

A Framework to Determine a Climate-Dependent Durability Index for the Building Enclosure

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BUILDING ENCLOSURE COMPONENTS are exposed to extreme weather shocks. Currently, component properties are measured based on existing standards. The majority of standards account for neither the occurrences of weather shocks nor variations in the climate zones. The development of a protocol combining the measured properties of the building enclosure components with the climate severity can provide a single attribute as an indicator of the component's long-term performance. To address this, a climate-dependent durability index (CDDI) framework is developed and presented in this article.

BACKGROUND

In Canada, design loads for the building enclosure are calculated in accordance with the *National Building Code of Canada* (NBCC), utilizing climatic loads determination.¹ The data listed within the NBCC are based on historical observations gathered 10 to 54 years before 2010. These data do not account for future climatic conditions for Canadian cities or for the effect of weather shocks on the components and systems. Extreme weather events are becoming more frequent, intense, and longer due to climate change. These events lead to weather shocks, which can adversely affect the expected performance of the exposed building enclosure components and systems. Weather shocks are occurrences of rapid and significant temperature variations, such as a hot summer day followed by sudden rain and a drop in temperature, or a cold winter day followed by a sudden increase in temperature. **Figure 1** shows two examples of weather shocks.

The National Research Council of Canada (NRC) developed a protocol outlined in CSA A123.26, *Performance Requirements for Climate Resilience of Low Slope Membrane Roofing Systems*,² to account for future extreme climatic loads in the design and construction of roofs.³ In this paper, weather shocks account for sudden unexpected weather events, where the number of occurrences

and magnitude are determined based on the future extreme climatic conditions.

These future climatic loads for main weather parameters such as wind, rain, and temperature can be found on the web-based tool Climate-RCI for a range of global warming magnitudes from 0.9°F to 6.3°F (0.5°C to 3.5°C).⁴ Based on the future climatic data, NRC is now addressing the effect of weather shocks as part of their recent Climate Resilient Built Environment Initiative.

These weather shocks can cause deterioration of a building enclosure's components, and when they occur in an increased and accelerated manner, it can lead to strength reduction and rapid deterioration of components and systems.

Establishing weather shock parameters is important because it allows development of an experimental protocol to simulate weather shock phenomena in controlled laboratory conditions. This facilitates the evaluation of how weather shocks affect components and their subsequent impact on systems.

The effect of weather shocks will be different for various components of the systems. The components that are exposed to the weather elements will behave differently compared to those that are not. Thermal expansion and contraction of components at different rates and the subsequent stresses placed on the materials can lead to breakage and cracks due to the induced tension on the material. Under such conditions, the exterior enclosure components can dislodge at the junctions or at the penetrations, and fasteners may protrude at the attachment locations. Damage is more likely

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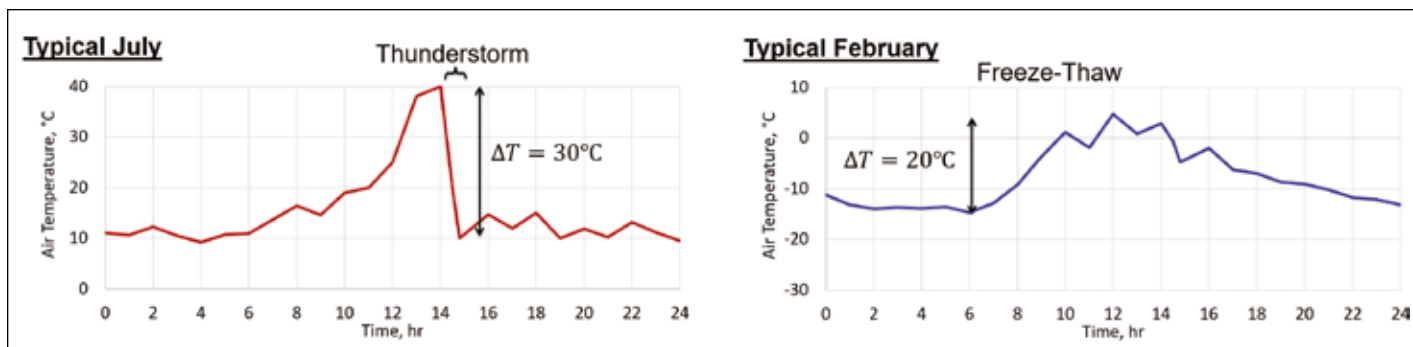


Figure 1. Typical hot and cold weather shocks.

to occur near penetrations where materials with very different compositions can be found.

While the issue of stresses created within the components due to the change in temperature is one that has been previously studied, with climate change, temperature (and consequently its fluctuation) is expected to be greater and more frequent. Therefore, developing a framework for how to determine the weather shock parameters and incorporate them into testing methodologies is critical to establishing the durability characteristics of the building enclosure components and systems.

Additionally, it is important to note that the weathering of components and the impact of thermal fluctuations can also significantly decrease the performance of the system. Evaluations of individual components do not adequately address system performance.

DEVELOPMENT OF A WEATHER SHOCK PROTOCOL

A framework was developed by using future climatic loads provided by Environment and Climate Change Canada and incorporating them into the experimental methodology.⁵ This framework, a weather shock protocol, can be applied to all building enclosure components and is not limited to roof components. Similarly, this protocol can be expanded to all weather elements. However, as stated in the introduction, this article focuses on main weather parameters such as wind, rain, and temperature.

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 9°F (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 was fit to a Poisson distribution (probability of exceedance is 2%), and the number of cycles for 50-year return

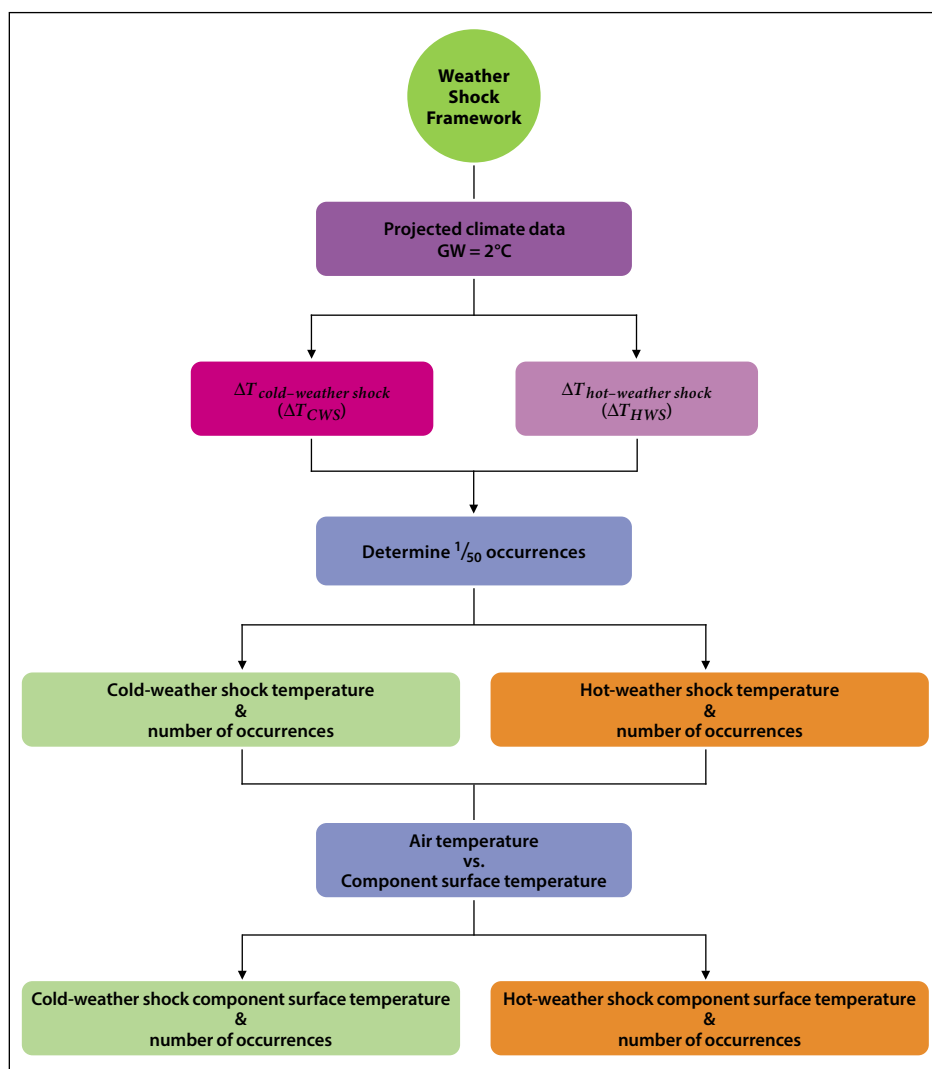


Figure 2. Weather shock framework summary. Note: GW = global warming. °F = (1.8×°C) + 32.

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. 2, assuming global warming magnitude as discussed in the introduction of this article.

The hot and cold weather shock values are initially obtained based on the air temperature. The surface temperature that a building enclosure component will achieve under a specific air temperature will differ based on its color, material composition, and position within the system. For example, the surface temperature of a darker-colored shingle can vary

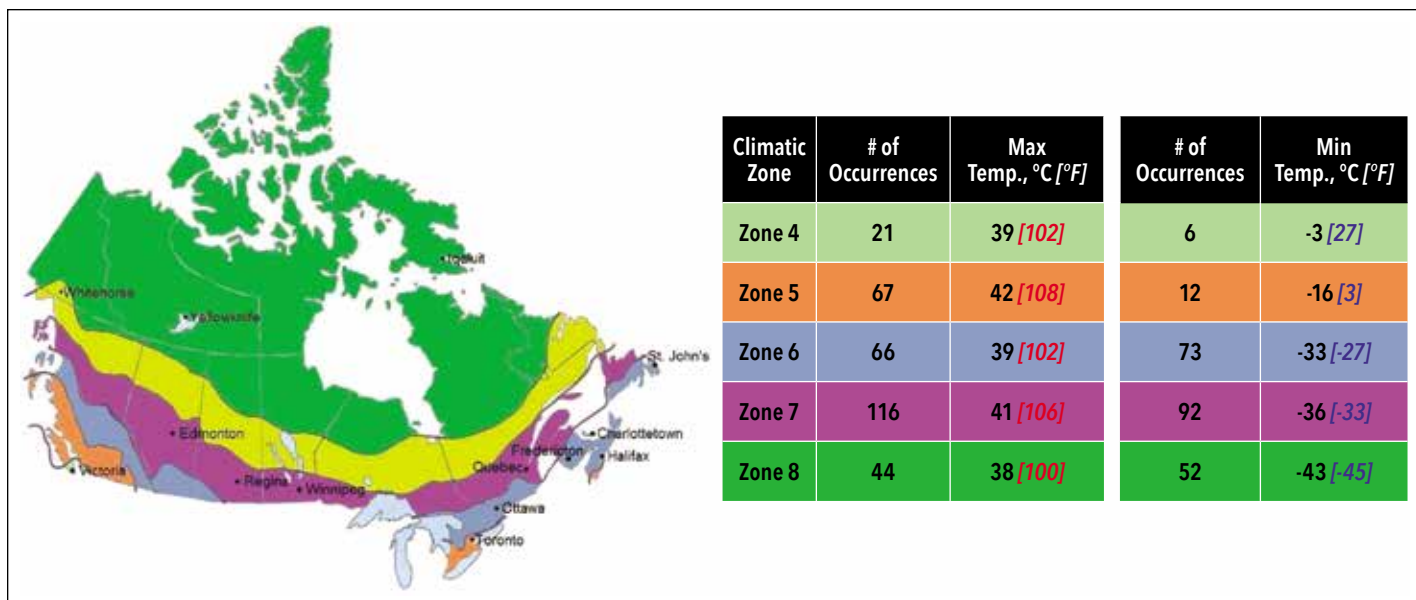


Figure 3. Climate zone map of Canada⁵ and weather shock data.

from that of a lighter-colored one with the same ambient temperature, and that has been taken into consideration by this article. The thermal changes can vary significantly depending on the color of the shingle.

Also, initially, only materials or components that are exposed to exterior weather elements are the focus of this article. That's why, in Fig. 2, establishing the relationship between the component surface temperature and air temperature is required. Thereafter, the hot and cold weather shock that the component will be experiencing in a scenario of 3.6°F (2°C) global warming magnitude is determined. As well, the parameters can be established for other global warming magnitudes ranging from 0.9°F to 6.3°F (0.5°C to 3.5°C).

INCORPORATION OF WEATHER SHOCKS INTO EXPERIMENTAL METHODOLOGY

The summary of the weather shock results for all the climate zones of Canada is shown in Fig. 3. For the framework, the concentration was on the maximum temperature for the hot weather shock to establish the worst-case scenario. Similarly, for the cold weather shock, the minimum temperature was considered. For a 50-year return period, the number of events is determined for the hot and cold weather shocks. For example, in the case of the Zone 6, there are 66 occurrences of hot cycles with a maximum temperature of 102°F (39°C) for a design return period of 50 years. Additional discussion on the development of weather shock parameters can be found elsewhere.⁵

Alternatively, the weather shock data can also be visualized using the existing climate zone map of Canada, as shown in Fig. 3. Zones 7A and 7B are combined for simplicity and have the highest number of weather shock occurrences for both the hot and cold weather shocks.

APPLICATION OF WEATHER SHOCK PARAMETERS

A weather shock protocol is demonstrated by taking a dark-colored asphalt roofing shingle as an example. For the dark-colored asphalt shingle, the component surface temperature was determined to be twice that of the air temperature.^{1,2,6,7} Note that dark-colored materials generally absorb more heat than light-colored materials. Using this information and following the framework, in Fig. 2, the cold and hot weather shock component surface temperatures and their respective number of occurrences are determined. Since the materials are currently evaluated at lab temperature, that temperature was maintained as the baseline. Also, to replicate the cycling that already naturally occurs with the change in seasons, the hot and cold weather shocks were alternated. Table 1 summarizes a weather shock protocol for dark-colored asphalt shingles.

An important step for incorporating the weather shock framework into routine lab testing is the determination of the hot and cold cycle's duration. During this, one should also account for the working hours to ensure the practicality of the experiments. One way to achieve this is by setting a practical duration for the entire weather shock cycle and adjusting the duration of each cycle accordingly. This approach must be achieved while ensuring that the total

number of fluctuations for hot and cold weather shocks is maintained.

The testing protocol for these conditions is detailed in Table 1. For example, in Zone 6, the weather shock protocol spans 21 days. Figure 4 depicts a typical daily profile for Zone 6, featuring four hot shocks and four cold shocks per day. The target temperature for a hot shock cycle, representing the asphalt shingle surface temperature, is twice the maximum air temperature. Specifically in Zone 6, with an air temperature of 102°F (39°C), the surface temperature of dark-colored asphalt shingles can reach 172°F (78°C).

Rainfall events are simulated in between hot cycles. A 5-minute rain event at a flow rate of 4.0 to 5.3 gal./min (15 to 20 L/min) is incorporated into the protocol during the hot shock cycle. This procedure is repeated for two hot shocks per day, except in Zone 8, where the rain event occurs only once a day.

DEVELOPMENT OF A CLIMATE-DEPENDENT DURABILITY INDEX (CDDI)

Building enclosure component properties are quantified based on standard test methods. For asphalt shingles, the most common residential roof covering, CSA A123.5⁸ or ASTM D3462⁹ provides specifications for the requirements of the standard properties (tear, tensile, and fastener pull-through [FP]). They are not test methods; rather, they reference various test methods depending on the property determination. The referenced test methods fail to address the changes in the properties due to weather shocks. These test methods can be used before and after

Table 1. Weather shock exposure requirement depending on Canadian climate zones

Parameter	Zone 4*	Zone 5	Zone 6	Zone 7	Zone 8
Hot shock target (HS_T), °C	78	84	78	82	76
Cold shock target (CS_T), °C	-3	-16	-33	-36	-43
Number of hot shocks per day	4	5	4	4	1
Number of cold shocks per day	1	1	4	3	1
Duration of weather shock, days	7	14	21	35	49
Duration of hot shock (T_{HS}), min	233	210	210	233	660
Duration of cold shock (T_{CS}), min	30	30	30	30	660
Duration of transition (T_T), min	30	30	30	30	30

*180 min of temperature hold at 23°C shall apply to Zone 4 at the beginning of each day

Note: °F = (1.8×°C) + 32

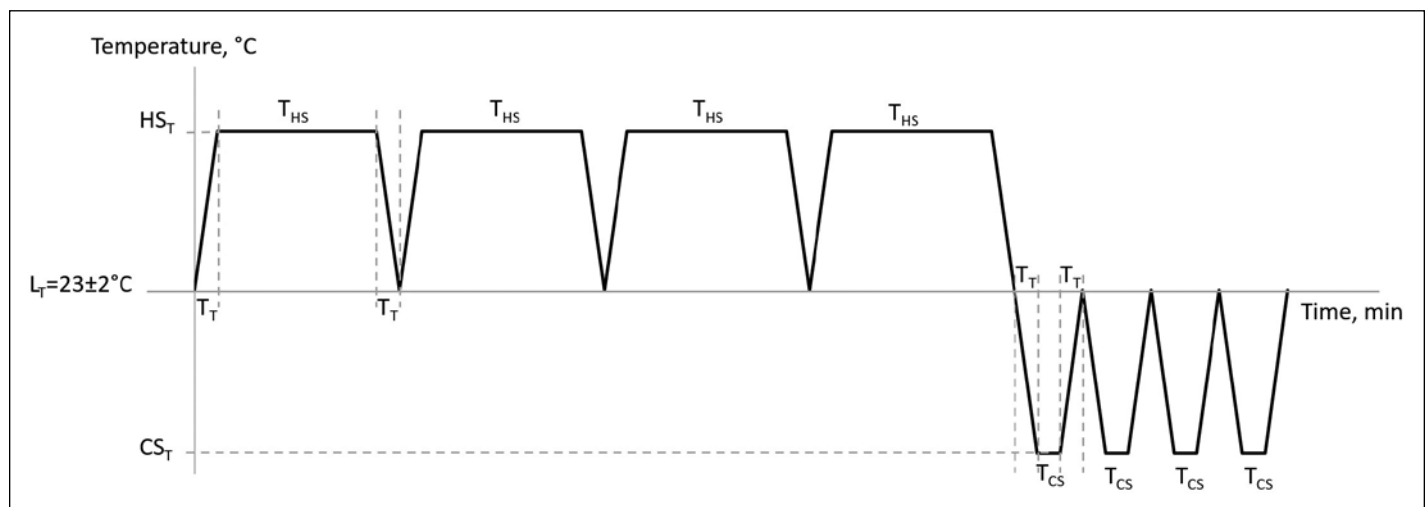


Figure 4. Daily weather shock protocol for Zone 6 for a dark-colored roof covering.

a shingle has been subjected to a weather shock. Also, these test methods are designed for the evaluation of products as manufactured. ASTM D3462 specifies that “physical and performance requirements after application and during in-service use of the products are beyond the scope of this material specification.” In addition, the measured properties (tear, tensile, and FP) are critical for the quality control determination in the manufacturing process and standard designations on the product labeling. On their own, none of these properties can provide an indication of the roof covering’s life-cycle performance nor how it relates to the end user’s (homeowner’s) decision to purchase a particular product. For example, the existing wind classifications (Class A, B, C, D, or F) of shingles are based on the static wind velocity test.

This creates a need for a science-based indicator to determine the long-term

performance of shingles for various Canadian climate zones. A protocol combining the measured properties of the shingle with the climate severity may provide a single attribute as an indicator of the shingle’s long-term performance.¹⁰ To address this, a framework for the development of a climate-dependent durability index (CDDI) is presented. The CDDI encompasses all measured properties that are evaluated, and it also includes deterioration due to weather shocks. Each of the properties can contribute to shingle durability and be assigned an importance factor. The importance factor can be assigned in relation to the corresponding impact each property has on shingle fragility. Investigations of field failure modes after major weather events can also provide a professional indication of which property can minimize the weakest links in the resistance chain. In general terms:

- Consider a shingle from a source (S1) and its measured properties as manufactured are P_1 , P_2 , P_3 , ... and P_n .
- An importance factor (IF) is assigned for each property as IF_1 , IF_2 , IF_3 , ... and IF_n .
- Assume S1 will be installed in a particular climate zone and exposed to weather shocks.

The properties of a durable shingle should not be significantly reduced due to weather shock exposure. Thus, the durability factor depends on the reduction in the property of strength. If the property reduces beyond a certain percentage compared to its as-received condition after weather shocks, that indicates that the durability of the shingle is low, while if the property reduction is low, that indicates that the durability of the shingle is higher. This article defines the durability factor (DF) depending on

Table 2. Classification based on the climate-dependent durability index (CDDI)

CDDI	Classification
$1 \leq \text{CDDI} < 2$	Bronze
$2 \leq \text{CDDI} < 3$	Silver
$\text{CDDI} = 3$	Gold

the corresponding percent reduction in property strength as follows:

- DF = 0 when the reduction is greater than or equal to 50% (reduction $\geq 50\%$)
- DF = 1 when the reduction is greater than or equal to 30% and less than 50% ($30\% \leq \text{reduction} < 50\%$)
- DF = 2 when the reduction is greater than 10% but less than 30% ($10\% < \text{reduction} < 30\%$)
- DF = 3 when the reduction is less than or equal to 10% (reduction $\leq 10\%$)

Based on the above discussion, the CDDI for a shingle can be expressed by the following equation:

$$\text{CDDI} = \sum_{i=1}^n P_i (I_i \times DF_i)$$

where
 i = one of the various properties that contribute to the CDDI.

The CDDI expresses the performance of a shingle in a holistic approach by considering the property's importance and its fragility to weather shocks. The CDDI can also be used for the common understanding of the homeowners with expected performance levels: bronze, silver, and gold, as shown in **Table 2**.

CONCLUDING REMARKS

This article presented a process to incorporate current and future projected weather shock parameters into the experimental testing of building enclosure components in the laboratory. The evaluation of building enclosure components and systems based on the developed weather shock exposure is critical and will help us better understand the durability of the building components and systems. A CDDI was developed based on the measured property data. The CDDI was used to express the performance in a holistic approach by taking the asphalt shingle as an example. Such presented CDDI provided a better in-service performance prediction. While installation is a crucial factor influencing the performance of asphalt shingles, its impact will be accounted for in the development of the CDDI at a later stage. 

REFERENCES

1. Canadian Commission on Building and Fire Codes. 2015. *National Building Code of Canada*. Ottawa, ON: National Research Council of Canada.
2. CSA Group. 2021. *Performance Requirements for Climate Resilience of Low Slope Membrane Roofing Systems*. CSA A123.26-2021 EDITION UPDATE 1. Mississauga, ON: Canadian Standards Association.
3. Baskaran, B., and F. Shyti. 2021. "A New Climate-Resilience Tool for the Commercial Roofing Community." *IIBEC Interface* 39 (11): pp. 8–16.
4. Government of Canada. "Wind-Roof Calculators on the Internet (Wind-RCI)." Last modified April 5, 2023. <https://nrc.canada.ca/en/research-development/products-services/software-applications/wind-roof-calculators-internet-wind-rci>.
5. Shyti, F., A. Gaur, and B. Baskaran. "A Weather Shocks Protocol to Investigate Building Envelope Components for Changing Climate." *Pushing the Envelope Canada* (Spring 2023): pp. 13–15.
6. Berdahl, P., H. Akbari, R. Levinson, and W. A. Miller. 2008. "Weathering of Roofing Materials—An Overview." *Construction and Building Materials* 22 (4): pp. 423–433.
7. Giammanco, I. M., T. M. Brown, and H. E. Sommers. 2015. *IBHS Roof Aging Farms: 2014 Measurement Summary*. Richburg, SC: Insurance Institute for Business & Home Safety.
8. CSA Group. 2020. *CSA A123.5:16 (R2020): Asphalt Shingles Made from Glass Felt and Surfaced with Mineral Granules*. Toronto, ON: Canadian Standards Association.
9. ASTM International. 2019. *ASTM D3462/D3462M-19: Standard Specification for Asphalt Shingles Made from Glass Felt and Surfaced with Mineral Granules*. West Conshohocken, PA: ASTM International. DOI: 10.1520/D3462_D3462M-19.
10. Shyti, F., B. Baskaran, and E. Dragomirescu. 2023. "Performance of Aged Asphalt Shingles and Development of Climate-Dependent Durability Index." In *Roofing Research and Standards Development*, Vol. 10, ed. S. Molletti and W. J. Rossiter, pp. 215–244. West Conshohocken, PA: ASTM International.

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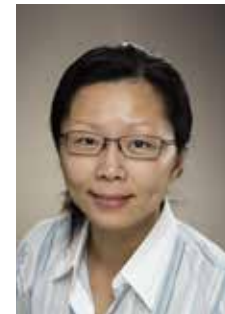
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