Gust effect factors of components and cladding wind loads for low-slope roofs on low-rise buildings

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Background

- Low-rise buildings are vulnerable to wind-induced forces, if they are located in low-seismic zones. Flow separation generates strong wind-induced suction pressure which causes significant damage to roof.
- Wind loads can be estimated by two methods: (i) gust effect factor method (G) which was developed using quasi-steady theory (QST). This method is widely used for along wind response for high-rise buildings and (ii) instantaneous peak pressure. This method is widely used for components and claddings (C&C).
- QST assumes Gaussian distribution of wind flow and negligible effects of body generated turbulence.

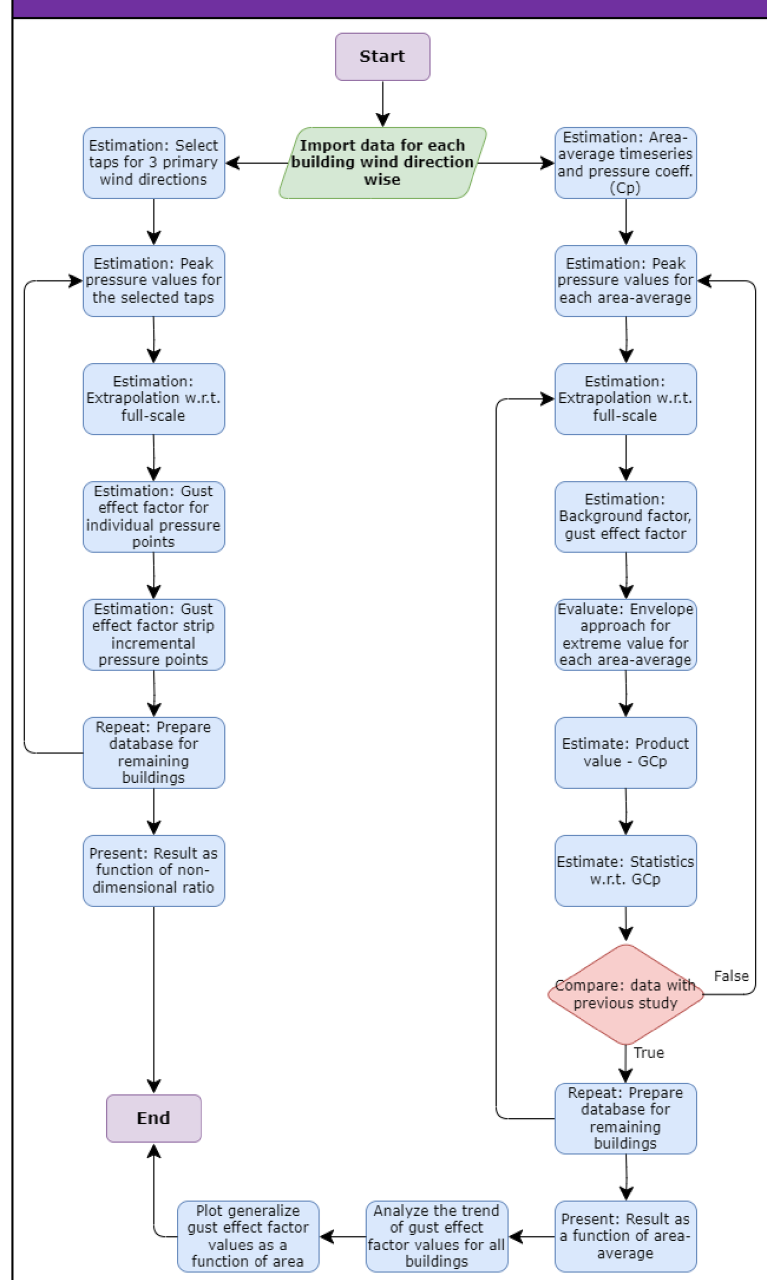
Motivation

- Low-rise buildings were assumed as rigid when G was developed. Hence, 0.85 constant value has been assigned in ASCE 7 since 2002.
- However, in recent time, architectural freedom, light weighted facades and increased use of roof top solar structures raises concern for structural flexibility.
- This might conflict the basic assumptions of G. Hence, its theoretical re-evaluation is necessary for building roofs.
- Prior research proves that QST is applicable for large-exposed area of roofs. However, its extent is yet to be determined.

Research objective

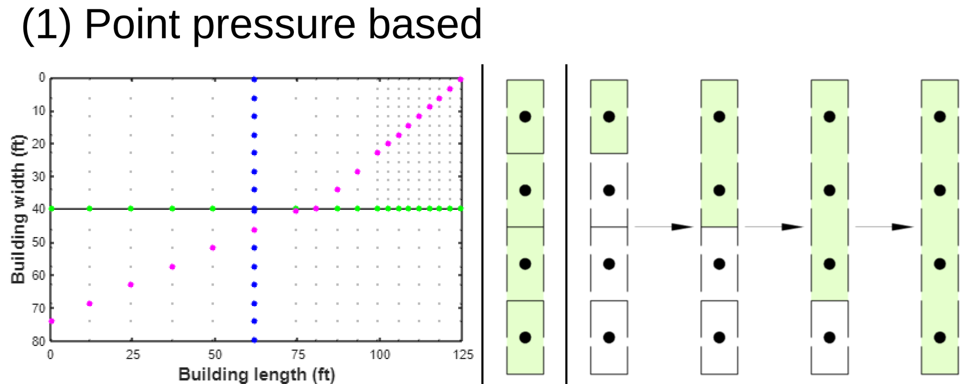
- **Hypothesis:** The G might lose the precision to predict correct wind-induced loads on small-exposed area of roofs.
- **Objective:** Evaluate G and assess its theoretical relevance for low-sloped gable roofs by progressively varying wind exposed area using 28 buildings from NIST database.
- For estimation of G, method of Wang and Kopp (2021) is used. Only low-sloped low-rise buildings are considered.

Procedure



- Result derivation methods

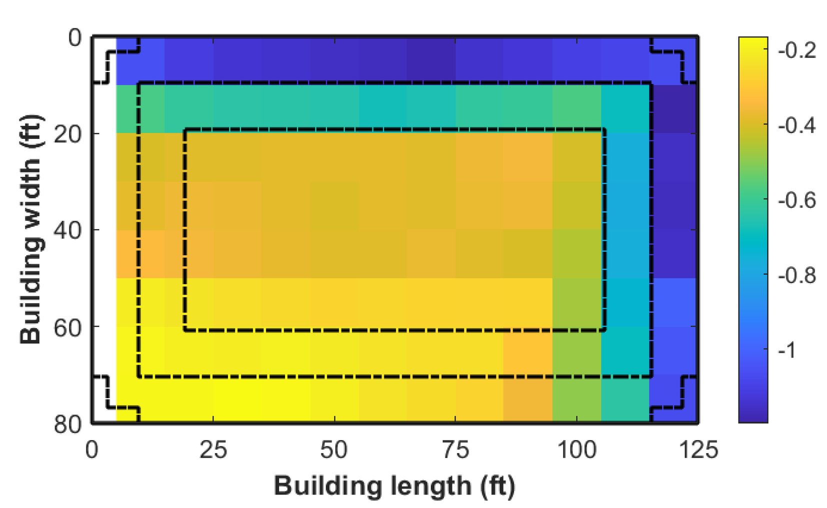
(1) Point pressure based



(a) (b) (c)

(a) Selected pressure points; (b) individual point pressure and (c) incremental point pressure

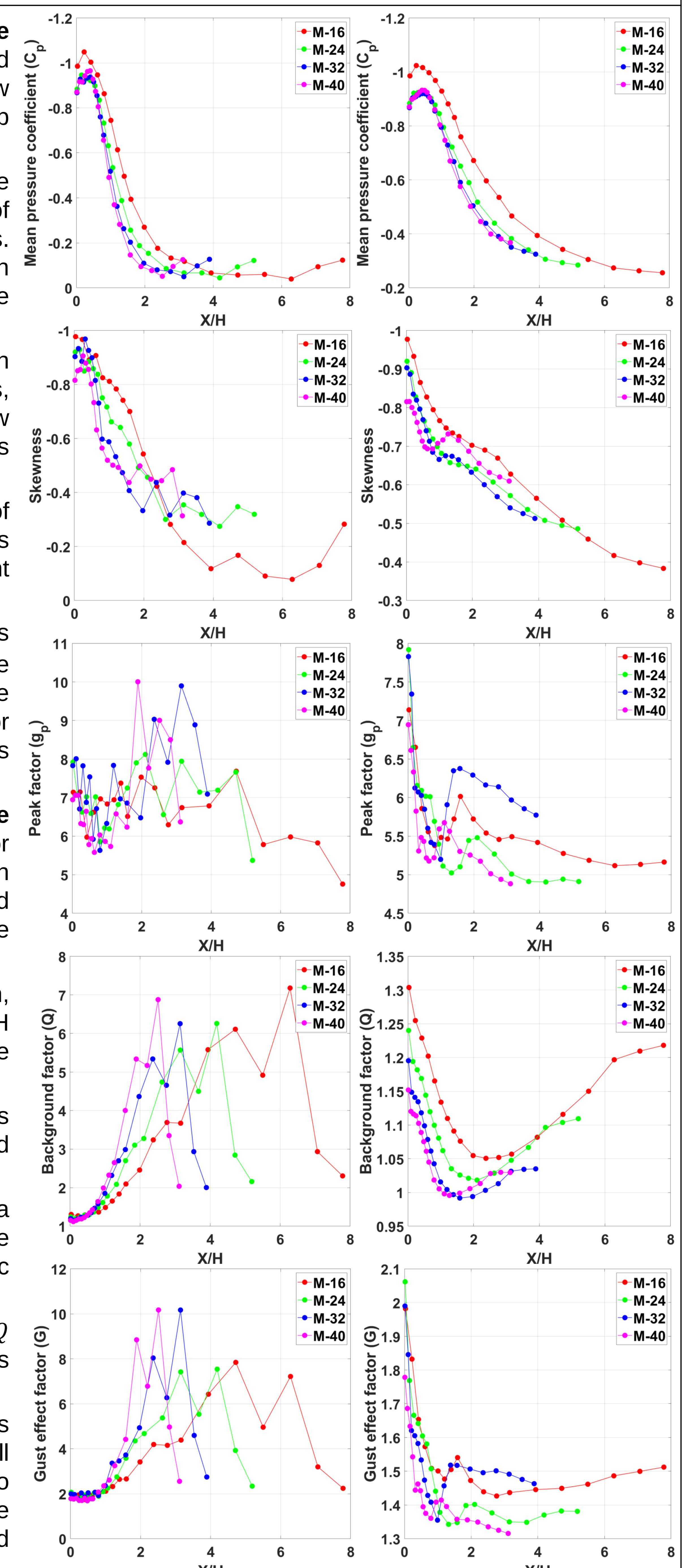
(2) Spatial varying area-average based



Result: point pressure based

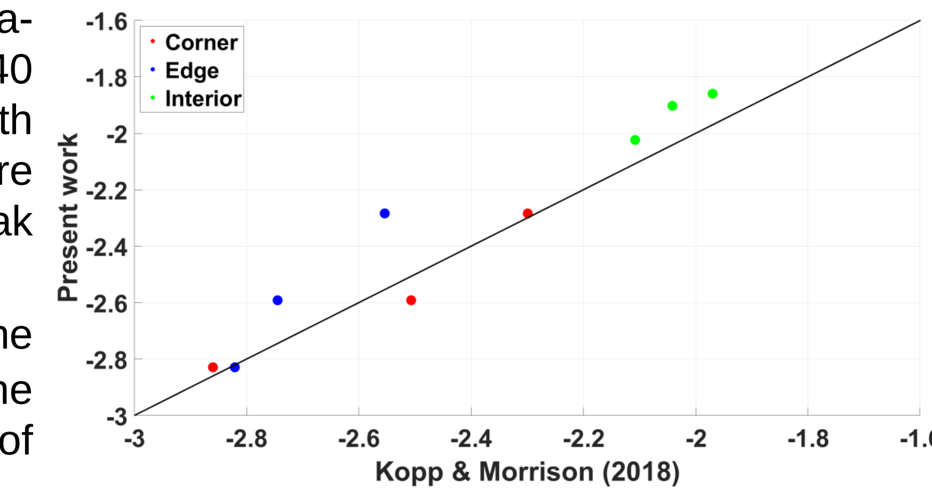
- Graphical results for wind direction 360° are shown. Point pressures are used to understand wind aerodynamics with respect to selected building configuration (M = L×B×H = 125'×80'×H) and streamline turbulence intensity.

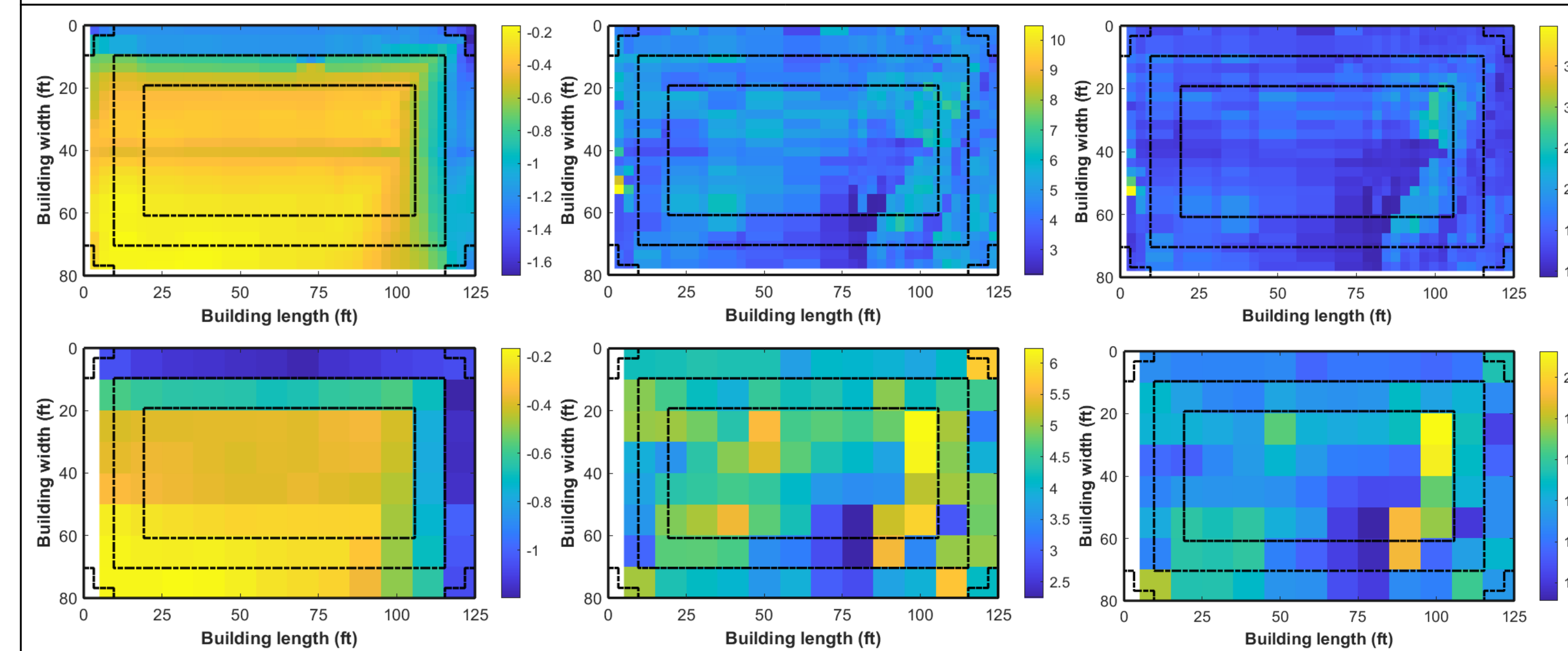
- **High suction pressure** was observed at windward edge as wind flow separates from sharp edge of bluff body.
- The pressure magnitude reduces as the effects of flow separation reduces. The same increases when flow reseparates from the trailing edge.
- **Statistical results**, such as skewness and kurtosis, indicate that wind flow near windward edges is highly non-gaussian.
- The magnitude of statistical results, reduces for incremental point pressure approach.
- **Peak factor (g_p)** is scattered. However, the same decreases as the distance increases for incremental points pressure.
- **Background response factor (Q)** increases for the distance < 2H which indicates body-generated turbulence effects are strength.
- For incremental approach, Q reduced for < 2H gradually; the same increases for > 2H.
- Higher Q for > 2H is observed due to reduced mean pressure.
- **Gust effect factor (G)** is a function of gust response factor and gust dynamic pressure factor.
- The trend is similar to Q which indicates that G is mainly depends on Q.
- Area-averaging effects reduces the overall magnitude of G due to dilution of peak pressure under the considered exposed area.



Result: Area-average pressure based

- **Comparison:** The obtained area-average based results from 125×80×40 (1:12) model were compared first with the already published data which were obtained by instantaneous peak pressure method.
- The magnitude of GC_p matches with the range of 0.002% to 11.8%. The difference might be caused by the use of different area-averaging technique.

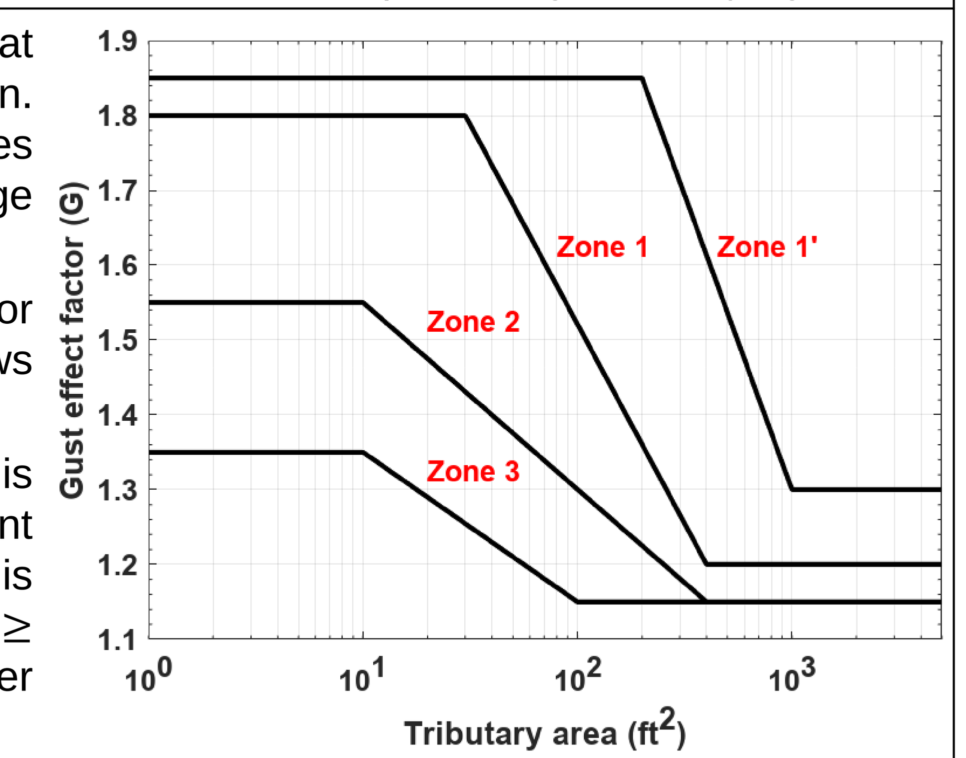




C_p plot Q plot G plot

- Shown spatial plots are 1:12 125×80×16. Zones are assigned as per Ch. 30, ASCE 7-22. Extreme pressure and respective parameters are extracted plotted against varying area.

- Skewness and kurtosis depicts that separated wind flow is non-Gaussian. However, it eventually becomes Gaussian, if the exposed area is large enough.
- The magnitude of Q is constant (1.0) for the exposed area ≥ 1000 ft^2. This shows QST is applicable.
- The derived magnitude of G is considerably higher than the constant value of 0.85 of ASCE 7-22. Derived G is nearly 1.15-1 for the exposed area ≥ 1000 ft^2. Shown plot is developed after reviewing all 28 buildings.



Conclusion

- Separated shear layer and conical vortices are majorly responsible for peak pressure at windward edges of roof or corners.
- The area-averaging technique reduces effects of peak pressure and instantaneous fluctuations. Hence, the effects of body-generated turbulence is noticeable if the exposed area is < 1000 ft^2.
- The existing constant value 0.85 for gust effect factor underestimates the wind-induced loads on C&C.
- QST is still applicable at roof region if the considered exposed area is large enough.

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