m^2 \cdot yr$ and 23.5 $kgCO_2/m^2 \cdot yr$ of carbon footprint. According to the government survey, the average carbon footprint of office buildings in Tokyo in 2019 is 85.2 $kgCO_2/m^2 \cdot yr$. Compared to this figure, this project achieved a 73% reduction. Because of a rather large CO_2 emission base unit on the power grid in Japan at 0.489 $kgCO_2/kWh$, the carbon footprint itself does not go too low. However, the energy use reduction measures used in the building were hugely successful in reducing it. The two types of ductless systems contributed to reduction of ducting material, prolonged service life of piping and reduction of embodied carbon through a lowered floor height. The only fluorocarbons used in this building is in the heat pump and the compressors in the desiccant outside air handlers. The refrigerant for the heat pump is R-410, while that for the compressor in the outside air handler is R-407, both of which impose a very small environmental footprint with ODP = 0. In Japan most office buildings of this size use the air-cooled VRF system, but our systems use a considerably smaller amount of fluorocarbons in comparison.

From “Electric Heat Pumps, Natural Ventilation For University Building”

Operation and Maintenance

One concern with VRF systems is leaking of refrigerants due to the increased amount of refrigerant piping throughout the building.

The design team used a custom-built spooling device to install pre-insulated line sets to connect the VRF units. This resulted in far fewer brazed connections and fittings throughout the building, which reduces the likelihood of refrigerant leakage. The design team provided full commissioning services during construction, as well as transition to sustainable occupancy services after the building was occupied. This allowed the building operator to interface with the engineering and construction team to learn and tune the building. Design engineers working with the building operator ensured that the design intent is realized in operations—the success of this program is apparent in the low operational EUI.

Another benefit this building has comes from the combination of a high-performance envelope paired with the VRF heat pump system: an energy-efficient building without sacrificing occupant comfort. The high-performance envelope acts as a barrier of energy transfer with the ambient conditions outside the building perimeter, and there is variation of internal temperatures due to external solar loads. The VRF systems are manufactured without a backup heating source, unlike the distributed heat pump systems of the past. These auxiliary heating systems were used to bridge the gap of night setback, which takes a significant amount of energy to overcome in the early morning hours of cold days or over the weekend. With this high-performance envelope and the VRF system, the building is kept comfortable throughout each day without an energy impact over the course of the year. The heat recovery of the VRF system moves energy around the building.

Cost Effectiveness

As part of the design of this project, an energy life cycle cost analysis (ELCCA) was completed to optimize the mechanical system selection. Four mechanical systems were evaluated on first cost, energy cost and maintenance costs over a 30-year period. Other factors such as electrical impacts and utility rebates were also included in the analysis. The four systems considered were:

- Overhead VAV with electric heat;
- Overhead VAV with hydronic heat;
- Variable refrigerant flow (VRF) with dedicated outdoor air system (DOAS); and
- Chilled beams with dedicated outdoor air system.

Shoebox energy models, cost models and maintenance cost models were created for all four systems and shared with WSU in two separate iterations. This resulting information was then inserted into the Washington State ELCCA spreadsheet. After the initial analysis, all four mechanical systems fell within the desired range of an EUI of 25 to 40. The chilled beam system was determined to not fit within the first-cost budget, so this mechanical system was eliminated from consideration.

More refined energy, cost and maintenance models were then developed for the remaining three systems. The ELCCA results show the overhead VAV with an electric heat system has the lowest energy life-cycle cost, but does not meet project requirements to exceed Standard 90.1-2007 by 50%. The VRF system was shown to have the second-lowest energy life-cycle cost, meet all of the request for proposal energy requirements and provide additional benefits not quantified in the analysis (i.e., minimized programming impacts for mechanical space, potential building height savings).

Environmental Impact

As discussed in the Innovation section, this building has extremely low energy use and Scope 2 GHG emissions. Additionally, the project includes a 20,000 gallon (75 700 L) rainwater cistern that collects water from the rooftop through a preliminary filter system. The rainwater is then pumped and treated through an ultraviolet and filter system to non-potable plumbing fixtures like toilets and urinals.

The system can provide 100% of the toilet and urinal flushing demand between September and June. With the combination of the rainwater harvesting system with low flow/ultralow flow fixtures, the potable water savings was greater than 60% compared to the baseline design standards of EPAct1992.