Full Scale Wind Testing to Determine the Role of Vertical Protrusions on Curtainwall Performance

Kehinde J. Alawode [a*], Krishna Sai Vutukuru [a], Amal Elawady [a, b],
Arindam Gan Chowdhury [a, b] and Guido Lori [c]

[a] *Florida International University, Miami, FL, United States, kalaw003@fiu.edu*
[b] *Florida International University, Miami, FL, United States, kvutu001@fiu.edu*
[c] *Florida International University, Miami, FL, United States, aelawady@fiu.edu*
[d] *Florida International University, Miami, FL, United States, chowdhur@fiu.edu*
[e] *Permasteelisa S.p.A., Vittorio Veneto, Treviso, Italy, g.lori@permasteelisagroup.com*

ABSTRACT:
Vertical protruding elements have been commonly used for building aesthetics and reduction of the energy demand. However, design code guidance for these types of curtainwalls are not currently available. This study investigates the effect of vertical protruding elements installed on a single skin façade system on the overall wind actions on the façade using full scale wind experiments. The results show that vertical protrusions can increase the pressure loads on the building surface (as evidenced by increased Cp) by as much as 30% for the condition covered in this study.

Keywords: vertical projections, curtain walls, wind effects, aerodynamic loading

1. INTRODUCTION

Glazed curtain walls or façades are a type of building envelope that primarily serve the purpose of separating the interior of the building and its contents and/or occupants from the exterior environment. Architects have increasingly used glass curtainwalls as facades in mid-and high rise structures for many reasons, including enhancing the resistance to corrosion, recyclability of glass, reduction of building energy consumption as it provides natural lighting, and recent improvements in glass coating technology (Pariafsai, 2016). With the growing need for energy-efficient buildings, the adoption of shading devices on buildings with glazed façades is increasing. Shading devices are usually projecting out of the curtain wall (vertical or horizontal), hereby reducing the amount of sunlight getting into the building. These devices could also have some aesthetic appeal.

A study focused on assessing wind actions on buildings with vertical projections was carried out by Stathopoulos and Zhu (1991) which experimentally simulated both open and urban terrain exposures using a model with an adjustable height, representing tall buildings and low rise buildings. Their results indicated that the effects of vertical projections are adverse and more pronounced at the edges. Also, the change in terrains had little to no effect on the Cps measured on walls with fins.

Chand and Bhargava (1997) considered the effects of both vertical and horizontal projections on wind pressure coefficients. They concluded that the effect of vertical projections on wind pressure distribution on a wall depends on the distance from the projection to the edge of the wall. With

* Lead presenter

projections at the wall edge increasing wind pressures at the corners while projections at a distance from the wall edge reduce pressures at points between the projection and the wall edge.

More recent studies on the effects of vertical projections such as Yang, et al (2020) have majorly focused on the effects of vertical projections on the aerodynamic loads (i.e Base moments and Across and Along Wind forces) on tall buildings. There are also a few numerical studies on the effect of wall projections on wind pressure coefficient such as Zheng et al, (2020).

This research project was motivated by the lack of guidance in major wind loading standards (e.g. Eurocode EN 1991-1-4:2005 and ASCE 7-16) regarding the effect of adding vertical projections on curtain walls on the overall wind actions on the system. This paper therefore presents a comparative experimental study on the wind pressures acting on a full-scale glazed curtainwall panels with and without vertical projections. Section 2 provides details of the experimental setup, materials and methodology, section 3 is a discussion of the results from the experimental study while section 4 summarizes the major findings of the study.

2. METHODOLOGY

2.1. Experimental Setup

The experimental study was carried out at the Wall of Wind (WOW) Experimental Facility (EF) at Florida International University. The WOW EF is an open jet wind tunnel with a 2 x 6 array of fans. The facility is capable of testing large and full scale models up to and at category 5 hurricane wind speeds of ∼70m/s (Gan Chowdhury et al. 2017). Wind speed and turbulence characteristic measurements at the center of the turntable were measured with Cobra probes. The mean wind speed at the center of the turntable and roof height (3.2m) of the test building was ∼21.97m/s. The roughness length z_0 was at 0.08m, which falls within the range of open-terrain exposure.

2.2. Model Configurations

The model used in this study is a full scale, a 3.65m by 1.83m rectangular building with a 3.2m height and a flat roof with 0.41m overhang. Figure 1 shows the plan of the model with vertical projections and the wind directions. The tests were carried out from 0° to 345° wind directions in 15° increments.

Two test configurations were tested in this study, a reference model ‘Without Vertical Projections’ configuration (*Model A*) and a ‘With Vertical Projections” configuration (*Model B*) which had 2 protruding V-shaped fins. On both configurations, the walls on one of the 3.65m length sides of the building were made from three glazed single-skin unitized façade units supported on rigid steel frames. The second wall was constructed from three sections of clear polycarbonate plates mounted on a wooden frame. A wooden vertical projection matching those on the glazed side was added to the wooden frame for Model B. The polycarbonate wall side has a dimension of 3.65m by 3.2m and its main purpose was to provide a similar geometric surface as the actual glazed façade that can be drilled to allow for the fixing of pressure taps. Figure 2 shows *Model A and Model B* configuration on the turntable at the WOW. The other two walls on the 1.83m length side of the building were made from wood, with a door structure at one of the walls to provide access to the inside of the model to allow for instrumentation of the model. During tests, the door was sealed. All the walls were fixed to a steel frame bolted to the turntable. The steel frame provided high rigidity, as needed for running high wind velocity tests.

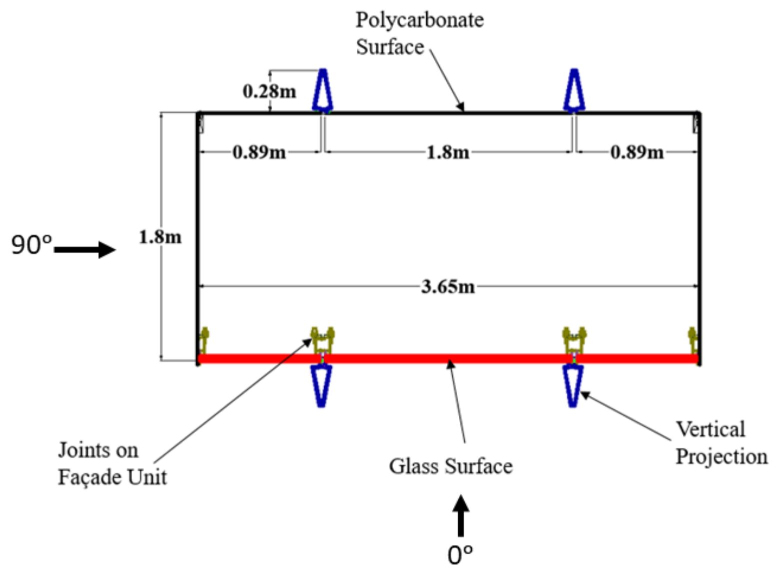


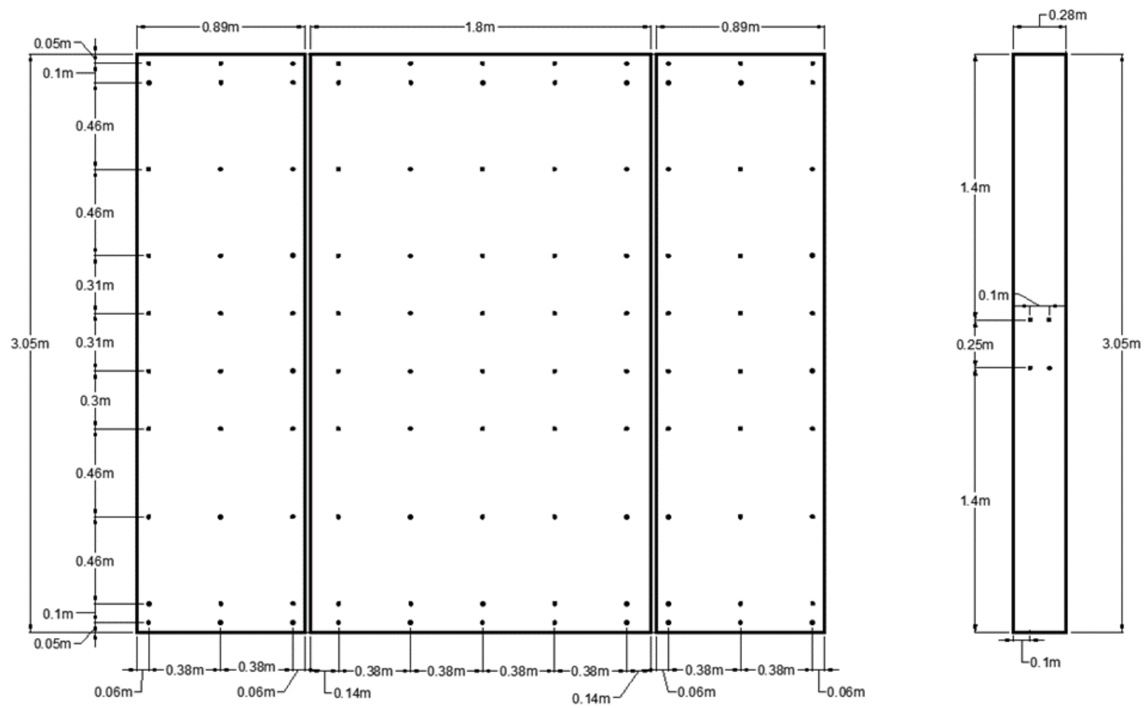
Figure 1. Schematic Plan of Test Model (Model B) and Wind Direction

(a) (b)

Figure 2. Test Model on the Turn Table at WOW (a) Model A (b) Model B

2.4. Instrumentation

Pressure on the polycarbonate wall of the model, the wooden fins, and inside the test building were measured using a total of 128 pressure taps (110 taps on walls, 16 taps on the fins and 2 taps inside the test building). The pressure taps had a denser resolution at the edges to ensure that the variation of pressure at those edges are captured appropriately. Figure 3 shows the tap locations on the polycarbonate wall. Each tube was connected to the ZOC33 Scanivalve pressure scanner module. Wind pressure data was acquired at 512Hz sampling frequency for a 1 min window. A tubing transfer function by Irwin et al. (1979) was used in the analysis given the long length of tubes used due to the size of the model. Wind directions were varied from 0° to 345° at 15° increments by rotating the automated turntable.



(A) (B)

Figure 3. Pressure Tap Layout on (A) Polycarbonate wall and (B) Wooden Vertical Projection

2.3. Data Analysis Method

The peak Cp values were estimated using the Partial Turbulence Simulation (PTS) method which was developed and validated at the WOW (Mooneghi, et al , 2016) to provide the missing data of low-frequency turbulence which is not obtainable at a large scale testing.

The pressure coefficients, both mean Cp_{mean} and peak Cp_{peak} values are defined by Equation 1 and 2:

$$Cp_{mean} = \frac{P_{mean}}{\frac{1}{2}\rho U_{mean}^2} \qquad (1)$$

$$Cp_{peak} = \frac{P_{peak}}{\frac{1}{2}\rho U_{3s}^2} \qquad (2)$$

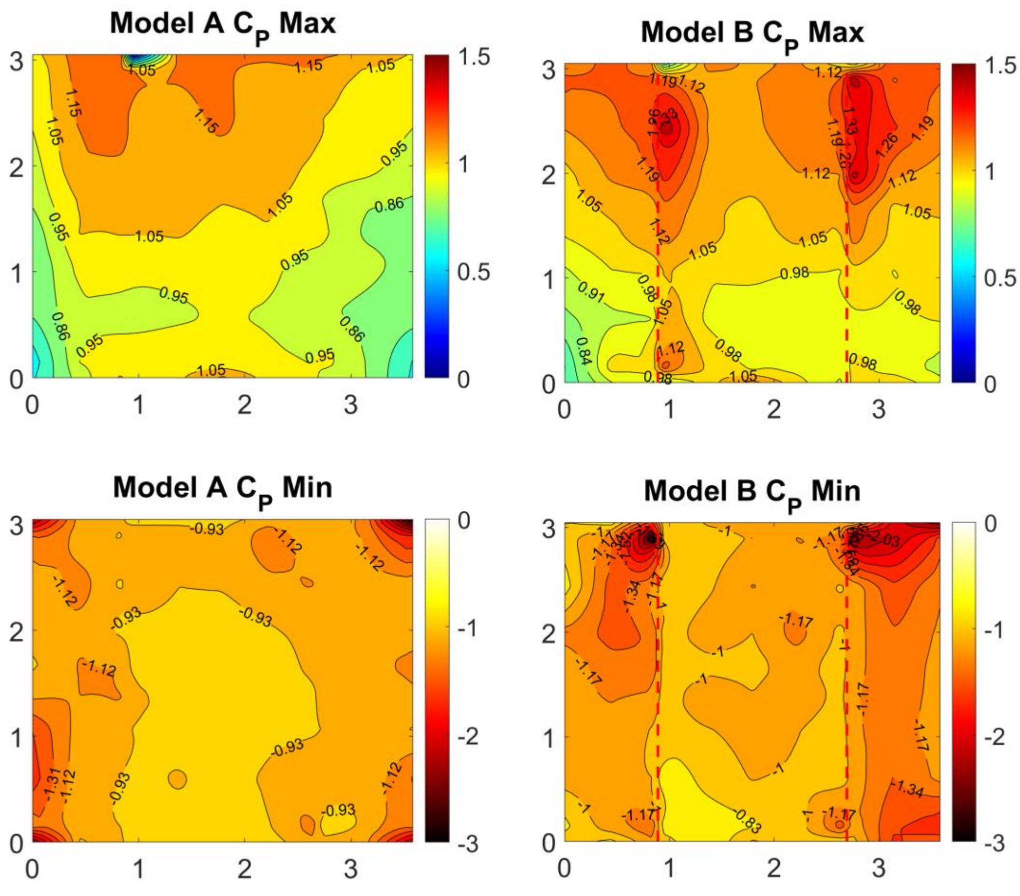
In Equation 1 and 2, U_{mean} and U_{3s} are the mean and peak 3s wind speeds at the roof height of the model, ρ is the air density while P_{mean} and P_{3s} are the differential mean and peak pressures. The area-averaged pressure coefficients presented were computed using Equation 3;

$$Cp_{avg.,peak} = \frac{\frac{\sum P_{k,peak}(t).A_k}{\sum A_k}}{\frac{1}{2}\rho U_{3s}^2} \qquad (3)$$

In Equation 3, $P_{k,peak}(t)$ is the pressure time history at pressure tap k. A_k is the tributary area of pressure tap k. Most of the data analysis and plots were carried out on MATLAB (2020) software.

3. RESULTS AND DISCUSSION

The distribution of the peak pressure coefficients (Cp) on the walls of Model A and Model B are compared in this section. The envelope (from all wind directions) of the Cp max and Cp min values on Model A and B is presented in Fig. 4. The results show a concentration of 30% higher Cp max at the positions of the vertical projections on Model B in comparison with model A. Cp min values are also higher on Model B in comparison with Model A across the wall.



(A) (B)

Figure 4. Envelope of Max Cp and Min Cp on (A) Model A and (B) Model B

At 0° wind angle, Cp peak at the edge of the walls are about 10% higher in Model B compared with those on Model A as shown in Fig 5. However, the central panel experienced about 12.5% higher Cp peak values in Model A compared to walls of Model B. This is similar to the observation by Stathopoulos and Zhu (1991). Also, on walls of Model B, Cp values in the vicinity of the vertical projections are much lower than those at the same positions on walls of Model A. A similar observation was made by Chand and Bhargava (1997).

At 45°, there is a lower Cp peak values on Model B at the left and middle panel in comparison with Model A. Also, the right panel of Model B indicate suction in comparison with positive pressure on Model A. This is due to the flow-impedance effect of the first and second vertical projection.

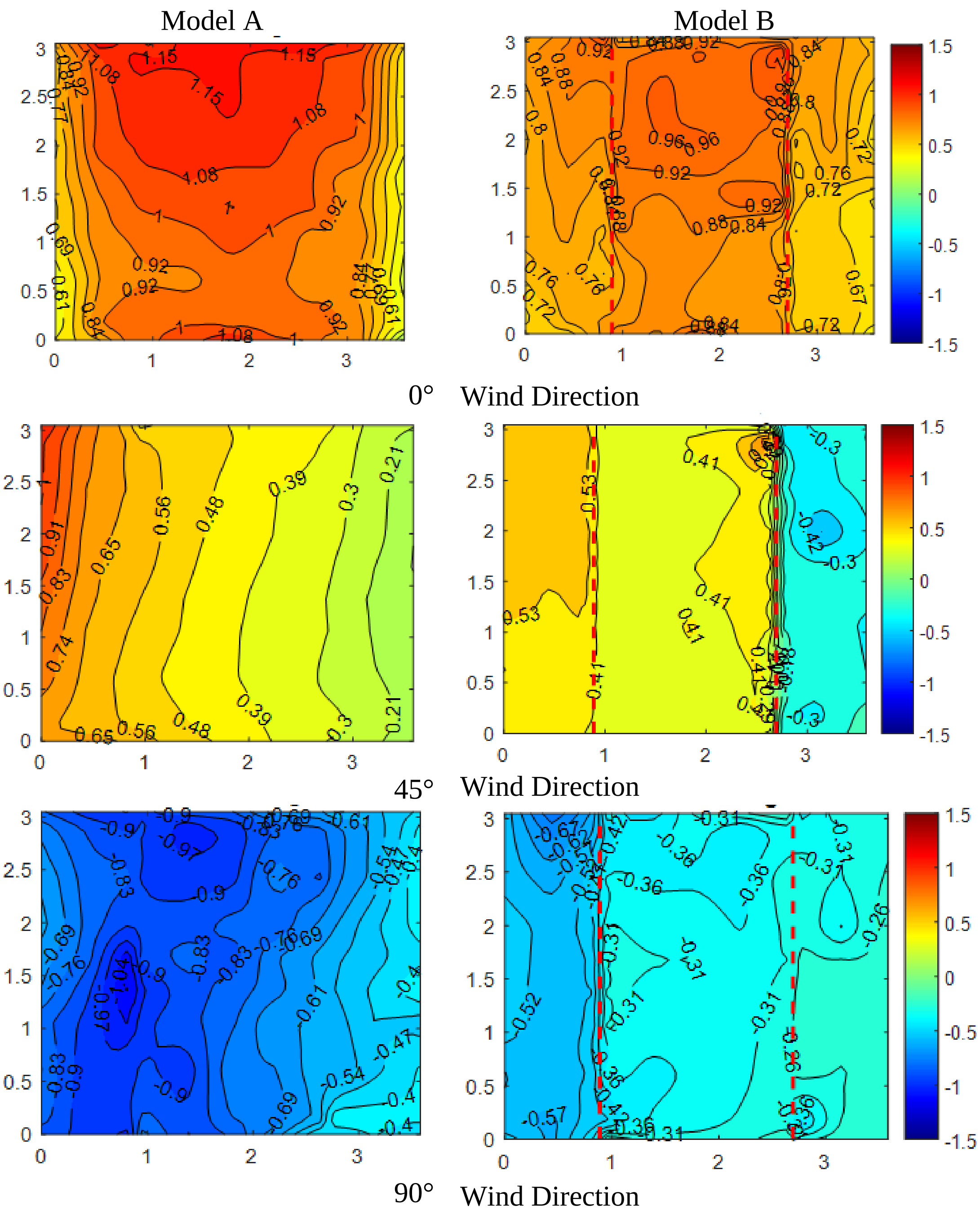


Figure 5. Cp Peak Contour plots for Model A and Model B at varying wind directions

At 90° wind direction, when the wind is parallel to the curtainwall, the suction across the wall of Model A is higher at the left and middle panel in comparison with those on Model B. The reason for this could be the formation of recirculation vortices behind the left vertical projection which reduce the suction. This observation at 90° (as shown in Fig 5) is contrary to the observation of

Stathopoulos and Zhu (1991), where suction increased (Cp mean) in the presence of vertical projections. The difference in the proximity of the projections to the wall edges in both studies, and differences in the number and depth of vertical projections used, could be the cause of the observed difference, as Stathopoulos and Zhu (1991) opined that the distance of the first projection from the edge of the wall plays a significant role in the measured Cp values.

Comparison of the area averaged 'envelope Cp max' from this experimental study, with ASCE 7-16 recommendation for components and cladding is presented in Table 1. The results indicate that the ASCE 7-16 underestimates the positive Cps on both models at Zone 4 and 5 and the negative Cps on both models at Zone 4. It was however conservative with the negative Cps at zone 5 in both models. Consequently, more experimental and numerical investigations are urged to complement available data on the wind actions on façade structures with projections.

Table 1. ASCE 7-16, Model A and Model B GCp Values

Zone	ASCE 7-16	Model A	Model B
4 (Positive)	0.8637	0.9651	1.0724
(Negative)	-0.9637	-1.0728	-1.2773
5 (Positive)	0.9179	1.0451	1.0708
(Negative)	-1.2358	-0.9291	-0.9879

4. CONCLUSION

Vertical projections influence the pressure values and pattern on claddings as they increase the overall positive Cp (by as much as 30%) at regions close to the projections and increase negative Cp (by as much as 26%). Further tests and numerical studies with different geometry and different projection configurations is recommended for future studies.

ACKNOWLEDGEMENTS

This paper is based upon work sponsored by the US National Science Foundation under the awards IIP 1841503 and I/UCRC Wind Hazard and Infrastrture Performance (WHIP) project # 2019-04. The authors also would like to thank Permasteelisa group for providing the curtain wall specimen. The opinions, findings, conclusions, or recommendations expressed in this article are solely those of the authors and do not represent the opinions of the funding agencies

REFERENCES

Chand, I., & Bhargava, P. K. (1997). Laboratory studies on the effect of external projections on wind pressure distribution on low-rise buildings. *Architectural Science Review*, *40*(4), 133–137.

Gan Chowdhury, A., Zisis, I., Irwin, P., Bitsuamlak, G., Pinelli, J. P., Hajra, B., & Moravej, M. (2017). Large-scale experimentation using the 12-fan wall of wind to assess and mitigate hurricane wind and rain impacts on buildings and infrastructure systems. *Journal of Structural Engineering (United States)*, *143*(7).

Irwin, H. P. A. H., Cooper, K. R., & Girard, R. (1979). Correction of distortion effects caused by tubing systems in measurements of fluctuating pressures. *Journal of Wind Engineering and Industrial Aerodynamics*, *5*(1), 93–107.

Mooneghi, A. M., Irwin, P., & Gan Chowdhury, A. (2016). Partial turbulence simulation method for predicting peak wind loads on small structures and building appurtenances. In *Journal of Wind Engineering and Industrial Aerodynamics* (Vol. 157).

Pariafsai, F. (2016). A review of design considerations in glass buildings. *Frontiers of Architectural Research*, *5*(2),

171–193.
Stathopoulos, T., & Zhu, X. (1991). Wind Pressures on Buildings with Mullions. *Journal of Structural Engineering*, *116*(8), 2272–2291.
Yang, Q., Liu, Z., Hui, Y., & Li, Z. (2020). Modification of aerodynamic force characteristics on high-rise buildings with arrangement of vertical plates. *Journal of Wind Engineering and Industrial Aerodynamics*, *200*(March), 104155.
Zheng, J., Tao, Q., & Li, L. (2020). Wind pressure coefficient on a multi-storey building with external shading louvers. *Applied Sciences (Switzerland)*, *10*(3).