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Wind - Roof Calculator on Internet (Wind-RCI)

(Feel the wind on your laptop)

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Abstract

Wind effect on roof is a complex phenomenon. Poor wind design is one of the common factors in roofing failures. RICOWI's wind investigation program on hurricane Charley and hurricane Katrina also confirmed this and challenged designers for proper roof wind design tools. To address this issue, National Research Council of Canada developed a web-based roof wind design calculator. It is named as Wind-RCI (Wind-Roof Calculator on Internet). Wind – RCI can minimize possible misinterpretations of code language. Calculation of cover wind uplift design loads is a function of various parameters such as roof type, slope, wind speed, building height, roof area, building terrain, building type and openings. As such, it involves several procedural steps. Wind-RCI integrates these procedural steps into a simple web based calculator. Demonstrating the viability and flexibility of the Wind - RCI is the objective of this paper.

Key words
Wind, Roof, Uplift, Design loads, Building Codes, Web based tools.

1. Introduction

Natural wind hazard damages have historically been dramatic, incurring losses of life and property around the world. Wind induced roof failure is one of the major contributors to insurance claims, and it is rising (AAWE,1997). Recently, members of the Roofing Committee on Weather Issues (RICOWI) completed two major wind investigations projects, documenting extensive roof damages (Figure 1), factual data and challenged designers for proper roof wind design tools. (RICOWI, 2006 and 2007). Similarly, the Federal Emergency Management Agency (FEMA) also published reports summarizing the observations, conclusions and recommendations of the Mitigation Assessment Team (MAT) in response to the recent hurricanes [FEMA 488,489 (2005) and 549 (2006)].

Figure 1: Roof damage during a high wind event

Wind flow around buildings creates both negative and positive fluctuations over a roofing system. The wind effect on roofing and its response is dynamic. Wind pressure distribution varies spatially over a roof and it can have high suction at the corner and perimeter, due to formulation of vortex and flow separations. Figure 2 illustrates the wind pressure variation on a building roof. This data represents wind tunnel measurements carried out by the National Research Council Canada (NRC) in the 30 x 30 ft (9 × 9) wind tunnel. These tests used full scale roofing components [10 x 10 ft (3 × 3 m) in size] at different building heights for wind directions perpendicular to the building face (normal wind) and at 45 degrees (oblique wind). A PVC roofing system was tested with pressure taps fitted in the PVC single ply membrane to measure the unsteady pressure loads on the roof (Savage et al., 1996).

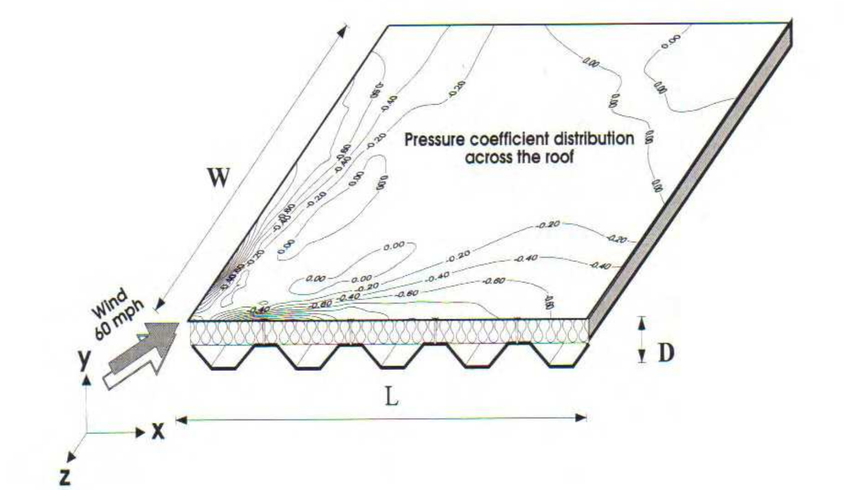


Figure 2. ***Spatial wind induced pressure distribution over a roof system***

To calculate wind uplift loads on roof coverings, designers use wind standards or building codes such as National Building Code of Canada (NBC-2005) and American Society of Civil Engineers (ASCE 7-05). Code provisions are a collection of facts and knowledge based on the experimental data measured by testing models in wind tunnels or full-scale measurement data, which are obtained from instrumented structures, field observations and consensus of expert opinions.

Wind load calculation for roof covering involves several procedural steps, since the design pressure is a function of various parameters such as roof type, slope, wind speed, building height, roof area, building terrain, building type and openings. Interpreting wind standards to identify the various parameters is indeed a time consuming process and it can often lead to misinterpretation and mis-interpolation of code language. Considering this complexity, RCIF has offered a research grant to NRC for developing a roof wind design tool. This tool is named as Wind-RCI (Wind-Roof Calculator on Internet). WIND-RCI is developed based on the National Building Code of Canada (NBC – 2005) and therefore it is applicable for all Canadian provinces and territories. Nevertheless, the paper also present and discusses the recently published NRCA's wind load calculator, which is developed based on the ASCE 7-05. This paper begins with the description of the roof covering design pressure calculation followed by the functionality of the Wind – RCI. Through case studies the paper demonstrates how it integrates the several procedural steps involved in the wind load calculation into a simple web load calculator.

2. WIND – RCI

NBC (2005) is a model code, which sets out technical provisions for the design of buildings in Canada. Wind – RCI computes the wind design using the - NBC 2005's Users Guide for Structural Commentary. NBC 2005 specifies that for structural components and cladding the design wind pressure is the algebraic sum of the external pressure and internal pressure across the specific component. This can be mathematically expressed as:

$$p = I_w q(C_e C_g C_p - C_e C_{gi} C_{pi}) \quad (1)$$

Where:

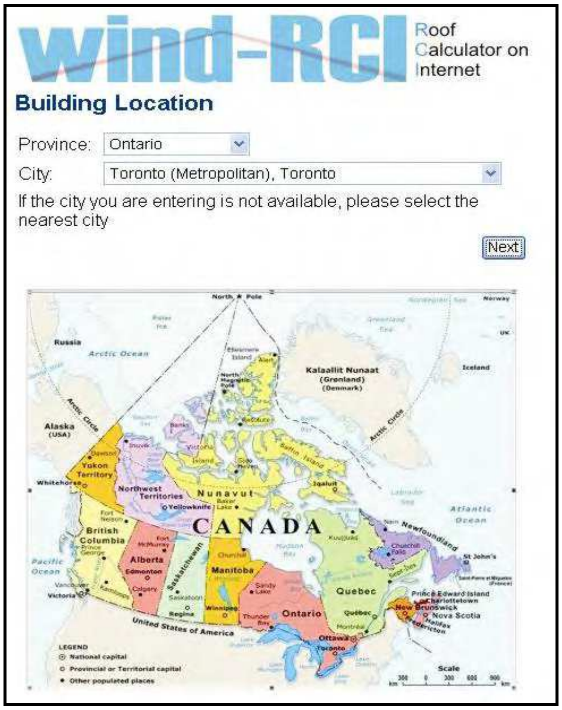
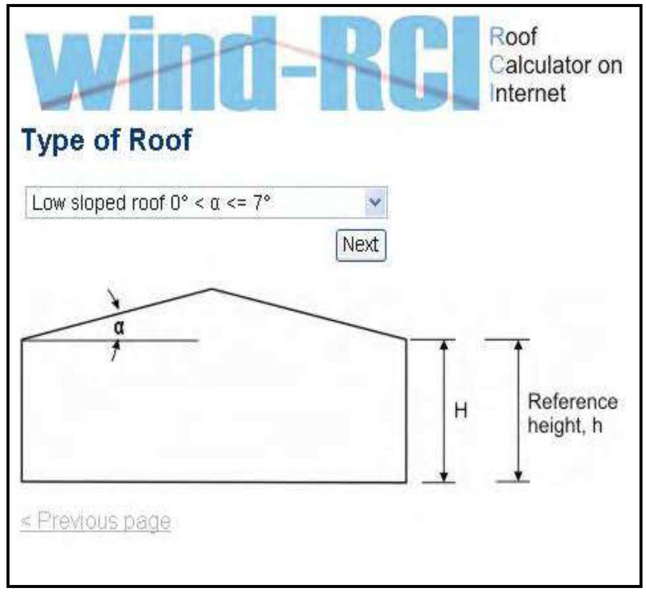
p	= design pressure,	I_w	=	importance factor
q	= reference velocity pressure,	C_e	=	exposure factor
C_g	= gust factor,	C_p	=	external pressure coefficient
C_{gi}	= internal gust factor,	C_{pi}	=	internal pressure coefficient

To obtain the design pressure as per the equation 1, a six steps procedure was developed by Baskaran and Smith, (2005) as follows:

1. Define corner zone
2. Calculation of dynamic pressure
3. Calculation of external pressure component
4. Calculation of internal pressure component
5. Calculation of design pressure Eq. 1
6. Load Diagram

Wind-RCI integrates these procedural steps into a simple web based calculator. Table 1 gives a quick snapshot of this web tool for a hypothetical building located in Toronto, Ontario. The Wind-RCI is capable of performing calculations for various parameters as listed in the Table 2. This includes building height ranging from low rise to high-rise, roof with various slope configurations from low slope to steep slope, building category both in terms of occupancies and openings. Thus the Wind – RCI is capable of providing a complete tool for determining the wind design pressures of a roof.

Table 1: Snapshot of Wind-RCI

<table>
<tr><th>Screen # 1</th><th>Screen # 2</th></tr>
<tr><td>
</td><td>
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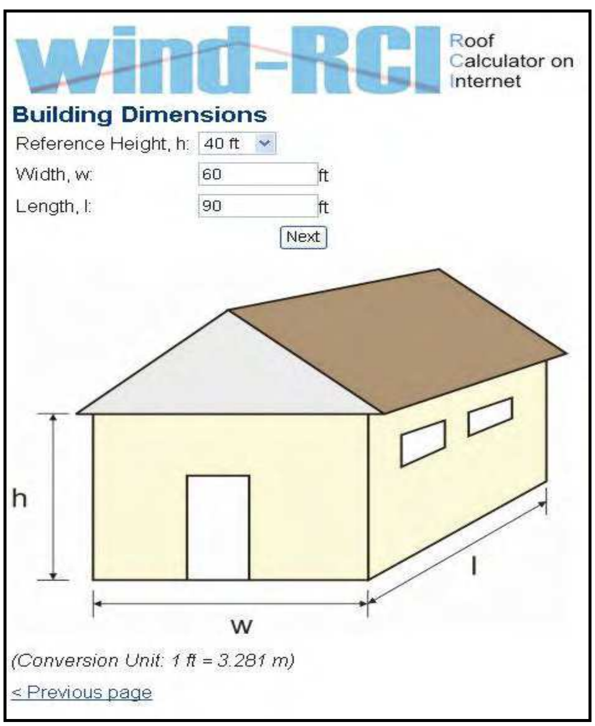
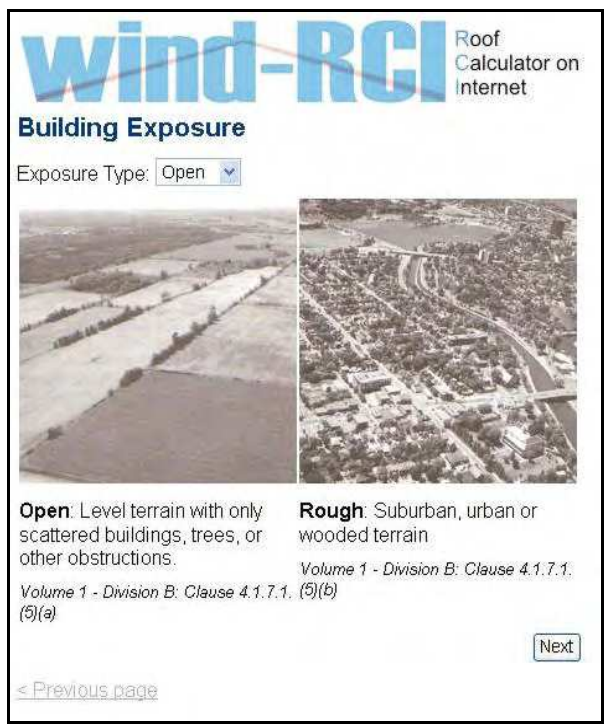
<tr><td>
</td><td>
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Screen # 5

wind-RCI Roof Calculator on Internet

Building Openings

Openings Category: Category 1

Category 1: Buildings without any large or significant openings, but having small uniformly distributed openings amounting to less than 0.1% of total surface area
(User's Guide, Commentary I, Sentence 31)

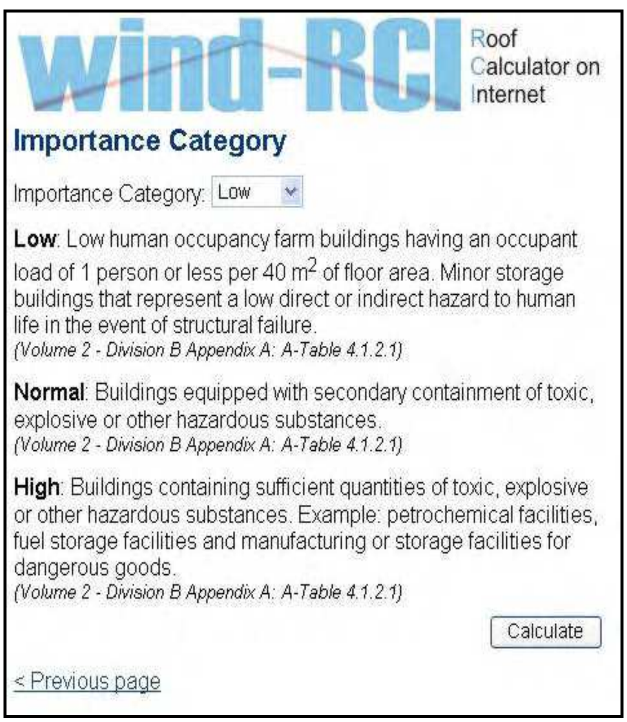
Category 2: Buildings, in which significant openings, if there are any, can be relied on to be closed during storms. Ex. Low rise buildings
(User's Guide, Commentary I, Sentence 31)

Category 3: Building with large openings through which gusts are transmitted to the interior. Ex. Sheds, industrial buildings
(User's Guide, Commentary I, Sentence 31)

Next

< Previous page

Screen # 6



wind-RCI Roof Calculator on Internet

Importance Category

Importance Category: Low

Low: Low human occupancy farm buildings having an occupant load of 1 person or less per 40 m^2 of floor area. Minor storage buildings that represent a low direct or indirect hazard to human life in the event of structural failure.
(Volume 2 - Division B Appendix A: A-Table 4.1.2.1)

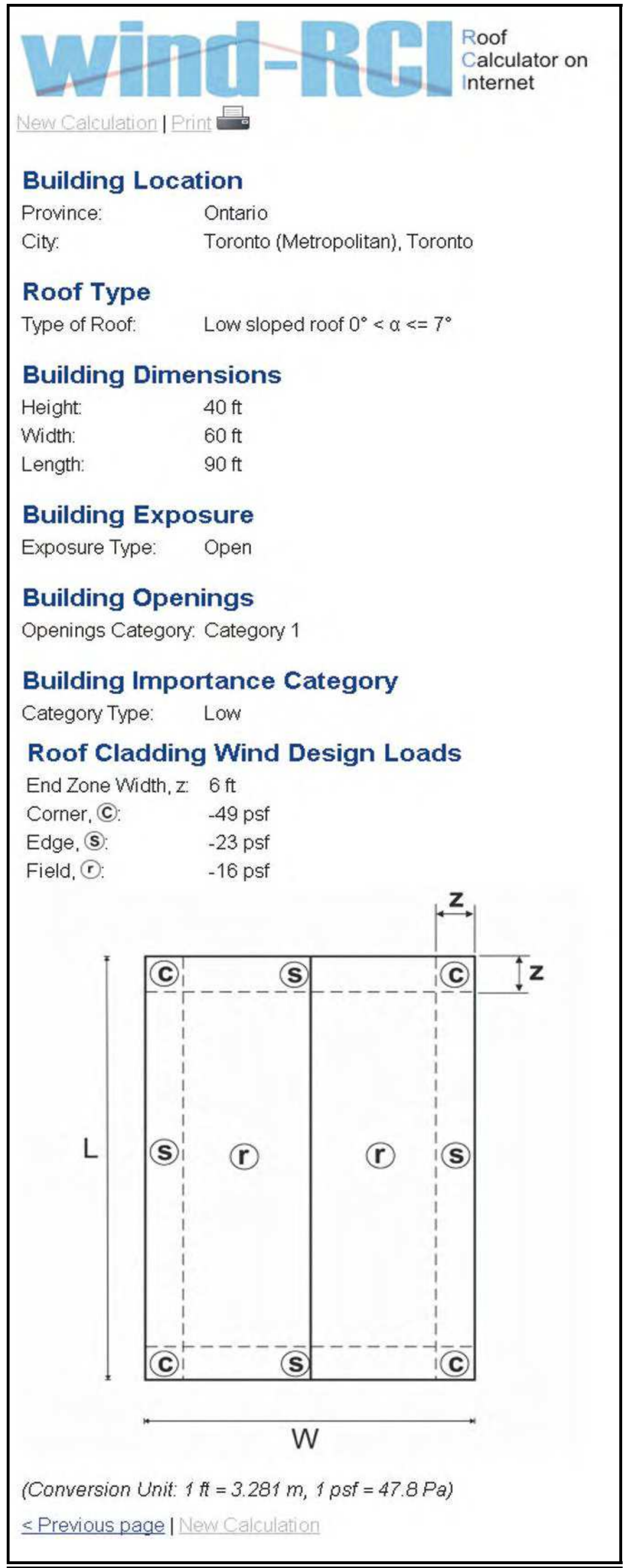
Normal: Buildings equipped with secondary containment of toxic, explosive or other hazardous substances.
(Volume 2 - Division B Appendix A: A-Table 4.1.2.1)

High: Buildings containing sufficient quantities of toxic, explosive or other hazardous substances. Example: petrochemical facilities, fuel storage facilities and manufacturing or storage facilities for dangerous goods.
(Volume 2 - Division B Appendix A: A-Table 4.1.2.1)

Calculate

< Previous page

Screen # 7



wind-RCI Roof Calculator on Internet

New Calculation | Print

Building Location

Province:	Ontario
City:	Toronto (Metropolitan), Toronto

Roof Type

Type of Roof:	Low sloped roof 0° < α <= 7°

Building Dimensions

Height:	40 ft
Width:	60 ft
Length:	90 ft

Building Exposure

Exposure Type:	Open

Building Openings

Openings Category:	Category 1

Building Importance Category

Category Type:	Low

Roof Cladding Wind Design Loads

End Zone Width, z:	6 ft
Corner, ©:	-49 psf
Edge, ⓢ:	-23 psf
Field, ⓡ:	-16 psf

(Conversion Unit: 1 ft = 3.281 m, 1 psf = 47.8 Pa)

< Previous page | New Calculation

Table 2: Capability of the Wind-RCI for parameter investigation

Building					Roof	
Type	**Height**	**Exposure**	**Openings**	**Importance**	**Type**	**Slope**
Low rise to medium rise buildings	H <=20 m (66 ft)	OPEN ROUGH	CATEGORY 1 CATEGORY 2 CATEGORY 3	LOW NORMAL HIGH	Low Slope	$\alpha <= 7^0$
					Stepped flat	$\alpha = 0^0$
					Gabled single-ridge	$\alpha <= 7^0$ $\alpha > 7^0$
					Gabled, multiple-ridge	$\alpha <= 10^0$ $\alpha > 10^0$
					Monosloped	$\alpha <= 3^0$ $\alpha > 3^0$
					Sawtoothed	$\alpha <= 10^0$ $\alpha > 10^0$
High Rise	H > 20 m (66 ft)				High-rise	

3. RoofWindDesigner (www.roofwindesigner.com)

Similar to Wind-RCI, the RoofWindDesigner is also a web based roof wind load calculator. RoofWindDesigner applies the American Society of Civil Engineers (ASCE) Standard No.-05 *"Minimum Design Loads for Buildings and Other Structures"*. It is developed by the National Roofing Contractors Association (NRCA), in cooperation the Midwest Roofing Contractors Association (MRCA) and the North/East Roofing Contractors Association (NERCA). Apart from computing the roof covering design pressures, it also recommends the roof covering uplift resistance by multiplying the calculated design pressures with a minimum safety factor of 2 (ASTM D6630). It is worth to note that the RoofWindDesigner is limited for calculating wind uplift on low rise building (the mean roof height, h, must be less than or equal to 60 feet ($h \leq 60$ ft). Moreover, one can use the RoofWindDesigner only for low slope configuration (roof incline less than 7.5 degrees, which is about 1½:12 slope).

4. Parametric Investigations Using WIND – RCI

To demonstrate the viability and flexibility of the Wind – RCI, various parameters that can influence design pressures are studied. These parameters can be grouped in two segments:

- one that is pertinent to the upcoming wind – effects of wind speed and terrain exposure and
- second that is pertinent to the building – effects of building height, openings and roof slope

Using the Wind-RCI all the parametric investigations are carried out through case studies. For discussion purpose, the paper presents design pressures only for the roof corner zones and not for the edge and field zones. Based on this approach, it is easier to understand the effect of the influencing parameters on the roof design pressures. Designers can develop similar inference for the edge and field zones with only variation in the magnitude of the design pressure. This is due to the fact that the intensity of pressure moderates as one moves away from the corner towards the field as discussed under the Figure 2.

4.1 Effect of Wind Speed on Wind Uplift Pressures

NBC 2005 uses mean hourly wind speed to determine the reference dynamic pressures, q. The dynamic pressures are based on the probability of being exceeded per year of 1 in 50. It is tabulated for major Canadian cities in the Appendix C of the NBC (2005). It is worth to mention that there is no wind speed map in NBC (2005) that is similar to the ASCE 7 (2005). Nevertheless, one can estimate the wind speed for a given dynamic pressure using the following equation.

$$q = CV^2 \tag{2}$$

Where q = reference wind pressure

C = factor which depends on atmospheric pressure and air temperature

V = wind speed

To investigate the effect of wind speed, a 50 ft (15 m) building is selected. The building has an importance factor 1, open exposure condition, and category 1 as internal opening provision. Beta version of the WIND-RCI can perform calculations for the provinces of British Columbia, Ontario and Quebec. For each province using the Appendix C of NBC (2005), two cities are selected such that they represent the minimum and maximum i.e q_{min}, and q_{max} dynamic pressure levels. The equation 2 was used to calculate the respective wind speeds. With these assumptions, Figure 3, illustrates the effect of wind speed on the design pressures. As shown in Figure 3, Harrington-Harbor in Quebec has the highest mean hourly wind speed of 89 mph (142 kmph) and therefore it’s roof corner zone has highest design pressures of 113 psf (5.4

kPa), while Armstrong in Ontario experiences the lowest mean hourly wind speed of 48 mph (77 kmph) and has a corner design pressure of 33 psf (1.6 kPa). Therefore the data clearly indicates that the roof cladding design pressures are directly proportionate to the upcoming wind speed. For the benefit of the US readers, equivalent 3 seconds gust wind speed are also calculated from the Canadian mean hourly wind speed and included in the Figure 3.

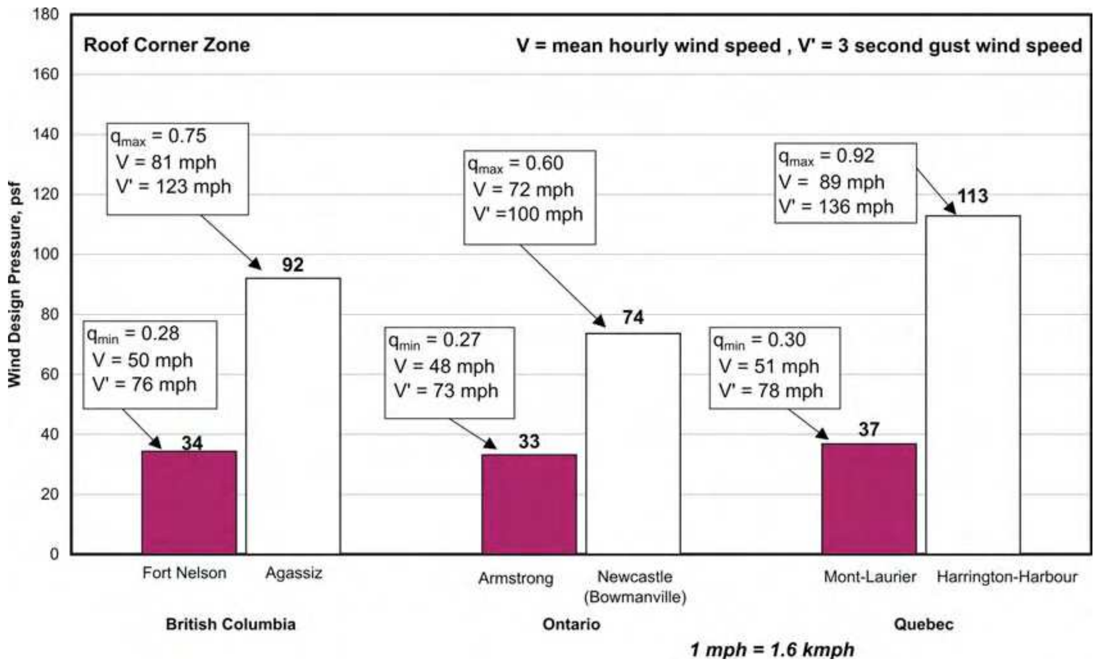
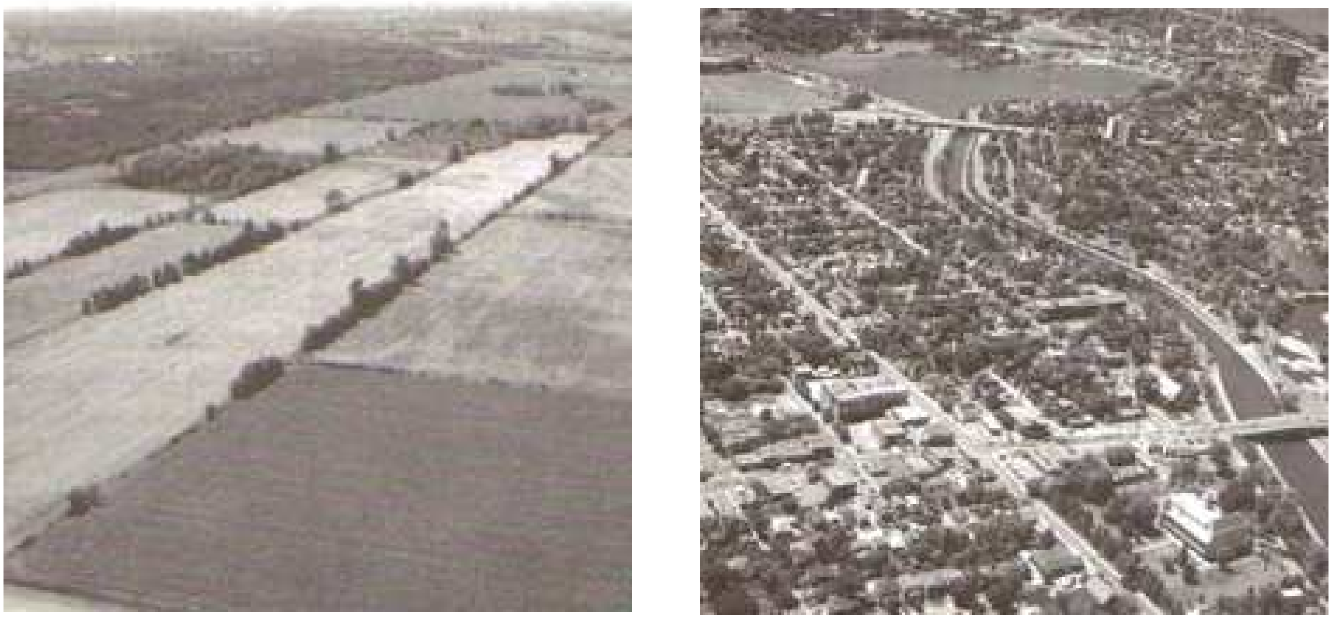


Figure 3: Effect of wind speed on wind uplift pressures

4.2 Effect of Exposure on Wind Uplift Pressures

Exposure means the ground roughness surrounding the building. The exposure factor characterizes the turbulence generated by the ground roughness and therefore it can directly reflect changes in wind speed. NBC 2005 defines exposure in terms of open and rough (urban) as shown in Figure 4. Designers often face challenges in identifying the appropriate exposure condition during the wind load calculations. Building exposure can change from the design stage to construction stage when the surrounding neighborhood develops and changes the design building landscape. In those situations, it may be useful for the designer to validate the original wind load estimation. Wind – RCI makes this process much easier. To demonstrate the exposure effect, in addition to the open country exposure calculations are performed using the Wind-RCI for urban exposure keeping the building configuration and other assumptions same as that of the section 4.1. Figure 5 shows such calculated wind uplift pressures.



(a) Open Exposure (b) Urban Exposure

Figure 4: Exposure types as per the NBC (2005)

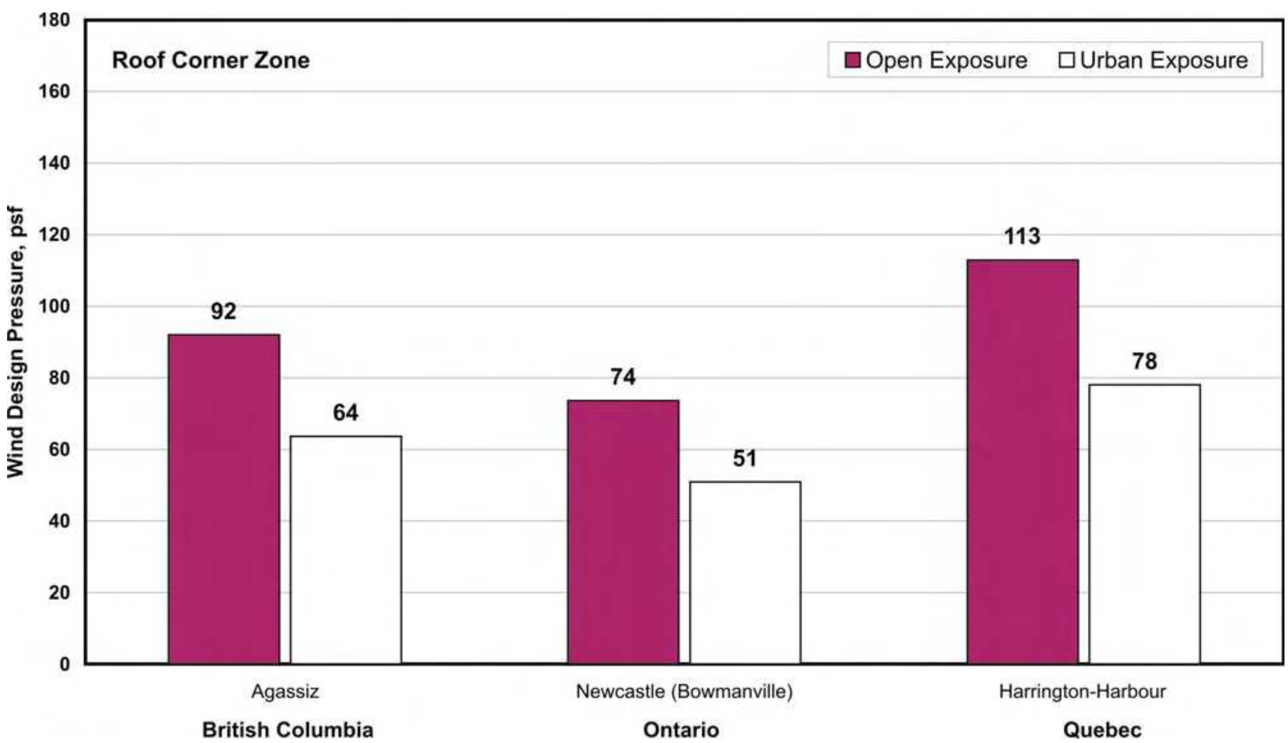


Figure 5: Effect of exposure on wind uplift pressures

Comparison of the data in the Figure 5 clearly indicates that the building located in the open exposure conditions has higher wind design pressure when compared to the building in urban exposure. With all the parameters kept constant, the data also indicates that the roof constructed in open exposure condition has 45 percent more roof corner design pressure in comparison to the building in urban exposure condition. Even though the data is presented for the roof corner zone, the trend will be similar for the other two zones namely edge and field.

4.3 Effect of Building Height on Wind Uplift Pressures

NBC (2005) provides for two sets of building heights, h <= 66 ft (20m) and h >66 ft (20m). To demonstrate the capabilities of the Wind – RCI, two additional building heights (30 and 70 ft) are selected. This can provide an indication, how much the wind uplift load changes when there is change of 20 ft (6 m) from the base configuration building which is 50ft (15 m) as presented in the Section 4.1. Figure 6 shows the computed design pressures for these three buildings. As per the NBC 2005, 30 (10 m) and 50 ft (15 m) buildings are low-rise buildings, while the 70 ft (20 m) building is a high-rise building. The graphical plot in the Figure 6 shows an increase in the design pressure as the building height increases. This is due to the fact that increase in height will increase the wind speed. As presented in the equation 2, the dynamic pressure will increase by the square of the wind speed.

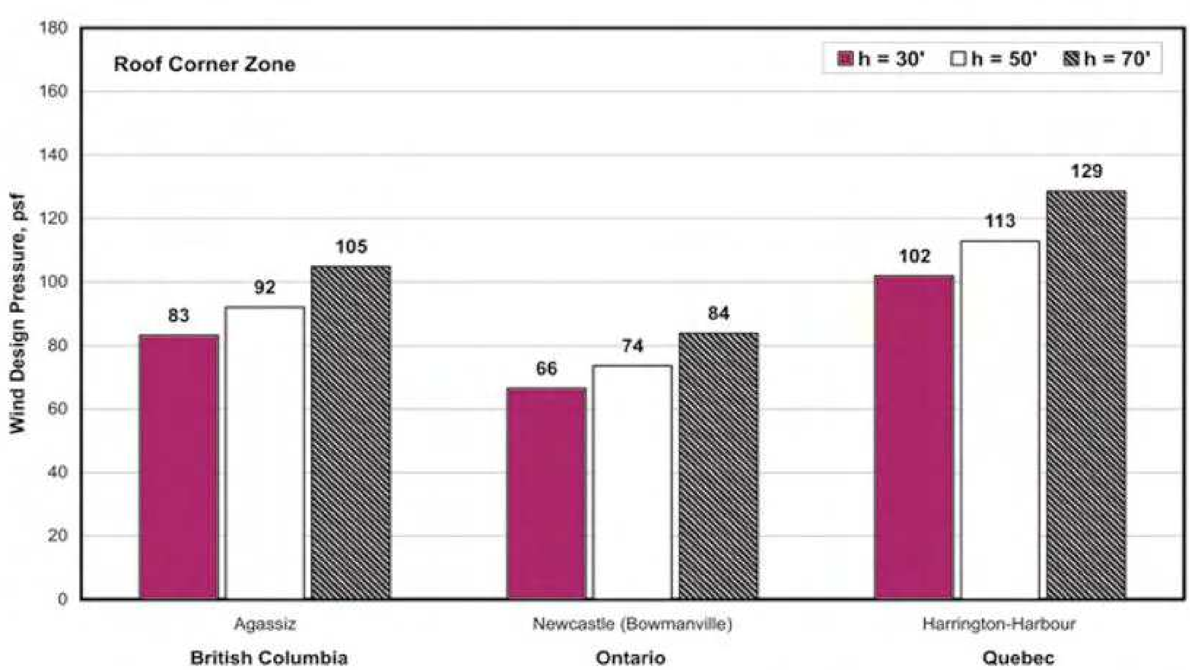


Figure 6: Effect of building height on wind uplift pressures

Changes in building height also change the corner zone (©) shape as depicted in Figure 7.

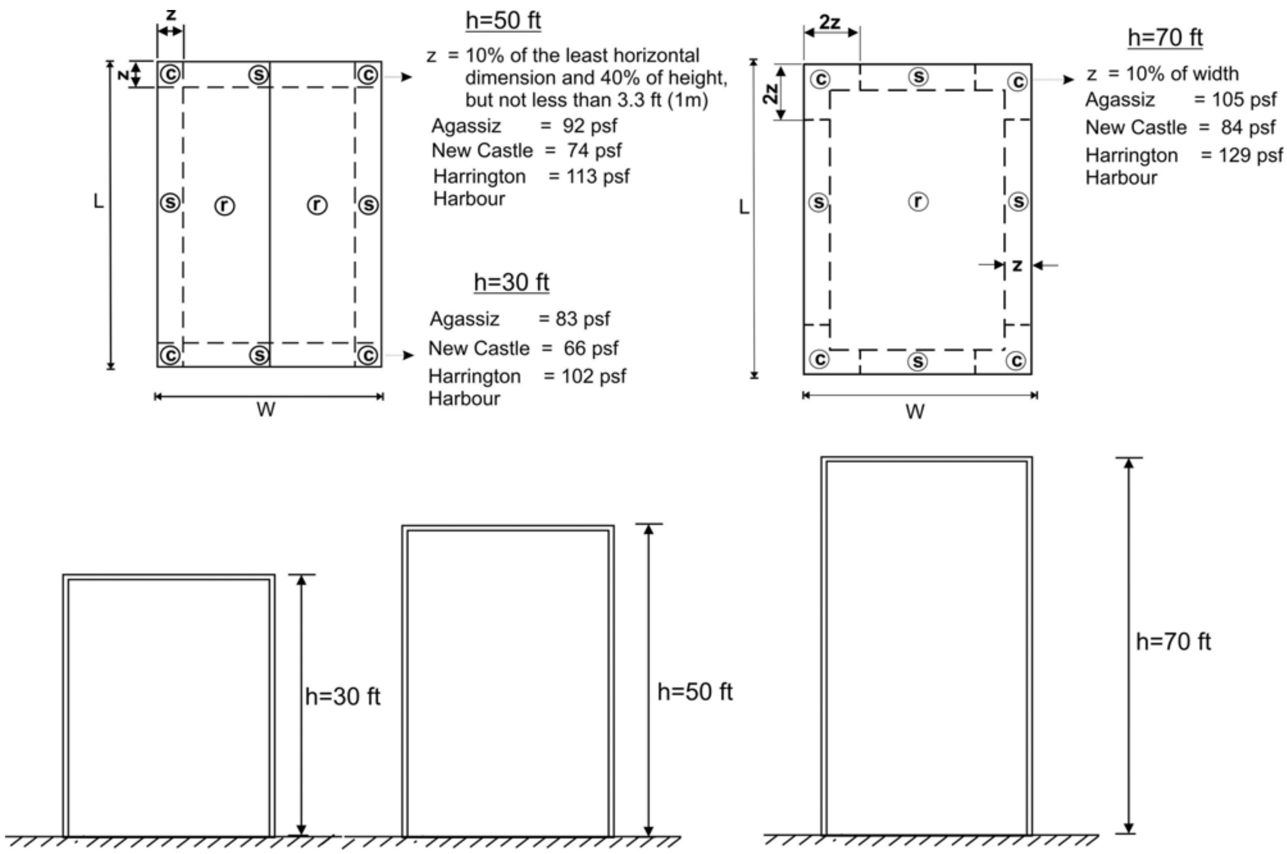


Figure 7: Comparison of corner zone - Low Rise vs. High Rise Building.

4.4 Effect of Building Openings on Wind Uplift Pressures

As discussed under the equation 1, $C_eC_{gi}C_{pi}$ term refers to the internal pressure component. The wind design pressure is calculated based on the algebraic sum of the external and internal pressure components. The magnitude of this internal pressure component depends on the amount and distribution of the openings in a building. It is rather difficult to quantify the size and distribution of openings for a given building due to variation in construction process and components used. To account for these uncertainties, the NBC 2005 provides ranges for the internal pressure coefficient in three categories as follows:

- Category 1: without large or significant openings, C_{pi} : -0.15 to 0.0
- Category 2: significant openings that can be closed during storms C_{pi} : -0.45 to 0.3
- Category 3: large openings through which gusts are transmitted C_{pi} : -0.7 to 0.7

In Wind – RCI, one can easily modify from one Category to other during wind uplift calculations. Previous examples (section 4.1 to 4.3) used Category 1 for internal pressure coefficient selection. Wind – RCI repeated the computations by selecting the other two categories. Figure 8 shows the calculated wind uplift pressures.

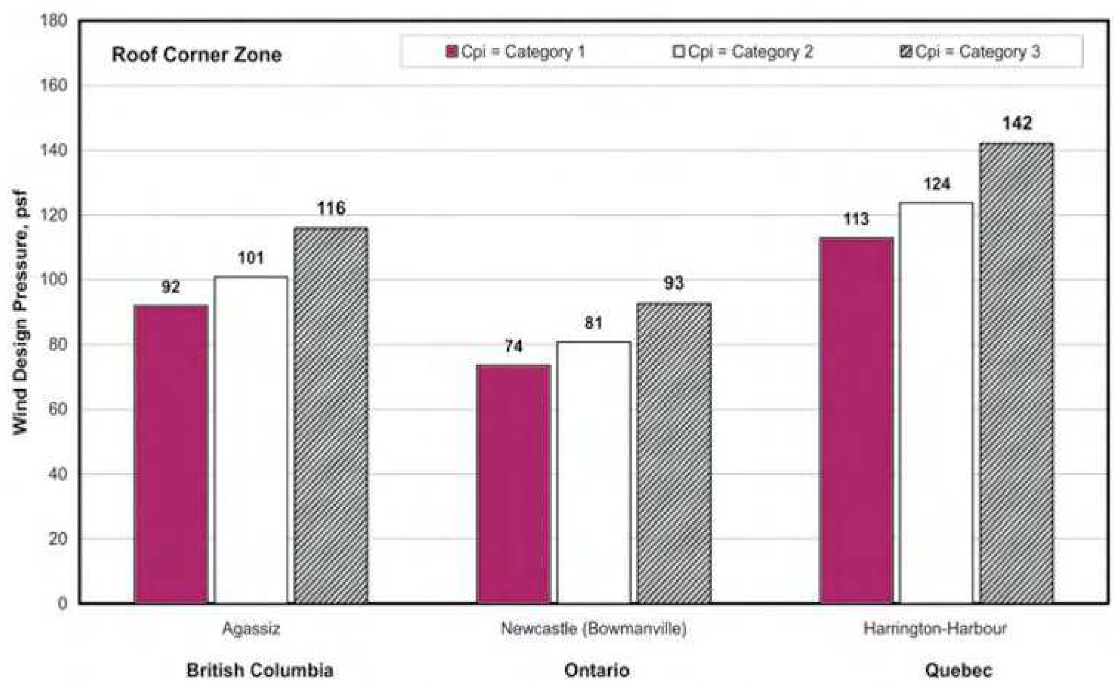


Figure 8: Effect of building openings in wind uplift design pressures

The building openings can influence the air intrusion (Dregger 1991., Baskaran et al. 2003, Molleti 2005) into a roofing assembly. Buildings with large openings and roof assemblies with air permeable components can significantly increase the design pressures. This relationship is clearly shown in Figure 8, with all the parameters kept constant, the corner design pressure increased by 10% and 26% when a Category 1 building changed to Category 2 and 3 respectively. Building's internal pressure characteristics can also change during the service life of a building. This can be a small variation when the HVAC requirement changes or moderate when building envelopes are refurbished. Also the internal pressure can change drastically and suddenly during catastrophe event such as window/door failure during high wind events (hurricanes). Baskaran et al (2007) investigated several such failures as part of the RICOWI's wind investigation program. In those scenarios, a roof assembly designed as Category 1 can experience significantly higher uplift due to sudden increase in the internal pressure component. Therefore, it is quite critical for the designer to understand this transition and design the roof assembly accordingly. Based on the field investigation data, Baskaran et al (2007) recommends that building with high probability of envelope (such as garage doors) failures during high wind events can be designed with the Category 3 internal pressure coefficient value. This conservative approach is a good design practice for wind mitigation measures provided that glazing and doors are not designed for windborne debris.

4.5 Effect of Roof Slope on Wind Uplift Pressures

Building aerodynamics changes when there is change in the roof slope. When the upcoming streamlines of wind hit the roof, the pressure distribution on the roof surface depends upon the extent to which the roof slope modifies the airflow. This can alter the wind pressure distribution and magnitude. It is worth to mention that the distribution presented in the Figure 2 corresponds to a low slope roof configuration ($\alpha <= 10^0$) so as the all the above calculations. Wind - RCI can perform calculation for various roof slope configuration as listed in the Table 2. Note that this is one of the major differences between the Wind-RCI and RoofWindDesigner, where the later is limited to only low slope roof configuration. To demonstrate the effect of roof slope, two additional roof slopes {medium ($10^0 < \alpha <= 30^0$) and steep ($27^0 < \alpha <= 45^0$)} are selected and calculations are repeated with the Wind - RCI. All other parameters are kept similar to that of Section 4.1.

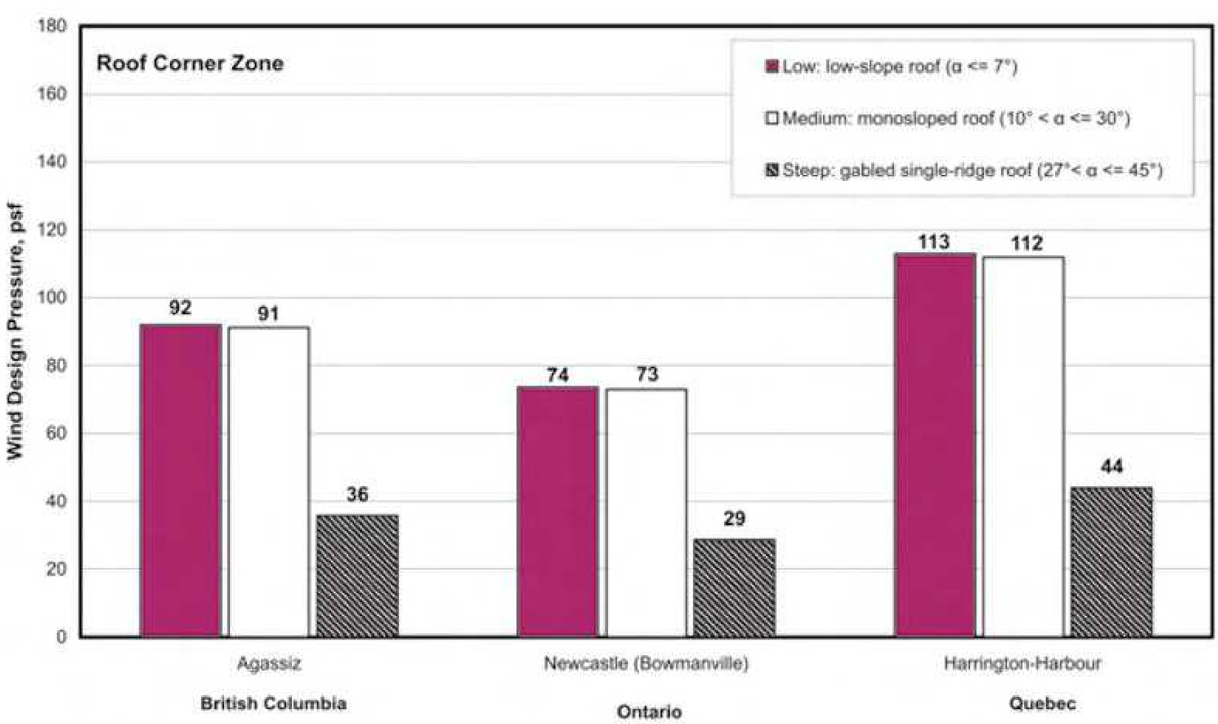


Figure 9: Effect of roof slope on wind uplift pressures

Figure 9 shows effect of roof slope on the computed design pressures. It is clear from Figure 9, that the roof slope modifies the design pressure and it is not directly proportional to the increase in the roof slope. This observation is different from the observation of previous parameters namely the exposure, height and building openings had on the design pressure. One cannot assume a linear relationship between roof slope and design pressure i.e by increasing or decreasing the roof slope can increase or decrease the design pressures. Alternatively whenever there is change in the roof slope, new calculations are warranted and as presented the Wind – RCI made that process easier.

Concluding Remarks

Wind - RCI is developed based on the National Building Code of Canada 2005 (NBC). NBC (2005) is a model code, which sets out technical provisions for the design of buildings in Canada. In the Wind – RCI, wind design loads are computed using the NBC 2005's Users Guide for Structural Commentary. A professional engineer certified the released Beta Version and the some of the benefits of this web-based tool are as follows:

- To obtain the design loads at the palm of the designers' hand.
- To minimize the complexity of the code referring and the involved calculations.
- To offer designers a faster and reliable tool for wind calculations.

The design pressures calculated by the Wind-RCI should be multiplied by an appropriate safety factor to obtain the required system resistance. Wind-RCI also has certain limitations such as; it does not provide calculations for the topographic/terrain influences on the building such as a structure situated on hills and escarpment and it cannot calculate design pressures for hipped roofs, for post disaster building configurations and for roofs with overhangs.

Acknowledgments

The presented research is being carried out for a consortium, the Special Interest Group for Dynamic Evaluation of Roofing Systems (SIGDERS) formed from a group of partners interested in roofing design. These partners included:

Manufacturers	Atlas Roofing Corporation, Canadian General Tower Ltd., Carlisle Syn Tec., GAF Materials Corporation, Firestone Building Products Co., IKO Industries Ltd., Johns Manville, Sarnafil Roofing, Soprema Canada, Stevens Roofing, Tremco and Trufast.
Building Owners	Canada Post Corporation, Department of National Defence, Public Works and Government Services Canada.
Industry Associations	Canadian Roofing Contractors' Association, Canadian Sheet Steel Building Institute, National Roofing Contractors' Association, RCI Inc. and Roofing Contractor Association of British Columbia.

References

American Association for Wind Engineering (AAWE), 1997. A Report on the “Worksop on Large-scale Testing Needs in Wind Engineering”, Washington, DC

American Society of Civil Engineers Standard ASCE 7-2005, “Minimum Design Loads For Buildings And Other Structures”.

Baskaran, A., Molleti, S. & Sexton, M. 2003. « Wind uplift performance of mechanically attached roofing systems with vapor barrier”, 9th Conference on Building Science and Technology, Vancouver, British Columbia, Canada, February 27-28.

Baskaran, A. and T.L. Smith. 2005. A Guide for the Wind Design of Mechanically Attached Flexible Membrane Roofs. National Research Council of Canada, Ottawa, Ontario, Canada, K1A 0R6.

Baskaran, A., Molleti, S., and Booth,R.J., 2006. “Understanding Air Barriers in Mechanically Attached Low Slope Roofing Assemblies for Wind Uplift.” Pp. 443-450 in Proceedings of the 3rd International Building Physics/Science Conference, Montreal, August 2006.

Baskaran, A., Molleti, S., Roodvoets, D., 2007. "Understanding low slope roofs under Hurricane Charley from field to practice," Accepted for publication: 6th Symposium on Roofing Research and Standards Development (Tampa, Florida, December 01, 2007), pp. 1-25,

Dregger, P,D. 1991, “Role of Air Retarders Deserves Closer Scrutiny”, *Professional Roofing*, p46-4

Federal Emergency Management Agency (FEMA)-488,2005, “Mitigation Assessment Team Report: Hurricane Charley in Florida”.

Federal Emergency Management Agency (FEMA)-489, 2005. ”Hurricane Ivan in Alabama and Florida: Observations, Recommendations and Technical Guidance”

Federal Emergency Management Agency (FEMA)-549, 2006. ”Hurricane Katrina in the Gulf Coast: Mitigation Assessment Team Report, Building Performance Observations, Recommendations, and Technical Guidance”

Hurricanes Charley and Ivan Wind Investigation Report, RICOWI Inc. Powder Springs, GA 30127,2006

Hurricane Katrina Wind Investigation Report, Powder Springs, Georgia : Roofing Industry Committee on Weather Issues, Inc. pp. 183, August 01, 2007

Molleti, S. 2006. “Performance Evaluation of Mechanically Attached Roofing Systems.” Ph.D. thesis, University of Ottawa, Ottawa, Canada.

National Roofing Contractors Association (2004), “Hurricane Charley: A Preliminary Report”, *Professional Roofing Magazine*, NRCA, October.

NRC (National Research Council). 2005. *National Building Code of Canada*, Part 5. Ottawa: National Research Council of Canada, Ottawa, Ontario, Canada, K1A 0R6.

Savage, M.G, Baskaran, A., Cooper, K.R and Lei, W., 1996. “Pressure Distribution Data Measured During the November 1994 Wind Tunnel Tests on a Mechanically-Attached, PVC Single-Ply Roofing System”, IAR Report LTR-A-003, National Research Council, Canada.