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WIND LOADS ON CANOPIES ATTACHED TO WALLS OF LOW BUILDINGS

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Abstract: Overhangs are commonly used in residential and industrial buildings for the convenience of residents and users. Canopies are very prone to wind due to the suction developing on their upper surface along with the pressure occurring on their lower surface (for most wind directions), which together may generate critical uplift forces causing serious damage. The current paper presents research data originated mainly from atmospheric boundary layer wind tunnel studies. Also, the paper will shed some light on the current deign provisions recently included in ASCE 7 (2016). Comparisons of the experimental results with the computational results and the provisions of wind codes and standards show significant discrepancies. Some of these differences are due to the various configurations used in the previous studies, e.g. building geometry, size and slope of overhangs, canopy location on the wall(s), existence of openings, as well as roof shape (flat, gabled or curved / arched).

1 INTRODUCTION

Low-Rise buildings are mainly used for residential purposes. Considering the conveniences of the residents of the building, various types of overhangs are used. These overhangs can be building eaves, patio covers or canopies or porches. For the sloped roofs (gable), there is a common tendency to have a projection of the slope towards the ground, thus introducing building eaves.

Patio covers are mainly attached to houses to shield the residents from weather conditions such as sun, snow and rain. Sometimes there are flat or sloped slabs at the entrance of the building with opening. These structures are called porch – See Figure 1 which shows the common configurations and practices.

Overhangs are essential parts of buildings, their existence may affect the wind loads on the building. Most impotently, wind load on overhangs is very critical as both of the surfaces i.e. upper and lower are simultaneously subjected to wind action. In the worst-case scenario, the induced-wind pressure top and bottom of the overhang will be in the same direction resulting in magnified net pressure acting on the overhang.

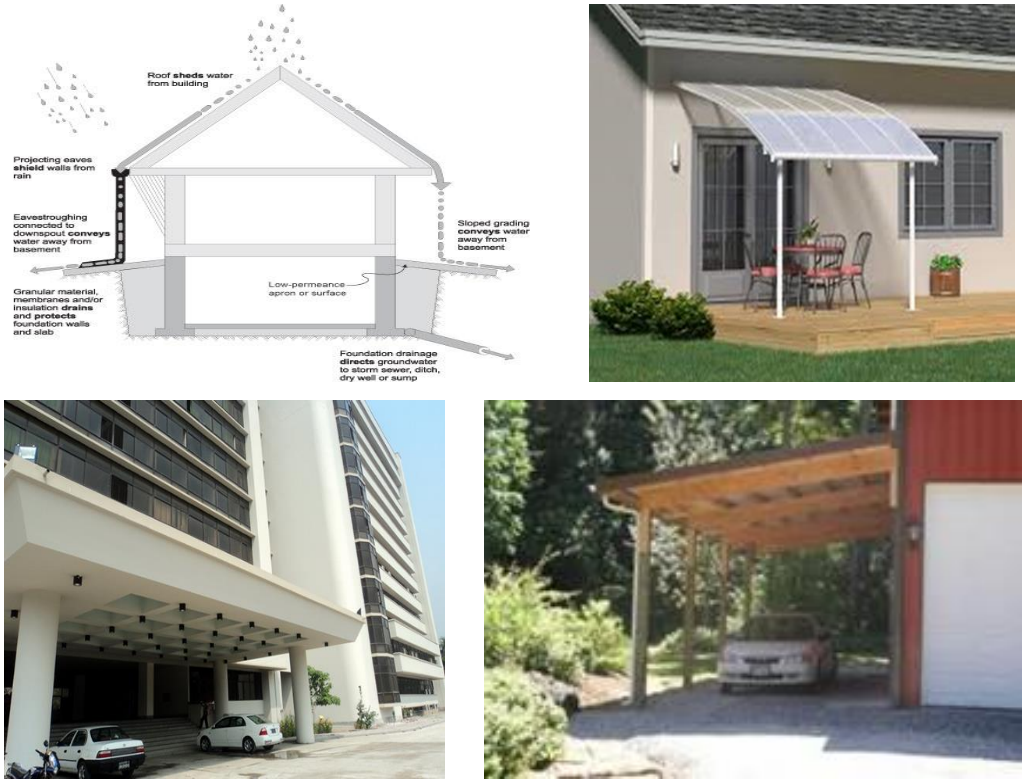

Figure 1: Various kinds building overhang (from left top clockwise eaves, canopies, carport and porches)

Unfortunately, studies are limited and have been conducted to investigate the wind pressures on canopies attached to low-rise building of relatively low height (i.e., 3.5 m < h <10.5 m, in which h is the building height). Also, very limited provisions are currently provided by the national wind codes and standards. The objective of this paper is to review the results of experimental studies for different overhangs of buildings, to compare the experimental pressure coefficients from different previous studies with the design provisions of current wind codes and standards, including Australian/New Zealand Standard (AS/NZS 1170.2, 2002), Indian Standard (IS: 875,Part 3, 2015) and American Society of Civil Engineers Standard (ASCE 7, 2016). Also, the paper will discuss the ongoing research carried out at Concordia University on this subject.

2 WIND CODE PROVISIONS FOR OVERHANGS

In this section, the design provisions provided by different national wind codes and standards will be discussed.

2.1 Australian/New Zealand Standard (AS/NZS 1170.2, 2002)

The Australian/New Zealand Standard (AS/NZS 1170.2:2002) has provision for attached patio covers in appendix D. These provisions were generated based on the wind tunnel study of Jancauskas and Holmes (1985). The equation of design wind pressure in Pascal unit according to AS/NZS 1170.2 (2002) is

[1] $p=0.6\,[V_{des,\theta}]2\ C_{p.n}\ K_a\ K_l\ C_{dyn}$

Where $V_{des,\theta}$ is design wind velocity in m/s which is based on 3 second gust speed and determined from $V_{sit,\beta}$,K_a is area reduction factor, K_l is local pressure factor, C_{dyn} is the dynamic response factor for building having frequency less than 1 Hz, $C_{p,n}$ is the net pressure coefficient acting normal to the surface when the wind is perpendicular to the wall of which the canopy is attached ($\theta=0^o$) for buildings with roof slope less than 10 degrees or less – See Figure 2. The recommended net pressure coefficients for various hc/h (h: Building height and hc: Canopy height) are shown in Figure 3. According to the code, canopies must be designed for both net upward and downward pressure. For wind direction parallel to the wall, AS/NZS 1170.2 (2002) recommends to treat the canopy as a free roof and the design net pressure coefficients should be obtained accordingly.

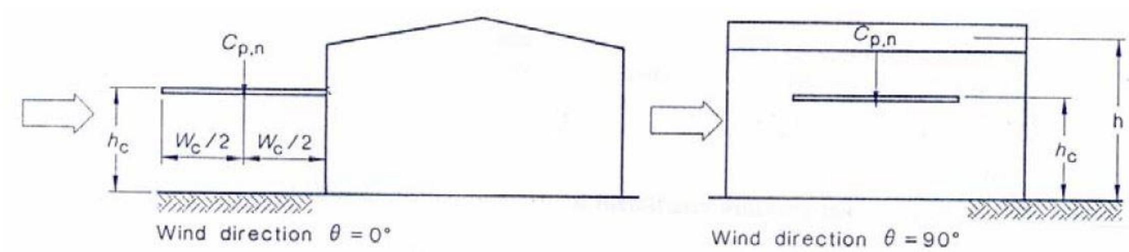

Figure 2: Sloping Roof Building with Attached Canopy (AS/NZS 1170.2:2002)

It should be mentioned that for h_c/h greater than or equal 0.75, the AS/NZS 1170.2 (2002) provides the design net pressure coefficients according to the ratio of (h_c/w_c), where w_c is the canopy width. In Figure 3, the worst possible values have been shown. All the lines in the graph show net positive and negative Cp values as a function of hc/h.

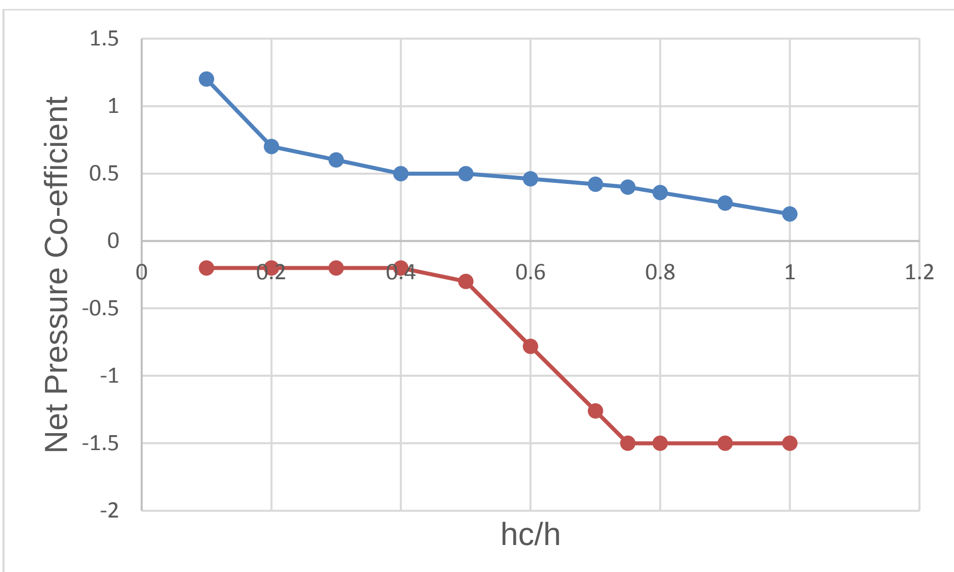

Figure 3: Net positive and negative Pressure Coefficient for different h_c/h

2.2 Indian Standard/Code (IS: 875 (Part 3), 2015)

As per Indian Standard, wind load on canopy is obtained using the following equation:

[2] $F=0.6(C_{pe}-C_{pi})AK_dK_aK_c(V_z)^2$

where V_z is design wind speed based on 3 second gust, A is surface area of canopy, K_d, K_a, K_c are respectively wind directionality factor, area averaging factor and combination factor, C_{pe} is pressure coefficient for upper surface and C_{pi} is pressure coefficient for lower surface. It only provides the values of pressure coefficients for only two direction: 0 degree and 180 degree. Point to be mentioned is, the pressure coefficients for the underside surface of the canopy (C_{pi}) can be one of the three values regardless of H_1/H_2 ratio (where H_1: Roof height; H_2: Canopy height). The term (C_{pe}-C_{pi}) act as net pressure coefficient. Figure 4 represent the worst possible net pressure coefficient in accordance with H_1/H_2

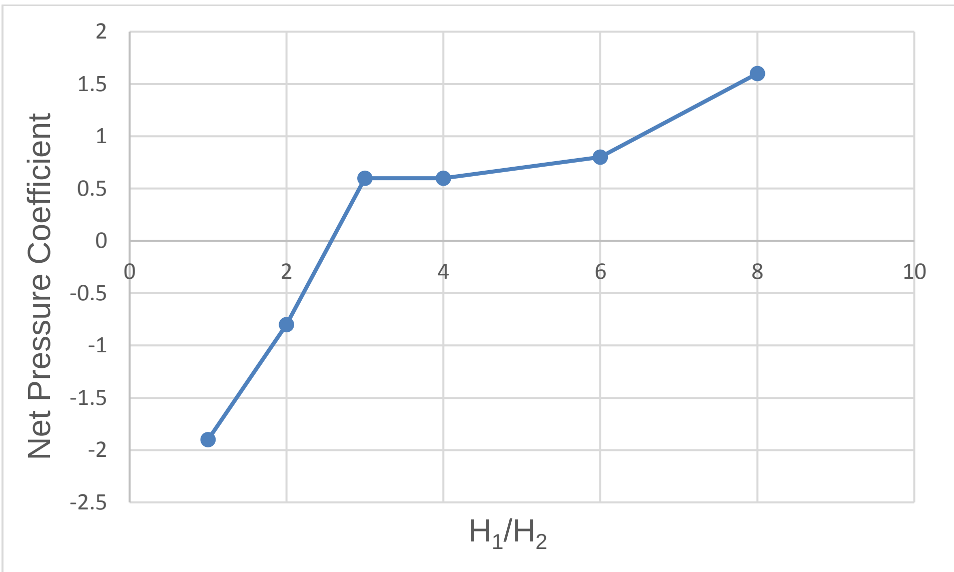

Figure 4: Equivalent Net Pressure Coefficient according to Indian Code

2.3 ASCE 7-16

Previously ASCE 7-05 and ASCE 7-10 did not have any specific provision for attached canopies. Attached canopies were considered as roof overhangs and were designed accordingly. But ASCE 7-16 has provision for attached canopy in Section 30.11 and is shown in Figure 5. The equation for design wind pressure on canopies attached to the wall of buildings with roof height less than 18.3 meters is:

[3] $p=0.613K_h K_{ht} K_d K_e V^2(GCp)$

Where p is design pressure in (N/m^2), K_h and K_{ht}, which are measured at mean roof height, are velocity pressure exposure coefficient and topographic factor respectively, K_d and K_e are wind directionality factor and ground elevation factor respectively, V is basic wind speed corresponds to a 3-s gust speed at 33 ft (10 m) above the ground in open country exposure and is is in m/s, GC_p is net pressure coefficients for attached canopies and are given in Fig. 30.11-1A–B (ASCE 7-16) for contributions from both upper and lower surfaces individually and their combined (net) effect on attached canopies. In comparison to other codes ASCE 7-16 considers canopy area to determine design pressure and it is limited to building height less than 18.3 meters.

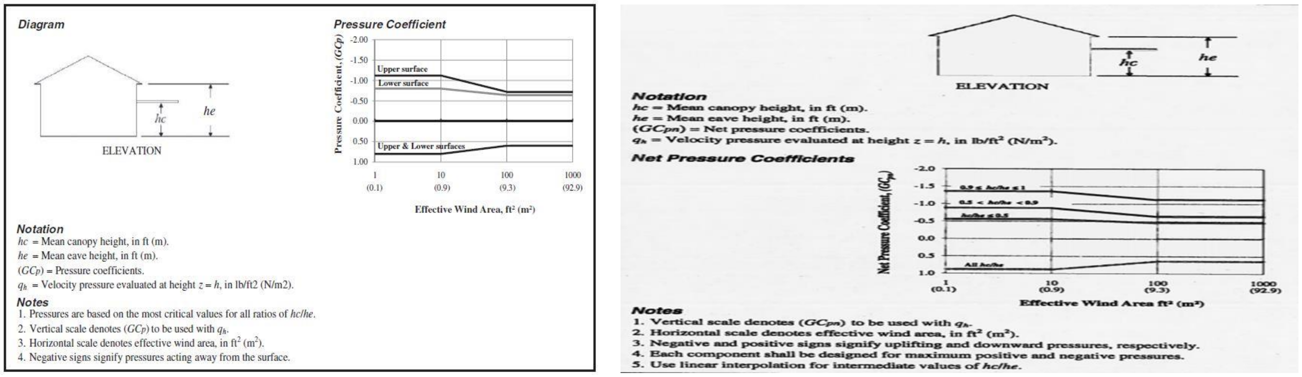

Figure 5: GCp with respect to Area and Canopy Height (ASCE 7-16)

3 RECENT STUDIES ON PRESSURE COEFFICIENT ON OVERHANGS

3.1 Effect of Wind on Eaves of Gabled-Roof Buildings having Higher Roof Slopes

Wind provisions have Cp values for eaves having roof slope less than 10°. Effect of wind on eaves having roof slopes greater than 10° was studied by Stathopoulos et al. (1994). The experiments were carried out in the boundary layer wind tunnel of the Building Aerodynamics Laboratory of the Centre for Building Studies at Concordia University. A geometric scale of 1:400 was used. Open country exposure was considered for all tests. Velocity profile represented by a power-law had exponent equal to 0.15. The maximum wind speed at gradient height in the wind tunnel was 13 m/s. Their study showed that Canadian and American standards were overestimating for this kind of eaves. Results of this study had been included in the diagrams currently available in SNBCC. Figure 6 shows eave pressure coefficient recommendation for Canadian Code.

3.2 Influence of Large Roof Overhangs on Cp Values

Presence of large overhangs not only changes Cp values of Roof, but also affects the Cp values of walls. Wiik et al. (1997) studied the phenomena by experimental and numerical simulation. The experiments were carried out in the industrial aerodynamic wind tunnel of the University of Hertfordshire, UK. This wind tunnel has a working section of 4.7 m. The atmospheric boundary layer was simulated by creating barrier at the entrance and boards with graded roughness elements on the floor of the wind tunnel. Two different configurations of models were used: one with ordinary overhang (0.3m) and another having large overhang (3.4m).

The study showed that the traditional stagnation point appears at about 2/3 of the height for ordinary roof and then the pressure reduces towards the roof. In case of the house with large roof overhang, the pressure has the stagnation point at the top of the wall. The study also found that model having large overhang had low Cp-values on roof than model having ordinary overhang. Since the Norwegian codification don't consider overhang case, which means even lower pressure at the top wall than shown here, the influence of an overhang must be important for the vertical stiffening of the gable wall.

3.3 Wind Pressure on Patio Covers

Pressure coefficient on patio cover was studied by Zisis et al. (2010) for low rise building. A 1:100 geometric scale building and patio cover model was constructed and tested for open exposure conditions. Three different models were tested to observe the effect of building height to patio height ratio. Simultaneous measurements of wind pressure/suction on each side of the patio cover were ensured by instrumenting pressure taps on both upper and lower side of patio cover. Figure 7 shows the final results of the study. Design net pressure coefficients, GCp, for patio covers recommended for possible inclusion in ASCE-7 were proposed by the study. Previously the recommendation was to use the same GCp for the roof. The Study also found out that considering canopy as a free-standing roof for 90 or 270 degree wind direction, as stated in the Australian code, is not sensible.

3.4 Wind pressure distribution on canopies attached to tall buildings

Roh et al. (2011) studied the net pressure coefficient on canopy attached to an L shaped tall building. But they did not perform any wind tunnel test, they used Computational Fluid Dynamics. Numerical analysis results were compared and investigated using ANSYS CFX 11 codes. Figure 8 shows the used configurations for the study. Results of the study shows that building geometry plays a very vital role on wind load on attached overhang as regular rectangular building have higher pressure of attached canopies whether L shape building causes mainly suction-see Figure 9. But, NBCC 2015 strictly prohibits the use of CFD for calculation wind pressure. As the study do not have any experimental validation, further studies are needed in this field

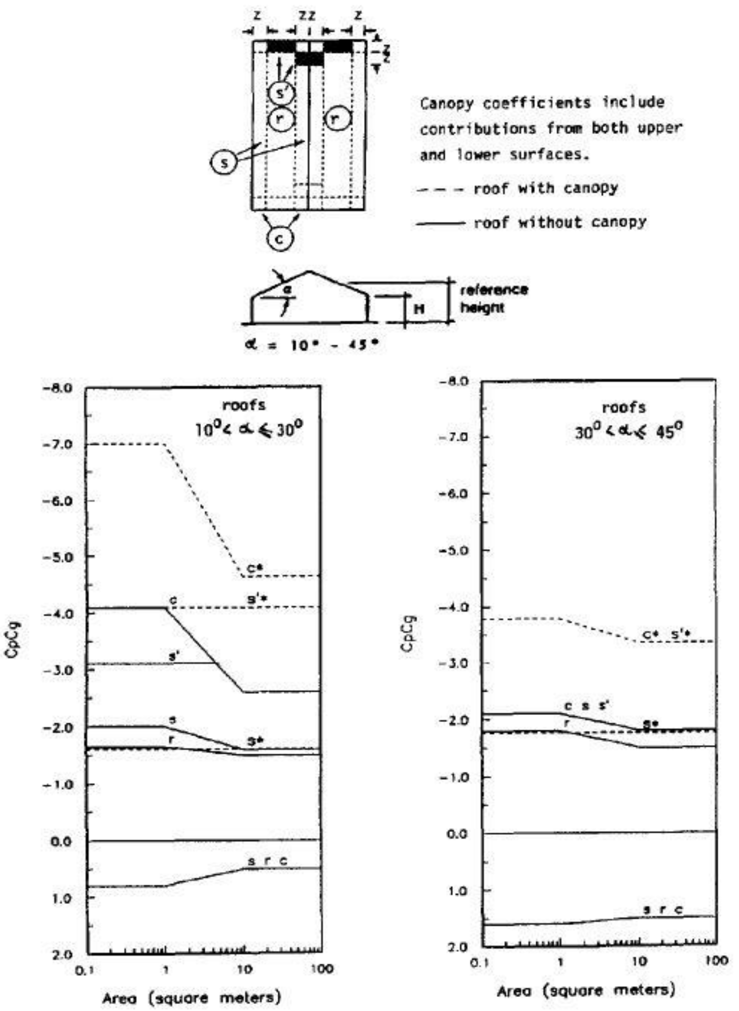

Figure 6: CpCg for eaves (Stathopoulos et al. 1994)

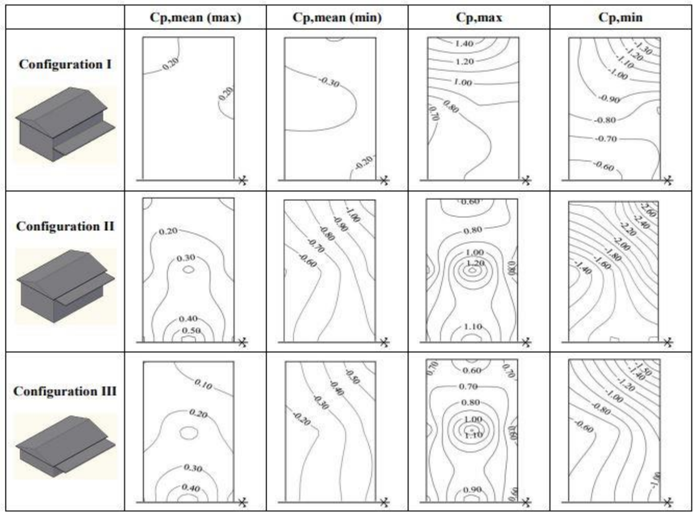

Figure: 7 Results of the study by Zisis et al. (2010)

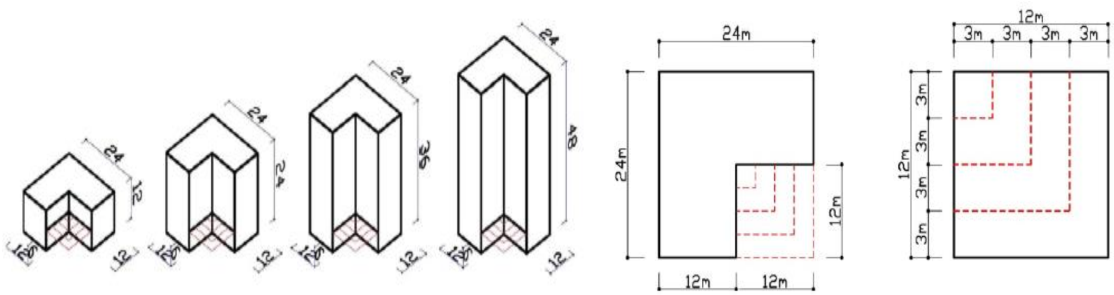

Figure 8: Models for the study by Roh et al. (2011)

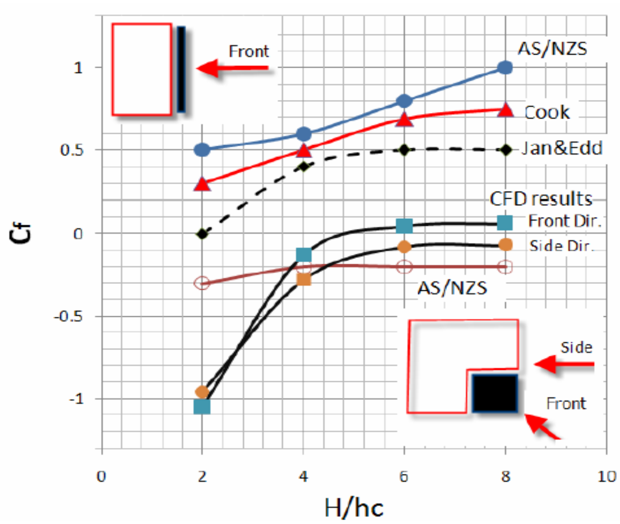

Figure 9: Comparison with other study and codes (Roh et al 2011)

4. COMPARISONS OF CODES AND VARIOUS STUDIES

The previous studies and available code provisions are compared in Figure 10. In Fig. 9, X axis shows ratios of building height and canopy height while in the Y axis most critical net pressure coefficients are shown. Results from study of Zisis et al (2009) and Roh et al (2011) are compared with Australian Standard (AS/NZS 1170.2:2002) and Indian Standard Code (IS: 875 (Part-3)-2015). Necessary scaling has been done wherever needed. In case of the provision of the code, the most critical net pressure coefficient has been considered. It is observed that there are lots of dissimilarities in net pressure coefficient between the codes and values from available research, which indicates the data deficiency for midrise and tall building cases.

5. CURRENT ACTIVITIES

As the comparison of the previous studies and provisions of different codes suggest a thorough investigation for canopies attached to midrise and tall buildings, a research has been initiated in the boundary layer wind tunnel of Concordia University. The research is being conducted by using three different building heights: 7, 18.5 and 37 meters. For each building height, there are several canopy heights so that different building and canopy height ratio can be tested. In total there are 14 configurations for testing. A geometric scale of 1 to 100 has been used. The canopy has a length of 36 meters and a width of 7.3 meters which are adjustable. The study is focused to provide reliable wind loads on canopy attached to mid-rise and hi-rise buildings. Figure 11 shows one of the models used in the study.

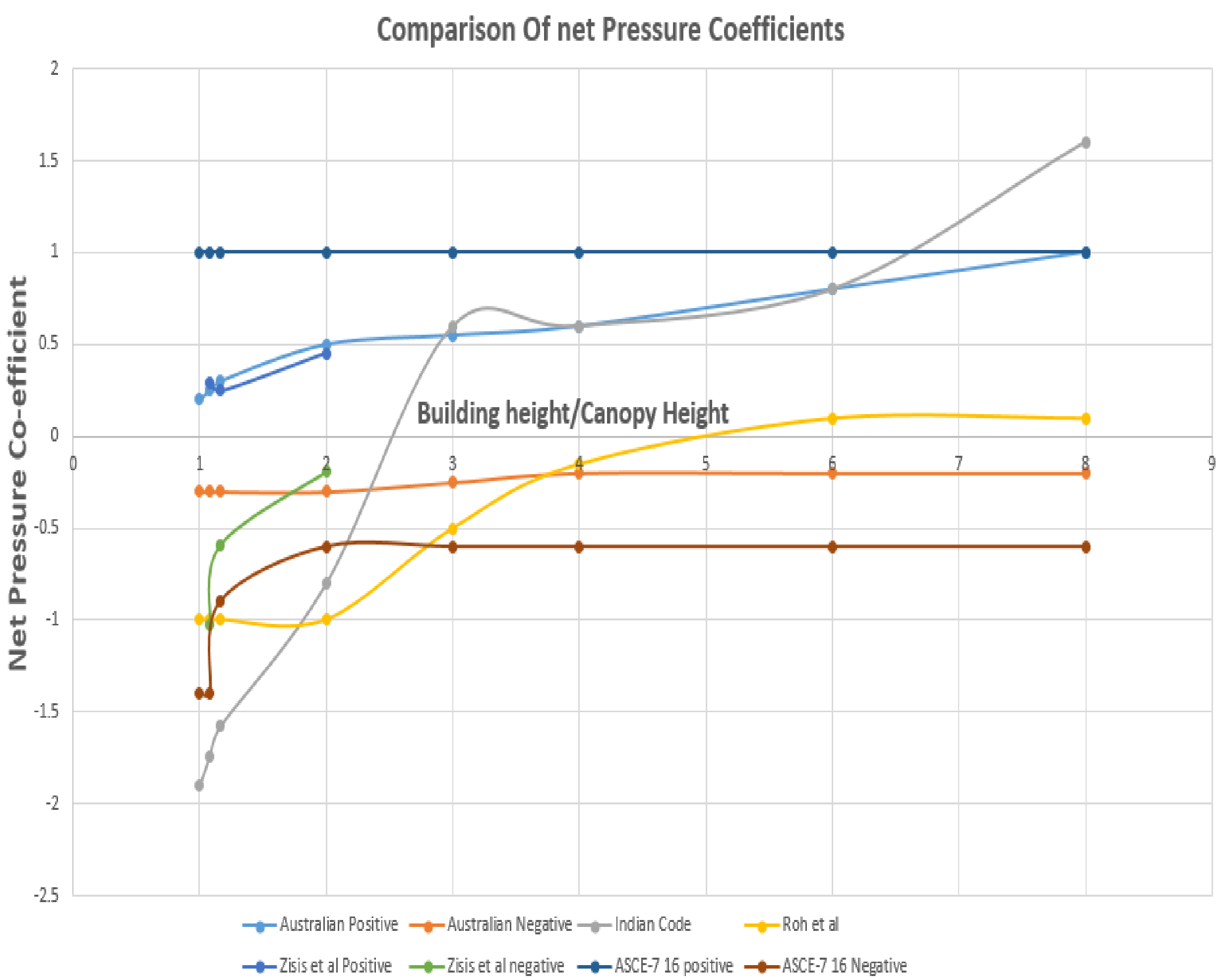

Figure 10: Comparison

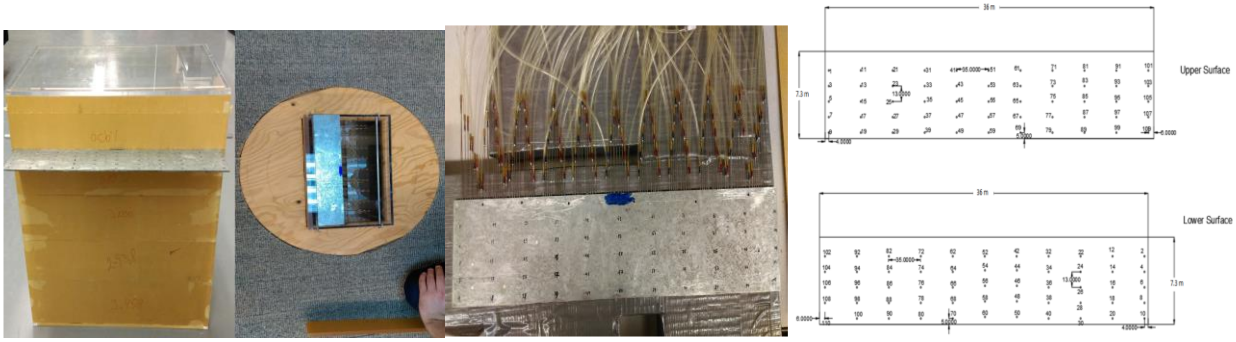

Figure 11: Current research activities (from left): the building model, model in wind tunnel, the canopy, details of canopy

6. **CONCLUSION**

Overhangs can be very vulnerable to wind due to the suction developing on their upper surface along with the pressure occurring on their lower surface (for most wind directions), which together may generate critical uplift forces causing lots of damage on these elements under strong winds. Damage of overhangs can cause further damage to building and people's lives. A dislocated canopy is a threat not only to the building it is attached, but also to the surroundings. So, the designers should be provided with reliable critical wind loads on canopies. Codes of practices from different region do not provide sufficient information while designing the overhangs and amount of experimental research work for attached canopy or patio cover is very little. Thus further studies are required to carry out to investigate the effects of attached canopies on wind loads on buildings. Special attention should be paid to study the pressure coefficient on canopies attached to a tall building.

7. References

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