

Adaptation of Low-Slope Roof Assemblies Against Projected Climate Severities: Evaluation of a New Standard

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IN 1994, THE National Research Council of Canada (NRCC) led the way to form a consortium-based research and development study group, the Special Interest Group for Dynamic Evaluation of Roofing System (SIGDERS), which includes representatives of manufacturers, contractor's associations, testing laboratories, homeowners, and insurance companies. The group's research led to the development of the CSA A123.21, *Standard Test Method for the Dynamic Wind Uplift Resistance of Membrane-Roofing Systems*,¹ which was first published in 2004 and subsequently revised in 2010, 2014, and 2020. Referenced in the *National Building Code of Canada (NBCC)*² since 2015 edition and adopted by the provincial codes, including the *Ontario Building Code (OBC)*,³ CSA A123.211 specifies the primary means of assessing a roofing system's resistance to counteract calculated wind loads and has become a pivotal point in the development of roofing specifications.

With the codification of CSA A123.21,¹ the design and construction of roof assemblies for buildings built in Canada are no longer a simple composition of layers of roof components, relying on the proprietary design of the system

by the manufacturer. Low-slope roof assemblies, excluding protected roof membrane assemblies, are now required to resist the project-specific wind uplift loads of three different zones of a roof area: the field, edges, and corners. To meet this requirement, each of the project team members, including designers, manufacturers, and installers, must play a pivotal role. However, there have unfortunately been cases in which team members have not adequately carried out their responsibilities, and a combination of errors and/or omissions have led to failures.

Addressing the project-specific challenges related to the wind load is a crucial starting point in achieving long-term durability of roof assemblies, but it is not the only concern. The other main challenge is to design roof assemblies that resist and manage precipitation. To address that challenge, project teams must take into account the NBCC² requirements for sizing drains and rainwater leaders. In addition, there are several qualitative measures followed in the industry that are either industry best practices or standards, including standards published by roofing contractors' associations, for example *Roofing Practices Manual of Roofing Contractor's Association of British Columbia*.⁴

With the changing climate and anticipated climate severities, there is a need to further enhance the above mentioned requirements for roof assemblies to resist increased wind load, to control and manage increased precipitation, and to counter increase in temperature from having an impact on the durability. To meet this need, NRC in collaboration with the SIGDERS committee has developed *Performance Requirements for Climate Resilience of Low Slope Membrane Roofing Systems (CSA A123.26)*,⁵ which addresses the severities related to wind and rain.

THE PERFECT STORM—A CASE STUDY

On December 14, 2021, a six-story multi-unit residential building under construction in the

Greater Toronto Area reported roof damage caused by a strong wind event (**Fig. 1**). The fully adhered thermoplastic polyolefin (TPO) roof assembly over concrete deck with a layer of vapor retarder, two layers of polyisocyanurate insulation, and a layer of high density polyisocyanurate coverboard had experienced wind uplift damages due to high wind conditions that reached up to 96.3 km/h (59.8 mph), as recorded by the nearby weather stations. The damage covered approximately 15 percent of the roof assembly, across four different locations. At first glance, the roof assembly failure appeared to be due to heavy wind conditions experienced at the time of the event that may have exceeded wind uplift design parameters. However, subsequent review determined that the wind conditions were found to fall within the expected wind load range for the site. The project experienced a series of missteps leading to the failure event, all potentially contributing to create a 'perfect storm' scenario. The potential contributing factors include: failure by the designer to specify project-specific wind uplift values in the design specification; alternative questionable methods of compliance employed by the manufacturer; and poor material handling, poor workmanship, and poor quality control by the contractors during construction (**Fig. 2, 3, and 4**). While the primary cause of failure can be attributed to one or more of the above missteps, this roof failure incident provided some insights that are valuable lessons learned. For further discussion of the issues noted herein, refer to the article by Ramachandran et al., "Wind Uplift Failure of a Roof Assembly: The Perfect Storm."⁶

MEETING CODE REQUIREMENTS FOR WIND UPLIFT

To satisfy code requirements for wind uplift, designers must first calculate and/or use the available online calculator to determine

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Figure 1. Failed roof assembly after heavy wind conditions.



Figure 2. Poor installation practices observed and corrected.



Figure 3. Exploratory opening investigation conducted post failure.



Figure 4. Removal of failed roof for repair.

the project-specific wind uplift values and include them in the project specifications. In addition, it is advisable for the designer to specify a requirement for the contractor to submit reports issued by third-party testing laboratories to confirm that the procured roof assemblies are rated to exceed the required project-specific wind uplift values. If the designer chooses to include basis-of-design roof assemblies in the specification, the designer may choose to research and/or work with manufacturers to identify rated roof assemblies that meet the project-specific requirements. Some manufacturers and third-party testing laboratories have posted online the roof assembly resistance reports with their ratings that can help the designer identify appropriate roof assemblies. NRC is in the process of developing a portal with database of tested roof assemblies from various manufacturers to provide a centralized resource. At the time of the roof

assembly procurement, the roofing contractor can work with manufacturers to identify a roof assembly that is rated to resist the project-specific wind uplift load requirements of all zones at each of the roof areas of the building, and present as a substitution request for designer's approval.

While the selection of a rated roof assembly is an important step, the general contractor and roofing trade must take responsibility for good workmanship and the correct installation of the selected system. It is critical to follow the manufacturer's instructions for the tested assembly, including the use of proper spacing, patterns, and installation timing for each of the components. Materials must be properly stored, and proper precautions taken at the time of installation to ensure the effective functioning of the components. For installation of assemblies during winter, those components that are affected by cold weather conditions, a winter-grade product

as offered by the manufacturer is to be used. Additionally, crews must pay attention to details at the time of construction, such as temporary seals at perimeter scuppers and openings, and along end of workday assembly terminations, to avoid loss of integrity of the roof assembly due to inclement weather including extreme weather conditions that may occur during installation. Quality control measures by the general contractor and roofing trades are essential to verify that materials and components are properly installed. A general conformance review by the designer and a qualified consultant as required is imperative during construction.

CALCULATING PROJECT-SPECIFIC WIND UPLIFT REQUIREMENTS

The project-specific wind uplift load values are calculated based on load-resistance-factor design (LRFD) with inputs including the

geographical location, terrain of the project site, openings in the building, height of the building, size of the roof area, and height of the parapet. NRCC has developed and published an online tool, Wind-RCI,⁷ that can calculate these values based on the user's project-specific input. This tool can be used to calculate the required size or width and corresponding wind uplift resistance values for field, perimeter, and corner zones of each roof area, as required, based on the building information and site location characteristics. The online tool has limitations: it is not applicable to buildings exceeding 45 m (150 ft) in height, and it should be cautiously used for buildings located in dense metropolitan locations where microclimatic site conditions may influence load values in ways not captured by the tool's calculations, for instance locations that experience wind tunnel effects in downtown core of major cities. It is important to note that, as is the case with any tool, it is the user's responsibility to verify the values generated by Wind-RCI.⁷

THIRD-PARTY LABORATORY TESTING TO RATE ROOF ASSEMBLIES

CSA A123.21¹ is a rigorous test method that simulates the effects of wind pressure on a roof assembly specimen. The test method is straightforward: a complete 3.7×7.3 m (12×24 ft) specimen composed of the layers of the tested roof assembly, which may include a thermal barrier, a vapor retarder, insulation layers, cover board, and a roofing membrane system, is installed on a deck, usually of corrugated steel, attached to a specially designed test rig (Fig. 5). An airtight chamber is then placed on the specimen to ensure airtightness at the junction where the chamber meets the bench (Fig. 6). An air suction system and computer-controlled shutters modulate the pressure and duration of the vacuum created in the chamber, simulating

the pressure effects experienced by roofs during their service life.

The test procedure consists of consecutive load cycles, in predetermined sequences, divided into five levels and two methods, and it is carried out to assess maximum stress until an evident roof failure is observed. The test may last up to 10 hours, depending on the performance of the assembly, during which time the test pressures and behavior of the roof specimen are constantly monitored. At the end of the test period, an investigation is carried out to understand the dynamics of the rupture, if any, and to assess possible improvement options to enhance the performance of the assembly (Fig. 7 and 8).

CHALLENGES EXPERIENCED IN MEETING THE WIND UPLIFT REQUIREMENTS

An issue experienced in the industry is for the designers to transfer the responsibility of determining wind uplift requirements to roofing contractors and/or manufacturers by referencing the building code in the specifications, rather than specifying the required project-specific wind uplift values. However, it is prudent for the designers to be informed of the code requirements and either verify the project-specific wind uplift values themselves or engage qualified professionals to provide verified values. Doing so eliminates ambiguity, upholds the standard of care, reduces risk and liability, and prevents cutting corners. In June 2018, the Canadian Roofing Contractors Association issued an advisory bulletin⁸ to communicate the responsibility of confirming project specific wind uplift loads lies with the designer and not the roofing contractor, and the reasoning for this design responsibility has been dissected at length by Klassen in a 2021 article.⁹

In addition to verifying the project-specific wind uplift values, the designer must obtain test reports supplied by a third-party testing facility

that uses apparatus properly calibrated as per the CSA A123.21¹ protocol, and verify that the tested rating of the proposed assembly meets the project-specific wind uplift load requirements for each of the roof areas for all zones. It is also important that the designer understands whether the manufacturer proposes to meet the requirements by using the extrapolation method set forth in the *Wind Design Standard Practice for Roofing Assemblies* (ANSI/SPRI WD-1).¹⁰ ANSI/SPRI WD-1 that provides calculation means to enhance securement. If that is the manufacturer's intention, the manufacturer should provide the details of calculation and any other information that the designer may require to assess the risk. The designer should assess the suitability of the extrapolation method by verifying the calculation and taking into account the mode of failure experienced during the original test. While the extrapolation method may be appropriate for mechanically attached roofing systems (MARS), it is not suitable in all circumstances for fully adhered roofing systems or partially adhered roofing systems (PARS). For instance, if a roof assembly's mode of failure is due to cohesive failure of one of the layers of a roof assembly at its ultimate capacity, improving the adhesion of the layers by reducing the spacing of the adhesives (which is a common approach for extrapolation) will not improve the overall performance of the roof assembly. Regardless of the amount and spacing of the adhesive, the roof assembly will experience cohesive failure of the layer at its ultimate capacity before reaching the project-specific wind uplift resistance values. The designer may specifically note that extrapolation methods of compliance and the use of noncalibrated testing facilities are unacceptable. The safest approach is to ensure that the rating of the proposed roof system is confirmed through third-party testing and meets or exceeds project-specific wind uplift resistance values for all roof zones.



Figure 5. Installation of a roof assembly specimen.



Figure 6. Airtight chamber mounted over the roof specimen.



Figure 7. Destructive testing upon completion of a test to evaluate the mode of failure.



Figure 8. Mode of failure observed upon completion of testing.

While it is critical that the designer exercise prudence during the design stage and verification at the procurement stage, these precautions will not be sufficient if the installers on site are not informed of or do not follow the same configurations of assembly securements that were used for the tested specimen (i.e., if they do not use the same attachment methods for the roof assembly layers). To ensure that the constructed roof assembly meets the code requirements, it is imperative that the project includes standard of acceptance or mock-up reviews, general conformance reviews, and quality assurance inspections.

The wind uplift loads at the corner are typically higher than at the edge and field conditions. Therefore, there is technically an option to install a roof assembly at the field and edge conditions that is rated lower than the assembly for the corner conditions. Choosing to install varied assemblies at the field, edge, and corner will have cost benefits, particularly on larger roofs. Such installations with varying performance ratings should be carefully evaluated on a case-by-case basis to verify that the variation will not have a performance impact at the transitions between the assembly types. Certain conditions may apply in projects that allow different roof assemblies for each of the zones; these conditions include maintaining the same roof composition for all zones in terms of materials, positioning of layers, and thickness of layers; maintaining a consistent thickness for all the assemblies; or using roof area dividers where variations are distinct.

PROJECTED CLIMATE SEVERITIES

In addition to meeting current code requirements, designers and contractors also

need to understand that further enhancements to the way roof assemblies are constructed for long term durability may be necessary to prepare for climate-change-driven events such as intense windstorms, heavy precipitation, and increased temperature. With the Earth's current surface temperature already reaching 1.5°C (2.7°F) warmer than pre-industrial levels, the occurrence of severe climate-related conditions is anticipated immediately and throughout the course of the service lives of existing and to-be-built building stocks. Among building envelope components, roofs tend to be especially vulnerable to climate-related risks due to their exposure to increase and variation in temperature, windstorms causing wind uplift failures, and extended water and snow retention. According to Engineers Canada,¹¹

Engineers have a significant role to play in addressing climate change issues and incorporating them into engineering practice in Canada... Engineers, under their professional code of ethics, play a fundamental role in ensuring construction and operation are continuously adapted to the impacts of climate change to ensure public safety.

SCOPE AND APPLICABILITY OF CSA A123.26

To support the design community in countering the anticipated effects of climate severities, the Task Group on Climate Resilience of Low Slope Membrane Roofing Systems developed CSA A123.26⁵ under the authority of the Technical Committee on Bituminous Roofing Materials and the Strategic Steering Committee on Construction and Civil Infrastructure. The document was published in 2021 as a national standard that meets the Standard Council of

Canada's requirements. The objective of CSA A123.26⁵ is to outline specific quantitative and qualitative requirements in the selection and detailing of low-slope membrane roofing systems to resist the impacts of anticipated climate severities. The standard addresses two main elements of the anticipated climate severities: wind and rain. Regarding wind, the pivotal requirement for the roofing system's long-term performance is resistance to wind loads, which includes the determination of project-specific wind uplift loads and selection of an appropriate assembly that can resist the determined load. Additional qualitative requirements in the standard are in line with the determined wind uplift loads. Regarding rain, the standard has design requirements for the roofing system to collect, manage, and dispose of anticipated additional rainwater due to climate severities, as well as several qualitative requirements.

CSA A123.26⁵ provides three performance levels for low-slope membrane roofing systems: Bronze, Silver, and Gold. The Bronze level represents the current requirements included in the NBCC² and *National Energy Code of Canada for Buildings* (NECB),¹² which do not take into account anticipated future climate severities. The Silver and Gold levels include provisions to counter the impacts of anticipated climate severities and the level of resilience required for the type of building and use.

NRCC has developed an online tool, Climate-RCI,¹³ based on the information from Environment and Climate Change Canada. This tool allows users to input a building's location in Canada and select a magnitude of global warming (0.5°C to 3.5°C [0.9 to 6.3°F]). Based on these inputs, the tool classifies the severity of wind, rain, and temperature for the building's location

as normal, severe, or extreme. Additionally, the tool provides quantitative design parameters: 1/50 hourly wind pressure and 1/50 one day rain, representing a 50-year mean recurrence for wind and rain, respectively, and anticipated maximum daily temperature for heat. The tool then requires the user to select a resiliency index of 1, 2 or 3, wherein the selection of a higher resiliency index, means the intent to achieve higher roof resilience. Resiliency index 1 aligns performance requirements with current provisions of NBCC² and NECB.¹² Resiliency index 3 is defined as follows: "Roofing systems are fully functional with required performance for normal and emergency operations irrespective of the climate conditions. Damage to contents is minimal in extent and minor in cost. Resiliency index 2 is for any level of performance requirement between Resilience Index 1 and 3. The user should select the resiliency index based on the expected function of the building (especially importance category and risk) and the resiliency required in terms of recovering from disturbances and adapting to climate severity. After the resiliency index for the project is selected, the tool produces a summary of design parameters for the project, including required roof performance level, whether Bronze, Silver, or Gold.

When the combination of climate index and resiliency index identifies a Bronze level roofing system for the entered inputs, the performance requirements are the current NBCC² and NECB¹² requirements, and the project-specific wind uplift values can be determined using Wind-RCI.⁷ When the roofing system is classified as Silver, it is assumed that the roof assembly will comply with the NBCC² and NECB¹² requirements as well as some additional requirements specified in CSA A123.26.⁵ Similarly, in case of the Gold performance level, the roofing assembly must meet the Bronze and Silver level requirements plus additional requirements specified in CSA A123.26.⁵ In the event of a conflict in requirements between the levels, the requirements of the highest level would take precedence. Figure 9 illustrates the various relationships between the climate category and resiliency index in the selection of the required performance.

CSA A123.26⁵ is applicable to adhesive applied roof systems (AARS), partially adhered roof systems (PARS), and mechanically attached roof systems (MARS). An AARS involves using adhesives to bond the roofing layers, mainly the cover board and insulation, on to lower

layers. A PARS involves using a combination of adhesive and mechanical fasteners to secure the roofing system to the substrate. In a MARS, the roofing system is secured to the substrate with mechanical fasteners such as screws or nails. CSA A123.26⁵ does not address the climatic adaptation requirements for the structural support (deck) below the roof assembly, which should be handled through enhancements to the structural design of the buildings.

RESISTANCE TO WIND UPLIFT LOADS

Using Climate-RCI,¹³ by inputting the project location and global warming magnitude, designers can determine the qualitative severity of the anticipated future wind conditions as either normal, severe or extreme and a quantitative 1/50 hourly wind pressure. For instance, the severity and wind uplift pressure value for a project located in Toronto (City Hall) with a global warming magnitude of 2°C (3.6F) is 'severe' and 0.46 kPa (9.67 psf) respectively. For the same location and a global warming magnitude of 3.5°C the severity is 'extreme' and wind pressure value is 0.50 kPa (10 psf). The wind pressure value is then used to calculate the factored wind loads either following the procedure outlined in section 4.1.7 of NBCC² or using Wind-RCI.⁷ It is to note that the required performance level for the roof, whether Bronze, Silver or Gold may vary depending on the selection of Resiliency Index.

Table 1 presents the wind uplift pressures determined for a hypothetical building of 9 m (30 ft) height in Toronto (City Hall), and its corresponding factored wind uplift loads

Climate Category	Resiliency Index 1	Resiliency Index 2	Resiliency Index 3
Normal	Bronze	Silver	Gold
Severe	Silver	Silver	Gold
Extreme	Gold	Gold	Gold

Figure 9. The application of climate category and resiliency index to identify a roofing assembly's performance level.

TABLE 1. Wind load determination for Toronto using Climate-RCI,¹³ Ontario

Global Warming Magnitude	Climate Severity for Wind	Wind Pressure Value	Factored Wind Uplift Load	Resiliency Index	Required Performance Level for Wind
<i>Source: Climate-RCI¹³</i>			<i>Source: Wind-RCI⁷</i>	<i>Source: Climate-RCI¹³</i>	
0.5°C	Normal	0.44 kPa	Corner -2.6 kPa	1	Bronze
			Edge -1.3 kPa	2	Silver
			Field -1.0 kPa	3	Gold
2°C	Severe	0.46 kPa	Corner -2.7 kPa	1	Silver
			Edge -1.4 kPa	2	Silver
			Field -1.1 kPa	3	Gold
3.5°C	Extreme	0.5 kPa	Corner -2.9 kPa	1	Gold
			Edge -1.5 kPa	2	Gold
			Field -1.2 kPa	3	Gold

Note: Above values are for a roof with no parapet

and required performance levels for different resiliency indices.

WIND UPLIFT RESISTANCE AT CORNERS AND EDGES

The presence of roof parapets can significantly minimize the effect of wind load at the roof perimeters, i.e., corners and edges. When calculating the factored wind uplift loads per NBCC² or using Wind-RCI⁷ to meet current code (Bronze level), the presence or absence of a parapet is one of the factors in determining the project specific requirements. For instance, for the above Toronto example, the factored wind uplift loads for the roof assembly with no parapet are Corner -2.6 kPa; Edge -1.4 kPa; and Field -1.1 kPa. The same roof with a 1 m (3 ft) parapet will have reduced factored wind uplift values of Corner -2.2 kPa, Edge -1.3 kPa, and Field -1.0 kPa. While the presence of a parapet reduces the wind uplift loads within the roof area, the wind loads against the parapet cladding and its components, particularly the top edge of the parapet, will be higher and is to be determined. For instance, in the above scenario, the factored wind loads for parapet cladding and metal edge components will be -2.9 kPa in suction for Corner and -1.7 kPa in suction for Edge, and a positive load of 1.4 kPa at the face of the parapet.

For the Silver and Gold level roofs, the values determined are required to be increased by 30% and 50% respectively if a parapet is not installed. **Table 2** presents the wind uplift values for each of the performance levels for the above example.

The alternative option of installing a 0.9 m (3 ft) high parapet must be installed as an extension of the main structural system of the building and meet the determined wind uplift loads. Installation of a roof parapet as an extension of the main structural system poses challenges in achieving continuity of the air barrier at the intersection detail between the exterior wall and roof assemblies. Lack of air

barrier continuity may contribute to wind uplift failures in addition to the potential condensation issues within the parapet assembly. Hence, the roof-to-exterior wall junction detailing at the base of a roof parapet installed as part of the main structural system requires special attention to ensure that the continuity of the air barrier is maintained.

In addition to the requirement to either install a 0.9 m (3 ft) high parapet or increase the performance requirements to counter the higher wind uplift loads for the roof perimeters, CSA A123.26⁵ includes a requirement to reinforce the field membrane termination using metal bars or plates with a maximum spacing of 152 mm (6 in.) to provide secondary protection against membrane lifting and peeling or pulling away from the roof perimeter. The required use of metal components to secure membrane termination to the structural elements such as metal decks may cause some thermal bridging around the fasteners. However, the risk of wind uplift failures and consequential repair or replacement of roof assembly trumps the marginal increase of thermal bridging at the roof perimeters. Another possible challenge with the installation of term bars and plates is the potential inhibition of rainwater drainage. As an alternative to the requirement to install the term bar and plates, the standard includes an option to further increase the wind uplift loads for the perimeter zones by 30% for parapets with a height greater than 914 mm (3 ft) and 50% for parapets with a height lower than 914 mm (3 ft).

Wind uplift loads are significant at parapets, particularly at the top edges, which experience complex wind aerodynamics. Cap flashings, including cleats and their fasteners, require an appropriate thickness and attachment spacing to resist the determined wind uplift load requirements as that of the roof assembly. The

wind forces on the parapet and cap flashing are complex and depend on the roof slope, parapet height, parapet shape, and internal pressure between the wall and edge metal. The cap flashings, particularly at the corners, have a high probability of failure, which can lead to further failure of the rest of the flashing, other parapet components, and the membrane of the roof system. In addition to the requirements listed in CSA A123.26,⁵ refer to ANSI/SPRI ES-1, *Wind Design Standard for Edge Systems Used with Low Slope Roofing Systems*,¹⁴ for further guidance. The CSA A123.26⁵ requires that the membrane flashing be fully adhered on the vertical upturn of the parapet, and wrapped over the top edge of the parapet, with fasteners securing the membrane flashing through cleats to limit failure.

ROOFTOP ADD-ONS

A critical issue related to the rooftop add-ons is their resistance to wind uplift loads. With regard to the design of rooftop add-ons, CSA A123.26⁵ requires that add-on components and their anchorages meet the wind uplift load requirements for the roof assembly. For vegetated roof assemblies, CSA A123.26⁵ references CSA A123.24, *Standard Test Method for Wind Resistance of Modular Vegetated Roof Assembly*,¹⁵ to determine the project-specific wind uplift loads and airflow conditions for either the built-in-place vegetated systems or the modular vegetated system. The intent of the test is to evaluate the overturning and/or displacement of the vegetated roof components mounted on the roof assembly samples when wind uplift loads are applied.

When there are exterior-mounted rooftop units such as mechanical, electrical, and communications equipment, air intakes, vent stacks, guywires, or solar panels, the attachments for the rooftop units and the supporting frames can be insufficient or missing. When the wind

TABLE 2. Wind load determination for Toronto (City Hall), Ontario

Roof Performance Levels	Location-specific wind loads per Wind-RCI ⁷			Location-specific wind loads per Wind-RCI ⁷ and Climate-RCI ¹³ with increase of 30% for Silver and 50% for Gold		
	Field wind load, kPa	Edge wind load, kPa	Corner wind load, kPa	Field wind load, kPa	Edge wind load, kPa	Corner wind load, kPa
Bronze	-1.0	-1.3	-2.6	-1.0	-1.3	-2.6
Silver	-1.1	-1.4	-2.7	-1.43	-1.82	-3.51
Gold	-1.1	-1.4	-2.7	-1.65	-2.1	-4.05

Note: 1kPa = 20.9 lb/ft².

Wind loads for Bronze categories are compliant with current NBCC requirements; wind loads for Silver and Gold categories are increased 30% and 50%, respectively, from the NBCC code requirements.

uplift load exceeds the self-weight of a rooftop unit, the unit could tip over, causing damage to the roof membrane. While CSA A123.26⁵ includes some prescriptive requirements for the anchorage of rooftop units, the main intent is to design rooftop units, including their components and anchorage, to meet the wind uplift loads required for the roof assembly.

CSA A123.26⁵ also addresses an issue related to the rubbing of rooftop components against the roof membrane system causing reduced service life. The standard requires that gas lines are mounted on supports at a minimum of 304 mm (12 in.) over the membrane surface to limit the potential for gas lines to rub against the roof membrane due to deflections between the supports. Similarly, the standard requires that lighting protection cables are secured to thermally nonconductive supporting elements to limit rubbing of the cables on the roof membrane. The minimum spacing requirements for the securement of cables are 914 mm (36 in.), 304 mm (12 in.), and 203 mm (8 in.), respectively, in the field, edge, and corner areas.

CSA A123.26⁵ addresses the common issue of corrosion of metal components in rooftop units and resulting damage to the roof membrane by requiring that rooftop units and their components, including body stands, anchors, and fasteners, be made out of nonferrous metals, stainless steel, or hot-dip galvanized steel with a coating designation of at least G-90.

RESISTANCE TO RAIN LOAD

Rainwater resistance of a roof assembly is a function of the watertightness of the membrane and flashings, the roof slope, drainage, flashing construction, and the ability of the system to evacuate the water.

The primary function of a roof assembly is to prevent precipitation from entering the space below by controlling and discharging the rainwater collected on the roof to either a storm water drainage system or the terrain adjacent to the building. To ensure that roof assemblies meet this objective, designers calculate rain loads and design a roof drainage system. The design process involves determining the appropriate number of drains and size of drains and scuppers, taking into account the roof slope, the type of roof finish, and the type of rainwater leaders. The number and size of drains are calculated based on the rainfall information from NBCC² and the maximum permitted hydraulic load of leader pipe available in OBC.³

The intent of the code is to ensure that the roof drainage system can carry off rainwater from the most intense rainfall that is likely to occur. Therefore, to meet current code requirements

(which would be applicable to a Bronze project), the designer needs to determine the maximum 15-minute rainfall intensity for the site location (1 in 10-year return), referred to as the "concentration time." This rainfall information can be obtained from Table C-2 in the NBCC² Appendix or the Ministry of Municipal Affairs and Housing's *Supplementary Standard SB-1, Climate and Seismic Data*.¹⁶ The hydraulic load in liters from a roof is equal to the maximum 15-minute rainfall intensity multiplied by the sum of area of the horizontal surface and one-half the area of the adjoining vertical surface (with the areas measured in square meters). For instance, based on the NBCC² Table C-2, the maximum 15-minute rainfall intensity (1 in 10-year return) for Toronto (City Hall) is 25 mm. NBCC² Table C-2 also provides information on 1-day rainfall that has 1 chance in 50 of being exceeded in any single year. The 1-in-50-year return value 1-day rainfall is used mainly to determine the additional (structural) dead load due to ineffective drains.

Anticipated rain loads for Silver and Gold level roof assemblies can be determined using the Climate-RCI¹³ tool. Unlike the NBCC² tables used for Bronze assemblies, Climate-RCI¹³ only provides 1-day rainfall projections. In absence of the maximum 15-minute rainfall intensity information, the extrapolation of 1-day rainfall data in the Climate-RCI¹³ tool is suitable as long as the structural systems will be designed to handle the weight of the projected 1-day rainfall. The 15-minute rainfall intensity can be calculated using the percentage difference between the 1-day rainfall data for Silver and Gold roofs from Climate-RCI¹³ and the 1-day rainfall values from the 2020 edition of NBCC.² Refer to **Table 3** showing an example of the rain load determination using extrapolation for 'severe' and 'extreme' conditions.

Table 7.4.10.9 of *Ontario Building Code* provides the maximum permitted hydraulic

load drained to a horizontal storm drainage pipe at 2% roof slope. Based on the determined rain load, assuming a drain and leader size of 152 mm (6 in.) with a drain slope of 2% under the roof and a roof area of 9290 m² (100,000 ft²), a total of 14 drains is required. Refer to **Table 4** showing comparative calculations for a 4" drain and for 'severe' and 'extreme' conditions.

ROOF DRAINAGE SYSTEM DESIGN

The intent of the building code is to discharge rainwater off the roof at the earliest possible time, but without adding stress to the drainage system during rapid acceleration of rainfall intensity; this purpose is achieved by allowing a certain amount of time for the rainwater to flow across and down the roof before it enters the gutter or drainage system. To determine the drain size and number of drains for an effective rooftop drainage system, the building code directs the designer to use the maximum 15-minute rainfall intensity and hydraulic load calculations.

In addition to the current building code requirement, CSA A123.26⁵ prescribes maximum runoff for rainwater by limiting the distance between the roof perimeter and drains and limiting the spacing between the drains. For roofing systems in the Silver category, the standard specifies that water on the surface cannot run more than 10.7 m (35 ft) to a drain and scupper. In the Gold classification, the maximum distance to a drain or scupper is 6.1 m (20 ft). Analysis shows that this maximum water runoff distance requirement overwrites the current code, adding a significant number of drains to the roof and limiting the current industry practice of using two-directional slopes and valleys. When the limiting distance for maximum runoff for rainwater is applied, to a 9,290 m² (100,000 ft²) roof, 45 roof drains are required for a roofing system in the Silver category. The SIGDERS

TABLE 3. Rain load determination for Toronto, Ontario

Rain Load Calculation	
Roof Area	9290 m ²
15-minute rain intensity per NBCC ²	25 mm
One Day rainfall per NBCC ²	97 mm
15-minute rain intensity for 'severe' condition per Climate-RCI ¹³	Unavailable
One Day rainfall for 'severe' condition per Climate-RCI ¹³	116.69 mm
Extrapolated 15 min rain intensity = (25 mm * 116.69 mm) / 97 mm	30 mm
One Day rainfall for 'extreme' condition per Climate-RCI ¹³	126 mm
Extrapolated 15 min rain intensity = (25 mm * 116.69 mm) / 97 mm	32.5 mm

TABLE 4. Number of drains and drain size determination for Toronto, Ontario

Determination of Drains	
Volume of rainwater (9290 m ² x 25 mm = 232.25 m ³)	232,250 liters
Hydraulic load of 4 in. diameter drain/drainpipe and 2% slope of drainpipe per Table 7.4.10.9 in OBC ³	5,970 liters
Number of 4 in. drains = 232,250 liters / 5,970 liters	39 drains
Hydraulic load of 6 in. diameter drain/drainpipe and 2% slope of drainpipe per Table 7.4.10.9 in OBC ³	17,600 liters
Number of 6 in. drains = 232,250 liters / 17,600 liters	14 drains
Volume of rainwater for 'severe' condition (9290 m ² x 30 mm = 278.70 m ³)	278,700 liters
Number of 6 in. drains = 278,700 liters / 17,600 liters	16 drains
Volume of rainwater for 'extreme' condition (9290 m ² x 32.5 mm = 301.92 m ³)	301,925 liters
Number of 6 in. drains = 301,925 liters / 17,600 liters	18 drains

Note: 1 in. = 25.4 mm; 1 ft = 0.305 m; 1 gal. = 3.79 L.

committee intends to review this CSA A123.26⁵ requirement given the impracticality of such an installation, questionable performance in terms of thermal bridging, and challenges related to the continuity of air barrier and waterproofing. Also, this drainage system requirement conflicts with the intent of the building code to reduce overstress on the drainage system.

RAINWATER RUNOFF MANAGEMENT ON ROOF SURFACES

Current industry practice in roof drainage design is to achieve a 2% minimum positive slope toward roof drains; typically, the roofing system will have two-directional drainage achieved using sloped structure toward a central valley with crickets built using tapered insulation at the center that lead runoff water to drains. This industry practice is further reinforced in CSA A123.26,⁵ which requires that roofing assemblies in the Silver and Gold categories achieve the minimum 2% positive slope for the main roof surface, which also includes a back slope at the crickets that is double the slope of the main roof. The Gold requirement prescribes that the entire roof structure to have a minimum of 2% positive slope.

Current industry practice also limits the interference to free drainage on the roof surface by suitably positioning rooftop units, rooftop accessories, and other openings or by using crickets around such interferences. For effective management of the drainage path, CSA A123.26⁵ includes a prescriptive requirement to position rooftop units, rooftop accessories, and other openings a minimum of 1.8 m (6 ft) away from roof drains, low points, or valleys to avoid restricting the flow of water to drains or scuppers.

RAINWATER DISCHARGE

Ensuring the effectiveness of drains and scuppers is a critical part of handling the discharge of rainwater. In addition to a prescriptive requirement for the minimum drain diameter, CSA A123.26⁵ includes several qualitative requirements for drains, such as the requirement for a sump at drains, specifications regarding the size and slope of the sump, and installation of strainers and screens with specific material choices and securement. CSA A123.26⁵ requires a minimum drain diameter of 76 mm (3 in.) for roofing assemblies in the Silver category and 102 mm (4 in.) for those in the Gold category. A sump is required at each main drain measuring minimum 1.2 x 1.2 m (4 x 4 ft), with a minimum 4% slope toward the drain. In the Silver and Gold classifications, every drain is required to have a corrosion-resistant metal strainer that is compatible with the adjacent materials and secured in place, and there must be drain screens secured to the drain strainers in a minimum of four locations to catch roof debris. These screens must be at least 609 mm (24 in.) in diameter and made from a corrosion-resistant material that is compatible with the adjacent materials. The screen must be installed with a zinc strip to minimize the unintentional growth of vegetation.

In alignment with the current industry practice to install secondary drainage for every roof area, CSA A123.26⁵ includes requirement to install secondary drains or scuppers to manage the overflow of rainwater in case of drain failures. The standard requires a minimum scupper opening height of 102 mm (4 in.) for roofing assemblies in the Silver classification and 152 mm (6 in.) for those in the Gold classification, and it prescribes that a scupper must be installed a minimum of

51 mm (2 in.) above the finished roof surface with proper flashing detail and located at the lowest point of roof or roof perimeter. The standard also prescribes that the width of a scupper opening must not be less than the circumference of the roof drain in the same roof area. However, upon evaluation, it was noted that a requirement to install scuppers with a width equal to the circumference of the main drains is excessive. For instance, the circumference of a 76 mm (3 in.) diameter drain is greater than 228 mm (9 in.) and the circumference of a 101 mm (4 in.)-diameter drain is greater than 305 mm (12 in.) This requirement is currently being reviewed by the SIGDERS committee for modification; in future editions of CSA A123.26,⁵ the requirement may specify that scuppers must have the same diameter as the main drains or a diameter equal to the height of the scupper.

Regarding the rainwater discharge onto grade, CSA A123.26⁵ calls for the termination of drainpipe 457 mm (18 in.) above grade with an elbow extension of 914 mm (3 ft) from the building onto splash pads at the outlet and/or counter-flashings on the wall. While this arrangement is a common industry practice, the requirement in the standard reinforces the significance of keeping the water away from the building as it is being discharged.

CONTINUITY OF WATERPROOFING, AIRTIGHTNESS, AND WEATHER RESISTANCE

The CSA A123.26⁵ roof performance requirements for the 'Silver' and 'Gold' categories specify that roof membranes, flashing systems, and other roof penetrations must be designed to be watertight and comply with CAN/ULC-S742, *Standard for Air Barrier Materials—Specification*.¹⁷ These requirements align with current industry practices for waterproofing and air barriers in roof assemblies.

In addition, CSA A123.26⁵ includes requirements to enhance the weather resistance of roof assemblies by limiting the impacts of snow accumulation, wind-driven rain, and water splashing off the roof membrane surface. The current common industry practice is for a 203 mm (8-in.) membrane upturn at roof penetrations and openings, including skylights, fire walls, roof curbs, transitions, and changes in plane in the interior field of the roof. According to CSA A123.26,⁵ roof assemblies in the Silver category must have an upturn of 355 mm (14 in.) and those in the Gold category must have a 457 mm (18 in.) upturn. The membrane upturn requirement on an exterior wall assembly within the field of a roof assembly may pose challenges

when the insulation is positioned within stud cavities. It could create a situation in which vapor retarder is doubled in the wall assembly. The upturn for the membrane flashing at the parapets is required to be at 304 mm (12 in.).

INSPECTION REQUIREMENTS

The wind and rain sections of CSA A123.26⁵ both specify need for independent inspectors to conduct quality assurance observations. For the Silver category, the requirement is to retain an independent inspector for at least 25% of the days of work, during major stages of the roofing application, including completion. The intent is for the inspector to review whether the work conforms to the standard, to the applicable governing building code, and to any quality assurance metrics established by the design specifications. For the Gold category, the requirement is to retain an independent inspector for 100% of the days of work. CSA A123.26⁵ offers alternative options such as in situ testing of the roof assembly for wind uplift, leak detection system for rain penetration, and flood testing of penetration flashings to either substitute for or reduce the 100% inspection requirement. These alternatives are discussed in later sections.

CSA A123.26⁵ requirements for quality assurance inspections conveys the criticality of construction reviews for a proper installation of the roof assembly. However, when a building envelope consultant with expertise in roofing is involved in the project, the intent of this requirement can be met without engaging an independent quality assurance inspector. If the requirement were modified to include a review by the already involved building envelope consultant with expertise in roofing as an alternative to a quality assurance inspector, that would avoid duplication in some projects and thus lower the costs of Gold and Silver projects.

In addition to the construction reviews as mandated by the CSA A123.26,⁵ it is recommended to conduct the following: review of project specifications (including project-specific wind uplift loads); shop drawings and submittals; wind uplift resistance report from the third-party laboratory; and mock-ups to establish the standard of acceptance. The above is recommended to be conducted by a qualified building envelope consultant or an independent quality assurance inspector.

In Situ Negative Pressure Uplift Test Option

Annex B of CSA A123.26⁵ includes an alternative option for PARs and AARs to reduce the quality assurance inspections particularly related to wind uplift resistance for the Gold category. In lieu

of construction reviews for 100% of the project days, in situ negative pressure uplift testing as described in Annex B of CSA A123.26⁵ allowing reduction of quality assurance inspections to 50% of project days. A minimum of two tests is required for every 5600 m² (60,300 sq. ft.) of roof area. The testing uses an in-situ pressure chamber, with deflection and pressure sensors mounted on the selected roof areas. The deflection of the roof membrane is monitored visually through a port and deflection sensor as the pressure differential is increased by increments of 720 Pa (0.104 psi) at 60-second intervals to a termination test pressure meeting project-specific requirements. While there is no direct correlation between this field test and the laboratory testing specified in CSA A123.21,¹ the in-situ testing results provide a good understanding of the performance of the roof assembly and may identify noncompliant installation.

Leak Detection System Option

Leak detection systems may be installed as an integral part of the assembly at the time of construction, or they can be installed using a nondestructive technique within one or two years after completion of construction. CSA A123.26⁵ specifies that an integral leak detection system installed during construction is suitable to reduce the Gold category requirement for quality assurance inspections from 100% to 25% of days.

Watertightness Testing Option

As an alternative option to the Gold category requirement of quality assurance inspection for watertightness on 100% of days, CSA A123.26⁵ allows the option of conducting flood testing. The specified testing method is a modified version of ASTM D5957, *Standard Guide for Flood Testing Horizontal Waterproofing Installations*,¹⁸ wherein a minimum test area of 3 × 3 m (9.8 × 9.8 ft) with at least one plumbing vent or any other roof penetration is flooded to a minimum depth of 25 mm (1 in.) for 24 hours to evaluate for water leaks.

While the test area is defined, the CSA A123.26⁵ standard does not indicate the number of such tests per roof or the number of tests for a certain extent of roof area. It is the authors' opinion that the number of tests be determined by the number of roof areas defined by the direction of slope and the selection of the test area by the quality assurance inspector.

SUGGESTIONS FOR FURTHER DEVELOPMENT OF CSA A123.26 AND ASSOCIATED TOOLS

In general, CSA A123.26⁵ streamlines various requirements to meet the wind and rain

effects of anticipated climate severities on roof assemblies. As the first design standard of its kind, it addresses several of the critical issues related to roof assemblies. However, it could be further enhanced to address the following:

- Given the projected increase in temperature due to climate change, in addition to the measures to counter the high wind conditions and increased rainfall, the standard may include in the future additional requirements focused on roof membrane material performance countering the temperature increase. It is recognized that additional research is required in this regard.
- Climate-RCI¹³ estimates anticipated climate severities for wind, rain, and heat; this tool may require further refinement to include additional metrics for freeze-thaw cycles, snow accumulations, hail, and so on. Similarly, CSA A123.26⁵ could be expanded to include requirements to counter such climate severities.
- CSA A123.26⁵ includes prescriptive requirements, both quantitative and qualitative, for the Silver and Gold categories, while defaulting to current codes and industry practices for the Bronze category. However, qualitative industry practices vary significantly across regions, provinces, and jurisdictions. It may therefore be prudent to revise the standard to document qualitative prescriptive requirements for the Bronze category. For example, the requirement for membrane upturns at penetrations might be specified.
- CSA A123.26⁵ clearly illustrates the significance of the high wind conditions anticipated at the parapet and includes some recommendations for the structural integrity of the parapet assembly, membrane, and cladding components attached to the parapet, including cap flashings and their components. This topic, particularly the requirements for the substrate to which these components are secured, can be further detailed. Additional requirements could help address air-barrier continuity challenges at the base of parapet where the parapet is part of the main structure.
- CSA A123.26⁵ may further develop the mounting requirements for rooftop add-ons, specifying whether they are allowed to be floating (not secured to the roof deck, but supported by self-weight or added weight) on the roof assembly or secured to main structural system. If floating, the standard may further include requirements about the required compressive strength of the roof assembly and

components, and about required isolators to reduce damage to the roof assembly.

- As discussed, CSA A123.26⁵ could be expanded to include requirements for specification review, preconstruction meetings, submittals (including the test reports), shop drawing reviews, and mock-up reviews for standard of acceptance. These requirements would be in addition to the requirements for periodic quality assurance reviews. Also, as discussed, a review by a qualified building envelope consultant might be offered as an acceptable alternative to the requirements for third-party quality assurance inspections.
- Considering that the intent of CSA A123.26⁵ is to help sustain the service life of the roof assembly, the standard may be expanded to include requirements for maintenance during operation, such as requirements for periodic reviews and pre-determined maintenance activities, including repairs and renewals.

CONCLUSION

With the changing climate and the likelihood of adverse weather conditions in the future, the design and construction of roof assemblies capable of resisting project-specific wind uplift values as required by the building code is just a starting point to achieve durable and resilient roof assemblies with long service lives. CSA A123.26⁵ aims to enhance the resilience of roof assemblies, particularly low-slope membrane roofs, against future climatic conditions by incorporating anticipated wind and rain loads, using data from Climate-RCI¹³ and improving the quality of roofing details. The requirements in the standard, both quantitative and qualitative, are intended to improve the performance of the roof assemblies and ensure durability by countering future climate severities, by reducing wind uplift failures, water ingress issues, safety issues, and maintenance. The standard also provides clearer guidelines for construction practices, which can support designers across regions, provinces and/or jurisdictions. 

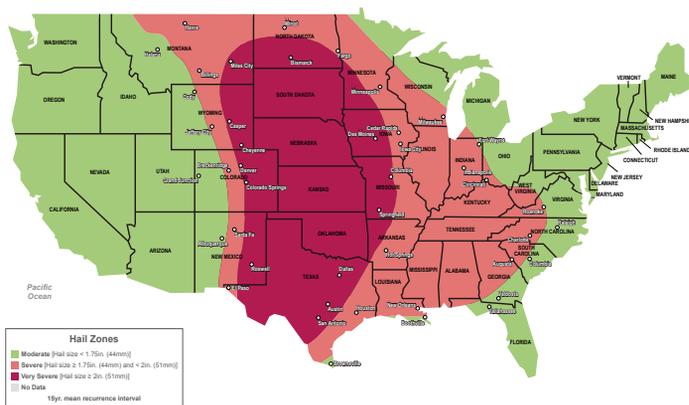
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