Observational study on the cool breeze effect of a through wall type air conditioner

Takaya Kato¹, Masayuki Ichinose¹, Shiro Tsukami² and Hirotaka Kubo²
¹ Tokyo Metropolitan University, 1-1 Minami Osawa, Hachioji city, Tokyo, Japan
² Nikken Sekkei Ltd., 2-18-3 Iidabashi, Chiyoda-ku, Tokyo, Japan

*Corresponding author’s e-mail: kato.takaya85@gmail.com

Abstract. An air conditioning system has been developed that can select the operation pattern of a through-wall type unit (TWU) according to the air conditioning needs. There is a night-time cool breeze mode like natural ventilation using a fan in modes. The thermal environment and ventilation volume of office buildings can be greatly influenced by outdoor thermal conditions, and it is necessary to grasp the actual conditions. Therefore, in this research, the observational study of thermal environment and ventilation performance was conducted, and was compared and analysed with the simulation result. The cross-section wind velocity distribution was characterized in each area, but the wind velocity in the residential area was about 0.1 to 0.2 m/s, and no draft was seen immediately below the bypass duct outlet. It was almost in agreement with the simulation results. The ventilation performance survey revealed that the windward side was slightly difficult to ventilate. However, there was no big difference in the age of air depending on the location. Moreover, there was no significant difference in the total ventilation volume even if the outdoor thermal conditions were different. It was confirmed that the TWU had expected performance and stable ventilation performance was secured.

1. Introduction

It is said that air conditioning uses about a half of building’s energy consumption. In recent years, the use of renewable energy has attracted attention as part of a building’s energy saving strategies and Business Continuity Planning (BCP) compliance. Natural ventilation is a method that utilizes passive energy efficiently in the appropriate seasons.

A previous report [1] noted that, an improved through-wall unit (TWU) was created by adding a new mode that uses indoor exhaust air for the compressor heat exchange and high-efficiency perimeter air-conditioning system was developed. In the perimeter zone, air conditioning is performed by the TWU and the central air conditioning system by combining various operation patterns of the TWU and the air handling unit (AHU) according to air conditioning applications. This enables selection or control corresponding to various air conditioning needs in an office building. This research shows that it is possible to achieve compatibility between energy saving and thermal comfort.

One of the features of this new system is a night-time cool breeze mode utilizing natural ventilation using the outdoor fan in selectable modes. Utilizing natural ventilation greatly influences the thermal environment and ventilation volume due to outdoor thermal conditions such as air temperature, relative humidity, wind velocity, and wind direction. There is a possibility that the thermal environment may be different at various places in a room, and it is necessary to understand the actual situation at various places in the room. In a previous report [2], analysis by Computational Fluid dynamics (CFD) was...
performed. It was confirmed that by conducting precise analysis on the whole building, a stable effect was obtained, regardless of the difference in building height and wind direction.

Therefore, in this report, the observational study results of the thermal environment and ventilation performance was reported as pre-occupancy verification, and is compared with simulation results.

2. Materials and methods

2.1. Target office building
The target office building is 100-meters in height and has a typical floor area of approximately 2800m². It is scheduled to be completed in March 2019. The air conditioning of the interior zone treated the interior load and the fresh air load with a single duct VAV method using an AHU installed in the machine room. The perimeter zone is air conditioned by TWU’s installed in a perimeter enclosure. Figure 1 shows the TWU layout. Measurements of night-time cool breeze mode was conducted. Figure 2 shows a conceptual diagram of night-time cool breeze mode. This mode can switch over when outside air cooling is enabled during overtime work hours. In this mode, the outside air intake is provided by the air supply louver in a common corridor using a bypass duct. In this mode, air conditioning stops, and energy is only used for fan power to maintain comfort and ventilation during overtime work hours. This saves tenants money from reduction in energy charges.

2.2. Schedule
Table 1 shows the air conditioning operation schedule during the measurement period. Measurements were done as a pre occupancy observational study. Heating operation was carried out for about 2 to 3 hours before the start of the measurements in order to make the initial conditions for night-time cool breeze mode uniform, and the room temperature was adjusted to about 21°C. The indoor fan was operated in the AC + V mode, and was in air blow operation without cooling or heating. And the outdoor fan operated with Hi stages.

Table 1. Air conditioning operation schedule.

| Date  | Time           | Air conditioning system | Remarks                        |
|-------|----------------|-------------------------|--------------------------------|
| 1/7   | 16:00–23:30    | Night-time cool breeze mode | 18:10–21:00 Stop: night-time cool breeze mode |
| 1/8   | 13:30–22:00    | Night-time cool breeze mode | 17:40–19:50 Stop: night-time cool breeze mode |
| 1/9   | 10:00–15:00    | Night-time cool breeze mode |
| 1/10  | 17:00–21:00    | Night-time cool breeze mode | 26 units in operation |
| 1/11  | 11:45–15:00    | Night-time cool breeze mode |

Figure 1. TWU layout.  
Figure 2. Night-time cool breeze mode.
2.3. Measurement of outdoor / indoor thermal environment
Outdoor weather conditions were collected by a weather sensor installed on the roof. The measurement data included air temperature, relative humidity, wind velocity, wind direction, air pressure, and illuminance. The measurements were made at 5 minutes intervals.

Figure 3 shows the indoor thermal environment data points. The air temperature, globe temperature, relative humidity, and wind velocity were measured at 1,100 mm above the floor level. Instruments for measuring the vertical temperature distributions in the interior zone and the perimeter zone were installed. Measurement heights were 100 mm, 600 mm, 1,100 mm, 1,600 mm, 2,100 mm, and 2,600 mm in the office space and the corridor.

Movement measurements were carried out in 3 places (WEST area, NORTH area, and EAST area) in the office building, shown in Figure 4. Measurement points are as shown in Figure 5, and the measurements were conducted while narrowing the time interval near the bypass duct. Also, at the same time as the movement measurements, wind velocity near the outlet of each bypass duct was measured by the average number of minutes.

2.4. Measurement of ventilation performance
Calculations of the age of air were conducted by tracer gas method [3], [4] and calculation of ventilation volume was conducted by indoor and outdoor air pressure difference to understand the ventilation performance of the target building.

2.4.1. Age of air. In this measurement, indoor air concentration response using a tracer gas step-down method was conducted. CO₂ was used as the tracer gas, and the CO₂ concentration measurement points are as shown in the Figure 6. The unit of age of air is time and is defined as the average time until fresh outside air, flowing in from the air supply port, reaches a certain point in the room. The smaller the age of the air, the more that the air is fresh, and it is used to express indoor ventilation efficiency. The local
mean age of air calculated from the CO₂ concentration decay from data of 10 points was compared and the distribution of indoor ventilation performance was examined. For the calculation of the local mean age of air, the concentration decay curve was regressed from the measured data compared to the outside air concentration, and the local mean age of air was calculated by trapezoidal integration. Equation (1) was used to calculate the local mean age of air. Measurements of outdoor CO₂ concentration were carried out on the first floor the north side of the building.

\[
\tau_p = \int_0^\infty \frac{C_r - C_o}{C_r0 - C_o} \, dt
\]  

(1)

\( \tau_p \): Local Mean Age of Air \([\text{h}]\)
\( C_r \): Room Concentration \([-]\)
\( C_{r0} \): Initial Room Concentration \([-]\)
\( C_o \): Outdoor Concentration \([-]\)
\( t \): Elapsed Time \([\text{h}]\)

2.4.2. Ventilation volume. Figure 7 shows measurement point of indoor and outdoor differential pressure. Also Figure 8 shows outdoor fan characteristics of the TWU in the previous report [5]. The ventilation volume was calculated from the measurement results of the differential pressure gauge built in the inside of the TWU at the outer periphery of the target building and the relationship between the displacement volume and indoor and outdoor differential pressure obtained by results of full-scale performance experiments. The indoor pressure is detected on the exhaust air side of the TWU. The outdoor pressure is always released under assumption of 0Pa in the wind pressure resistant sensor box. The inside and outside differential pressure were measured by TWU of each direction.

**Figure 6.** Measurement points of CO₂ concentration.

![Figure 6. Measurement points of CO₂ concentration.](image)

**Figure 7.** Measurement points of indoor and outdoor differential pressure.

**Figure 8.** Outdoor fan characteristics of the TWU.

![Figure 7. Measurement points of indoor and outdoor differential pressure.](image)

![Figure 8. Outdoor fan characteristics of the TWU.](image)
3. Result of thermal environment measurements

3.1. Movement Measurements
Table 2 shows the outdoor weather conditions during the movement measurements. Figure 9 shows the results of the movement measurement carried out on January 8th and 9th. The figure shows cross-sectional wind velocity distribution. The wind velocity in the occupied areas was changing at 0.1m/s ~ 0.2m/s and there was no strong current of air is generated. This was almost in agreement with predictions using CFD analysis. There was no draft under any conditions and orientation just under the bypass duct. In the WEST area, an air flow extending straight down along the wall from the bypass duct was seen. The wind velocity increases near the vicinity of the windows through the floor from the bypass duct. In the NORTH area, there is an air flow which goes from the blowout opening toward the window surface. Unevenness was observed in the wind velocity distribution. In the EAST area, there was a tendency for the wind velocity to become around 1,400 mm from the floor level. Unevenness was observed in the wind velocity distribution. In either condition especially in the WEST or NORTH areas, in general terms, a breeze (0.1 ~ 0.2m/s) tended to flow in the upper part of the room with almost no wind in the occupied area of floor level +1,500 mm or less. This is presumed to be the influence of the TWU at the outer perimeter sucking indoor air from the baseboard slit of the perimeter enclosure.

Figure 10 shows the measurement results of the bypass duct wind velocity at the time of movement measurements. Regardless of the outdoor thermal conditions, the wind velocity at the outlet of each bypass duct is almost the same.

The wind velocity fluctuation at the outlets of 10 bypass ducts are the same for both the wind direction and the wind velocity on both days. Since the outlet of each bypass duct is the same 600 square ceiling air diffusers, it is inferred that the difference in wind speed current air flow difference. The northern side P5, 6, etc., which is away from the south air supply port, has a small air volume and it flows easily to the EAST and WEST areas.

Table 2. Outdoor thermal conditions.

| Date | Time | Main wind direction | Average wind velocity | Average air temperature | Average relative humidity |
|------|------|---------------------|-----------------------|-------------------------|--------------------------|
| 1/8  | P.M. | ESE                 | 0.72[m/s]             | 9.3[°C]                 | 42.8[%]                  |
| 1/9  | A.M. | WNW                 | 3.27[m/s]             | 5.6[°C]                 | 29.1[%]                  |

WEST area (1/8)

WEST area (1/9)
4. Results of ventilation performance measurement

4.1. Age of air

Figure 11 shows wind rose, and Figure 12 shows the time series change of wind velocity at the time of tracer gas method on January 7th. Figure 13 shows wind rose, and Figure 14 shows the time series change of wind velocity at the time of tracer gas method on January 8th. Although there were some wind direction fluctuations depending on the time on either day, there was hardly any time where the...
wind direction changed significantly. The main wind direction was from the North and the wind velocity was about 0.5 m/s~1.0 m/s on January 7th. The main wind direction was from the North-northwest direction and the wind velocity increased from 1.0 m/s to 2.0 m/s with the passage of time.

Figure 15 shows the CO₂ concentration decay process and local mean age of air distribution on January 7th and Figure 16 shows the CO₂ concentration decay process and local mean age of air distribution on January 8th. The concentration change at each point during the decay process on each day is almost the same. It was confirmed that the local mean age of air becomes longer at the location on the windward side, although the local mean age of air does not differ greatly at each point except for location C10. This is thought to be because it is difficult for the windward side air to be slightly exhausted. The difference in the local average age of air between 1/7 and 1/8 seems to be since the initial concentration of CO₂ was low on January 7th.
4.2. Ventilation volume
Table 3 shows outdoor thermal conditions during night-time cool breeze mode of each day. Figure 17, 18, 19, 20, 21, and 22 show indoor and outdoor differential pressure occurrence frequency distribution by direction of each day. And Table 4 shows the ventilation volume by each direction and the total ventilation volume. The occurrence frequency of the large differential pressure. On January 9th and 11th, when the outdoor wind velocity was fast, the occurrence frequency of a large differential pressure was high compared to other days. The indoor and outdoor differential pressure has a high occurrence frequency from 0 to 50 Pa on any day. From Figure 8, since the air volume of TWU in that case almost no difference, there was no significant difference in that total ventilation volume depending on each day. Although outdoor thermal conditions differed on each day, there are no large difference in total ventilation volume. It was confirmed that stable ventilation was performed by the cool breeze effect using the ventilation performance of TWU. And under this condition that all the units were operated, the number of air changes of about 4.8 times/hour was secured, and the number of air changes was the same as previous report [5] of the airside economizer mode. In the previous report [2], CFD analysis assumes that the actual operation will be performed, and since analysis is performed with the outdoor fan (Lo stage) with 32 units of TWU, there is a difference in ventilation volume.

Table 3. Outdoor thermal conditions.

| Date  | Direction   | Average wind velocity (m/s) |
|-------|-------------|-----------------------------|
| 1/7   | N           | 0.60                        |
| 1/8   | N, ESE      | 0.68                        |
| 1/9-1 | SSW, WNW    | 3.92                        |
| 1/9-2 | WNW         | 3.76                        |
| 1/10  | SSW, N      | 0.78                        |
| 1/11  | SSW, NW     | 3.47                        |

5. Conclusion and Discussion
In this paper, the cool breeze effects of a through wall type air conditioner at night-time cool breeze mode were reported by the observational study of thermal environment and ventilation performance. And the measurement results were compared and analysed with the simulation results.

The cross-section wind velocity distribution was characterized in each area, but the wind velocity in the occupied area was about 0.1 to 0.2 m/s, and there was no draft was even under any wind condition under the bypass duct. This nearly coincided with predictions performed by CFD analysis. The ventilation performance survey revealed that the windward side was slightly difficult to ventilate. However, there was no big difference in age of air depending on the location. Moreover, there was no significant difference in the total ventilation volume even if the outdoor thermal conditions were
different. It was confirmed TWU had expected performance was exhibited and stable ventilation performance was secured.

Figure 17. Indoor and outdoor differential pressure occurrence frequency (1/7).

Figure 18. Indoor and outdoor differential pressure occurrence frequency (1/8).

Figure 19. Indoor and outdoor differential pressure occurrence frequency (1/9-1).

Figure 20. Indoor and outdoor differential pressure occurrence frequency (1/9-2).
Figure 21. Indoor and outdoor differential pressure occurrence frequency (1/10).

Figure 22. Indoor and outdoor differential pressure occurrence frequency (1/11).

Table 4. Ventilation volume per unit (m³/h).

| date  | SW  | W   | NW  | NE  | E   | SE   | total  |
|-------|-----|-----|-----|-----|-----|------|--------|
| 1/7   | 2520.0 | 7560.0 | 2520.0 | 5880.0 | 7560.0 | 2520.0 | 28560.0 |
| 1/8   | 2520.0 | 7560.0 | 2520.0 | 5880.0 | 7560.0 | 2520.0 | 28560.0 |
| 1/9-1 | 2520.0 | 7499.0 | 2514.6 | 5866.0 | 7560.0 | 2520.0 | 28479.7 |
| 1/9-2 | 2520.0 | 7519.4 | 2519.3 | 5878.2 | 7560.0 | 2520.0 | 28516.9 |
| 1/10  | 2520.0 | 5040.0 | 2520.0 | 4200.0 | 5040.0 | 2520.0 | 21840.0 |
| 1/11  | 2517.5 | 7419.5 | 2286.8 | 5793.5 | 7542.1 | 2511.0 | 28270.4 |

References

[1] Tsukami S, Kubo H, Ichionse M and Kato T 2019 Proc. Int. Conf. Outline of the new air conditioning system with improved through-wall type air conditioner for a high-rise office building (Tokyo: Japan/Sustainable Built Environment Conference)

[2] Kubo H, Tsukami S, Ichinose M and Kato T 2019 Proc. Int. Conf. CFD study with consideration of the surrounding buildings using a through-wall type air conditioning system (Tokyo: Japan/Sustainable Built Environment Conference)

[3] The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan 2011 SHASE-S 116-2011 Ventilation Rate Measurement of a Single Room Using Tracer Gas Technique

[4] The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan 2017 SHASE-S 115-2017 Field Measurement Methods for Ventilation Effectiveness in Rooms

[5] Haneji T, Nagase O, Tsukami S and others. 2017 Proc. Academic. Conf. The study of an improved horizontal floor wall-through type air-conditioning system, which cascade-uses the exhaust heat from a room. Part 3, Part 4 and Part 5 (Kochi: Japan/The Society of Heating, Air-conditioning and Sanitary Engineers of Japan) pp 193-204