CELEBRATING THE AEC INDUSTRY'S RISING STARS

CONSTRUCTION CANADA

January 2021 Vol. 63 No. 1

EMERGING LEADER AWARDS

MEET THE WINNERS

Protecting **Vegetated Roofs** from the Wind

Considerations for snow guard design

Net-zero buildings made simple with ICFs

Repair strategies for failing concrete structures

Photo courtesy of Greg Van Riel


Photo courtesy of Terry Guscott

WIND DESIGN PROCESS

for Modular Vegetated Roofing Systems

By Karen Liu, PhD

Vegetated or green roofs offer multiple benefits to urban areas. They help manage stormwater, reduce energy demand, mitigate urban heat island, improve air quality, and enhance biodiversity. As a result, many municipalities are offering various forms of incentive programs to encourage green roof adoption. In 2009, the City of Toronto adopted the *Green Roof Bylaw* and became the first city in North America to require green roofs on most new buildings covering 20 to 60 per cent of the available roof space based on the building's size. Additionally, it also offers \$100/m^2 to encourage green roof installation through its Eco-Roof Incentive Program. Since then, over 600 green roofs covering 465,000 m^2 (5 million sf) collectively have been constructed in Toronto and it has become one of the top North American municipalities with most green roof constructed.[1]

Many green roofs in Toronto are located on high-rise buildings and lakefront properties that experience high wind *(Figure 1, page 2)*.They must be secured against wind forces to meet performance requirements and ensure public safety. The *Toronto Green Roof Construction Standard* governs the design and construction of green roofs and sets out the minimum requirements to meet the City's objectives. On the issue of wind, the standard requires an engineer-stamped report providing design wind pressures for the green roof and outlining how they are addressed.[2] However, technical information on wind resistance of green roof was lacking.

To address this gap, the National Research Council Canada (NRC), in collaboration with the members of the Canadian green roof industry, conducted a three-year research project to study the wind performance of green roofs. The research findings led to the development of a new national standard—the Canadian Standards Association (CSA) A123.24-15, *Standard Test Method for Wind Resistance of Modular Vegetated Roof Assembly*, which evaluates the wind resistance of the vegetated roof assembly and enables designers to select the appropriate system for their projects.

Wind effects on vegetated roofing assemblies

When wind hits the wall of a building, the air moves upward and increases its speed and creates positive pressure on the wall. The air continues to travel up and over and creates a negative suction on the roof *(Figure 2, at right)*. The distribution of wind forces is non-uniform across the roof, with considerably higher localized forces in the corner and edge regions than the field of the roof. While the magnitudes of these pressures vary with the wind speed, the spatial distribution remains unchanged.

FIGURE 1 - A green roof installed on a high-rise building in Toronto. Photo courtesy of Greg Van Riel

The negative pressure or wind-induced suction affects both the roofing system and the vegetated system, but in different ways. A roof membrane is impermeable and attached to the roof structure, so the wind uplift pressure creates suction that lifts it like a sail. In comparison, a vegetated system is unattached to the roof structure and is permeable, akin to a sail with tiny holes. Wind can move through the green roof, which creates pressure equalization, thus reducing the net overall uplift.

Intensive green roofs consist of large plantings such as trees and bushes thriving in deep, growing media with saturated weight typically ranging from 200 kg/m^2 (41 psf) to over 1000 kg/m^2 (205 psf). Wind uplift is not usually a major concern due to the heavy weight. Nevertheless, for exposed rooftops on high-rise buildings where high winds are expected, it is recommended to anchor the trees, or the root balls, to the structural elements to prevent blowing off.

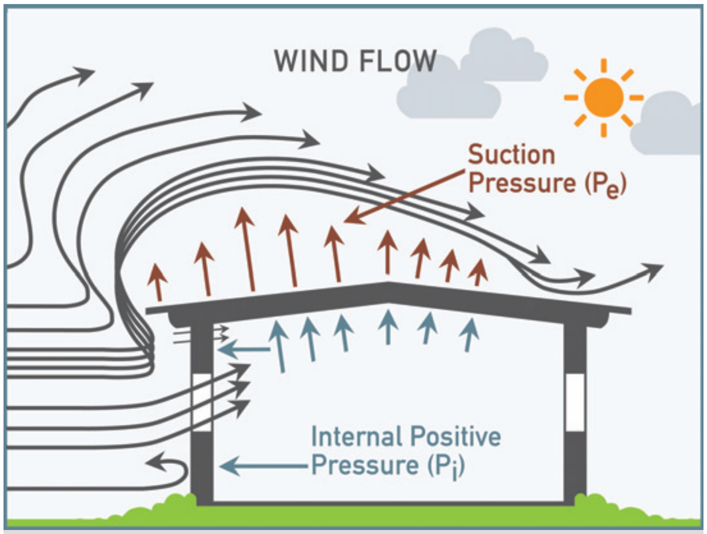

FIGURE 2 - Wind flow over building creating suction on the roof. The schematic is referenced from "The Effects of Dynamic Wind Loads on Roofing Systems", by Bas Baskaran. Visit www.nrc-publications.canada.ca/eng/view/accepted/?id=67e80225-a9d8-4088-a3aa-9e69ca7e960d. Illustration courtesy of KLDESIGN

Extensive green roofs contain small vegetation, such as sedums, grasses, and perennials growing in shallow growing media with design load typically in the range of 50 to 200 kg/m^2 (10 to 41 psf). These lightweight systems are more affected by wind *(Figure 3, page 3)*. Additionally, exposed growing media are prone to scouring and displacement, particularly in the corner and edge regions of the roof where localized wind forces are higher. As typical green roof growing media are mineral-based and granular in nature, they are more likely to be displaced than cohesive growing media with higher clay contents. Erosion control nettings, tackifiers, and hydromulches can be used to reduce wind erosion, particularly during establishment stage when the vegetation has not yet rooted firmly into the growing medium.

Wind effects on modular vegetated systems

Vegetated modules contain mature vegetation that are pre-grown on mats or in trays and delivered at near complete vegetation coverage. Compared to traditional built-in-place systems, modular systems have the advantages of significantly shorter establishment time and lower maintenance needs. The mature roots bind the growing medium together and the high vegetation coverage protects the medium from scouring. Research has also shown high vegetation density increases surface roughness and reduces wind forces experienced by the green roof. As a result, the German FLL Green Roof Guidelines recommend using pre-vegetated systems on high wind areas.

Wind tunnel studies showed the weight and design of the vegetated modules, such as trays and mats, govern their

FIGURE 3 - Extensive systems are lightweight and more susceptible to wind uplift.

wind uplift behaviour.[3] Wind suction creates uplift force on the vegetated modules. When the uplift force exceeds the module weight, it can become airborne and overturned.

The modules are permeable and have gaps at the joints, which allow air to enter and equalize the underside pressure and the surface pressure. Pressure equalization reduces the net uplift force on the module. The higher the pressure equalization, the higher wind force is needed to lift the module, the higher its wind resistance.

Interlocking mechanisms between the modular trays allow the uplift force to be shared among the modules, thus allowing the vegetated system to collectively resist higher wind forces. However, if one module does become airborne, the wind drag can lift adjacent modules as they are interlocked. This can create a domino effect where all the modules are overturned.[4]

Vegetated mats also reduce the net wind uplift forces through pressure equalization. Their large size (1 x 2 m, [39 x 78 ft] typical) allows the uplift force to be shared over a larger area, making them more difficult to lift. However, mat uplift can still occur if the wind is high enough (e.g. at corner region of the roof) when the net uplift force is greater than the mat weight *(See "Wind Flow Testing of Vegetated Mats," page 4)*.

Vegetated modules come in a wide range of weight. They also vary in material and design, so the degree of pressure equalization differs considerably from one assembly to another. Therefore, it is necessary to test and determine the wind resistance. This can be done using the CSA A123.24 standard test method.

CSA A123.24-15

CSA A123.24-15 determines the wind resistance of modular vegetated roof assembly (MVRA), consisting of a roofing system (RS) and a vegetated system (VS), when subjected to dynamic wind flow and loading cycles. It is applicable to modular vegetated systems that are pre-grown offsite with a minimum of 80 per cent vegetation coverage.

Each MVRA is subjected to the following two tests to measure its wind uplift resistance and wind flow resistance.

Wind uplift resistance

The MVRA is installed on the test table, instrumented with pressure and deflection sensors, and subjected to dynamic wind load cycles to simulate wind suction on the roof in accordance to CSA A123.21, *Standard test method for the dynamic wind uplift resistance of membrane-roofing systems (Figure 4, below)*. The test is terminated when the specimen fails as defined in CSA A123.21 or when the net uplift deformation of the above-deck components exceeds 2L/240, where L is the deck structural span.

FIGURE 4 - A vegetated mat system is ready for wind uplift testing.

Wind flow resistance

The MVRA is installed on a test rig, which is placed in front of an airflow machine and yawed at 45 degrees to the airflow to simulate corner wind effects *(Figure 5, page 4)*. The test starts with a wind speed and continuously moves up at 10 km/h (6.2 mph) increments until failure occurs, as defined by overturning of any components within the test assembly or sliding or displacement of any components greater than 25 mm (1 in.).

FIGURE 5 - A vegetated mat system is ready for wind flow testing.

Wind design process of vegetated roofing assemblies using CSA A123.24

The significance of CSA A123.24-15 is it determines the resistance of the MVRA. This enables designers to compare the resistance to the design values and determine if an assembly is secured against the wind uplift for a specific project by following a few simple steps.

FIGURE 6 - The airflow machine generated wind using twin fans.

Step 1 - Determine the project's design wind load (P_D) and the design wind speed (V_D) using the *National Building Code (NBC)* or the Wind-MVRA online calculator at www.nrc-cnrc.gc.ca/eng/services/windrci.

Step 2 - Request the wind uplift resistance (PR) and the wind flow resistance (V_R) of the modular vegetated roof assembly, as determined per CSA A123.24-15 from the green roof supplier.

Step 3 - The MVRA is secured against wind forces for the project if the following conditions are met:

- wind uplift resistance (P_R) is higher than the design wind load (P_D); and
- wind flow resistance (V_R) is higher than the design wind speed (V_D).

Wind Flow Testing of Vegetated Mats

Vegetated mats contain mature plants growing on a carrier filled with growing medium. A basic carrier is made of a thin mat of coconut coir fibres, which decompose on the roof over time. Advanced polymeric carriers consist of a 3D entangled mesh bonded to a geotextile fabric, which promotes root anchorage and mat integrity. This durable carrier can be easily rolled up for roof membrane repair and replaced after.

The vegetated mats are rolled out on other layers such as growing medium, water retention, drainage, filter, and root barrier to form a vegetated system. Adjacent mats are usually installed on a built-in overlap so the roots grow and connect the mats together naturally over time. A vegetated mat system is most vulnerable to wind uplift during the establishment period (approximately the first four to eight weeks after installation) before the roots have a chance to grow through the layers and stitch them together.

This is what happened to Specimen A at 160 km/h (99 mph) during the Canadian Standards Association (CSA) A123.24-15, *Standard Test Method for Wind Resistance of Modular Vegetated Roof Assembly*, wind flow testing *(Figure 6, above)*. Specimen A was a modular vegetated roof assembly (MVRA) consisting of four components—sedum mat, retention fleece, drainage layer, and root barrier. Wind caused increased fluttering of the vegetated mat and finally lifted its corner facing the airflow, making the mat airborne and causing the entire system to fly off.

Specimen B was a MVRA consisting of the same four components as Specimen A except the sedum mat was of a different design, which was also thicker and heavier. Specimen B sustained the maximum capacity of the air flow machine at 200 km/h (124 mph) without failure.

Wind can damage vegetation. Specimens C and D contained sedum mat and perennial mat respectively and both sustained 200 km/h (124 mph). After the flow test that lasted approximately 45 minutes, the sedum laid flat and pointing away from the wind flow direction, but the low-profile succulent did not suffer much damage. On the other hand, some of the herbaceous plants on the perennial mat were stripped of foliage while others suffered desiccation *(Figure 7, page 5)*.

The Wind-MVRA is a useful online tool for wind design of modular vegetated roof assembly that is developed and maintained by NRC. The designer inputs the building specifics (location, dimensions, exposure, opening, and importance category) and the program outputs the design wind load (P_D) and design wind speed (V_D) based on data from *NBC* 2015.

Since the resistance depends on pressure equalization, which can vary with many factors, such as vegetation growth, moisture content, and permeability of the MVRA, it is critical to test the MVRA for resistances and go through the wind design process to ensure the green roof is secured against uplift *(See "More Notes on CSA A123.24," below)*.

Conclusion

Like any building envelope components, vegetated roof assemblies must be designed properly to resist wind forces to ensure durability and public safety. Designers should follow best practices from existing guidelines. CSA A123.24-15 provides a means to determine the wind resistance of modular vegetated roof system. Engineers should ask green roof suppliers for wind resistances of their systems and follow the wind design process to select the appropriate assembly for their projects. Alternatively, some green roof suppliers retain professional engineers to perform the wind design process on behalf of their clients.

[FIGURE 6]

Specimen	MVRA System	Weight	Sustained Wind Speed	Failure Mode
A	Sedum mat I	35 kg/m^2 (7.1 psf)	150 km/h (93 mph)	System flew off
B	Sedum mat II	47 kg/m^2 (9.6 psf)	200 km/h (124 mph)	No failure*
C	Sedum at III	99 kg/m^2 (20.2 psf)	200 km/h(124 mph)	No failure*
D	Perennial mat	175 kg/m^2 (35.8 psf)	200 km/h(124 mph)	No failure*

* Maxed out air flow machine capacity
Wind flow test results of four modular vegetated roof assembly (MVRA) specimens.

More Notes on CSA A123.24

Vegetated roof assembly (VRA) is the combination of roofing system (RS) and vegetated system (VS). The wind uplift resistance of VRA is evaluated using the same test procedure for evaluating the wind uplift resistance of roof membranes (i.e. the Canadian Standards Association [CSA] A123.21, *Standard test method for the dynamic wind uplift resistance of membrane-roofing systems*). Since there are gaps between VS and the roof membrane surface and around the edges, air can readily enter and equalize the pressures above and below the VS to avoid overturning, so the wind uplift resistance of the modular vegetated roof assembly (MVRA) should be at least that of the RS. Therefore, the VS supplier may choose to report the wind uplift resistance of the RS obtained from CSA A123.21 as the sustained pressure. The designer can use the wind uplift resistance of the RS obtained from the CSA A123.21 and the wind flow resistance of the VS obtained from CSA A123.24-15, *Standard Test Method for Wind Resistance of Modular Vegetated Roof Assembly*, to proceed with the wind design process for the VRA.

The wind flow resistance is determined by dividing the sustained wind speed, which is defined as the incremented speed level before failure occurs, by a minimum safety factor of 1.5, as per CSA A123.24-15. Since the airflow machine can deliver a wind speed of 200 km/h (124 mph) at maximum capacity (current at time of publication), this limits the maximum sustained wind speed of any VS tested to 200 km/h, which corresponds to a maximum wind flow resistance of 133 km/h (82 mph) after applying the 1.5 safety factor. This can become an issue for projects with design wind speed greater than 133km/h. Wind engineers will need to review the specifics and offer professional opinions for these projects.

The designers should note CSA A123.24-15 is not applicable to mechanical attached roofing system, but appropriate for adhesive adhered roofing system and partially adhered roofing system. Currently, CSA A123.24-15 is applicable to modular vegetated roofing system only and not built-in-place systems, where young vegetation are planted in growing substrate on the roof. However, the CSA A123 technical committee is in the process of revising the standard to include built-in-place VRA in the next revision of the standard based on new research findings coming out of National Research Council Canada (NRC).

FIGURE 7 - Sedum plants did not suffer much damage after the wind flow test.

FIGURE 8 - Herbaceous plants lost foliage and suffer desiccation after the wind flow test.

References:

[1] **Read the article**, "The Green Revolution Spreading Across Our Rooftops," at www.nytimes.com/2019/10/09/realestate/the-green-roof-revolution.html.

[2] **Consult the Toronto Green Roof Construction Standard Supplementary Guidelines** at www.toronto.ca/wp-content/ uploads/2017/08/7eb7-Toronto-Green-Roof-Construction-Standard-Supplementary-Guidelines.pdf.

[3] **Read the paper**, "Development of a Standard Test Method to Determine the Wind Resistance of Vegetated Roof Assemblies", by S. Molleti, A. Baskaran, F. De Souza, at www.iibec.org/wp-content/uploads/2015-cts-baskaran.pdf.

[4] **See Note 3.**

CONSTRUCTION
CANADA

Article is reprinted for educational purposes and was originally written for Construction Canada magazine. To read the article online visit **www.constructioncanada.net**.

Karen Liu, PhD, is green roof specialist at Next Level Stormwater Management. Before joining the private sector, Liu was a lead researcher of the green roof programs at the National Research Council Canada (NRC) and the British Columbia Institute of Technology. In recent years, Liu was a key participant in the research consortium that developed the first national wind testing standard for vegetated roofing, the Canadian Standards Association (CSA) A123.24-15, Standard Test Method for Wind Resistance of Modular Vegetated Roof Assembly. Additionally, she has vast practical experience having worked on hundreds of green roof projects across North America, Europe, and Asia. At NLSM, Karen works on special projects and wind and stormwater calculations. Karen is based in Vancouver, British Columbia. She can be reached at 416-637-5772 x9 or by email at karen@nlsm.ca.