9th Asia-Pacific Conference on Wind Engineering
Auckland, New Zealand
3-7 December 2017

Implications of Vented Facade on Curtain Walls, Partition Walls and Exhaust Fans in Tall Buildings

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Abstract

The rise of tall buildings featuring operable facades for natural ventilation is bringing much attention to the wind effects of vented facades in buildings as a design issue. This paper presents the some of the wind effects on curtain walls, internal partition walls and mechanical exhaust fans in tall residential buildings. Three case studies have been presented to show how some of these design issues can be addressed at an early stage of the design through appropriate wind tunnel testing and analysis.

Introduction

Over the last few years, the number of buildings over 100m in Australia has increased significantly, with over 100, mostly residential towers, planned, constructed or under construction in Melbourne alone [4]. Due to the higher energy cost of using mechanical systems for heating or cooling and the desire to minimise the carbon footprint, many of these buildings are featuring operable facades, especially at higher levels to provide natural ventilation. However the benefits of natural ventilation can easily be overshadowed if the effect of the increase in wind pressures as a result of facade venting is not considered on other components of the building such as curtain walls and internal components. Unfortunately, at present, the Australian Building Standards do not extensively address the implications of wind effects on tall buildings with operable facades [1, 7].

Considerations of Wind Effects on Vented Facades

Most buildings are considered as bluff bodies and the wind flow around them is based on the differences in pressure distributions around and within the buildings, whereby the wind flow paths will travel from regions of high pressures to low pressures. Positive pressure regions are created on the wind facing sides (windward sides) of a building and the separation of the flow around the windward building edges creates negative pressure regions (suctions) on the opposite sides (leeward sides), roof and side walls. The wind flow paths around a building with facade openings are illustrated in figure 1.

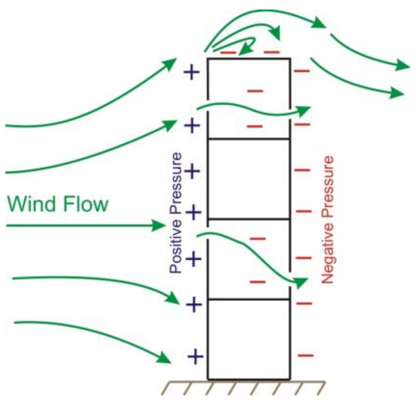

Figure 1. Illustration of wind flow path around a building with facade openings

In general, tall buildings with operable facades tend to have a greater magnitude of internal negative pressure as during windy conditions, residents would typically keep windward facing windows/doors shut and leave leeward/sidewalls facing windows/doors open. Dominant openings on tall buildings can cause external pressures to act on internal partition walls, which would result in failure if not adequately designed. Additionally, the increase in wind pressure difference as a result of multiple simultaneous openings in the facades could result in failure of curtain walls near those openings and could also affect the performance of the building mechanical air handling systems. Some of the main consequences, classified into three categories, of vented facades are:

- Safety issue
    - Injuries from doors slamming shut
    - Inability to open doors in an emergency
    - Failure of internal components
    - Inability to reach fire escape or keep fire escape clear of smoke
- Building issue
    - Wind generated noise
    - Lift doors malfunction
    - Odour pollution
    - Deflection of external windows/doors
    - Malfunction of mechanical systems
- Legal issue
    - Not fit for purpose
    - Who is accountable for damages
    - Relocating residents
    - Compensation

Many of these issues can be addressed during the design phase through appropriate wind tunnel testing and analysis.

The placement of operable windows/doors can be modelled more effectively as well as designed for adequate stiffness and strength for the appropriate high wind loads and ensuring they seal properly to avoid deflection or damage and minimise the risk of wind generated noise.

To prevent uncontrolled venting and minimise odour pollution, mechanical exhaust fans that vent locally can be designed to overcome most of the external positive pressure situations and rely on dampers to ensure they remain shut when not in use or when airflow starts to reverse, i.e. driven by an external positive pressure to negative internal pressure.

Dominant openings can be addressed by a 'Building Management System' to ensure all operable facades and external exhaust vents are closed in a strong wind event. This can be as simple as requiring all residents to close operable facades during strong wind conditions and when the apartment is unoccupied. Alternatively an automated system such as a snap-shut mechanism on the operable facades that would activate under a specified wind pressure could be used to ensure the operable facades are shut when required.

Wind Tunnel Studies Addressing Vented Facade Issues

Wind tunnel modelling of the wind effects on buildings has been well established for many decades and rely upon obtaining similitude between the wind tunnel model and the full-scale building. This can be achieved by using a wind tunnel capable of producing turbulent boundary layer models of the natural wind, a geometrically similar scaled model (typically 1/300 to 1/400) of the building and proximity, and a sufficiently high Reynolds number (especially for curved buildings with smooth facades) to achieve acceptable flow similarities. The general use of boundary-layer wind tunnels and similitude requirements for these purposes have been discussed in various depths by Davenport and Isyumov [3], Cermak [2] and Melbourne [6].

The facade pressures determined for a tall building are external pressures to which some allowance for internal pressure must be made by allowing for the worst case venting through an opening, or for general porosity if all external openings are considered as closed. Since most of the tall residential buildings have operable facades that have the ability to be sealed, the wind tunnel facade pressure studies are for all external openings closed, with allowance for internal pressure based on an internal pressure coefficient as defined by the Australian Wind Loading Standard, AS/NZS 1170.2:2011 [1]. Figure 2 shows a typical wind tunnel setup of a 225m tall building instrumented with approximately 450 pressure taps, with a higher density of pressure taps near corners and discontinuities.

Figure 2. Wind tunnel setup of a 225m tall building instrumented with pressure taps

Prior to wind tunnel testing, the likely locations of operable windows/doors and mechanical exhausts on the facades are identified and pressure taps are placed near them on the model. This allows for analysis of various vented facade scenarios to assist the design team to determine the following:

- Pressures on the windward curtain walls for leeward windows being left open.
- Snap-shut window pressures required for various prescribed differential pressures across internal partition walls.
- Frequency of occurrence of windows shutting due to wind action
- Frequency for which a prescribed apartment exhaust fan pressure rise would be insufficient to overcome the wind pressure.

Case Studies

Curtain Wall Pressures Consideration

This case study presents the significant increase in curtain wall pressures on the windward facade due to operable windows being open on the leeward sides at Level 62 of a 237m tall residential building in the Melbourne Central Business District (CBD).

Figure 3 presents the Level 62 floor plan with the locations of operable facades highlighted in green and the locations of the pressure taps on the wind tunnel model indicated by the numbered red dots. Two arrows have been sketched on figure 3 to illustrate the possible pressure paths within that level for two vented facade scenarios as follows:

(1) Blue arrow, illustrating a possible pressure path within an apartment for an operable window on the side wall near tap location 20C being left open.

(2) Purple arrow, illustrating a possible pressure path across different apartments for an operable window on the leeward side near pressure tap location 40C being left open.

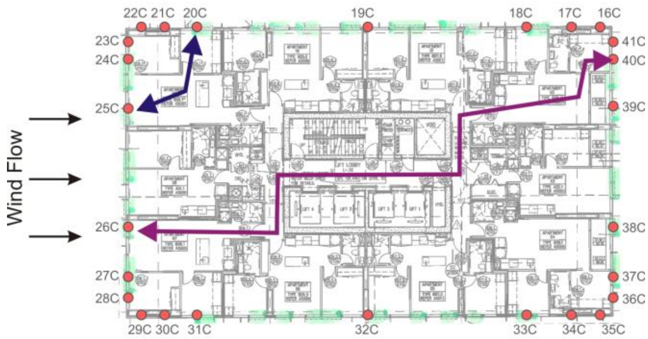

Figure 3. Pressure tap locations at Level 62 with arrows indicating possible pressure paths for a vented facade scenario.

The Ultimate Limit State design pressures near the 2 windward operable windows near pressure tap locations 25C and 26C, with and without facade venting on the leeward sides have been calculated and presented in table 1. The results show that the curtain wall near pressure taps 25C and 26C will experience an increase of approximately 45% (~1000 Pa) in design pressures during Ultimate Limit State wind conditions.

Without Facade Venting		With Facade Venting		% increase in Curtain Wall Pressures
Pressure Tap	ULS Pmax, Pa	Pressure Tap	ULS Pmax, Pa	
25C	2383	25C (venting at 20C)	3489	46%
26C	2102	26C (venting at 40C)	2969	41%

Table 1. Windward curtain wall design pressures at Level 62 with and without facade venting for Ultimate Limit State conditions.

Internal Partition Wall Consideration

This case study presents the estimated snap-shut window pressures and expected number of hours per year (based on a 45° wind direction sector) the snap-shut windows would be expected to activate for 3 prescribed pressure differences across the internal partition walls (0.5kPa, 0.75Kpa and 1.0kPa) at Levels 28 and 70 of a 235m tall residential building in Sydney. The likely highest differential (net) pressures across the internal partition walls was determined by analysing the pressure data for all pressure taps at each of the 2 levels for all combinations of simultaneous open windows/doors for all wind directions.

The snap-shut pressures required for a prescribed net pressure across the internal partition wall was evaluated using equation (1) as follows:

$$\Delta P_{snapshut} = \frac{1}{2} \times \rho \times \left(C_{p,local} - C_{p,internal}\right) \times \overline{V}_h^{\,2} \qquad (1)$$

where $\overline{V}_h$ is the local hourly mean wind speed, ρ is the density of air, $C_{p,local}$ is the local external pressure coefficient and $C_{p,internal}$ is the internal pressure coefficient.

The local hourly mean wind speeds were evaluated using equation (2) as follows:

$$\overline{V}_h = \sqrt{\frac{2 \times \Delta P}{\rho \times C_{p,diff}}} \qquad (2)$$

where ΔP is the prescribed net pressure across the partition wall and $C_{p,diff}$ is the differential pressure coefficient associated with the likely highest differential pressures.

The frequency of occurrence (hours per year) of a window shutting due to wind action was estimated by referencing the local hourly mean wind speeds from equation (2) as equivalent hourly mean wind speeds at 10m in an open terrain. This allowed integration with an applicable cumulative probability distribution of the Bureau of Meteorological hourly mean wind speeds for Sydney as a function of wind direction.

The results are presented in table 2 and show that the snap-shut pressures at the 2 levels are similar for a prescribed net pressure across the internal partition walls but the frequencies of occurrence increased for the higher level. This analysis would assist the design team to determine the appropriate internal partition walls to use at various levels and their impact on the 'Building Management System'.

Level	Pressure Difference across Internal Partition Wall (Pa)					
	500		750		1000	
	Snap-shut Pressure	#hours/year	Snap-shut Pressure	#hours/year	Snap-shut Pressure	#hours/year
Level 28	350 - 400	125 - 270	525 - 600	70 - 100	700 - 790	~35
Level 70	290 - 440	210 - 385	440 - 660	100 - 285	585 - 880	40 - 150

Table 2. Snap-shut window pressures and frequency of occurrence for 3 prescribed net pressures across the internal partition walls at 2 levels for a 235m building in Sydney CBD

Apartment Exhaust Fans Consideration

This case study presents the expected number of hours per year that an apartment exhaust fan with a maximum pressure rise of 150 Pa on the facades of a 235m tall residential building in Sydney CBD would be expected to be insufficient to overcome the wind pressures. A similar methodology for estimating the number of hours per year snap-shut windows will be expected to activate is used, with the difference being the use of the measured external pressure coefficients near the exhausts with an allowance for internal pressure for an equally permeable facade case (i.e. all operable windows/doors closed and the only venting is though the exhaust opening). Due to the unlikelihood that exhaust fans would be continuously operated over a period of 1 hour or more, the hourly mean wind speeds have been expressed for lesser average time periods using factors from Durst [5] prior to being used with to Bureau of Meteorological cumulative probability distribution of hourly mean wind speeds at 10m in an open terrain as a function of wind direction for Sydney. Table 3 presents the estimated total number of hours per year for all wind directions combined, an apartment exhaust fan with a maximum pressure rise of 150 Pa would be expected to be insufficient to overcome the wind pressure rise for a range of external pressure coefficients for 2 periods of continuous operation (up to 1 hour and up to 10 minutes). As expected, the number of hours the 150 Pa fan pressure rise would be exceeded increases as the pressure coefficient increases. This analysis would enable the design team and building management team to determine the acceptable number of hours that exhaust fans can be inoperative and consequently the various fan pressure rise systems to use across the facades.

Cp,external	#hours/year 150 Pa fan pressure rise would be exceeded	
	Continuous operation of 30-60mins	Continuous operation of <10 mins
1	900	625
1.5	1300	950
2	1600	1100
2.5	1875	1400

Table 3. Number of hours per year a 150 Pa fan pressure rise exhaust would be exceeded for a 235m building in Sydney CBD

Conclusions

This paper has outlined the significant impact that vented facades have on the design of curtain walls, internal partition walls and performance of mechanical exhaust fans in tall buildings. The main consequences, many of which can cause serious damage to the building and residents have also been outlined. Three case studies have illustrated how wind tunnel analysis can assist the design team to mitigate many of those consequences. It is recommended that the wind effects of vented facade on tall buildings be discussed in further details in the Australian Building Standards to advise users on the implications.

References

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