Feature

Three Decades of Scientific Advancement to the North American Roofing Community

By Appupillai (Bas) Baskaran, F–IIBEC, PEng, PhD

This paper was presented at the 2024 IIBEC International Convention and Trade Show.

ON NOVEMBER 16, 1994, members of the roofing community met at the National Research Council Canada (NRC) and formed a group with a common focus of evaluating roofing systems under dynamic environment. Thus, a Special Interest Group on Dynamic Evaluation of Roofing Systems (SIGDERS) was created. The mandate of SIGDERS joint research program is to carry out generic, precompetitive research of benefit to all its members. SIGDERS's operation is one of a kind, not only for its legacy as a long-lasting research and development (R&D) consortium, but also for the following industry impacts it created:

- Static versus dynamic evaluations of roofs, and the pros and cons of each
- Diagnosis of a weak link to enable innovation
- Nominal versus design tensile strength of steel deck, and the importance of each
- Investigation of the innovation of membrane seaming
- Differences between air leakage and intrusion
- How much roof edge matters
- Wind science of vegetated roofs
- Climate adaptation of commercial roofs

These advancements were delivered with details consecutively for 20 years at the IIBEC conventions. This article is an "extraction" from all those presentations. It will be delivered as a symbolic icon of the SIGDERS's contribution to the North American roofing community. The article also highlights current R&D efforts at the NRC focusing on residential and climate adaptation area.

Q1: WHAT ARE THE ATTRIBUTES OF WIND ON ROOF?

Wind is a random process. When it separates from roof edges, it creates zones of suction (negative) pressure. This suction has two characteristics: (a) it varies from one zone of the roof to the other (spatial variations); (b) it varies from one period of time to another (fluctuation with respect to time). One can simplify the spatial variations from zones of higher to lower suction as corner, edge, and field. A statistical approach is used to simplify the time fluctuations as mean, peak, and standard deviation (**Fig. 1**).

Q2: WHAT ARE THE STEPS IN THE WIND UPLIFT DESIGN OF A ROOF?

The complex process can be simplified into three steps, and a case study is presented below.

Step 1: Calculate the Design Wind Uplift

The Canadian model code *National Building Code of Canada* (NBCC) specifies wind load requirements to design of roof assemblies for the nation. In the US, the American Society of Civil Engineers (ASCE) standard 7 is widely used. In accordance with the ASCE 7 or NBCC or using Wind-Roof Calculator on the Internet (Wind-RCI) at http://nrc.candada.ca/en/research-development/products-services/software-applications/wind-load-calculators-roof-cladding-vegetated-roof-assembly, calculate the design wind load (PD) for various zones of the roof cladding (for example: field = 1,341 Pa [28 psf], edge = 1,724 Pa [36 psf], and corner = 2,681 Pa [56 psf]). Wind-RCI is an online calculator that conservatively estimates the wind loads on roofing claddings, and the first version was developed using an RCI Foundation grant.

Note: Designing the roof system according to ultimate limit state (ULS) requires multiplication of 1.4 (principal wind load effect factor) to the wind loads for various zones.

Step 2: Select the Roofing System

Determine the uplift resistance of the roofing system in accordance with the requirements of CAN/CSA A123.21, which is the only compliance standard by the NBCC. The US has several wind uplift test methods, including FM 4474 and UL 1896.

Step 3: Correlation

Select a roofing system and related components with uplift resistance higher than the design load (**Fig. 2**).

Q3: WHAT IS CSA A123.21 AND HOW WAS IT DEVELOPED?

The Canadian model code NBCC specifies wind load requirements for the design of roof assemblies. To comply with the NBCC, the CSA A123.21 standard provides test requirements for resistance evaluation. Tested resistance should be equal to or greater than the design load. First published in 2004, CSA A123.21 was subsequently revised/ edited in 2010 and 2014, with the latest edition published in 2020. The R&D for the standard was developed by the National Research Council Canada (NRC) industry-based Consortium, "Special Interest Group for Dynamic Evaluation of Roofing Systems (SIGDERS)."

Q4: WHAT ARE THE DIFFERENT TYPES OF LOW-SLOPE MEMBRANE ROOFING SYSTEMS?

The roofing assembly consists of a deck and roofing membrane. It may include components such as vapor barrier or retarders, insulation, cover board, etc. The roofing system consists of components above the deck. The standard is applicable to low-slope membrane roofing systems that fall in one of three categories, each of which describes the way the roof system is secured to the deck/ structure as indicated below.

Mechanically Attached Roofing System (MARS): a system in which the roofing membrane is intermittently attached to the deck using fasteners, as shown in **Fig. 3**.

Partially Attached (hybrid) membrane Roofing System (PARS): a system in which the roof membrane is bonded to the substrate using adhesives, and a minimum of one component below the membrane is intermittently attached to supporting structure using fasteners, as shown in **Fig. 4**.

Adhesive Applied membrane Roofing System (AARS): a system in which the roof membrane is bonded to the substrate using adhesives, and all the other components below the roofing membrane are integrated using adhesives, as shown in **Fig. 5**.

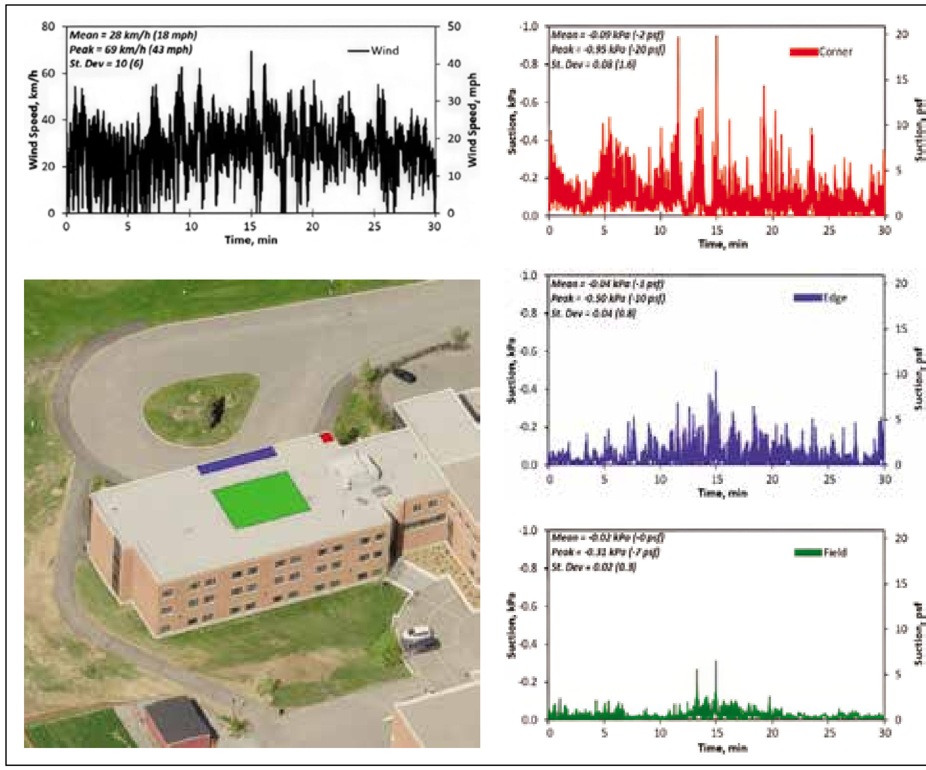

Figure 1. *Wind and its effects on a school building roof measured in Ottawa.*

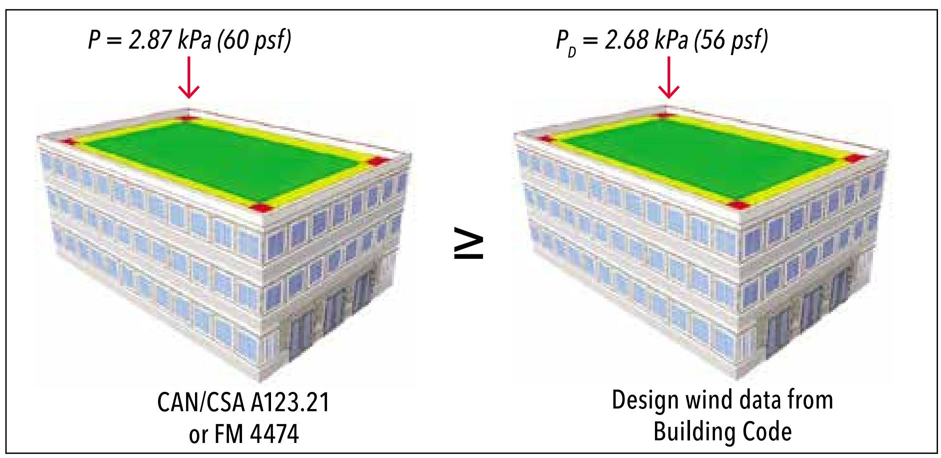

Figure 2. *Wind uplift resistances should be higher than the design values.*

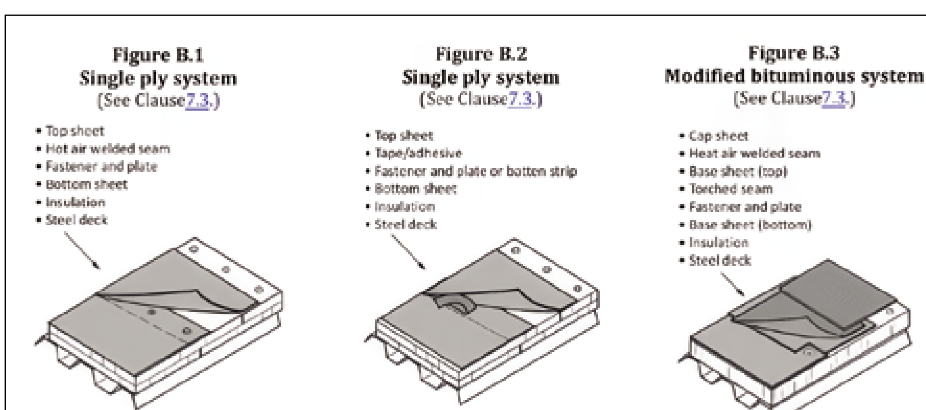

Figure 3. *Typical component arrangement of a mechanically attached roofing system.*

Q5: WHAT IS THE "WEAKEST LINK" CONCEPT IN THE DETERMINATION OF WIND UPLIFT RESISTANCE?

Wind induces load on the roof. It is resisted by each component by their resistance. This can be illustrated through a force resistance link diagram respectively for MARS in **Fig. 6**, PARS in **Fig. 7**, and AARS in **Fig. 8**.All resistance links shall remain connected to ensure the system will be durable and keep the roof in place. Failure occurs when the wind uplift force is greater than the resistance of any one or more of these links. This understanding helps to choose the appropriate roof components and construction techniques at the early design stage or by replacing/adding components to improve wind uplift resistance during the reroofing.

Q6: WHAT IS THE ROLE OF STRUCTURAL DECK?

Deck provides structural support, and it must have adequate strength and rigidity to support dead and live loads. These loads either induce compressive or tensile forces or a combination of forces. Steel, concrete, and wood are three common deck materials used for the MARS/AARS/PARS. There is a lot of research related to the use of steel decks on commercial roof systems. Therefore, this article only focuses on the use of steel decks on commercial roofs. However, although SIGDERS has limited research data on concrete deck and wood deck, both deck types are known for having moisture migration issues.

The wind uplift induces tensile forces, which are transmitted to the deck through the structural or pneumatic load path or a combination of both. Therefore, the deck's tensile strength and its attachment to the joists are critical as they can influence the wind uplift resistance of a roof system.

a) deck attachment methods with joists

Welding or fastening to a structural joist are the two common field attachment practices. Two identical sets (welded versus fastened) of MARSs with modified bitumen (MB) and thermoplastic membrane were constructed and investigated at the Dynamic Roofing Facility (DRF) of the NRC. Specimens that were installed on decks that were fastened to the joists performed better than the welded specimens. The weld was the weakest link, as shown in **Fig. 9**.

b) deck strengths

Steel deck strengths are determined by the combination of the thickness and yield strength.

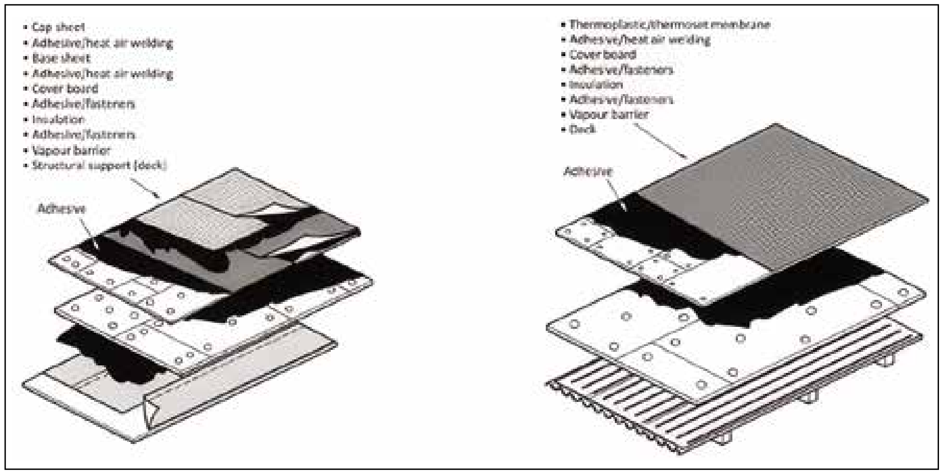

Figure 4. *Typical component arrangement of a partially attached (hybrid) membrane roofing system.*

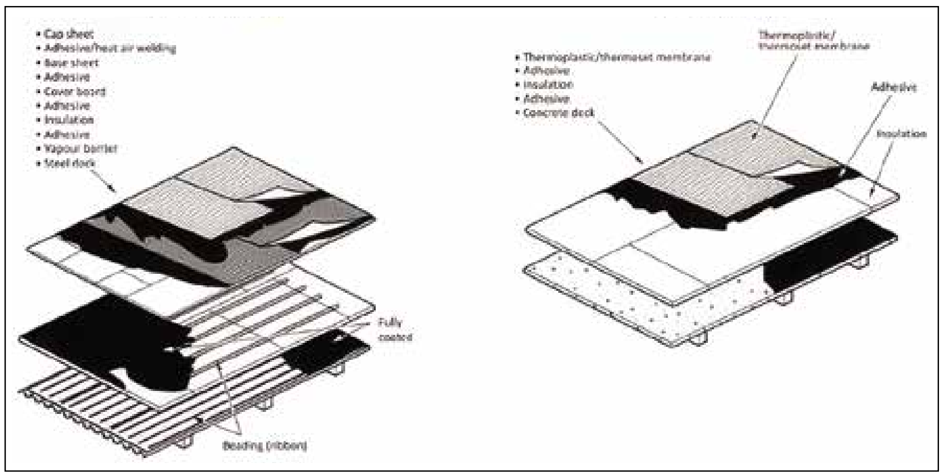

Figure 5. *Typical component arrangement of an adhesive applied membrane roofing system..*

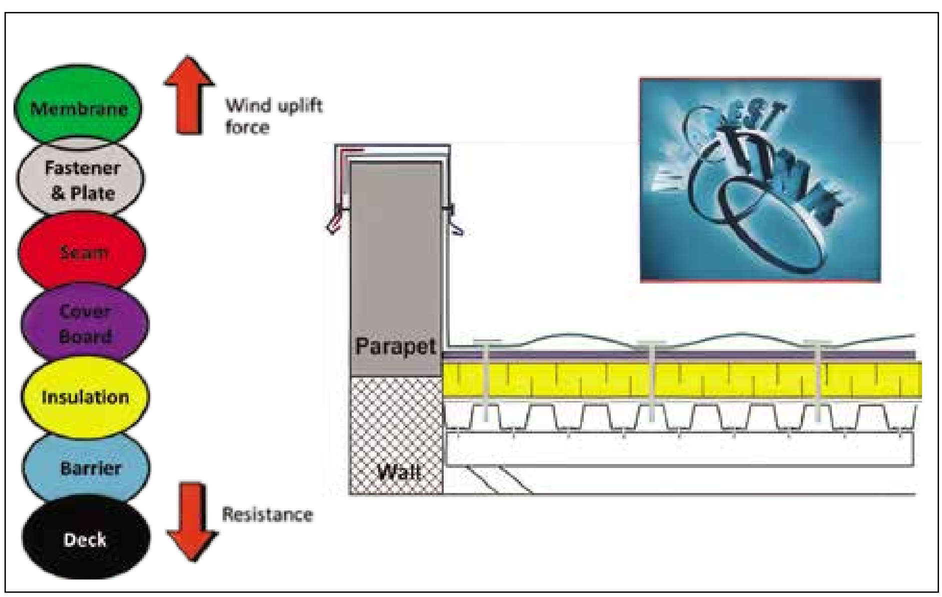

Figure 6. *Force resistance link diagram: mechanically attached roofing system.*

The most common decks used in North America are 22 ga and 20 ga with 230 MPa (33 ksi) and 550 MPa (80 ksi). Two identical MARSs with thermoplastic membranes were constructed and tested at the DRF of the NRC. The first specimen that was installed on 22 ga, 550 MPa steel deck had a lower sustained pressure of 7.90 kPa (165 psf) than the second system, and

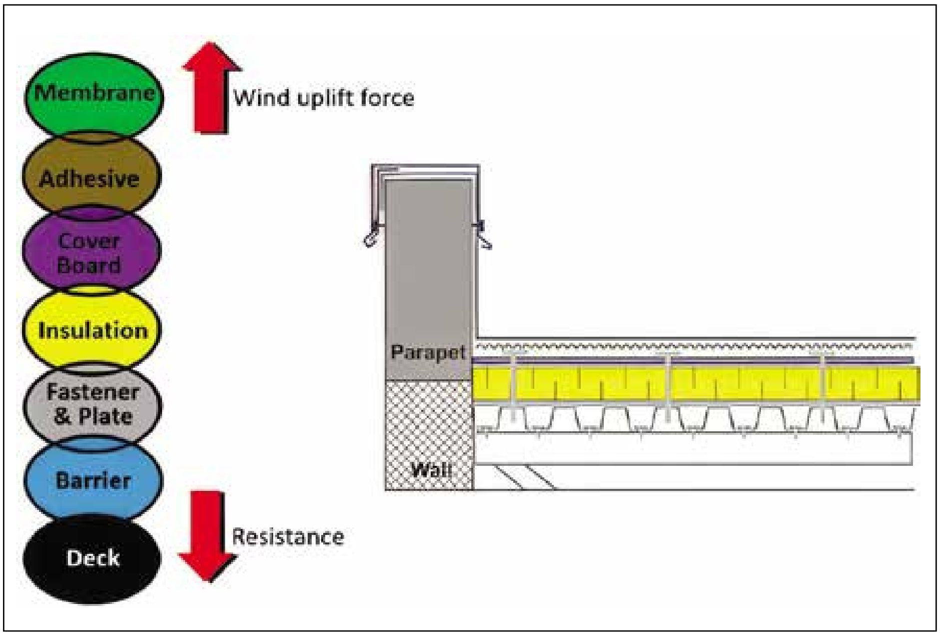

Figure 7. *Force resistance link diagram: partially attached (hybrid) membrane roofing system.*

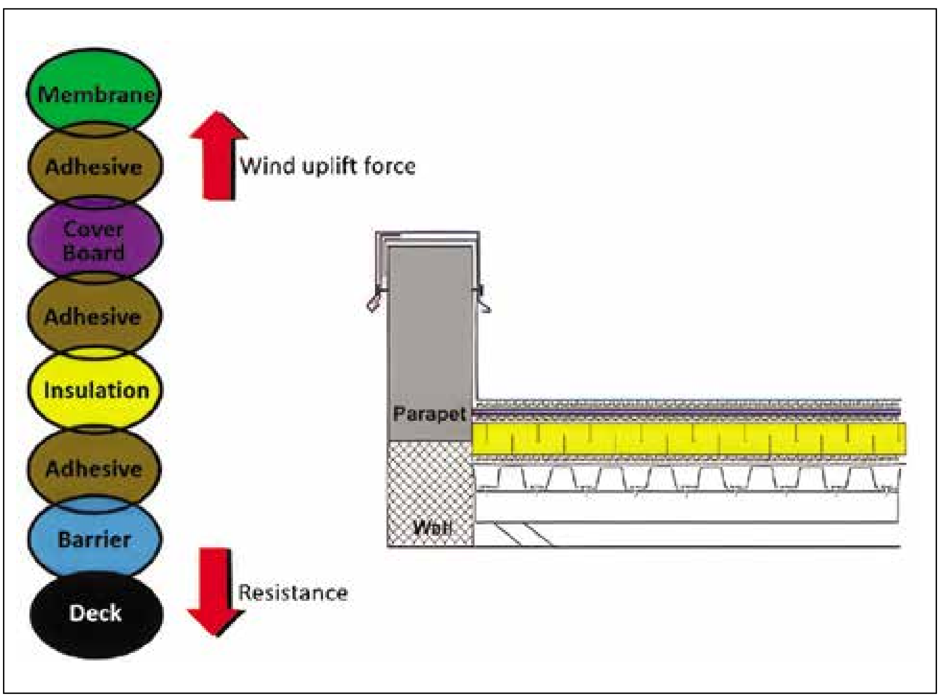

Figure 8. *Force resistance link diagram: adhesive applied membrane roofing system.*

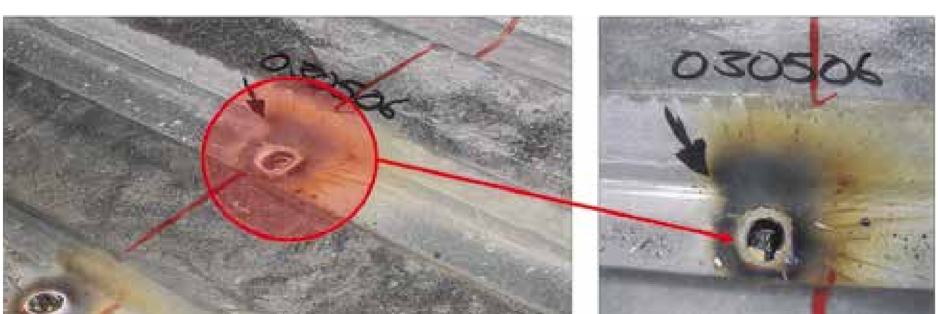

Figure 9. *Deck weld failure mode.*

the failure mode was determined to be due to the membrane fastener having pulled out from deck, as shown in **Fig. 10**. The second specimen was installed on 20 ga, 550 MPa steel deck and passed a sustained pressure of 8.62 kPa (180 psf).

Q7: WHAT IS THE ROLE OF MEMBRANE?

Common membranes are thermoset, thermoplastic, and MB. The membrane must have adequate strength to withstand the stress from wind uplift. The physical/mechanical properties of a membrane such as thickness and tensile strength vary from product to product depending on the chemical composition and the reinforcement materials. As shown in **Fig. 11**, the membrane was stretched around the fastener plates, leading it to pull out from the fastener plate; this is known as the "cookie cut" failure. In this case, the membrane was the weakest link for that roofing system. Replacing it with a thicker and/or higher tensile strength membrane will help to increase the wind uplift resistance of the system.

Membrane seam strength is an important parameter that influences wind uplift resistance in MARS. The seam must resist fluttering and pulling forces due to wind uplift force. Some manufacturers supply membranes with factory seams, but most of the manufacturers require seaming during construction. There are three different types of seam application methods for MARS. Thermoplastic membrane seams are hot-air welded by a robotic machine. Thermoset membrane seams have tape and/or adhesive. MB membrane seams are heat air welded. The SIGDERS research showed that using improper speed and temperature for hot/heat air welding results in a very weak seam, as shown in **Fig. 12**. Manufacturers have invented new seam application technologies such as self-adhered seam or torch-free seam in recent years, with claims that the new seam application technologies are better than the traditional methods.. Further research is needed to investigate the welding window (temperature and speed), the influence of ambient temperature to self-adhered seam and torch-free seams on wind uplift resistance.

For the MARS with thermoplastic membrane, there are two seaming techniques, one-side weld (OSW) and double-side weld (DSW), as shown in **Fig. 13**. The SIGDERS research showed the roofing system with DSW performed better than OSW. DSW system sustained a minimum of 15% higher wind uplift resistance than OSW system. The OSW system develops an asymmetrical force by pulling the bottom membrane. The fasteners

Figure 10. *Fastener pullout from the steel deck.*

Figure 11. *Membrane pullout from the fastener plate in mechanically attached roofing system.*

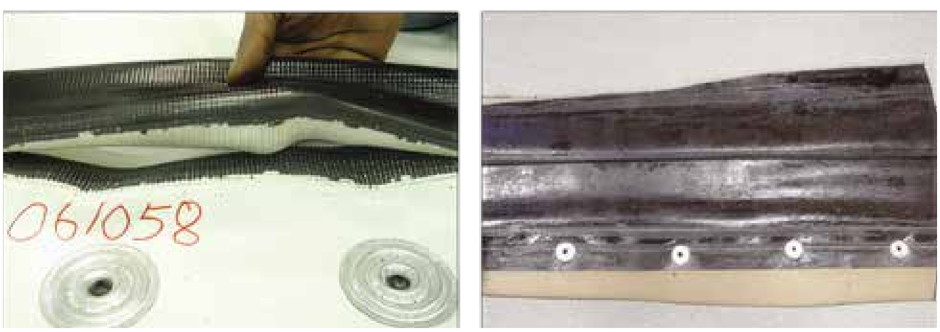

Figure 12. *Membrane seam failure.*

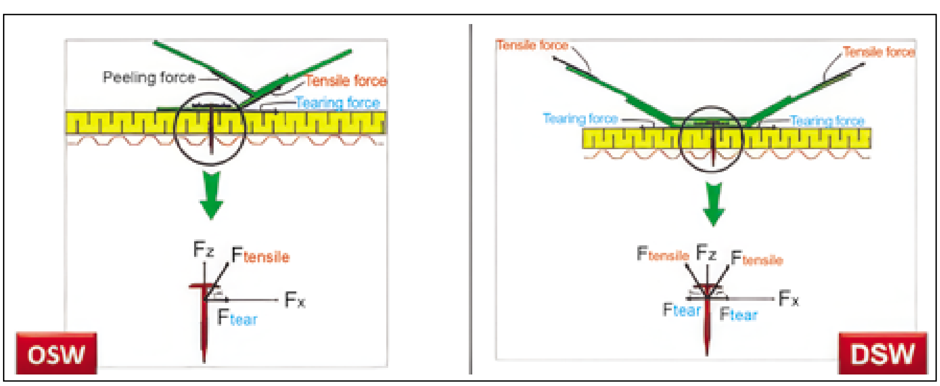

Figure 13. *One-side weld versus double-side weld for mechanically attached roofing system.*

are experiencing a single-direction wind load, which will rock the fasteners sideways and cause fatigue deformation at the steel deck/fastener engagement locations. This fatigue ultimately results in the fastener pullout from the steel deck. The DSW system develops symmetrical forces along the horizontal direction; this minimizes the rocking action on fastener.

The membrane width ranges from 1.83 m to 3.66 m (6 ft to 12 ft).The spacing between two fasteners on the seam is called fastener spacing, and the spacing between two rows of fasteners on the seam is called fastener row spacing. The recommended practice is to orient the fastener rows perpendicular to the steel deck flange, as shown in **Fig. 14**.

Q8: WHAT IS THE ROLE OF INSULATION/COVER BOARD?

In addition to the deck and membrane, insulation is also important substrate/roofing component in a roofing system. The primary function of insulation is to act as a thermal barrier for the roofing system. The cover board enhances the resiliency and durability of the system. It is installed below the membrane and above the insulation to minimize the deterioration of other components during the service life of the roof. Substrate should have sufficient compressive strength and pull-through strength. A weaker pull-through strength can cause a "cone cut" on the substrate board, as shown in **Fig. 15**. In the AARS and PARS, the membrane is adhered to the top surface of the insulation/cover board. The interface peel strength between the membrane and the substrate should be able to resist the shear forces created from the wind uplift force to avoid the types of failures shown in **Fig. 16**.

Q9: WHAT IS THE ROLE OF A VAPOR BARRIER (VB)?

A VB offers a certain resistance to airflow in addition to its primary function of limiting vapor diffusion into the roofing system from indoors. Based on SIGDERS research, systems' wind uplift resistance increased by 25% to 50% for systems with a VB than the systems without a VB, as shown in **Fig. 17**. The wind uplift resistance was varied depending on the air permeability of the VB and type of roofing system. Also, in the field, poly and kraft paper are more delicate materials that may not stand up to foot traffic, materials being dragged over them (puncture) and the effects of heat or solvents when the roof membrane is applied (assuming that there is a continuous connection between the VB and the membrane at the perimiter and openings). Self-adhered membranes with a tri-laminate facer, for example, will stand up to the rigors of the site activity better.

Q10: WHAT IS THE ROLE OF FASTENERS AND PLATES?

Accessories, fasteners, and plates are used to secure either the membrane or insulation or both to the structural deck.

Fastener/Deck Engagement: The fastener tip and thread design will determine the fastener pullout resistance (FPR) with

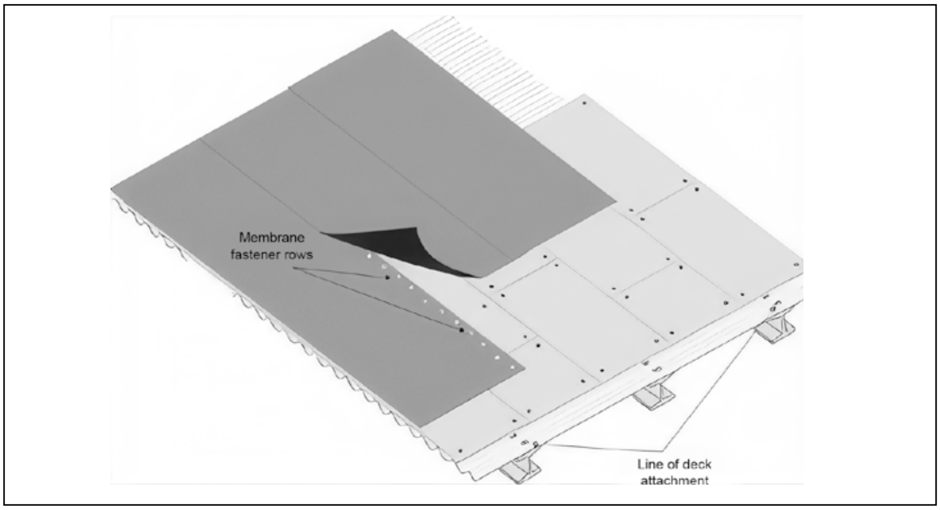

Figure 14. *Membrane fastener rows are perpendicular to the deck flanges.*

Figure 15. *Substrate pullout from the fastener and plate for a partially attached (hybrid) membrane roofing system.*

Figure 16. *Facer delamination failures for an adhesive applied membrane roofing system.*

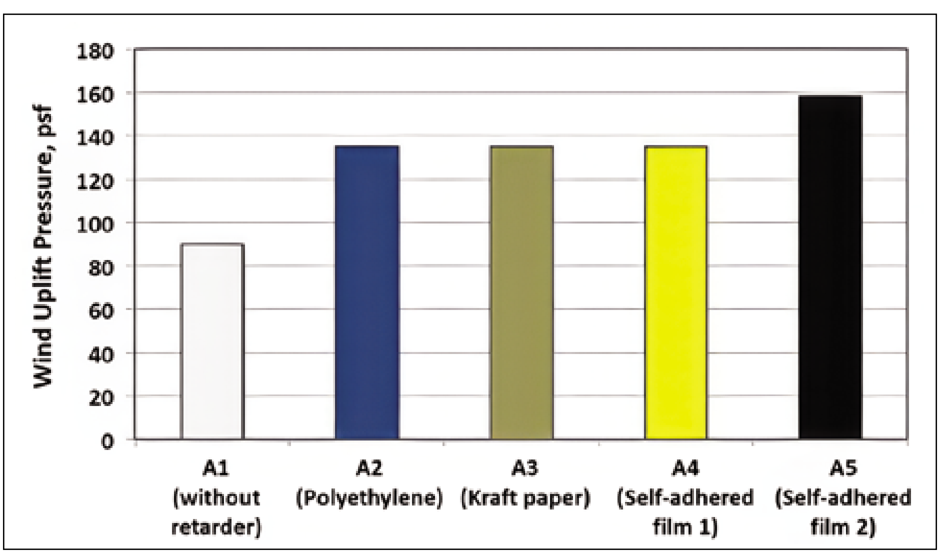

Figure 17. *Wind uplift resistance with different type of vapor barriers.*

respective deck engagement. **Fig. 18** shows three different fastener sizes along with the physical characteristics of the head, tip, and thread. **Fig. 19** shows plotted FPR data for five fasteners with four different types of decks. The data shows that the FPR is higher with a greater shank diameter, irrespective of the deck types. The data also shows that the FPR for two different sources with the same fastener type (#15 or #21) measured different values, respectively.

Fastener Plate/Membrane Engagement in a MARS: This engagement keeps the membrane in place. The barbed plates provide a better clamping force compared to smooth ones. The flat, smooth plate allows membrane slippage and tearing along the fastener shank, as shown in **Fig. 20** (left), even at low wind uplift pressures. At high wind uplift pressures, the barbed plate bends due to the membrane billowing and loses its clamping force; the membrane is stretched along the deformed plate portion, which results in the membrane being torn as shown in **Fig. 20** (right). If the membrane tensile strength was lower than the wind uplift load, the membrane would stretch and tear around the fastener plates.

Fastener Plate/Membrane Engagement in a PARS: The membrane is adhered to the top surface of the insulation. The insulation is secured to the deck with fasteners and plates. Based on SIGDERS research, systems with smooth-surface insulation plates increased the wind uplift resistance by 50% more than systems with textured insulation plates. **Fig. 21** illustrates the failure modes for different insulation plate configurations. Textured hexagonal plates offer the required contact area with the membrane only through the outer and middle rims of the plates. Smooth circular metal and plastic plates have a larger contact surface area to increase the bonding strength with the membrane.

Q11: WHAT IS THE ROLE OF ADHESIVE, ADHESIVE AMOUNT, AND CURING TIME?

Adhesive curing time is the key factor to determine the adhesive bond strength. The higher the adhesive bond strength, the better the wind uplift resistance. For a scenario tested by SIGDERS, a system failed below 2.87 kPa (60 psf) with 14 days of curing time. The system had a wind uplift resistance of 3.59 kPa (75 psf) with 21 days of curing time and a wind uplift resistance of 4.31 kPa (90 psf) with 28 days of curing time. The failure modes for 14, 21, and 28 days are adhesive failure between the cap and base sheet interface, a cohesive failure between the cap and base sheet interface, and the VB

Figure 18. *Physical characteristics of the fasteners.*

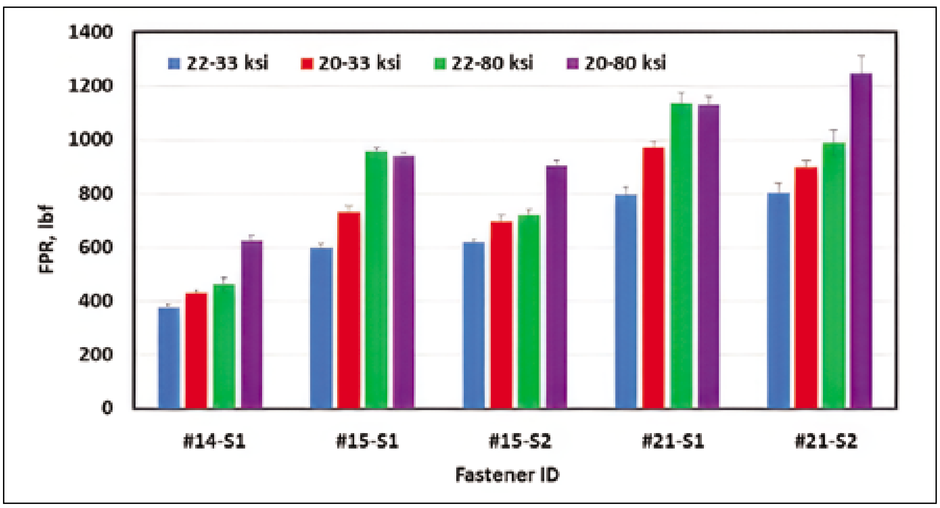

Figure 19. *FPR for different deck types.*

Figure 20. *Fastener plate/membrane engagement against wind uplift in mechanically attached roofing system.*

detached from the deck interface, respectively, as shown in **Fig. 22**.

Q12: IS THERE AN IMPACT OF AIR INTRUSION ON A LOW-SLOPE ROOF?

Air intrusion is when the conditioned indoor air enters into the building envelope assembly and cannot escape to the exterior environment with the roof membrane acting as an air barrier. Air intrusion can be a major driving force for movement of moisture in the form of water vapor into a MARS. **Fig. 23** showed the condensation happening below the roof membrane on one of the commercial roofs during field investigation. Limiting air intrusion is critical for good roof design practice, it helps increase wind uplift and thermal resistance, minimize moisture accumulation and condensation issues.

Based on SIGDERS's research, ASTM D7586, *Standard Test Method for Quantification of Air Intrusion in Low-Sloped Mechanically Attached Roof Assemblies*, was developed in 2011. A series of tests were carried out by the SIGDERS consortium to quantify air intrusion rate for a MARS. The result showed the system with a VB decreased the air intrusion volume by 50% to 80% depending on the bubble pressure (the pressure on the top of the insulation/cover board), membrane deflection, and volume change, as shown in **Fig. 24**.

Q13: WHAT ARE THE ATTRIBUTES OF A VEGETATED ROOF ASSEMBLY (VRA)?

In a VRA, a roofing system and a vegetated system are assembled together, as shown in Fig. 25. A roofing assembly consists of a deck and roofing or waterproofing membrane. It includes components such as vapor barriers or retarders, insulation, cover board, etc. A modular vegetated system consists of pre-grown or precultivated vegetation (modules, blankets, or mats), growth media, a root barrier, pavers, and a drainage system. In industry practice, a VRA is sometimes referred to as a green roof. However, the term "green roof" can be misleading because it can be interpreted differently, as follows:

- "Green roof" could be a reference to the color of the roof (e.g., a copper roof).
- "Green roof" is used loosely to denote roofs with environmentally friendly products such as those made from recycled materials (e.g., bio-based insulations).
- Roofs with energy-efficient components such as highly reflective roofing membranes (e.g., white single plies or MB roof with reflective coating).

Based on this, a VRA is defined as intentional placement of an engineered vegetated system over the roof system (**Fig. 25**).

Q14: HOW DOES A VRA RESPOND TO WIND?

Wind aerodynamics on a VRA can be viewed as action, whereas the response of the VRA is the reaction. Not all VRAs react to wind in a similar manner. The response of a vegetated system depends on several factors, such as the membrane attachment method, vegetation type, weight, design, and installation method (e.g., edge restraint conditions). The complex wind dynamics on VRAs can be simplified as effects due to pressure and flow. Responses of the vegetated system to flow include sliding, overturning, and scouring (**Fig. 26**). Responses of the vegetated system to wind-induced pressure include fatigue and uplift.

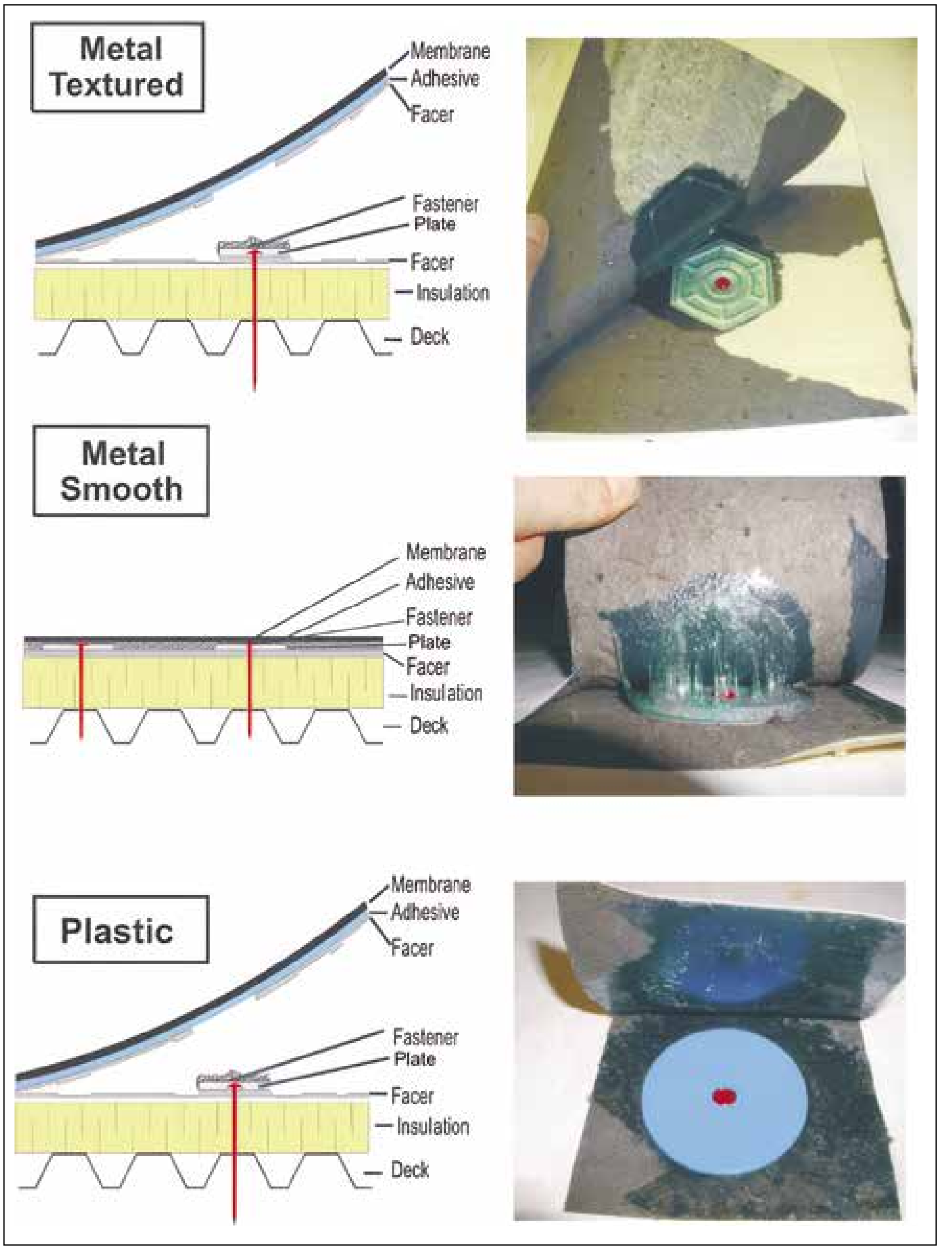

Figure 21. *Failure modes observed with different insulation plate configurations in partially attached (hybrid) membrane roofing system.*

Q15: IS THERE A TOOL OR STANDARD AVAILABLE TO VALIDATE MY VRA DESIGN?

The wind uplift resistance of the VRA can be evaluated in accordance with CAN/CSA A123.24, *Standard Test Method for Wind Resistance of Vegetated Roof Assembly*. The test results can be compared to the calculated design parameters in Q4 above for pass/fail scenarios.

Q16: WHY ARE VRAS SUBJECTED TO UPLIFT AND FLOW RESISTANCE TESTS?

An uplift test only evaluates the pressure resistance of the VRA, since the membrane acts as an air barrier in a conventional roofing system. Wind flow aerodynamics can simulate the vegetated system's overturning, scouring, and sliding failure mechanisms. To mimic the wind effects on the VRA (refer to Q14), both uplift and flow testing are needed.

Q17: CAN I USE THE WIND UPLIFT DATA FROM A ROOF SYSTEM TEST?

Yes, in a scenario where the VRA has the same roofing system as the one tested under CAN/CSA A123.21, *Standard Test Method for the Dynamic Wind Uplift Resistance of Mechanically Attached Membrane-Roofing Systems*, the manufacturer or client may choose to use the uplift resistance data obtained from CAN/ CSA A123.21. Then the manufacturer or client has to perform only the flow test as per Section 7 of CAN/CSA A123.24 to obtain the flow resistance.

Q18: WHAT ARE THE TYPICAL COMPONENTS OF AN ASPHALT SHINGLE ROOFING (ASR)?

Residential roofs utilize different material coverings such as metal, tile, and shingles. Asphalt shingles are used on almost 90% of Canadian residential roofs because of their affordability, ease of installation, and adaptability. Residential roof is composed of four major components: asphalt shingle, underlayment, wood sheathing and insulated attic (**Fig. 27**). In addition, accessories such as vents, sealant, nails, and eave protection also form part of the ASR.

Q19: ARE THERE ANY MISSING LINKS IN THE CURRENT CODE?

The current code does not address the following:

- There is no guide for specifiers to have their design meet or exceed the specified wind loads.
- There are no specific climate requirements for materials. The code only provides generic loads that materials are expected to perform against.
- There is no climate adaptation of future loads.
- The code does not provide material installation requirements.

Q20: HOW TO CLASSIFY THE FUTURE CLIMATIC CONDITIONS BE QUANTIFIED?

As mentioned in Q1, there is a tool available named Climate-RCI that calculates the design load by accounting for future climatic conditions. It can be accessed at https://nrc.canada.ca/en/research-development/products-services/software-applications/climate-rci.

Climate-RCI has been developed by NRC. It takes into account projected changes in weather elements (wind, rain, and temperature) and provides the design loads for 696 cities across Canada. The climatic loads are classified into three climate zone severity classes: normal, severe, and extreme. This tool also forms part of CSA A123.26, *Performance Requirements for Climate Resilience of Low Slope Membrane Roofing Systems*.

Q21: CAN FUTURE WEATHER SHOCKS BE MODELLED FOR ROOFING AND OTHER BUILD-ING ENVELOPE MATERIALS?

Based on discussions with the industry, a framework was developed using future

Figure 22. *Failure modes varied with curing time for an adhesive applied membrane roofing system.*

Figure 23. *Condensation below the roof membrane.*

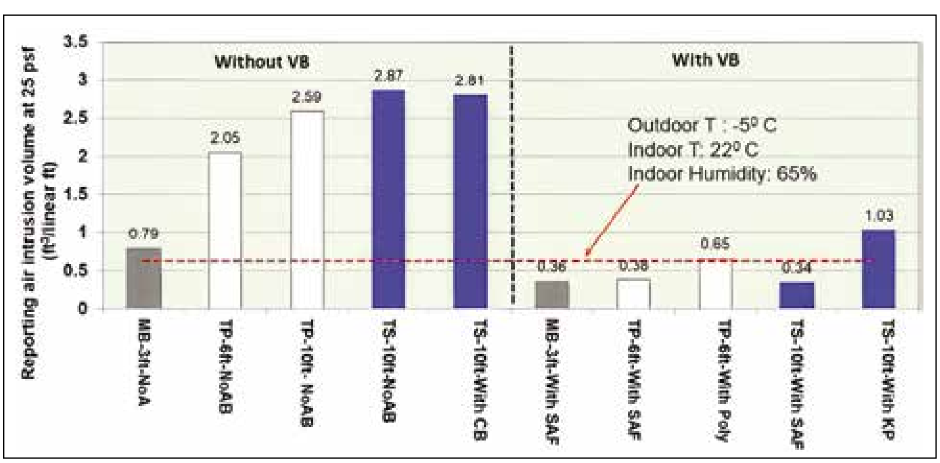

Figure 24. *Air intrusion volume with and without the vapor barrier.*

climatic loads and how to incorporate them into the experimental methodology. Initially, hourly temperature time series available for 564 locations across Canada were analyzed for hourly fluctuations. The data available for these locations spanned 10 to 20 years, with the majority of the locations having 15 years of data available. A threshold value of 5°C was chosen to identify the instances of hourly fluctuations above the threshold. The number of these cycles per year obtained from the time series were fit to a Poisson distribution (probability of exceedance is 2%), and the number of cycles for 50-year return periods was determined. For the analyses, the period from May to August was considered summer, during which a hot-weather shock would occur, and the period from December to March was winter, during which a cold-weather shock would occur. The above is summarized in **Fig. 28**.

The hot-and cold-weather shock values are initially obtained based on air temperature. The surface temperature that a roof component will reflect under a specific air temperature will differ based on the component and its position within the system. That is why there is a need to establish the relationship between the component temperature and the air temperature.

Thereafter, the hot- and cold-weather shocks the component will be experiencing in a scenario of 2°C global warming magnitude can be determined. This framework can be followed for all building envelope components and is not limited to roof components. As well, the parameters can be established for other global warming magnitude ranges from 0.5°C to 3.5°C.

Q22: CAN I APPLY WEATHER SHOCK PARAMETERS FOR DURABILITY EVALUATION OF ROOFING COMPONENTS?

Materials are currently evaluated at lab temperatures. Materials age and deteriorate differently when they experience weather shock cycles. Using the information from the framework in **Fig. 28** the hot- and cold-weather shock component temperatures and their respective number of occurrences are determined. Also, to replicate the cycling that already naturally occurs with the change in seasons, the hot- and cold-weather shocks were alternated. An important step for incorporating the weather shock framework into testing is the duration of the hot and cold cycles to ensure practicality of the experiments. An example of how this can be achieved is by setting a practical duration of the entire weather shock cycle and adjusting the

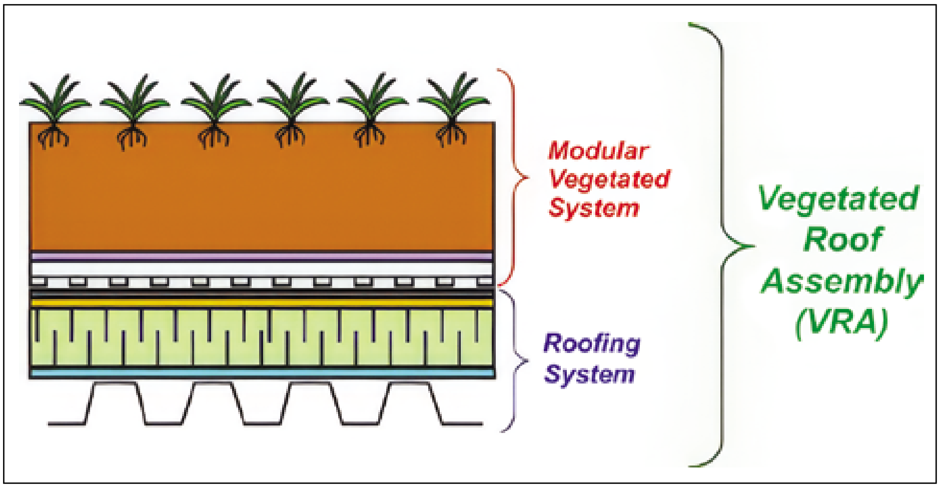

Figure 25. *Roofing system and vegetated system assembled together to form the vegetated roof assembly.*

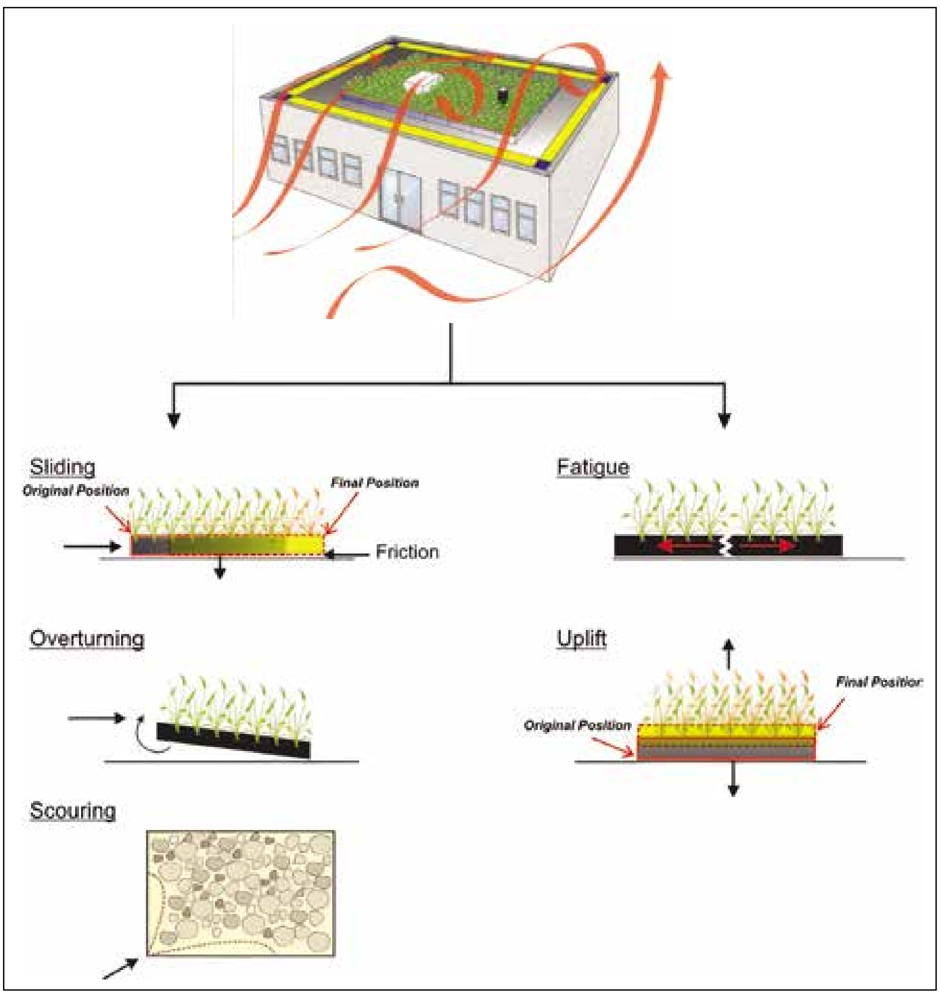

Figure 26. *Wind aerodynamics and failure mechanisms of a vegetated roof assembly.*

duration of each cycle. This must be achieved while ensuring that the total number of fluctuations for hot and cold weather shocks is maintained. An example of a dark-colored roof covering (asphalt shingle) is shown in **Fig. 29**. The hot- and cold-weather shock cycle has a total duration of 15 days. Within each day there are 8 hot- and 6 cold-weather shock cycles. The duration of 15 days, along with the breakdown of 8 hot and 6 cold cycles a day and the duration of each cold and hot cycle, can be changed to better reflect the building envelope material being evaluated. An asphalt shingle will not absorb and retain heat in a similar manner to a beige wall siding. Therefore, the factors that must be respected when determining the composition of the cycles are:

- The cold and hot component weather shock temperatures
- The number of weather shock occurrences

Q23: CAN A CLIMATE-DEPENDENT DURABILITY INDEX (CDDI) BE DEVELOPED FOR ROOFING COMPONENTS?

By taking asphalt shingles, for example, the CDDI can be explained as follows. Shingle composition and behavior are complex, and attributing performance once installed as part of a system to an individual property is difficult and inadequate. Developing a science-based indicator that would combine key properties with the exposed climate severity of the material may provide a more comprehensive indicator of the material's long-term performance. The CDDI was developed to accomplish this. The CDDI combines five critical properties: tear strength, overlap strength, fastener pull-through, tensile strength, and granule loss.

For each of these properties, the durability factor and importance factor are calculated. The durability factor depends on the property's reduction in strength after exposure to the climate zone-dependent weather shock protocol. If a property is greatly reduced, that is an indication that the durability of the shingle is low. The durability factor ranges from 0 to 3. A durability factor of 0 is corresponds to reduction in strength greater than 45%, and durability factor of 3 is corresponds to reduction in strength less than 5%. A higher durability value indicates a more durable shingle. The importance factor is assigned to each of the five critical properties based on the mode of field failures and industry consensus. The importance factor for each property is greater than zero but less than 1, as follows: tear = 0.2; overlap strength = 0.3; fastener pull-through = 0.2; tensile = 0.1; and granule loss = 0.2. By combining the durability factor and the importance factor for each of the critical properties, one can determine the classification level of CDDI, which can be either silver (CDDI greater than 2 and less than 3) or gold (CDDI = 3).

Q24: WHAT IS THE IMMEDIATE NEED FOR COMMERCIAL ROOFING?

Alterations to existing roofs (AER) have a major market share compared to new construction. In some regions of North America, AER market share is over 70%. AER includes, but is not

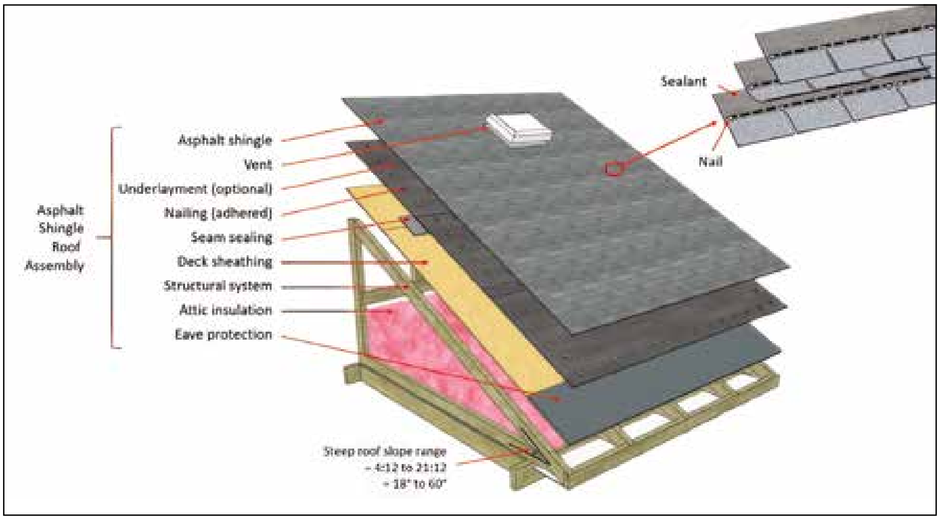

Figure 27. *Typical components of Asphalt Shingle Roofing (ASR).*

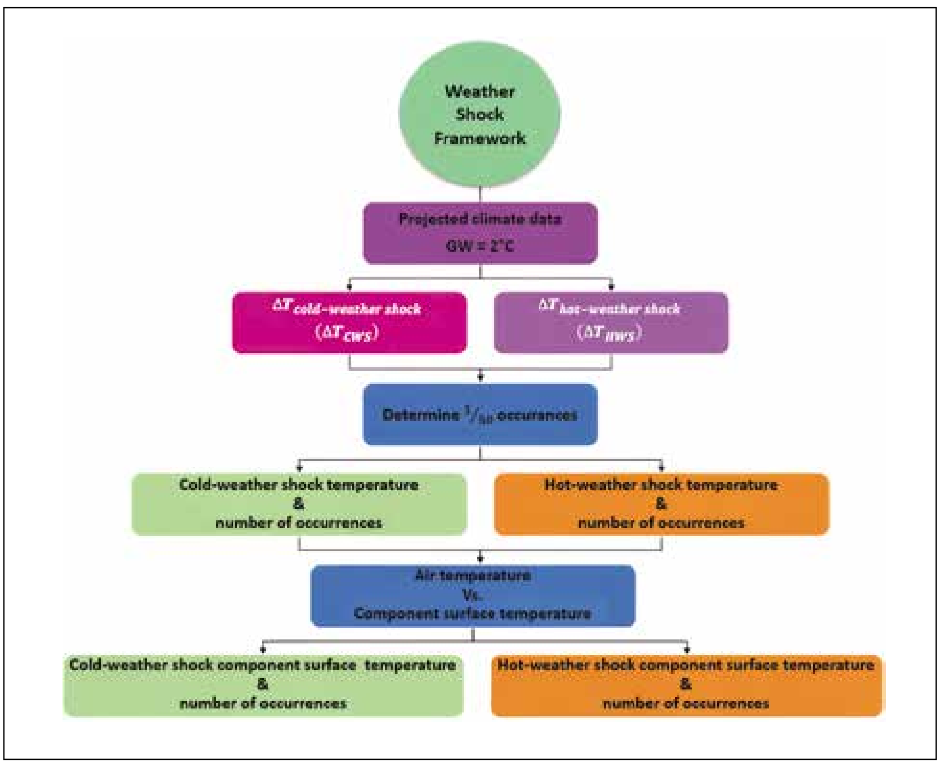

Figure 28. *Weather shock framework.*

limited to, reroofing, resurfacing, recovering, and upgrading for energy efficiency and high wind events.

Unfortunately, as a roofing community, there is no consensus in the terminology. Moreover, existing limited code specifications are misunderstood due to variations in the terminology at various levels. The NRC is undertaking a nationwide consultation process to gather the state of the current design practice. One of the main objectives of this consultation is to develop building code requirements. Both current climatic and future climatic conditions will be considered. A framework is presented in **Fig. 30**.

Q25: AS A ROOFING COMMUNITY, HOW CAN WE PLACE THE BUILDING OWNER IN THE "SWEET SPOT"?

A holistic approach is proposed so that the building owners enjoy the "sweet spot." Basically, there are three requirements that need to be collectively integrated, including:

- **Load** specification accounting for future climatic conditions
- **Resistance** evaluation through testing incorporating the climatic load
- **Installation** with quality assurance metrics

Figure 31 illustrates that when the three requirements are combined, then the sweet spot is achieved. The sweet spot indicates the shared segment of load, resistance, and installation. The bigger the sweet-spot segment, the longer the service life of roofing assemblies.

CLOSING REMARKS

This paper presented selected accomplishments of the ongoing roofing consortia at the NRC. The Q&A format has been used to address the wide range of topics. Over the last 20 years, most of these developments have been presented at the annual IIBEC conventions, for which the author is

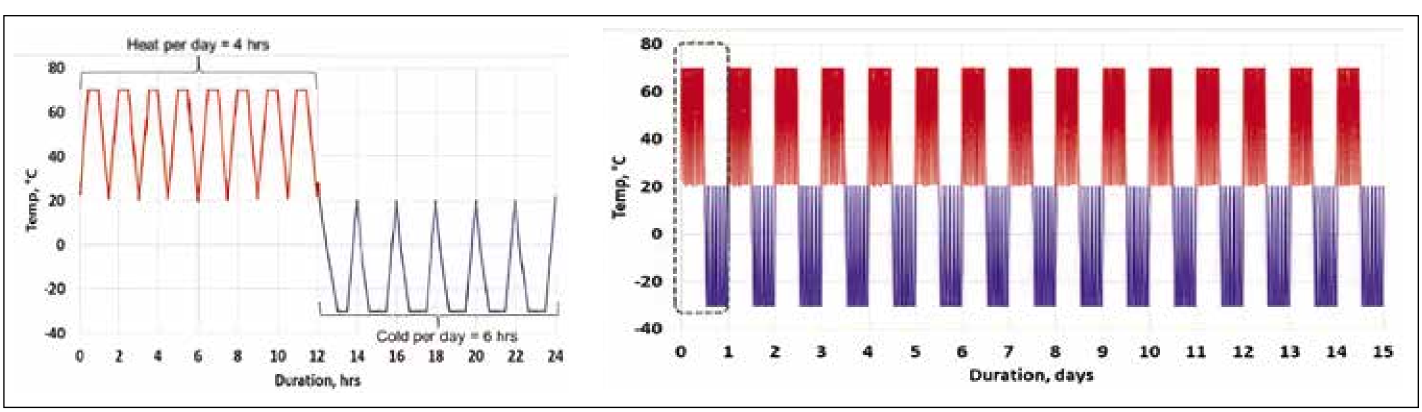

Figure 29. *Example of the application of the hot- and cold-weather shock for a dark-colored roof covering.*

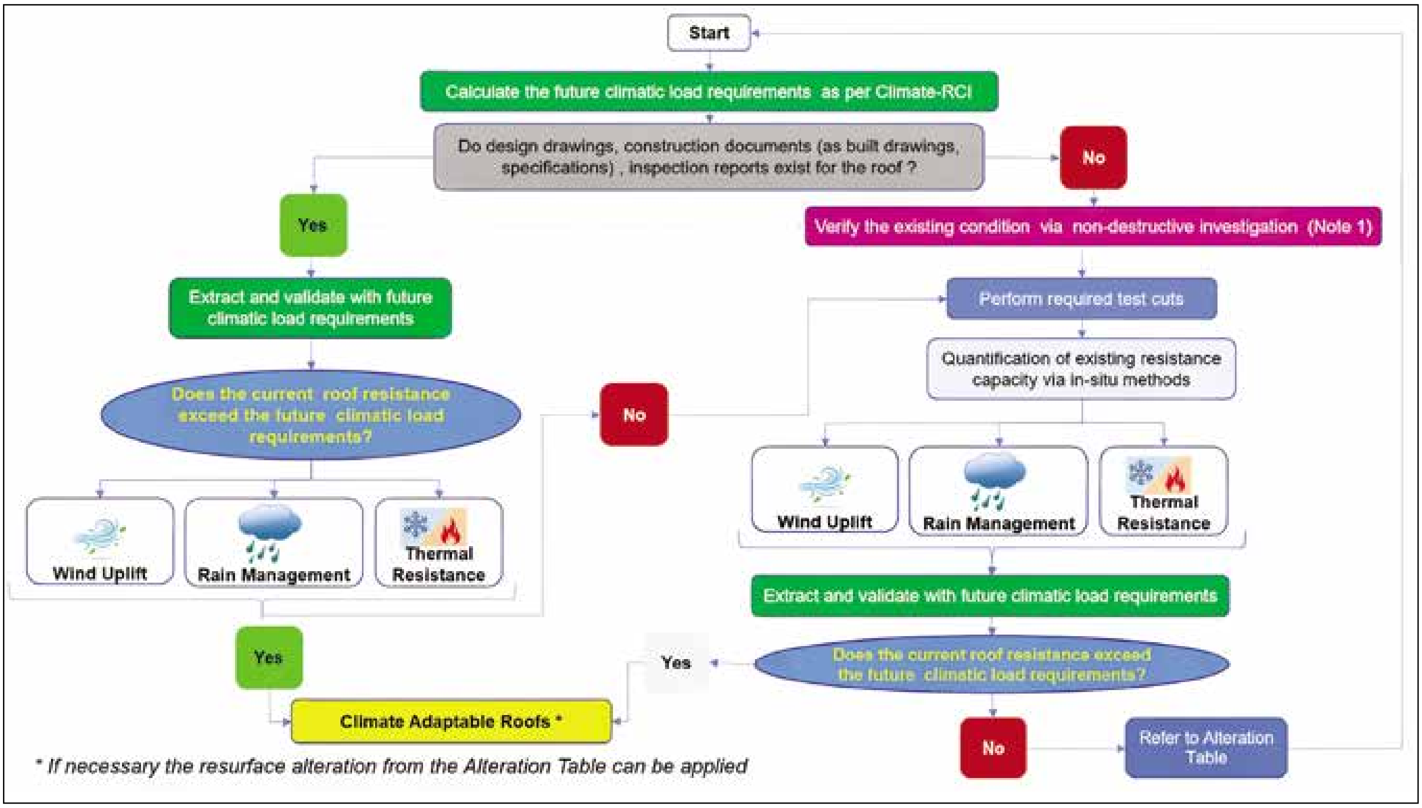

Figure 30. *Framework for climate-adaptable roofs.*

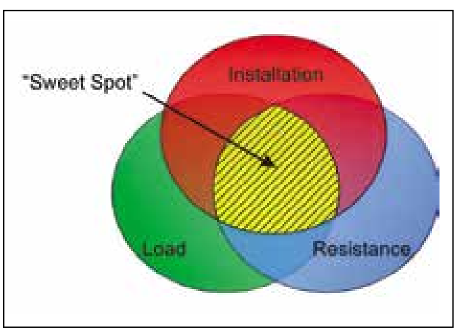

Figure 31. *Holistic approach for climate adaptation requirements of roofs.*

grateful for. This long-lasting industry consortium has published over 100 peer-reviewed publications. Readers who would like to get additional details or data for any of the questions or topics are requested to email the author.

DEDICATION

The author would like to dedicate this paper to James "J.P." Sheahan, who introduced the author for the first time at the IIBEC convention, and Katharine Spavins for her continued welcome to IIBEC.

ACKNOWLEDGEMENT

The author extends heartfelt appreciation and sincere gratitude to the esteemed members of SIGDERS:Atlas Roofing Corp., Canada Post Corp., Canadian Sheet Steel Building Institute, Canadian General Tower Ltd., Canadian Roofing Contractors Association, Carlisle SynTec Systems, Cemfort Inc., Chem Link, Department of National Defence, DuPont Performance Building Solutions/Dow Roofing Systems, Duro-Last Roofing Inc., Element, Elevate/Holcim/Firestone Building Products Co., EXP, GAF Materials Corporation, Genflex Roofing Systems, IIBEC/RCI Inc., IKO Industries Canada, Industrial Risk Insurers, ITW Buildex, Johns Manville Corporation, JPS Elastomerics Corp./ Stevens Roofing Systems, National Roofing Contractors Association, OMG Roofing Products, Polyglass, Prospex Roofing Products Ltd., Public Works and Government Services Canada, Rockwool/ Roxul Inc., Roofing Contractors Association of British Columbia, Sika Sarnafil/Sarnafil, Soprema Canada Inc., Target Corp., Tremco Inc., Trufast Corporation/Altenloh, Brinck & Co., and Vicwest Steel.

Their valuable insights, collaborative spirit and unwavering support throughout the project have played a significant role in the successful completion of this publication.

ABOUT THE AUTHOR

BAS BASKARAN, F-IIBEC, PENG, PHD

At the National Research Council of Canada, **Bas Baskaran,** *F-IIBEC, PEng, PhD is researching the wind effects on building enclosures through experiments and computer modeling. As an adjunct professor at the University of Ottawa, he supervises graduate students. As a professional engineer, he is a member of various committees and is a research advisor to various task groups of the National Building Code of Canada. He has authored and/or co-authored over 300 research articles and received over 25 awards. Baskaran was recognized by Her Majesty Queen Elizabeth II with the Diamond Jubilee medal for his contribution to fellow Canadians.*

Please address reader comments to chamaker@iibec.org, including "Letter to Editor" in the subject line, or IIBEC, *IIBEC Interface*, 434 Fayetteville St., Suite 2400, Raleigh, NC 27601.