Wind Engineering Joint Usage/Research Center
FY2024 Research Result Report

Research Field: Wind Hazard Mitigation/Wind Resistant design
Research Year: FY2024
Research Number: 24242003
Research Theme: Impact of Tornado vortex induced aerodynamic loads on structural projections in low rise buildings

Representative Researcher: Prof. Rajesh Goyal

Budget [FY2024]: 3,00,000 Yen

*There is no limitation of the number of pages of this report.
*Figures can be included in the report, and they can also be colored.
*Submitted reports will be uploaded to the JURC Homepage.

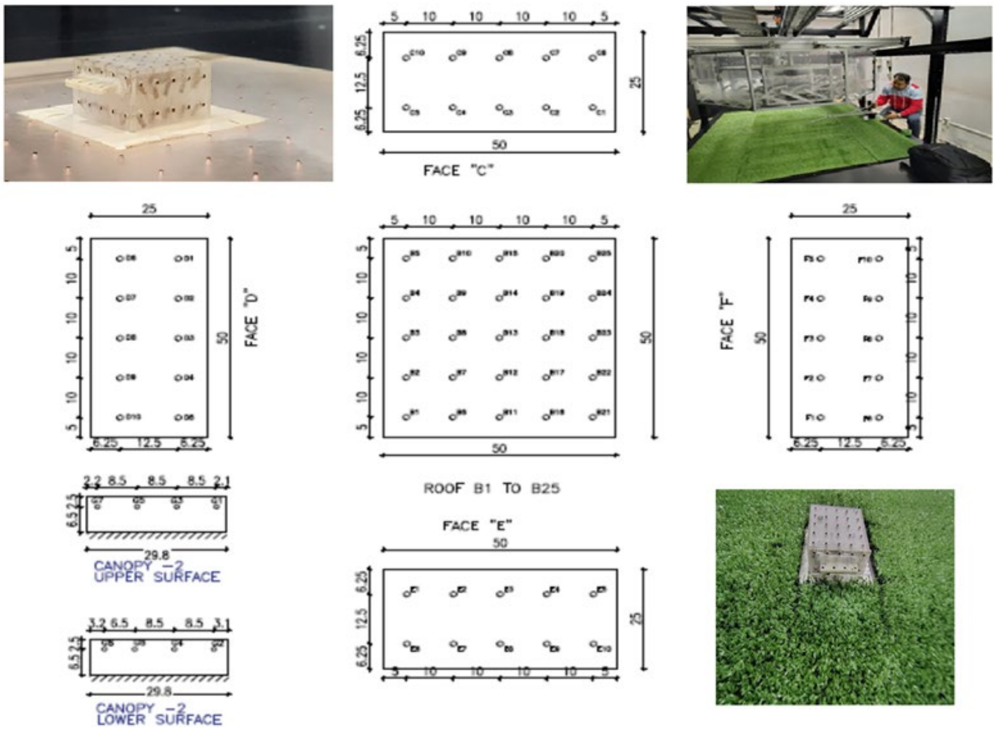
1. Research Aim:

- To evaluate the damage of in low rise structure and attached canopies due to aerodynamic loads caused by tornadoes like flow under different surface roughness.
- To enhance the wind pressure database of low-rise buildings with attached projections.

It was proposed to conduct extensive study on low rise buildings with attached canopies at 10-degree angles for different parameters under the influence of tornado induced vortexes. The building models can be tested for attached canopy at different roughness coefficients.

2. Research Method

The building models were prepared using Perspex sheets having attached canopies of different lengths. In the present phase of study, one canopy was prepared at 10 deg angle and the roughness of the surrounding surface of the building were changed. Canopy of 29.8 mm length attached to $3/4^{th}$ height of the model building from the ground. The models were prepared for measuring the surface pressure on all the surfaces on tornado simulator. For measuring the surface pressure on the surfaces of building models, pressure tapings were provided. With the help of pressure tapings, the pressure on the surfaces of building models was measured using the pressure measuring instruments. Exploded view of the pressure points on model surface and canopies are shown in Figure-1.

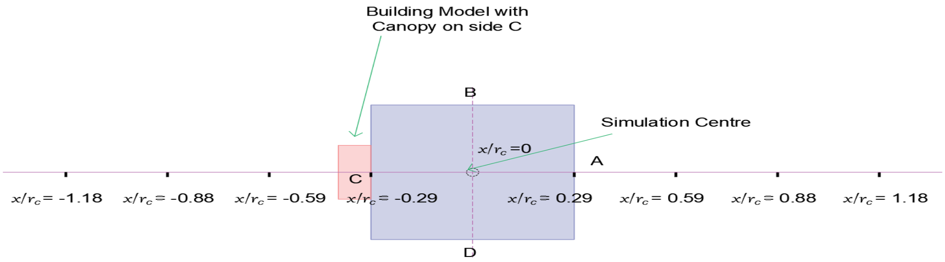


3. Research Result

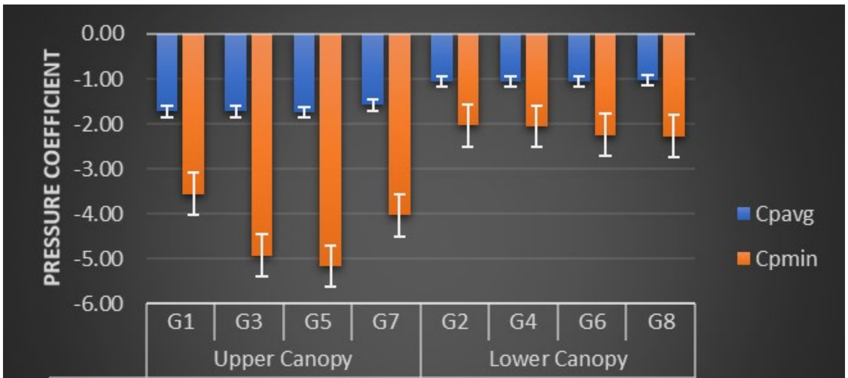
Some series of experiments were conducted with a tornado-like flow simulator in Tokyo Polytechnic University. In these experiments temporal variations of wind pressure coefficients were measured for different distance between the centers of tornado-like flows, different surface roughness and building models. The distances were normalized by radius of maximum wind of the swirling flows. Mean components of the pressure coefficients are shown in Figure-2. The presented components are for canopy length 29.8 mm, fixed at 3/4th height of building from the surface. The results are prepared by collection of time series data on the building model surface, canopy surface and surroundings, when tornadoes approach the building in x and y direction and leave the building in both directions. The distributions of the pressure coefficients were affected by separation of flows at the edge of a building model and pressure defect of the swirling flows. Some of the outcomes of the study are as follows:

1. Anti-symmetry was observed in pressure distribution on opposite sides.
2. Roof center experience lesser pressure coefficients compared with the roof edges when the tornado is center of model, specially on the face 'D' as compared to face 'F' because pressure tapings of the roof at this position acts as windward and leeward pressure points respectively.
3. Maximum pressure coefficient on roof at smooth terrain was experienced when tornado was 30m away from the center of building and at same location coefficient of pressure dropped in the case of roughness.
4. At x/rc = 0, for both terrain conditions there was no significant change in the pressure at the upper surface of canopy, but lower surface saw a drastic drop of 33% when roughness was incorporated
5. At x/rc = 0.88, introduction of rough terrain reduced pressure coefficient by about 15% on upper surface of canopy and 27% at lower surface of canopy.
6. At x/rc = -0.88, introduction of rough terrain reduced pressure coefficient by about 35% on upper surface of canopy and 18% at lower surface of canopy.

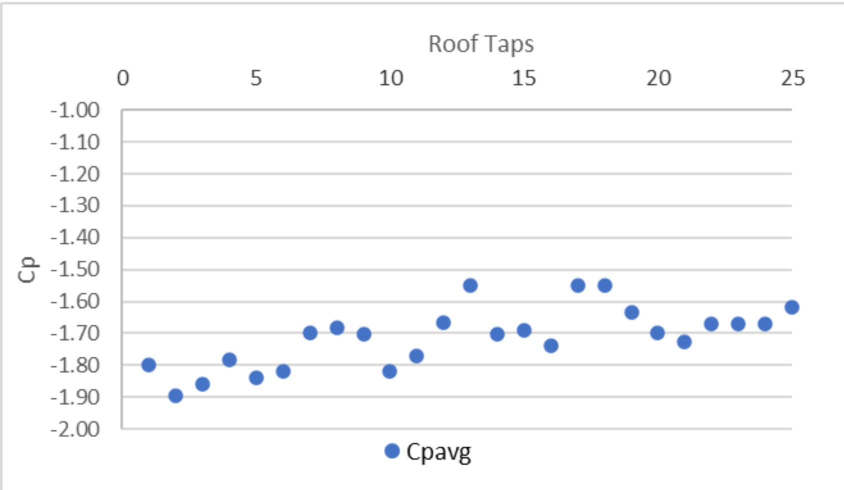
Canopy Length 30mm, Height 18.75mm Slope 10-degree, X = 0mm



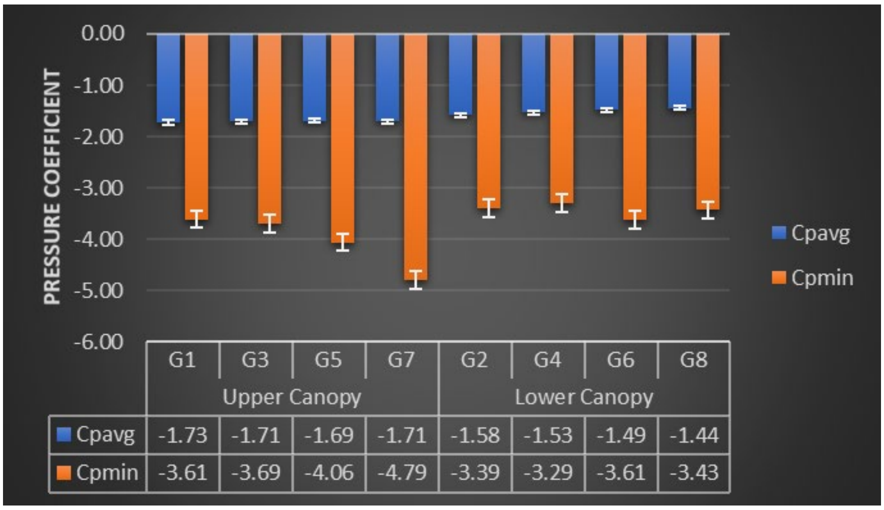
Building Model with rough terrain



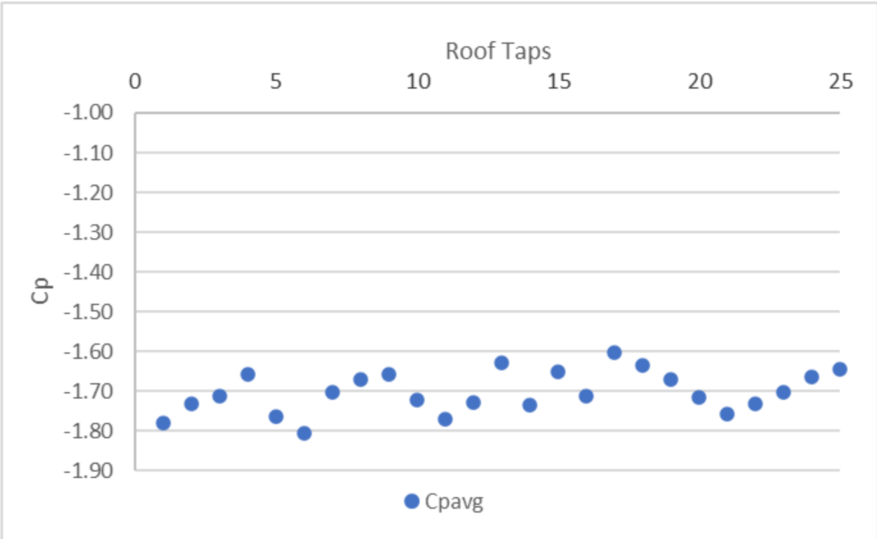
	G1	G3	G5	G7	G2	G4	G6	G8
	Upper Canopy				Lower Canopy			
Cpavg	-1.72	-1.73	-1.74	-1.58	-1.06	-1.06	-1.06	-1.03
Cpmin	-3.56	-4.93	-5.17	-4.04	-2.04	-2.06	-2.25	-2.27



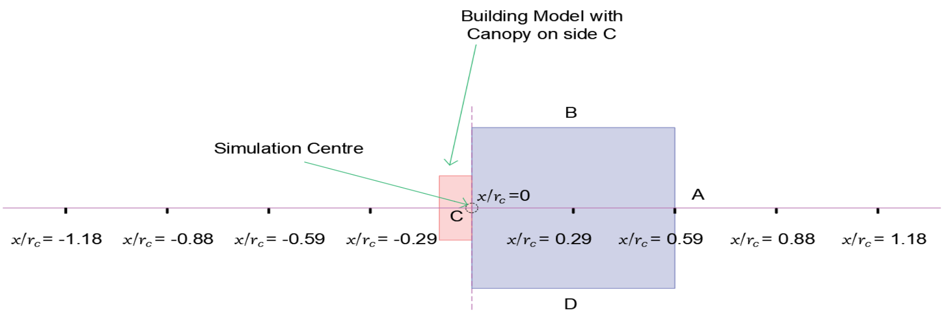
Building Model with smooth terrain



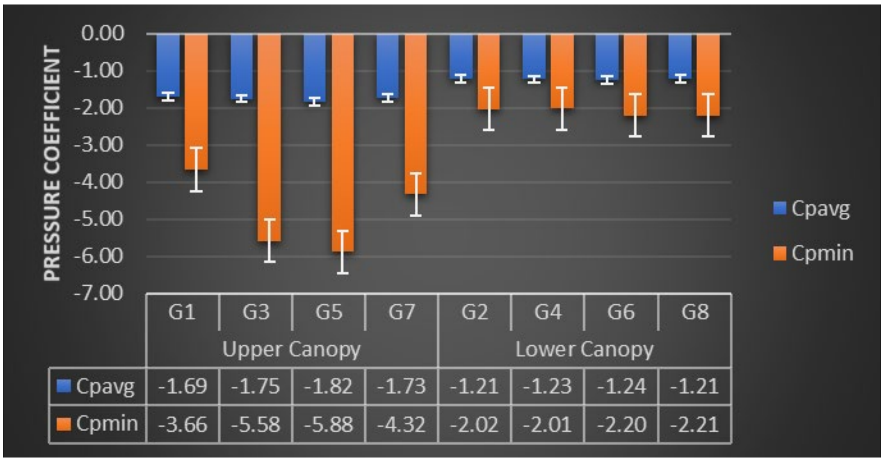
	Upper Canopy				Lower Canopy			
	G1	G3	G5	G7	G2	G4	G6	G8
Cpavg	-1.73	-1.71	-1.69	-1.71	-1.58	-1.53	-1.49	-1.44
Cpmin	-3.61	-3.69	-4.06	-4.79	-3.39	-3.29	-3.61	-3.43

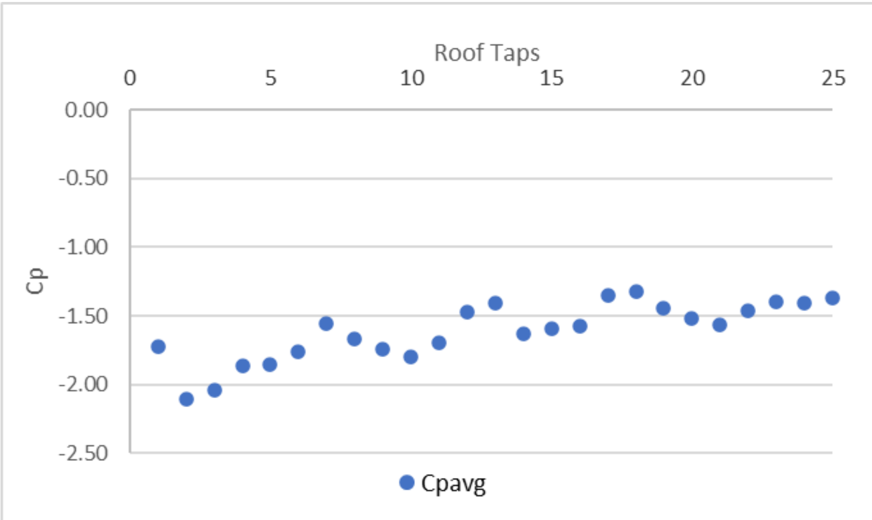


Canopy Length 30mm, Height 18.75mm Slope 10-degree, X = 25mm

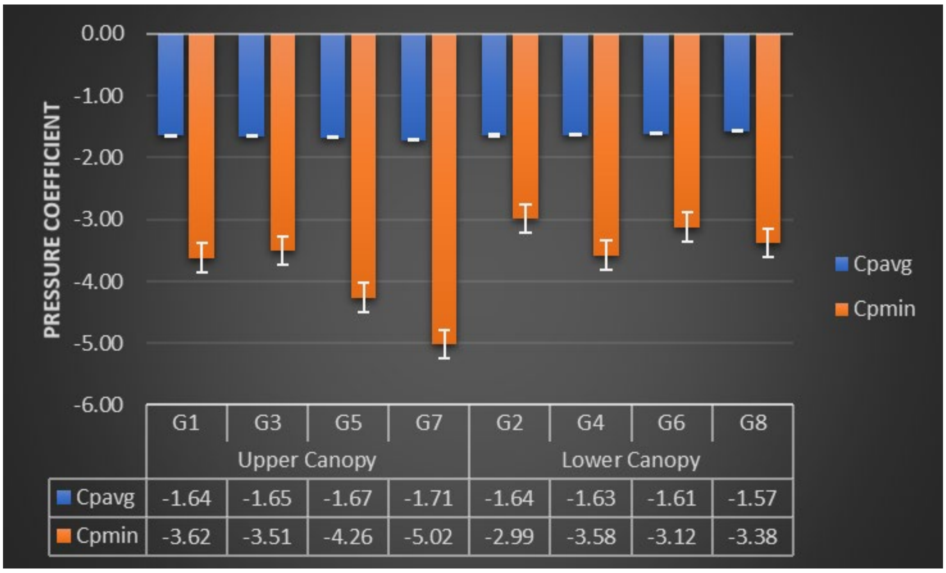


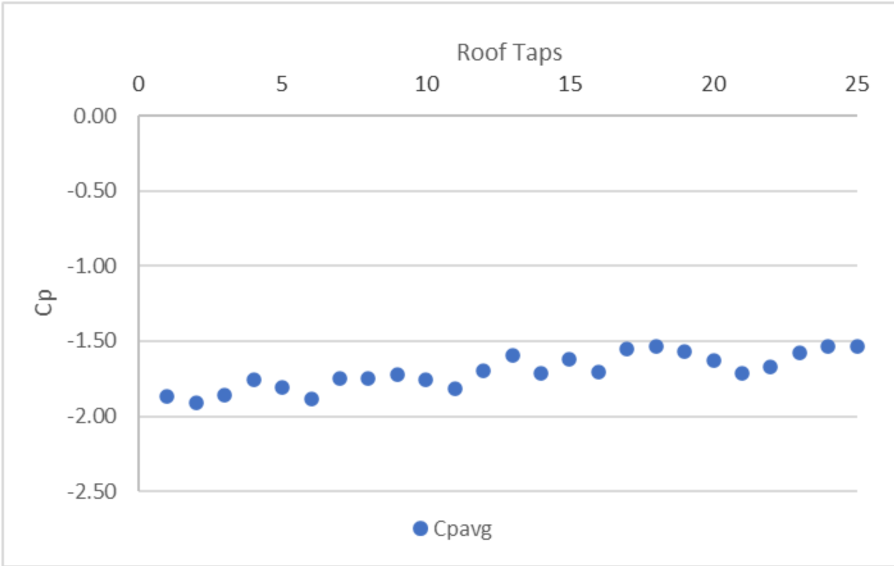
Building Model with rough terrain



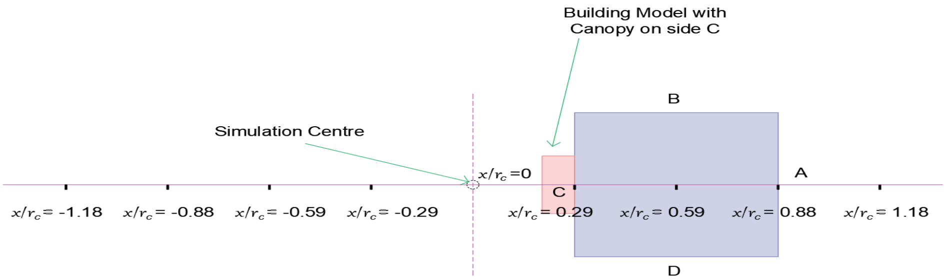


Building Model with smooth terrain

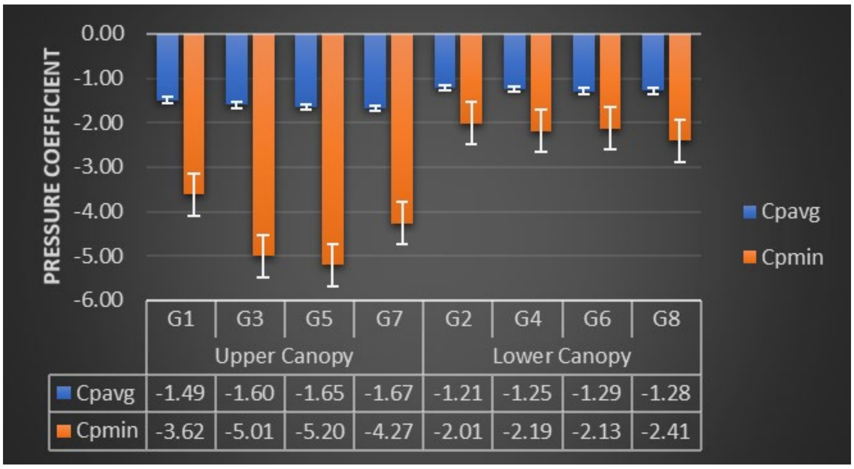


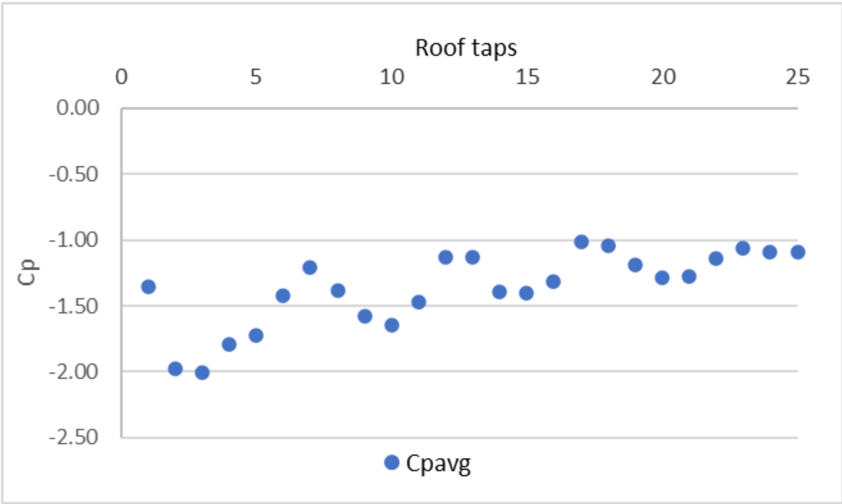


Canopy Length 30mm, Height 18.75mm Slope 10-degree, X = 50mm

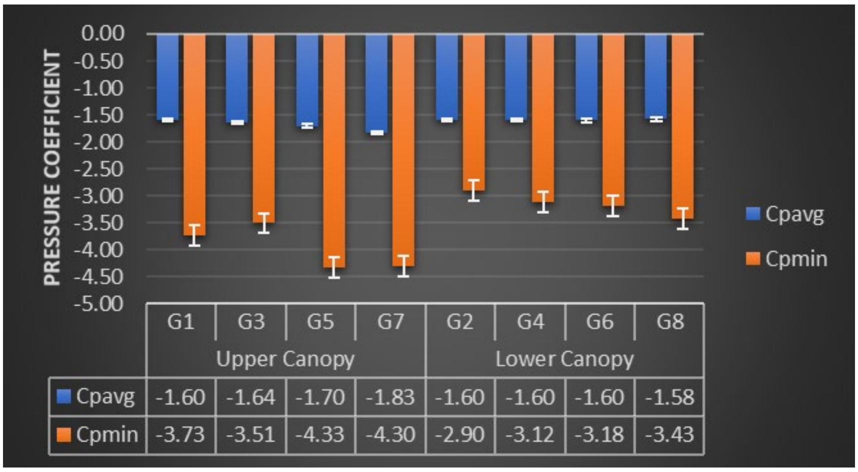


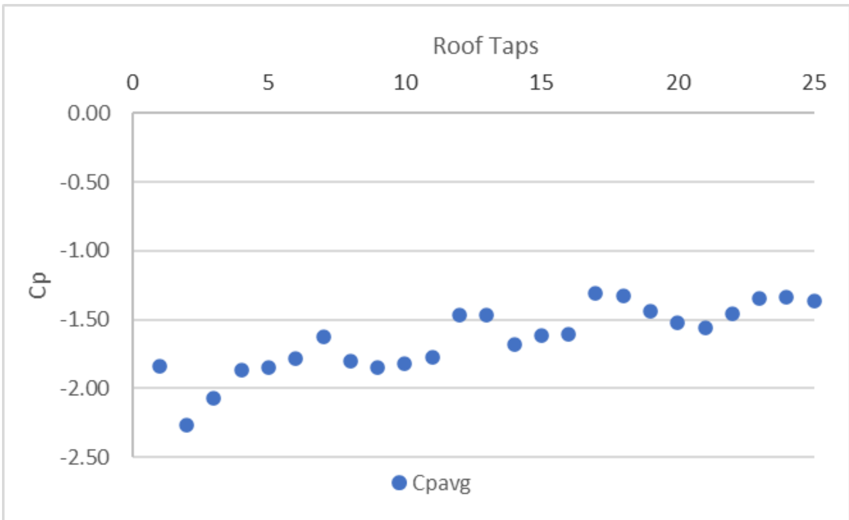
Building Model with rough terrain



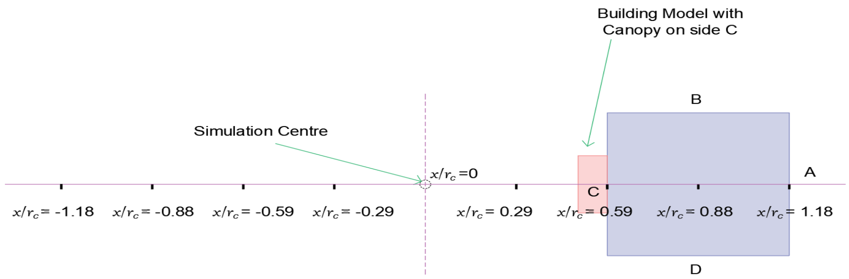


Building Model with smooth terrain

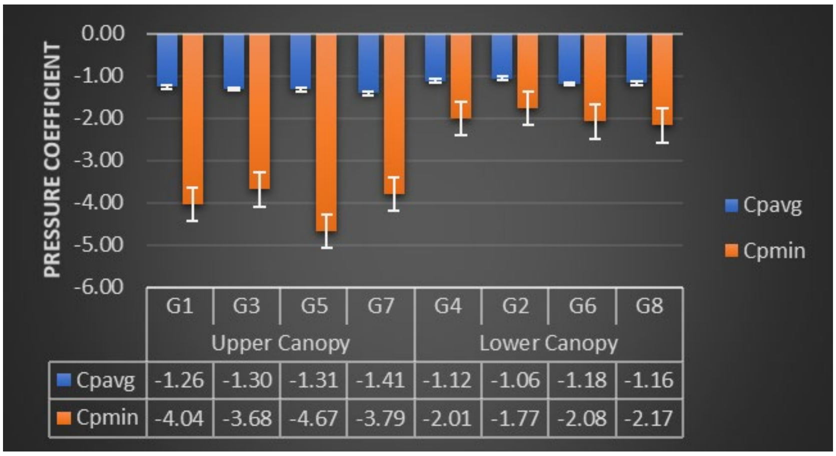




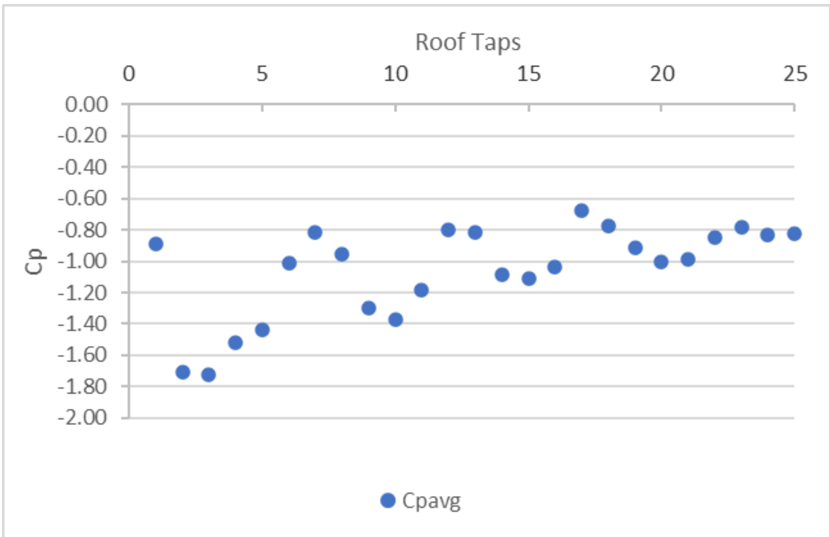
Canopy Length 30mm, Height 18.75mm Slope 10-degree, X = 75mm



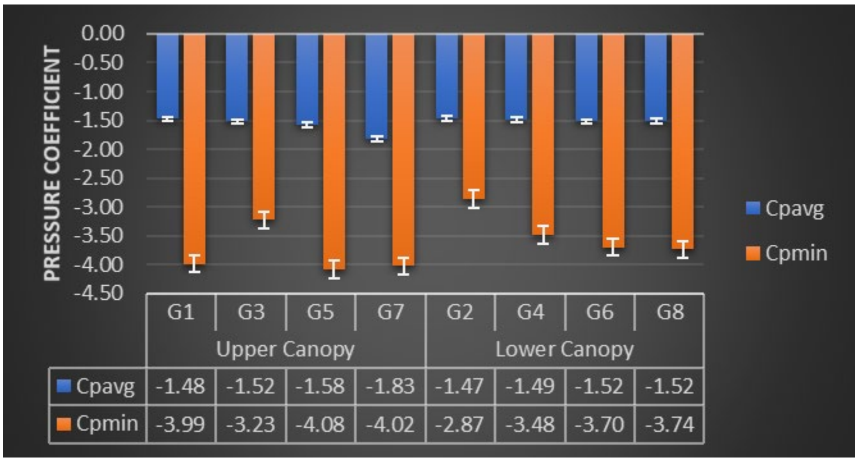
Building Model with rough terrain



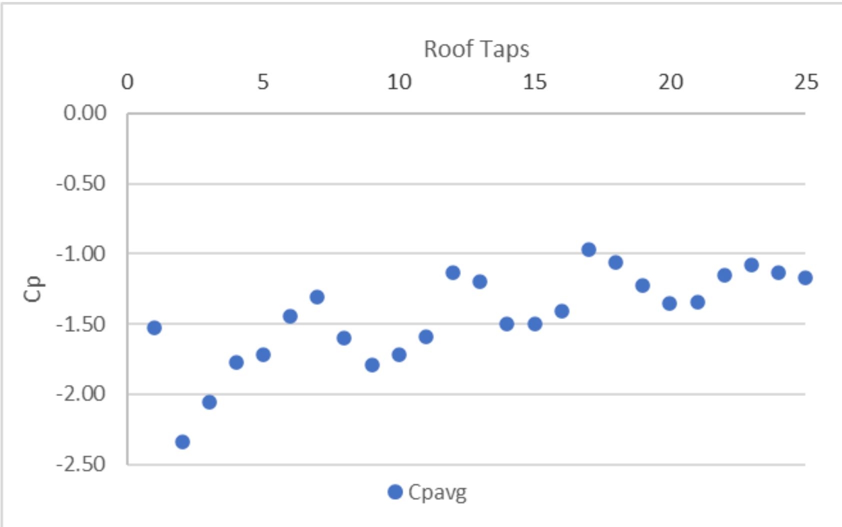
	G1	G3	G5	G7	G4	G2	G6	G8
	Upper Canopy				Lower Canopy			
Cpavg	-1.26	-1.30	-1.31	-1.41	-1.12	-1.06	-1.18	-1.16
Cpmin	-4.04	-3.68	-4.67	-3.79	-2.01	-1.77	-2.08	-2.17



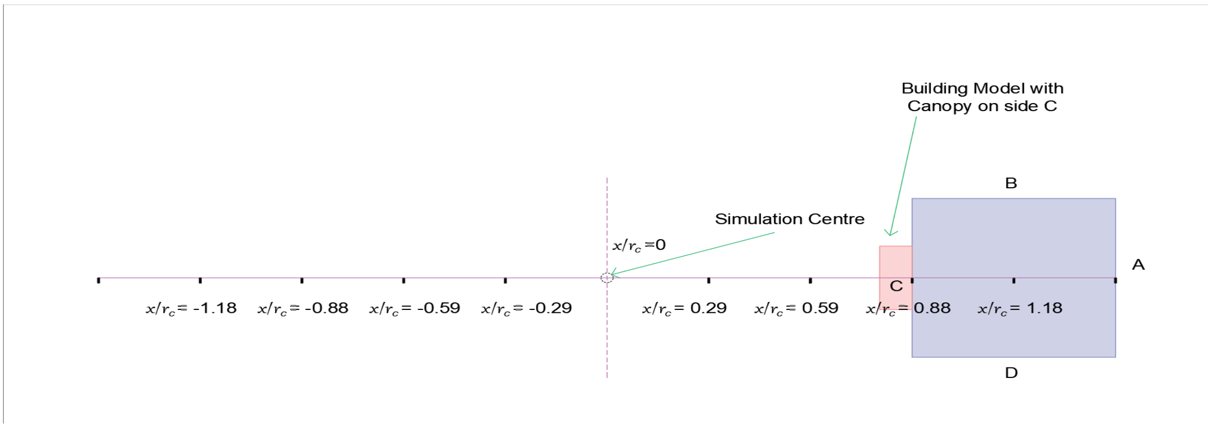
Building Model with smooth terrain



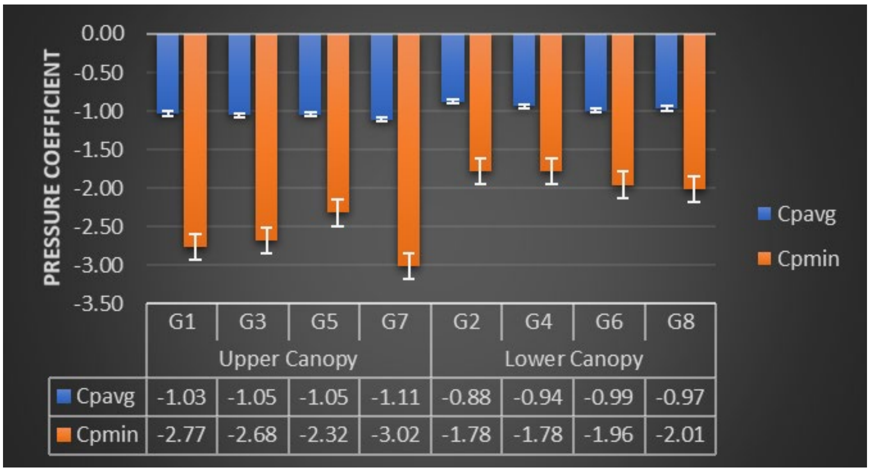
	Upper Canopy				Lower Canopy			
	G1	G3	G5	G7	G2	G4	G6	G8
Cpavg	-1.48	-1.52	-1.58	-1.83	-1.47	-1.49	-1.52	-1.52
Cpmin	-3.99	-3.23	-4.08	-4.02	-2.87	-3.48	-3.70	-3.74

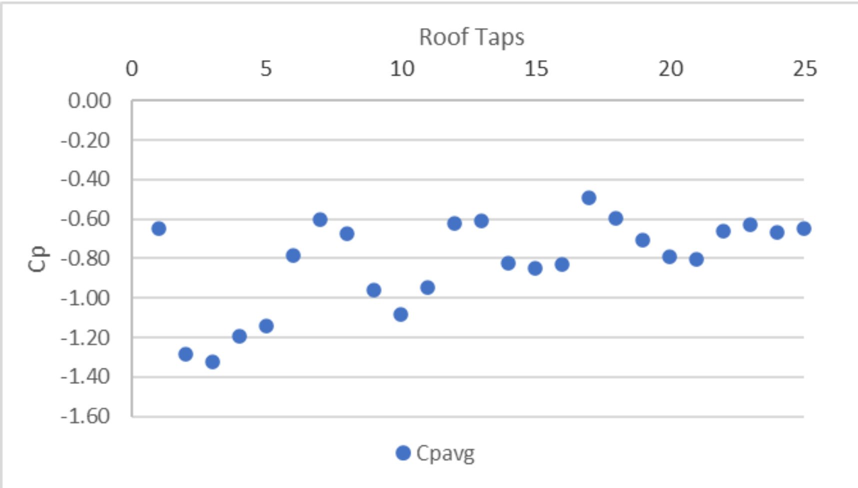


Canopy Length 30mm, Height 18.75mm Slope 10-degree, X = 100mm

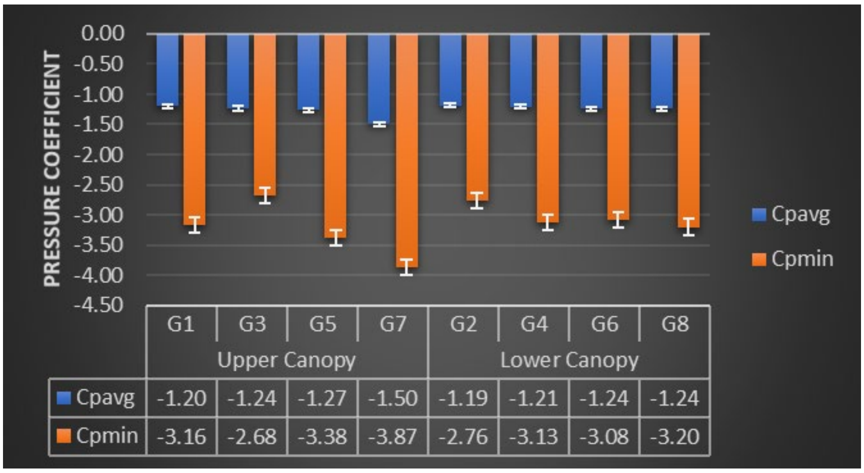


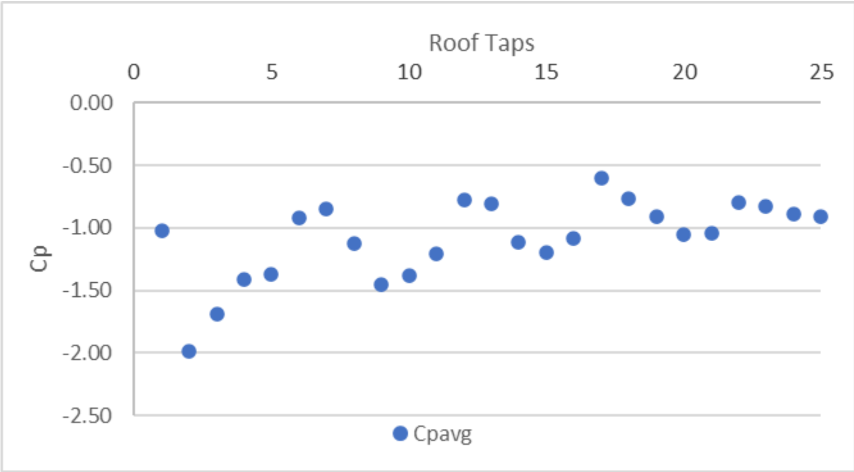
Building Model with rough terrain



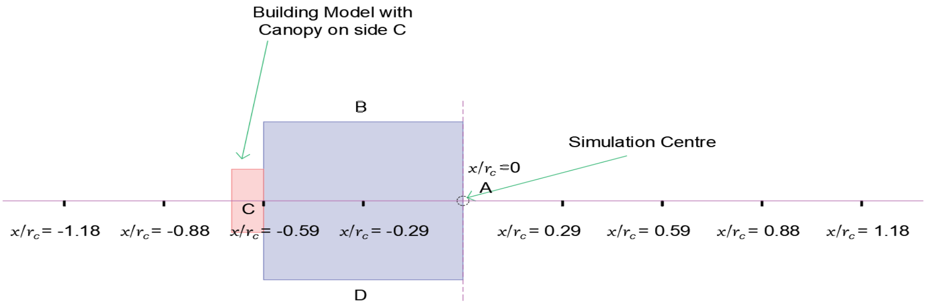


Building Model with smooth terrain

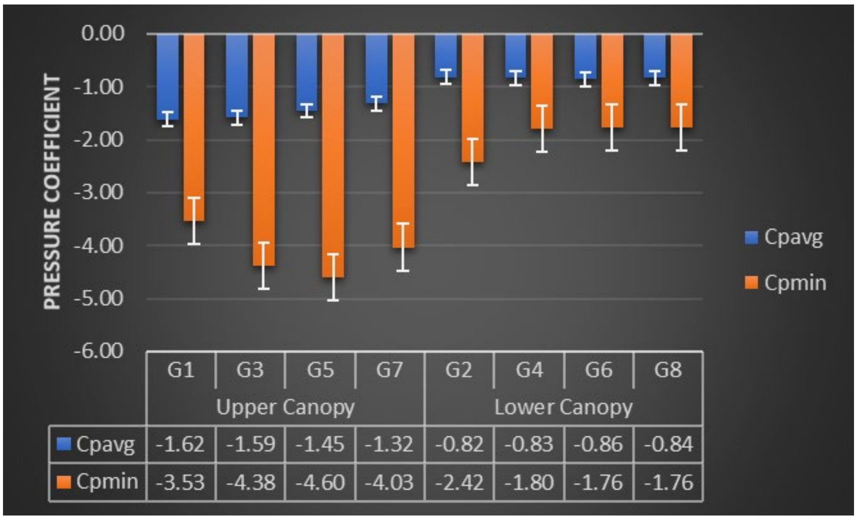


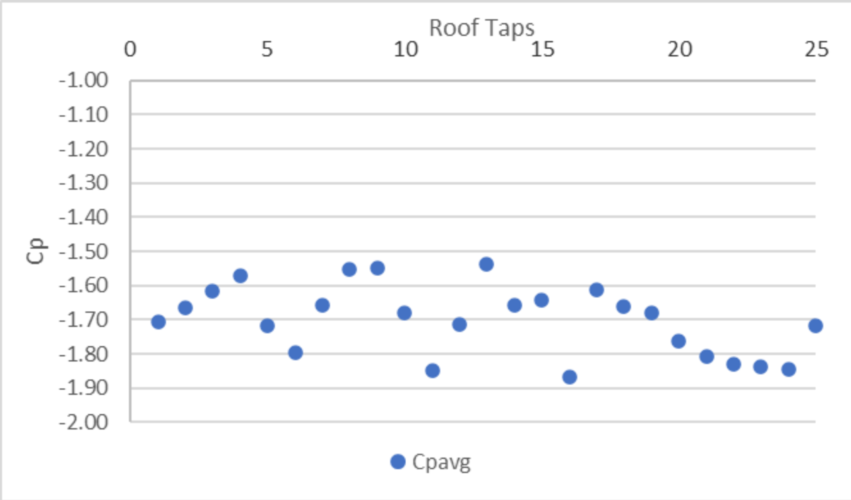


Canopy Length 30mm, Height 18.75mm Slope 10-degree, X = -25mm

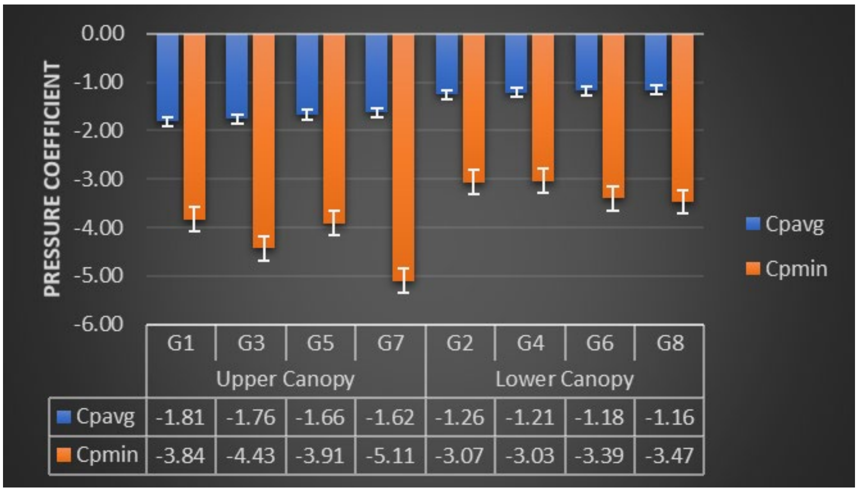


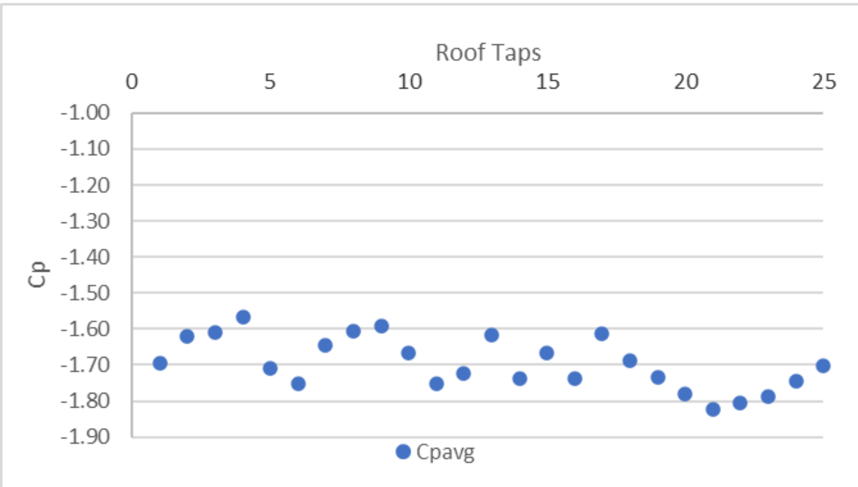
Building Model with rough terrain



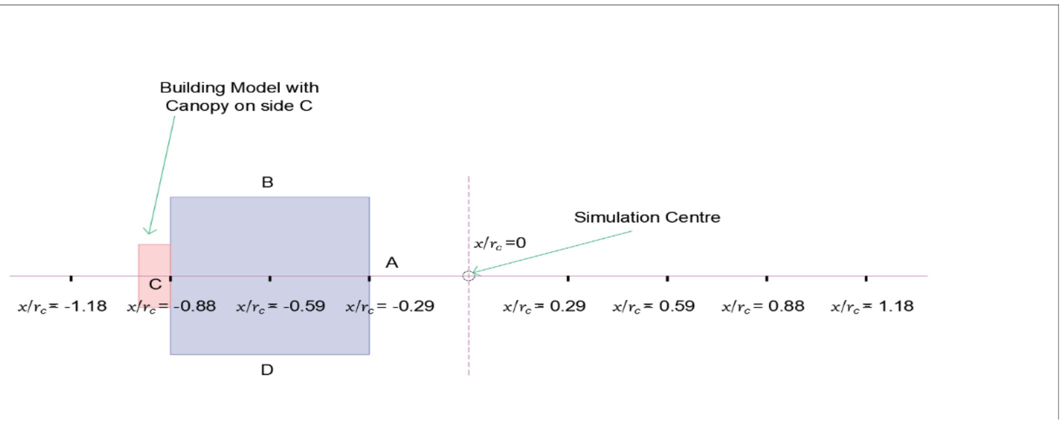


Building Model with smooth terrain

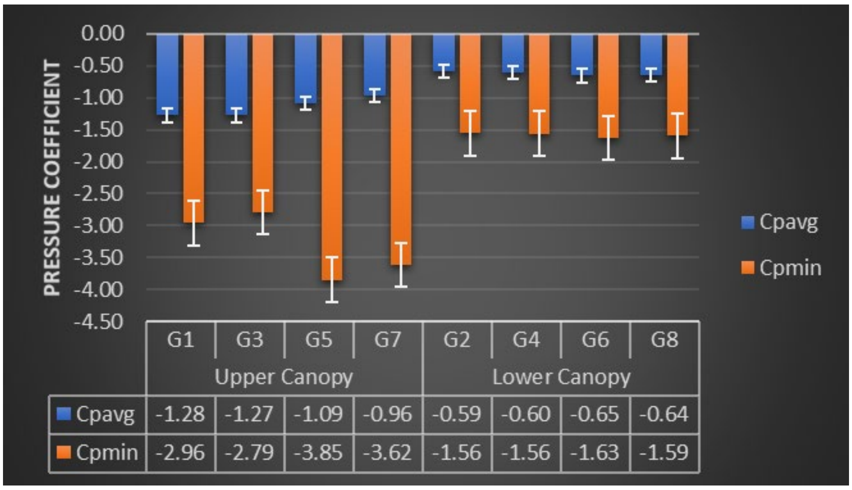




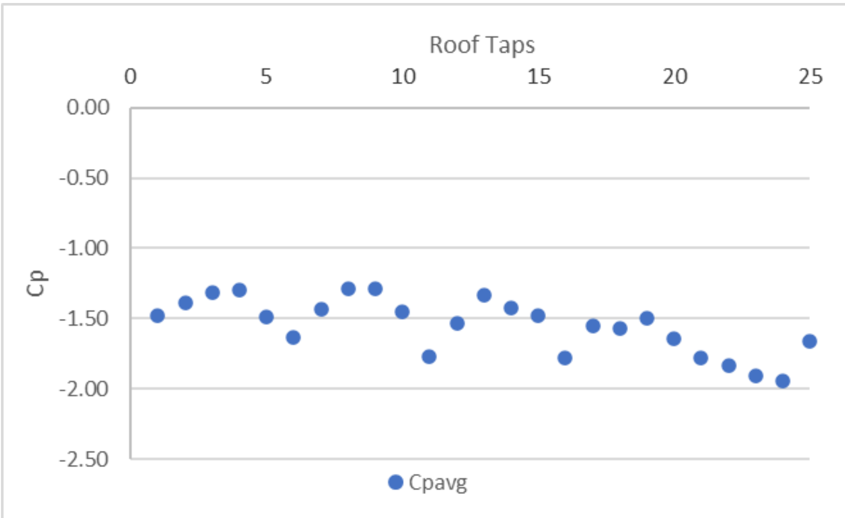
Canopy Length 30mm, Height 18.75mm Slope 10-degree, X = -50mm



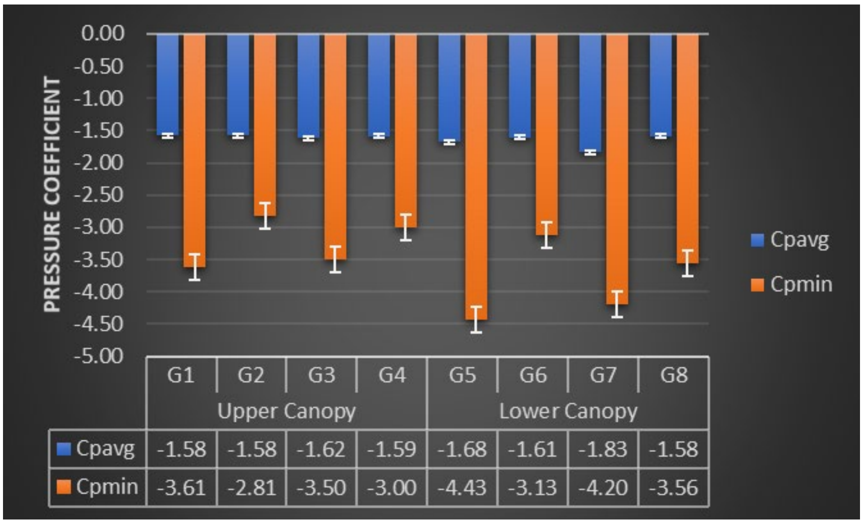
Building Model with rough terrain

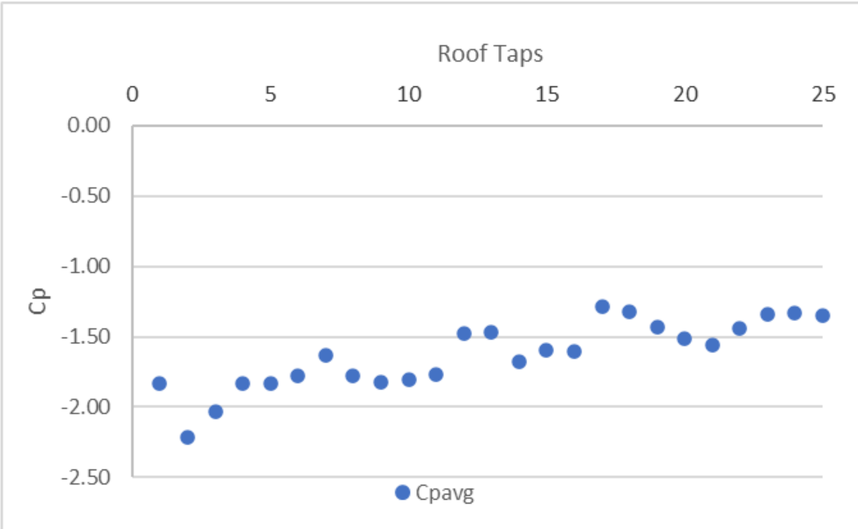


	Upper Canopy				Lower Canopy			
	G1	G3	G5	G7	G2	G4	G6	G8
Cpavg	-1.28	-1.27	-1.09	-0.96	-0.59	-0.60	-0.65	-0.64
Cpmin	-2.96	-2.79	-3.85	-3.62	-1.56	-1.56	-1.63	-1.59

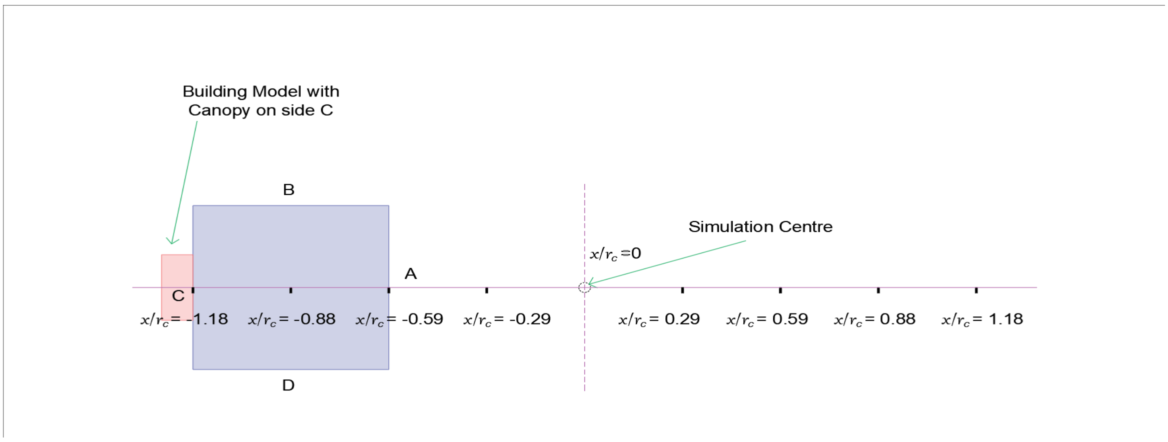


Building Model with smooth terrain

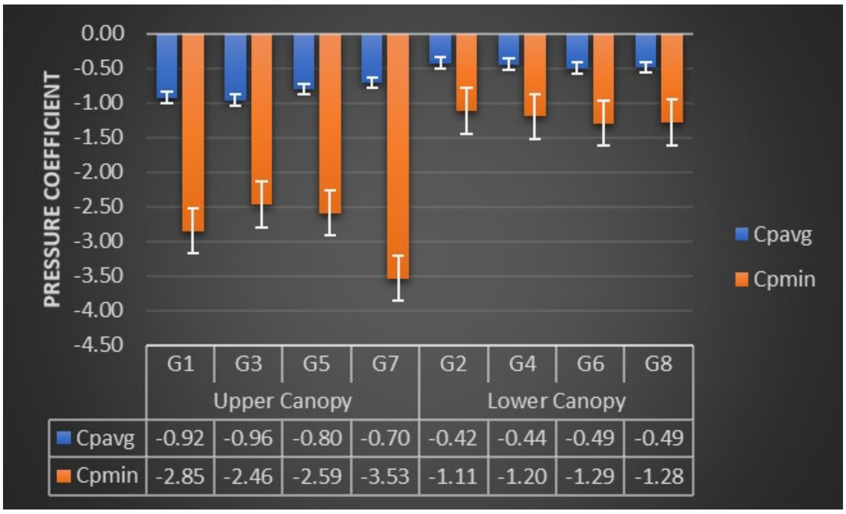


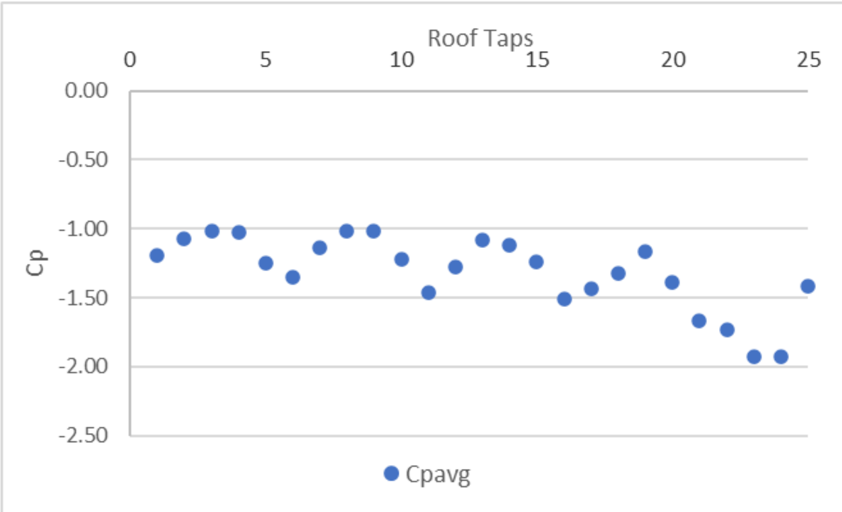


Canopy Length 30mm, Height 18.75mm Slope 10-degree, X = -75mm

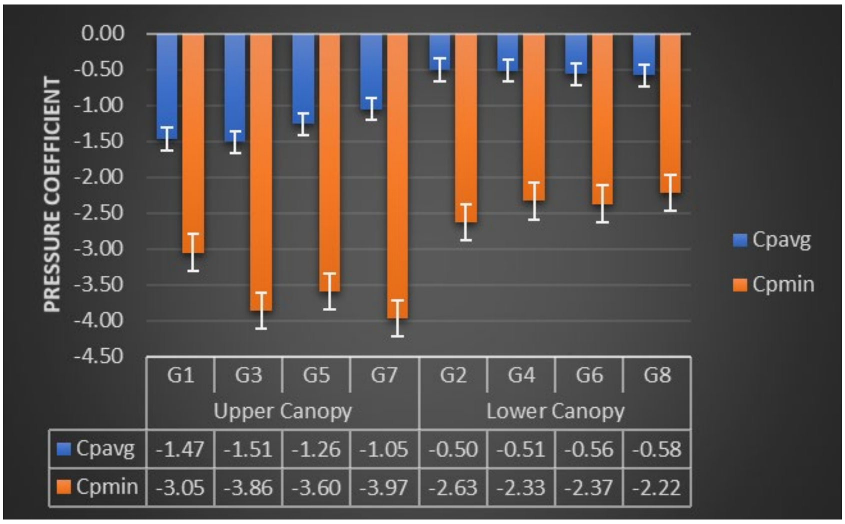


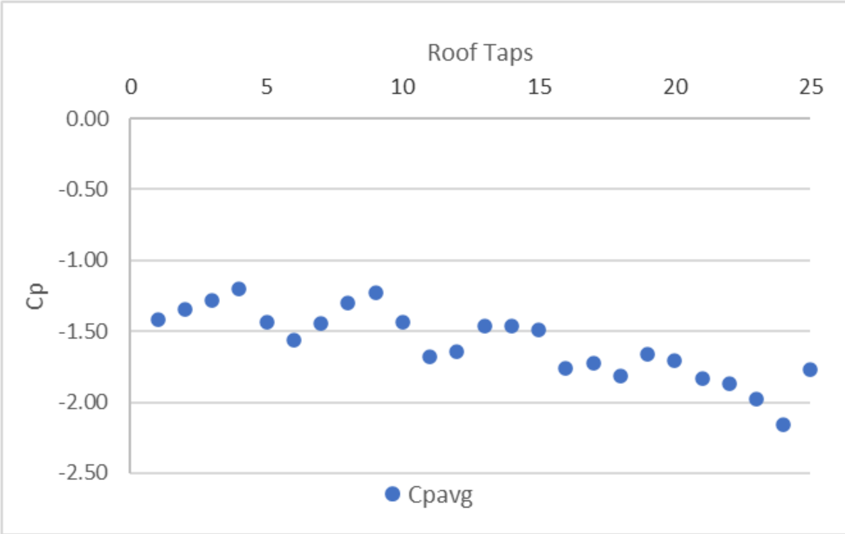
Building Model with rough terrain



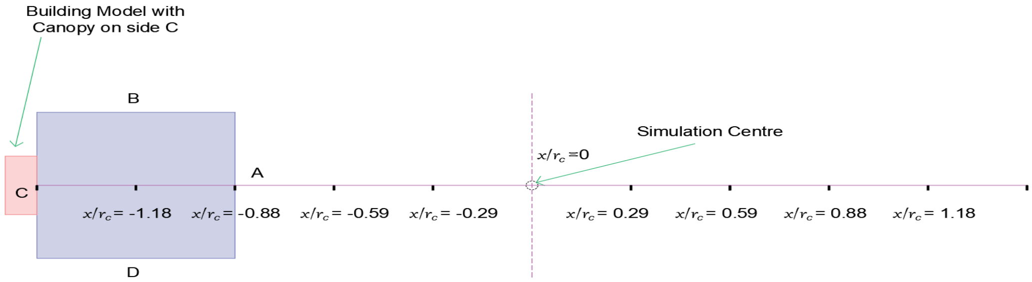


Building Model with smooth terrain

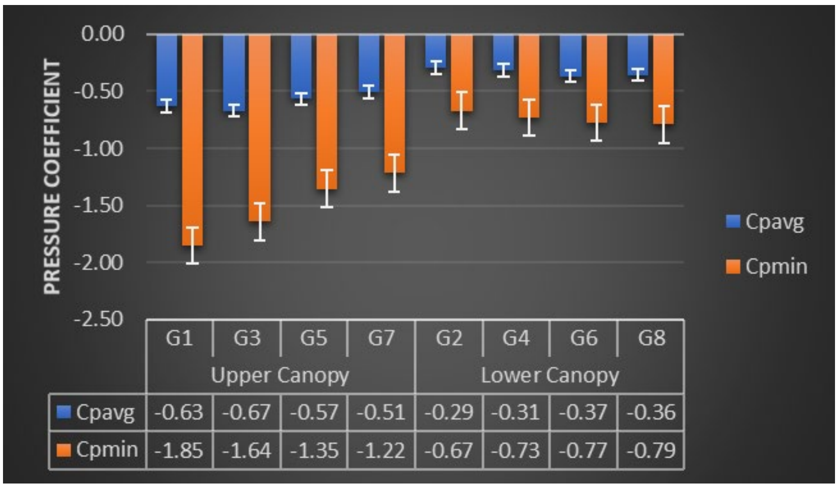


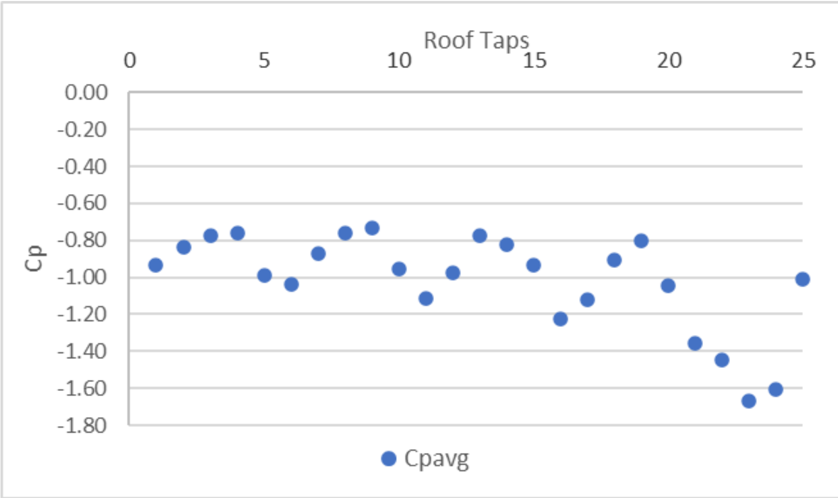


Canopy Length 30mm, Height 18.75mm Slope 10-degree, X = -100mm

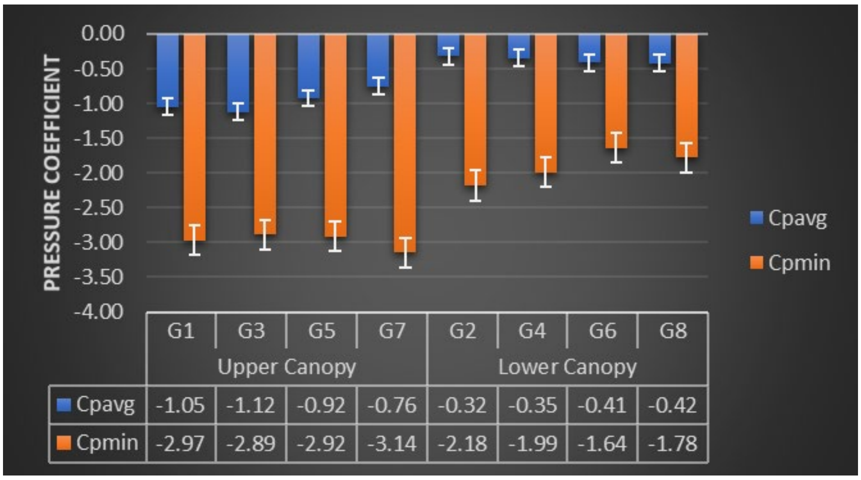


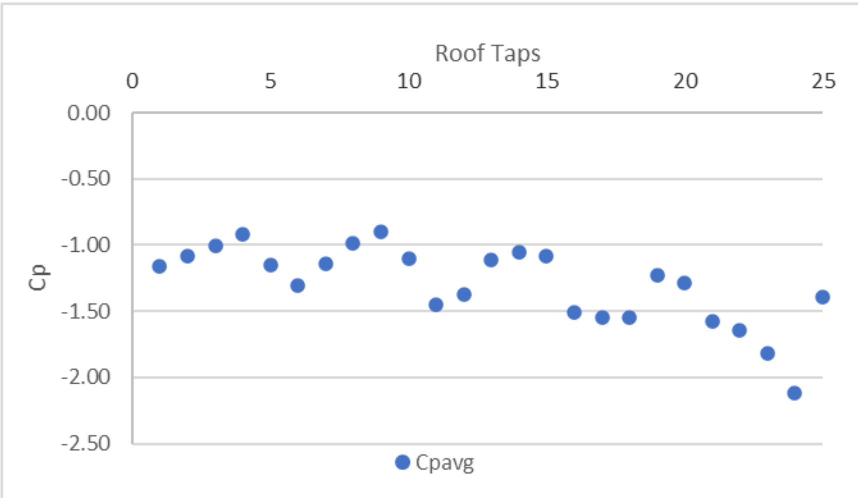
Building Model with rough terrain





Building Model with smooth terrain





4. Published Paper etc.
[Underline the representative researcher and collaborate researchers]

[Presentations at academic societies]
1. One conference paper accepted in CIB World Building Congress WBC2025: Sustainable built environment – the role of the construction community in meeting The United Nation Sustainable Development Goals (UN SDGs), Purdue University. Titled "Evaluation of Wind Pressure on the Low-Rise Buildings and Surrounding Terrain under the Influence of Tornado Like Vortex Induced Aerodynamic Loads"

[Published books]
1.
2.

[Other]
Intellectual property rights, Homepage etc.

5. Research Group
1. Representative Researcher
Rajesh Goyal, Professor, NICMAR Institute of Construction Management and Research, Delhi-NCR, Bahadurgarh, India

2. Collaborate Researchers
1. Nakul Gupta, Associate Professor, NICMAR Institute of Construction Management and Research, Delhi-NCR, Bahadurgarh, India
2. Masahiro Matsui, Professor, WERC, Tokyo Polytechnic University, Japan

6. Abstract (half page)

Research Theme Impact of Tornado vortex induced aerodynamic loads on structural projections in low rise buildings
Representative Researcher (Affiliation): Prof. Rajesh Goyal, NICMAR University, Pune, India

Summary

This research proposes extensive study on low rise buildings with attached canopies at 10-degree angle for different parameters under the influence of tornado induced vortexes. The building models can be tested for attached canopy at different roughness coefficient as shown in fig. 1. In order to measure surface pressures directly, pressure tapping points were placed on the model's walls and roof surfaces. The tornado's position was changed laterally by 10 m, 20 m, 30 m and 40m and longitudinally on both sides of the neutral axis by 10 m, 20 m and 30 m while the pressure was being measured. As compared to building models with roughness and without roughness the magnitude of coefficient of pressure decreased, especially on the lower canopy. The average tornado pressure on roof was not affected significantly by the presence of the roughness, especially when the building location was inside the vortex core radius. Roof and upper canopy experienced higher pressure coefficient compared with the lower canopy. It was found that $x/rc = 0.88$, introduction of rough terrain reduced pressure coefficient by about 15% on upper surface of canopy and 27% at lower surface of canopy and when the tornado location was at $x/rc = -0.88$, introduction of rough terrain reduced pressure coefficient by about 35% on upper surface of canopy and 18% at lower surface of canopy.