Performance of Whole-building Pressurization as Countermeasure against Stack Effect in High-rise Office Building

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ABSTRACT

This paper deals with pressurization using HVAC systems on each floor as a countermeasure against stack effect generated in the winter in high-rise office buildings that do not use revolving doors at the entrance. A whole-building pressurization system is installed in a 23-story building located in Tokyo in order to prevent various problems caused by the stack effect, e.g. noise generation at elevator doors or large heating loads and deterioration of the thermal environment at a 2-story entrance hall due to the increase of outdoor air infiltration through automatic entrance doors. Pressurization is realized not by increasing supply air volumes but by reducing exhaust air volumes on each floor.

Measurements were made on 4 days in the winter to evaluate the performance of the pressurization system. Outside conditions such as outside temperatures, wind speeds and directions, and the indoor thermal environment such as air temperature distributions, air velocity distributions, globe temperatures and PMV's at the entrance hall (on the 1st basement and 1st floors) were measured using data acquisition systems. Pressure differences between the indoor and the outdoor were measured on the 1st basement, 1st, 7th and 17th floors. Pressurized air volumes were set at 2 cases of 500 or 2000 $m^3/(h\cdot floor)$.

According to the measurement results, negative pressures generated at the entrance hall were decreased by 10 Pa or more by increasing pressurized air volume from 500 to 2000 $m^3/(h\cdot floor)$. At the same time, indoor velocities showed a sharp drop and indoor air temperatures were kept high with the higher pressurized air volumes. These results demonstrate that the whole-building pressurization systems are effective as countermeasures against problems caused by the stack effect in high-rise office buildings while conserving energy by reducing heating loads at the entrance halls and also reducing electric energy consumed for exhaust fans on each floor.

1. INTRODUCTION

According to previous papers (Tamura et al. 1966; Hayakawa et al. 1978), large indoor and outdoor air temperature differences caused by the stack effect in high-rise buildings in the winter season may cause problems, such as the infiltration of large quantity of the outside air into the buildings through entrances and basements, wind noise attributable to the pressure differences across doors, and adverse effects on the operation of doors. An effective measure to address these problems is to increase the air tightness on lower floors by installing revolving doors at entrances. However, there are increasing cases where the revolving doors are withheld from use because of concerns about the safety of the doors and the limitations on the number of people walking through the doors. This paper reports the results of field measurement in the winter in a high-rise office building that employs a whole-building pressurization system that is expected to be an effective measure to mitigate the stack effect as an alternative to the revolving doors.

2. OUTLINE OF FIELD MEASUREMENT

2.1 Measuring object

The measuring object is a 23-story high-rise office building with three basement levels located in midtown Tokyo. Figures 1 and 2 show the section and entrance floor plan of the building, respectively. The 112.6m-high building has a total floor area of 59,742 m^2. The entrance is an interior open space extending from the 1st basement level to the 1st floor.

2.2 Measuring method

The field measurement was carried out on February 13 (Tuesday) to 16 (Friday), 2007. Tables 1 and 2 list measurement items and conditions, respectively. Air flow rate for pressurization using the air-conditioning system was about 500 $m^3/(h \cdot floor)$ on February 13, 14 and 16 and about 2,000 $m^3/(h \cdot floor)$ on February 15. Climate conditions, room temperatures (including temperatures in the staircase, parking lot in the basement), thermal environments in the entrance (air temperature, air velocity and others), indoor and outdoor pressure differences (in the entrance and on the 7th and 17th floors) were continuously measured. Measuring points are shown in Figures 1 and 2. The situations of the thermal measurement in the entrance hall are shown in Photo. 1.

3. RESULTS OF FIELD MEASUREMENT

3.1 Climate conditions and others

Figure 3 shows the climate conditions on February 14 to 16, 2007. Minimum air temperatures were 9 to 10°C on February 14 and 15 and slightly lower at 6.6°C on February 16. The wind direction was dominantly from the north, and it was windy during the day on February 15 (maximum wind velocity: a little

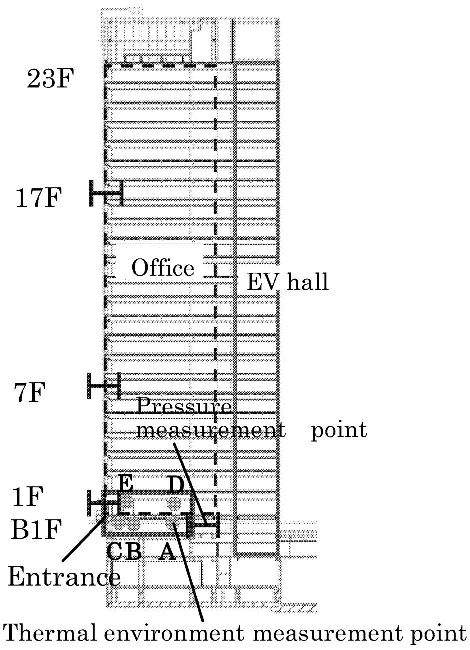


Figure 1 Section of the building.

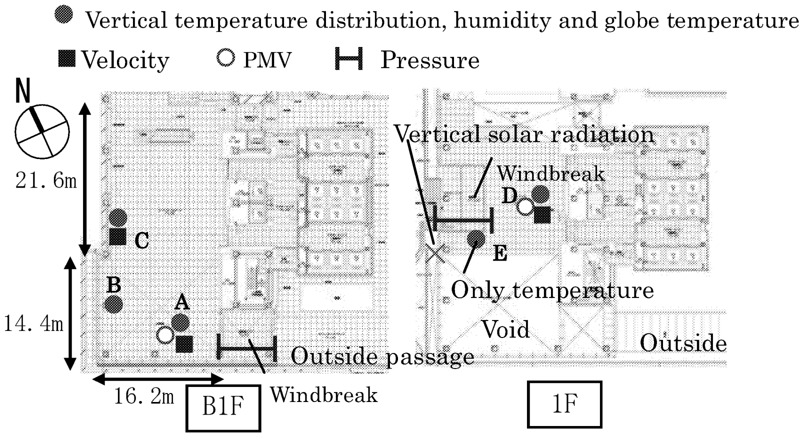


Figure 2 Plan of the entrance hall.

(1) Points A (front) and B on B1F.

(2) Point D on 1F.

Photo. 1 Thermal measurement in the entrance hall.

less than 10 m/s). The elevator (EV) shaft temperatures (on the 15th and PH 2nd floors) were 18 to 22°C, and the staircase temperatures were 17 to 19°C on the 1st floor and 20 to 23°C on the 17th floor, and the basement parking lot temperatures were 13 to 15.5°C (figures omitted).

3.2 Pressure distributions

Figure 4 shows a change over time in the indoor and outdoor pressure differences on the floors. Of the measured data at intervals of one second, only the data at intervals of one minute is plotted in the figure (the same applies for the following changes over time). The pressures in the entrance were lower than the atmospheric pressure in large areas of the building until 8:00 when the HVAC (heating, ventilating and air-conditioning) system started up and from 18:30 onward when the HVAC system was turned off. The entire building was slightly pressurized and the pressures in the building tended to be higher than the atmospheric pressure during air-conditioning hours. There were many hours when the pressures in the 1F entrance were lower than the atmospheric pressure on February 15 and 16. The reason for this seems to be the high wind velocities and the wind pressures acting from the 1F entrance to the outside wind direction on those days. Figure 5 shows the average of indoor and outdoor pressure differences (data at intervals of one second averaged for one hour) before and after the air-conditioning system started up and turned off. The negative pressures on the 1st and 1st basement floors were resolved by the pressurization, which confirmed the effectiveness of the pressurization system. The pressures before the HVAC system started up were higher immediately before the HVAC system was turned off. This seems to be affected by the less number of people in the

Table 1 Measurement items.

Climate conditions	Air temperature, air humidity, horizontal total solar radiation, wind speed and direction. Obtained from the BEMS (Building Environmental Management System).
Pressure difference between the onside and the outside	Measured by manometers (MKS BARATRON TYPE270).
Indoor air velocity	FL+0.1m and 1.1m. Measured by ultrasonic anemometers (Kaijo DA600-TR90AH). Output 30-second avarage values with measuring frequency of 20 Hz.
Vertical temperature distribution	Floor surface temperatures, air temperatures at FL+0.1m, 0.6, 1.1, 1.7, 2.2, 2.8m. Measured by T-type thermocouple（diameters in 0.1 mm, with 1 wire）
Indoor humidity	FL+1.1m. Measured by relative humidity sensors (VAISALA HMP45D).
Globe temperature	FL+1.1m. Measured by globe temperature meters (diameters in 150mm) and T-type thermocouple（diameters in 0.1 mm, with 1 wire）.
PMV	FL+1.1m. Measured by B&K Thermal Comfort Meter (Type 1212). Assumed 1.2 clo, 1.4 met, and vapor pressure of 0.3 kPa.
Air temperature over doors	Measured by T-type thermocouple（diameters in 0.1 mm, with 1 wire）
Vertical solar radiation	Measured by precious solar radiation meter (EKO Instruments MS-402F).
Air temperatures in elevator shafts and machine rooms	Measured by T-type thermocouple（diameters in 0.2 mm, with 10 wires）. In machine rooms on the 15th floor and PH-2nd floor.
Air temperatures in staircases and basement parking lot	Measured by stand-alone type thermometers（SHINYEI HA3633）

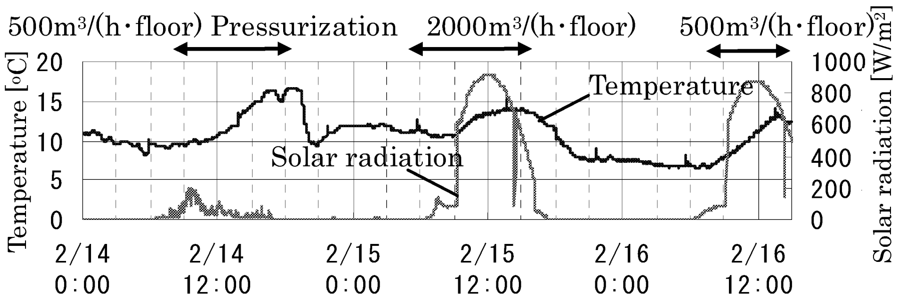
Table 2 Measurement conditions.

Pressurized air volume	While HVAC systems are ON from Feb. 13 to 14 and on Feb. 16 ⇒ Pressurization of 500 m^3/(h·floor) While HVAC systems are ON on Feb. 15 ⇒ Pressurization of 2000 m^3/(h·floor)
Time for pressurization	Basic pressurization time is from 8:30 to 18:30 on weekdays. Exceptions: 8:00 to 23:00 for 4 floors, 7:00 to 21:00 for 1 floor, 7:00 to 19:00 for 1 floor, 8:30 to 22:30 for 1 floor. HVAC susytems were OFF on the 21st and 22nd floors because of construction work.
Measuring time step	1 minute for climate conditions and air temperatures in staircases and basement parking lot. 1 second for the other automatic measurements.
Others	Measured from 21:00 on Feb. 13 (Tuesday) to 15:00 on Feb. 16 (Friday) in condition of real occupancy. For floors without occupancy, HVAC systems were ON from 8:30 to 18:30. The other data such as room temperatures on each floor were obtained by BEMS.

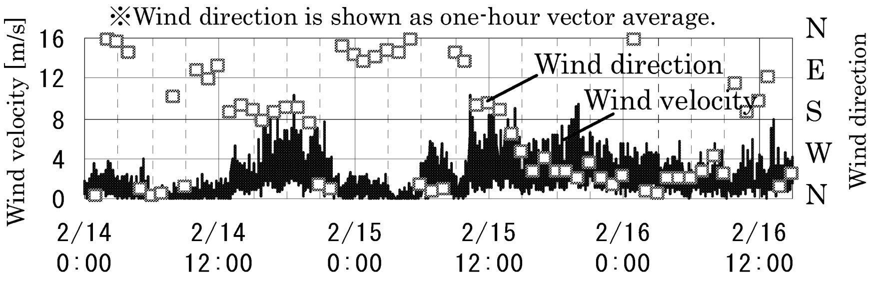
evening than in the morning. Looking into the pressures on the 1st and 1st basement floors before and after the pressurization, the pressures at an air flow rate for pressurization of 2,000 m^3/(h･floor) were higher than at an air flow rate for pressurization of 500 m^3/(h･floor) by about 2 Pa and 7 Pa in the morning and evening, respectively. This difference seems to be caused by the effects of wind pressure in addition to the difference in the air flow rate for pressurization because wind velocities were very high on February 15 when the air flow rate for pressurization was 2,000 m^3/(h･floor).

3.3 Indoor air velocities

Figure 6 shows a change over time in indoor air velocity (at FL + 1.1 m and 0.1 m) at the entrance. The air velocity is expressed by the absolute value of air velocity calculated from the three-dimensional components measured with ultrasonic anemometers. As can be seen from the figure, although the air velocities on the 1st basement floor and near the entrance doors on the 1st floor increased as the doors opened, the air velocity levels were controlled by the pressurization during air-conditioning hours. Figure 7 shows the average of indoor air velocities (data at intervals of one second



(1) Outside air temperature and horizontal total solar radiation



(2) Wind velocity and direction

Figure 3 Climate conditions (February 14 to 16, 2007).

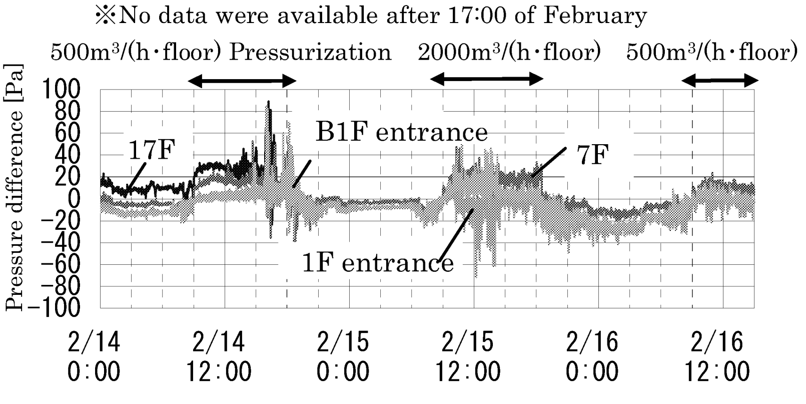
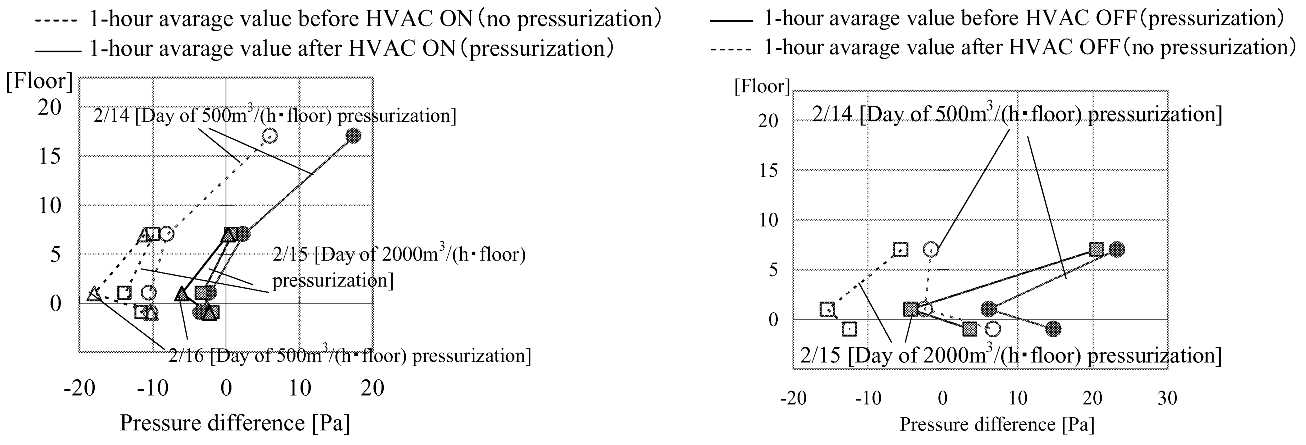


Figure 4 Variations of pressure difference between the outside and inside.

averaged for 30 minutes) before and after the HVAC system started up and was turned off. The effects of the pressurization were verified by the difference in the average of indoor air flow velocities before and after the air-conditioning system was turned off. The reason that indoor air velocities were rather high after the HVAC system (pressurization) started up seems to be the more number of people and the longer time period over which the entrance doors opened.

3.4 Air temperatures

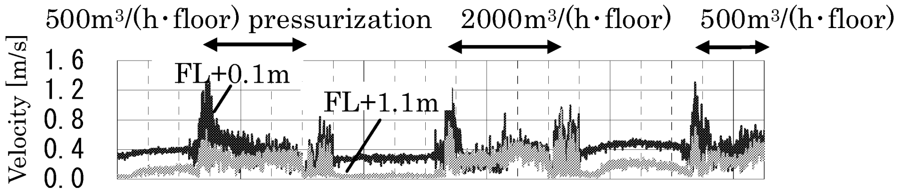
Figure 8 shows a change over time in the air temperature (at FL + 0.1 m and 1.1 m) in the entrance. Air temperatures dropped to 13 to 15°C on the 1st basement floor and 15 to 17°C on the 1st floor before the HVAC system started up, and were maintained at about 20°C and 18 to 20°C at FL + 1.1 m and FL + 0.1 m, respectively, on the 1st basement floor, and at 20 to 25°C on the 1st floor during HVAC hours. There were no large drops in room temperature due to the operation of the entrance doors during HVAC hours, indicating the effectiveness of the pressurization. Temperature fluctuations on the 1st floor were slightly larger than on the 1st basement floor due to the effects of wind pressures on February 15 and 16.



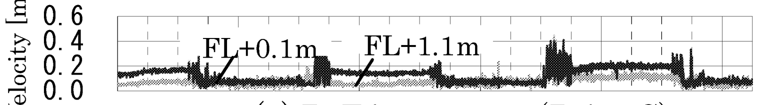
(1) Before and after HVAC ON (8:30)

(2) Before and after HVAC OFF (18:30)

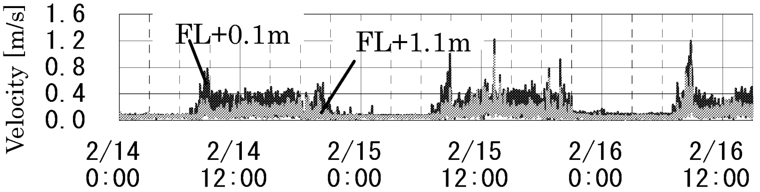
Figure 5 One-hour average values for pressure difference before and after HVAC ON and OFF.



(1) B1F near entrance (Point A)



(2) B1F inner part (Point C)



(3) 1F near entrance door (Point D)

Figure 6 Variations of indoor velocity.

4. CONCLUSIONS

The field measurement was carried out in the high-rise office building, equipped with the pressurization system as a measure to address the stack effect in the winter, located in Tokyo. As a result, the field measurement confirmed that the whole-building pressurization system is effective at mitigating the stack effect.

ACKNOWLEDGMENTS

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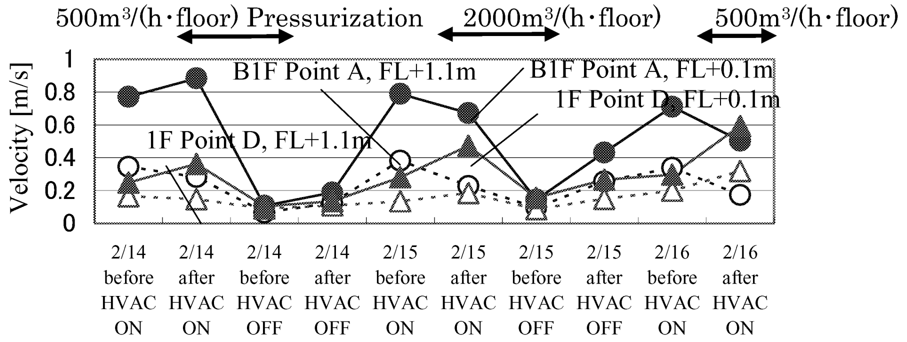
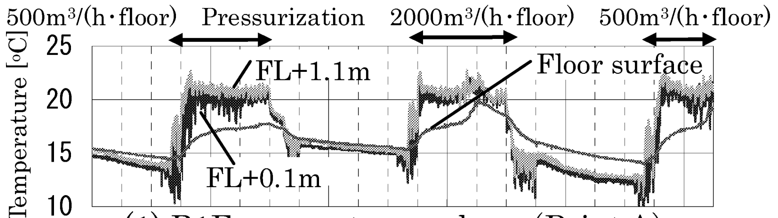
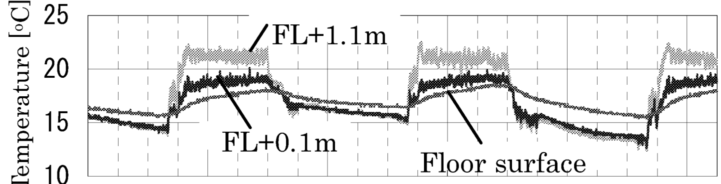


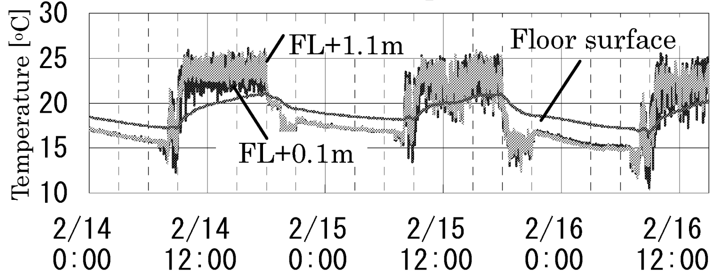
Figure 7 30-minute average values for indoor air velocity before and after HVAC ON and OFF.



(1) B1F near entrance door (Point A)



(2) B1F inner part (Point C)



(3) 1F near entrance door (Point D)

Figure 8 Variations of air temperature in entrance.