Exploring best practices to integrate low carbon resilience into rooftop systems

Prepared by: Yang Li, UBC Sustainability Scholar, 2025
Prepared for: Karin Johnson, Senior Climate Action Planner and Patrick Nnoka, Corporate Energy & Emissions Specialist, Climate Action Division, Energy and Climate Action Department, City of New Westminster

July, 2025

Disclaimer

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organizations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of City of New Westminster staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of City of New Westminster or the University of British Columbia.

Acknowledgements

The author acknowledges that the work for this project took place on the unceded ancestral lands of the Musqueam.

We recognise and respect that New Westminster is on the unceded and unsurrendered land of the Halkomelem speaking peoples. We acknowledge that colonialism has made invisible their histories and connections to the land. As a City, we are learning and building relationships with the people whose lands we are on.

The author would like to thank the following individuals for their contribution, feedback, and support throughout this project:

City of New Westminster: Patrick Nnoka, Karin Johnson, Laura Sampliner, Angela Zhang, Ryan Coleman, and Ken Cheng.

Cover photo courtesy of City of New Westminster

Contents

List of Figures

List of Tables

Executive Summary

This report explores best practices for integrating low-carbon, climate resilient features into rooftop systems such as solar photovoltaics, solar thermal, green roofs, and cool roofs on Part 3 buildings in the City of New Westminster. The study supports the City's climate action goals by identifying opportunities for rooftop designs and retrofits that reduce emissions, enhance energy resilience, and improve climate adaptation. Drawing from policy reviews, technical analysis, and interviews with City staff, the report evaluates key performance, cost, and operational trade-offs across systems. A high-level checklist was developed to help guide future rooftop retrofit planning. Research suggests that integrated rooftop strategies offer the greatest co-benefits in urban settings. Lessons from New Westminster and leading cities worldwide highlight the importance of aligning rooftop investments with lifecycle capital planning and climate equity priorities.

Abbreviations

GHI: Global horizontal irradiance

DNI: Direct normal irradiance

DHI: Diffuse horizontal irradiance

GTI: Global tilted irradiance (in an inclined plane)

TMY: Typical meteorological year

BC Hydro: British Columbia Hydro and Power Authority

BIM: Building Information Modeling

CAEP: Community Energy and Emissions Plan

EE: Energy Efficiency

FCI: Facility Condition Index

GIS: Geographic Information System

GHG: Greenhouse Gas

GHI: Global Horizontal Irradiance

GTI: Global Tilted Irradiance

HVAC: Heating, Ventilation, and Air Conditioning

kW/kWh: Kilowatt/Kilowatt-hour

MURB: Multi-Unit Residential Building

NRCan: Natural Resources Canada

O&M: Operations and Maintenance

PV: Photovoltaic (solar power system)

PV/T: Photovoltaic Thermal Hybrid System

1 Introduction

The City of New Westminster is committed to reducing its overall carbon footprint and will strive to achieve net zero carbon emissions by 2030, in alignment with the City's Corporate Energy and Emissions Reduction Strategy (City of New Westminster, 2022). By 2030, all new and replacement heating and hot water systems will be zero emissions. In the building sector, community carbon emissions for all homes and buildings will be reduced significantly. The City of New Westminster continues to invest in renewable energy generation, including solar photovoltaics (PVs) system, to enhance local grid resilience. By 2030, the city aims to generate 2% of its electricity from local renewable sources, rising to 5% by 2050 (City of New Westminster, 2022). Current urban solar gardens (details can be found in section 5.1 on Urban Solar Gardens in New Westminster) on city properties illustrate successful community-scale renewable energy integration, demonstrating their feasibility and scalability.

1.1 Project objectives

The purpose of this project is to explore how mitigation and adaptation measures can be incorporated into rooftops and to develop a checklist (Appendix A: High-level Checklist) to help guide decision-making when a rooftop is being designed or being replaced. Research questions include, but are not limited to:

1) What key factors should be considered when evaluating the potential of rooftop spaces for installing solar panels, green roofs[1], cool roofs[2], and rooftop solar thermal systems[3] in multi-unit residential and commercial buildings?
2) To what extent do the available options compete with each other in roof systems?
3) To what extent can the available options be combined?
4) What are the best practices for monitoring and maintaining these systems?
5) What data/information is needed in the early stages of planning during the retrofit or design of buildings to help determine the feasibility of these options?

1.2 Scope and definition

This study focuses on Part 3 buildings, as defined by the BC Building Code. This encompasses all buildings taller than three storeys or with footprints exceeding 600 square meters, along with

[1] Refer to page 12 of Volume 2 of the Integrated Stormwater Management Plan for definition.

[2] Cool roof definition

[3] Solar thermal definition

certain smaller buildings serving specific purposes, such as malls, offices, apartments, hospitals, daycares, schools, places of worship, theatres, and restaurants.

This study examined four types of roof-top systems and their applications within these building types:

- **Solar Photovoltaics (PVs):** These systems convert energy from the sun into electricity (Natural Resources Canada, 2011a, 2011b).
- **Solar thermal technologies:** Also known as active solar systems, These technologies capture solar radiation and actively transfer the heat via pumps or fans for storage or immediate use (Natural Resources Canada, 2010).
- **Green Roofs**: These rooftops feature drainage layers and growth media that support live vegetation.
- **Cool Roofs**: These systems utilize reflective materials or coatings to reduce surface temperatures and minimize heat absorption into buildings (ENERGY STAR, 2025).

2 Background and policy

The City of New Westminster recognizes rooftops as critical assets in achieving sustainability and climate resilience objectives. Building on previous initiatives, such as community solar gardens, the City seeks to use rooftop spaces for renewable energy generation and green infrastructure integration. This background section synthesizes key municipal policies and strategic documents.

Table 1 integrates explicit and inferred connections from policy documents to the targeted rooftop systems, including solar PVs, solar thermal systems, green roofs, cool roofs.

New Westminster's policy documents emphasize the strategic focus on renewable energy generation, climate resilience, and green infrastructure integration. Key city policies, including the Community Energy and Emissions Plan and the Corporate Energy and Emissions Reduction Strategy, highlight specific targets for increasing local renewable energy generation, through solar photovoltaics and solar thermal systems, to support grid resilience and achieve carbon neutrality by 2030. Initiatives, such as community solar gardens, exemplify successful local renewable implementation, provide practical frameworks for future rooftop projects.

The Integrated Stormwater Management Plan, Biodiversity and Natural Areas Strategy, and Urban Forest Management Strategy reinforce the role of green roofs in managing stormwater, to reduce urban heat island effects, enhance biodiversity, and contribute to the city’s targeted increase in urban forest canopy coverage to 27% by 2030. Furthermore, the Facility Asset Management Plan emphasizes the integration of technologies, such as designing for larger capacity HVAC systems, installing emergency generators, and improving site drainage system design, in building design and retrofits to conduct vulnerability assessments and resilience upgrades in response to anticipated climate-related risks.

The City's Green Building Policy emphasizes the need for a transition to Net Zero Energy Buildings. A climate equity framework, which was developed and identified in a previous UBC Sustainability Scholar project, recommended climate equity indicators, including urban heat island index, heat vulnerability, proximity to green space, and access to solar PV systems. In 2019, Council declared a climate emergency and committed to taking bold action to achieve the greenhouse gas reductions required to keep global temperature increases below 1.5°C. Council went further through the development of the eight Bold Steps for Climate Action with the goal of moving New Westminster towards a zero carbon future by 2050, as depicted in Figure 1.

Figure 1 The City of New Westminster's Eight Bold Steps for Climate Action (photo credit: City of New West)

Table 1 Summary of background policy documents and related rooftop system targets

Background policy document	Target related				Key notes
	Solar PVs	Solar Thermal System	Green Roofs	Cool Roofs	
Community Energy and Emissions Plan (October 2022)	Expand solar PV systems, increase local renewable generation to 2% (2030) and 5% (2050). Community solar gardens as examples of successful implementation.	Expand solar thermal opportunities to enhance renewable integration	Recommended by Biodiversity Strategy and Urban Forest Management Plan; support biodiversity, stormwater management, and carbon sequestration	(Not explicitly mentioned)	Emphasizes renewable energy storage and generation to enhance grid resilience; integration of natural systems for climate adaptation
Corporate Energy and Emissions Reduction Strategy (September 2020)	Invest in smart electrical grids to support rapid PV electrification in buildings and transport by 2030.	Encourages zero-emission heating and hot water systems by 2030	(Not explicitly mentioned)	(Not explicitly mentioned)	Targets carbon neutrality by 2030, zero-emission buildings and transport; supports integration of renewable energy and emissions reduction
Urban Forest Management Strategy	(Not explicitly mentioned)	(Not explicitly mentioned)	Supports green roofs to enhance biodiversity, urban cooling, and contribute to the urban forest canopy expansion to 27% by 2030	Indirectly supports cool roofs through urban cooling	Enhancing green infrastructure to manage climate resilience, urban cooling, and biodiversity

Facility Asset Management Plan (February 2024)	Recommends incorporating renewable energy sources like PV in facility upgrades to address climate resilience	Supports renewable energy systems for increased resilience	Recommends green roofs to enhance building resilience against climate risks, manage stormwater, and improve site drainage systems	Supports implementation to reduce heat impacts	Highlights vulnerability assessments and climate resilience strategies for facility management, promoting upgrades that integrate renewable and adaptation measures
Integrated Stormwater Management Plan Volume 1 & 2 (March 2017)	(Not explicitly mentioned)	(Not explicitly mentioned)	For stormwater mitigation, improved runoff control, and ecological benefits; specifically pages 12-13 of Volume 2 focus explicitly on green roof functionality.	(Not explicitly mentioned)	Provides technical guidance for stormwater infrastructure and emphasizes significant ecological and stormwater management benefits of green roofs
Biodiversity and Natural Areas Strategy (April 2022)	(Not explicitly mentioned)	(Not explicitly mentioned)	Encouraged for biodiversity enhancement; recommends plant species adapted for rooftop installations to maximize habitat creation	(Not explicitly mentioned)	Identifies rooftop gardens and green roofs as key strategies for biodiversity enhancement, habitat creation, and ecological compensation for urban development footprint

3 Research methodology and study area

Figure 2 illustrates the overall workflow of this study, which follows a systematic and iterative process comprising six key stages. The process begins with the definition of the research scope and objectives, establishing the study's foundational direction. This is followed by a comprehensive review of relevant policies and background documents to contextualize the research within municipal and sustainability frameworks. The third step involves a literature review targeting peer-reviewed studies to identify key evaluation factors, competitive dynamics, and integration potential of rooftop systems. The fourth step focuses on the development of a decision-making framework, integrating the findings from previous steps. In the fifth stage, a preliminary checklist is designed to support practical rooftop assessments. Finally, the study concludes with recommendations and a proposed outline for future application and refinement. Each step builds upon the last, ensuring a structured approach to understanding and guiding rooftop mitigation and adaptation strategies.

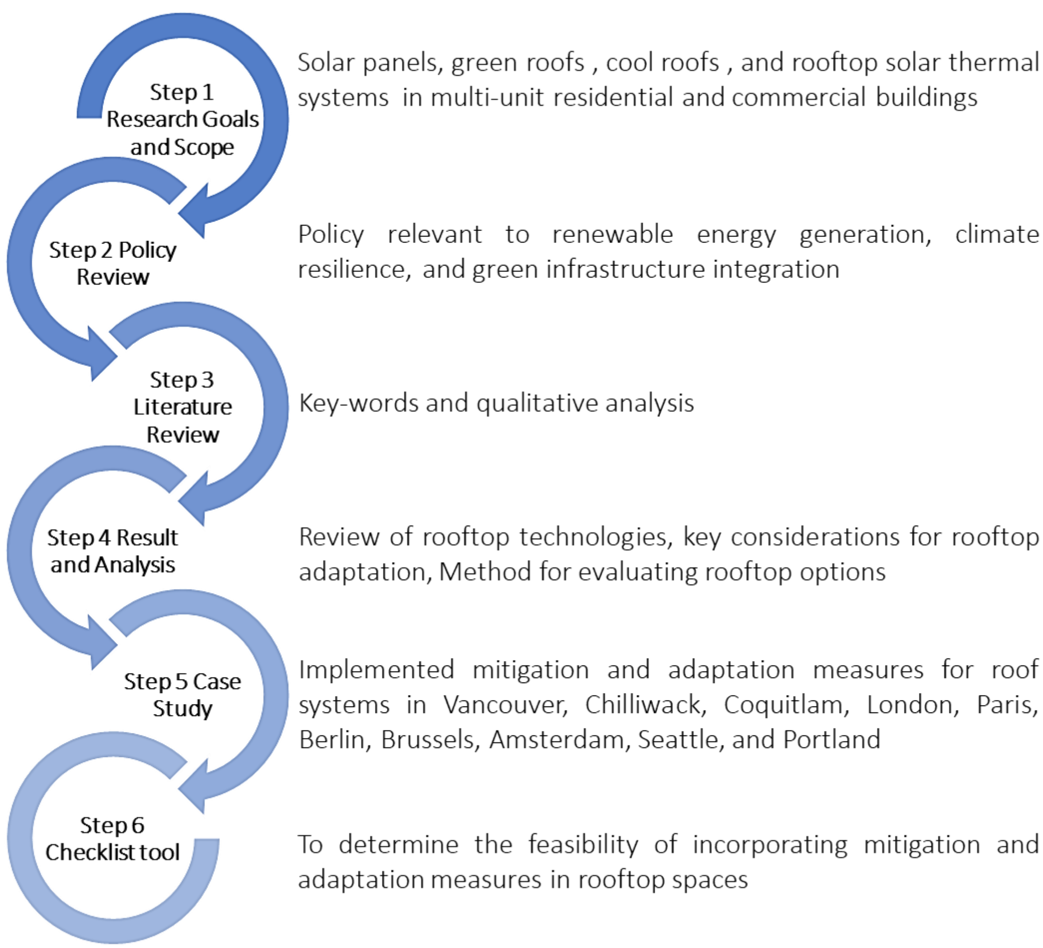
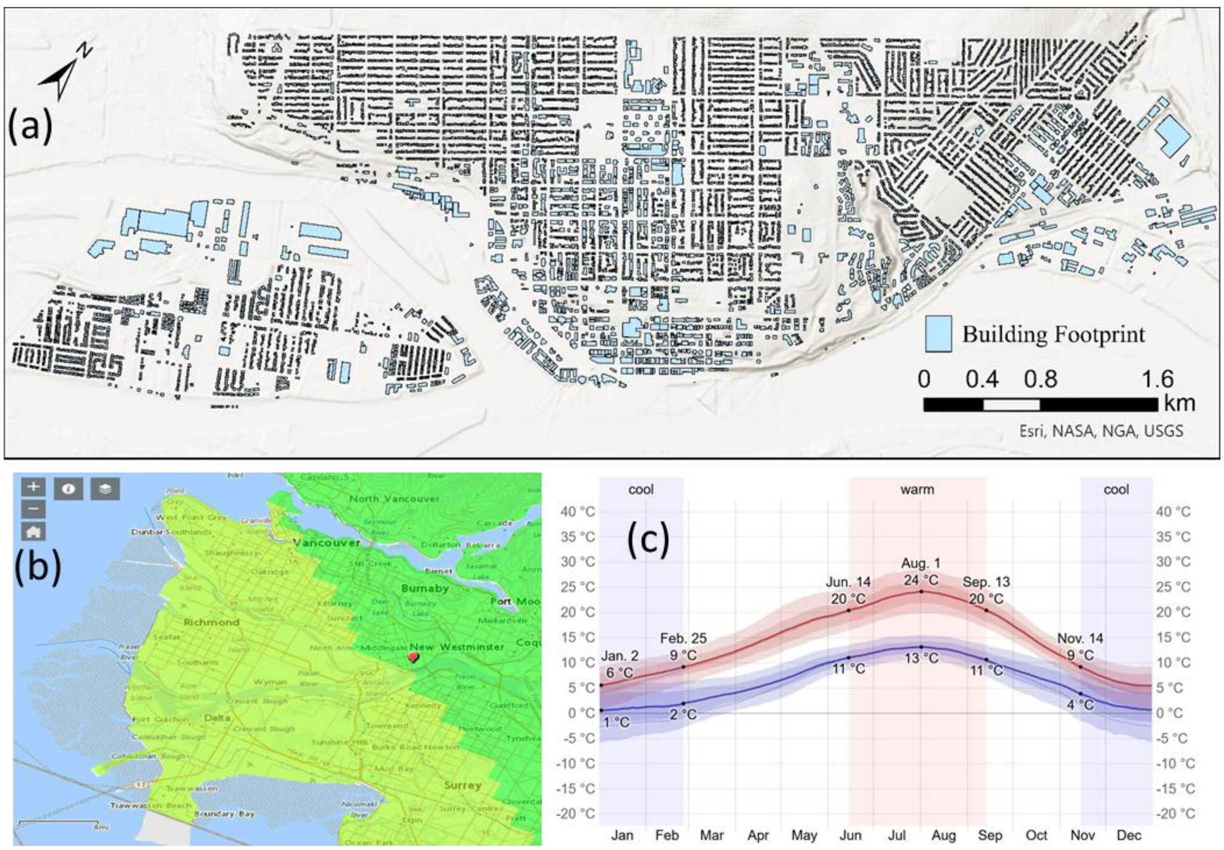


Figure 2 Workflow of this study

Figure 3 presents an overview of the spatial and climatic conditions relevant to rooftop system evaluation in the City of New Westminster. This information helped to narrow down the types of roof-top systems included in the study. Panel (a) displays the 2D building footprint map, illustrating the density and distribution of structures across the study area. Panel (b) shows the city's photovoltaic (PV) potential and solar resource availability, with color-coded gradients indicating mean annual and monthly PV yield as well as solar insolation levels. This data provides insights into the spatial variability of solar energy availability when applying solar thermal or PV roof-top systems. Panel (c) illustrates the annual temperature profile of the region, highlighting seasonal variations from cool winters to warm summers. The temperature curve helps contextualize rooftop system performance, particularly for evaluating energy savings from green and cool roofs or the efficiency of solar thermal systems.



Photovoltaic potential, annual (kWh/kWp)	0 - 500	500 - 600	600 - 700	700 - 800	800 - 900	900 - 1000	1000 - 1100	1100 - 1200	1200 - 1300	1300 - 1400	1400 +
Photovoltaic potential, monthly (kWh/kWp)	0 - 20	20 - 40	40 - 60	60 - 80	80 - 100	100 - 120	120 - 140	140 - 160	160 - 180	180 - 200	200 +
Mean daily global insolation (kWh/m2)	0 - 0.8	0.8 - 1.7	1.7 - 2.5	2.5 - 3.3	3.3 - 4.2	4.2 - 5	5 - 5.8	5.8 - 6.7	6.7 - 7.5	7.5 - 8.3	8.3 +
Mean daily global insolation (MJ/m2)	0 - 3	3 - 6	6 - 9	9 - 12	12 - 15	15 - 18	18 - 21	21 - 24	24 - 27	27 - 30	30 +

Figure 3 Landscape, yearly temperature and PV maps in studied area

(a) 2D Building Footprint in studied area, map authorized by Yang Li, original data sources from (BC Assessment Authority, 2024); (b) Photovoltaic potential and solar resource maps in the City of New Westminster, data sources from Photovoltaic potential and solar resource maps of Canada; (c) yearly temperature variation in studied area, © *WeatherSpark.com*.

4 Results

To support rooftop retrofit decision-making, this section presents a comparative evaluation of four rooftop systems: solar PVs, solar thermal systems, green roofs, and cool roofs. Each system was assessed in terms of its purpose, performance, climate suitability, GHG mitigation and adaptation value, and maintenance needs (Table 2). The following table provides a high-level comparison.

Table 2 Comparisons of four type of roof-top systems

Category	Solar PV	Solar Thermal	Green Roof	Cool Roof
Primary function	Electricity generation	Heat generation (water/space)	Stormwater mgmt., insulation	Reflect solar heat
Performance efficiency	15–20% (electrical)	35–50% (thermal)	Retains 50–80% of rainfall; lowers surface temp by 20–40°C	Reflects 60–90% sunlight; reduces roof temp by 20–30°C
Climate suitability	Broad (sun-access required)	Broad (better in sunny areas)	Best in temperate/rainy zones	Best in sunny/hot regions
GHG mitigation potential	Offsets 0.3–0.5 tCO_2/kW/year	Offsets 1–2 tCO_2/year/building	Indirect via insulation & vegetation	Reduces AC demand by 10–20%
Adaptation benefits	Grid resilience, backup	Reduces gas/electric heating load	Urban heat island, biodiversity	Urban heat mitigation
Installation complexity	Moderate (requires inverter & panel mounting)	Moderate (pumps, collectors, storage)	High (structure, drainage, planting)	Low to moderate (coatings or membranes)
Maintenance needs	Low (cleaning, inverter checks)	Medium (fluid replacement, sensors)	High (plant care, drainage)	Low (recoating every 7–10 yrs)
Typical lifespan	25–30 years (panels)	20–25 years (collectors)	20–50 years (membrane plus vegetation)	10–20 years (coating dependent)

Best use case	Buildings with high electricity demand and unshaded roof space	Buildings with high DHW demand	Urban buildings needing stormwater and thermal benefits	Cooling needs in flat-roof buildings in warm climates

4.1 Review of rooftop technologies

Urban rooftops can host a variety of sustainable technologies that provide energy savings, reduce building heat gain, and manage stormwater.

4.1.1 Solar Photovoltaics (PVs)

Purpose and scope: Solar PV panels produce on-site renewable electricity, offsetting a building's grid consumption and lowering greenhouse gas emissions. They are typically installed on rooftops or integrated into roof structures of apartments, offices, and commercial buildings. PV systems help meet a portion of a building's electrical demand (lighting, appliances, etc.) with clean energy, thus supporting energy independence and climate goals (Zhang et al., 2025). They operate silently with minimal maintenance (modules often carry 25-year warranties (BC Housing Research Center, n.d.)) and can be scaled from small installations on low-rise multifamily buildings to large arrays on commercial rooftops.

There are two primary operational models for PV systems in urban contexts: net metering and load displacement. Net metering allows buildings to export surplus electricity back to the grid, earning utility bill credits. Load displacement, on the other hand, refers to self-consumption of solar energy within the building to reduce energy drawn from the grid without exporting surplus (SEPA, 2015). This model is common for individual retrofits and is often more straightforward to implement when local interconnection or utility credits are limited.

Performance: Modern crystalline silicon PV modules exhibit conversion efficiencies in the 15–20% range (laboratory or premium modules slightly higher) (Zhang et al., 2025). This means a fraction of the incident solar radiation is converted to electric power, with the rest lost as heat. The energy output of a PV system depends strongly on solar resource and system size. A common benchmark is the specific yield in kWh per kW of installed capacity. Typical yields range from about 1,000 kWh/kWp to over 2,000 kWh/kWp per year depending on location and climate (Carilec, 2019). For example, many mid-latitude regions receive sufficient sun for roughly 1,100–1,500 kWh per kW annually, whereas sunnier regions (low latitudes or arid climates) may exceed 1,800–2,000 kWh/kW (World Bank, 2020). In fact, 93% of the world's population lives in areas with an average daily PV potential of 3–5 kWh per kW (approx. 1,100–1,800 kWh per kW yearly), indicating broad applicability of solar PV across climates (Carilec, 2019). Performance does decline modestly with high temperatures and non-ideal orientation, but even in cloudy or temperate climates PV can generate significant energy over a year. Many multi-unit buildings can self-produce a sizeable portion of their annual electricity needs with available roof space – studies show PV systems can cover upwards of 50–75% of residential building consumption in favorable cases (Borodiņecs et al., 2024).

Typical commercial or residential rooftop PV systems reduce building electricity bills and can produce 100–200 W per square meter of panel under peak sun, translating to several hundred kWh per square meter annually (Zhang et al., 2025). Climate suitability is broad, though regions with higher solar insolation will yield proportionally more energy. In summary, PV technology offers a reliable means of harvesting solar energy for power, with performance on the order of 1 MWh/year per kW in many locales and higher in sunny climates (Carilec, 2019).

Detailed case studies can be found in 5.2 Examples of successful rooftop systems in Vancouver, Chilliwack, Seattle, and Amsterdam.

Mitigation and adaptation potentials:

- On-site electricity generation reduces dependence on grid-supplied fossil energy.
- In Canada, rooftop PV can offset 40–75% of a typical building's annual electricity demand depending on roof size and solar access (Natural Resources Canada, 2016).
- Each kilowatt of PV avoids 0.3–0.5 tonnes of CO_2/year, depending on local grid intensity.
- Enhances energy resilience by decentralizing supply; systems with battery backup support critical loads during outages.
- Reduces transmission losses in dense urban grids.

Best practices for monitoring & maintenance:

- Use real-time monitoring systems to track performance and detect faults (e.g., string mismatch, inverter failures) (Keating et al., 2015).
- Panels should be cleaned 1–2 times/year in areas with dust, pollen, or bird activity to prevent >5% energy loss (Nezamisavojbolaghi et al., 2023).
- Annual visual inspections for degradation, cracked modules, or loose wiring (NREL, 2017).
- Inverter replacement typically needed after 10–15 years; panels last 25–30 years (Walker et al., 2023).

4.1.2 Solar Thermal Systems

Purpose and scope: Solar thermal systems (often solar water heaters) use rooftop collectors to absorb sunlight and produce heat for domestic hot water or space heating. In multi-unit residential buildings, solar thermal panels are commonly used to pre-heat water for all the units (reducing gas or electric water heating demand), while commercial buildings (hotels, hospitals, etc.) may use them for hot water or process heat. The typical setup includes flat-plate or evacuated tube collectors on the roof, a circulating fluid that carries heat, and storage tanks. The objective is to achieve fuel savings (e.g., lower natural gas or electricity use for water heating) and provide a renewable heat source. Solar thermal is a passive renewable system, and once installed, it uses free solar energy to meet a portion of the building's heating needs, thereby cutting energy bills and emissions (U.S. DOE, 2025b). Unlike PV, it cannot directly supply electricity, but by handling water heating loads it indirectly reduces overall building energy use.

Performance: Quality solar thermal collectors can achieve an efficiency of roughly 35–50% in converting incident solar radiation into usable heat (Climate Action Accelerator, 2025). This is higher than PV's electrical efficiency, since thermal conversion is less constrained by semiconductor limits. In practical terms, a well-designed solar hot water system can supply 50% or more of a building's annual hot water demand in many climates (U.S. DOE, 2025b). The solar fraction (the portion of the load met by solar) typically ranges from 0.5 to 0.75 for common systems – meaning 50–75% of the water heating energy comes from the sun, with the remainder supplied by backup heaters (U.S. DOE, 2025b). For example, in Canada a standard solar thermal setup (6 m^2 of flat-plate collectors, 270 L tank) provides about 1,500–3,000 kWh of heat per year, which is roughly 40–50% of a household's water heating energy (NRC, 2000). In sunnier regions, output can be higher; generally, each square meter of collector can yield 400–700 kWh of thermal energy annually depending on climate. Efficiency varies by technology: flat-plate collectors (most common) might capture 40% of sunlight as heat, whereas evacuated tube collectors can reach 50% under optimal conditions (Climate Action Accelerator, 2025), especially in colder weather due to better insulation. In terms of impact, installing a solar thermal system can cut water heating bills by 50–80% on average (U.S. DOE, 2025b). This corresponds to several hundred dollars saved annually for a multi-family building, and a significant reduction in fossil fuel use. Climate applicability is wide: even in temperate or cool climates, solar thermal contributes useful energy (though output is highest in summer). Freeze protection and proper sizing are important in cold regions, but modern systems can be designed for year-round use virtually anywhere. Overall, solar thermal collectors effectively turn sunshine into hot water with seasonal efficiencies 2–3 times higher than electric PV for the same area, making them a strong choice for reducing conventional heating energy in buildings (Hachchadi et al., 2023).

Detailed case studies can be found in 5.2 Examples of successful rooftop systems.

Mitigation and adaptation potentials:

- Directly replaces fossil-fueled heating (e.g., natural gas), reducing CO_2 emissions.
- A well-sized system can meet 50–75% of domestic hot water needs, cutting 1–2 tonnes CO_2/year in a mid-sized building (Kalogirou, 2004).
- Enables thermal service during grid interruptions.
- Cuts summer demand for hot water heating, aiding grid stability.

Best practices for monitoring & maintenance (U.S. DoE, 2025):

- Installed at inlet/outlet temperature sensors for real-time performance tracking.
- Inspect annually for leaks, pressure drops, corrosion in pipework, and stagnation in glycol systems.
- Drain and refill heat transfer fluid every 3–5 years for flat-plate or evacuated tube systems.
- Use antifreeze mix or drain-back systems in cold climates.

4.1.3 Green Roofs

Purpose and scope: Green roofs (also known as vegetated roofs or rooftop gardens) are roof surfaces that are partially or completely covered with living vegetation over a waterproof membrane. The key objectives of green roofs in urban buildings are stormwater management, thermal insulation/heat mitigation, and biodiversity/amenity. By absorbing and retaining rainfall, green roofs drastically reduce runoff volume and delay peak flows, helping alleviate storm sewer loads in cities (EPA, 2021). They also shield the roof and provide evaporative cooling: plants and soil absorb solar energy and use it to evaporate water, which cools the roof surface and the surrounding air. This leads to lower roof temperatures and reduced heat transfer into the building, cutting air-conditioning needs. Additionally, the soil layer adds insulation, improving energy efficiency in both summer and winter. Urban planners also value green roofs for their ability to combat the urban heat island effect by cooling the microclimate, as well as for creating green space for urban agriculture or leisure in dense cities. In summary, a green roof's scope spans environmental (rainwater retention, air quality improvement), thermal (building energy savings, cooler cities), and social (aesthetic and recreational) benefits, making it a multifaceted sustainability strategy for rooftops (US EPA, 2014).

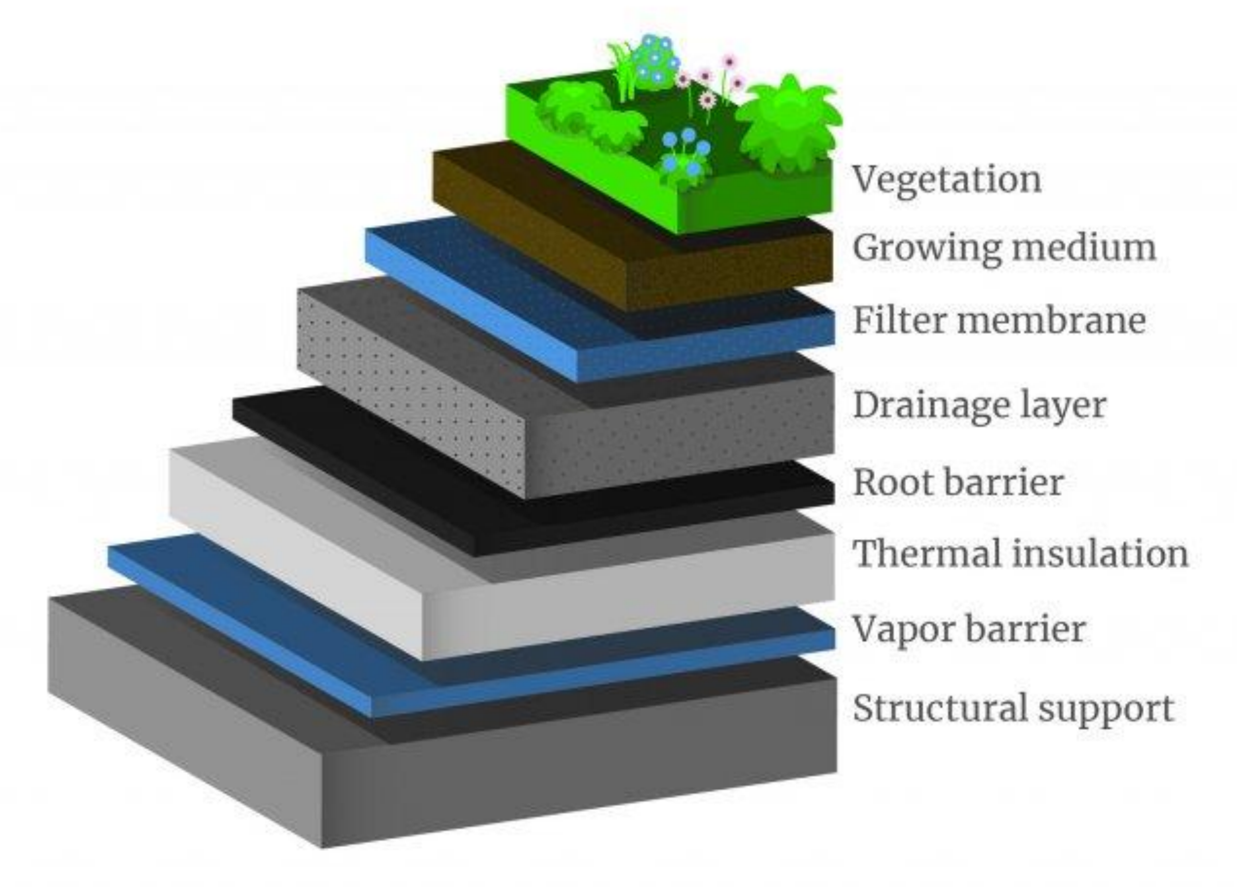


Figure 4 Typical green roof layers (EPA, 2021)

Performance: A well-designed green roof can retain a large fraction of rainfall events. On an annual basis, extensive green roofs (thin soil 10 cm) typically retain 50–60% of total rainfall in temperate climates, and virtually 100% of small rain events during growing season months (PennState, 2025). For instance, a 4-inch (10 cm) sedum roof in Pennsylvania captured about 50–60% of yearly precipitation in a study (PennState, 2025). During intense storms, the green roof slows and reduces runoff – overall runoff volume reductions of 30–90% have been reported across events, with greater effectiveness for smaller storms (EPA, 2021). In terms of thermal effects, green roofs significantly lower roof surface temperatures. Measurements show the vegetated surface can be 30°C cooler than a conventional bare roof on a hot summer day. (For example, midday surface temperatures on a green roof might be 25°C versus 55°C on black tar.) This cooling translates to interior benefits: one study found green roofs reduced a building's cooling load by up to 70%, and lowered indoor air temperatures by as much as 15°C in summer (in an unconditioned top floor) (US EPA, 2014). Such large improvements may represent best-case scenarios; more typically, energy modeling and experiments indicate green roofs can yield around 10–30% reductions in cooling energy use for the top floors, depending on climate (Jia et al., 2024). In Seoul, for instance, a green roof was estimated to save over 2 kWh/m² of cooling energy (nearly 30% of total HVAC use) under current climate conditions (Jia et al., 2024). The insulation and thermal mass of the soil also provide a small heating energy benefit in winter (though green roofs are primarily a cooling strategy). Beyond energy, the vegetation layer filters air pollutants and can sequester carbon, and the roof membrane's lifespan is extended (protected from UV and temperature extremes). Stormwater metrics: green roofs often retain 80%+ of rain from small storms and 50% of annual rainfall (EPA, 2021). Thermal metrics: surface temperature drops of 20–40°C and associated HVAC savings of 10–30% are achievable (US EPA, 2014). Ultimately, the performance depends on roof design (depth, plant selection) and climate – greener, thicker roofs yield more stormwater and cooling benefits at the cost of weight and maintenance. Even lightweight extensive green roofs, however, reliably offer environmental benefits in urban settings.

Detailed case studies can be found in 5.2 Examples of successful rooftop systems in Paris.

Mitigation and adaptation potentials:

- Moderate cooling of roof surface reduces building cooling energy by 10–30%, lowering electricity-related GHGs.
- Promotes carbon sequestration through biomass accumulation (small but non-negligible).
- Reduces urban albedo, indirectly lowering cooling energy use city-wide.
- Retains 50–80% of rainfall annually, easing pressure on storm sewers.
- Relieves urban heat island and reduces rooftop and surrounding air temperatures by 1–3°C.
- Maintains more stable indoor temperatures, especially during heat waves.

Best practices for monitoring & maintenance (City of Annapolis, n.d.):

- Twice-yearly checks (spring and fall) for plant health, drainage blockages, and waterproof membrane integrity.
- Remove invasive species to maintain native ecosystem.
- Irrigation needed during establishment or in prolonged droughts.
- Thin spots or erosion-prone areas should be replanted every few years.

4.1.4 Cool Roofs

Purpose and scope: Cool roofs are roofs designed or treated to reflect sunlight and emit heat more effectively than standard roofs. They typically have a high-albedo (high reflectance) surface, often bright white or light-colored coatings, membranes, or shingles that minimizes solar heat absorption. The goal is to keep the roof and building cooler, thereby reducing the need for air conditioning and mitigating the urban heat island effect. Cool roof strategies are particularly relevant for commercial buildings with large flat roofs and for multi-family buildings in warm climates, though they can be applied anywhere a roof can be made reflective. By simply using reflective roofing materials (or coatings over existing roofs), cool roofs offer a passive cooling technique: less solar energy is stored as heat in the building, so interior temperatures remain lower and HVAC loads drop (Stone, 2023; U.S. DoE, n.d.). On a city scale, when covering large percentages of a city's rooftops with reflective materials, municipalities actively cool ambient air temperature by a few degrees during heat waves, to improve outdoor comfort and air quality (Stone, 2023). Considerations are needed for cool roofs in colder climates as they reflect winter sun that might have provided slight heating, however, studies show that the winter heating penalty is usually much smaller than the summer cooling savings in most climates (U.S. DoE, n.d.).

Figure 5 A typical cool roof system. A Cool Roofing product shows higher solar reflectance compared to other conventional roof materials of the same color (BIM International, 2025).

Performance: A typical dark roof (e.g., black asphalt) might reflect only 5–20% of sunlight, whereas a cool white roof can reflect 60–90%. This dramatic difference keeps surface temperatures much lower. On a sunny summer afternoon, a conventional flat roof can reach 65–80°C, while a highly reflective white roof might stay around 40–50°C – roughly 30°C cooler (California Air Resources Board, 2025). The U.S. Department of Energy (DOE) reports that under identical conditions, a reflective roof was over 50°F (28°C) cooler than a dark roof (U.S. DOE, 2025a). By reducing heat flux into the building, cool roofs yield significant air-conditioning energy savings. In hot climates, switching from a dark to a cool roof can cut annual cooling energy use by 10–15% (for a one-story or top-floor space) (U.S. DoE, n.d.). For example, a study found that an 85% reflective roof reduced total building energy consumption by about 12% in a hot climate scenario (Bamdad, 2023). More broadly, modeling across different climates shows cool roofs can save anywhere from 15% up to 35% of cooling electricity, with larger percentage savings in regions with high AC demand (Zhao et al., 2024). One field analysis by the U.S. DOE indicates that installing a white reflective roof on a commercial building yielded energy savings worth up to $0.20 per square foot per year (in cooling-dominated climates) (U.S. DoE, n.d.). In addition, indoor temperatures in buildings without air-conditioning are markedly improved. A cool roof can lower indoor air by several degrees, improving comfort and health during heat waves (U.S. DOE, 2025a). Key performance indicators for cool roofs include solar reflectance (often ≥0.70 for "cool" materials) and thermal emittance (≥0.8 is common). Many cool roof products have a Solar Reflectance Index (SRI) above 80, whereas a standard dark roof might have SRI near 0–20 (U.S. DOE, 2025a). In summary, a cool roof's impact is straightforward: by reflecting the majority of sunlight, it can reduce roof surface temperatures by 20–30°C and cut cooling energy use by 10–20% on average (higher in one-story buildings or hotter climates) (U.S. DOE, 2025a). This makes cool roofs a cost-effective means of lowering building energy bills and reducing urban heat. (In cooler climates, the net annual energy benefit may be smaller but still positive in many cases.) Importantly, the benefits of cool roofs scale with adoption, whole neighborhoods of reflective roofs can measurably lower ambient air temperatures and improve air quality by mitigating the heat island effect (Stone, 2023). Thus, cool roofs serve as a practical technology for more sustainable and comfortable buildings in warming cities.

Detailed case studies can be found in 5.2 Examples of successful rooftop systems.

Mitigation and adaptation potentials:

- Reduces building cooling load by 10–20%, cutting electricity use and GHG emissions from air conditioning.
- Increases solar panel efficiency if used in conjunction with PV.
- Passive cooling strategy for buildings without the need for mechanical ventilation.

- Alleviates urban heat island effect when widely adopted.
- Can help lower extreme indoor temperatures during heat events.

Best practices for monitoring & maintenance:

- Biannual cleaning to maintain solar reflectance; dust and grime can reduce reflectivity by >10%.
- Reapply reflective coating every 7–10 years depending on product and exposure (Dikshit, 2017).
- Look for cracks, peeling, or pooling water that could compromise performance.

4.2 Key considerations for rooftop retrofitting

Before selecting a rooftop system, it’s essential to integrate structural, environmental, financial, and regulatory considerations into each phase of project development, starting from feasibility, through to detailed design, implementation and operations. During feasibility, assess roof condition, load capacity, orientation, shading, and incentive structures to determine technical viability and alignment with capital plans. In the design stage, engineer integration paths (e.g., racking, drainage, wiring, coatings), specify procurement requirements, and model expected energy or water benefits. Finally, in implementation and upkeep, plan sequencing with roof replacements, set maintenance protocols (cleaning, herbicide controls, repainting), and establish performance monitoring systems to support long-term functionality and cost-effectiveness. Structuring rooftop retrofits this way ensures they align with building lifecycle stages, budget cycles, and facility management resources.

4.2.1 Structural and technical requirements

Roof load-bearing capacity, shape, and slope are fundamental. One barrier to green roof adoption is the greater load on the building structure and roof shape/slope, along with property ownership issues in multi-unit buildings (Rosasco & Perini, 2019). These technical requirements are common across systems. A flat, sturdy roof is often needed for green roofs or heavy solar thermal tanks, whereas PV panels can be mounted on various slopes but still require structural support. In multi-family buildings, property rights over a shared roof can complicate decisions, making governance and coordination a factor as well.

4.2.2 Economic considerations

Upfront installation costs and ongoing maintenance are key. Higher initial and maintenance costs relative to a conventional roof can hinder green roof implementation. Similar cost considerations apply to solar PV and thermal (e.g., panel costs, inverter replacement, etc.), though PV costs have dropped significantly in recent years. Life-cycle cost analyses (including energy savings or generation) are often used to evaluate long-term viability. Incentives or subsidies can tip the balance, for instance, tax credits have been influential for spurring PV installations.

Beyond upfront installation costs and ongoing maintenance, financial incentives can significantly impact project viability. Solar PV benefits from substantial incentives, e.g., BC Hydro rebates up to $5,000 for residential and $25,000+ for multi-unit/commercial systems, plus federal Canada Greener Homes grants and PST exemptions, reducing effective cost by up to 50 % or more (BC Hydro, n.d.; BLUETTI Canada, 2025; Solutions, 2024). Green roofs also attract support in some regions: Toronto's Eco-Roof Incentive Program offers up to $100,000 per project for residential, commercial, or institutional installations. Other municipalities, such as Saskatoon, provide stormwater fee rebates, and Port Coquitlam expedites permitting for green roof projects (Green Building, 2024).

4.2.3 Slope and orientation impacts

The roof's orientation (azimuth) and tilt angle toward the sun, as well as shading from surrounding structures, directly affect solar panel and solar thermal output. Installers typically optimize panel tilt and orientation to maximize solar capture (e.g., facing south in the Northern Hemisphere) (U.S. Energy Information Administration, 2014). Even partial shading (from nearby buildings, trees, or HVAC equipment) can significantly reduce PV output, so assessing shading is a key step in evaluating PV potential. Modern GIS and LiDAR-based studies reinforce that usable rooftop area is constrained by shading and roof geometry (Idrovo-Macancela et al., 2025). In urban cores with tall buildings, limited unshaded roof space can be a factor deciding how much PV or thermal can be installed.

4.2.4 Maintenance and operational requirements

Different options have different maintenance needs. Green roofs require irrigation (in dry climates), weeding, and structural waterproofing checks; solar panels need cleaning and occasional servicing; cool roof coatings might need reapplication over time. Evaluating a roof's potential should include the building owner's capacity to maintain the system and the expected lifespan of the roof vs. the technology. For example, green roofs can extend the waterproof membrane life by protecting it from UV and temperature extremes (Cascone, 2019), whereas installing PV may require penetrations or ballast that should be coordinated with roof replacement cycles.

4.2.5 Climate resilience and adaptation measures

Local climate greatly influences which technology is most beneficial. Both green and cool roofs aim to reduce building cooling loads, but their effectiveness depends on ambient climate conditions and building characteristics; for example, a cool roof (high reflectance) might be more effective in a hot sunny climate, while a green roof's insulation and evapotranspiration are valuable in others (Jia et al., 2024). For solar technologies, the local solar irradiance is critical: regions with high sunshine hours have greater PV and solar thermal potential. Buildings with high year-round hot water demand (e.g., apartments or hotels) may particularly benefit from solar thermal collectors, whereas those with large electricity use can offset more with PV.

4.2.6 Competition and trade-offs among rooftop options

4.2.6.1 Opportunity cost of space – energy vs. environmental benefits

Installing PV panels tends to deliver the highest direct benefits in most scenarios, consistently outperforming other single-use options in terms of energy generation and emissions reduction (Maurer et al., 2023). Also in this study, a roof covered with PV produced much more value (in energy or carbon savings) than the same roof used exclusively as a green roof or cool roof. This implies a competitive relationship: dedicating area to a non-PV use comes at the cost of foregone renewable electricity generation. However, those alternative uses provide benefits that PV does not, such as stormwater management, urban heat mitigation, or amenity space. The Maurer et al. study noted that a PV-green roof combination (sometimes called a "biosolar roof") was a *"robust" decision option across multiple criteria,* suggesting that integrated solutions may alleviate the strict either-or trade-off (more on combinations in the next section).

4.2.6.2 Thermal effects and urban climate

If one evaluates "performance" more broadly, PV panels and reflective or green surfaces have opposite impacts on the urban microclimate. A study demonstrated a potential city-scale trade-off: widespread PV deployment (dark, energy-absorbing panels) can increase local ambient temperatures due to lower roof albedo, whereas cool or green roofs would have reduced those temperatures (Khan et al., 2024). In the study in Kolkata, the authors found that widespread rooftop PV installations could increase daytime urban temperatures by up to 1.5 °C. This highlights a trade-off: while solar PV enhances renewable energy generation, it may worsen the urban heat island effect, unlike green or cool roofs which are designed to cool the environment. Thus, city planners must balance climate adaptation goals (cooler cities via high-albedo or vegetated roofs) with climate mitigation/energy goals (more solar power). Some researchers suggest this competition can be managed by combining approaches (e.g., PV on a green roof can maintain some cooling while generating energy), or by offsetting PV's warming effect through other measures.

4.2.6.3 Green roofs vs. Cool roofs (for building energy savings)

Green and cool roofs essentially compete as passive cooling strategies. A comparative study examined which of the two yields greater building energy savings under various climates (Jia et al., 2024). Generally, cool roofs (white or reflective surfaces) have an immediate advantage in sunny climates by reflecting more solar radiation, thereby keeping buildings cooler. Green roofs provide insulation and evaporative cooling but can sometimes be less effective at pure heat reflection. In fact, another study indicated that adding a reflective white membrane (cool roof) under PV panels increased annual PV output by 3.4%, whereas a vegetated (green roof) under PV increased it by 1.8% (UNSW SYDNEY, 2022). This implies that, purely for enhancing solar panel efficiency, a cool roof is more effective than a green roof. A study extended this comparison globally: they reported that PV-on-white roofs consistently outperformed PV-on-green roofs in energy output, and this performance gap may widen under future hotter climates (Hassoun & Cook, 2024). However, they also found an interesting nuance in tropical climates with high rainfall, PV-green roofs excelled, likely because the frequent rain and high humidity amplify the cooling benefit of vegetation. These findings highlight that the “competition” between green vs. cool roofs for improving solar performance or saving energy can swing based on climate context.

4.2.6.4 Solar PV vs. Solar Thermal

PV panels (for electricity) and solar thermal collectors (for hot water/heat) can also be seen as competing uses of rooftop area, especially in buildings that need both power and hot water. In a given roof area, you might install PV modules or thermal collectors (or a mix). The best choice depends on energy demand profiles and relative efficiencies. Solar thermal collectors typically have higher instantaneous efficiency (they can capture 50–70% of sunlight as heat, versus 15–20% electrical efficiency for PV panels), but they only address thermal loads (water or space heating). PV, on the other hand, generates electricity that can flexibly be used for any purpose (including operating heat pumps or electric water heaters to cover thermal needs). With the falling cost of PV, some studies have noted a trend of PV being favored over dedicated solar thermal in urban retrofits, because electricity is versatile. For multi-unit residential buildings with significant hot water demand, however, rooftop solar thermal can directly cut gas or electric water heating usage. No single study dictates a universal winner here. it’s a trade-off between using area for one form of energy vs. another. For example, a study compares stand-alone PV and thermal systems to hybrid systems, and emphasizes that available roof area often constrains total solar energy capture; thus, building owners must evaluate whether their priority is reducing electricity consumption, heating demand, or a balanced approach (they often find a mix can be optimal) (Röhrig et al., 2023). In short, PV and solar thermal compete for sun-exposed roof space, and the decision may come down to which energy need is more pressing for the building and which technology offers better returns given local conditions (including whether the building has alternative heating sources).

4.2.7 Potential for combining and integrating rooftop technologies

Many researchers advocate integrating multiple solutions on the same roof to maximize benefits, turning competition into synergy.

4.2.7.1 Biosolar Roofs (Green Roof + Solar PV)

Mounting solar panels above a green roof can create a mutually beneficial system. A study investigated such PV-green roof synergy in a “double roof” experimental setup. They found significant improvements in both building performance and panel efficiency compared to a standard PV-only roof: the vegetated roof kept the indoor environment more stable (about 6% more comfortable by their comfort index) and cooled the PV panels by up to 8°C, which in turn increased the PV energy yield by approximately 18% (Alonso-Marroquin & Qadir, 2023). This is a remarkably high boost, highlighting strong synergy in that case. (Other studies in milder climates have reported smaller but still positive gains, e.g., a Swiss simulation showed 2% PV output increase with a green roof, as noted earlier (UNSW SYDNEY, 2022). Several reviews, such as (Alonso-Marroquin & Qadir, 2023; Fleck et al., 2022), systematically examine PV-green roof combinations across climates, generally confirming that these “biosolar” roofs can improve solar efficiency in hot conditions and simultaneously provide ecosystem services (stormwater retention, urban heat mitigation) without sacrificing roof area to only one function. In practical terms, combining PV and a green roof is quite feasible on flat commercial roofs, because panels are typically mounted on racks allowing vegetation underneath. Key considerations include maintaining sufficient panel height and spacing for plant health and access for maintenance. A case study can be found in Vancouver in the section of 5.2 Examples of successful rooftop systems.

4.2.7.2 Cool roof + Solar panels

Another integration approach is to apply a reflective “cool” roof coating on all roof surfaces around and underneath PV panels. This isn’t a combination in the stacking sense, but rather treating the exposed roof areas to boost performance. A high-albedo roof surface helps keep not only the building cool but also the PV modules themselves, yielding that 3.4% increase in annual PV output (UNSW SYDNEY, 2022). While 3–4% gain may seem modest, it is a simple, low-cost intervention (painting the roof white or installing reflective membranes). And importantly, a white roof continues to passively cool the building areas not covered by the PV modules. An integrated PV and cool roof is essentially a PV system installed on a reflective roof. Both can operate simultaneously on the same area. Field experiments in hot climates (Vasilakopoulou et al., 2023; Wai et al., 2025) have shown PV panel efficiencies improve when the ambient roof temperature is lowered by cool roof coatings. Therefore, these two technologies combine nicely: one addresses building cooling and panel temperature, and the other produces electricity. PV on a white roof was consistently the top performer in energy terms under most climates – essentially endorsing the PV+cool roof combo as a high-yield configuration (Hassoun & Cook, 2024). The main limitation is that a cool roof's benefits are mostly felt in cooling-dominated climates; in cold climates, a highly reflective roof could slightly increase heating needs in winter. Integrating PV doesn't change that fact, so designers should consider climate suitability. Nonetheless, coupling PV with a cool roof is a straightforward integration that many new commercial buildings employ (reflective membrane roofing with PV arrays on top).

Detailed case studies can be found in 5.2 Examples of successful rooftop systems-Portland.

4.2.7.3 Hybrid Photovoltaic-Thermal collectors (PV/T)

Rather than mounting separate PV panels and thermal collectors, hybrid PV/T modules combine both functions in one unit. These systems produce electricity and capture usable heat from the same panel area (for example, PV cells laminated on a thermal absorber with water or air circulating to collect heat). A study showed that such hybrid panels can significantly increase the total energy harvested per square meter of roof compared to installing either technology alone (Röhrig et al., 2023). In essence, one advantage of PV/T is the ability to generate electricity and heat simultaneously, boosting the overall efficiency of roof usage. By cooling the PV cells, the thermal extraction also helps maintain electrical output. Numerous designs (water-cooled, air-cooled, heat-pump integrated, etc.) have been tested in the past decade (*PVT Modules*, n.d.). While PV/T collectors can be more expensive and complex, they illustrate the principle of combining solar technologies to avoid competition. For multi-unit residential buildings, a PV/T system could supply both power and hot water within the same footprint, which is attractive for maximizing solar utilization on a constrained roof. A comprehensive review elaborates on advances in PV/T, noting improved materials and efficiencies in recent years (Tiwari et al., 2023). The research consensus is that PV/T can achieve higher combined efficiency (60–80% of sunlight converted to useful energy when you add heat and electricity outputs) and thus is a promising way to merge solar PV and thermal needs on buildings.

4.2.7.4 Partitioning roof space for multiple uses

Another form of combination is simply dividing the roof into zones, for instance, installing PV panels on one portion, a green roof or rooftop garden on another, and maybe allocating a section to solar thermal collectors or skylights. While this is more of a design choice than a technology integration, some studies have looked at the optimal mix of uses for a given roof. A study introduced the concept of “multifunctional roof retrofitting” where an urban roof area could be portioned to different technologies to maximize overall benefits (power, carbon reduction, water management) (Pan et al., 2024). Their scenario analyses for a city indicated that a combination strategy (some PV, some green roof) can yield a balanced outcome, providing significant renewable energy generation while also delivering cooling and stormwater runoff reduction. This suggests that the rooftop options are not entirely mutually exclusive: a large commercial roof could host both PV and a rooftop garden side by side, for example. The extent to which options can be combined is of course limited by practical considerations (you wouldn’t typically overlay a cool roof and a green roof on the exact same spot, but you could have a green roof in one section and a cool roof coating on another section of a complex roof). Some high-rise buildings even combine three: they might have solar thermal panels for hot water, PV panels for electricity, and an area of green roof for amenity and insulation, all on the same rooftop. The integration needs careful planning (PV panels don’t excessively shade the green portion unless intended), but case studies have shown it’s feasible.

5 Case studies and best practices

5.1 Urban Solar Gardens in New Westminster

Source from (Energy Save New West, 2024)

The City of New Westminster launched an Urban Solar Garden consisting of two community-owned solar photovoltaic arrays installed on civic building rooftops (Queensborough Community Centre and the City Works Yard). Each array in this system is 50 kW (156 panels) and feeds into the local grid. This project enables residents and businesses (including those in multi-unit buildings) to subscribe for local renewable power and receive credits on their utility bills, demonstrating climate leadership. Both 50 kW arrays were fully subscribed and, by the end of 2021, the two solar gardens had collectively generated over 325 MWh of clean electricity. The project won a 2019 Environmental Award and showcased how community investment can spur urban solar development. Subscribers benefit from long-term energy savings without needing their own rooftop systems. This case illustrates the success of a city-led, community-funded solar initiative on multi-use facilities. Navigating solar potential, technical feasibility, and community engagement early in the process were key to the success of this initiative.

5.2 Examples of successful rooftop systems

5.2.1 Vancouver

Project: TELUS Garden in downtown Vancouver is a 1-million sq.ft. mixed office and residential development known for integrating Vancouver's largest rooftop solar PV array with extensive green roof terraces.

Figure 6 An example of PV system in TELUS Garden in downtown Vancouver

Photo credit: TELUS Garden receives LEED Platinum certification • SustainableBiz Canada • Sustainable Business News

Systems: A 300-panel (65 kW) solar array on the office tower's roof generates 65,000 kWh/year (about 80% less reliance on grid energy). It also features 10,000 sq.ft. of rooftop gardens and vegetated terraces on six levels, including an employee-tended organic food garden.

Objectives: Fulfill LEED Platinum sustainability by reducing energy use and emissions (the building's district energy system plus solar cuts CO2 by >1 million kg/year), provide stormwater management and amenity space with green roofs, and showcase corporate environmental leadership.

Outcomes: The combined design yields an 80% reduction in conventional energy demand. The solar-powered lighting and rainwater irrigation for the gardens improve efficiency, and the green roofs help insulate the building and reduce the urban heat island effect. Vancouver's example underscores how integrating solar panels with green roofs in a high-rise can simultaneously save energy and create usable green space.

Vancouver Convention Centre's 6-acre living roof is another example, the largest in Canada, providing habitat and insulating the commercial building.

Source from (McLean et al., 2016; RJC, 2022)

Figure 7 An example of green roof at the top of Vancouver Convention Center, Vancouver BC

Photo Credit: Vancouver Convention Centre

5.2.2 Chilliwack

Project: The Fraser Valley Regional District (FVRD) Head Office in downtown Chilliwack installed a rooftop solar PV system to lead by example in a smaller city context.

Figure 8 The installation of solar panels on the building's rooftop in downtown Chilliwack

Photo Credit: Hope Standard

System: 66 solar panels (23 kW capacity) were commissioned in 2019.

Objectives: Reduce the building's grid consumption and showcase renewable energy's viability to the community, aligning with the FVRD's vision of healthy, sustainable communities.

Outcomes: The array produces an estimated 23,000 kWh annually; within the first months of operation, it had already generated 13.7 MWh, enough to power the building's server room for three months. The project received a $25,000 grant and garnered local media attention, helping inspire other regional investments in solar. Chilliwack's case demonstrates that even mid-size commercial buildings can successfully adopt rooftop solar, yielding energy savings and community awareness.

Chilliwack was also the site of a six-year roof study on membrane color and insulation performance, guiding best practices for cool roof design in the region.

Source from (Hope Standard, 2019; Rockwool, n.d.)

5.2.3 Coquitlam

Project: Coquitlam has encouraged green roofs and solar energy on new developments through policy guides rather than a single marquee project. The city's Green Development Guide features case studies to inform local builders. For example, it highlights The Silva, a 16-storey multi-unit residential tower in nearby North Vancouver for its eco-roof design.

System: The Silva incorporated a 4,100 sq.ft. vegetated roof (covering 35% of its roof) planted with drought-tolerant species.

Objectives: Reduce stormwater runoff and insulate the building. Outcomes: The green roof retains significant rainfall and led to a 27% reduction in stormwater volume from the site. The building also achieved 14% energy savings versus conventional, and became the first LEED-certified high-rise in Canada.

Coquitlam encourages similar designs locally, for instance, using solar hot water on condos or installing solar-ready infrastructure.

Source from (The City of Coquitlam, 2008)

5.2.4 Seattle

Project: The Bullitt Center in Seattle is a six-story commercial building widely regarded as one of the world's most sustainable office buildings. It was designed to meet the rigorous Living Building Challenge.

Figure 9 The Bullitt Center has 575 solar panels on the roof, creating a 14,000 square-foot array to generate electricity

Photo Credit: Solar Panels | Bullitt Center

System: A 575-panel solar PV array is deployed as a broad rooftop canopy (14,000 sq.ft in area) extending beyond the building's footprint. It has an installed capacity of 244 kW.

Objectives: Enable the building to operate net-zero (even net-positive) for energy in Seattle's cloudy climate, and prove that net-zero energy is feasible for mid-rise commercial structures.

Outcomes: The Bullitt Center's solar roof generates about 230,000 kWh of electricity per year, slightly more than the building consumes annually, making it truly net-positive. In its first full year (2014) it produced 243,700 kWh while the building used only 152,900 kWh – exporting surplus power back to the grid. This performance has continued over its first decade, exceeding energy expectations. The excess summer generation offsets winter deficits, using the grid as storage. Aside from energy, the Bullitt Center's roof also collects rainwater for building use, and the structure features composting toilets and toxin-free materials, making it a model of self-sufficiency.

Source from (DEI Creative in Seattle WA, n.d.)

5.2.5 Portland

Project: Portland has implemented green roofs ("ecoroofs") for decades to manage stormwater and heat in its many low-rise multi-unit and commercial buildings. E.g., the Brewery Blocks – Block 4 (M Financial Center) is a showcase mixed-use development in downtown Portland.

Figure 10 Brewery Blocks in downtown Portland

Photo Credit: Brewery Blocks: M Financial | Portland, OR — Edlen & Co.

Systems: Its design includes a 13,000 sq.ft. ecoroof atop a lower podium and a south-facing solar PV array on the high-rise tower. The ecoroof, with hardy sedums, moderates the building's heating and cooling needs and retains rain (mitigating runoff), while the solar panels (200+ modules) generate about 4.5% of the building's electricity demand. After launching incentives in 2008, over 100 ecoroofs were built through the city's "Grey to Green" program, and by 2013 Portland boasted 500+ green roofs installed on local buildings. This foundation led Portland in 2019 to adopt one of the strongest green roof mandates in the U.S., requiring most new buildings over 20,000 sq.ft. to cover 60% of roof area with vegetation.

Objectives: Reduce combined sewer overflows (Portland's heavy rains previously caused sewers to spill into the Willamette River) and provide insulation, habitat, and urban cooling.

Outcomes: Completed in 2003, this project helped Portland earn a reputation for large-scale private green roofs. The ecoroof and other sustainability measures contributed to LEED Gold certification. Citywide, Portland's green roofs are credited with keeping millions of gallons of stormwater out of sewers each year and reducing the urban heat island effect, while rooftop solar projects (often in combination with ecoroofs) are steadily growing.

Source from (Edlen & Co., 2021; Green Roofs for Healthy Cities, 2025)

5.2.6 London

Project: The Beddington Zero Energy Development (BedZED) in south London, England is a landmark sustainable housing community of 82 homes plus offices.

Figure 11 BedZED - the UK's first major sustainable community

Photo Credit: BedZED - the UK's first major zero-carbon community – Bioregional

Systems: BedZED combined rooftop solar technologies with green roofs. It has extensive solar panels (integrated into rooftops and facades) that, after a renewable energy upgrade, supply 20% of the development's energy demand. It also implemented roof gardens on each building, composed of vegetated terrace roofs that grow native plants and absorb rainwater.

Objectives: The green roof gardens not only provide residents with private outdoor space and habitat for butterflies, but also attenuate and reuse rainwater though the original rainwater-harvesting system.

Source from (Bioregional, n.d.; Coullare, 2020)

5.2.7 Paris

Projects: A 2015 French law mandates that all new commercial buildings must have either solar panels or a green roof covering part of the roof. This policy aims to improve urban habitat, manage stormwater, and increase renewable energy in dense cities. In Paris, this has spurred numerous projects: for example, the Paris Expo Porte de Versailles Pavilion 6 now hosts the world's largest urban rooftop farm (known as "Nature Urbaine"). This 14,000 m² roof farm (about two football fields in size) is covered with soil-less organic crops instead of the traditional zinc roof.

Figure 12 World's largest urban farm on a Paris roof-top

Photo Credit: Valode & Pistre Architectes Atlav AJN

Objectives: Enhance urban resilience by producing food locally, utilizing roof space for green infrastructure, and cooling the city.

Outcomes: When fully operational in 2020, the farm was projected to grow 30 different plant species and yield about 1,000 kg of fresh produce per day in peak season, maintained by a team of 20 gardeners. The produce supplies an on-site rooftop restaurant and the local community. Additionally, countless smaller Paris rooftops have been retrofitted with gardens or photovoltaic arrays in response to the green roof law.

Source from (Harrap, 2019; Lawson, 2015)

5.2.8 Berlin

Project: Berlin, Germany actively promotes integrated “biosolar” roofs through incentive programs. The city introduced GründachPLUS (Green Roof Plus) to fund green roof installations, and SolarPLUS to subsidize adding PV panels on those same roofs. GründachPLUS offers up to €55 per m^2 for green roof projects over 100 m^2, targeting retrofits in dense urban areas. SolarPLUS then covers 65% of the additional cost of mounting solar panels atop the green roof (up to €15,000 per project).

Objective: Encourage building owners to install vegetation and solar together, recognizing that green roofs cool the underlying roof and can boost solar panel efficiency by keeping temperatures lower.

Outcomes: This dual-incentive approach has spurred numerous combined installations across Berlin. Early studies in Berlin have observed up to 4–6% higher PV output on green roofs compared to conventional roofs (due to the cooling effect). The vegetated roofs also retain rainwater and support urban biodiversity. In practice, Berlin’s approach improves urban climate resilience (through reduced runoff and heat) while increasing renewable energy generation.

Many Berlin apartment blocks and commercial buildings are now adding rooftop gardens under GründachPLUS and installing tenant-shared solar (“Mieterstrom”) systems under SolarPLUS, providing lower-cost solar power to residents.

Source from (Brears, 2024)

5.2.9 Brussels

Project: “SolarMarket” at Halles d’Anderlecht Brussels, Belgium achieved a milestone by installing a 2 MW building-integrated PV (BIPV) roof on a 19th-century heritage market hall.

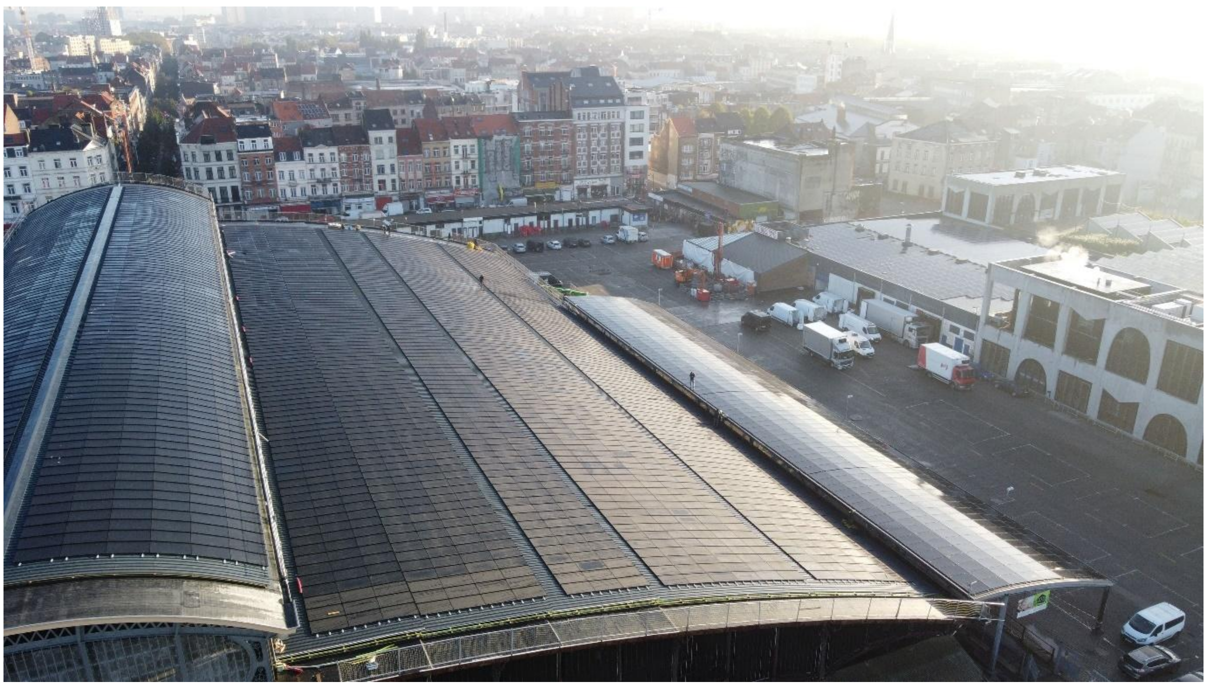


Figure 13 The SolarMarket – the first BIPV installation on heritage building in Brussels

Photo Credit: «SolarMarket» opens – first BIPV installation on heritage building in Brussels - SolarPower Europe

System: The historic zinc roof was renovated with modern solar slates that preserve its appearance while generating power.

Objectives: Show that even protected historic commercial buildings can adopt solar technology without aesthetic loss.

Outcomes: Opened in 2021, this SolarMarket installation is the largest urban BIPV project in Europe, producing the equivalent of the electricity used by 703 households and avoiding 754 tons of CO_2 emissions annually. It also marked the first-time local heritage authorities approved solar panels on a listed building, paving the way for more retrofits. Brussels has paired this with social innovation: citizens were provided the opportunity to cooperatively invest in the project, and the site educates visitors on renewable energy.

In parallel, Brussels is experimenting with green roofs for urban agriculture. On a supermarket in the city, the Lagum Project created a 2,000+ m^2 rooftop garden growing over 60 plant species. In one season it harvested 2 tonnes of fruits and vegetables for a community social restaurant and food aid, while engaging local residents.

Source from (Magyar, 2022; SolarPower Europe, 2021)

5.2.10 Amsterdam

Project: The Edge – Amsterdam's iconic 15-story office tower (Deloitte's headquarters) – is often cited as "the greenest office building".

Systems: The Edge's roof and south façade are covered with 65,000 sq.ft. (6,000 m^2) of solar panels, forming the largest PV array on any office building in Europe. These panels, along with additional panels on nearby structures, supply the building with renewable electricity.

Objectives: Achieve an ultra-sustainable, energy-positive building that generates more power than it uses annually. The design also incorporated rainwater harvesting and intelligent lighting/HVAC systems.

Outcomes: Opened in 2015, The Edge attained BREEAM "Outstanding" with a record-high sustainability score. It uses 70% less electricity than a typical office of its size, thanks to efficiency and on-site generation. The solar PV system produces enough surplus to cover all employee laptops, smartphones, and even charge electric vehicles. The building's success demonstrated that in Amsterdam's climate, a combination of a vast solar roof, smart energy storage, and usage monitoring can push a large commercial building beyond net-zero. It also provides a comfortable environment as the atrium and north-facing green walls maximize daylight while the solar panels double as sunshades on the south side.

Source from (BRE Group- Sustainability, n.d.)

5.3 Lessons learned from local and international experiences

Case studies from Vancouver, Chilliwack, Brussels, Berlin, and New Westminster reveal three key insights. First, municipal leadership through funding programs, permitting support, and demonstration projects can significantly accelerate rooftop adoption. For instance, Berlin's dual incentives for biosolar roofs (GründachPLUS and SolarPLUS) led to widespread integration of PV and green roofs on dense urban buildings. Second, system integration (e.g., combining PV with green or cool roofs) consistently yielded better environmental and performance outcomes than stand-alone systems, especially under varying climate conditions. Third, both local and international examples underscore the importance of coordinated planning, including early feasibility assessments, alignment with capital renewal cycles, and clear maintenance responsibilities. In New Westminster, the Urban Solar Garden's success hinged on early interest group engagement, site suitability assessments, and community buy-in, offering a model that could be extended to other rooftop technologies.

6 Summary

This study evaluated the technical and policy landscape for rooftop adaptation systems in New Westminster, focusing on solar PV, solar thermal, green roofs, and cool roofs. Through literature review, spatial analysis, policy synthesis, and stakeholder interviews, the study identified key opportunities and constraints for implementation. Solar PV showed the highest direct GHG mitigation potential, while green and cool roofs offered strong urban heat and stormwater management benefits. Solar thermal systems were most effective in buildings with consistent hot water demand. Each system presented trade-offs in terms of structural feasibility, economic return, and long-term maintenance. Integrated approaches, such as PV-green roof combinations were found to optimize benefits when tailored to building context. A decision-support checklist was developed to guide project planning across City departments and support future climate-resilient retrofits.

7 Recommendations

Rooftop retrofit planning should be aligned with the City's capital renewal cycles to ensure timely integration of solar PV, green roofs, cool roofs, or solar thermal systems. Early feasibility assessments evaluating structural load, shading, and energy needs, can help identify suitable buildings. While solar PV benefits from established rebates, the City should also pursue funding for green infrastructure and cool roof upgrades through programs like CleanBC and federal adaptation grants.

Integrated systems, such as PV paired with green or cool roofs, offer higher performance and should be prioritized where feasible. Internal coordination across planning, engineering, and energy management teams is essential, as is incorporating long-term maintenance requirements into procurement and design stages. High-visibility civic buildings should be prioritized to showcase leadership and maximize public benefit.

Some actions for the city to consider include:

1. Commissioning a renewable energy study across Civic facilities to identify opportunities for renewable energy as part of future roof replacement projects, and to support the capital planning process for renewable energy projects.
2. Exploring a pilot of community led urban solar garden on multi-unit residential buildings or commercial buildings to expand the program outside of civic buildings.
3. Supporting the encouragement of solar generation in the community through the following:
    a. Providing a tool for members of the community to inform them on their building's potential to generate electricity using solar panels. Examples of similar tools include the City of Victoria's Solar Rooftop Calculator.
    b. Providing incentives/top-ups for roof top technologies, and advocating for the incentives from the province for these technologies.
    c. Providing design guidelines that encourage/enforce the inclusion of these technologies in roof top designs or retrofits. Examples include the City of Coquitlam's Green Development Design Guideline and the City of Toronto's Green Standard.
4. Strengthening internal coordination between the Capital Planning, Facilities, and Energy Management teams to ensure rooftop retrofit opportunities are identified early in building lifecycle planning.
    a. Establishing a formal screening process, based on Facility Condition Index (FCI), roof replacement schedules, and solar feasibility data
    b. Prioritizing retrofit-ready buildings and reduce missed opportunities due to timing misalignment.
5. Develop a standardized pre-feasibility checklist or internal workflow that can be used across departments.
    a. This framework should include criteria for technical viability (e.g., shading, slope, structural loading), economic feasibility (e.g., payback, incentives), and policy alignment (e.g., GHG targets, climate adaptation goals).
6. The city could consider piloting hybrid systems, such as biosolar installations, on high-visibility civic buildings like libraries or recreation centers.
    a. These pilots can serve as public-facing demonstration projects and test integrated procurement, maintenance, and performance tracking processes.

References

Alonso-Marroquin, F., & Qadir, G. (2023). Synergy between Photovoltaic Panels and Green Roofs. *Energies*, *16*(13), Article 13. https://doi.org/10.3390/en16135184

Bamdad, K. (2023). Cool roofs: A climate change mitigation and adaptation strategy for residential buildings. *Building and Environment*, *236*, 110271. https://doi.org/10.1016/j.buildenv.2023.110271

BC Assessment Authority. (2024). *BC Assessment Residential Inventory* (Version 6) [Dataset]. Abacus Data Network. https://abacus.library.ubc.ca/dataset.xhtml?persistentId=hdl:11272.1/AB2/WV3PO5

BC Housing Research Center. (n.d.). *Consumer Guide – Solar Photovoltaic Systems for Multi-Unit Residential Buildings*.

BC Hydro. (n.d.). *Rebates for solar panels and battery storage*. Retrieved June 27, 2025, from https://www.bchydro.com/powersmart/residential/rebates-programs/solar-battery.html

BIM International. (2025). *Sustainable Roofs | BMI International*. https://bmigroupinternational.com/products/pitched-roofs/sustainable-roofs?utm_source=chatgpt.com

Bioregional. (n.d.). *BedZED – the UK's first major sustainable community*. Bioregional. Retrieved May 24, 2025, from https://www.bioregional.com/projects-and-services/case-studies/bedzed-the-uks-first-large-scale-eco-village

BLUETTI Canada. (2025). *BC Solar Panel Rebate and Incentives 2024*. BLUETTI Canada. https://www.bluettipower.ca/blogs/knowledge-base/bc-solar-panel-rebate-and-incentives-2023

Borodiņecs, A., Lebedeva, K., & Odineca, T. (2024). Evaluation of household electricity consumption in multi-apartment buildings for optimization of rooftop PV systems. *Energy and Buildings*, *325*, 114971. https://doi.org/10.1016/j.enbuild.2024.114971

BRE Group- Sustainability. (n.d.). *The Edge Amsterdam*. Retrieved May 24, 2025, from https://bregroup.com/case-studies/the-edge-amsterdam

Brears, R. C. (2024, December 11). Maximizing Urban Sustainability: Benefits of Green Roofs with Solar Panels. *Mark and Focus*. https://medium.com/mark-and-focus/maximizing-urban-sustainability-benefits-of-green-roofs-with-solar-panels-21f9f85832a1

California Air Resources Board. (2025). *Cool Roofs: How They Work | Cool California*. https://coolcalifornia.arb.ca.gov/cool-roofs-how-they-work

Carilec. (2019). *Page 76—CARILEC CE Industry Journal_Oct_2019*. https://www.carilec.org/cejournal/CARILEC_CE_Journal_Oct_2019.html#p=76

Cascone, S. (2019). Green Roof Design: State of the Art on Technology and Materials. *Sustainability*, *11*(11), Article 11. https://doi.org/10.3390/su11113020

City of Annapolis. (n.d.). *Green Roofs Maintenance Fact Sheet*.

City of New Westminster. (2022). *Community Energy and Emissions Plan 2050*. https://www.newwestcity.ca/database/files/library/CEEP_2050.pdf

Climate Action Accelerator. (2025). *Solar thermal energy—Climate Action Accelerator*. https://climateactionaccelerator.org/solutions/solar-thermal-energy/

Coullare, M. (2020, December 16). Reimagining Roof Gardens: A Case Study of the UK's First Large Scale Net-Zero Community. *Medium*. https://mcoullare.medium.com/reimagining-roof-gardens-a-case-study-of-the-uks-first-large-scale-net-zero-community-1017d9a2723a

DEI Creative in Seattle WA. (n.d.). *Solar Panels | Bullitt Center*. Retrieved May 24, 2025, from https://bullittcenter.org/building/building-features/solar-district-1/

Dikshit, S. (2017). *Sheila Dikshit Chief Minister, Delhi*.

Edlen & Co. (2021). *Brewery Blocks: M Financial | Portland, OR*. Edlen & Co. https://www.edlenandco.com/projects-legacy/bb-m-financial

Energy Save New West. (2024). *Urban Solar Garden | Energy Save New West*. https://energysavenewwest.ca/urban-solar-garden/

ENERGY STAR. (2025). *Cool Roofs | ENERGY STAR*. https://www.energystar.gov/products/cool-roofs

EPA. (2021). *NPDES: Stormwater Best Management*.

Fleck, R., Gill, R., Pettit, T. J., Torpy, F. R., & Irga, P. J. (2022). Bio-solar green roofs increase solar energy output: The sunny side of integrating sustainable technologies. *Building and Environment*, *226*, 109703. https://doi.org/10.1016/j.buildenv.2022.109703

Green Building. (2024, September 25). *Green Roofs Around the Globe: Policies and Incentives of Various Countries*. https://greenbuildingcanada.ca/green-roofs-world-canada-policies-incentives/

Green Roofs for Healthy Cities. (2025). *Portland Oregon's Green Roof Requirement Under Threat | Doug Crimin*. Living Architecture Monitor. https://livingarchitecturemonitor.com/articles/portland-oregons-green-roof-requirement-under-threat-wi23

Hachchadi, O., Rousse, D. R., Irandoostshahrestani, M., & Mechaqrane, A. (2023). Techno-economic assessment and environmental impact of photovoltaic and conventional solar water heating systems in cold climates. *Energy Conversion and Management*, *297*, 117725. https://doi.org/10.1016/j.enconman.2023.117725

Harrap, C. (2019, August 13). World's largest urban farm to open – on a Paris rooftop. *The Guardian*. https://www.theguardian.com/cities/2019/aug/13/worlds-largest-urban-farm-to-open-on-a-paris-rooftop

Hassoun, L., & Cook, L. M. (2024). Global Analysis of Combined Photovoltaic Green and Cool Roofs Under Climate Change. *Advanced Sustainable Systems*, *8*(12), 2400097. https://doi.org/10.1002/adsu.202400097

Hope Standard. (2019, October 25). *FVRD building in Chilliwack installs solar panels*. Hope Standard. https://www.hopestandard.com/news/fvrd-building-in-chilliwack-installs-solar-panels-2051946

Idrovo-Macancela, A., Velecela-Zhindón, M., Barragán-Escandón, A., Zalamea-León, E., & Mejía-Coronel, D. (2025). GIS-based assessment of photovoltaic solar potential on building rooftops in equatorial urban areas. *Heliyon*, *11*(1), e41425. https://doi.org/10.1016/j.heliyon.2024.e41425

Jia, S., Weng, Q., Yoo, C., Xiao, H., & Zhong, Q. (2024). Building energy savings by green roofs and cool roofs in current and future climates. *Npj Urban Sustainability*, *4*(1), 1–13. https://doi.org/10.1038/s42949-024-00159-8

Kalogirou, S. A. (2004). Solar thermal collectors and applications. *Progress in Energy and Combustion Science*, *30*(3), 231–295. https://doi.org/10.1016/j.pecs.2004.02.001

Keating, T. J., Walker, A., & Ardani, K. (2015). *Solar Access Public Capital (SAPC) Working Group: Best Practices in PV Operations and Maintenance; Version 1.0, March 2015; Period of Performance, January 1, 2014 - December 31, 2015* (No. NREL/SR--6A20-63235, 1215055; p. NREL/SR--6A20-63235, 1215055). https://doi.org/10.2172/1215055

Khan, A., Anand, P., Garshasbi, S., Khatun, R., Khorat, S., Hamdi, R., Niyogi, D., & Santamouris, M. (2024). Rooftop photovoltaic solar panels warm up and cool down cities. *Nature Cities*, *1*(11), 780–790. https://doi.org/10.1038/s44284-024-00137-2

Lawson, T. (2015). On Rooftops of Paris, Expect Green Roofs and Solar Panels—YES! Magazine Solutions Journalism. *YES! Magazine*. https://www.yesmagazine.org/environment/2015/08/20/france-green-roofs-law-solar-panels

Magyar, Á. (2022). *2 tonnes of vegetables are grown on a supermarket roof in Brussels*. Euronews. https://www.euronews.com/green/2022/05/25/brussels-grows-fruits-and-vegetables-on-top-of-a-supermarket

Maurer, B., Lienert, J., & Cook, L. M. (2023). Comparing PV-green and PV-cool roofs to diverse rooftop options using decision analysis. *Building and Environment*, *245*, 110922. https://doi.org/10.1016/j.buildenv.2023.110922

McLean, S., Print, C. S. W. W. H. A. in a W. V. of, & Bands, online outlets H. the author of the book H. C. (2016). *TELUS Garden receives LEED Platinum certification*. https://sustainablebiz.ca/telus-garden-receives-leed-platinum-certification

Natural Resources Canada. (2010, July 4). *Solar Thermal*. https://natural-resources.canada.ca/energy-sources/renewable-energy/solar-thermal

Natural Resources Canada. (2011a, April 27). *Solar Photovoltaic Energy*. https://natural-resources.canada.ca/energy-sources/renewable-energy/solar-photovoltaic-energy

Natural Resources Canada. (2011b, July 20). *Solar Photovoltaic Energy in Buildings*. https://natural-resources.canada.ca/energy-efficiency/solar-photovoltaic-energy-buildings

Natural Resources Canada. (2014, January 14). *Solar resource data available for Canada*. https://natural-resources.canada.ca/energy-sources/renewable-energy/solar-resource-data-available-canada

Natural Resources Canada. (2016, April 7). *Photovoltaic potential and solar resource maps of Canada*. https://natural-resources.canada.ca/energy-sources/renewable-energy/photovoltaic-potential-solar-resource-maps-canada

Nezamisavojbolaghi, M., Davodian, E., Bouich, A., Tlemçani, M., Mesbahi, O., & Janeiro, F. M. (2023). The Impact of Dust Deposition on PV Panels’ Efficiency and Mitigation Solutions: Review Article. *Energies*, *16*(24), Article 24. https://doi.org/10.3390/en16248022

NRC. (2000). *Solar Water Heating Systems: A Buyer’s Guide [PDF] [ecku4qvp5mc0]*. https://vdoc.pub/documents/solar-water-heating-systems-a-buyers-guide-ecku4qvp5mc0

NREL. (2017). *New Best-Practices Guide for Photovoltaic System Operations and Maintenance*. https://docs.nrel.gov/docs/fy17osti/68281.pdf

Pan, Z., Wang, C., Yu, B., Chen, Z., Yuan, Y., Li, G., Zhang, J., & Xiao, T. (2024). Assessing multifunctional retrofit potential of urban roof areas and evaluating the power and carbon benefits under efficient retrofit scenarios. *Journal of Cleaner Production*, *444*, 141270. https://doi.org/10.1016/j.jclepro.2024.141270

PennState. (2025). *Stormwater Quantity*. Department of Plant Science. https://plantscience.psu.edu/research/centers/green-roof/research/stormwater/stormwater-quantity

PVT Modules: Our Energy Solution. (n.d.). Sunmaxx PVT. Retrieved May 3, 2025, from https://sunmaxx-pvt.com/solution/

RJC. (2022, September 28). *The green roof revolution: Canadian successes and best practices - RJC Engineers*. https://www.rjc.ca/rjc-media/blog/green-roof-canadian-successes-best-practices.html

Rockwool. (n.d.). *Chilliwack Building Case Study | ROCKWOOL*. Retrieved May 11, 2025, from https://www.rockwool.com/north-america/advice-and-inspiration/case-studies/chilliwack-case-study/

Röhrig, P. M., Martens, J., Körber, N., Kurth, M., & Ulbig, A. (2023). Analysis of PVT hybrid roof-top systems for the energy supply of electricity and heat for buildings. *2023 IEEE PES Innovative Smart Grid Technologies Europe (ISGT EUROPE)*, 1–5. https://doi.org/10.1109/ISGTEUROPE56780.2023.10407104

Rosasco, P., & Perini, K. (2019). Selection of (Green) Roof Systems: A Sustainability-Based Multi-Criteria Analysis. *Buildings*, *9*(5), Article 5. https://doi.org/10.3390/buildings9050134

SEPA. (2015). *Ratemaking, Solar Value and Solar Net Energy Metering—A Primer*. https://www.energy.gov/sites/prod/files/2015/03/f20/sepa-nem-report-0713-print.pdf?utm_source=chatgpt.com

SolarPower Europe. (2021). *«SolarMarket» opens – first BIPV installation on heritage building in Brussels—SolarPower Europe*. https://www.solarpowereurope.org/press-releases/press-release-7

Solutions, E. and C. (2024, June 27). *B.C.'s future powered by clean energy*. BC Gov News. https://news.gov.bc.ca/releases/2024EMLI0036-001020

Stone, E. (2023, August 17). *A "cool roof" can help you beat the heat—And save money*. LAist. https://laist.com/news/climate-environment/a-cool-roof-can-help-you-beat-the-heat-and-save-money

The City of Coquitlam. (2008). *Coquitlam Green Development Guide—Practices that are transforming our cities*. https://www.coquitlam.ca/DocumentCenter/View/399/Green-Development-Guide-PDF#:~:text=16%20storey%2C%2067%20unit%20residential,ENVIRONMENTAL%20PERFORMANCE

Tiwari, A. K., Chatterjee, K., Agrawal, S., & Singh, G. K. (2023). A comprehensive review of photovoltaic-thermal (PVT) technology: Performance evaluation and contemporary development. *Energy Reports*, *10*, 2655–2679. https://doi.org/10.1016/j.egyr.2023.09.043

UNSW SYDNEY. (2022). *Impact of cool roofs on the performance of PV systems*.

U.S. DoE. (n.d.). *Cool Roofs Are Ready to Save Energy, Cool Urban Heat Islands, and Help Slow Global Warming*.

U.S. DOE. (2025a). *Cool Roofs*. Energy.Gov. https://www.energy.gov/energysaver/cool-roofs

U.S. DOE. (2025b). *Estimating the Cost and Energy Efficiency of a Solar Water Heater*. Energy.Gov. https://www.energy.gov/energysaver/estimating-cost-and-energy-efficiency-solar-water-heater

U.S. DoE. (2025). *Solar Water Heating System Maintenance and Repair*. Energy.Gov. https://www.energy.gov/energysaver/solar-water-heating-system-maintenance-and-repair

U.S. Energy Information Administration. (2014). *Solar photovoltaic output depends on orientation, tilt, and tracking—U.S. Energy Information Administration (EIA)*. https://www.eia.gov/todayinenergy/detail.php?id=18871

US EPA, O. (2014, June 17). *Using Green Roofs to Reduce Heat Islands* [Overviews and Factsheets]. https://www.epa.gov/heatislands/using-green-roofs-reduce-heat-islands

Vasilakopoulou, K., Ulpiani, G., Khan, A., Synnefa, A., & Santamouris, M. (2023). Cool roofs boost the energy production of photovoltaics: Investigating the impact of roof albedo on the energy performance of monofacial and bifacial photovoltaic modules. *Solar Energy*, *265*, 111948. https://doi.org/10.1016/j.solener.2023.111948

Wai, C. Y., Chau, H.-W., Paresi, P., & Muttil, N. (2025). Experimental Analysis of Cool Roof Coatings as an Urban Heat Mitigation Strategy to Enhance Thermal Performance. *Buildings*, *15*(5), Article 5. https://doi.org/10.3390/buildings15050685

Walker, A., Desai, J., Gunda, T., & Jackson, N. (2023). *Operation and Maintenance of PV Systems: Data Science, Analysis, and Standards* (No. NREL/TP--5C00-85819, 2228955, MainId:86592; p. NREL/TP--5C00-85819, 2228955, MainId:86592). https://doi.org/10.2172/2228955

World Bank. (2020). *Solar Photovoltaic Power Potential by Country* [Text/HTML]. World Bank. https://www.worldbank.org/en/topic/energy/publication/solar-photovoltaic-power-potential-by-country

Zhang, Z., Qian, Z., Chen, M., Zhu, R., Zhang, F., Zhong, T., Lin, J., Ning, L., Xie, W., Creutzig, F., Tang, W., Liu, L., Yang, J., Pu, Y., Cai, W., Pu, Y., Liu, D., Yang, H., Su, H., … Yan, J. (2025).

Worldwide rooftop photovoltaic electricity generation may mitigate global warming. *Nature Climate Change*, *15*(4), 393–402. https://doi.org/10.1038/s41558-025-02276-3

Zhao, S., Hai, G., & Zhang, X. (2024). An Analysis of the Influence of Cool Roof Thermal Parameters on Building Energy Consumption Based on Orthogonal Design. *Buildings*, *14*(1), Article 1. https://doi.org/10.3390/buildings14010028

Appendices

Appendix A: High-level Checklist

This checklist is designed to guide staff, consultants, and decision-makers through the planning, design, and implementation process for integrating low-carbon, climate resilient features into rooftop systems such as solar photovoltaics, solar thermal, green roofs, and cool roofs on Part 3 buildings in the City of New Westminster.

Step 1: Assess solar access and roof suitability

Start by evaluating whether your building receives adequate sunlight to support solar PV or solar thermal systems. Rooftop relevant data, such as building footprints, rooftop heights, and tree coverage that can help you assess shading, orientation, and rooftop slope.

Key questions to consider:

- Is the roof shaded by nearby buildings, trees, or equipment?
- Is the orientation of the roof generally south-facing or flat?
- Are there obstructions like vents or mechanical units that limit usable area?

If the rooftop appears unshaded and structurally open, contact a structural engineer or a solar consultant with clear lists of metrics to:

- Conduct a solar irradiance assessment (such as using NRCan or internal tools),
- Estimate annual energy production for solar PV or thermal, and
- Recommend optimal racking and tilt solutions if the roof is flat.

Step 2: Evaluate roof condition and capital planning alignment

Before proceeding with design, assess the age and condition of the roof. Retrofits should align with capital planning timelines and roofing lifecycles to avoid duplicating work or removing systems prematurely.

Questions to guide this step:

- When was the roof last replaced? What is its expected remaining life?
- Are there signs of aging membranes (e.g., Thermoplastic Polyolefin layers, TPO) or insulation issues?
- What is the current condition, such as Facility Condition Index (FCI), of this building/facility?

If the roof is due for replacement within the next 5–10 years, coordinate with engineer team to:

- Bundle the retrofit with roof replacement or envelope upgrades,
- Assess structural capacity (especially for solar thermal or green roofs), and
- Confirm the type and load capacity of roofing materials.

Step 3: Engage stakeholders and define project goals

Project success depends on clear goals and early involvement of decision-makers, e.g., clarify and identify community's or local government's interests and goals. The City of New Westminster's Urban Solar Garden succeeded because of strong coordination between energy planners, facilities managers, and the community.

At this stage, engage:

- Internal stakeholders (Energy, Engineering, Facilities, Planning),
- External partners (community organizations or utilities), and
- Residents or building users (e.g., in multi-unit residential buildings).

Clarify the project's purpose:

- Is the goal to reduce energy bills for the building or common areas?
- Is the project part of a shared program like the Urban Solar Garden?
- Are equity, visibility, or resilience co-benefits part of the objectives?
- Are new buildings and innovations aligning well with the standards, i.e. LEED or CAGBC standards?
- Depending on the goal, the system selection may differ (e.g., net metering vs. load displacement, or green roofs for stormwater management).

Step 4: Conduct technical and financial feasibility assessment

Once alignment is reached, initiate technical and economic analysis. Engage qualified engineers and consultants to evaluate the rooftop's structural capacity and compatibility with electrical systems.

Technical considerations:

- Does the roof structure support the weight of green roofs or thermal systems?
- Are electrical panels, metering systems, and conduit access in place?
- Can the system be connected to the grid under a city's interconnection rules?

Financial considerations:

- What is the total installed cost, including design, permits, and contingency?
- Are there incentives or grants (e.g., CleanBC, Greener Homes) available?
- What is the estimated simple payback period, ROI, and maintenance cost?

Step 5: Finalize design, procurement, and monitoring plan

If feasibility is confirmed, proceed to final design and implementation. At this stage, it's important to:

- Select experienced contractors who understand procurement and rooftop retrofits,
- Coordinate timing with planned roof work or HVAC upgrades,
- Include performance specifications in RFPs if applicable (e.g., for solar inverters or irrigation systems on green roofs).

Plan for long-term monitoring and maintenance:

- Who is responsible for upkeep, internal or external providers?
- Are warranty and service contracts (typically 1-5 years) included in the procurement?
- Will the system include real-time monitoring for energy production or vegetation health?

Project teams can proactively identify and resolve common barriers to rooftop adaptation by following this checklist.

Appendix B: Solar resource data available for Canada (Data sources from (Natural Resources Canada, 2014))

Dataset	Source	Time Coverage	Radiation components	Time resolution	Spatial resolution
CWEEDS (free) http://climate.weather.gc.ca/prods_servs/engineering_e.html	Ground stations (Environment Canada)	1998-2016 (station-dependent)	GHI, DNI, DHI	Hourly	564 stations
CWEC (free) http://climate.weather.gc.ca/prods_servs/engineering_e.html	Ground stations (Environment Canada)	TMY	GHI, DNI, DHI	Hourly TMY	564 stations
CERES (free) ftp://climate_services:msc_services@ftp.tor.ec.gc.ca/Climate_Services/	Ground stations (Environment Canada)	1974-1993 statistics	GHI, DNI, DHI, GTI	Monthly statistics	144 stations
PV Maps (free)	Ground stations (Environment Canada)	1974-1993 means	GHI, GTI	Monthly means	60 arc seconds, 2 km
SUNY (free) ftp://ftp.nrcan.gc.ca/energy/SOLAR/	Satellite (GOES)	2002-2008	GHI, DNI	Hourly	1/10° (8 by 11 km at 45°N)
NASA POWER (free) https://power.larc.nasa.gov/	Satellite	1983-now	GHI, DNI, DHI, GTI	Daily	1° (80 by 110 km at 45°N)
Green Power Labs ($) http://www.greenpowerlabs.com/solarfortheworld.php	Satellite (GOES)	2007-now	GHI, DNI, DHI	30 minutes	1 km
Turquoise Technology Solutions ($) http://sunmetrix.com/	Satellite (GOES)	2006-now	GHI, DNI, DHI	1 hour	1/30° (3 km)
Clean Power Research ($) http://www.cleanpower.com/	Satellite (GOES)	1998-now	GHI, DNI, DHI	1 minute	0.01° (1 km)
SolarGIS ($) http://solargis.info/	Satellite (GOES-EAST)	1999-now	GHI, DNI, DHI, GTI	1 minute	250 m

3TIER ($) http://www.3tier.com/en/	Ground stations (GEBA) & satellite	1981-1990; 1986-2005 statistics & TMY	GHI, DNI, DHI, GTI	1 minute TMY	Any location
High-Resolution Solar Radiation Datasets High-Resolution Solar Radiation Datasets- Natural Resources Canada	Ground stations (NRCan)	Selected days in 2014 and 2015	GHI, GTI	10 milliseconds to 1 minute	41 stations across two sites