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Numerical investigation on the combined effect of the stack effect and wind pressure of a high-rise office building

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SUMMARY:
The vertical airflow is generated in high-rise buildings due to the stack effect caused by temperature differences between the inside and the outside of the building, which may result in severe problems. In this paper, based on the results of wind tunnel test, the COMIS model is applied to the investigation of the combined effect of stack effect and wind pressure of a 360 m super high-rise office building in northern China. The simulation is carried out considering the influence of environmental factors, which are the wind speed velocity, wind attack angle and temperature, and the human behaviour, which is the opening-closing condition of the doors in Floor 1. The results confirm the remarkable influence of all these factors and point out that the related problems will be exacerbated in winter while alleviated in summer due to combined effect. Several methods are also proposed to solve the pressure problems.

Keywords: stack effect, wind pressure, pressure distribution, super high-rise building

1. INTRODUCTION

Super high-rise building with frame-core tube structures integrates large variety of vertical shafts, such as elevator shafts, duct shafts, and ventilation shafts. Due to the thermal pressure difference caused by the temperature difference between inside and the outside, air flows from outdoor to indoor or from indoor to outdoor through the openings and gaps of the building, which is called stack effect. In hot summer or cold winter, severe problems such as strong airflow from doors, unpleasant noises through gaps, problems opening and closing elevator doors and hall doors, and difficulty in controlling the indoor temperature and ventilation systems. Specially, these above problems can be exacerbated by wind (Khoukhi M et al, 2007) and human behaviours such as opening or closing a door, which are remain detailed surveyed. So it is urgent to comprehensively reveal the combined effect of the stack effect, wind pressure and human behaviours.

2. DESCRIPTION OF THE BUILDING AND SIMULATION SETTINGS

The building is a 360 m super high-rise one located in Jinan, shandong province, China, which is cold in winter and severely affected by stack effect. With 68 storeys above a 3-storey basement, the building was divided into five function zones: the basement, the business zone with podium, the office zone with a lobby on Floor 34, the hotel zone and the equipment zone, and there are also

6 refuge layers. The building is completely decorated with curtain wall as its façade. Elevator shafts are the most important vertical paths of airflow in this building. The details of the building and main elevators are shown in Fig.1.

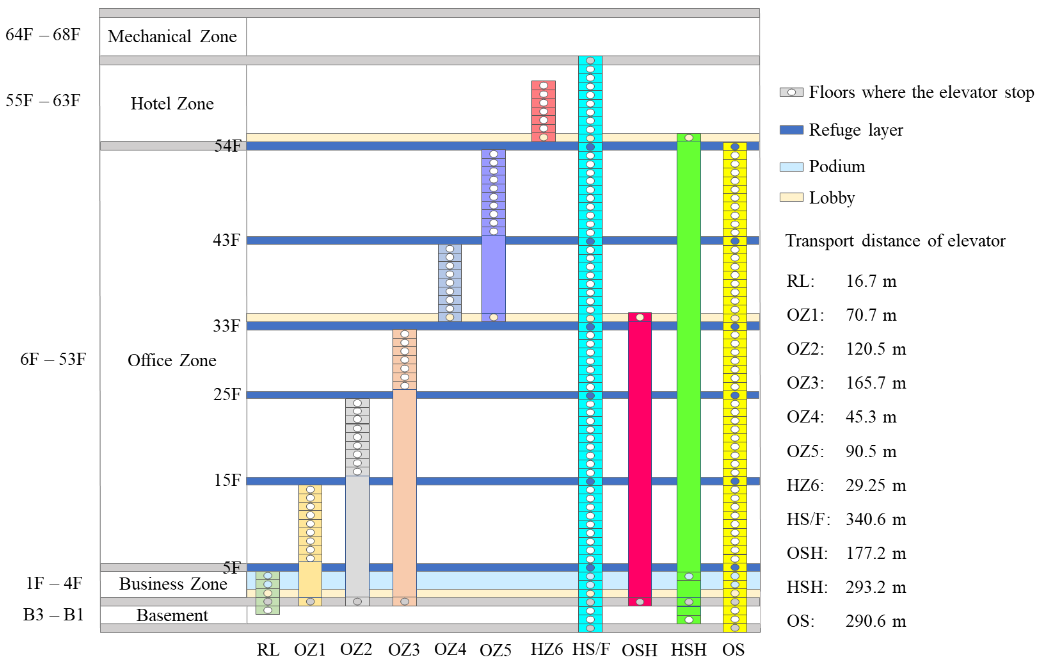
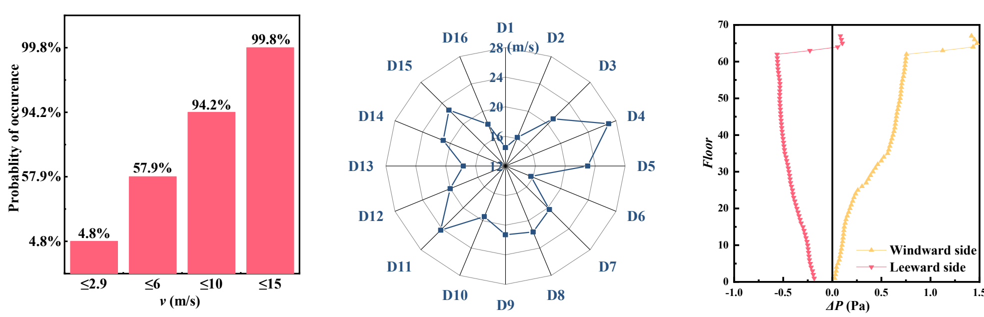


Figure 1. Five zones and the main elevators of the building

The airtightness parameters of various doors are selected according to the Curtain wall for building (GB/T21086-2007) and reference (Jo J.H et al, 2007). The extreme inside and outside temperature in winter and summer are found in Design code for heating ventilation and air conditioning of civil buildings (GB50736-2012). As shown in Fig.2, The wind speed data is derived from the statistics of measured data from local meteorological station and 90° is used for simulation according to the wind rose of extreme wind speed under the 50-year return period. According to the wind tunnel test results, the wind pressure coefficients of each facade are obtained by interpolation of each measuring point layer.



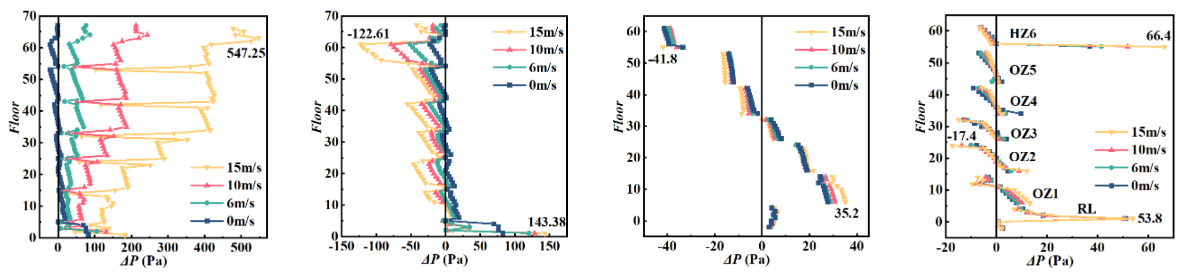
(a) statistics data of wind speed (b) wind rose of extreme wind speed (c) wind pressure coefficients

Figure 2. Wind speed and direction of the building and wind pressure coefficient

3. ANALYSIS OF SIMULATION RESULTS

3.1. The pressure difference distribution when the doors and windows are closed

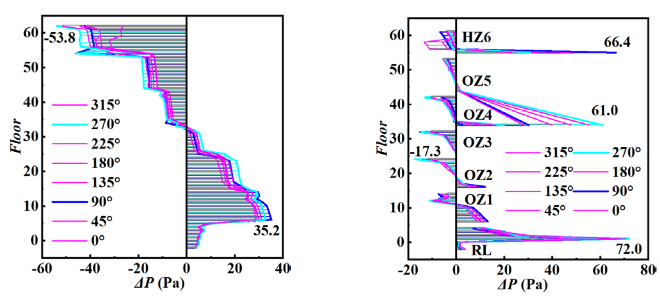
As shown in Fig.3 (a) and (b), when the wind speed is 0 m/s, the pressure difference of curtain wall and the one of elevator door are linearly distributed within the refuge layers, and the pressure difference of all refuge layer is close to 0 Pa. As the wind speed gradually increases from 0 m/s to 15 m/s, the profile is gradually dominated by wind pressure, showing a nonlinear distribution, which is like that of the wind pressure coefficients. Pressure difference of refuge layer curtain wall is dominated by wind speed. As shown in Fig.3 (c) and (d), the pressure difference of the long-distance elevator HS/F doors presents a linear variation and has a leap between different function zones. The one of seven short-distance elevator doors have similar rule in respective operating zones, so the maximum pressure difference is located at the top and bottom of each zone. As shown in Fig.4, for all elevators, the pressure difference varies with the change of wind attack angle, but the maximum all appears at the angle of 90° and 270°. The pressure difference on the refuge layers fluctuates significantly, indicating its vulnerability.



(a) ΔP of curtain wall at windward side (b) ΔP of curtain wall at leeward side

(c) ΔP of the long-distance elevator HS/F door (d) ΔP of different short-distance elevator doors

Figure 3. Pressure distribution of curtain wall and elevator door under increasing wind speed

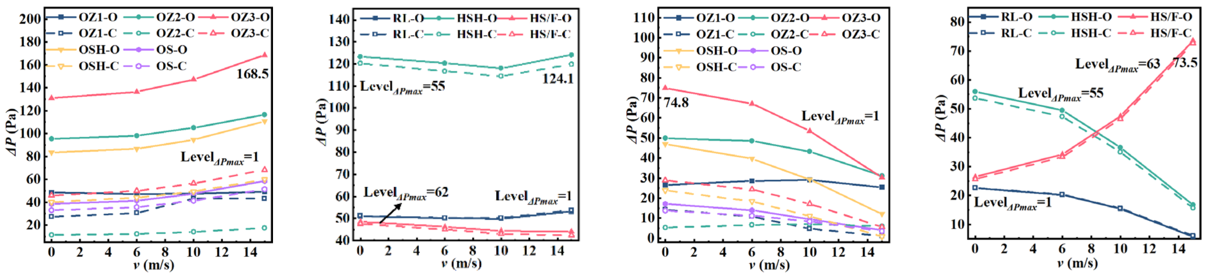


(a) ΔP of the long-distance elevator HS/F door (b) ΔP of different short-distance elevator doors

Figure 4. Pressure distribution of elevator door under different wind attack angle

3.2. The effect of opening-closing condition of the doors on Floor 1 and the temperature difference

As shown in Fig.5, regardless of the outdoor wind condition and temperature difference, when the door is open, the elevator door pressure difference of OZ1, OZ2, OZ3, OSH and OS increase significantly, while the ones of RL, HSH and HS/F fluctuate little. To find the reason, we can see that for the elevators whose maximum pressure difference appear on Floor 1, there is no partition between the curtain wall and the elevator door. However, there are at least one partition for the RL, HSH and HS/F. As wind speed increases, the maximum pressure difference of the elevator doors goes up in winter while goes down significantly in summer, which demonstrates the opposite influence of human behavior in winter and summer. This is because the increase of wind speed will strengthen the top - to - bottom airflow caused by stack effect in summer and offset the increased pressure due to the opening of the door on Floor 1.



(a) $\Delta P_{\max}$ of elevator doors greatly affected by the opening-closing condition on Floor 1 in winter

(b) $\Delta P_{\max}$ of elevator doors slightly affected by the opening-closing condition on Floor 1 in winter

(c) $\Delta P_{\max}$ of elevator doors greatly affected by the opening-closing condition on Floor 1 in summer

(d) $\Delta P_{\max}$ of elevator doors slightly affected by the opening-closing condition on Floor 1 in summer

Figure 5. The maximum pressure difference of elevator door with the increase of wind speed

5. CONCLUSIONS

From the results obtained in this study, it may be concluded the following:

(1) The increase of wind speed will aggravate the pressure difference of most elevator doors in winter and thus intensify the stack effect, and reduce the pressure difference of most elevator doors in summer and thus alleviate the stack effect on the contrary. The wind attack angle has a significant effect on the pressure difference, but the specific case study should be conducted based on the local wind conditions.

(2) The opening-closing condition of doors on Floor 1 will significantly affect the pressure difference of the elevator door that functions through the Floor 1 and has no partition with the curtain wall and have opposite influence in winter and summer.

(3) The elevator doors on the first floor, the upper and lower floors of the refuge layer and near the top of the building are the most vulnerable positions, which need to be protected.

(4) Improving the air tightness level of the envelope, additional partition of the elevator door in the vulnerable positions, revolving door instead of flat door on Floor 1, increasing the motor torque of the elevator door will effectively alleviate the elevator door fault caused by the stack effect

ACKNOWLEDGEMENTS

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