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Researching Innovative Strategies to Mitigate Overheating and Increase Resilience in Multi-Family Buildings

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Disclaimer

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

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Executive summary

In response to the changing global climate, Vancouver B.C. has witnessed a rise in the occurrence of heat domes during the summer months. The extreme heat events experienced in the summer of 2021 have shed light on the insufficient cooling infrastructure in many residential buildings across the British Columbia lower mainland. The existing buildings contribute to almost 60% of emissions in the City of Vancouver, with multi-family buildings (such as condos, apartments, and rental properties) being major contributors. These emissions not only exacerbate the impact of extreme weather events, like heatwaves, but also affect vulnerable communities. To address this challenge and achieve the 2030 climate targets set in the Climate Emergency Action Plan, it is imperative to rapidly retrofit existing buildings and reduce emissions. However, the retrofit solutions must not only focus on reducing greenhouse gases but also enhance the buildings' resilience to cope with the increasingly extreme and uncertain climate. To meet this objective, a review of passive technical solutions is conducted to determine the most appropriate approach from a technological and practical perspective. Specific options that are reviewed are as follows:

- Behavior changes to mitigate overheating
- Natural Ventilation Systems
- Green Roofs
- White Roofs
- Green Walls
- External Shading Systems
- Window treatments and technologies

After evaluating the passive technical options, we have reached the conclusion that relying solely on these solutions may not be sufficient to meet the objectives. We have scored these options based on their feasibility in terms of effectiveness, ease of retrofit, availability, cost, co-benefits, and maintenance requirements, considering the equity and affordability concepts outlined in city strategies. The top-performing options are semi-transparent shades and white roofs due to their ease of installation, cost-effectiveness, and minimal maintenance needs.

Considering all the passive measures, we have conducted an extensive study of each measure's types and options, retrofit policies, available incentives from other jurisdictions, case studies, local vendors, and cost estimations. This analysis allows us to compare each measure individually and against one another to identify the most suitable option for retrofits.

In our assessment, retrofitting with intensive green roofs and green walls emerged as the costliest and most complex options, and green roofs proved to be the best option, as they do not require structural estimation and are more affordable in terms of maintenance and installation.

Regarding solar shading devices, their effectiveness is maximized when installed on the appropriate side of the building, considering the solar angle and coupling with natural ventilation.

When it comes to window treatments, window films are the most affordable option, but their effectiveness falls short compared to high-performance windows like double-pane and triple-pane windows. Although triple-pane windows are approximately 30% more effective than double-glazed

windows, the cost difference makes double-glazed windows the optimal choice for mitigating heat during retrofits.

White roofs present an economical option for reducing the urban heat island effect by reflecting heat from the roofs. However, for taller buildings, they might cause glare. To address this issue, cool roof colors with less glare are available and can be utilized for shorter buildings.
The solutions researched in this paper are summarized in the table below and have been scored (out of 5 - with 1 being low and 5 being high) based on the feasibility measures derived from strategies and interviews:

	Passive Cooling Solutions		**Effectiveness at reducing temperatures**	**Local Availability**	**Co-benefits (e.g., emissions reduction, water storage)**	**Ease of retrofitting**	**Cost**	**Maintenance needs**	**Final Score**
1-ROOFS	Green Roofs	Intensive	XXXX	XXXX	XXXXX	X	X	X	16/25
		Extensive	XXX	XXXX	XXX	XX	XX	XX	16/25
		Blue-Green Roof	XXX	XXXX	XXXX	X	XX	XX	16/25
	White Roofs	White Roofs	XX	XXXXX	XX	XXXX	XXXX	XXXX	21/25
2- Walls	Green Walls	Vegetative façade	XX	XXX	XXX	X	X	X	11/25
		Living wall	XX	XX	XXX	X	X	X	10/25
3- Window	Solar Shading devices	Perforated screens	X	X	X	X	X	XXX	8/25
		Semi-transparent shades	XXX	XXXXX	X	XXXXX	XXXX	XXXX	23/25
		Vertical Shades	XXX	XXXX	X	XXXX	XXX	XXXX	19/25
		Horizontal overhangs	XXX	XXXX	X	XXXX	XXX	XXXX	19/25
	Window treatments	Window films	XX	XXXX	X	XXXX	XXXX	XXXX	19/25
		Double Pane Window	XXX	XXXXX	X	XXX	XXX	XXXX	19/25
		Triple Pane Window	XXXX	XXXXX	X	XXX	XX	XXXX	19/25

Table 1 Comparing different measures for mitigating overheating based on their feasibility scores.

1. Introduction

1.1 Background

In June 2021, British Columbia, Canada experienced its deadliest weather event to date, as temperatures reached unprecedented levels. The resulting week-long heatwave led to over 600 deaths caused by heat-related issues. Many of the victims were trapped indoors with insufficient cooling systems. The impact of extreme weather events on vulnerable populations, especially in cities like Vancouver, is a growing concern.

Existing buildings in Vancouver contribute significantly to greenhouse gas emissions, making it crucial to address this issue. (Extreme Heat and Human Mortality: A Review of Heat-Related Deaths in B.C. in Summer 2021, 2022) Nearly 60% of emissions in the City of Vancouver come from existing buildings, with multi-family buildings such as condos, apartments, and rental properties being a significant contributor. These emissions disproportionately affect vulnerable populations, who are more susceptible to extreme weather events like heatwaves. To achieve our 2030 climate targets outlined in the Climate Emergency Action Plan, we must rapidly retrofit existing buildings to reduce emissions. However, emission reduction alone is not enough. Retrofit solutions must also enhance building resilience in the face of an increasingly extreme and uncertain climate.

The Province of British Columbia is expected to experience significant climate changes in the coming decades, including rising temperatures, heavier rainfall, longer drought periods, more frequent heatwaves, and more severe wildfires. These climate impacts pose serious risks to buildings and the safety, well-being, and financial investments of their occupants. Over the last century, the average temperature in the province has already risen by 1.4°C, resulting in noticeable effects on the built environment in various regions. (Strebly et al., 2019)

It is evident that our current building codes and standards are based on historical experiences and do not adequately account for the implications of a warmer world on the health, comfort, and safety of building occupants. Therefore, it is crucial to design new buildings and retrofit existing ones with resilience in mind, ensuring the comfort and safety of occupants throughout the lifespan of the buildings. (Strebly et al., 2019)

Overheating in multi-family buildings presents a specific challenge that requires innovative strategies for mitigation. As temperatures rise, the risk of overheating becomes more significant, endangering the well-being of residents. Traditional building design approaches may not be sufficient to address this issue since they were not developed with future climate conditions in mind.

To tackle this challenge, innovative strategies must be employed in the design and construction of multi-family buildings. These strategies should primarily focus on improving thermal performance, reducing heat gain, and enhancing natural ventilation. By implementing these measures, we can ensure that our buildings are resilient and capable of maintaining comfortable living conditions even during extreme weather events.

Fortunately, there are potential solutions that can address multiple goals and priorities outlined in City strategies such as the Resilient Vancouver Strategy, the forthcoming Climate Justice Charter, and the Rain City Strategy. By embracing these solutions and incorporating them into building design and retrofitting efforts, we can reduce greenhouse gas emissions, improve building resilience, and protect vulnerable populations from the impacts of climate change.

1.2 Objectives

The main objective of this project is to review passive solutions for addressing overheating in multifamily buildings during the summer, while also identifying potential barriers to implementing cooling retrofit projects. This will be achieved through a series of comprehensive steps, including:

- Evaluating the feasibility, policy implications, and challenges associated with various cooling retrofitting technologies for multifamily buildings in the city of Vancouver.
- Prioritizing solutions that are both easy and affordable for individual unit owners in multifamily buildings to implement, with an emphasis on equity considerations.
- Incorporating several critical factors into our recommendations, such as cost, durability, installation complexity, range of shading provided, level of automation, retrofit potential, user adjustability, and local after-sales support.
- Noting the potential difficulties associated with installing new elements, such as green roofs or exterior shading, due to the requirement of consent from building owners, the majority of which are often tenants.

To provide the most comprehensive and useful analysis, recommendations, and case studies, this project will draw upon a range of sources, including literature reviews, interviews with experts and stakeholders, drawing reviews, and site observations. By leveraging these resources, we hope to answer critical questions related to existing technologies, policies, and regulations, building materials, and industry expert views to make the most informed recommendations possible.

1.3 Scope and Methodology

1-The report reviews the technical options in passive systems category, and evaluates each technology based on Co-benefits, relevant city plan, feasibility for existing buildings, durability, installation complexity, range of cooling and shading provided, local sale, and cost.

2-The evaluations are based on a review of public domain literature, interviews with experts and stakeholders, drawing reviews, and site observations.

3- The report aims to answer questions about existing technologies, policies and regulations, and industry expert views to make recommendations.

1.4 Review of Relevant City Strategies

To explore effective passive strategies for mitigating overheating, this report examines the key factors outlined in various city strategies. By considering these factors, we can prioritize different heat mitigating measures. The following table provides a summary of the most significant factors identified after analyzing the strategies.

While all the strategies share a common focus on addressing extreme heat events, they each emphasize specific aspects, as summarized in the following table:

City Strategies / Main Factors	Rain City Strategy	Resilient Vancouver	Climate emergency Action Plan	Climate justice charter Vancouver
Rainwater Harvesting	✓			
Sustainability	✓	✓	✓	✓
Mitigating Urban Heat Island	✓	✓		✓
Affordability		✓		
Safety		✓		
Equity				✓
Health	✓	✓		✓
Emission Reduction		✓	✓	

Table 2 Main factors of city strategies

1.4.1 Rain City Strategy

Recognizing growing pressure on our natural and built water systems, Vancouver is creating a Rain City Strategy to ensure the long-term resilience and sustainability of water resources, and the health of the residents and environment through the integration of green infrastructure. Additionally, the urgency to adapt to the impacts of climate change, as recognized by the Vancouver City Council's declaration of a climate emergency, further underscores the need for proactive measures. The Rain City Strategy is a comprehensive initiative that seeks to achieve the primary objectives, all of which align with the goals of this research:

Harvest and reuse water: The strategy prioritizes the efficient utilization of rainwater to alleviate the strain on municipal water resources. By implementing innovative green roof and envelope systems to mitigate overheating, the collection and reuse of rainwater in multi-family buildings contribute significantly to water conservation efforts and bolster the overall sustainability of the built environment. (Rain City Strategy, 2019)

Mitigate the urban heat island effect: The urban heat island effect refers to the phenomenon where urban areas exhibit higher temperatures compared to their surrounding rural areas. This report highlights the importance of mitigating this effect and presents various strategies to achieve that goal. By incorporating measures such as green roofs, painted roofs, and vegetated facades, we can significantly reduce heat absorption and retention. Consequently, these interventions will contribute to creating cooler indoor and outdoor environments within multi-family buildings and across the urban landscape. (Rain City Strategy, 2019)

Increase the total green area that treats urban rainwater runoff: green areas play a crucial role in managing rainwater runoff and promoting environmental sustainability. The Rain City Strategy aims to increase the green areas within urban spaces, including multi-family buildings, to effectively treat rainwater runoff. Implementation of green roofs, vegetated facades, and the use of deciduous trees can enhance this objective by providing additional green spaces that aid in rainwater absorption and filtration. (Rain City Strategy, 2019)

Climate Emergency and the Need for Adaptation: The declaration of a climate emergency by the Vancouver City Council highlights the urgent need to address the impacts of climate change. Rising sea levels, extreme rain events, milder winters, and increased heat pose significant risks to communities, infrastructure, and ecosystems. Multi-family buildings, as integral components of urban areas, must adapt to these changes to ensure resilience. Embracing innovative strategies aimed at reducing overheating would prove highly advantageous in mitigating the extreme impacts of climate change. (Rain City Strategy, 2019)

To mitigate overheating and enhance resilience, it is crucial to implement innovative strategies that align with the Rain City Strategy objectives. By integrating green roofs, painted roofs, vegetated facades, and the strategic use of deciduous trees, multi-family buildings can effectively reduce the heat island effect and create more sustainable, resilient environments. These strategies promote energy efficiency, enhance thermal comfort, and contribute to overall climate resilience, thereby helping communities adapt to the challenges posed by climate change. (Rain City Strategy, 2019

1.4.2. Resilient Vancouver

This section will discuss the Resilient Vancouver Strategy, which aligns with the goals of this research by aiming to enhance the capacity of the buildings and infrastructure to reduce chronic stresses, and to withstand and recover from inevitable shocks. By 2050, hot days will be 4 C hotter and heat waves more frequent; rainfall event intensity will increase 33–63 per cent. Extreme heat and cold are already impacting Vancouverites. The city of Vancouver recognizes the urgent need to address the increasing impacts of climate change, particularly the rising temperatures and more frequent heat waves predicted for the future.

As part of the Resilient Vancouver strategy, the city aims to enhance the resilience of its buildings to better serve the needs of the community and enable effective recovery from disasters, while also adapting to future conditions. One of the key aspects of this strategy is to prioritize safety and affordability for tenants when considering building improvements, ensuring that the well-being of residents is a central focus. In addition, the strategy emphasizes the importance of maximizing co-benefits, such as reducing emissions and promoting green buildings, when implementing upgrades.

To achieve greater resilience in buildings, the Resilient Vancouver strategy proposes several measures. These include the implementation of Heat Recovery Ventilation (HRV) systems, the installation of operable windows to provide natural ventilation, rainwater harvesting, planting trees that provide shade, as they can help reduce the heat island effect, and the integration of solar panels for renewable energy generation, which contributes to the overall sustainability of the buildings.

1.4.3 Climate emergency Action Plan

In Vancouver, the combustion of natural gas for heating purposes is a significant contributor, accounting for 55% of carbon pollution. Additionally, the construction process itself produces emissions through the production and transportation of building materials, both locally and globally. To address this issue and reduce carbon pollution, innovative strategies are required to mitigate energy use and emissions in the process of retrofitting multi-family buildings. These strategies should focus on transforming how buildings are heated, cooled, designed, and constructed. By implementing efficient and sustainable technologies and architectural designs, we can significantly reduce the energy demand for cooling and heating, thus minimizing overheating while simultaneously lowering carbon emissions.

1.4.4 Climate Justice Charter Vancouver:

High indoor temperatures, particularly in homes without air conditioning and on higher floors, pose significant health risks during extreme heat events. In the context of this research, it is crucial to consider communities that face disproportionate impacts from climate change. These communities experience uneven and unfair consequences of climate change, which can directly affect their health and well-being. (A climate justice charter for Vancouver, 2022)

Certain communities, such as those living or working outside, experiencing homelessness, people with existing health conditions, pregnant individuals, people with disabilities, elders, and children and youth, bear the brunt of climate change impacts. They are particularly vulnerable to extreme heat events. People living in rental housing may also face housing precarity and have limited resources to adapt their homes to reduce the impacts of climate change, such as installing cooling systems, air filtration, and insulation. Additionally, individuals with low incomes and those who are influenced by systemic inequities may struggle to afford food, utilities, and necessities, exacerbated by rising costs associated with climate change. (A climate justice charter for Vancouver, 2022)
This Charter also emphasizes the importance of equitable access to nature and the planting of Indigenous plants. By integrating green spaces and prioritizing Indigenous flora, Vancouver can create healthier, more resilient communities.

2. Mitigation Measures in New Buildings

The focus of this project is to investigate passive cooling solutions in existing buildings. However, it is worth mentioning the efforts underway in new buildings as a precedent. Specific to regulations, efforts are currently underway to incorporate overheating provisions into building codes across Canada National Building Code (NBC). In response to recent extreme heat events and associated fatalities in British Columbia, the Province plans to introduce requirements in the BC Building Code, based on proposed changes in the National Building Code (NBC).. These new requirements aim to mitigate the risks associated with overheating in new homes. The proposed change will mandate a summer design temperature that living spaces within a dwelling unit must be capable of maintaining. This can be achieved through the addition of mechanical cooling or, where feasible, through passive design measures. It is of utmost importance to adopt these measures to ensure the safety and well-being of the city's residents during extreme weather events. (Public Review, BC Building Code 2023, Proposed change to reduce the risk of overheating in dwelling units, 2023)

In the City of Toronto, for example, they are the first city in North America to create a policy that says new buildings must have green roofs. This requirement started on February 1, 2010, and applies to most new buildings that are larger than 2,000 square meters. The rule says that the green roof must cover between 20% and 60% of the roof area, depending on how big the building is. (Torrance et al., 2013)

Due to the ongoing extreme weather conditions, buildings designed to be comfortable now might become uncomfortable in the future, like the existing buildings that need retrofit now for overheating. Buildings that are energy efficient are particularly at risk of overheating because they can trap more heat in the summer. To prevent this, designers need to use both passive and active strategies to cool buildings and make sure they stay comfortable to live in. (Strebly et al., 2019)

2.1 Behavior change to mitigate overheating.

Overheating occurs when the temperature in a space rises excessively, posing significant health risks to its occupants, particularly vulnerable populations. Studies have shown that exposure to temperatures above 26°C is associated with increased mortality rates and medical emergencies (Strebly et al., 2019). To mitigate overheating, it is recommended to design occupied spaces to maintain temperatures below 24-25°C during winter and 27-28°C during summer, as suggested by ASHRAE Standard 55. However, it's important to note that specific requirements may vary depending on the intended use of the space and the characteristics of its occupants. (Strebly et al., 2019)

Implementing behavioral actions can contribute to addressing overheating, and tenant engagement is crucial in this regard. Occupants can actively participate by adopting certain behaviors such as unplugging electronics when not in use, employing cooking methods that generate less heat, and utilizing operable windows to reduce the amount of heat generated inside the building and maximize the passive cooling. These actions, though effective, require further elaboration and exploration beyond the scope of this report.

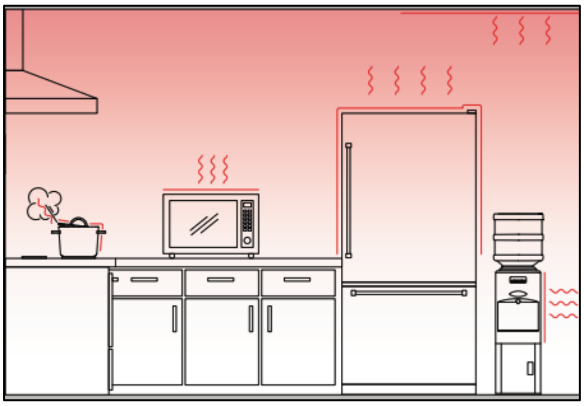


Figure 1 Various sources of heat inside a building unit

2.2 Operable Windows and Natural Ventilation

Figure 2 Windows are pictured open at an apartment building in the Downtown East side neighborhood of Vancouver last summer. Scientist Alexandra Rempel says letting in cooler night air can lower temperatures substantially during extreme heat events. (Ben Nelms/CBC)

In dwellings, operable windows are required for ventilation, typically amounting to 4% of the floor space. Despite the challenge of limited cross ventilation in multifamily dwellings, the Pacific Northwest experiences a significant drop in nighttime air temperatures, providing cooling potential if adequate air exchange is achieved. After a heatwave in June 2021, residents were advised to open windows in the morning, resulting in lowered indoor temperatures. Continuous partial opening of windows throughout the night allowed for significant cooling, reducing dangerous heat index hours.

Improved natural ventilation control, with windows open during cooler outdoor air periods, effectively lowered indoor temperatures and heat indices. Restricting ventilation to night and morning hours further reduced peak indoor temperatures during heatwaves. Optimizing natural ventilation by opening windows when outdoor air first became cooler in the evening and closing them when outdoor air started warming in the morning demonstrated the full potential of cooling.

Implementing this strategy not only promotes survivability during extreme heat but also reduces dependence on air conditioning and mechanical systems, even during heatwaves when managing cooling loads is crucial. (Rempel et al., 2022)

Figure 3Affordable senior housing facility, BC,Low Hammond Rowe Architects

Combining natural ventilation through operable windows with exterior shading significantly improves efficiency. In an experiment conducted on an affordable senior housing facility in BC, the original design resulted in 2,788 overheating hours. Adding horizontal and vertical shades reduced thermal discomfort to 1,864 hours. Further incorporating operable windows, open from 6 am to 10 pm when temperatures exceeded 23°C, reduced overheating to just 162 hours. This highlights the effectiveness of this combined approach in addressing overheating and enhancing thermal comfort. (Strebly et al., 2019)

2.3 Roof Retrofit Solutions and Technologies

Words and Phrases	Definition
Eco Roof	Green roofs and cool roofs, known collectively as 'eco-roofs'.
Green Roof	A green roof is an above-grade extension constructed on top of a man-made structure, designed to support the growth of vegetation in a specialized growing medium
Cool or White Roof	A cool roof or white roof is a roofing system with an exterior surface that reflects the sun's rays and reduces heat build-up from the sun's thermal energy.
Living Roof	Green roofs are sometimes also referred to as eco-roofs, vegetated roofs, living roofs or sod roofs.
Multi Family Building	Multi-family buildings are classified as residential properties that comprise more than two dwelling units. They are characterized by their multi-story structure, typically encompassing multiple floors from 2 to 6, and feature a flat roof design.

Table 3 Definition of new words

2.3.1 Green roofs

2.3.1.1 Co-benefits of Green Roofs

Green roofs (also known as vegetation or living roofs) are an example of a 'no regrets' adaptation measures that can serve multiple societal goals. For example, they can offer a number of co-benefits), such as increased biodiversity, improved air quality, reduced noise, and mitigation of the urban heat island effect and climate change, as well as having the ability to harvest rainwater and reduce surface runoff. Similarly, they offer additional private benefits to property owners through improved energy savings, thermal comfort, improved building performance, and aesthetics. They serve as an additional insulating layer, reducing heat gain during summers and heat loss in winters while protecting the roof's waterproof membrane from damage caused by sunlight or punctures, thus extending its lifespan, and can potentially increase property values. (Wilkinson & Dixon, 2016) (Chomowicz, 2013) (The GRO Green Roof Code 2014)

The most important benefit of green roofing systems is stormwater retention, which is a key consideration in stormwater management policies in North America. However, achieving higher water retention standards can potentially impact plant health and the overall functioning of green roofs (Droz & S. Mackenzie, 2023). Conventional roofs contribute to environmental issues through increased stormwater runoff, habitat damage, water pollution, and heat absorption. In contrast, green roofs mitigate these negative effects by providing green space and incorporating multiple layers, including a soil-like growing medium and resilient plants. Examples include Vancouver's Convention Centre, featuring a large "living roof" with native plants and rainwater recovery systems, while residential green roofs typically have thinner soil layers and low-growing plants (Droz & S. Mackenzie, 2023).

2.3.1.2 Cooling Impacts of Green Roofs

It found that green roofs have a significant cooling effect during sunny days, with a maximum heat flux difference of 15W/m2 compared to regular roofs. At night, the indoor air temperature is about 2.5°C higher for green roofs. Green roofs also reduce temperature fluctuations on their outer surface by 32.5°C, and the temperature difference between green roofs and regular roofs increases with higher solar radiation. Under normal conditions, green roofs act as a heat sink during the day and a heat source at night, while regular roofs behave oppositely. However, when buildings are air-conditioned, the temperature patterns of green roofs become like regular roofs. Solar radiation has the strongest correlation with heat flux through both roof types, but this correlation weakens under air-conditioned conditions. Net solar radiation is the primary heat gain for both roofs, while evapotranspiration and net long wave radiation are the main heat dissipation mechanisms for green roofs. Maintaining high soil water content benefits the thermal performance of green roofs. (He et al., 2016)

2.3.1.3 Installation Considerations of Green Roofs

In general, installing a green roof requires more time and labor than a conventional roof needs. Additional material must be applied according to specifications. The planting can be handled by a roofing contractor or by a contracted landscape company.
. (*Green Roofs: Federal Energy Management (FEMP) Federal Technology Alert* 2004)
A structural engineer should be involved in assessing the capacity of an existing roof structure to safely support the additional loads of a retrofit roof. Based on these estimated loads, a decision is made whether strengthening works are necessary, although this can be costly and may affect the economic viability of the retrofit (Wilkinson & Dixon, 2016).

2.3.1.4 Cost of Green Roofs

The cost of a green roof is estimated to be approximately double that of a quality metal roof per square foot. However, this can vary based on the roof design, geographic area, materials used, the contractor selected and the owner's willingness to contribute labor. Although green roofs have higher upfront costs compared to conventional roofing, their extended lifespan makes them cost-competitive in the long run.

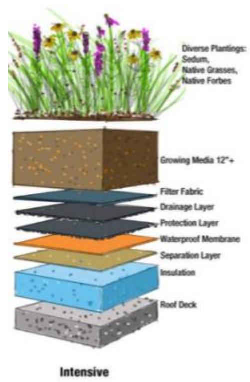
In contrast to sectors like photovoltaics (PVs) or biofuels, the expansion of green roofs and green walls (also known as building-integrated vegetation, BIV) is primarily influenced by actions taken at the city level rather than national policies. The adoption of green roofs is typically driven by building codes and regulations, as well as financial incentives.

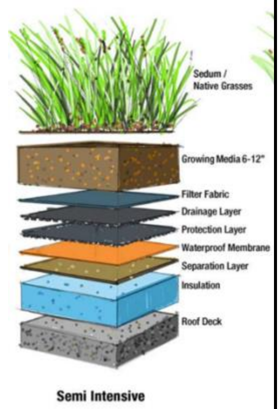
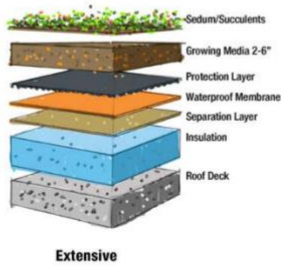
When it comes to the market size, previous estimates (Ranade, 2013) indicate that the global green roof market will reach $7 billion. This includes a $2 billion market for suppliers of polymeric materials, with the remaining portion allocated to vegetation, installation, and maintenance. These estimates reflect the declining costs associated with green roofs, thanks to the utilization of incentives and regulations. By 2017, the installation costs for green roofs decreased by 28%, dropping from an average of $38 per square foot in 2012 to $23 per square foot in 2017.

Europe has been at the forefront of the green roof market's expansion over the past two decades. For instance, Germany has 86 million square meters of green roofs out of a total of 104 million square meters, with 10% of flat roofs being green. Similar growth patterns have been observed in Switzerland, where Basel has achieved 70% of its green roof target. Despite these achievements, there is still significant potential for green roof growth in other European cities, such as London and Copenhagen. It is estimated that 15% of commercial office roofs in Melbourne's Central Business District (CBD) could be retrofitted as green roofs. However, the sector faces several key challenges. While most green roofs worldwide primarily feature sedum plants or utilize drought-resistant irrigation, there is a shift towards incorporating greater species diversity in green roof designs, with payback periods extending up to 30 years. (Wilkinson & Dixon, 2016)

2.3.1.5 Types and Options of Green Roofs

The choice between intensive and extensive green roofs depends on the building's structural characteristics. Extensive systems are typically preferred for existing buildings not designed for heavy loads, while intensive green roofs are suitable for buildings designed to support additional loads and offer benefits in terms of plant variety, thermal performance, and runoff control. Extensive green roofs are generally more cost-effective, easier to install and maintain, and require drought-tolerant plants. Modular systems are recommended for their ease of application and maintenance, without the need for anti-root membranes (Wilkinson & Dixon, 2016).

Green Roof Type	Definition	Picture
Intensive	Intensive green roofs, also called Roof Gardens, are like traditional gardens on rooftops. These roofs need deeper soil (over 200mm) and can be heavier. They require more maintenance, including watering. Intensive green roofs have lots of plants, big shrubs, and trees with soil that is 300mm to 1500mm (12 inches or more) deep. They can weigh more than 45 lbs. per square foot, about 50 lbs. on average. (*The GRO Green Roof Code,* 2014)	

<table>
<tr><td>Semi-Intensive</td><td>Medium depth, green roofs that usually use more substantial grasses, perennials, or smaller shrubs. The soil or grow media/substrate layer is usually 150mm to 300 mm: 6-12” and the entire system has a saturated weight of less than 40 lbs. per square foot, average being about 30 lbs. per square foot.</td><td></td></tr>
<tr><td>Extensive</td><td>Shallow, lightweight green roofs that usually use sedums or shallow root grasses. The soil or growth media/substrate layer is usually shallower than 150 mm or 6” and the entire system has a saturated weight of less than 25 lbs. per square foot, average being about 20 lbs. per square foot.</td><td></td></tr>
<tr><td>Blue/Green Roofs</td><td>An ultra-high water retention green roof system that not only retains high volumes of water for enhanced stormwater mitigation, but the system also provides for passive irrigation utilizing wicking geotextiles and specialized wicking cylinders.</td><td></td></tr>
<tr><td>Bio solar Green Roofs</td><td>Bio solar green roofs are a combination of green roofs and solar panels. They seamlessly integrate these technologies to make the most of both. These roofs not only capture solar energy but also enhance biodiversity, especially in extensive green roof systems. (Bio solar green roofs – combining solar panels and green roofs ,2019)</td><td></td></tr>
<tr><td>Flat green roof</td><td>Many flat roofs will become extensive green roofs, and flat roofs offer limited possibilities for intensive green roofs due to weight-bearing constraints and budgetary considerations. They have consistent water drainage and provide less diversity for plant growth. However, variations in growing media topography can be achieved by</td><td></td></tr>
</table>

	adding depth in areas that can support the extra load.	
Sloped Green Roofs	Sloped green roofs are less common in North America compared to Europe because they require additional structure to hold the growing media, which increases costs. However, sloped roofs allow for a wider range of plant species, with the upper regions draining faster and creating niches for drought-tolerant plants, while the lower areas retain more moisture and support different plant varieties. Sloped roofs can be vulnerable to soil erosion and plant displacement due to gravity, wind, and dry conditions. They may also provide areas of partial to full shade, requiring careful selection of plant species that can adapt to varying light conditions.	

Table 4 Green Roof types and options

2.3.1.6 Green Roof Case Studies

The following table shows four examples from different countries to explain how an existing building can be upgraded with a green roof for different purposes. However, it's important to remember that the green roof design should match the roof's strength. For buildings made of concrete, it's not enough to just look at it - a structural engineer needs to be consulted. In most cases, green roofs with soil less than 10cm deep should be enough to support the roof's weight.

Precedent	Total cost	Green roof type	Programming	Picture
107 Cheapside London, UK	£282/m2 (C$480/m2)	Intensive green roof	-Creating an amenity space -Enhancing biodiversity	
Gladstone Hotel, Toronto, Canada	C$101/m2	Extensive green roof	-Reducing heating and cooling costs -Implementing Measures to Address Flooding Issues -GHG emission reductions of 59 kg of CO2	

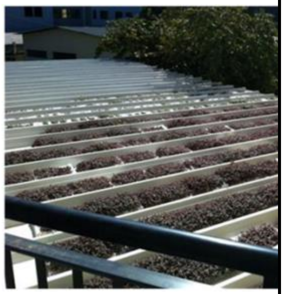
Surry Hills Library, Sydney, Australia (City of Sydney ,2013)	—	Extensive green roof	- Improving the air-quality system using the natural filtering properties of plants. - Reducing by 50% the need for artificial cooling. -Enhancing Energy Efficiency	
Oswaldo Cruz Foundation (FioCruz), Rio de Janeiro, Brazil	—	Extensive modular system	-The main reason for retrofitting is solar reflection towards the next building, which has windows facing the existing roof. -FioCruz implemented a low-cost project by repurposing vaccine boxes as planting containers for a low-cost green roof technology. The initiative aimed to spread the use of green roofs on a city-wide scale.	

Table 5 Green Roof Case Studies

2.3.1.7 Green Roof Policy Precedents from Other Jurisdictions

1) City of Toronto

Existing buildings such as apartment buildings can benefit from green or cool roofs. However, there may be limitations in these buildings, such as the amount of roof space taken up by mechanical equipment, or a gravel roofing system. For example, Toronto's Eco-Roof Incentive Program provides grants to assist building owners to install green or cool roofs. Since 2009, the program has successfully supported the installation of over 140 eco-roofs (106 cool roofs and 36 green roofs completed) and helped to establish over 280,000 m2 of eco-roof space (equivalent to 47 football fields).(*Reducing Health Risk from Extreme Heat in Apartment Buildings,* 2015)

Building age is an important factor when considering retrofits. Many of Toronto's apartment buildings without air conditioning were built between roughly 1945 and 1984. This presents an opportunity, as many of these buildings have systems, such as the windows, roofing system or building envelope, that have reached the end of their useful lives and require replacement. Property owners could consider a variety of options that enhance cooling when replacing or refurbishing these systems. Financing programs are available to support building improvements, but these programs are limited in scope and the level of funding available. (*Reducing Health Risk from Extreme Heat in Apartment Buildings,* 2015)

<u>**Cost and Financial Assistance for Green Roofs in Toronto**</u>

In 2016, an evaluation was done on the Eco-Roof Incentive Program in Toronto. The goal was to find ways to increase awareness, encourage more people to participate, and promote the use of eco-friendly roofs. The report suggests some changes based on the review. To encourage the adoption of green roofs, it is recommended to increase the incentive to $100 per square meter and provide financial support for assessing the structural integrity of roofs. For cool roofs, it is proposed to allow partial roof upgrades and approve cool roofs for new buildings below a certain size limit. The report also highlights the need to remove financial limits for eco-roof projects. (*Eco-Roof Incentive Program Review & Update* 2016)

The analysis done by the consultant shows that green roofs have additional costs and take a long time to pay back the investment. These roofs require more upfront expenses like consultant fees, assessments of the structure, and specialized materials, which makes it difficult for people to choose this type of roof. The consultant spoke to the green roof industry in Toronto and found that the extra costs for extensive green roofs built there can be around $182 per square meter. To illustrate the costs and benefits, the consultant developed case studies of green roof projects that received grants. Based on these studies, the average cost to install these roofs was $371 per square meter, which further highlights the high cost of retrofits and the need to increase the current incentive to make it more affordable. (*Eco-Roof Incentive Program Review & Update* 2016)

The consultant found that the cost of assessing the structure of existing roofs is a major obstacle for retrofits when the roof's stability is uncertain. This assessment can be quite expensive, reaching up to $3,000 when done by a professional engineer. This means that potential participants in the program must pay this cost upfront just to find out if they can proceed with the green roof retrofit. Because of this high upfront expense, some people may choose not to explore the option of installing a green roof at all. (*Eco-Roof Incentive Program Review & Update* 2016)

Financial Support	**Real Average cost**	**Structure assessment**	**Structural assessment incentive**	**Payback Period**
$100 / m2 installed	$371 /m2	$3,000 roughly	up to $1,000.00	Long

Table 6 Financial Support for green roof in city of Toronto

2) The City of Chicago

The City of Chicago recognized the detrimental effects of urban heat islands and poor air quality on human health and quality of life. In response to a severe heat wave in 1996 that resulted in numerous deaths, particularly among senior citizens, the city took action by implementing the Energy Conservation Code in 2001. This code mandated that all new and retrofit roofs meet a minimum standard for solar reflectance, with a requirement of 0.25 reflectance (Lawlor et al., 2006).

To address the issues of roof reflectivity, urban heat islands, and air quality, the city's Bureau of the Environment identified green roofs as an effective solution. Green roofs are covered in vegetation, which helps absorb heat, provide insulation, and improve overall environmental conditions. Based on these findings, the city developed an ordinance to promote the use of green roofs (Lawlor et al., 2006).

In order to encourage the incorporation of green elements in construction projects, the City of Chicago offers several programs. The Department of Buildings administers three main programs: the

Green Permit Benefit Tier Program, the Green Permit Program, and the Solar Express Program (City of Chicago - Green Building Permit Programs,2022).

The Green Permit Benefit Tier Program provides expedited permit processing and potential fee reductions for qualifying projects. Residential projects must achieve certification under LEED for Homes or Green Globes rating systems to be eligible. Additionally, all projects must implement green strategies or technologies in order to receive incentives. The Green Permit Program prioritizes the review process for projects that include specific green elements such as green roofs and rainwater harvesting systems (City of Chicago - Green Building Permit Programs,2022).

Cost Considerations in Chicago

In the United States, green roof costs -including everything from waterproofing to plants -tend to range from $180 to $250 per square meter, depending on how intensive the system is. The initial capital and ongoing maintenance costs of a green roof are offset by some long-term cost savings - most notably roof maintenance and replacement and utility costs. A vegetated roof, on average, can be expected to prolong the life of a conventional roof by at least 20 years because the vegetation prevents the roof from being exposed to ultraviolet radiation and cold winds. (*Green roofs: best management practices*)

3) New York City

New York City, with a population of around 8.1 million people, faces environmental challenges such as stormwater and sewage pollution and the urban heat island effect. To address these challenges, there is a growing interest in implementing green roofs as a solution. However, New York is lagging behind other cities like Portland, Chicago, and Washington D.C. in terms of green roof policies. (Lawlor et al., 2006)

The current number of green roofs in New York City is 736, covering approximately 60 acres or 0.15% of the total rooftop surface area. The potential for increasing the sustainability and resilience of the city, as well as improving the quality of life for residents, is significant due to the large number of buildings in New York. Most green roofs, around 90%, are found on private property, with the majority of those installed on residential buildings (254). (Maxwell & L. Treglia)

Two new laws, Local Laws 92 and 94, have been passed as part of NYC's Climate Mobilization Act to enhance sustainable roof policies. These laws mandate the installation of solar panels or green roofs on all new constructions and major roof renovations. They also raise the reflectiveness requirements of existing cool roofs. However, certain exceptions based on fire code setbacks, mechanical equipment, and recreational spaces are considered. The laws are applicable to projects approved on or after November 15, 2019. The NYC Department of Buildings bulletin provides detailed requirements. (NYC's sustainable roof laws, 2019)

Key highlights of the laws include:

Coverage of new constructions and major roof renovations on existing buildings.
Requirement of a "sustainable roofing zone" on all available roof areas, which can be achieved through solar photovoltaic (PV) systems, green roofs, or a combination of both.
A five-year grace period for certain affordable housing and distressed buildings.
Application to projects approved on or after November 15, 2019.

For new constructions and major roof renovations, building owners must install a sustainable roofing zone on 100 percent of the available roof area. The specific requirements depend on factors such as roof slope, connected area, and solar capacity. (NYC's sustainable roof laws, 2019)

New York State recently passed a green roof tax abatement of up to $15 per square foot. For eligible non-mandated projects, NYC offers subsidies through the Green Infrastructure Grant Program. (NYC's sustainable roof laws, 2019)

Earth Pledge, a non-profit organization, is playing a crucial role in bringing together various stakeholders to assess the costs and benefits of green roofs. They have conducted research, educated stakeholders, and implemented green roof projects. The organization has initiated the New York Green Roof Policy Task Force, organized symposia, and workshops, and developed online resources like the Green Roof Toolbox. They are also involved in research studies, including monitoring green roofs in Long Island City, and developing stormwater modeling tools for Lower Manhattan.

The effectiveness of Earth Pledge's efforts can be seen in the support they have received from government agencies and the completion of several green roof projects. The organization has also partnered with community groups, housing organizations, and schools to promote green roofs in low- and moderate-income communities.

New York City has provided financial incentives for green roof projects via both a tax abatement and a grant program. However, neither has been particularly effective at incentivizing green roofs. The tax abatement has been expired, and, in the eight years that it was offered, only seven property owners were granted abatements. Meanwhile, the grant program has funded only thirty-five green infrastructure projects in the eight years since it was launched and has done so at great expense. These efforts can be strengthened. (Savarani, 2019)

4) The City of Portland

Portland, Oregon is known as a leader in green roof implementation in North America. The city covers a large area and has a temperate climate with heavy rains in fall and winter and a dry season in summer. The main motivation for green roofs in Portland is stormwater management, particularly reducing combined sewage overflow. The city has quickly developed and implemented policies supporting green roofs, and it has funded demonstration projects based on success in Germany. While green roofs are not required for private buildings, they are mandatory for new city-owned facilities. Portland offers incentives such as floor area bonuses and reduced stormwater management charges for buildings with green roofs. The city has a comprehensive outreach and education program, and its success has led to widespread adoption of green roofs in both public and private sectors. Portland's phased approach, research-backed policies, and public engagement have contributed to its success in promoting and implementing green roofs.

City	Summary of Policy Precedents
Toronto	○ Toronto requires new buildings larger than 2,000 square meters to have green roofs covering 20-60% of the roof area. ○ The Eco-Roof Incentive Program provides grants for installing green or cool roofs in existing buildings. ○ Over 140 eco-roofs have been supported, including 106 cool roofs and 36 green roofs, covering over 280,000 square meters.

	○ Retrofitting older buildings presents opportunities for enhancing cooling systems, but funding programs have limitations. ○ Evaluation suggests increasing incentives for green roofs to $100 per square meter and providing financial support for structural assessments. ○ Green roofs have higher upfront costs, averaging $371 per square meter for retrofits in Toronto, emphasizing the need for financial incentives. ○ Assessing roof structures for retrofits can be costly, discouraging potential participants. ○ All green roofs in Toronto, whether voluntary or required by the Green Roof Bylaw, must conform to the Toronto Green Roof Construction Standard.
NYC	○ The current number of green roofs in NYC is 736, covering approximately 60 acres or 0.15% of the total rooftop surface area. ○ Most green roofs are found on private property, with the majority installed on residential buildings. ○ Two new laws, Local Laws 92 and 94, mandate the installation of solar panels or green roofs on new constructions and major roof renovations. ○ Building owners must install a "sustainable roofing zone" on 100% of the available roof area for new constructions and major roof renovations. ○ New York State offers a green roof tax abatement of up to $15 per square foot. ○ NYC provides subsidies through the Green Infrastructure Grant Program for eligible non-mandated projects. ○ Financial incentives provided by NYC, such as the tax abatement and grant program, have not been very effective in incentivizing green roofs and can be improved.
Chicago	○ The City of Chicago implemented the Energy Conservation Code in 2001 to address urban heat islands, poor air quality, and promote the use of green roofs as a solution. ○ Chicago offers programs to encourage green elements in construction projects, including the Green Permit Benefit Tier, which provides expedited processing and potential fee reductions, and the Green Permit Program, which prioritizes the review of projects with specific green elements such as green roofs and rainwater harvesting systems. ○ Green roof costs in the US range from $180 to $250 per square meter, including waterproofing and plants. ○ Green roofs have long-term cost savings in roof maintenance, replacement, and utility costs. They can prolong the life of a conventional roof by at least 20 years.
Portland	○ Portland, Oregon is a leader in green roof implementation in North America. ○ The main motivation for green roofs in Portland is stormwater management, specifically reducing combined sewage overflow. ○ The city has swiftly developed and implemented policies to support green roofs, drawing inspiration from successful projects in Germany. ○ Private buildings are not required to have green roofs, but new city-owned facilities must incorporate them. ○ Portland provides incentives such as floor area bonuses and reduced stormwater management charges for buildings with green roofs. ○ The city has a comprehensive outreach and education program, which has contributed to the widespread adoption of green roofs in both the public and private sectors. ○ Portland's success in promoting and implementing green roofs can be attributed to its phased approach, research-backed policies, and active public engagement.

Table 7 Summary of policy precedents for green roofs

2.3.1.7 Green Roof Companies and links

Any roofing contractor who is committed to high-quality work should be qualified to install a green roof under the supervision of an experienced and knowledgeable consultant. (*Green Roofs: Federal Energy Management (FEMP) Federal Technology Alert* 2004) To facilitate convenient access to a comprehensive list of green roof contractors, we have provided the following table.

	Green Roof company	Website	Location
1	Duron Group	Duron Group	Vancouver
2	Laurentian roofing	Laurentian	Vancouver
3	ZinCo	Zinco	Quebec and Ontario
4	Onni Group	Onni Group	Vancouver
5	bcgreenroof	bcgreenroof	Vancouver
6	Vitaroofs	vitaroofs	Ontario
7	Architek	Architek	Vancouver
8	xeroflornorthamerica	xeroflornorthamerica	Ontario
9	Etera (Produces sedum tiles as an innovative option for immediate on-roof planting and instant 'Green Roof)	Etera	Washington
10	Soprema (They have various details for different systems and Products)	Soprema	Various Locations in Canada

Table 8 Green roof companies and links

Green Roof Retrofit Analysis	
Average Cost	○ $172/m2
Effectiveness at reducing temperatures	○ Very Effective- Reduces the interior temperature by 7 degrees Celsius on average
Local Availability	○ There are locally available companies.
Co-benefits	○ Increased Biodiversity ○ Improved Air Quality ○ Noise Reduction ○ Mitigation of Urban Heat Island Effect ○ Climate Change Mitigation ○ Rainwater Harvesting and Runoff Reduction ○ Energy Savings ○ Extended Roof Lifespan ○ Increased Property Values ○ Stormwater Retention ○ Enhanced Urban Resilience ○ Improved Thermal Performance ○ Local food production
Compatibility with City Strategies	○ It is compatible with all the city strategies
Ease of retrofit	○ Can be used on most building types that have concrete, wood, or composite (wood fibers and cement) roof decks. ○ Green roofs can be used in place of conventional gravel-ballasted roofs. ○ Metal roofs expand and contract and are thus not suitable for a green roof retrofit. ○ Construction and installation processes are very similar to those for conventional roofs and do not require specialized tools or equipment.

Structural Considerations	○ Existing roof' structure should be assessed and strengthening measures should be considered, if needed. ○ This process can be costly and impact the economic feasibility of the retrofit. ○ Extensive systems are typically preferred for existing buildings not designed for heavy loads
Maintenance	○ High Cost

Table 9 Green Roof Retrofit Analysis

2.3.2 White / Reflective Roofs

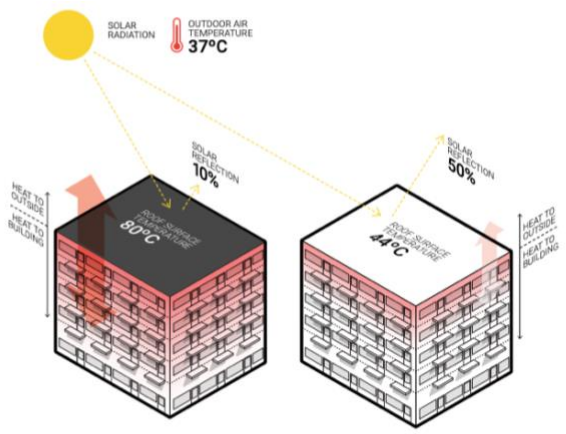


Figure 4 A comparison of two buildings' surface temperature with white roof and conventional roof

This section discusses the "cool roof" option, an alternative method for retrofitting a roof. Cool roofs reflect sunlight and release absorbed radiation more efficiently than standard materials, resulting in lower heat retention. They can be achieved by applying a cool roof treatment, such as paint, or by integrating it into the roof layers. Cool roof paints have higher reflectivity and thermal emittance than regular materials. Advancements in technology allow for darker-colored pigments with enhanced reflectivity in the non-visible near-infrared spectrum. However, darker roofs are not as reflective as light-colored ones. Cool roofs also help reduce heat absorption and the urban heat island effect. (Wilkinson & Dixon, 2016)

Cool roofs can extend the life of roofs, reduce energy costs, and help residents stay healthy during periods of high urban temperatures. Local governments can use cool roofing programs to fulfill environmental justice needs by identifying neighborhoods with vulnerable populations and promoting cool roofs in those areas. They can target cool roofs to urban heat islands, thus increasing the effectiveness of their initiatives. Cool roofs also contribute to mitigating climate change and reducing air pollutant emissions. (P. Hoverter, 2012)"

Many studies have shown that making buildings more reflective and better at emitting heat can save a lot of energy and reduce the temperature. For example, by using white reflective surfaces on roofs, the surface temperature can be reduced by 24 degrees Celsius on average. This can lead to an 11% decrease in air-conditioning energy use, resulting in significant cost savings. In the United States, cooling energy savings in residential buildings range from 12% to 25% when these strategies are implemented. Older houses with poor insulation and air distribution systems in the roof space benefit the most from these improvements. Even in different climates, using cool roof paints can lead to significant energy savings, especially in buildings with high cooling loads. (Wilkinson & Dixon, 2016)

2.3.2.1 Policy and Installation Considerations for Cool Roofs

Cool roofs are cost effective in most temperate-to-warm locales, but governments must still answer two specific questions:

-First, in which neighborhoods are cool roofs beneficial?

-Second, which policy tools are optimal for the community?
The local climate and neighborhood characteristics will inform where adopting cool roofs will be most appropriate. The economic viability of cool roofs is influenced by local weather patterns. Governments must consider the trade-off between lower summer cooling costs and potentially higher winter heating costs. In most US climates, cool roofs offer greater benefits during the summer, outweighing the winter penalties, especially in areas with heavy snowfall. However, in cold, cloudy northern climates, cool roofs may not be the optimal choice. It is important for governments to consider future climate changes when evaluating cool roof effectiveness. (P. Hoverter, 2012)

Cool roofs are suitable for buildings that cannot support the weight of green roofs or have steep slopes. While cool roofs can be physically installed on many structures, they are most effective in specific neighborhoods and with certain building combinations. For instance, cool roofs on shorter buildings surrounded by taller buildings can reflect light and transfer heat to the taller structures, potentially causing unwanted glare for residents or workers. The cooling benefits of cool roofs primarily extend to the levels just beneath the roof, providing limited or no benefit to lower floors in tall buildings. Consequently, cool roofs are particularly advantageous in areas with one- or two-story buildings. (P. Hoverter, 2012)

2.3.2.2 Types and Options of Cool Roofs

There are various cool roof options available for different types of roofs, such as asphalt shingles, wood shingles and shakes, polymer shingles, clay tiles, concrete tiles, metal shingles or tiles, single-ply membranes, built-up roofs, spray polyurethane foam roofs, and standing-seam metal roofs. The choice of color is crucial, with white roofs reflecting the most sunlight, but dark materials with special pigments can also enhance solar reflectance. Installing a cool roof during new construction or when replacing an existing roof is the easiest and most cost-effective option. Retrofitting existing roofs with cool coatings is possible but incurs additional material and labor costs. (*Cool roofs*. Energy.gov. (n.d.))

Cool Asphalt Shingles	**Flat White Roof**	**Cool Metal Roof**
		

Table 10 Three main options of cool roof. Resource:(How 'Cool Roofs' can help property owners manage Louisville's urban heat island effect, 2021)

2.3.2.3 White Roof Case Studies

Case Study	Programming	Picture
Salem Oregon, US (Ames Case Study 2023)	○ The roof coating system is easily maintained by facility maintenance. ○ White reflective roof coating saves money on cooling costs. ○ Extended the life of the roof for decades. ○ Avoided expensive tear-off and landfill costs. ○ Additional environmental benefits: ○ Reduced material sent to landfill. ○ Energy efficient. ○ Long-lasting. ○ Reduced risk of mold inside the facility. ○ Utilized sustainable roofing materials.	
Nationwide Scottsdale Insurance Company, Arizona, US (WALKER, 2009)	○ Retrofit Project ○ Reduced Thermal Shock ○ Increased Energy Efficiency ○ Reduced Roof Surface Temperature (by 12 degrees, 13.5%)	
Life Extension and Reroof Portland, Oregon, US *Case studies*. Clarity Roof. (n.d.). https://www.clarityroof.com /blank-3	○ Roof Size: 79,000 sq. ft. ○ Roof Type: BUR with 80 mil TPO overlay ○ Solar Size: 5.0mW ○ Roof Warranty Delivered: 25yr NDL. ○ Client Savings: $350,000	

Table 11 Case studies of white roof

2.3.2.4 Policy precedents of Cool Roofs

In response to the urban heat island (UHI) effect and the escalating frequency of severe heat waves, an increasing number of cities, particularly those located outside of traditionally hot regions, such as Chicago, Denver, Philadelphia, Baltimore, and New York City, are implementing regulations or endorsing the use of cool roofs. These cities recognize their vulnerability to heat impacts, as they often lack sufficient cooling infrastructure and acclimation to high temperatures, unlike cities like Phoenix and Las Vegas, which have historically experienced hotter climates. (Schneider , 2022)

<u>Cool Roof Incentives</u>

1) City of Toronto

The City of Toronto has financial rebates for cool roof installations in their Eco-Roof Program:

- $5 / m2 for a cool roof with a new membrane
- $2 / m2 for a cool roof coating over an existing roof

2) **City of Louisville**

To address urban heat issues, the Louisville Metro Government has initiated the Cool Roof Incentive Program, available to both residents and businesses. The program, administered by the Office of Sustainability, offers financial incentives to property owners who install cool roofs. Under this program, property owners can receive $1 per square foot of cool roof installed. The objective is to incentivize the installation of cool roofs covering at least 100,000 square feet of area. The Office of Sustainability provides a maximum incentive of $2,000 for residential buildings, including multi-family units, granting $1 per square foot for new or retrofit steep-slope and flat or low-sloped cool roofs. The program targets districts with high heat levels, characterized by a prevalence of pavements and buildings and a lack of tree canopy and open space. These areas experience a more pronounced urban heat island effect, making them a priority for cool roof implementation. (*How 'Cool Roofs' can help property owners manage Louisville's urban heat island effect* 2021)

3) **California**

Cool roof initiatives in California have gained significant support and are being actively promoted through various channels and local programs. To ensure widespread acceptance and adoption, residents and businesses are being informed about the financial incentives available for cool roof installations. CoolCalifornia.org Funding Wizard is a valuable tool that helps individuals, businesses, and local governments find grants, incentives, and rebates for sustainable projects, including cool roofs. Energy Upgrade California, a collaborative effort involving state agencies, counties, cities, utilities, and community organizations, offers rebates and incentives for implementing energy-efficient measures like cool roofs. Many communities and local governments have also taken steps to develop their own cool roof programs, such as the City of Berkeley's requirement to install cool roofs on commercial buildings and the City of Chula Vista's increased minimum cool roof requirements. Additionally, resources like the U.S. EPA's Compendium of Strategies and the Cool Roofs and Pavements Toolkit provide comprehensive guidance and information on the science, technology, economics, and implementation of cool roofs. (*Cool roofs: Taking action | cool California*)

City	Summary of Policy Precedents
Toronto	○ Eco-Roof program promotes sustainable and climate-adaptive buildings in Toronto. ○ Incentives for retrofitting ICI buildings in designated areas and new large buildings citywide. ○ Incentives: $2-$5/sqm for cool roofs (up to $50,000/award). ○ Initial funding: $2.4 million over 5 years ○ Grants available for installing green roofs and cool roofs in Toronto. ○ Cool roof incentives: $5/sqm for new membrane, $2/sqm for coating existing roof.
Louisville	○ Louisville Metro Government's Cool Roof Incentive Program addresses urban heat issues. ○ Financial incentives are provided for installing cool roofs to residents and businesses.

	○ Property owners can receive $1 per square foot of cool roof installed. ○ Objective: Cover at least 100,000 square feet with cool roofs. ○ Administered by the Office of Sustainability. ○ Maximum incentive of $2,000 for residential buildings, including multi-family units. ○ Supports new installations and retrofitting of different roof types. ○ Prioritizes districts with high heat levels, lack of tree canopy, and excess pavements and buildings. ○ Target areas experience pronounced urban heat island effect.
California	○ Cool roof initiatives in California are actively promoted through various channels and local programs. ○ Financial incentives for cool roof installations are communicated to residents and businesses. ○ CoolCalifornia.org Funding Wizard helps find grants and incentives for sustainable projects, including cool roofs. ○ Energy Upgrade California offers rebates for energy-efficient measures like cool roofs. ○ Many communities and local governments have their own cool roof programs. ○ Resources like the U.S. EPA's Compendium of Strategies and Cool Roofs and Pavements Toolkit provide guidance on cool roof implementation. ○ SMUD's Residential Cool Roof Program provides incentives for installing cool roofs on residential properties. ○ The program covers both flat roofs and steep slope roofs using qualified cool roof materials. ○ Cool roofs reflect heat and lower surface temperatures. ○ In 2008, the program completed 119 residential cool roof projects, covering 189,000 square feet.

Table 12 Summary of Policy Precedents for white roofs

Cool Roof Retrofit Analysis	
Average Cost	○ $22/m2
Effectiveness at reducing temperatures	○ Effective- Reduces the interior temperature by 4 degrees Celsius on average
Local Availability	○ There are locally available companies.
Co-benefits	○ Mitigation of Urban Heat Island Effect ○ Energy Savings ○ Extended Roof Lifespan ○ Reduce greenhouse gas emissions
Compatibility with City Strategies	○ It is compatible with all the city strategies
Ease of retrofit	○ Can be used on most buildings
Structural Considerations	○ No Considerations
Maintenance	○ Low Cost

Table 13 Cool Roof Retrofit Analysis

2.3.2.5 Comparison of White Roofs and Green Roofs

The presence of a green roof helps to decrease heat transfer through multiple mechanisms such as shading, evapotranspiration, absorption, and the insulating qualities of soil and water. Field experiments have demonstrated that a green roof maintains lower temperatures during the day compared to a metal roof. The most significant temperature reduction occurs during the peak cooling load period, mainly due to the absorption of solar radiation. When comparing the surface temperature of white roofs and green roofs, the green roof stays cooler with a slight time delay because of its additional thermal mass. When examining internal temperature conditions, both green roofs and cool roofs exhibit variances of approximately 3°C on a 35°C Day. Both types of roof modifications effectively lower internal temperatures, with white roofs achieving a decrease of up to 4°C and green roofs up to 7°C. Other factors to consider for green roofs include maintenance requirements, load-bearing capacity, and water availability for irrigation. However, as mentioned earlier, green roofs often provide intangible benefits such as improved well-being and increased productivity for those who can view or have access to them. (Wilkinson & Dixon, 2016)

In summary, the circumstances whereby the cool roof option is most beneficial are:

■ buildings that mainly have a cooling load.

■ buildings with a large roof-to-total-surface-area ratio.

■ buildings with roofs that are not overshadowed for more than 20% of the time.

■ buildings with a PV solar array on them.

As outlined above, the circumstances whereby the cool roof option is favored over a retrofit green roof alternative are where there are significant aspects of cost, maintenance (including availability of water), structural load, and roof pitch. (Wilkinson & Dixon, 2016)

Roof type	Average Cost	Internal Temperature Reduction	Insulation of the roof	Mitigation of urban heat island	Ecosystem services	Structural considerations	Maintenance
Green roof	$172/m2	7C	Increases the R-value	More effect	Biophilic, biodiversity, absorption of emissions, stormwater retention	Yes	High cost
Cool roof	$22/m2	4C	No effect	Less effect	No effect	No	No maintenance needed

Table 14 Comparison of White Roofs and Green Roofs

2.4 Wall Retrofit Solutions and technologies.

2.4.1 Green walls

The term "Green wall" encompasses various forms of vegetated wall surfaces, and its application to existing buildings' external walls holds significant potential. By implementing vertical greening in urban communities, the landscape environment can be enhanced, creating 3D ecological stepping islands within urban green networks and extending ecological benefits from the built environment. The urgency for this approach arises from recent climate events, emphasizing the importance of restoring the natural relationship between building form and inhabitants to mitigate heat, reduce carbon emissions, and enhance urban livability.

Green walls have gained popularity as sustainable design elements in the construction field, supported by numerous studies highlighting their benefits. Research has shown that vertical greening systems can reduce interior temperatures, decrease power consumption for air-conditioning, and delay solar heat transfer compared to concrete buildings. Green walls have also been found to effectively decrease noise pollution and absorb sound at different frequencies, especially with greater vegetation coverage. (El Menshawy et al., 2022)

Furthermore, life cycle analyses have shown that green wall systems, including direct and indirect greening systems, and planter box living walls, are environmentally favorable choices, leading to reduced energy demand for heating. In Mediterranean climates, green walls have proven their cooling potential, mitigating outdoor and surface temperatures, enhancing thermal comfort, and reducing the urban heat island effect. They have also been shown to improve relative humidity and decrease carbon dioxide concentration near the walls. (El Menshawy et al., 2022)

Studies conducted in Colombo metropolitan, Sri Lanka, revealed that green walls significantly reduce temperatures, increase relative humidity, and decrease carbon dioxide concentration compared to bare walls. Additionally, green walls have positive impacts on micro-climate and human thermal comfort, resulting in energy savings, positive perceptions from occupants, improved visual comfort, and high levels of satisfaction.(El Menshawy et al., 2022)

Figure 5 Cable supported green wall

Cable-supported green wall facade exemplifies an innovative approach to vertical greening. Traditionally, greening walls involved using climbing plants like ivy, Russian vine, and Virginia creeper that attach directly to porous brick and stone surfaces. Trellises and wires are sometimes added to aid plant growth while limiting direct contact with the wall. The establishment of dense evergreen foliage can happen relatively quickly, but on older buildings, it is carefully managed to avoid obscuring windows and openings. This dense foliage also provides a habitat for birds and invertebrates, adding ecological value. Even in small and challenging spaces, the potential for implementing green walls remains promising.

2.4.1.1 Types and Options

Green walls come in a variety of configurations ranging from the simplest and the most basic to the most complex and high-tech design. Green walls vary in their types and systems, and this leads to different approaches in design, installation and maintenance. According to the type of vegetation and the used supporting structure, green wall systems can be divided into two major groups: green façades and living walls. (El Menshawy et al., 2022)

2.4.1.2 Green façades

Green façades utilize climbing or hanging plants that grow on walls, either upwards or cascading downwards, categorized into direct and indirect greening systems. In the direct system, plants adhere directly to the wall, with roots in the ground or planter boxes. In contrast, the indirect system requires additional supporting structures for non-adhesive plants, with roots also in the ground or planter boxes, placed at intervals along the height of the building to achieve rapid coverage. Indirect green façades create an air gap between the building surface and vegetation, functioning as "double skin façades." Common subcategories in the marketplace include cable and wire rope net systems, metal mesh systems, and modular trellis panel systems. (El Menshawy et al., 2022)

2.4.1.3 Living walls

Living walls are a recent innovation in wall cladding, offering environmentally friendly materials with complex infrastructures involving supporting structures and attachment methods. Unlike green façades, living walls support vegetation rooted in an attached substrate to the wall, allowing rapid coverage of large surfaces and uniform growth along vertical spaces, making them adaptable to different buildings and accommodating a wide variety of plant species. There are two main types of living walls: Continuous systems pioneered by Patrick Blanc, featuring synthetic fabric layers with pockets for plants and growing media, and Modular systems composed of containers like vessels, trays, and panels, supporting pre-vegetated plants. As the marketplace continues to evolve, new types of green façades and living walls emerge regularly. (El Menshawy et al., 2022)

Types of green wall			Reducing urban heat island effect	Moderating building's internal temperature via external shading	Greening system cost	Maintenance cost	Irrigation System Requirement
Green facade	Direct Greening	Planted into the soil	XX	XX	X	X	—
		Planted into Planter Box	XX	XX	X	X	X
	Indirect Greening	Planted into the soil	XX	XX	XX	XX	—
		Planted into Planter Box	XX	XX	XX	XX	X
Living Wall	Continuous System	Felt System	XXX	XXX	XXX	XXX	XX
	Modular System	Planter Box System	XXX	XXX	XXX	XXX	XX
		Panel System	XXX	XXX	XXX	XXX	XX

Table 15 Types and Options of green wall

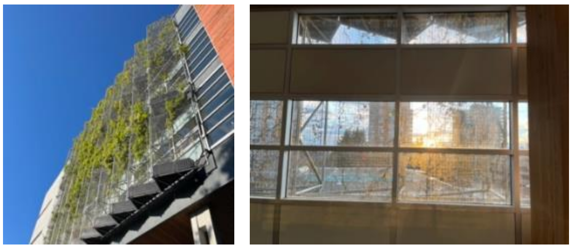


Figure 6 CIRS building at UBC-Right: Green wall in winter-Left: green wall in summer

Using deciduous plants as a natural shading solution on a frame behind windows is an ingenious way to address both the challenges of harsh summer sun and cold winter days. The strategic placement of these plants can effectively block the sun's glare and reduce thermal effects during the scorching summer months, thereby improving the building's energy efficiency and indoor comfort. An exemplary implementation of this concept can be found in the CIRS (Centre for Interactive Research on Sustainability) building at the University of British Columbia (UBC). The building features a specially designed frame behind the windows that allows deciduous plants to grow and flourish during the spring and summer seasons. As the plants mature, they create a lush green canopy, shielding the interior from excessive heat and sunlight. However, during the winter months, the deciduous plants shed their leaves, allowing sunlight to penetrate the building, thus harnessing the natural warmth of the sun to enhance passive heating and reduce reliance on artificial heating systems.

2.4.1.4 Case studies of Green Walls

Precedent	Total cost	Area	Programming	Picture
RMIT University, Melbourne, Victoria	230,000$	122 m2	-Built on an existing building -Green facade on north and west-facing walls -Planter boxes at the base support climbing plants on a trellis.	
Triptych Apartments, Victoria, Australia (*Green façade, Putney* 2021)	$350,000	206m2	-New Building, Residential -Rainwater sustains thriving plants in the green wall. -Green wall provides habitat and visual amenity.	
Putney, UK (*Green façade, Putney* 2021)	—	400m2	-Traditional green façade with climbers on a trellis. -Stainless-steel trellis with Jakob wire system installed. Climbers planted and trained to cover 60% of the wall in three years. -Green façade reduces heat loss, heat gain, and offers weather and UV protection.	

OASIS d'ABOUKIR, Paris (Briz et al., 2015)		250 m2	-It's a private initiative -On a previous concrete wall -It is south-oriented	

Table 16 Case studies of Green Walls

Green Wall Retrofit Analysis	
Average Cost	○ $172/m2
Effectiveness at reducing temperatures	○ Very Effective- Reduces the interior temperature by 7 degrees Celsius on average
Local Availability	○ There are locally available companies.
Co-benefits	○ Increased Biodiversity ○ Improved Air Quality ○ Noise Reduction ○ Mitigation of Urban Heat Island Effect ○ Climate Change Mitigation ○ Rainwater Harvesting and Runoff Reduction ○ Energy Savings ○ Extended Roof Lifespan ○ Increased Property Values ○ Stormwater Retention ○ Enhanced Urban Resilience ○ Improved Thermal Performance ○ Local food production
Compatibility with City Strategies	○ It is compatible with all the city strategies
Ease of retrofit	○ Can be used on most building types, new frames or other structural details should be considered
Structural Considerations	○ Structural support from the exterior wall to install the green wall frames.
Maintenance	○ Very High Cost

Table 17 Green Wall Retrofit Analysis

2.5 Window Retrofit Solutions and technologies.

2.5.1 Exterior Solar Shading Devices

The Pacific Northwest region experiences dry summers, similar to warm-summer Mediterranean and cold semi-arid climates. These climates offer passive cooling advantages due to lower cloud cover, resulting in more intense solar radiation and cooler nighttime temperatures compared to humid regions at similar latitudes. Thus, methods like window shading and natural ventilation are more effective in this region. Summer nights in the Pacific Northwest have average temperatures of 15°C (59°F) or below, with clear skies facilitating cooling from warm surfaces. However, most residential buildings in the area are not designed to handle extreme heat. Contrary to the baseline condition, apartments often have indoor roller shades or venetian blinds. Light-colored, glossy, or metallic shades can reflect much of the incident solar radiation back through the glass, preventing interior warming (Rempel et al., 2022). However, while interior window shades are often used, they are less effective as they allow solar gains to enter the space, causing the shades themselves to absorb heat. (Strebly et al., 2019)

2.5.1.1 Installation Considerations for Exterior Shading

While exterior shading retrofitting seems like an ideal option in the Pacific Northwest region due to its suitable climate, there are hindrances to retrofitting buildings in this area. Existing design limitations, high costs, and the need for integrated planning are factors that pose challenges (Shading, Films, and Window Attachments - SFWA, 2016). Despite the increasing interest in these shading products, end users often lack an understanding of the energy-saving benefits and maintenance challenges they offer. Moreover, a prevalent trend is the application of external shading devices for aesthetic reasons rather than energy efficiency, which limits their potential advantages. Additionally, if all owners do not agree to install the shading device, a single unit cannot implement it separately due to the negative impact on the facade's aesthetics, and strata owners are usually hesitant to make permanent changes, such as installing exterior shading devices that may involve punching the envelope.

2.5.1.2 Types and Options of Exterior Shading

To minimize unwanted solar gains during summer and reduce cooling loads, buildings should include horizontal shading on south facades while optimizing shading for daylighting and solar heat gains in winter. Balconies can function as shading devices, blocking incoming solar radiation in summer, and allowing winter sun through patio doors. Fenestration on the south facade should be shaded using overhangs or architectural shading devices while avoiding thermal bridging. To address overheating on western facades, vertical fins can provide shading from intense solar gains when the sun is lower in the sky. (Ramslie, 2016).

For optimal cooling, operable shades of any material and position should be deployed when direct solar radiation is incident upon the window surface, i.e., when solar heat gain is at its peak, and retracted during cooler outdoor conditions to facilitate heat loss through radiation and convection (Rempel et al., 2022). Designers can consider multiple types of exterior window shading.

1) FIXED SHADES can block direct radiation from the sun in the summer while allowing passive heating in the winter.

- Fixed exterior shading devices (projecting louver above a window, can offer good protection from high-angle-summer sun on south facing windows)
- Balcony overhangs
- Reduced window-to-wall ratio (Maybe portable reflective partitions to block the heat in summer)
- A slatted or perforated shade (providing effective natural ventilation as it will preserve enough free area for airflow while providing sun protection)

2) OPERABLE SHADING can be adjusted as needed, either manually or automatically.

- Manually operated shades give occupants more control but rely on occupants to be present to be effective.

- Automatically controlled shades are more reliable in preventing unwanted solar gains but reduce occupants’ control over their space and are more expensive to install and maintain.

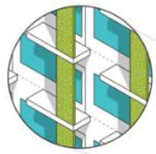
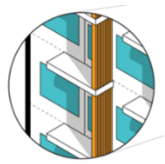
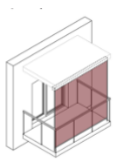
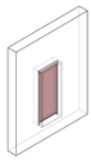
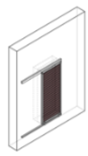
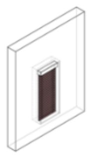
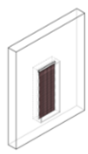
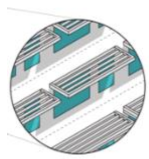
<table>
<tr><th>Shading Type</th><th colspan="2">How it works</th><th>Picture</th></tr>
<tr><td>Perforated Screens</td><td colspan="2">mounted outside of a window or on a balcony can effectively block solar gains but will also reduce passive heating potential in the winter and will obstruct some of the view.</td><td></td></tr>
<tr><td>Vertical Shades</td><td colspan="2">can be effective on any orientation; however, they will reduce passive heating in the winter.</td><td></td></tr>
<tr><td rowspan="5">Semi-Transparent Shades
(Adjustable exterior shading devices)</td><td rowspan="5">can be used to block solar gains while allowing a view through to the outside.</td><td>Exterior fabric screen for balconies and large openings</td><td></td></tr>
<tr><td>Exterior fabric blind mounted to window</td><td></td></tr>
<tr><td>Sliding shade panel</td><td></td></tr>
<tr><td>Roller shutter</td><td></td></tr>
<tr><td>Spanish-style roller blind</td><td></td></tr>
<tr><td>Horizontal Overhangs</td><td colspan="2">are best on the south façade as they block high angle summer sun while allowing low angle passive solar heating in winter.</td><td></td></tr>
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Table 18 Types and Options of Exterior Shading

2.5.1.3 Vegetation as Exterior Shading

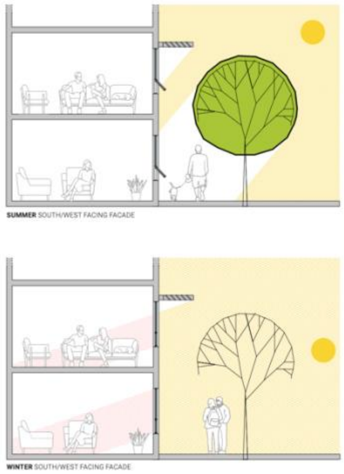


Figure 7 Up: Summer south/west facing facade-Dawn: Winter south/west facing facade

Exterior shading can be achieved through carefully selected and designed vegetation. During the summer, deciduous trees and other foliage can effectively shade windows, while in the winter, they allow solar gains to enter. Designers should consider the height of the vegetation, both current and future, as well as its distance from the building. Planting deciduous trees on the south and west facades can help mitigate summer heat gain while still allowing winter heat gain when the trees are bare. Priority should be given to planting on these facades wherever possible, as they can offer valuable passive cooling benefits.

While vegetation can provide effective shading for all building orientations, it will require regular maintenance and can lead to increased water usage, particularly significant as the climate warms and droughts become more prevalent. To address this, owners are encouraged to consider incorporating greywater and/or rainwater capture systems (Strebly et al., 2019).

2.5.1.4 Case studies for Exterior Shading

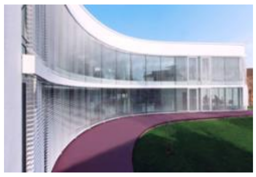
Precedent	Shading Type	Programming	Picture
The Brook at False Creek, Vancouver, BC	Automatically controlled shades	○ Avoids relying on occupants to remember to lower them. ○ Shades are -Semi-transparent so occupants can still enjoy an unobstructed view.	
Headquarters for Saegeling Medecine Technologies, Heidenau, Germany (Beck et al, 2010)	external sun shading systems with white plastered surfaces	○ It is a DGNB-certified building with an effective solar shading systems. ○ Special Venetian blinds with adjustable slats control sunlight and glare.	
Clapham Park – London, UK (Duco, *Clapham Park - Londen*)	Aluminium sliding panels with wooden blades	○ Renovation Project. ○ The decision was taken in June 2008 to tackle the whole site and to renovate a total of 975 housing units.	

Table 19 Case studies for Exterior Shading

2.5.1.5 Cost of Exterior Shading

Application	Technology type	Cost per sq.ft. Window Area	Cost per window
Exterior Shading	Roller Shade	$3	$33
	Solar Screen (Fixed Panel)	$4	$45
	Motorized louvered shade	$30	$375
	Motorized louvered/ Hinged Shutters	$30	$375
	Motorized Solar Screen/Roller Shade	$30	$500

Table 20 Cost of Exterior Shading

2.5.1.6 Companies that Install Exterior Shading Products

Company	Shading Type	How It Works
Talius (https://www.talius.com/)	Habitat Screens	Reduces ambient room temperature by approximately 11 degrees Celsius. Reduces the need for artificial cooling
	Roll shutters	Reduces cooling energy demand by as much as 50-80%
MHZ (https://www.mhz.de/en/products/#c122313)	Awnings	Ideal for balcony, terrace, and window
	Shading systems	can be used on horizontal, angled, and large surfaces
	External Venetian blinds	Control incoming light and visibility through the blind
	Metal blinds	high transparency for optimum visibility to the outside

Table 21 Companies that Install Exterior Shading Products

Exterior Shading Retrofit Analysis	
Average Cost	○ $33-$500 per window
Effectiveness at reducing temperatures	○ Very effective when couples with natural ventilation
Local Availability	○ There are locally available companies.
Co-benefits	○ Energy Savings ○ Glare reduction
Compatibility with City Strategies	○ It is compatible with all the city strategies
Ease of retrofit	○ Suitable for most buildings, modifications to the envelope require the owner's consent.
Structural Considerations	○ No Considerations
Maintenance	○ Medium Cost

Table 22Exterior shading retrofit analysis

2.5.2 Window films and treatments

Windows serve multiple purposes, including providing access, outlook, daylight, and ensuring safety egress. To achieve a balance between heat and natural light in buildings, factors such as sizing, orientation, and glazing choices need to be carefully considered. The energy balance of a building depends on factors like the season, building type, and its operation. In cold weather, windows should retain heat and maximize solar radiation, while in hot weather, they should minimize heat gain and allow for heat to be shed. The performance of windows should be specified based on the region's heating and cooling loads to achieve optimal energy balance.

High-performance windows, such as triple-glazed windows with low-e glass and well-insulated frames, are recommended for cold climates. However, double-glazed windows with low-e coatings, low-conductive frames, and inert gas are prevalent in many OECD member countries. Single-glazed windows with poor insulation are still sold in various regions, resulting in higher U-values and discomfort for occupants.

Improving solar control is necessary to address issues like excessive heat and glare. Advanced solar control glazing that reflects near-infrared light while transmitting visible light performs better than clear or tinted glass. Combining such glazing with exterior architectural shading offers an improved solution. Automated exterior shading systems are the most effective technology currently available to modulate solar energy hitting the glass and improve occupant comfort, although they can be costly.

Window coatings, such as low-emissivity coatings, reduce the amount of radiation transferred through windows while allowing light to pass through. Dynamic glazing, such as electrochromic glazing, is being commercialized and offers the potential to modulate solar heat while maintaining a view to the outdoors. These glazing have demonstrated energy savings in lighting, cooling load reduction, and peak electricity reduction. However, further research and economies of scale are needed to make dynamic solar control cost-effective for mainstream markets (LaFrance, M. 2023).

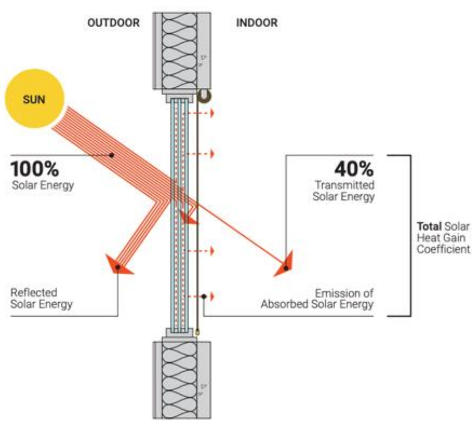


Figure 8 Performance of a glazing with SHGC of 0.4

Solar Heat Gain Coefficient (SHGC) is an important element in glazing selection and can be optimized for each façade of a building. Selecting glazing with an appropriate SHGC means finding the right balance between preventing overheating and reducing a building's thermal energy demand. A SHGC of 0.4 means that 40% of the solar heat gains that land on the outside window surface enter the space. A low SHGC reduces the risk of overheating. However, a SHGC lower than 0.28 starts to impact Visible Light Transmittance (VLT), which can make spaces darker and require additional lighting energy, adding more internal gains (heat) to the space. Conversely, a high SHGC allows more solar radiation to pass through the glazing, which reduces the building's need for heating energy but can increase the risk of overheating.

Electrochromic glazing technology allows for automatic or manual control of a glazing tint and solar heat gain properties. These products have a similar effect to exterior automatically controlled operable shades.

2.5.2.1 Types and Options

Window Treatment		Definition
Window Film		Window film is best for homes in regions with **long cooling seasons.** Silver, mirrorlike film is typically more effective than colored transparent film, and east- and west-facing windows benefit most because of their greater potential for heat gain when the sun rises and sets.
	Low emissivity (Low-E) glass	Low-E glass controls light and solar heat gain by applying a thin metal coating (silver or tin oxide) to the inner surface of the exterior glass pane. It reflects heat outward in warm climates and absorbs heat in cooler climates, ensuring year-round comfort.
	Double Glazing	Double paned windows feature two panes of glass with a gas-filled pocket in between. They deliver outstanding energy efficiency, maintaining a consistent interior temperature within the building all year round.
	Triple Glazing	Triple paned windows do everything that double-glazed windows do, just a little bit better. They are approximately 15% more expensive than double-paned windows
	Tinted glazing	A home with tinted glass windows can reduce heating from the sun by up to 84%. Different types of tinted glass window films reduce different levels of energy absorption.
Smart Window	**Electrochromic Glass**	These windows use electricity to offer homeowners the ability to control how much heat and light can pass through.
	Photochromic Window Tint	Photochromic tint is altered by its exposure to UV rays.
	Thermochromic Glass	Similar to photochromic tint, the tint of thermochromic glass is dictated by outside elements—in this case, heat.
	Suspended-Particle Glass	This type of glass leverages nanoparticles that are suspended in liquid. When voltage is applied to these particles, they align and allow light to pass through. When electricity is removed, the particles become randomly organized, blocking and absorbing light.

Table 23 Window treatment types and options

2.5.2.2 Cost of window treatments

Application	Technology type	Cost per sq. ft. Window Area	Cost Per Window
Window Film	Applied Film (Standard Solar Control	$6	$80
	Applied Film (Advanced or spectrally selective	$10	$125
Glazing	Tinted Glass	$ 8-14	-
	Double-glazing	-	$300
	Triple-glazing	-	$550-$850
Smart Window		$ 50-150	-

Table 24 Cost of window treatments

2.5.2.3 window treatments companies and links

	companies	Info	Location
1	View Smart Windows	○ View Smart Windows use AI to adjust tint based on outdoor conditions for comfort and natural light. ○ Customizable experience through mobile apps for setting tint schedules or manual adjustment. ○ View Immersive DisplayTM turns windows into interactive surfaces for entertainment, video conferencing, and more. ○ Benefits of View dynamic glass: Up to 18% annual energy savings and up to 23% peak cooling load reduction.	Vancouver
2	Window film systems	○ Solar Reflective Film ○ Heat Control Window Film	Vancouver
3	TITAN	○ Substantial heat rejection provides energy savings and enhanced comfort ○ Clear to lightly tinted, allows up to 70% of the visible light through your windows ○	Vancouver

Table 25 window treatments companies and links

2.5.2.4 Window treatment case studies

Precedent	Programming	Picture
Chabot College, California	○ New dynamic glazings offer the potential to modulate solar heat (variable SHGC) through the glazing while maintaining a full view to the outdoors, such as electrochromic glazing, which changes opacity in response to voltage and thus allows control over the amount of light and heat passing through	
A three-story historical stone building in the cold climate of Sweden	○ 35% reduction in the unwanted heat gains due to the application of the low-E window film improved the thermal comfort, so that the percentage of total occupant hours with thermal dissatisfaction fell from 14% (without films) to 11% (with films). ○ A considerable reduction in energy consumption which leads to 50% reduction of payback period from 30 years to 15 years.	
An Apartment in Netherland	○ With the innovative smart window, which combines thermochromic coating and a standard low-e coating, a single household can achieve annual energy cost savings ranging from 29.2%	

Table 26 Window treatment case studies

2.5.2.5 Window Treatment **Incentive Programs**

Utility Programs are special programs provided in different states (like Arizona, California, Colorado, etc.) that offer incentives for using window films. These programs aim to encourage the use of window films for energy-saving purposes.

Out of the 27 utility programs reviewed, 19 of them offer fixed incentives for specific types of window films, while 8 programs offer customized incentives based on individual building performance.

The incentives are typically given as a certain amount of money per square foot of window space covered by the film. To be eligible for these incentives, the window films must meet certain requirements related to their ability to reduce solar heat gain (SHGC). Some programs may offer different rebate amounts based on how much the SHGC is improved after the installation.

Custom Incentive Programs determine the rebates based on the projected annual energy savings in dollars per kilowatt-hour (kWh), which is estimated using building performance models both before and after the installation of the window films. Some programs have standard calculations for cost and savings, while others may require the submission of all cost and savings estimates for pre-approval. Many local utility companies offer a per window rebate for ENERGY STAR or other energy-efficient windows. In some areas, this could mean a **$200 or more rebate per window.** (Sabo & Morien, 2023)

In Europe, the uptake of window films is generally higher compared to the United States due to several reasons:

1. European buildings are traditionally designed without heavy reliance on air conditioning due to milder weather conditions, leading to more widespread acceptance and use of window films.
2. This greater acceptance allows for the adoption of higher-cost window film products.
3. Simpler mechanical systems are used in European buildings, further promoting the use of window films for energy efficiency.
4. Higher energy costs in Europe have created a culture of energy conservation, making energy-saving technologies like window films more popular.
5. Building codes in some European countries encourage the use of window films before granting HVAC permits, ensuring greater application of these technologies.
6. Different European countries have varying preferences for window film technologies, with Germany focusing on exterior shading, France favoring fabric-based solutions, and the UK preferring louvers and operational systems. (*Shading, Films and Window Attachments (SFWA)* 2016)

	Fixed External Shades	Manual Shades	Automatic Shades	Vegetation	SHGC	Window Coating
Livability	✓ ✓	✓		✓ ✓		
Aesthetic	✓ ✓			✓ ✓		
Not Additional maintenance required					✓ ✓	✓ ✓
Controllability		✓ ✓	✓			
No increase in need for indoor lighting					✓	
Glare Control	✓			✓	✓	✓

Table 27 Comparison of shades and window treatments

Window Film and Treatment Retrofit Analysis		
Average Cost	**Films**	$ 80-125
	New Window	$ 300-850
Effectiveness at reducing temperatures	**Films**	○ They are effective but better to use with other measures
	New Window	○ Using Double pane window with improved u Value and SHGC is **Very effective**
Local Availability		○ There are locally available companies.
Co-benefits		○ Reducing glare ○ Better insulation ○ Reducing UV ray
Compatibility with City Strategies		○ It is compatible with all the city strategies
Ease of retrofit		○ Can be used on all the buildings (Films are more appropriate for jurisdictions with mild winters)
Structural Considerations		○ No Considerations
Maintenance	**Films**	○ Low Cost
	New Window	○ High cost

Table 28 Window Film and Treatment Retrofit Analysis

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