Feature

Engineering Tomorrow's Envelopes: Smart Blue Roofs Pioneering Sustainable Building Practices

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This paper was presented at the 2024 IIBEC/OBEC BES.

INTRODUCTION

Urbanization has altered the natural hydrological cycle, leading to significant challenges in managing stormwater in densely populated areas. The reduction in green spaces has resulted in increased surface runoff, higher solar radiation absorption, and diminished evaporation rates, all of which complicate water management in urban settings.[1] With climate change fueling more frequent and severe storm events, traditional stormwater systems are becoming increasingly inadequate, resulting in localized flooding that endangers public safety and property.[2,3]

To address these challenges, there is a growing focus on blue roof technologies, which offer opportunities for managing rooftop runoff. Blue roof systems capture rainwater and store it temporarily, allowing it to evaporate, be stored for reuse, or be released over time to reduce the peak flow into the municipal stormwater system.[4] Additionally, blue roofs enhance urban microclimates and conserve water by storing rainwater for irrigation and toilet flushing.[1,3] They can also lower cooling demands through evaporative cooling during hot weather.[1] Research highlights the effectiveness of blue roofs in reducing stormwater runoff, especially in older urban areas with combined storm and sanitary sewers, where the risk of sewer overflows is particularly high.[3]

Given that low-slope roofs account for approximately 28% of urban surfaces in North America, according to satellite imagery studies, they represent an opportunity for stormwater management. This can mitigate environmental impacts and promote sustainable urban development amid ongoing urbanization and climate change.[4,5]

TECHNOLOGY CLASSIFICATION

The concept of a blue roof has gained prominence as an innovation for stormwater management, setting it apart from traditional vegetative roofs. Blue roofs can be categorized based on their stormwater detention methods into the following designs:

Roof-integrated design (RID) utilizes either the entire roof or a portion thereof, with modifications made to roof drainage inlets to achieve a slower drainage rate into a leader pipe, allowing water to accumulate on the roof surface, as shown in **Figure 1.**[6]

RID systems can be passive or active. Passive systems incorporate roof dams and checks or drain inserts with an orifice that reduces flow compared with conventional drains, as shown in **Figure 2.** A check-dam system is constructed with a series of partitions or weirs, each fitted with openings at their lowest point. These openings are strategically created to avert the continuous water pooling and to facilitate a steady flow of rainwater toward the roof's drainage point.[1] On the other hand, active systems feature remotely controlled valves often governed by programming to manage detention levels. These active systems may also utilize algorithms and sensors to adapt to varying weather conditions. By anticipating and responding to weather patterns, active RID systems optimize stormwater detention and release, mitigating the risk of overflow during intense rainfall events.[4] Whether passive or active, RID necessitates a roofing system capable of performing under volumes of ponded water for possibly extended periods of time as compared to typical low-slope roof system designs.

Modular tray design (MTD) incorporates modular systems, such as tray-based systems, which can be positioned on rooftops to store and manage stormwater. These trays are typically filled with porous media, enabling controlled drainage through weep holes at the base, complemented by various outlet drains customizable to project requirements.[4] The flexibility of this design allows for selective installation across diverse roof surfaces, particularly in areas with structural loading constraints or where rooftop equipment must be accommodated.[4] The trays can either be freestanding, secured in place with weighted materials, or attached directly to the roof structure. MTD systems demand less maintenance than other methods; they can offer water detention capacity separated from the roofing membrane, making them a practical retrofit choice or an additional feature without necessitating extensive roof assembly modifications.[4]

"Blue-green" roofs integrate features of both blue and vegetative roofs by incorporating vegetation and growing medium layers above ponded water. Blue-green roofs can either utilize roof-integrated or modular designs. They are designed like traditional vegetative roofs but feature an expanded drainage layer, facilitating enhanced evapotranspiration and enabling a controlled, gradual release of stormwater.[7,8]

HISTORY AND MODERN APPLICATIONS

Low-sloped roofs are defined by roofing membrane systems installed on slopes of 25% (1 in 4) or less.[9] Flat roofs, a subset of low-sloped roofs, have a minimum slope of 2% (1 in 50) to ensure proper drainage.[9] The historical use of

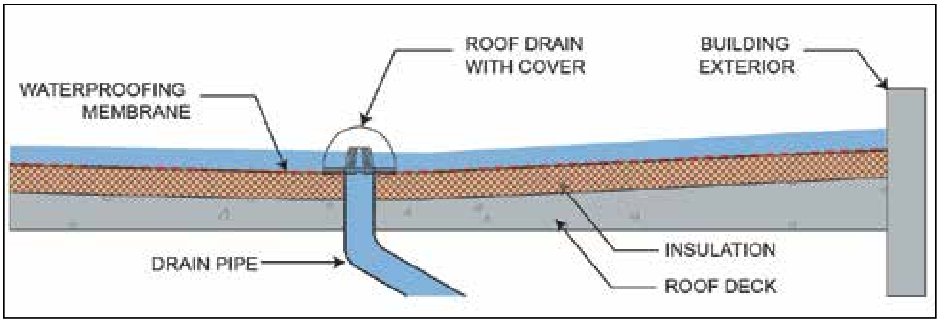

Figure 1. *Roof-integrated design.*

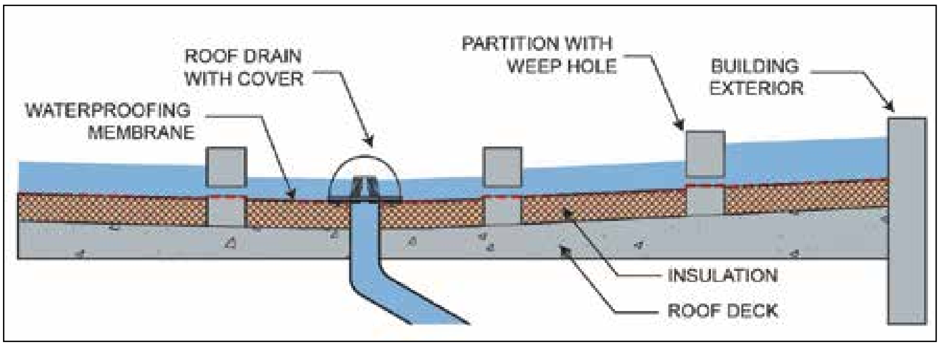

Figure 2. *Check-dam system cross-section with multiple partitions.*

low-sloped roofs can be traced back to ancient civilizations in the Mediterranean, Africa, and Asia, where the climate was conducive to such architectural designs.[10] In contrast, regions with more severe weather conditions, characterized by heavy rainfall, traditionally favoured pitched roofs to prevent water accumulation and potential structural damage.[10]

The 19th century saw an increase in low-sloped roofs for residential buildings in urban areas across Europe and North America. Traditionally, these low-sloped roofs utilized tar and gravel surfaces, which provided an effective barrier against water as long as proper drainage was maintained. This method involved layering roofing felt, applying mastic, and embedding silver-gray gravel into the top layer to prevent the surface from drying out.[10] However, these materials were less successful in colder climates, where ice dams and sagging could impede water flow and disrupt drainage.[10] European construction laws influenced low-sloped roof trends to maximize building heights within city landscapes.[10] Notable architects such as Le Corbusier and Frank Lloyd Wright also popularized low-sloped roofs in residential architecture during the early 20th century. Le Corbusier's "Five Points of a New Architecture," published in 1926, promoted low-sloped roofs' functional and aesthetic benefits, advocating for their use as gardens and terraces to reclaim urban green spaces.[11]

The 1960s introduced bituminous felt roofing sheets, offering a lightweight and cost-effective alternative for roof coverage. Despite these advantages, the material was prone to leaks and had a limited lifespan.[12,13] This was due to the nature of the bituminous material, which could become brittle and crack under extreme weather conditions, leading to water ingress and damage. In addition to bituminous felt, other roofing systems, such as metal roofs and EPDM roofing systems, were also being used.

In the 1970s, the roofing industry saw the advent of vegetative roofs, which were complemented by advanced waterproofing and drainage systems, culminating in the development of low-maintenance "extensive vegetative roofs" by the decade's end.[14] In the mid-2000s, many municipalities across North America began encouraging vegetative roofs for new public and private buildings, recognizing the potential savings from reduced energy consumption, mitigation of the urban heat-island effect, and decreased stormwater infrastructure costs.[15] In 2009, Toronto became the first city in North America to mandate vegetative roofs for certain new developments, along with stipulating minimum construction standards.[16]

In the 2010s, blue roofs emerged as an approach to stormwater management. The New York City Department of Environmental Protection conducted several pilot studies in 2011 and 2012 to evaluate the effectiveness of blue roofs. These studies involved the installation of various modular tray systems and check-dam systems at multiple sites to monitor rainfall retention and detention rates. At one location, four different tray systems were tested at a community center to measure their outflow rates and assess performance. Similarly, at a storage facility on Metropolitan Avenue, the roof was divided into sections to test various drain inlet modifications and tray systems. These pilot projects consistently demonstrated peak flow reductions of 85% to 90%.[17] However, the study did not explore the impact of different roof membrane types and their long-term performance.

Subsequent research has broadened the scope of blue roof studies. Campisano et al.[18] conducted a full-scale pilot installation of a MTD system on the University of Catania's campus in Catania, Italy. The study compared a section of the roof equipped with the MTD system against an unmodified section, observing an average of 54% retention efficiency and 72% detention efficiency for MTD system.[18]

Almaaitah et al.[19] assessed a blue-green roof's hydrologic and thermal performance during the 2021 growing season at the George Vari Engineering and Computing Centre at the Toronto Metropolitan University. The roof was comprised of a 50 mm compost layer, a 250 mm substrate, a filter sheet, a 50 mm drainage layer, a root barrier, and a roofing membrane arranged from top to bottom. The membrane and drain system were not mentioned in the study. The research highlighted the roof's water retention capability, with average rates between 85% and 88% and peak stormwater attenuation of 82% to 85%.[19] Temperature-wise, the study observed a mean air temperature reduction of 1.4°C to 2.5°C, varying with the type of vegetation.[19] Notably, the cooling effects were more significant in the afternoon and evening, while a warming trend was noted in the early morning.[19]

While prototypes exist for tray systems, check-dammed systems, and blue-green roofs, limited research and case studies exist for RID systems, flagging a potential area for further research and development. This gap in research limits practitioners' understanding of RID systems and their performance across various membrane types.

RELEVANT CANADIAN CODES AND STANDARDS

While specific standards for blue roofs have yet to be established within Canadian building codes and standards, the principles for general roof design remain pertinent. This section examines how existing roofing codes and standards can be adapted to blue roof applications, ensuring their functional and structural integrity.

The 2020 *National Plumbing Code* (NPC) contains provisions for roof drainage relevant to blue roofs. Section 2.4.10.4(1) determines the maximum hydraulic load used to establish the minimum leader size for the roof drain. For roof drains with flow controls, the hydraulic load is determined using a 25-year rainfall intensity-duration-frequency curve provided by Environment Canada.[20] NPC clauses 2.4.10.4(2) and (3) stipulate that water stored on the roof should not remain for more than 24 hours and have a maximum depth of 150 mm (6 in.).[20] Additional clauses in the NBC 2015 specify the location of drains, which must be no more than 15 m (49 ft) from the edge of the roof and no more than 30 m (98 ft) from adjacent drains.[20] Additionally, overflow scuppers must be installed no more than 30 m (98 ft) apart along the perimeter of the building to prevent structural overloading of the roof if drains fail.[20] However, the NPC does not mandate specific roofing membranes.

Many regionally specific codes, such as the 2012 *Ontario Building Code* (OBC), share requirements comparable to those of the NPC drainage guidance. The distinction lies in the sourcing of environmental data, where references in the OBC must adhere to the Ministry of Municipal Affairs and Housing (MMAH) Supplementary Standard SB-1 instead of NPC data.[21]

Different municipalities and regions may also have specific stormwater management and retention requirements. For example, the Toronto Green Standard (TGS) Version 4 applies to new site plan applications for four-story or higher residential buildings and all industrial, commercial, and institutional (ICI) developments.[22] Within the water quality and efficiency prerequisite WQ1.1, Water Balance, Quality & Quantity Control, there is a mandate to retain 50% of the total average annual rainfall volume, remove 80% of total suspended solids, and control *E. coli* for discharges to Lake Ontario or waterfront sites.[22] Peak flow control is also required; however, challenges arise in implementing blue roofs under prerequisite WQ1.3, On-site Green Infrastructure, due to conflicting requirements, such as minimum vegetative roof coverage, which can be up to 80% of available roof space.[22] These requirements pose challenges in blue roof implementation, with the standard specifications supporting vegetative roof infrastructure. Designers may consider implementing blue roofs in the remaining available roof space or installing a hybrid blue-green roof to meet the Toronto bylaw requirements. The City of Toronto also has a Wet Weather Flow Master Plan, which sets wet-weather flow-management targets for water balance, quality, and quantity. Table 1 in Section 2.2.1, Water Balance, lists examples of on-site stormwater management practices depending on the type of land use.[23] For example, commercial and industrial buildings may implement vegetative roofs, rooftop restrictors, and rainwater harvesting.

CSA A123.26:21, *Performance Requirements for Climate Resilience of Low Slope Membrane Roofing Systems,* lists even more stringent recommendations related to drainage. The standard outlines the requirements for low-sloped membrane roofing systems to achieve different ratings related to climate adaptation. According to Clause 7.2.8, water should not run more than 10.7 m. (35 ft) to a primary drain or scupper to achieve a silver performance rating.[24] For a gold performance rating, Clause 7.2.13 stipulates that water should not travel more than 6.1 m (20 ft) to a primary drain or scupper.[24]

CSA 478:19, *Durability in Buildings,* provides minimum requirements to assist designers in making design decisions, reviewing construction, and performing building maintenance in existing and new construction projects.[25] Blue roofs can influence the lifespan and performance of a building due to their unique construction and environment. For example, Sections 4.3 and 4.4 of this standard state that all foreseeable agents and mechanisms that could impact durability and performance must be considered and accounted for during design, construction, repair, and maintenance.[25] Similarly, Section 8.3, clauses (b) and (c), specify that the materials selected must be appropriate for the structure's environment, design loads, and differential movements.[25] Section 4.6.2 stipulates that a maintenance and inspection plan should be developed for building components, including repair and replacement.[25] This makes proper material selection for the waterproofing membrane and a thorough maintenance and repair plan essential for blue roofs.

Leak detection is an important consideration for blue roof systems. It can provide quality assurance during construction and a mean of leak diagnostics and monitoring for the life cycle of the roof assembly. In considering leak detection during design, the following standards offer guidelines and requirements for electronic-detection components: ASTM D7877, *Standard Guide for Electronic Methods for Detecting and Locating Leaks in Waterproof Membranes,* and ASTM D823, *Standard Practice for the Use of a Low Voltage Electronic Scanning System for Detecting and Locating Breaches in Roofing and Waterproofing Membranes.*[26,27]

Lastly, CSA B805:22/ICC 805:22, *Rainwater Harvesting Systems,* provides comprehensive guidelines for the design, materials, installation, and operation of rainwater harvesting systems, covering potable and non-potable applications and water treatment.[28] It can apply to blue roofs if detained water is reused within the building for potable or non-potable uses.

CASE STUDY

Building Description

The Credit Valley Conservation (CVC) Head Office, located at 1255 Old Derry Road in Mississauga, ON, consists of two buildings, A and B, connected by a one-story corridor. Constructed circa 2010, Building A is a four-story steel-framed structure with a one-story garage on the southeast elevation (**Fig. 3** and **4**). The floors and roof slabs are supported by steel beams connected to steel columns anchored to cast-in-place footings. Building A has three roof sections: the main roof (A-1), the garage roof (A-2), and the elevator pit room (A-3), as shown in **Figure 5.** Mechanical equipment on the west side of roof A-1 sits within an open-air screen enclosure. The approximate area of roof A-1 is 645 m^2 (6943 ft^2).

The main roof structure of Roof A-1 is a 250 mm (10 in.) thick hollow-core slab. On top of the slab is a concrete topping that measures 230 mm (9 in.) at the perimeter, tapering to 50 mm (2 in.) at the center to facilitate drainage. The existing roof assembly is a conventional system that includes a self-adhered vapour barrier, 125 mm (5 in.) of EPS insulation adhered in place, and a 12.7 mm (1/2 in.) fibre board adhered in place. The system is capped with a single-ply fully adhered TPO membrane, as depicted in **Figure 6.**

Roof A-1 does not have overflow scuppers. The existing parapet height is 400 mm (16 in.). Building A has seven drains. CVC Head Office Building A was designed in 2008 by Montgomery Sisam Architects Inc. Accordingly, the 2006 *Ontario Building Code* was the applicable building code at the time of design and permit issuance. Design loading was in accordance with Part 4 of Division B. Environmental loading data for Mississauga was per Supplementary Standard SB-1.

FEASIBILITY STUDY

Project Background

In October 2017, the CVC authority began exploring the feasibility of implementing an RID blue-roof pilot project installation at their office building. This pilot project was seen

Figure 3. *CVC Building A—Overview.*

Figure 4. *CVC Site Plan.*

as an opportunity to test the effectiveness of this emerging technology in managing storm peak load, reducing energy consumption, and determining the non-potable demand that could be met by the existing rainwater harvesting (RWH) system.[10] Over the following months, CVC engaged with internal and external stakeholders to refine the project concept and secure funding. Due to its size and relatively minimal mechanical and conduit congestion, Roof A-1 was identified as a candidate for the installation of the blue roof system.

In light of the prevailing code regulations in 2017, which allowed a maximum rainwater drain-down time of 24 hours per day and a maximum roof rainwater level of 150 mm (6 in.), CVC entered pre-consultation and technical discussions with the City of Mississauga Building Department to determine the legislative requirements for a blue roof. In addition to complying with the general requirements of the OBC, two alternative solutions were proposed under OBC Division C to maximize the benefits of a blue roof.

The first alternative, Solution A, proposed extending the maximum allowable rainwater drain-down time to six days. This extension aimed to increase the amount of water stored while also including provisions for reducing the likelihood of mould or mildew growth and the risk of illness from unsanitary conditions caused by contaminated surfaces and vermin.[29] This latter concern was particularly pertinent in relation to Culex mosquitoes, whose larval development cycle can be as early as five days with favourable environmental conditions.[30] Culex mosquitoes in this region are known to carry the West Nile virus, and stagnant water without treatment may lead to increased larval development, potentially spreading the

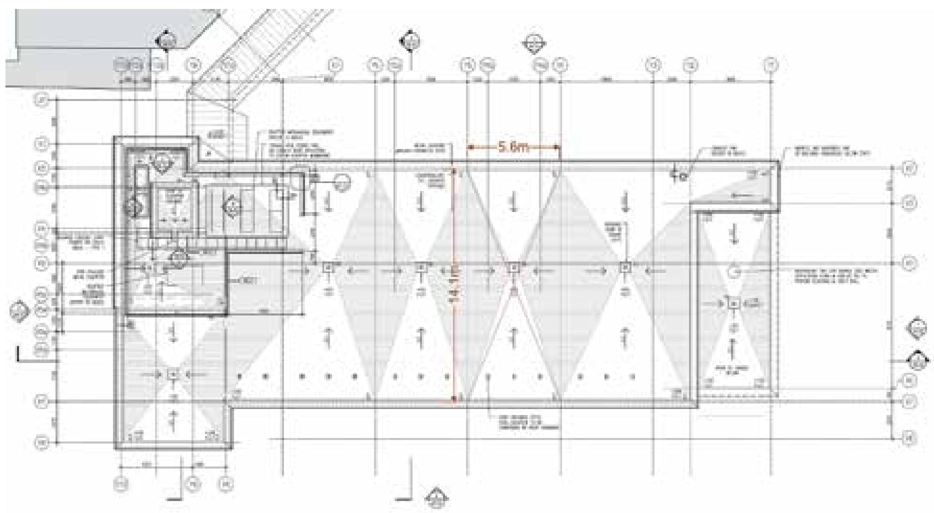

Figure 5. *Building A—Existing Roof Plan.*

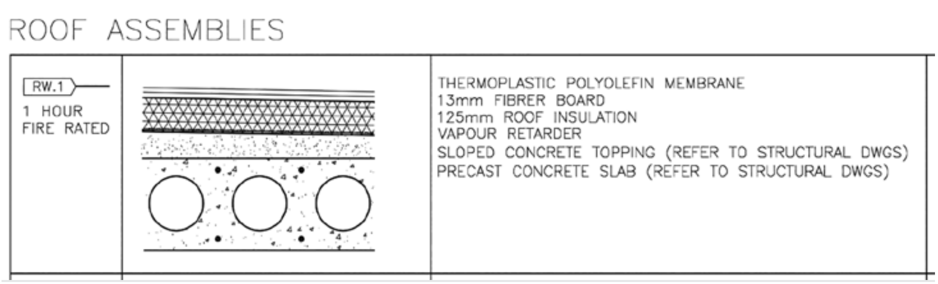

Figure 6. *Existing A-1 roof assembly.*

disease.[31] According to this alternative solution, all accumulated rainwater must be treated every two days per CSA B805 standards to control bacteria and protozoa.[28,29]

The second alternative, Solution B, suggested increasing the maximum allowable roof rainwater level from 150 mm (6 in.) to 250 mm (10 in.). The City of Mississauga requested a detailed structural assessment and the inclusion of additional overflow scuppers to manage this increased capacity and alleviate the risk of structural overloading on the existing structure.

Structural

The original structural deck was designed to accommodate dead, live, variable, and wind loads, according to OBC 2012, Table 4.1.2.1.A. Dead loads include the self-weight of the

TABLE 1. Snow and rain loads as per Table 4.1.2.1A in 2012 OBC.[21]

City	Snow (without considering snow drift)		Water	
	Loading kPa (psf)	Precipitation mm (in.)	Loading kPa (psf)	Precipitation mm (in.)
Mississauga	1.28 (27)	130 (5.1)	1.11 (23)	113 (4.4)
Toronto	1.12 (23)	114 (4.5)	0.95 (19)	97 (3.8)

structure, permanent construction materials, roof assembly, overburden, rooftop equipment, and architectural components. Live and variable loads account for occupants, movable equipment, and environmental factors such as snow, ice, and rain. For most roof structures, the variable snow or rain load is equal to or greater than the dead load, with the dead load calculated at 1.25 kPa (26 psf) and the variable load at 1.5 kPa (31 psf), per OBC Table 4.1.3.2.A.[21]

The rainwater storage capacity, integral to blue roof technology, imposes a variable load due to rain. Importantly, OBC Article 4.1.6.4.(3) specifies that snow and rain loads do not coincide and should not be combined in the same load calculation.[21] Consequently, the capacity of an existing roof to support a rainwater storage capacity is equal to the design snow or rain load. Based on the 2012 OBC and regional precipitation data, hydraulic rain load calculations indicate that snow load typically governs design in Mississauga and Toronto, as shown in **Table 1.**

It is common practice that an increase of up to 5% in variable load is acceptable without requiring structural reinforcement, translating to increasing ponding from 130 mm (5 in.) to 137 mm (5.4 in.) in Mississauga. However, CVC's requirement to store up to the maximum allowable amount of water necessitated a detailed assessment and potential roof structural reinforcement. Design loads for the Roof A-1 were calculated, factoring a basic snow load of 1.3 kPa, wind uplift of 1.3 kPa, and a basic superimposed dead load (SDL) of 1.6 kPa. Additionally, the average sloping topping dead load was 4.7 kPa, varying from 2.8 kPa to 6.6 kPa, as shown in **Figure 7.**

Accordingly, it was determined that the existing low-sloped roof can support basic seasonal blue roof technology without additional reinforcement, with a maximum snow load of 1.3 kPa plus 0.6 kPa in allowances or a maximum ponding depth of 180 mm (7 in.). The blue roof system drains should remain opened to avoid ponding during the winter months.

Roof Assembly

Considering Roof A-1's existing TPO roof assembly condition and performance risks, full roof replacement as part of the blue roof pilot was contemplated. Roof cut tests completed by CVC's roofing contractor confirmed moisture present below the existing TPO membrane at several locations. Concerns were raised regarding risks and the impact of future leaks below the new blue roof, including building operations disruption and hollow core structural roof slab deterioration. CVC elected to replace the full roof assembly as part of the blue roof project. Considerations and factors reviewed in making final new roof system design decisions are presented below.

DESIGN

Overview

To implement the blue roof project on Roof A-1, a separation was needed to isolate existing rooftop building mechanical and weather monitoring instrumentation systems installed on the west section of the roof. Roof A-1 was divided by a new segregation barrier into two distinct areas: Zone 1 (the western third of the roof, which is to remain a conventionally drained low-sloped roof) and Zone 2 (the eastern remaining roof area designated for blue roof water retention), as depicted in **Figure 8.** Zone 3, the lower garage roof (Roof A-2), falls outside this project's scope.

Roof Assembly

The new replacement roof assembly at Zone 2 (the blue roof area), as a retrofit, was to at least achieve the same thermal and condensation resistance performance levels of the existing TPO roof. Additional design decisions were guided by four key objectives established by the CVC. First was ensuring the new roof assembly could allow for and perform under planned maximum water storage volumes, above the membrane, for prolonged periods outside of winter conditions. The second objective was maintaining the high reflectivity white roof membrane surfacing design feature to reduce solar heat gain and building cooling energy loads. The third objective required that the roof membrane not impact the stored water's quality and resist potential chlorine and algaecide water treatment additives. Finally, the roof membrane needed to withstand light foot traffic for demonstration and maintenance purposes.

For the new roof membrane, the design team considered fully adhered membranes with redundant, multi-ply, and seamless applications to improve leak resistance and roof durability. A summary of the options reviewed is provided in **Table 2.** All options included the same insulation and vapour barrier details.

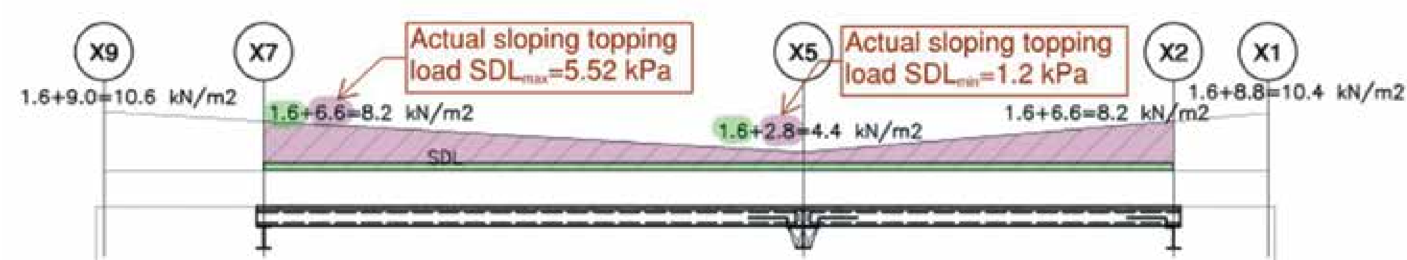

Figure 7. *Superimposed dead load SDL cross-section diagram.*

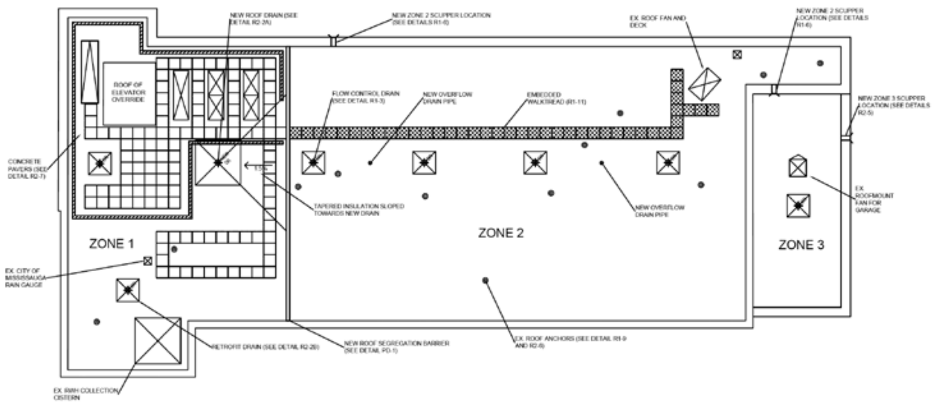

Figure 8. *Roof Plan.*

TABLE 2. Roof membrane design option.

Option No.	Description
1	Like-for-Like Single-Ply TPO Roof Membrane System
2	2-ply Modified Bitumen SBS Roof Membrane System
3	PMMA Liquid-Applied Roof Membrane System Applied over 1-ply Modified Bitumen SBS Base Sheet

Given the following considerations, the Option 3 roof assembly, including a PMMA liquid-applied membrane system over a 1-ply modified-bitumen SBS base sheet, was ultimately selected.

- The PMMA liquid-applied membrane is installed in a seamless application and can withstand the ponded water hydrostatic pressure anticipated in the RID blue roof pilot.[32] Combined with a 1-ply modified-bitumen SBS base sheet below, Option 3's membrane system is multi-ply and redundant. The PMMA chemical structure consists of polymer chains chemically bonded with one another, resulting in homogenous, seamless installation.[32] It also provides UV resistance and chemical stability, including at chlorine levels above expected treatment threshold of 1 mg/L (8.35x10^{-6} lb/gal).[32]
- Option 1 was not selected, as the single-ply TPO membrane includes seams not suitable for prolonged periods of ponded water and lacks the multi-ply redundancy desired. In addition, TPO membranes tend to be more slippery when wet as compared to the other membranes considered, adding safety risk associated with occasional foot traffic outside designated walkways.
- Option 2, although a multi-ply and redundant membrane system, also includes seams. While there have not been specific RID blue roof studies related to the impact of ponding water on membrane seams, the Canadian Roofing Contractors Association (CRCA) advises against flood testing (i.e., ponding water) as a form of leak detection due to ponded water's hydrostatic pressure impact on seam bond.[33] In addition, modified bitumen cap sheets rely on embedded granules for UV protection. Under sustained ponded water, granules may become disturbed, reducing the membrane's UV protection.
- Conventional BUR and ballasted roof assemblies were not considered, as the gravel/ballast adds dead load, decreasing available capacity for water storage.

Construction cost estimates were prepared for the three options considered. Option 1 was the least costly. Option 2 was ~20% and Option 3 was ~40% more costly than Option 1. All options included a white membrane and EFVM leak detection conductive medium.

The full new roof assembly is illustrated in **Figure 9.** On top of new self-adhered vapor barrier is an adhered in-place glass-faced closed-cell polyisocyanurate foam core insulation layer. Above the insulation is a leak detection conductive medium, an adhered in-place asphaltic overlay board layer composed of a mineral-fortified asphaltic core formed between two asphalt-saturated fiberglass mat reinforcements. The roofing membrane system includes a 1-ply torch-applied modified-bitumen SBS membrane base sheet covered with the two-component PMMA liquid membrane with fleece fabric reinforcement. The PMMA membrane system resin is pigmented to result in designed high reflectively white finish.

At the parapets, above the PMMA membrane upturn height, the roof membrane is comprised of 1-ply torch-applied modified-bitumen SBS cap sheet membrane installed over the modified-bitumen SBS base sheet. The parapets are then protected with galvanized steel metal flashings. Roof designated walkways within the blue roof area are comprised of plastic bead and sand particles embedded into the PMMA topcoat during application.

All roof system components are specified by the same roofing manufacturer to maintain consistency and compatibility. As with all considered assembly options, the final assembly was designed to meet the calculated wind uplift pressures and reviewed against relevant standards, such as CSA A123.21:20, *Standard Test Method for the Dynamic Wind Uplift Resistance of Membrane-Roofing Systems.*[34]

Leak Detection

Leak detection and roof performance monitoring was added as a design objective to manage the risk associated with the planned ponded water over the roof assembly. Electronic leak detection (ELD) using an electric field vector mapping (EFVM) system meant as a diagnostics and monitoring tool, was integrated into the new roof assembly by introducing an electronic-detection-conductive medium. ASTM Guide D7877 and ASTM Practice D8231 guided the electronic-detection-conductive medium selection and design.[26,27] The conductive medium sits between the polyisocyanurate insulation and the asphaltic cover board, comprised of welded stainless steel mesh. In consultation with the roofing membrane manufacturer, the conductive medium was placed below the coverboard instead of directly below the membrane system to protect the liquid-applied membrane. The mesh grid, spaced out at 50 mm by 50 mm (2 in. by 2 in.), is connected through a contact plate and cable to a connection box. During ELD testing, a low-voltage charge is applied through the connection box via a portable pulse generator.

Roof Drainage and Scuppers

The new replacement roof assembly included the following drainage scope to accommodate the blue roof mechanical system design. **Figure 10** and **Figure 11** illustrate the blue roof drains connecting to the mechanical systems below the roof deck.

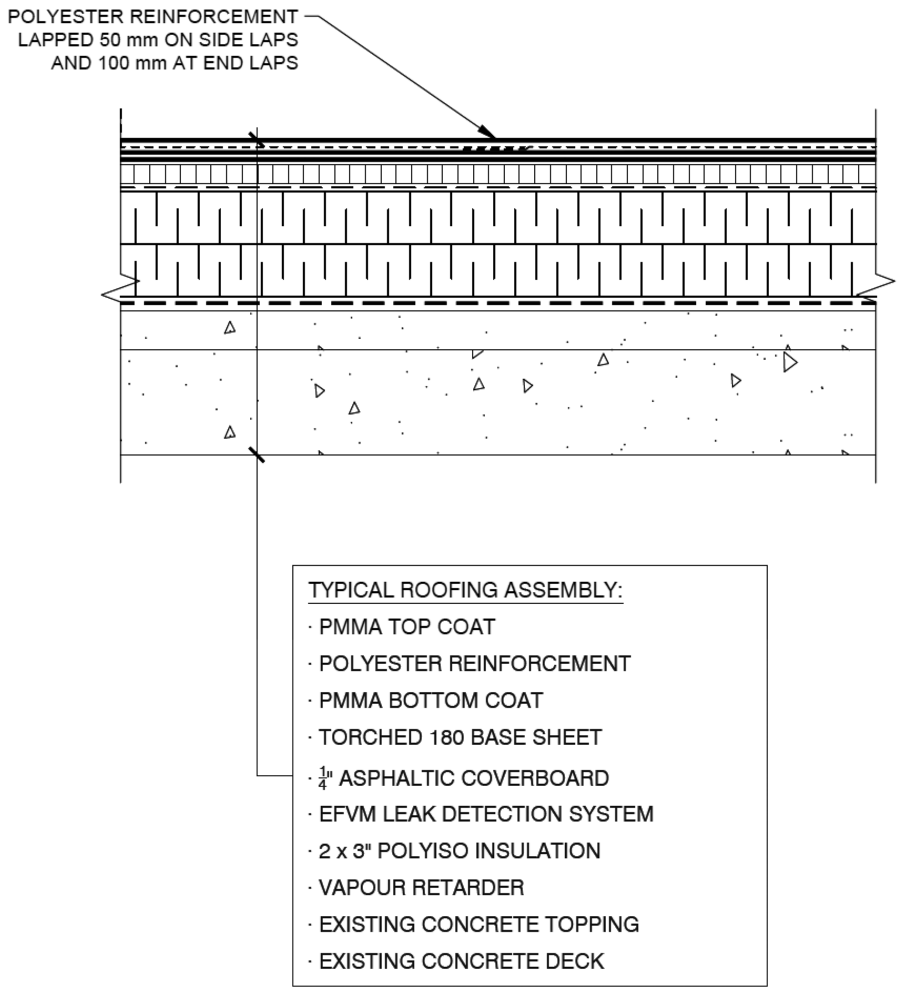

Figure 9. *Final roof assembly.*

- Upgrade the primary roof field drains, including adding a field drain within the blue roof zone, to tie-in the new roof assembly to the new blue roof mechanical sensors, valves, and water treatment/storage systems below the deck.
- Add new field overflow drains equipped with extension pipes rising above the roof membrane up to the maximum planned blue roof water depth.
- Add new overflow scuppers through the parapets set at the height of the maximum planned blue roof water depth.

The primary roof field drains control flow and pond water, and when the blue roof is inactive (e.g., in the winter months), they provide primary drainage to meet building design. These drains were retrofitted to include vandal-proof cast aluminum domes and hinged access gates, pan-formed aluminum drain bodies, and cast aluminum clamping rings. The retrofit drains connected to the rainwater leaders below the deck via mechanical coupling connections instead of U-flow friction insert seals, as the pipes may experience high flow rate and temporary backup conditions during blue roof drain down.

The overflow field drains and scuppers divert water, and meet the roof's drainage requirements, if the levels on the blue roof reach maximum planned storage capacity. The overflow scuppers cut into the parapets' drain through downspouts terminating at grade, as illustrated in **Figure 12.** They were placed along the roof edge to make scuppers easier to inspect and were designed to complement the architectural style of the building, integrating with the overall design.

CONSTRUCTION

Construction commenced with removal of the existing roof assembly, followed by adjustments to existing roof anchors to extend them above the maximum planned water level. Surface preparation included cleaning and priming of the existing concrete surface for vapour barrier application, while insulation was installed staggered and tightly butted. ELD conductive medium mesh was installed followed by coverboard and 1-ply modified-bitumen SBS base sheet. Surface cleaning was carried out to remove any loose granules, dust, or dirt prior to the liquid-applied PMMA system application. PMMA system application is sensitive to high temperatures, which could lead to improper curing. Ambient and substrate temperatures were closely monitored throughout the process to verify application conditions.

Uncovered concealed conditions during construction, including original structural roof deck precast panels construction tolerances, required some modifications to overflow drain

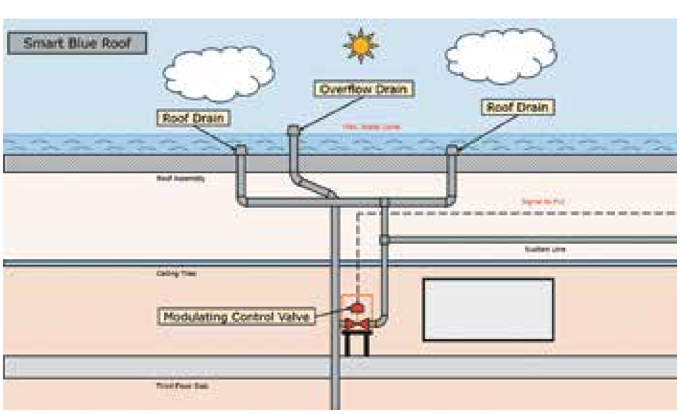

Figure 10. *Rooftop drainage schematic.*[3]

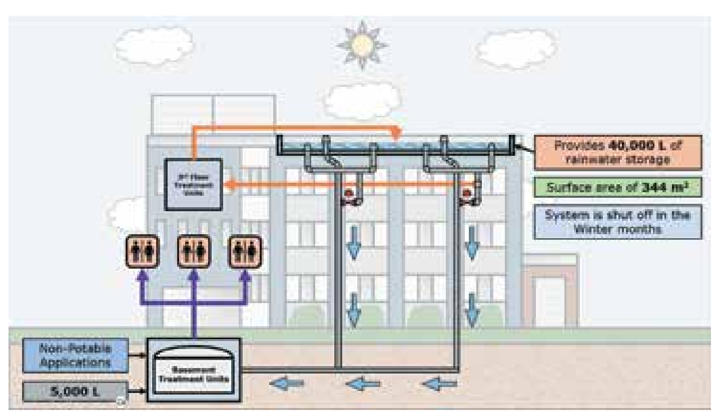

Figure 11. *Blue roof mechanical system connecting to rooftop drains.*[3]

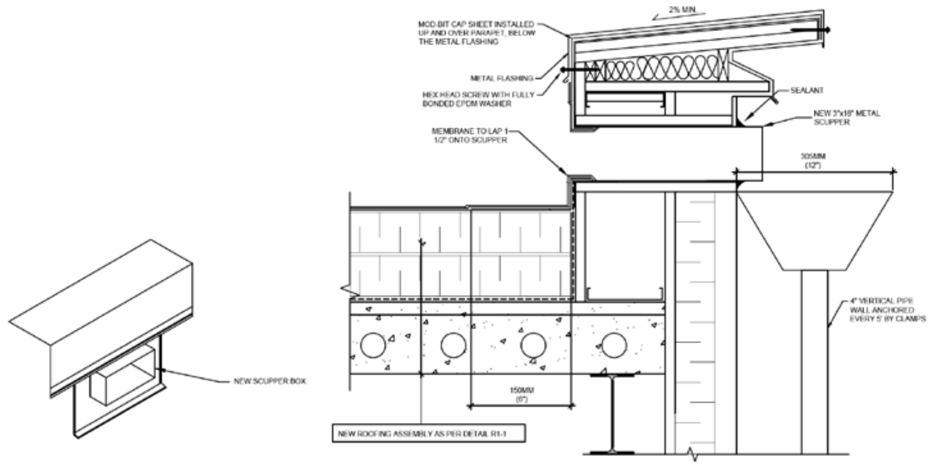

Figure 12. *Scupper and parapet detail.*

and scupper levels to meet planned blue roof design water storage capacity loads. Multiple methods to validate final installed new roof membrane levels were employed. Based on these actual site conditions, final blue roof water storage volume and overflow drainage heights were confirmed. Hand tape measurements, laser levels, and total station surveys were completed during several stages during new roof assembly construction to confirm that the planned maximum storage capacity water levels were maintained.

After construction was completed and installation was commissioned, blue roof water flood testing was conducted to validate the roof and flow control systems integrity. Mobile truck pumped 16,000 L (4,200 gal.) of water onto the roof, and a systematic monitoring program was implemented to confirm the absence of leaks and proper operations of the mechanical systems.

DISCUSSION

Implementing this blue roof pilot project at the CVC Head Office in Mississauga is testing this emerging and innovative approach to urban water management and climate resilience. It provides valuable insights into the feasibility and practicality of blue roofs installations in municipal settings, highlighting benefits and challenges encountered during the design and construction phases.

The pilot project incorporated an ongoing maintenance and monitoring program. The mechanical system includes drain sensors and control instruments to regulate flow. These components are scheduled for regular maintenance and monitoring to ensure proper performance. The roof assembly's embedded EFVM conductive medium allows for regular testing for moisture ingress and diagnostics in case of leaks.

Blue roofs, by design, increase the risk by intentionally ponding water. Structural load analysis, and incorporating redundancy and fail-safe mechanisms to the design, manages the risks. The design includes two separate types of overflow drainage pathways (i.e., scuppers and drainpipes) to prevent water accumulation beyond safe levels. The roof membrane system and the drain sensors include intentional redundancy to manage risks over the life cycle of the design. Preliminary analysis conducted by the CVC concluded that the blue roof pilot, in conjunction with their existing RWH, can harvest 8.84 m^3/day (2,300 gal./day) of non-potable water, surpassing their current demand of 5.68 m^3/day (1,500 gal./day).[35] It is also projected to save approximately 11.6 GJ of energy annually, translating to 3,210 kWh of electricity and a cost reduction of $302 annually due to the cooling effects of ponding water.[35] Accordingly, the system could reduce greenhouse gas emissions by about 0.18 tonne (0.2 ton) of CO^2e annually.[35] CVC has installed monitoring equipment to gather data over the next two years to confirm these projections.

Over the coming years, the CVC aims to evaluate the total volume of stormwater diverted from the storm sewer system, monitor roof surface temperatures reduction due to the blue roof, estimate annual water savings from rainwater reuse, and calculate energy savings from rooftop evaporative cooling.[35] In addition, TMU is researching this pilot project. Their primary objective is to investigate the public health hazards related to standing water on the roof and consider strategies to mitigate such risks.[36] They will also assess the rationale of the 24-hour time limit for standing water described in the *Ontario Building Code.*[36] The authors of this paper will continue to review and monitor the roofing assembly and its long-term performance.

Figure 13. *Roof assembly installation in progress.*

Figure 14. *Blue roof flood testing in progress.*

CONCLUSION

Intentionally ponding water on building's roofs commands greater interrogation of each design element. Designers need to reconsider some of the conventional wisdom and accepted best practices in managing water on roofs. Instead of efficiently moving water off the deck, as most roofs are designed, risk management is employed to sustain ponded water for prolonged periods.

Blue roof systems can present a promising mitigation strategy to the pressing challenges of urban stormwater management, exacerbated by urbanization and climate change. Through comprehensive understanding of technology classification, historical context, modern applications, and case studies, the impact and risks of this innovative approach on buildings can be managed.

ACKNOWLEDGMENTS

The authors would like to sincerely thank Credit Valley Conservation for their invaluable support and collaboration throughout the implementation of the blue roof project described in this paper. We also acknowledge the support of Enviro-Stewards and Trio Roofing Systems, who contributed to the success of this endeavour.

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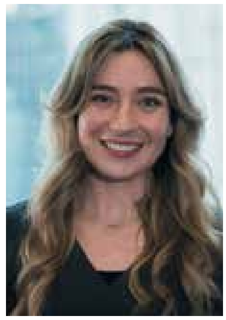

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