Winds Are Changing in Canada:

Verifying Wind Load Code Provisions on a Low-Slope Gabled Roof with Field Measurements and Wind Tunnel Data

By Mauricio Chavez, PhD, and Bas A. Baskaran, PhD

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Figure 1a. The building selected to verify the code provisions for low-slope roof. Figure 1b (next page). Building dimensions and instrumented area: NW and SW corner. Note: 1' = 1 ft = 0.3048 m.

The wind load provisions for low-slope roofs in the 2020 *National Building Code of Canada* (NBCC),[1] as well as the provisions in the American Society of Civil Engineers' 2010 edition of *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-10),[2] were established in the 1970s based on findings from boundary layer wind tunnel experiments by Stathopoulos[3] and Surry et al.[4] Wind pressure measurement tools have significantly improved during the past 50 years, and verification of those pressure coefficients using experimental data obtained by modern devices and complementary approaches has been required. Recently, Kopp and Morrison[5] revisited the provisions for low-slope roofs and completed an extensive wind tunnel simulation using modern digital techniques to verify the provisions in ASCE 7-10. The researchers concluded that both design pressure coefficients and the size of the roof zones needed enhancements. The recommendations were considered by ASCE, and the provisions were partially increased as well as the roof zones modified in ASCE-7-16.[6] In Canada, NBCC did not adopt the proposed changes for low-slope roofs, and therefore the pressure coefficients and roof zoning were unchanged.

The changes to wind load provisions in ASCE 7-16 motivated the National Research Council of Canada (NRC) in collaboration with the Special Interest Group on Dynamic Evaluation of Roofing Systems (SIGDERS) consortium to conduct a wind load investigation to verify the suitability of the current wind load provisions for low-slope roofs. The investigation aimed to benchmark wind load specifications with the wind load measured from an in-situ building and wind tunnel simulations. The synergy of full-scale measurements with wind tunnel simulations is recognized to be a powerful approach to validate code provisions. The full-scale data provide the real physics (right scale and right dynamic interactions), whereas the wind tunnel simulations provide configurations not possible to obtain from field measurements. This "tridimensional" approach of field versus wind tunnel versus code provides a valuable perspective to verify the suitability of code provisions. This article presents the work done by NRC-SIGDERS to verify the suitability of the current wind provisions for low-slope roofs in NBCC. It is anticipated that this research will contribute to the discussion of whether the current NBCC code provisions need to be revised or not.

FIELD MONITORING: IOWA BUILDING

Field monitoring is a challenging research domain, particularly if the objective is to compare results with code provisions. The induced variability of the approaching flow due to the

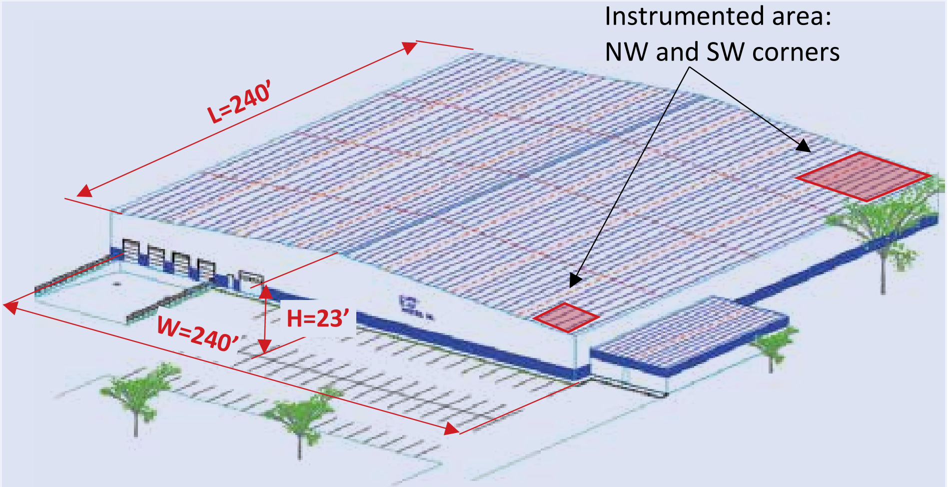

Figure 1b.

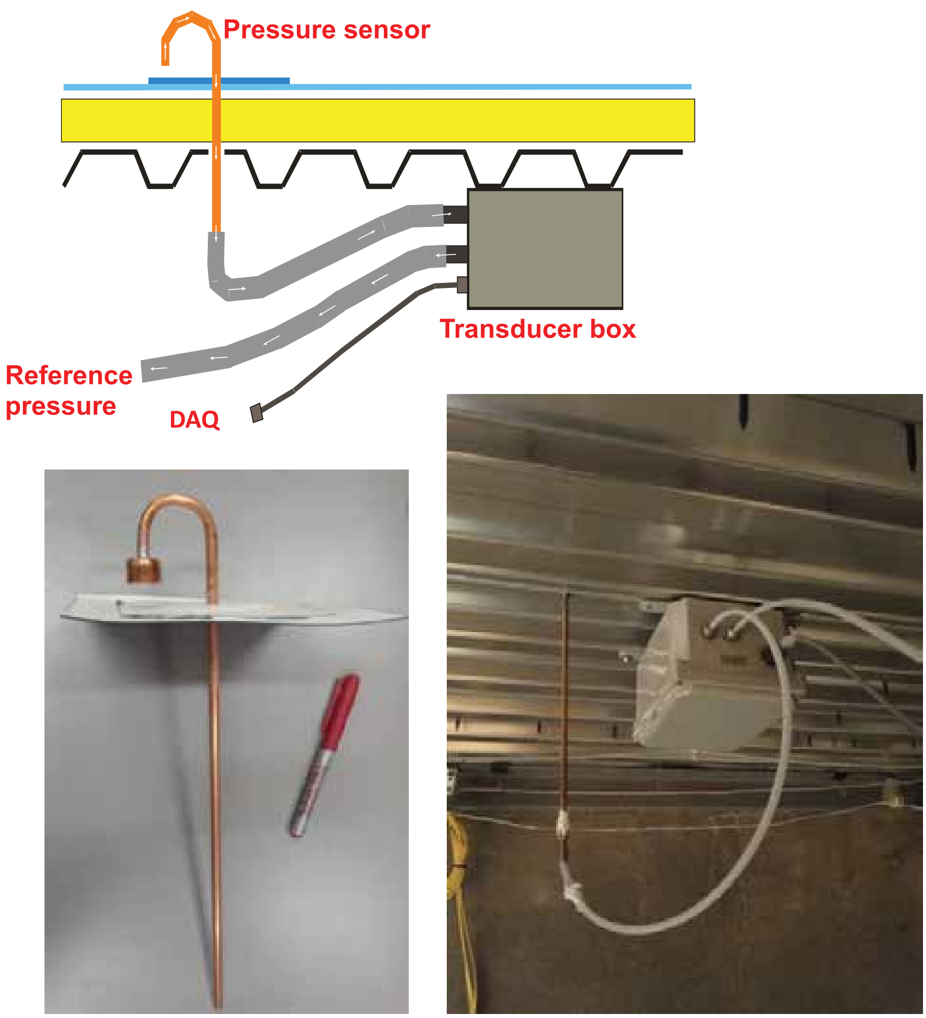

Figure 2. ***Details of the pressure sensor developed by National Research Council of Canada to evaluate wind load on the roof. Note: DAQ = data acquisition system.***

building itself or upwind surroundings makes it very difficult to generalize the roof wind load. To minimize the uncertainties and maximize the validity of comparisons of field data and code provisions, the selection of the building is a critical component of this research. The selection process includes three main criteria:

- Geometry: The selected building must be an ideal representation of the building specified in the code.
- Wind exposure: The location should be in open terrain to avoid or minimize the effect of adjacent buildings.
- Accessibility to the roof deck (to allow the instrumentation installation).

To overcome these challenges, NRC requested the collaboration of SIGDERS. SIGDERS is a North American nonprofit organization composed of roofing manufacturers and provincial roofing contractor associations. SIGDERS has been a key actor in this research for two reasons. First, they provided the required network to identify the suitable building for field monitoring, and they helped get the building owner’s approval to install pressure sensors on the roof. Second, as a “final user” of code provisions, their advice regarding the practicality of provisions and design requirements has been essential to integrate science and real-world conditions.

Based on the previously noted selection criteria, the research team selected the building shown in Fig. 1a, b to verify the code provisions for low-slope roof buildings [Fig. 4.1.7.6.C in NBCC]. The building—hereafter referred to as the IOWA building—is a manufacturing plant in Sigourney, Iowa. It is situated in open terrain with a neighboring construction located to the north. It has a square shape plan measuring 240 × 240 ft (73 × 73 m), a ridge height of 23 ft (7 m), and a roof slope of 1.4 degrees (2.5%) with no parapets. Additional details of the IOWA building and roof components can be found in Chavez et al.[7]

Two areas on the roof were instrumented (northwest corner 30 × 30 ft [9 × 9 m], and southwest corner 60 × 60 ft [18 × 18 m]) as shown in Fig. 1b, with a total of 21 pressure taps. The taps were strategically distributed to capture wind loads on the three roof zones (Corner, Edge, and Interior) defined by NBCC. The core of wind load monitoring is the pressure sensor approach developed by NRC. **Figure 2** shows some details of the sensor. The device is built using a 12-in.-long (300-mm) and ¼-in.-diameter (6.4-mm) copper tube, which is bent at the external end to prevent rainwater intrusion. The external end is located close to the membrane to capture the static pressure acting on the membrane. The internal end is connected to a flexible tube (10 to 12 in. [250 to 300 mm] long) that is connected to the pressure transducer box where the wind pressure is converted into an electrical signal. A reference pressure is required to quantify the differential pressure, and a data acquisition system is necessary to store and process the data.

The field data are collected continuously at a rate of 100 samples per second, which generates a massive amount of data. A post-processor was developed to extract sections (segments) of

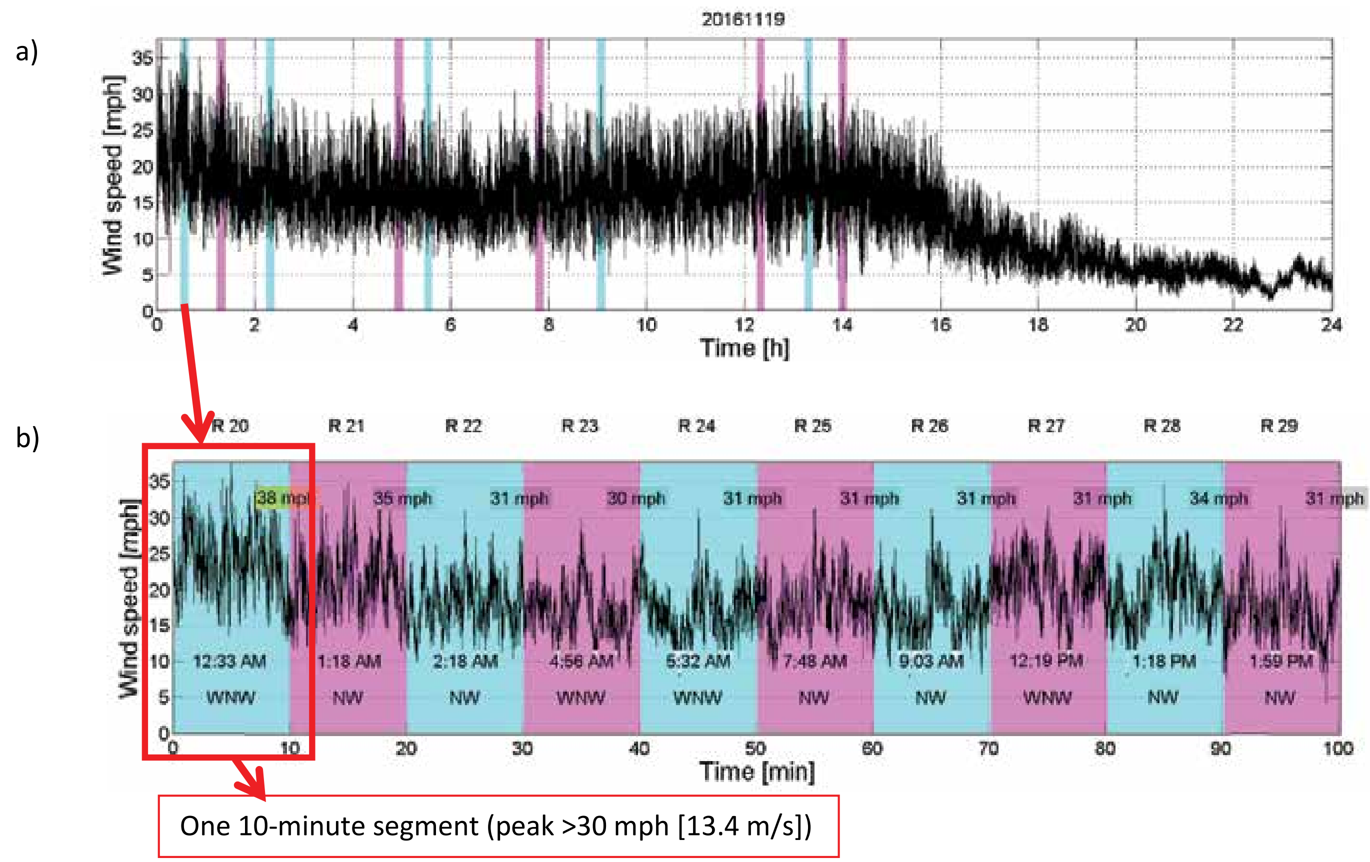

Figure 3. ***Data from field monitoring: (a) typical wind speed time history; (b) example of data segmentation into 10-minute records (November 19, 2016). Note: 1 mph = 0.447 m/s.***

relevant data that respond to a predetermined criterion. Basically, the post-processor scans the continuous time history and searches for wind speed peaks greater than 30 mph (13.4 m/s), then segments of 10 minutes of data (5 minutes before and after each wind speed peak) are extracted to generate the database required for further analysis. **Figure 3a** shows a typical example of a wind time history (24 hours) and the segmentation process. **Figure 3b** shows the concatenation of all the segments collected for this specific day. During monitoring of the IOWA building, 92 segments of data were collected and used for the completion of the project. These instrumentation and measurement techniques have been successfully applied in the previous NRC-SIGDERS field monitoring programs (Ottawa site,[8,9] Rialto site,[9] and Vancouver site[10,11]).

WIND TUNNEL EXPERIMENTS

In addition to field monitoring, data were also collected using the conventional wind tunnel approach. Scaled wind tunnel models of the IOWA building were tested by the Building Aerodynamics Laboratory of Concordia University in Montreal, Quebec, and the Boundary Layer Wind Tunnel Laboratory of Western University in London, Ontario.

The major advantage of wind tunnel models is the opportunity to evaluate the effect of wind for all wind directions. This is possible because the model is installed on a turntable, which allows investigators to change the approaching wind direction as desired by rotating the model. In this study, the wind was evaluated for all wind azimuths to ensure that the critical wind direction is included in the analysis. Another advantage of wind tunnels is the option to install a significant number of pressure taps (many more than is possible in field studies). By increasing the pressure tap density, there are more chances to capture the critical peak pressures on the roof. It should be recalled that the wind load on the roof is not uniform, with a great gradient close to corners and roof edges.

The wind tunnel laboratories that participated in this research used their own criteria to evaluate the IOWA building. For example, the geometric length scales were 1:250 and 1:200 for the Concordia and Western tests, respectively. Concordia installed 194 pressure taps, whereas Western installed 534 taps. The roof-height velocities were 9.1 m/s (20.4 mph), with a turbulence intensity of 14%, and 5.12 m/s (11.5 mph), with a turbulence intensity of 19.5%, for Concordia and Western, respectively. Note that turbulence intensity is the ratio of the fluctuating wind velocity over the mean wind speed. **Figure 4** presents the experimental setup, close-up pictures, and pressure models.

It is important to understand that even though wind tunnel simulations have proven to be an effective tool to investigate wind loads on roofs, they remain simulations, with several assumptions and approximations. This is why the tandem field and wind tunnel evaluation is observed as a powerful and promising approach to advance the credibility of design loading. Details of the comparisons of wind tunnel data with field measurements can be found in Chavez et al.[12]

FIELD VERSUS WIND TUNNEL VERSUS NBCC 2020

The wind loads on the roof cladding are presented in terms of the combined external pressure coefficient and gust effect factor C_pC_g. C_pC_g is the nondimensional coefficient used to study the forces resulting from wind-building interactions. **Figure 5** summarizes the results of this investigation. The graphs compare C_pC_g from the three sources (field data and the two wind tunnels) with NBCC code provisions for the three roof zones (Corner, Edge, and Interior). These comparisons allow verification of the suitability of the current

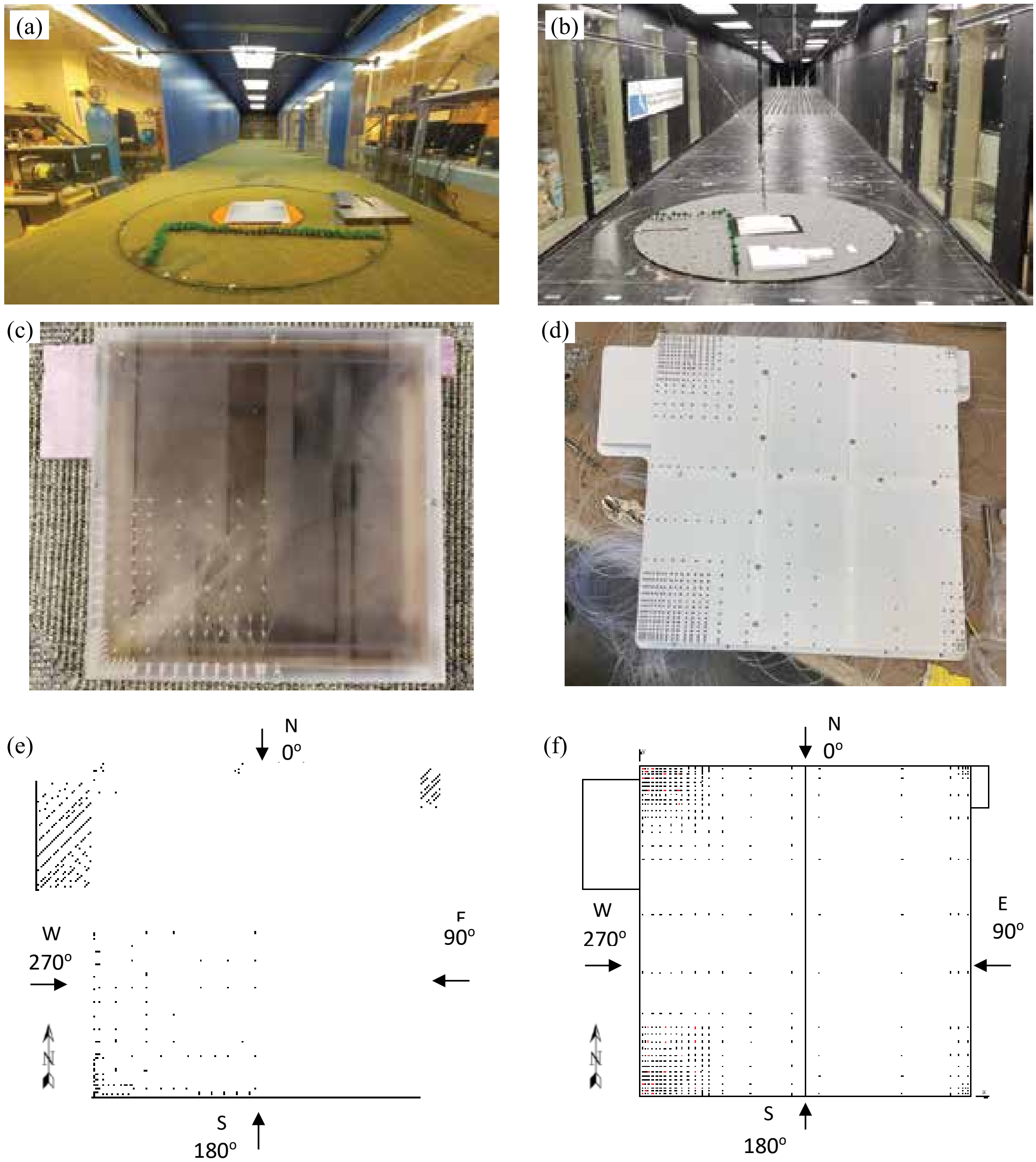

Figure 4. ***Wind tunnel testing was conducted at the Building Aerodynamics Laboratory of Concordia University and the Boundary Layer Wind Tunnel Laboratory of Western University: (a) wind tunnel test setup at Concordia; (b) wind tunnel test setup at Western; (c) close-up view of Concordia model; (d) close-up view of Western model; (e) tap layout for Concordia model; (f) tap layout for Western model.***

provisions. To interpret the results, it should be understood that the solid black lines representing code provisions are the design pressure coefficients as a function of the tributary area under consideration. It is assumed that the provisions are developed conservatively enough to cover the worst-case scenario in terms of wind load over the roof. Therefore, to verify the suitability of the code provisions, all wind load measurements (in the field or wind tunnel) should be below the provisions.

Figure 5a shows the C_pC_g measured by the Concordia and Western laboratories in the wind tunnel, and the C_pC_g measured in the IOWA building for the Corner Zone. The cloud of data points is the result of measurements at different locations within the roof zone. The range of those data points illustrates that some locations are more sensitive to wind effects (high suction) than others. For the field data, the bracket on the data point shows the inherent variability of field measurements.

The results for the Corner Zone show that the C_pC_g data from Concordia and Western are mostly below the code provision, except for a few extreme cases from Western that were above the provisions. For the field data, the average C_pC_g was –5.7, which is in fairly close agreement with the current provision. The Western results were higher than the Concordia results; the differences are because the wind profiles used in the simulations are different. As described previously, Western applied a more turbulent flow than Concordia, and greater turbulence implies greater flow variability and greater peak pressure. The greater number of pressure taps (or high-pressure tap resolution) used by Western may also increase the chances to capture more peak pressure. Besides the discussion regarding wind tunnel techniques, the important conclusion of Fig. 5a is that, based on the results from these three approaches, there is not clear evidence that the current provision for the Corner Zone in NBCC[1] needs to be modified.

Figure 5b shows the results for the Edge Zone. In contrast with the previous case, the results

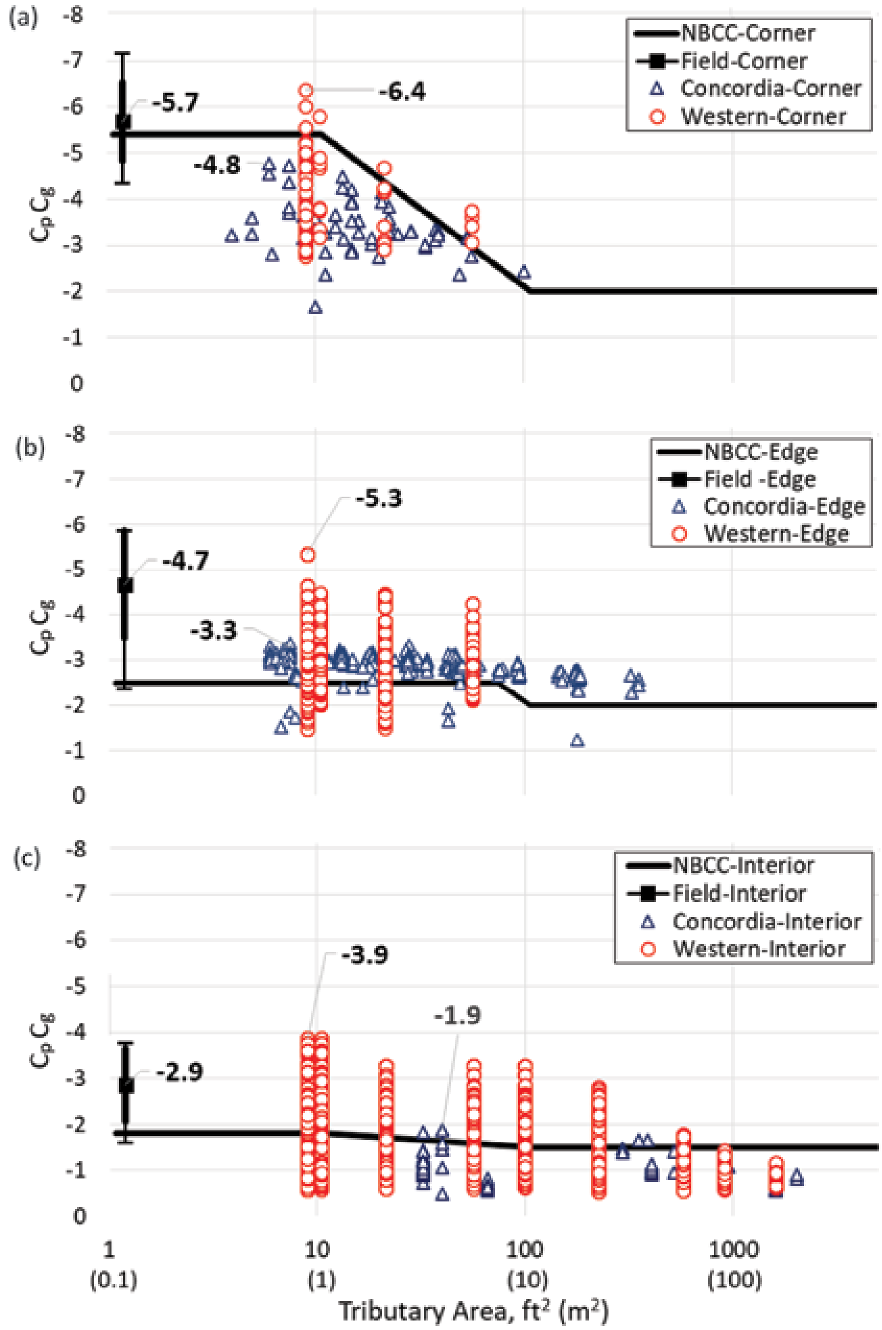

Figure 5. *NBCC provisions versus wind tunnel and field data (a) corner, (b) edge, and (c) interior. Note: NBCC = National Building Code Canada.*[1]

show that the C_pC_g data from the Concordia and Western laboratories and from the field measurements are almost all above the code provision. This finding can be interpreted as evidence that the current NBCC provision for the Edge zone is currently underestimated and needs to be enhanced. It can be observed that the ensemble of data points from the Western wind tunnel simulations and the field measurements is similar to the data obtained in the Corner Zone. Therefore, it seems logical to infer that the code provision for the Edge Zone could be established to be equal to the Corner Zone provision. In other words, the Edge and Corner Zones could be merged as a single "Perimeter" Zone. Such a change could be an important simplification in the code.

Figure 5c shows that the Interior Zone C_pC_g data from Concordia are mostly lower than the code provision, whereas the data from Western and the field investigation are higher than the provision. Thus, the Western and field data provide some evidence that the code provision for the Interior Zone is currently underestimated, but Concordia's critical values are close to the code provisions suggests that the provision for the Interior Zone is conservative enough. The comparison of field and wind tunnel data is not conclusive regarding the necessity to revise the Interior Zone provisions; therefore, no changes for these provisions are indicated.

CLOSING REMARKS

This article summarizes research conducted to verify the suitability of the current low-slope roof wind load provisions in NBCC.[1] The results from field measurements in the IOWA building and two independent wind tunnels were consistent in demonstrating that the Edge Zone provision is currently underestimated by NBCC[1] and needs to be increased. This research does not provide a specific new value for the Edge Zone. However, the data show that the actual wind load on the Edge Zone is close to the wind load on the Corner Zone. Therefore, the current study suggests that merging the Edge and the Corner Zone provisions into a single "Perimeter" provision is feasible. Thus, the low-slope gabled roof provisions would be composed of two roof zones only: Perimeter and Interior (**Fig. 6**).

This proposed change would simplify the code. Simplicity in codification is important to make the construction process easier and reduce the risk of worker errors during construction. The suggested code change would address the current underestimation of the Edge Zone (wind load upgrade), and would provide code simplification to minimize failure due to installation deficiencies (constructability upgrade).

ACKNOWLEDGMENTS

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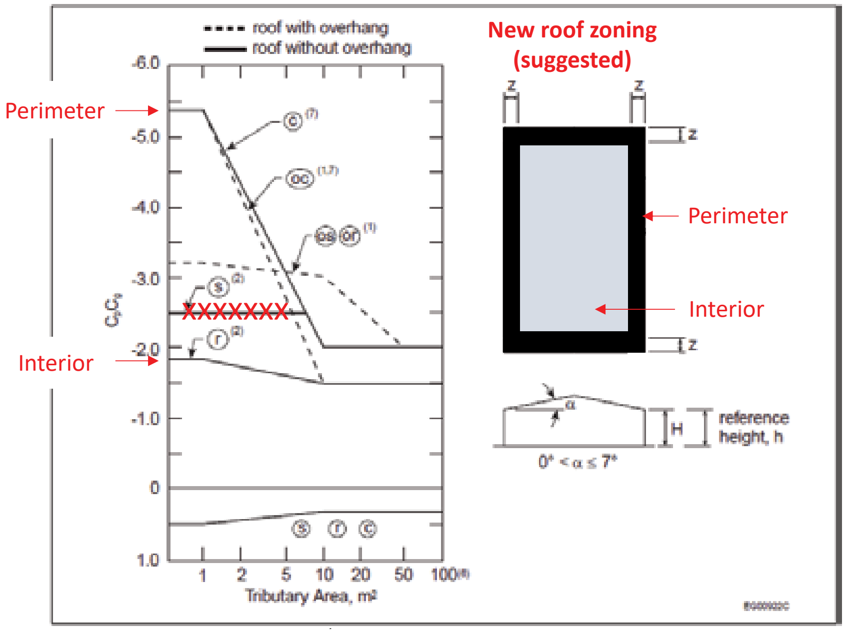

Figure 6. ***NBCC provisions modified to illustrate the suggested new provisions and roof zones. Note: NBCC = National Building Code Canada.[1]***

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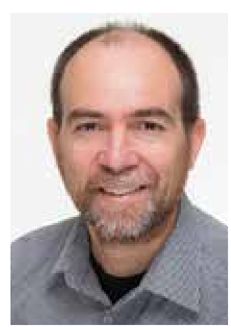

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