A New Through-Wall Air Conditioning System with Improved Performance for High-Rise Office Buildings

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Abstract.

As one type of perimeter air conditioning (AC) systems, there is a through-wall unit (TWU) that processes perimeter heat by exchanging heat with an outdoor fan from an exterior grill on the outer wall of a building. In this study, we improved the TWU by adding a new operation mode to cascade-use room exhaust air for the compressor heat exchange and developed a high efficiency perimeter air-conditioning system. This paper shows the outline of the new air-conditioning system by combining various operation patterns of the TWU. This enables selection corresponding to various air-conditioning needs in an office building, and it improves comfort and saves energy. In addition, the TWU exhaust performance tests of a sash shape model and a full scale model were carried out. From the viewpoint of exhaust performance when using a TWU in a high-rise building, and achieving the necessary cooling and heating capacity, it was confirmed that this would perform well.

1. Introduction

As one type of perimeter air conditioning systems, there is the “through-wall unit” (TWU) that processes perimeter heat by exchanging heat with an outdoor fan. Generally, the TWU is divided into an outdoor compressor section and an indoor heat exchanger section. The outdoor section carries out heating and cooling by exchanging heat with the outside air. Therefore, the heating and cooling capacity of the TWU varies greatly depending on the outside air temperature.

There are some TWU models with an external air cooling function to take in fresh air. There are advantages to these models such as ease in accommodating overtime work hours of tenant spaces by taking in outside air during overtime work.

In this study, the TWU was improved by adding a new operation mode to cascade-use room exhaust air for the compressor heat exchange and to develop a high efficiency perimeter air-conditioning system. This paper shows the outline of the new air-conditioning system by combining various operation patterns of the TWU. This enables selection corresponding to various air-conditioning needs in an office building, and it improves comfort and saves energy.[1]

In addition, the TWU exhaust performance tests were conducted of a sash shape model and a full scale model. From the viewpoint of exhaust performance, when using a TWU in a high-rise building, and it was confirmed that it could achieve the necessary cooling and heating capacity.[2]

Based on the results of this study, this air conditioning system was introduced to D-Building. D-Building is a super high-rise office building built across the railway track where the surrounding environment is open. It is planned as a building with good BCP performance. Figure 1-1 shows the exterior of the building and the interior floor view.
2. Outline of an improved through-wall unit (TWU)

The specifications of the TWU are shown in Table 2-1, and the enclosure appearance is shown in Figure 2-1.

A TWU is an integrated outdoor/indoor unit with a built-in compressor on the inside, so it is possible for it to respond quickly, such as switching the air conditioning mode or use during overtime work. Each TWU is equipped with a perimeter installed remote controller to start and stop cooling/heating, switch air volume (Hi · Med · Lo, 3 stages), and to change the temperature setting.

The improved new operation mode of the TWU exhausts indoor air with an outdoor fan, and switches the mode of exhaust/outdoor circulation by external signals according to the CO2 concentration in the room.

The comparison of the TWU energy efficiency in cooling and heating modes is shown in Figure 2-2. The efficiency of the TWU can be improved by exhausting indoor air when compared with the outdoor circulation mode. The operation patterns can be switched by automatic control.

| Cooling Capacity | Heating Capacity | Air Volume of Outdoor Fan | Air Volume of Indoor Fan |
|------------------|------------------|--------------------------|-------------------------|
| 3.6 kW           | 4.0 kW           | Hi | Med | Lo |
| 840 CMH          | 660 CMH          | 480 CMH |
| Motor            | Power Supply     | Capacity | Hi | Med | Lo |
| 1.77 kW          | 1.77 kW          | Hi | Med | Lo |
| 660 CMH          | 570 CMH          | 480 CMH |

Figure 1-1 D-Building (Exterior and Interior floor)

Figure 2-1 Through-Wall Unit appearance
The four operation patterns of the TWU are shown in Figure 2-3. Details of each operation pattern are described below.

1. **AC mode**: In normal AC mode, the outdoor air (OA) entering from the OA inlet is exhausted to the outside through the exhaust air (EA) outlet, and the indoor fan is operated.

2. **Ventilation (V) mode**: In ventilation (airside economizer or night-time cool breeze) mode, indoor air that enters from the RA inlet is exhausted out of the room through the EA outlet, and the indoor fan stops.

3. **AC+V mode**: In AC and Ventilation mode, indoor air from the return air (RA) inlet is exhausted through the EA outlet, and the indoor fan is operated.

4. **Business Continuity Plan (BCP) mode**: This is a disaster air intake mode. In order to supply fresh air from the outside in the event of a disaster, the motorized damper (MD) is controlled by an external signal and allows supply of outdoor air to the room.
3. Outline of a new air conditioning system with improved performance

Assuming an office building, the interior zone is designed to handle the AC load and the fresh air load with a single duct variable air volume (VAV) system by an air handling unit (AHU) installed in the machine room in the building core. The perimeter zone is air-conditioned by TWU’s, which are devised as a new AC system that combines the operation pattern of the TWU’s according to the air conditioning needs of the users.

This new air conditioning system is able to select an operation mode according to air conditioning needs of the users, while maintaining a stable ventilation rate. In consideration of the noise of the surrounding urban environment, rather than incorporate the fresh air intake from the outer wall directly into the room through the corridor, fresh air is incorporated by an exhaust fan in the TWU at the perimeter. See Figure 3-4.

Regarding air conditioning control, two types of daytime and night-time modes were selected: "Normal AC mode" and "Fresh air cooling mode" for daytime, and "Night-time normal mode" and "Night-time cool breeze mode" for overtime hours.

Figure 3-1 to 3-5 show conceptual diagrams of each air conditioning system.

3.1. Normal AC mode

In the daytime, air conditioning is supplied to the office by the AHU, and indoor air is exhausted by the TWU installed in the office perimeter enclosure. The operation pattern of the TWU changes so that CO₂ concentration in the room becomes the control value.

When the number of occupants increases and the indoor CO₂ concentration is high, the number of TWU’s operating in "AC+V mode" increases and the remaining TWU’s operate in "AC mode".

Proportional control of the fresh air intake VAV is performed according to the exhaust amount of the TWU.

3.2. Airside economizer mode

When the airside economizer mode is used, such as during the intermediate seasons, the AHU increases the fresh air volume from the central control, and the TWU operates in the "V mode".

The fresh air introduced from the AHU is exhausted from the outdoor fan of the TWUs. The fresh air intake of the AHU selects and controls the one having the larger VAV opening rate by the airside economizer control or by the CO₂ control.
3.3. Night-time normal mode

During night-time overtime work, AHU’s with high power consumption are shut off, and the office workers operate only the TWU’s with a local control switch, which saves energy and maintains comfort.

Both the AHU’s and TWU’s are shut off at a specified business closing time, according to a central schedule, but the TWU’s, can be operated when an office worker turns on the local control switch, such as "AC mode".

During overtime work hours, it is possible to start or stop air conditioning, adjust the air flow rate, and adjust the temperature setting by a local control switch. With this single unit operation, the building operator or owner can accurately calculate the overtime air conditioning charges for each tenant. To prevent someone from forgetting to turn off units after overtime hours, all TWU-AC’s are shut off at regular intervals.
3.4 Night-time cool breeze mode

When fresh air cooling is enabled during overtime work hours, the night-time cool breeze mode is utilized.

TWU’s in “AC mode” are changed to "AC+V mode". The fresh air intake is supplied from a louver in the corridor, adjacent to the office space.

In the night-time cool breeze mode, by introducing cool air from the corridor, comfort can be maintained during overtime work hours and the necessary ventilation volume is adjusted. This is more energy efficient than using the "night-time normal mode" with only fan power, and it benefits tenants as well.

Tenants who are using the night-time cool breeze mode from the central monitoring board will automatically switch from the normal mode to the night-time cool breeze mode, for times when the outside air temperature and humidity are appropriate.

3.5 BCP fresh air intake mode

At the time of a disaster, all TWU’s are set to "BCP mode" from central monitoring, and fresh air supply is provided with the fresh air intake port in the corridor. This enables natural ventilation without using electricity for AHU’s and TWU’s when the power supply is lost.
4. TWU exhaust performance test (sash shape model)

4.1. Outline of TWU exhaust performance test

The outline of this experimental system is shown in Figure 4-1, the sash shape model studied is shown in Figure 4-2, and the simulated sash is shown in Figure 4-3. In this new air conditioning system, TWU’s exhaust indoor air, but in high-rise buildings wind pressure applied to the sash may lower the exhaust capacity. Therefore, for sashes, it is necessary to consider shapes that make it more difficult for wind pressure to be applied to the TWU.

Simulation was carried out using a CFD analysis tool for 6 patterns of sash shape with various positions and lengths of the sash wind shield. As a result, in the case of a typical TWU, it is understood that although the air supply / exhaust port is the same, it is possible to not reduce the exhaust volume by distributing the opening to the upper and lower areas. In consideration of not only the outdoor wind, but also the façade design and rationality, the sash shape was decided as ① in Figure 4-2 and a simulated sash was made at 1/4 scale for use in an experiment.

| Condition | Air Velocity: 15m/s (Maximum wind speed at the Tokyo Tower (107 m)) |
|-----------|--------------------------------------------------|
| ①         | ![Section](image)                                 |
| ②         | ![Section](image)                                 |
| ③         | ![Section](image)                                 |
| ④         | ![Section](image)                                 |
| ⑤         | ![Section](image)                                 |
| ⑥         | ![Section](image)                                 |

| Opening Area (㎡) | 0.34 | 0.34 | 0.42 | 0.34 | 0.42 | 0.34 |

The experiment simulated outdoor wind pressure on the building by using a blower. The air speed of the blower was selected for 3 different conditions, 5m/s as the average wind speed in Tokyo, 13.5m/s as the maximum wind speed at Tokyo Tower (107 m above ground) and 10m/s as a speed between these two values. The blowing position was at the front of the sash, at an upper oblique angle of 45° and a lower oblique angle of 45°.
When the target value of the exhaust air volume is based on an office building with a floor area of 2,000m²/floor, the required fresh air volume is 12,000 CMH. Assuming that the TWU’s are installed at about 35 units/floor, and, assuming that an air conditioning system can be provided if 350 CMH of exhaust air is exhausted from each TWU, the target value was set at 350 CMH/unit.

4.2. TWU exhaust performance test results
4.2.1. Expected exhaust air volume by calculation
Table 4-1 shows the estimated exhaust air volume (calculated value) at each wind speed, and assumed that the blower position is in front of the sash. The rated external static pressures of the Hi, Med, and Lo setting of TWU and the wind pressure were converted using the calculation formula below.

\[ P_v = \frac{V^2 \times \rho}{2} \]

\( P_v \): Air Pressure, \( V \): Air Velocity, \( \rho \): Air density (\( \approx 1.2 \))

| Air Velocity | Air Pressure (Pa) | TWU exhaust air volume |
|--------------|-------------------|------------------------|
| 0 m/sec      | 0                 | Hi 840 CMH, Med 660 CMH, Lo 480 CMH |
| 5.0 m/sec    | 15                | Hi 810 CMH, Med 624 CMH, Lo 444 CMH |
| 10.0 m/sec   | 60                | Hi 696 CMH, Med 468 CMH, Lo 180 CMH |
| 13.5 m/sec   | 110               | Hi 522 CMH, Can not exhaust, Can not exhaust |

4.2.2. Experiment results
The visualization of air flow is shown in Figure 4-3, and the experiment results are shown in Table 4-2.
The exhaust air volume at the time of experiment, was calculated in the same way as the method for calculating the assumed exhaust air volume, and the value of the static pressure measured at each wind speed was added to the outside static pressure of the TWU fan motor, and applied to the fan motor characteristics table.

Figure 4-3 Visualization of air flow
(Left: 5.0 m/s; Center: 10.0 m/s; Right: 13.5 m/s)
### Table 4-2 TWU exhaust air volume at each outside air velocity (experiment results)

| Air Velocity | Wind direction | TWU exhaust air volume |
|--------------|----------------|------------------------|
|              |                | Hi         | Med         | Lo         |
| 0 m/sec      | —              | 840 CMH     | 660 CMH     | 480 CMH    |
| 5.0 m/sec    | front          | 816 CMH     | 630 CMH     | 456 CMH    |
|              | Upper 45°      | 816 CMH     | 624 CMH     | 450 CMH    |
|              | Lower 45°      | 810 CMH     | 618 CMH     | 438 CMH    |
| 10.0 m/sec   | front          | 738 CMH     | 528 CMH     | 288 CMH    |
|              | Upper 45°      | 684 CMH     | 444 CMH     | 84 CMH     |
|              | Lower 45°      | 684 CMH     | 444 CMH     | 84 CMH     |
| 13.5 m/sec   | front          | 426 CMH     | Cannot exhaust | Cannot exhaust |
|              | Upper 45°      | 240 CMH     | Cannot exhaust | Cannot exhaust |
|              | Lower 45°      | 378 CMH     | Cannot exhaust | Cannot exhaust |

In the experiment results, and the assumed exhaust volume by calculation, almost equivalent results were obtained up to the wind speed of 10 m/s. At the wind speed of 13.5 m/s, the result was less than the assumed exhaust volume, but the exhaust volume at the front of the wind angle exceeded the target of 350 CMH.

### 5. TWU exhaust performance test (real sash model)

#### 5.1. Outline of exhaust performance test (real sash model)

Figure 5-1 shows the situation where the TWU is installed in a wind tunnel. The actual performance test was conducted by connecting the sash and the TWU at the sash-maker's test site. In this actual performance test, the TWU exhaust capacity test was added to the other test items.

![Figure 5-1 Exhaust performance test (real sash model)](image_url)
5.2. Results

5.2.1 Watertight performance test result
At a positive pressure of 3,980 Pa (wind speed 81.4 m/s), water spout amount of 8 L/m²/min, water film amount of 30 L/m/min, it was confirmed that there was no water leakage from the TWU in AC mode and the sash.

5.2.2 Dynamic wind resistance test result
It was confirmed that there is no harmful deformation and damage at the positive pressure of 3,980 Pa (wind speed of 81.4 m/s) and the negative pressure of -3,760 Pa (wind speed of 79.2 m/s) for the TWU in AC mode.

5.2.3 TWU Exhaust Capacity Test Results
During the test, an air volume measuring duct was connected to the TWU indoor exhaust port in the exhaust mode, the average wind speed for 5 seconds was measured by an anemometer, and the exhaust air volume was calculated from the area. Table 5-1 shows the experiment results of TWU exhaust air volume. It was confirmed that an air volume of 480 CMH or more can be secured up to 200 Pa (wind speed 18.3 m/s) even at positive pressure and negative pressure.

### Table 5-1 TWU exhaust air volume at each outside air velocity (experiment result)

| Test pressure | Target air volume | Exhaust air volume |
|---------------|-------------------|--------------------|
| Positive pressure |                  |                    |
| 60 Pa | 840 CMH | 1,130 CMH |
| 130 Pa | 840 CMH | 1,130 CMH |
| 200 Pa | 840 CMH | 1,130 CMH |
| Negative pressure |                 |                    |
| -60 Pa | 840 CMH | 1,100 CMH |
| -130 Pa | 840 CMH | 1,100 CMH |
| -200 Pa | 840 CMH | 1,100 CMH |

6. Conclusion and Discussion
This report outlines an improved through-wall unit (TWU) and describes a new air conditioning system, assuming an office building that combines operation patterns according to air-conditioning needs. The efficiency of the TWU can be improved by using the indoor exhaust heat and, at the time of overtime work, by using a cool breeze mode.

This paper describes the exhaust performance results of a TWU by experiments simulating wind pressure on a high-rise building. Based on the experiment results, it was confirmed that the exhaust performance and the cooling and heating capacity could be satisfied when the wind speed is up to 10 m/s.

In addition, full-scale performance experiments were conducted and it was confirmed that a TWU has wind pressure resistance and watertight performance, and is able to provide exhaust air volume of 480 CMH or more, at up to 200 Pa (wind speed 18.3 m/s) under both positive and negative pressure.

### References

[1] Kubo H, Haneji T and others. 2016 *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 1 (Kagoshima:Japan/SHASE)* p 213-216.

[2] Kubo H, Haneji T and others. 2016 *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 2 (Kagoshima:Japan/SHASE)* p 217-220.