I have a feeling we're not in Kansas anymore, Toto (Part 1)

Designing low-slope roofs for wind uplift resistance

Taking wind seriously

Most of us have experienced strong winds or seen, even first-hand, the effects of hurricanes or tornadoes. In 2016, my son and I spent an eye-opening week in the Louisiana delta, working as volunteers in an organization to help with residential reconstruction following Hurricane Katrina, one of the most devastating storms in US history. Even the 1939 film classic, *The Wizard of Oz*, made a lasting impression on generations of kids and adults. These experiences and stories remind us that wind is a powerful force of nature. Still, most people find wind a mysterious phenomenon, and many don't realize that even mild winds can do a lot of damage to buildings that are poorly designed or constructed. What is more, wind-generated structural damage has less to do with the actual *pushing* force of the wind, and more to do with the *negative pressure* forces wind can generate, if given the right conditions.

Photo credit unknown

Those 'right conditions' generate powerful destabilizing forces on any surface, similar to *lift*. Pilots and sailors understand *lift*, which is what keeps an aircraft in the air and makes it possible for a sailboat to sail into the wind[1]. While *lift* is an interesting and complex concept, it is important to understand that wind generates a kind of *lift* effect on any surface, and especially on a horizontal roof surface, because of pressure changes in the air above it – specifically, negative pressure that pulls or sucks the roof surface upward. An increase in wind velocity coincidentally increases this pressure. The effects of lift on a roof surface are notably illustrated by the "membrane flutter" visible on a mechanically attached single-ply membrane roof (click the image below to watch the video).

Membrane flutter video

[1] Sailboats can sail 'to windward' (also referred to as 'to weather') but not directly into the wind. For more about how sailboats sail to weather, pick up any of a number of introductory books on sailing.

When we think about a roof damaged by wind, a steep roof missing shingles probably comes to mind. But shingle loss is very different from the kind and degree of damage that wind can cause by exerting negative pressure on a low-slope roof[2]. Shingles shed water, and while they create a unified shedding surface, and are "tabbed" to each other, each shingle is still a separate component of the roof surface. In strong winds, it's rare for the entire shingled roof covering to blow away at the same time. Conversely, low-slope roofs are designed and constructed to waterproof a building, and so their individual components are sealed together to function in unison. If wind is able to move a flat roof system (all the roof components that are fastened together, but excluding the deck that supports them), everything will move or be stressed at once.

As wind speed doubles, wind strength quadruples. This means that a wind blowing 20 km/h is *four times as strong* as a wind blowing 10 km/h. It also means that wind speed and strength increases with altitude, so that wind felt at roof level nearly always will be more forceful than wind blowing at the earth's surface. Consequently, roof design must naturally evolve in response to building height; not all roofs can be expected to resist the same wind pressure loads.

Of course, the dynamics of wind as it passes over and around a building are more nuanced than I have described here – how the roof system behaves in windy conditions is also a function of the pressures exerted on all walls and on the underside of the roof deck (because of building openings or a discontinuous air barrier). Furthermore, the building's proximity to other structures, and its location, shape, size and openings all will influence the behaviour of the roof system in windy conditions. How the designer approaches these issues will also be influenced by the type of roof specified for the building.

Conventionally insulated roofs are the most common low-slope membrane roof type in British Columbia, and the primary focus of this article, but there are many ways to construct a low-slope membrane roof. Both the National Building Code of Canada (NBCC) and the 2018 release of the British Columbia Building Code (BCBC), together with the **RoofStar Guarantee Standards** (published online in the **Roofing Practices Manual**, or RPM)***,*** address the design and construction of new low-slope membrane roof assemblies. Good design requires an understanding of the standards, why they matter, and how to successfully apply them.

This article is written about *new* roof design and construction, to help designers and contractors understand

- the dynamics of wind and its effects on low-slope roofs
- what components in roof design influence the effects of wind on a roof assembly
- what differentiates the Canadian wind test methods from US (FM Global) test methods
- how to interpret the requirements set out in the BC Building Code and National Building Code, and in the RoofStar Guarantee Standards, to use wind-tested roof assemblies
- what to do with roofs supporting vegetation or overburdens

Code Requirements

In 1994, the Institute for Research in Construction (IRC) formed a consortium of regulators, construction associations, roofing material manufacturers and other interested parties, called the *Special Interest Group for [the] Dynamic Evaluation of Roofing Systems* (SIGDERS), to develop a method of testing roof systems that could, in turn, generate better ways of keeping that system attached to the building. Out of

[2] A roof with a slope equal to or less than 1:3. Commonly referred to as a "flat roof".

that extensive work, nearly twenty years later, the CSA Group produced **CAN/CSA A123.21** *Standard test method for the dynamic wind uplift resistance of membrane-roofing systems*. The Standard sets out the way in which roof systems may be tested, in order to determine the maximum lift forces the roof system can withstand before it fails.

Photo credit: Mons Aase

In 2015, the NBCC rewrote the requirements for calculating environmental loads on buildings, including the negative pressure loads exerted on roof surfaces. These changes were included in Part 4 (Structural Design) and Part 5 (Environmental Separation) of Division B. The Code also specified acceptable means for selecting a roof assembly capable of resisting the upward (negative) pressure loads wind exerts on the roof surface. Chief among those options are Tested Assemblies – roof assemblies tested in laboratory conditions, according to the methodologies codified in CAN/CSA A123.21-14.

On April 1, 2017, the RCABC adopted the requirements of the NBCC for all newly constructed roofs, including full-replacement roofing, as part of the RoofStar Guarantee Standards. More recently, in September 2018, the BCBC adopted the same measures included in the NBCC. That will have a significant impact on new construction permits, beginning December 10, 2018 when the new BC Building Code comes into effect.

Building Design and Wind

The wind loads exerted on the surface of a low-slope roof are never uniform. For one thing, upward wind pressures are strongest where the wind strikes the building. The effect of wind on the roof surface is also influenced by the angle at which the wind meets the roof edge. Turbulence, and resistance created by the roof surface, reduces the lifting power of wind as it travels across a roof. Consequently, roof areas "downwind" experience lower negative wind loads. Generally speaking, though, wind generates the strongest uplift force along the roof perimeter, and especially at the corners.

Some uplift can be mitigated by changing the roof edge profile. Parapets are a common way to induce a measure of turbulence that interferes with the wind's ability to pull up on the roof membrane. In fact, wind loads along the roof perimeter and in the corners are nearly always reduced as parapet height increases. Of course, the securement of the membrane on the parapet itself is critical, or wind will simply lift it away. The Wind-RCI online calculator takes parapet height into account for taller buildings, and dramatically illustrates the mitigating effects of parapets.

Roof system securement is the critical piece, but knowing how to effectively secure the roof system to the building begins with a proper calculation of Specified Wind Loads. Once the designer has calculated the

Specified Wind Loads for the roof, a system of materials and their securement can be selected. This is where tested roof assemblies shine. By identifying Tested Assemblies as an acceptable method for securing a roof system to resist Specified Wind Loads, the BCBC and NBCC make things relatively simple for the *Design Authority*. To be clear, other options besides Tested Assemblies are available to the *Design Authority*, and we'll briefly explore those below, but Tested Assemblies provide a measure of certainty designers did not have until 2015.

Unfortunately, the NBCC is often misunderstood. We'll take a look at both, and make the case for a truly Canadian approach to roof design.

"FM 1-90" or CSA? Understanding the Codes and Standards

The 2015 National Building Code introduced improved methods for designing wind-resistant roofs. Chief among those changes was the adoption of CAN/CSA A123.21 as a reliable method for testing the effective wind resistance of a roof assembly. Still, some designers, builders and manufacturers have not fully understood the changes in the NBCC, why or even if they are important for roof design, and what role the CAN/CSA A123.21 Standard plays in the design process. As a consequence, not everyone is 'on board' with the changes, and building specifications written today still invoke the "FM 1-90" standard, sometimes with a nod to the CSA test method, and often with little or no explanation about what to do with either of them.

Some of the confusion lies in a failure to appreciate the difference between the whole and its parts. "FM 1-90" (a misnomer we'll discuss below) is a test standard and a component in a body of broad-coverage building material and construction standards generally referred to as 'FM Global Standards', established by the world-wide commercial property insurer *FM Global* to manage insurance risk. Like Lloyds of London, a consortium of underwriters established in the 17th Century to insure ship and cargo[3], FM Global developed underwriting standards for construction materials and assemblies, to remove or at least restrict some of the risk in underwriting buildings. FM Approvals is the gate-keeping certifying body that approves materials and services for use on FM-insured risks. But, FM's Standards focus on hazard-specific issues like fire resistance or structural stability, in an effort to mitigate underwriting risk through objective risk managed designs and methods.

Like the so-called "FM 1-90", the CAN/CSA A123.21 Standard is a method of testing roof assemblies, and it too is a component of a body of broad-ranging standards – the National Building Code of Canada. CAN/CSA A123.21 forms *part of the requirements* under Part 5 Environmental Separation (this Part is the same in the BCBC). However, both the National Building Code (Canada) and the British Columbia Building Code are quite different in their united intent and scope from FM Approvals; in short, both the NBCC and the BCBC provide a template for building construction, focused primarily on occupant and public safety and liveability. Both Canadian codes also interfaces with other national standards, including the National Energy Code, the Canadian Electrical Code (Part I), the National Fire Code, and the National Plumbing Code.

[3] Established during the Tea Trade, Lloyd's developed and refined ship construction standards to reduce losses at sea. Some of those standards are still applicable today, although Lloyd's has expanded beyond the maritime market and now insures both Personal and Business property and casualty risks.

While “FM 1-90” and the CAN/CSA A123.21 Standard are often both referenced in design specifications, they are in fact quite dissimilar, and while each is appropriate for the parent code it supports, Canadian construction design should be focused exclusively on the Canadian standard and either the NBCC or the BCBC. To fully appreciate why, one needs to understand the fundamental differences between the two test standards, and how they fit into their respective parent codes.

FM Standard 4470 is a broad-based set of requirements for Class 1 (non-combustible) roof assemblies. Negative wind pressure resistance just happens to be *one* characteristic the assembly must be tested for. The procedures for the wind resistance test are detailed in the Standard, and cross-referenced to another FM Standard, 4474 (*American National Standard for Evaluating the Simulated Wind Uplift Resistance of Roof Assemblies Using Static Positive and/or Negative Differential Pressures).* In both Standards, roof assemblies are tested in a 12’x24’ mock-up and must be able to withstand a maximum “pressure differential” of 90 lb/sf.

That pressure differential is part of the basis for the so-called “FM 1-90” standard. Truth be told, there is no such thing as a stand-alone “FM 1-90” standard (sometimes referred to, even in construction specifications, as “I-90”). Rather, “FM 1-90” is a colloquialism that has made its rounds among specifiers, consultants and builders, often with little or no understanding of what it means (I know because I once was one). It is a combination of two different FM Standards requirements: on the one hand, the requirement for a Class 1 (fire-resistant) roof, and on the other hand, a concurrent requirement that the Class 1 roof achieve a maximum negative wind pressure resistance of at least 90 lb/sf. This pairing, commonly expressed as “1-90”[4], is *de rigeur* for several FM Approvals (FM 4450, 4451 and 4470). And 90 lb/sf isn’t the only threshold FM standards reference; some require a maximum wind uplift resistance of only 60 lb/sf, or as much as 120[5].

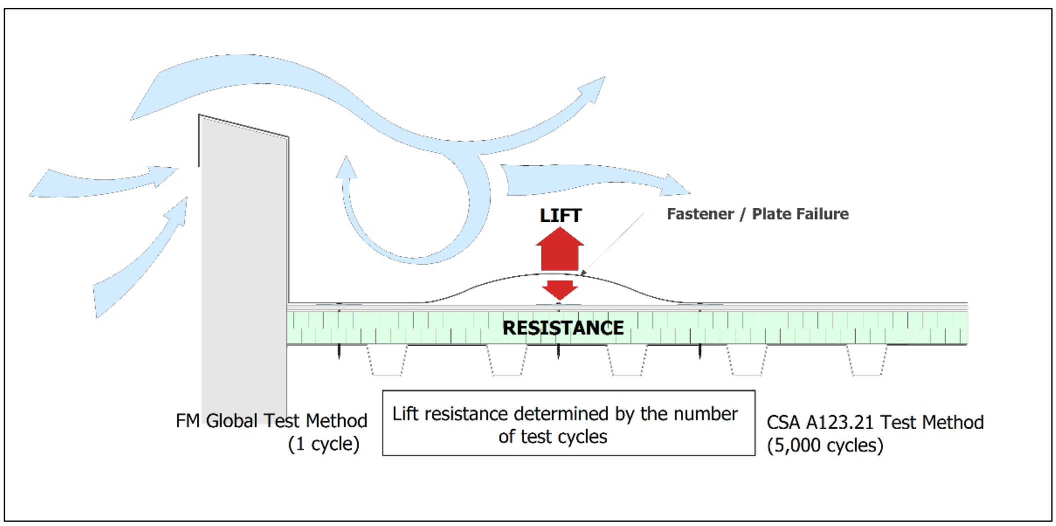
[4] The shorthand “1-90” is used even within the FM Standards themselves (see FM Standard 4451, 4.3.1)

[5] Contrary to the belief of many people, the “90” reference has always been about negative pressure, not about wind speed, although one is a factor of the other.

The word “static” is the key to understanding the wind uplift requirements in FM Standards 4470 and 4474. The test procedure outlined in Appendix C of FM 4474 requires a test period of only *60 seconds*, at a static rate of pressure. The same requirement is stated in Standard 4470, *4.3 Wind Uplift Resistance*.

While a static test may be useful for underwriting purposes, it doesn’t represent real-world wind dynamics. Wind never blows at a constant rate; it gusts, pushes hard for a while, and then backs off, only to repeat this in endless variations. As wind speed modulates, so does the negative pressure it exerts on a roof surface. The variability in wind speed and pressure occurs because winds are generated both by moving atmospheric pressure systems and by solar radiation that causes local or regional thermals (ascending warm air columns). Pressure variability is also a product of wind deflection caused by structures, geography and colliding air masses. SIDGERS understood this, and developed a *dynamic* test method – CAN/CSA A123.21 – that simulates the natural cycles of wind variability.

Whereas FM Global standards are risk-management focused and proprietary, the CAN/CSA A123.21 standard is part of a building code focused on public and building occupancy safety. Furthermore, the CAN/CSA standard is focused solely on the effects of wind, and ignores other factors such as fire resistance or live loading; those are concerns addressed in other parts of the BCBC, the NBCC, or provincial and national fire codes. And because the CSA test method is solely about wind, its aim is to determine how much negative wind pressure a roof assembly is capable of resisting, even when that pressure is modulated in multiple cycles. To do that, the CSA-based test replicates real-world wind dynamics for up to 5,000 cycles over the course of the test. A test can last up to five *hours*, depending upon whether or when a roof assembly fails.



Safety factors also differentiate one standard from the other. A safety factor is used to reduce a tested performance limit, in order to allow for variables that otherwise might increase roof membrane wind loads. All FM Approvals utilize a fairly cautious safety factor of ‘2’, but that is understandable given a test duration of only 60 seconds. The CSA standard requires that the “maximum sustained pressure” of a roof system be divided by a safety factor of only 1.5. The safety factor is lower than that used by FM Approvals because the CSA test is dynamic and cycles the roof through numerous loads and rests over a five hour period, to determine its resilience under constant change.

The CAN/CSA A123.21 test method, as a component part of both the BCBC and NBCC and their respective approaches to wind-resistant roof design, instills confidence in the building design community, because it simulates real wind dynamics. Many Tested Assembly reports can be downloaded from the RCABC Roofing Practices Manual. But front-running roof standards, and tested roof assemblies, are only part of what makes a roof wind-resistant. Good design, and clear construction specifications are critical, and although designing a wind-resistant roof assembly may not be quite as simple as tapping the heels of your shoes together three times, it really is as easy as three steps. Check out Part 2 of this article to find out how.

About the author:

James Klassen is a RoofStar Technical Advisor and staff writer with the **Roofing Contractors Association of British Columbia**. He is an experienced roofing estimator, a former Occupational Health and Safety professional and independent Insurance Claims Adjuster, and has extensive experience as Facilities Manager for a large private school in British Columbia's Fraser Valley, overseeing building maintenance, grounds management, custodial services, school transportation maintenance and driver education, and capital project planning.
