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CONSTRUCTION

Literature Review of the Fire Risk and State of Regulations for Vegetated Roof Assemblies

Research Report

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Executive Summary

A literature review of the fire risk and state of regulations regarding the design and installation of Vegetated Roof Assemblies (VRAs) was undertaken in support of the work of the Canadian Commission on Building and Fire Codes[1] (CCBFC) Standing Committee on Fire Protection (SC-FP) Task Group on Vegetated Roof Assembly Fire Safety[2] (TG-VRAFS). The original scope of the TG-VRAFS included a review of available information on fire risks associated with VRAs on buildings, to inform initial discussions of the TG-VRAFS about the possibility of introducing mitigation measures in the context of the National Building Code (NBC) and National Fire Code, to some extent. The study excluded post-occupancy fire prevention measures and considerations, such as maintenance. This study was accomplished by checking available databases for fire incidents where a VRA may have been a contributing factor and by reviewing Canadian and international technical standards and regulations related to the mitigation of fire risk for VRAs.

The main objectives of the work were as follows:

1. Conduct a literature review of fire incidents, in Canada, the United States (U.S.) and European countries, where a VRA was a contributing factor;
2. Provide a summary of industry technical standards and guidelines related to mitigation of fire risk for VRAs; and,
3. Provide a summary of known standards, guidance documents or other documents that are referenced by authorities having jurisdiction in Canada.

A review of test methods that are currently used for evaluating and regulating the fire performance of VRAs revealed that there is a lack of test methods that are specifically developed for VRAs. In Canada, the U.S. and some European countries, VRAs are currently tested in accordance with a few test methods that were developed for conventional roof assemblies. Therefore, it is possible that the fire performance of VRAs is not being appropriately tested as some critical features and unique attributes that are pertinent to the fire behaviour of VRAs may not be reflected in test methods for conventional assemblies. However, one American National Standard, ANSI FM Approvals 4477 (21), that was developed for evaluating the fire performance of VRAs is available. This test standard utilizes two fire test methods for conventional roof assemblies, ASTM E108 (7) and NFPA 276 (18).

There is limited research that has been undertaken to characterize the fire behaviour of VRAs and evaluate how well the current test methods address the fire risks. This highlights the need for further research to be conducted in this area, which could include a detailed analysis of the test

[1] Effective November 2022, the CCBFC was replaced by the Canadian Board for Harmonized Construction Codes (CBHCC), which assumed responsibility for the development of the National Model Codes of Canada. For the purpose of this report, CCBFC is still referenced, based on the timing that this research was initiated and mostly prepared.
[2] After initiation of the research to support the anticipated start of the TG-VRAFS, the TG was deferred during the 2020-2025 code cycle. Therefore, this research was completed with the intent to support the initial discussions of a future TG-VRAFS work.

methods and guidance documents identified in this work, in the Canadian context. In addition, there is a need to determine if current test methods are appropriate for evaluating the fire performance of VRAs. This could help identify the gaps that would need to be addressed in future research.

With regards to the review of fire incidents recorded in fire statistics databases for Canada, the U.S. and European countries, it was found that the number of reported fire incidents involving VRAs was very limited. This was consistent with a review of news and social media information. Although existing databases often incorporate characteristics that are commonly used in fire incident reporting systems, reported fire incidents in the databases did not show evidence of there having been significant or unexpected fire events involving VRAs. This is likely because they are a relatively new building feature.

The review of regulations in selected Canadian jurisdictions revealed that the NBC 2020 (23) neither mandates the installation of VRAs nor provides specific fire requirements for VRAs. Since a VRA is part of the roof assembly, it is required to comply with the regulatory requirements for conventional roof coverings. Municipal and provincial governments, such as the City of Toronto and Province of Quebec, which have shown an interest in promoting the installation of VRAs, are developing bylaws and/or technical guides with references to relevant national or international VRA standards and guidelines. The City of Toronto mandates the installation of VRAs on all new large combustible or non-combustible buildings greater than 2000 m^2. The bylaw includes a specific construction standard for safe design and installation of VRAs. The Province of Quebec does not mandate the installation of VRAs, but only allows their installation on non-combustible buildings in accordance with a technical guideline. In both cases it is acknowledged that VRAs may not comply with the conventional roof covering fire classification standard, thus it may not possible to determine a fire performance classification - as required by the applicable code. Therefore, these regulations, standards and guidance are mainly based on two primary design considerations as acceptable solutions to achieve code compliance. Those considerations focus on specific design aspects to reduce the Vegetated System (VS) fire load (without composition, type and size of vegetation and other VS components), and preventing fire propagation to adjacent elements that may be clad with combustible materials (e.g., parapets, wall, mechanical equipment) by specifying vegetation-free areas. A VS consists of components such as root barrier, drainage system, soil filter, growing media, vegetation, and an erosion control system. At the time of preparation of this report, no other Canadian jurisdictions were found to have specific fire performance regulations or guidance for VRAs.

It is currently understood that the fire performance (and fire classification) of VRAs is likely not being properly assessed using test standards for conventional roof coverings (e.g., shingles or membranes). This is because many of the test methods do not account for the unique characteristics of VRAs, which could result in a failure to achieve the regulatory objective of reducing the fire risks, such as in the case of a VRA under drought conditions. In the authors' opinion, this is a deficiency that could limit the ability of regulatory authorities to effectively address fire risks associated with the adoption of VRAs. As building codes evolve to increasingly accommodate resiliency and sustainability considerations, there is a need to develop a better understanding of the fire behaviour of VRAs and, if necessary, determine whether current test methods are appropriate for evaluating their fire performance.

1 Introduction

This report presents a literature review of the management of fire risks associated with Vegetated Roof Assemblies (VRAs) in Canada and other international jurisdictions. This was undertaken in support of the future work of the Canadian Commission on Building and Fire Codes[3] (CCBFC) Standing Committee on Fire Protection (SC-FP) Task Group on Vegetated Roof Assembly Fire Safety[4] (TG-VRAFS), to consider the possibility of introducing mitigation measures in the National Building Code (NBC) and National Fire Code.

The main objectives of the research that is summarized in this report were as follows:

1. Conduct a literature review of fire incidents, in Canada, the United States (U.S.) and European countries, where a VRA was a contributing factor;
2. Provide a summary of industry technical standards and guidelines related to mitigation of fire risk for VRAs; and,
3. Provide a summary of known standards, guidance documents or other documents that are referenced by authorities having jurisdiction (AHJs) in Canada.

It is the authors' opinion that during the last decade, environmentally friendly (i.e., associated with low Greenhouse Gas emissions) roof coverings have been gaining attention in the construction industry due to the demand to embrace sustainable practices in many sectors of society. In this regard, VRAs (also referred to as "Green Roofs" in some parts of Europe and "Vegetative Roof Systems" in the U.S.) are playing an increasingly greater role in the desire to achieve urban sustainability and climate change adaptation due to their multiple environmental benefits (1). Therefore, some jurisdictions that are encouraging (and in some cases mandating, e.g., City of Toronto Green Roof bylaw (2)) the installation of VRAs in the built environment. However, the promotion of VRAs brings a greater responsibility to provide guidance and suitable regulations to ensure fire safety in their design, installation and operation.

A VRA is a combination of the Roof System (RS) and a Vegetated System (VS); as illustrated in Figure 1. A RS is typically composed of a waterproofing membrane, cover board, insulation, vapor barrier, and a structural substrate, such as metal deck, reinforced concrete, precast concrete, or wood substrate. A VS consists of components such as root barrier, drainage system, soil filter, growing media, vegetation, and an erosion control system. A VRA is usually installed on flat or low-sloped rooftops commonly found on institutional, commercial, and industrial buildings.

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[3] Effective November 2022, the CCBFC was replaced by the Canadian Board for Harmonized Construction Codes (CBHCC), which assumed responsibility for the development of the National Model Codes of Canada. For the purpose of this report, CCBFC is still referenced, based on the timing that this research was initiated and mostly prepared.

[4] After initiation of the research to support the anticipated start of the TG-VRAFS, the TG was deferred during the 2020-2025 code cycle. Therefore, this research was completed with the intent to support the initial discussions of a future TG-VRAFS work.

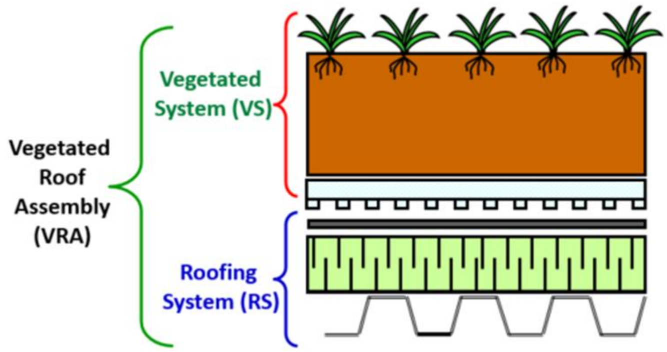

Figure 1. The Vegetated Roof Assembly (VRA) consists of two components: Vegetated System (VS) and Roofing System (RS) (3).

Research on VRAs in Canada has been largely focused on their structural design and performance (1). There has been limited research on fire risks, notable among which is the work by Gerzhova et al. (4). This work resulted in the development of a radiation model, based on wildland fire science, to investigate the risk of fire spreading from green roofs to adjacent buildings. Some regulations, e.g., City of Toronto Green Roof bylaw (2), address this risk by requiring vegetation-free zones or perimeters.

The objectives of the work summarized in this report were accomplished by reviewing available databases and relevant literature for fire incidents where a VRA may have been a contributing factor and by summarizing Canadian and international technical standards, guidelines and regulations related to the mitigation of fire risks for VRAs.

Scope

The scope of the work summarized in this report was as follows:

1. Review of fire incidents focusing on existing fire information databases in Canada and the U.S., published literature and online news articles.
2. Review of Canadian, U.S. and European technical standards and guidelines related to the mitigation of the fire risks associated with VRAs.
    - Note that analysis of the effectiveness of mitigation measures, suitability of test standards and guidelines, and post-occupancy maintenance measures or guidelines was excluded from the work plan.
3. Review of regulatory approaches and known design standards, guidance documents and other relevant documents that are utilized by AHJs in Canada.

2 Overview of the State of Technology on VRAs

There are not many studies on the flammability of vegetated roof materials. It is generally acknowledged that the fire behaviour of vegetated roof materials is difficult to assess due to the large variety of plants, configurations and time dependent properties of the materials. Notable research in Canada has been conducted at Laval University (5; 4). The research focused on modelling the thermal conductivity of dry specimens and conducting bench-scale flammability experiments using apparatus such as the Cone Calorimeter. One of the conclusions of the research was that vegetated roofs had better fire performance than conventional roof coverings, such as bitumen membranes, as evidenced by lower values of heat release rates on the vegetated growing medium in dry and moist conditions.

In the U.S., the 2018 International Building Code (IBC) (6), Section 1505, introduced a requirement for VRAs[5] to meet the same fire classification requirements as conventional roof coverings and roof assembly materials, requiring testing in accordance with ASTM E108 (7) or UL 790 (8) and to be installed in accordance with the ANS/SPRI VF-1 (9) design guide for fire safety.

In Europe, a German organization, Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V., or the German Landscape Research, Development and Construction Society, (FLL), developed a design guide for green roofs that included limited guidance on fire prevention measures for growing media and drainage materials (10). The FLL guide provides general principles and requirements for planning, execution and maintenance that were supported by the state-of-the-art in all applicable disciplines when it was developed in the 1990s. With regards to fire prevention measures, the FLL guide recommends adherence to building regulations in local jurisdictions, which require green roofs to meet the fire performance requirements in the DIN 4102-7 test standard (11). It is reported (12) that the FLL guide is widely recognized and accepted as the benchmark in Germany and neighboring European countries.

In the United Kingdom (U.K.), a publication by a government ministry (13) reviewed the current guidance documents that are available and illustrated the results of various types of tests that have been carried out on green roofs and green wall systems. The document also provides guidance on fire performance aspects of green roofs and walls, and maintenance recommendations. The main guidance documents for fire prevention that were referenced are: the GRO Green Roof Code (12), ANSI/SPRI VF-1 (9), ASTM E108 (7) and the FLL guide (10). A summary of these test standards and guidance documents is provided in Section 4, except for DIN 4102-7 (11), which was not reviewed in this work.

3 Review of Fire incidents

The two major databases of fire statistics that were reviewed in an attempt to extract information about fire incidents related to VRAs were:

1) The National Fire Information Database (NFID)[6] in Canada (14), and;

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[5] In the IBC, VRAs are referred to as 'vegetative roof systems'

[6] The NFID was developed in 2016 by the Canadian Association of Fire Chiefs (CAFC) and the Council of Canadian Fire Marshals and Fire Commissioners (CCFMFC), with the objective of demonstrating a pilot for Canada's first

2) The National Fire Incident Reporting System (NFIRS) in the U.S (15).

Both of these databases do not include a specific data field for VRAs. This finding has been echoed by other researchers (16).

There were very few fire incidents documented in the literature where a VRA played a contributing factor. For instance, recent studies (5; 4) documented three fires that happened in Portland, Oregon (U.S.), London (the U.K.), and Montreal (Canada) in 2018. In all of the cases, it was reported that sparks ignited dry overgrown grass. However, all of the fires were successfully extinguished by the fire service and there was minimal damage, likely because the fires were small.

Therefore, the current authors did not find any evidence that VRAs pose a significant fire risk in in the aforementioned fire statistics databases nor published literature, including news outlets.

4 Fire Test Methods and Guidelines for VRAs

Unlike for structural design, durability and fire performance aspects of conventional roof assemblies, it was found that there is a deficit of fire performance guidelines and test methods that are specifically developed for VRAs. In Canada and the U.S., the authors' understand that VRAs are currently tested in accordance with the following test methods that were developed for conventional roof coverings and assemblies: CAN/ULC-S107M (17), ASTM E 108 (7), UL 790 (8) or NFPA 276 (18). Test specimens are generally evaluated for their ability to resist the surface flame spread, ignition due to fire brands and downward flame propagation through a deck. In the ASTM E108 (7) and CAN/ULC-S107 (17) test methods, which are identical, the best rating achieved is Class A. This rating may be considered to be effective against severe fire exposure. This rating has been used in the evaluation of vegetated roofing systems by test laboratories, such as FM Global in the U.S. Other tests used outside North America, more specifically in Europe, include CEN/TS 1187 (19), BS EN 13501-5 (20) and DIN 4102-7 (11).

A brief summary of the details of the main test methods is provided in Section 4 on Fire Test Methods.

The regulatory practice in Canada with regards to addressing the fire risk of VRAs is discussed in the Section 5 on Jurisdiction Review.

Fire Test Methods

national system for aggregating reported information on fire incidents involving structures, vehicles and outdoors from seven jurisdictions.

This section provides summary descriptions of the test methods, which are often associated with VRAs.:

4.1.1 CAN/ULC-S107, Methods of Fire Tests of Roof Coverings and ASTM E108 / UL 790, Standard Test Methods for Fire Tests of Roof Coverings

The Standards Council of Canada (SCC) and Underwriters Laboratories of Canada (ULC) Standards CAN/ULC-S107 (17), ASTM International ASTM E108 (7) and Underwriters Laboratories (UL) UL 790 (8) test methods are similar. All of the test methods in these standards are applicable to conventional roof covering materials and are intended to measure the relative fire-performance characteristics of roof coverings when exposed to fire originating from sources outside a building on which they may be installed. The roof coverings considered are intended for installation on either combustible or non-combustible decks. The following fire test methods are included:

- A Intermittent-Flame Test;
- B Spread-of-Flame Test;
- C Burning-Brand Test;
- D Flying-Brand Test;

For conventional roof assemblies, the tests are conducted on a specimen that is constructed from white pine lumber and measures 1.0 m wide by 1.3 m long.

Three classes of fire test exposures are described in this Standard, as follows:

- Class A – Resistant to severe fire exposures and are not expected to produce flying brands.
- Class B – Resistant to moderate fire exposures, are not readily flammable and are not expected to produce flying brands.
- Class C – Resistant to light fire exposures are not expected to produce flying brands.

4.1.2 NFPA 276, Standard Method of Fire Test for Determining the Heat Release Rate of Roofing Assemblies with Combustible Above-Deck Roofing Components

The U.S. National Fire Protection Association (NFPA) standard test method NFPA 276 (18) evaluates fire performance by determining the heat release rate from below the deck of conventional roofing assemblies that have combustible above-deck roofing components when the assemblies are exposed to a fire from below the roof deck.

Fire exposure is provided by heptane-fired burners such that the flames impinge on the underside of the roof deck assembly to a predetermined exposure condition. A substitution method is used to evaluate the combustion heat energy contributed by the test specimen.

4.1.3 ANSI FM Approvals 4477-2021

In the proposed American National Standard Institute (ANSI) and FM Global Approvals standard for vegetative roof systems, ANSI FM Approvals 4477 (21), the fire testing references ASTM E108 (7) and NFPA 276 (18). The test covers requirements for vegetated roof systems on a roof assembly. Performance is evaluated with regard to fire from above and below the structural deck, foot traffic and root barrier resistance. The evaluation of fire performance from exposure above the roof deck is evaluated in accordance with ASTM E108 (7). The evaluation of fire performance from below the roof deck is conducted in accordance with NFPA 276 (18).

The vegetated roof deck sample is required to contain the growing media and vegetation, and all other components of the system may be included in the sample.

4.1.4 DD CEN/TS 1187:2012 / BS EN 13501-5 / DIN 4102-7, Test methods for external fire exposure to roofs

The British Standards Institution (BSI) Group standard, DD CEN/TS 1187 (19) and the German standard DIN 4102-7 (11), specify four methods for determining the performance of roofs to external fire exposure. The four methods assess the performance of roofs under the following conditions: “a) test 1 - with burning brands; b) test 2 - with burning brands and wind; c) test 3 - with burning brands, wind and supplementary radiant heat; d) test 4 - with two stages incorporating burning brands, wind and supplementary radiant heat. “

The tests evaluate the fire spread across the external surface of the roof, within the roof (tests 1, 2 and 3), the fire penetration (tests 1, 3 and 4) and the production of flaming droplets or debris falling from the underside of the roof or from the exposed surface (tests 1, 3 and 4). The application of tests 2 and 3 excludes certain roof shapes and attached appliances that are described in the test method.

The four tests (tests 1, 2, 3 and 4) do not imply a ranking. Each test is separate, without the possibility to substitute or exchange one test for another.

BS EN 13501-5 (20) is a British Standard that provides fire classifications of roof assemblies using the DD CEN/TS 1187 (19) test method.

Guidance Documents

4.2.1 ANSI/SPRI VF-1: External Fire Design Standard for Vegetative Roofs

The ANSI and Single Ply Roofing Industry (SPRI) standard ANSI/SPRI VF-1 (9) provides a design guide for external fire spread resistance of vegetated roofing systems to achieve minimum requirements. The standard is based on installation of firebreaks (1.8 m wide), area divider (4 m wide) and border zones (1m wide) to limit the potential for fire spread for large roof areas. These vegetation-free zones are required depending on the relative location with others features on the roof. The limiting dimensions are based on the requirements in the FLL guide (10).

The ANSI/SPRI VF-1 document states that ASTM E-108 (7) and UL 790 (8) can be used for testing vegetated roof systems.

4.2.2 FM 1-35 (2020): Vegetative Roof Systems

The FM Global Property Loss Prevention Data Sheet FM 1-35 (22) provides recommendations to prevent fire spread for installations of vegetative roof systems, occupied roof areas and decks. The guide establishes a minimum 50 cm non-vegetated border zones as separation from any penetration in the roof, and recommends partitioning the roof area into sections no larger than 1,450 m^2 separated by a vegetation free border zone of 0.9 m. It also recommends avoiding vegetation types with high risk of seasonal dormancy such as grasses and mosses, and limiting the vegetation height to a maximum of 0.9 m.

4.2.3 FLL Green Roof Guide (FLL guide)

The German Landscape Research, Development and Construction Society (FLL), developed a design guideline document for the planning, construction and maintenance of Green Roofs (10) that includes limited guidance on fire prevention measures for growth media and drainage materials. With regards to fire protection, the guide recommends that applicable building regulations in respective jurisdictions should be followed. Many of the regulations require roofs to have either sufficient resistance to external fire exposure from flying brands, in accordance with the DIN 4102-7 test standard (11) and radiant heat or other constraints, such as greater separation distances from adjacent buildings. The DIN 4102-7 test standard (11) is used for evaluating the fire performance of roof coverings when exposed to flying brands and radiant heat.

4.2.4 The Green Roof Organization (GRO) Green Roof Code

The Green Roof Organisation (GRO) is an independent not-for-profit trade association representing roofing industries in the U.K. and it specializes in sustainable products. The GRO published a Code (12), which outlines the best practice considerations for the design, installation and maintenance of green roofs. The GRO Code (12) acknowledged that much of their guidance is based on the FLL Guide (10) and reaffirmed that it was foundational in many green roof guidance documents around the world, including Switzerland, Austria, Japan and North America. However, the GRO Code provides limited guidance on fire safety and specifically directs users to comply with Part B of the Building Regulations in England, which covers fire safety matters within and around buildings by referencing a guidance document published by U.K. Ministry of Housing, Communities & Local Government (13). However, the aforementioned U.K. government guide recommends adhering to the fire performance requirements in ANSI/SPRI VF-1 (9), which require conformance to the ASTM E108 (7) or UL 790 (8) test methods.

5 Canadian Jurisdiction Review

This section provides an overview of the most relevant regulations and guidance, regarding the fire safety of VRAs, that are referenced by Canadian jurisdictions.

National Building Code of Canada (NBC)

Division B of the 2020 edition of the NBC (23), Sentence 3.1.15.1.(1) requires the classifications of roof coverings to be determined in accordance with the CAN/ULC-S107 test method (17) for large buildings. As discussed in Section 4, the CAN/ULC-S107 (17) test method is based on a spread-of-flame test and is applicable to any roof covering material. The suitability of the test method for testing a VRA can be questioned because it is essentially a living system. Parameters such as moisture content, dryness, growth stage, etc., which are not considered in the aforementioned standard, have an impact on the fire performance of a VRA (5; 4). For example, to verify compliance with the NBC it is not clear if the tests should be conducted on a VRA in normal growing condition or after conditioning to simulate drought conditions, which could potentially present a higher fire risk. Based on this uncertainty, the suitability of current requirements for roof coverings in the NBC for evaluating the fire performance of VRAs should be investigated.

Since the NBC does not specify the requirements that are applicable to VRAs, local governments that are interested in promoting VRA have been developing bylaws with references to relevant national and/or international standards. Their goal is to ensure safety in design and installation of VRAs while alleviating the local government's liability concerns. In Canada, the City of Toronto and the Province of Quebec have made much progress in the development of VRA regulations, a summary of which is presented in the next section.

5.2 Toronto Green Roof Construction Standard (TGRCS)

In Ontario, it is not mandatory to install VRAs in accordance with specified guidelines. However, the City of Toronto introduced policies to promote and de-risk the adoption of VRAs. In 2009, Toronto was the first city in North America to introduce a bylaw (Green Roofs, Toronto Municipal Code Chapter 492(2)) mandating the installation of VRAs on new buildings[7] (combustible or non-combustible) having a gross floor area of 2000 m^2 or greater. Depending on the floor area, the required minimum area of vegetation on the VRA was permitted to vary from 20% to 60% coverage.

The mandatory design, construction and maintenance requirements of VRAs are contained in the Article IV of the bylaw, which is entitled: Toronto Green Roof Construction Standard (TGRCS) (24). The bylaw is clear that the TGRCS requirements shall be complied with while also satisfying

[7] Including new additions to existing buildings

the related requirements in the Ontario Building Code (OBC 2017) (25). It also stipulates that TGRCS does not replace or alter any existing OBC requirements, or define a single code-compliant VRA design.

To provide designers and general public with a better understanding of the requirements in the TGRCS, the City of Toronto published the Supplementary Guidelines to the TGRCS (24). The guide outlines some of best practices from a number of VRA references and explanatory material including the OBC 2017 provisions.

The OBC 2017 has the same requirements for roof covering classifications as the NBC 2020 (23). The OBC, Section 3 requirement states:

> *3.1.15.1. Roof Covering Classification*
>
> *(1) A roof covering classification shall be determined in conformance with CAN/ULC-S107, "Fire Tests of Roof Coverings".*

Even though the bylaw (2) requires VRA designs to conform to OBC, the supplementary Guidelines to the TGRCS (24) acknowledge the limitations of CAN/ULC S107 (17) to properly classify the fire performance of a VRA, and the current absence of a suitable test method to appropriately evaluate the fire performance of VRAs. Thus, the Supplementary Guidelines (24) states:

> *Green roof coverings (including plant material) may not comply with the "Fire Test of Roof Coverings" standard, particularly if vegetation is dormant. At this point in time, there is no widely accepted testing method developed for Green Roofs".*

To complement the above requirement, the TGRCS (24) includes specifications based on firebreaks to reduce the fire risk. Firebreaks are gaps in the continuity of vegetation that are intended to limit or reduce fire spread in the event of a fire event. The firebreaks are specified as vegetation-free zones or the minimum distance that needs to be maintained around rooftop elements. The requirement for vegetation-free zones was adopted from the FLL guide(10). Thus, the TGRCS states:

> *§ 492-9. TGRCS: Mandatory provisions.*
>
> *F. Fire safety.*
>
> *Where roof penetrations, intersecting walls, parapets, upturns or mechanical equipment are clad with combustible materials the design shall include a vegetation-free border zone abutting such features and the vegetation-free border shall be equal to the vegetation height at maturity but in no case be less than 0.5 metres.*

Since there is currently no widely accepted fire testing standard to classify VRAs, the TGRCS provides a list of "*Best Practices*" that a VRA project should consider. The list is based on various international standards and guidelines including FM 1-35 (22) and FLL guide (10). The recommendations mainly aim to reduce the fuel load by specifying the type and size of the vegetation, maintenance program, and composition of the growing media. The goal is to provide solutions to satisfy the requirements in the OBC 2017 [23] to limit fire growth and spread across the roof coverings. It also provides requirements for firefighting such the installation of portable extinguishers and adequate water supply and/or fire hoses. It should be noted that the FLL guide (10) considers a VRA to have enough fire resistance only if the design, installation and maintenance is undertaken in accordance with the FLL guide (10).

Province of Québec Technical criteria for the construction of green roofs

In the Province of Quebec (QC), the installation of VRAs is not mandatory and none of the cities have contrary requirements. The Quebec Construction Code (QCC) 2022 (26) considers a VRA to be part of the building. Therefore, since January 8th 2022, VRAs are required to meet the requirements in the QCC which are based on the NBC 2015 with amendments for Quebec.

VRAs are required to meet the roof covering requirements specified in the QCC. Some of those requirements may be difficult to meet considering the composition of VRAs (e.g., fire performance requirements may not comply with QCC particularly if the vegetation is in drought condition). To better regulate the design and installation of VRAs, the agency of the Government of Quebec that is responsible for building regulations, the *Régie du bâtiment du Québec* (RBQ), published the technical conditions that a VRA project should meet to get approval. The document entitled "*Critères techniques visant la construction de toits végétalisés*" (27) is based on the best practices and standards related to VRA design and installation used by the VRA industry (national and international) and it is referenced by the municipalities/cities that are facilitating VRA adoption, such as the TGRS (24) specification by city of Toronto.

According to the RBQ technical criteria, VRAs are only permitted on non-combustible buildings having a maximum height of 46m with a roof slope less than 17%, and flat amenities (27). Any deviations from those conditions much be approved by the RBQ. RBQ also requests that the regulations of local fire department shall be consulted during the early stages of the project.

Regarding fire requirements, although the RBQ technical criteria [24] focus primarily on the firebreaks (or vegetation-free areas) of the VRA, it also provides some requirements on the combustibility of the VRA in particular when the vegetated system is used on ballasted roofs (i.e., the vegetated system is used to provide uplift resistance for the roof elements that are not mechanically attached to the roof deck).

For the vegetation-free areas, the RBQ technical criteria [24] specifies 0.5m clear distance from roof top elements which is consistent with the TGRCS [22]. The guide included additional restrictions of 0.9m and 1.8m as minimum separation distances depending on the type of rooftop element considered. The detailed vegetation-free area scenarios can be found in RBQ technical criteria [24]. To address the concerns about the combustibility of VRAs, the RBQ has several requirements based on the type and area of the vegetation, as well as the maintenance protocols employed to reduce the fuel load and the risk of propagation during a fire event. RBQ technical criteria [23] specifies that the roof system (component below the vegetated system) has to be Class A as per the CAN/ULC-S107 (17) fire classification. When the vegetated system is used as part of a ballasted roof, the VRA should meet the ANSI/SPRI VF-1 (9) specification with a growing media composed of 80% of inorganic material and vegetation consisting of grass and/or succulent plants.

Other guidelines

The City of Vancouver Building By-law 2019 (28) is based on the British Columbia Building Code (BCBC) 2018 (29), including some unique design and construction provisions. The requirements for roof covering fire classification determination for large buildings are the same for the Vancouver Building By-law 2019 (28), BCBC 2018 (29) and NBC 2020 (23). The City of Vancouver developed the Rain City Strategy as an effort to manage stormwater (30). The strategy sets an ambitious vision and actions around the implementation of green rainwater infrastructures (GRI) to capture, store and better manager rainwater (30). VRAs are considered one of the key GRI that needs to be promoted. The City of Vancouver is currently exploring multiple municipal tools – including regulation, design standards, and best practices – how to support and advance the implementation of the strategy (31). It can be expected that VRA fire requirements will be part of the forthcoming regulatory obligations.

No specific fire performance regulations for VRAs were found in any other Canadian provinces or cities. However, local governments provide guidelines on firebreaks or vegetation-free area recommendations, such as the City of Calgary guidance document (32), which provides firebreaks recommendations and illustrations (drawings) to assist the VRA designers.

6 Conclusions

6.1 Review of Fire Incidents

To date, there are almost no reported fire incidents involving VRAs in the fire statistic databases (i.e., NFID and NFIRS) and literature sources that were reviewed. These databases often incorporate existing characteristics that are widely identified in many fire incident reporting systems. Since VRAs are a relatively recent development in building design and have had limited adoption, it is likely that associated fire statistics have not been reflected in existing fire reporting systems.

Very few fire incidents are documented in the literature where a VRA played a contributing factor. In the cases found during this review (5; 4), it was reported that sparks ignited dry overgrown grass, and all of the fires were successfully extinguished by the fire service, and there was minimal damage.

Fire Test Methods for VRAs

A review of the test methods that are currently used for evaluating and regulating the fire performance of VRAs revealed that there is a lack of test methods that are specifically developed for VRAs. In Canada, the U.S. and some European countries, VRAs are mostly tested in accordance with test methods that were developed for conventional roof assemblies. However, one American National Standard, ANSI FM Approvals 4477 (21), that was developed for evaluating the fire performance of VRAs is available. This test standard utilizes two fire test methods for conventional roof assemblies, ASTM E108 (7) and NFPA 276 (18). Therefore, it is uncertain if the fire performance of VRAs is being appropriately evaluated, as some critical features and unique attributes are not reflected in test methods for conventional assemblies.

There is limited research that has been undertaken to characterize the fire behaviour of VRAs and evaluate how well the current test methods address the fire risks. This highlights a need for further research to be conducted in this area, which could include a detailed analysis of the effectiveness of test methods and guidance documents identified in this work, in the Canadian context. In addition, there is a need to determine if current test methods are appropriate for evaluating the fire performance of VRAs. This could help identify the gaps that would need to be addressed in future research.

Although, this study found no strong evidence of increased fire risk due to VRAs, this could potentially change if their installation became prevalent. Therefore, it would be prudent to undertake research to support the development of appropriate regulations to manage potential fire risks of VRAs.

6.3 Jurisdictional Review

The review of regulations revealed that the NBC 2020 (23) does not provide specific fire requirements for VRAs. Since VRAs are part of the roof, they are required to comply with the fire test standards for conventional roof coverings. However, since a VRA is an organic living system, test methods for conventional roof coverings may not be appropriate, as discussed in the summary of fire test methods for VRA. Further, a VRA may not conform to the roof covering standards, especially if the VRA is tested simulating drought conditions.

Local governments interested in promoting the installation of VRAs are developing bylaws or/and technical guides with references to national or international VRA standards and guides to provide solutions to achieve compliance with the applicable code. The City of Toronto which mandates the installation of VRA on all new large combustible or non-combustible buildings (greater than 2000 m^2) in accordance with the Green Roof bylaw [2]. The Toronto Green Roof Construction Standard (TGRCS) (24) specifies minimum requirements for the design and construction of VRAs. In the province of Quebec, the agency of the Government of Quebec that is responsible for building regulations, the Régie du bâtiment du Québec (RBQ), published the technical conditions that a VRA design should meet to get approval. The document intitled "*Critères techniques visant la construction de toits végétalisés*" (27) permits the installation of VRAs only on non-combustible buildings having a maximum height of 46m with a roof slope less than 17% and essentially flat VRA amenities.

The fire requirements for both the TGRCS (24) and the RBQ technical criteria (27) are design conditions that are required to achieve code compliance. Those conditions focus on specific design aspects to reduce the fuel load (composition and maintenance of VRAs) and prevent fire spread to adjacent rooftop elements or adjacent buildings by specifying vegetation-free areas (or comply with minimum distance requirements to other roof top elements). The City of Vancouver is currently working to develop guidance and regulations to support the launched Rain City Strategy (32) – an ambitious plan and set of actions to better manage stormwater that is expected to also include some fire performance requirements for VRAs. No other Canadian municipalities were found to have specific fire performance and prevention requirements for VRAs.

It is generally understood that the fire performance (and fire classification) of VRAs cannot be properly assessed using test standards for conventional roof coverings (e.g., shingles or membranes). This is because such test methods do not account for the unique characteristics of VRAs, which could result in a failure to adequately capture associated fire risks, such as those under drought conditions. In the authors' opinion, this is a significant deficiency that limits regulatory authorities to de-risk the adoption of VRAs. As building codes evolve to increasingly accommodate resiliency and sustainability concepts, there is a need to develop suitable VRA fire performance test methods.

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