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Mitigating UHI Effects in Canadian Communities Using Nature Based Solutions

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Executive Summary

Driven by the global emission of greenhouse gases, Canada's climate has changed and will continue to develop, where on average the warming experienced in Canada has been approximately double the magnitude of global warming. In addition, increases in anthropogenic heat emissions and a reduction of green spaces and surface albedo due to rapid land transformation has directly impacted the energy balance of urban environments. As a result, urban areas are experiencing elevated temperature relative to their rural surroundings otherwise known as the urban heat island (UHI) effect. The federal government of Canada released the strengthened climate plan in 2020, which emphasizes using nature-based solutions (NbS) for their ability to reduce the UHI effect and the potential of overheating while providing one of more desired eco-system services. This report evaluates the potential effectiveness of NbS at reducing the risk of overheating under Canadian climate conditions by completing a review of studies investigating the use of surface greenery (SG) and surface reflectivity (SR) to reduce overheating within Canada. In addition, a review of Canadian bylaws and policies that specify the use of SG and SR to reduce urban temperatures is completed. Combined, the findings from this review could be used to assist in estimating the percent coverage/adoption of NbS techniques on buildings and urban scales, providing a benchmark on the parameters to be assessed within a particular domain. These coverage/adoption estimates could then be used in future simulations to investigate the efficacy and benefits of these techniques. Outgrowth from this work may be able to aid in the development of tools and design guidelines that policy makers and urban planners could use when implementing NbS in their communities to reduce the risk of overheating.

Mitigating UHI Effects in Canadian Communities Using Nature Based Solutions

1 Introduction

Through a combination of global greenhouse gas emissions, land transformation and reduced surface albedos, Canada's climate is "experiencing some of the most rapid temperature changes observed worldwide (OCA (Council of Canadian Academies)., 2022). These same factors are causing urban areas to experience elevated air and surface temperatures relative to their rural surroundings otherwise known as the urban heat island (UHI) effect (Health Canada, 2020). In some cases, the UHI effect can create periods where pedestrians and occupants of free running buildings experience heat stress; a particular concern in cold-climate cities where heat-vulnerable populations may not be able to adapt to rising temperatures. The use of mechanical cooling infrastructure, such as air conditioning, may serve the needs of a building, but the heat emissions directly impact the energy input to urban environments (Ichinose, Shimodozono, & Hanaki, 1999) (Fan & Sailor, 2005). These added anthropogenic sources of heat can contribute to a feedback loop where increased outdoor temperatures lead to increased cooling loads, that in turn exhaust thermal energy to the environment, further raising outdoor temperatures and subsequent cooling load requirements for buildings. Increased outdoor temperatures can also affect the population, from loss of urban environmental quality to increased risk of heat-related mortality and morbidity (Health Canada, 2020). Global statistics indicate that on average approximately half a million people have died annually from heat waves over the last two decades (Zhao & et al., 2021). The recent 2021 heat dome as occurred in British Columbia resulted in 619 excess deaths over a week of extremely high temperatures soaring to nearly 50 °C (BCCS, 2022). Similarly, the summer heat waves experienced in Montreal, Quebec, resulted in 280 excess deaths in 2010 (Bustinza, Lebel, Gosselin, Bélanger, & Chebana, 2013), and 66 excess deaths in 2018 (Lamothe, Roy, & Racine-Hamel, 2019). The strengthened climate plan released by the federal government, emphasizes the use of Nature based Solutions (NbS) as opposed to the use of mechanical cooling infrastructure such as air conditioning, given their ability to reduce the potential of overheating while providing one or more desired eco-system services.

A report by the IUCN Global Standard for Nature-Based Solutions defines NbS as "*actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits*" (IUCN, 2020). The standard however does not specify what solutions can and can not be considered NbS, nor does the standard provide clear examples of what constitutes as a solution. Instead, the standard has been written as a framework for the design of NbS to achieve one or more desired outcomes, or to reduce societal challenges, which can include the creation of open spaces, retention capacity for stormwater runoff, passive filtration for the reduction of air pollutants, CO_2 and GHG reduction, as well as habitat creation to name a few.

As reducing the risks associated with overheating are the societal challenges that the recommendations provided in this report are, if correctly applied, expected to help mitigate, attention is brought to the Health Canada report, "*Reducing urban heat islands to protect health in Canada – An introduction for public health professionals*". In this report four key measures are provided that communities could use to reduce the UHI effect and their related health impacts. These measures include: expanding vegetation cover; implementing climate sensitive urban design and planning; integrating natural ventilation and water features into urban designs, and; reducing waste heat production. A specific definition of NbS was not provided, but in the report, it is stated that: "*Many of the challenges currently facing urban areas, including those introduced or exacerbated by climate change, can be alleviated through naturally inspired design choices. Projects that harness the potential of natural systems are often described as nature-based solutions. These solutions may involve actions or designs that mimic, enhance, or support the functions of a natural system*" (Health Canada, 2020).

In the Canadian Standards Association report, "*Nature-Based Solutions for Coastal and Riverine Flood and Erosion Risk Management",* the authors discuss the fact that there are many terms that are either synonymous with, or resemble, the meaning of NbS, lying between purely natural (green) and conventional (grey/hard structural) solutions (Vouk, Pilechi, Provan, & Murphy, 2021). Therefore, NbS can be employed to address a broad range of societal challenges, and restoration of ecosystems or the enhancement of biodiversity within an environment is not necessarily their only objective. Accordingly, NbS can be used to bring together conventional grey infrastructure and natural ecosystems in what is termed hybrid or grey-green solutions. These hybrid solutions are often inspired by natural processes and may contain design elements that mimic, enhance, conserve or support nature to achieve one or more desired eco-system services.

As such, in this report NbS are defined as solutions that mimic, enhance, conserve or support nature, and which fall within a spectrum between purely natural (green) and conventional (grey/hard structural), and that can be harnessed to address one or more societal challenges. Using this definition, a review of studies in which investigations were conducted, within Canadian cities, on the effects of increasing surface reflectivity/albedo (ISR) and increasing surface greenery/vegetation (ISG) is offered, together with a review of any current Canadian bylaws or current policies, specifying the use of ISG and or ISR to reduce urban temperatures. The findings will conclude as a reference point to determine which NbS scenarios should be suggested for meso-scale simulations and could help determine if any specific UHI reduction strategy is being targeted along with any architype buildings or any specific areas within cities. This summary could also be used by researchers or policy makers to address knowledge gaps and to refine and develop new policy and bylaws going forward. In addition, this review could allow future studies to estimate the percent coverage/adoption that UHI reduction strategies may achieve in cities, the values of which could be used in simulations to predict future climates scenarios.

2 Review of Canadian Studies on Nature-based Solutions

To evaluate the potential effectiveness of NbS at reducing the risk of overheating under evolving climate conditions across Canada, a review of studies investigating the use of surface greenery (SG) and surface reflectivity (SR) was performed. The findings from this review are presented in the following sections and could be used as a reference against which to compare any future simulations in which the effectiveness of SG and SR within a particular urban space has been investigated.

2.1 Increased Surface Greenery / Vegetation (ISG)

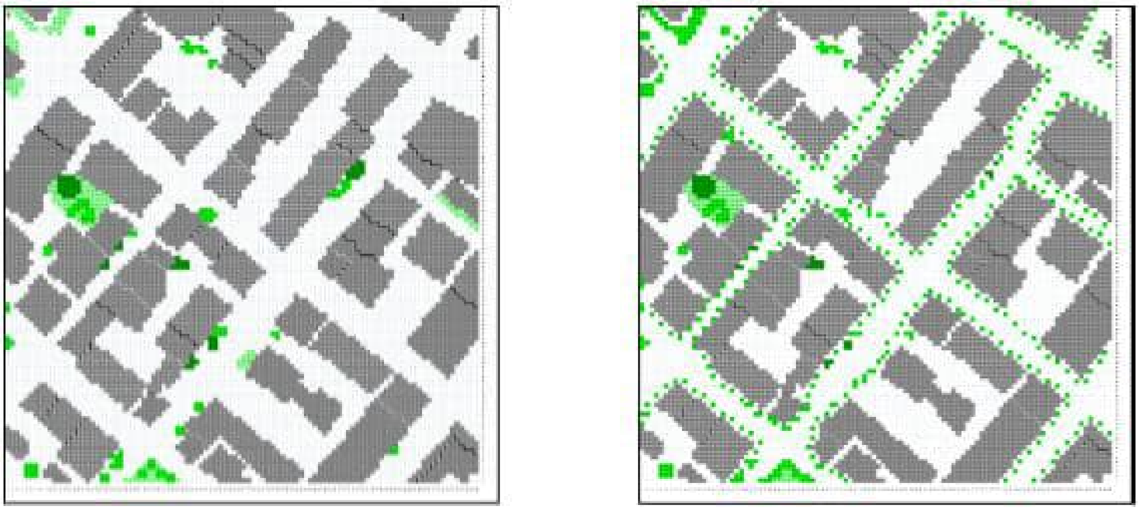
In general, plants can decrease surface and air temperatures through shading and evapotranspiration. The solar radiation, that would otherwise be incident on a surface, is blocked from reaching the surface below and is either reflected or absorbed by the leaves (Dardir & Berardi, 2021). Additional energy is dissipated when radiation absorbed by vegetation or growing medium is dissipated through transpiration from the leaves and evaporation from the growing medium. The surface temperature reductions resulting from evapotranspiration are usually less than that achieved from shading; however, the process is effective at reducing ambient air temperatures of a larger area and into the evening (Koch, Ysebaert, Denys, & Samson, 2020). Urban vegetation can also alter the convective boundary conditions around a structure by creating a wind barrier next to a surface altering the energy transfer to or from the covered surface. In a report published by The Council of Canadian Academies, a review was conducted to describe how vegetation might be used to sequester carbon and reduce GHG emissions from the atmosphere, describing them as nature-based climate solutions (NBCS) (OCA (Council of Canadian Academies)., 2022). The review was conducted to determine if NBCS could reduce enough emissions from the atmosphere to mitigate some of the effects of climate change. The ability for urban trees to remove and store carbon from the atmosphere is dependant on the species selected and the amount of water they receive however, it is estimated that on average urban trees removed over 4 Mt CO_2 e per year between 1990 and 2018 in Canada. Despite these findings the increase in urban tree cover was found to have only a modest impact on total GHG emissions equivalent of the energy used for planting, maintenance and irrigation were considered. As such the authors determined that urban trees alone would not be sufficient to mitigate the effects of climate change in Canada, and that other conservation, restoration and reduction measures would be required. Despite this, many surfaces could benefit from added vegetation; however, the urban environment can be a harsh place for plants to grow and survive. As such, unique strategies have been developed to increase the likelihood that vegetation will survive in both horizontal and vertical environments. In addition to their abilities to reduce urban overheating, vegetation can bring multiple social, economic and environmental benefits to the urban environment, such as, the creation of open spaces, retention capacity for stormwater runoff, passive filtration for the reduction of air pollutants, CO_2 and GHG reduction, as well as habitat creation to name a few. Table 1, provides a summary of studies investigating the use of SG as a means of mitigating the effects of UHI within Canada, including information on the location used within the simulations, the simulation tools used, the SG strategy simulated, a summary of the simulation parameters used, and a summary of the study's findings. The table presents a summary of the highlights and limitations of these studies if only to provide future work a reference for their studies. The two simulation tools used within the studies were ENVI-met and WRF, where ENVI-met is a 3D urban climate modeling tool for simulating the microclimatic effects of buildings and vegetation and WRF is a mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications respectively.

Table 1: Studies investigating the use of SG as a means of mitigating the effects of UHI within Canada

Location	Strategy & Simulation Tool	Results	Highlights and Limitations
Toronto ON, Toronto Metropolitan University 2016 (Berardi U. , 2016)	Vegetated roof ENVI-met Roof combos A: 0.15 m soil depth and Leaf area index (LAI) 1 B: 0.15 m soil depth and LAI 2	**Ground level (1.8 m)** Air temperature: Reduction of 0.2°C and 0.4°C compared to base case at noon for roofs A and B respectively. Reduction at mid-night of 0.7°C and 1.1°C for green roofs A and B respectively. Mean Radiant Temperature (MRT): Negligible reduction achieved by roof A and 0.2°C for B at noon. Reduction of 0.1°C and 0.3°C at min-night for roofs A and B respectively. **Roof top (15 m above the ground, 2 m above the roof)** Air temperature: Reduction of 0.2°C and 0.4°C compared to base case at noon for roofs A and B respectively. Reduction at mid-night of 1.6°C and 2.6°C for green roofs A and B respectively. Mean Radiant Temperature: Reduction of 15.8°C and 21.7°C achieved by roof A and B at noon.	Highlights • Shows the difference between ground level and roof top measurements and the importance of defining a frame of reference. Limitations • Lacking a description of the size of the vegetated area used to achieve these results, • Other environmental parameters required to quantify overheating such as wind speed and relative humidity not described.
Montreal QB – City central area. A high-density residential area next to the city's main commercial area and university. 2016 (Wang & Akbari, 2016a)	Implementation of Street Trees – Tree size and spacing ENVI-met	Decreasing the Sky view factor (SVF) from approximately 0.47 to 0.4 could decrease the average air temperature at a height of 1.8m by 1.2°C, where the average air temperature at a height of 1.8m could be reduced by 3.3°C by decreasing the SVF from 0.47 to 0.1. The greatest MRT reduction of 40°C was achieved at 10 am by reducing the SVF from approximately 0.47 to 0.1. This was achieved at a height of 1.8m. Decreasing the SVF from approximately 0.47 to 0.1 could result in a 4°C and 2°C air temperature reduction at 20 and 60 m height respectively.	Highlights • Simulated vegetation parameters described. • Results presented using SVF allowing comparison to other works analysing effects of street trees. Limitations • Other environmental parameters required to quantify overheating such as wind speed & relative humidity not described.

Location	Strategy & Simulation Tool	Results	Highlights and Limitations
Montreal QB – The addition of vegetation to Concordia University 2016 (Wang & Akbari, 2016b)	Street Vegetation Planting ENVI-met The addition of vegetation to Concordia (see Figure 1 for graphical increase).	The addition of vegetation lowered air temperature between 0.2 – 0.3°C between (8 am to 7 pm) and 0.03 – 0.19°C between (8 pm to 7 am) The added vegetation reduced MRT between 1.1 – 3.0°C between (6 am to 6 pm) and only 0.1 – 0.4°C during the night. Wind speed in the tree planted area increased by approximately 0.2 – 0.5 m s^{-1} compared to the base case. The considering all environmental parameters together, the Perceived Environmental Temperature (PET) was reduced between 0.6 – 2.1°C between (6 am to 6 pm) and 0.1 – 0.4°C during the night.	Highlights • Discussed effects that an increase in vegetation had on multiple environmental parameters and thermal comfort • Can be used as a general guide showing how an increase may affect multiple parameters. Limitations • Other than graphically, the amount, type and size of vegetation used to achieve results was not all described, thus preventing comparisons of results to other studies.
Toronto ON 2016 (Wang, Berardi, & Akbari, 2016c)	Additional vegetation coverage ENVI-met **Base model vegetation coverage** Detached 26.6% Middle-rise 13.5% High-rise 1.5% **Green model vegetation coverage** Detached 36.6% Middle-rise 23.5% High-rise 11.5%	Going from base model vegetation to green model vegetation scenario resulted in, • 0.5°C air temperature reduction at 12:00 pm, • 0.8°C, 0.6°C and 0.8°C air temperature reduction at 16:00, • 0.6°C, 0.5°C and 0.6°C air temperature reduction at 1:00 am at a height of 1.8 m for the detached, middle-rise and high-rise areas respectively. Going from base model vegetation to green model vegetation scenario resulted in 8.3°C, 6.1°C and 6.2°C mean radiant temperature reduction at 15:00 at a height of 1.8 m for the detached, middle-rise and high-rise areas respectively.	Highlights • Simulated vegetation coverage described • Results presented in a manner that allowed easy comparison between scenarios analysed within & outside particular study • Presented how urban form can affect level of change resulting from an increase in vegetation. Limitations • Other environmental parameters required to quantify the risk of overheating such as wind speed and relative humidity not described.

Location	Strategy & Simulation Tool	Results	Highlights and Limitations
Greater Toronto Area ON, (Brampton and Caledon) 2020 (Berardi, Jandaghian, & Graham, 2020)	Greening Scenarios WRF, ENVI-met **Moderate Green Scenario** (MGS) **Intensive Green Scenario** (IGS) Mesoscale: MGS (50% increase in vegetation) IGS (80% increase in vegetation) Microscale: MGS (increasing the number of trees from 445 and 469 for Brampton and Caledon to 585 and 617) IGS (increasing the number of trees from 445 and 469 for Brampton and Caledon to 1064 and 1325)	**WRF - Mesoscale** **MGS:** average daily, air temperature reduction between 0.8 – 1.3°C, wind speed decrease 0.2 – 0.4 m/s, relative humidity increase 7%. Maximum 2 m air temperature reduction of 1.5°C and 2°C for Brampton and Caledon respectively. **IGS**: average daily, air temperature reduction between 1.5 – 2.0°C, wind speed decrease 0.3 – 0.5 m/s, relative humidity increase 9%. **ENVI-met Microscale** **MGS:** Spatially averaged air temperature reduction at 5pm around 0.1°C, maximum air temperature reduction between 0.39 – 0.59°C. **IGS:** Spatially averaged air temperature reduction at 5pm between 0.4 – 0.56°C, maximum air temperature reduction between 1.29 – 1.51°C	Highlights • Simulated vegetation parameters described. • Results presented in a manner that allowed easy comparison between scenarios analysed within the particular study and outside the study. • Environmental parameters required to quantify the risk of overheating such as wind speed and relative humidity included within the study. • Presented how geographic location can affect the UHI reduction capabilities of mitigation strategies. Limitations • Results are limited to the greater Toronto area.



Base vegetation around Concordia | Increased vegetation scenario

Figure 1: Graphical representation of the vegetation simulated around Concordia University, Montreal Quebec (Wang & Akbari, 2016b)

2.2 Increased Surface Reflectivity (ISR)

Typically, materials found within the urban environment are darker in colour, have a higher heat capacity and are non-porous compared to materials found in natural environments. Because of this, urban areas tend to absorb and store more incoming solar radiation and retain less water compared to their surroundings. In respect to buildings, and depending on the exposed surface, absorbed solar energy is either transmitted through the façade to a conditioned space by conduction or released back to the urban environment by radiation and convection. ISR can be used as a means of restoring the reflectivity of a surface to reduce the amount of solar energy that is absorbed by a surface (Hendel, 2020). Studies investigating the use of SR as a means of mitigating the effects of UHI within Canada are given in Table 2, including information on the location used within the simulations, the simulation tools used, the SR strategy simulated, a summary of the simulation parameters used, and a summary of the study's findings. The table presents a summary of the highlights and limitations of these studies if only to provide future work a reference for their studies.

In a study conducted by Frie, et al. (2022), an attempt was made to calculate the current albedo of Montreal Island. The study was conducted to confirm whether the default and baseline albedo value of 0.2 used in simulations was representative of a Canadian city. In addition, the study was conducted to determine what level of increase in total city albedo could reasonably be expected by implementing different cool roof options within Montreal. Satellite imaging and digital maps were used to create a geographic layout of the city based on land use categories of roofs, roads, vegetation and other impervious surfaces. By assigning typical albedo values to the land use category areas within the geographical model of the city, a spatially averaged albedo value of 0.19 ± 0.057 was calculated. As such the default albedo used within simulations, was found to fall within the range of uncertainty for the calculated values, suggesting that the default albedo is an acceptable representation of the current total albedo for Montreal Island. The authors suggest that similar calculations be performed for other cities within Canada so that a more realistic understanding of what is possible in terms of improving the total albedo of an urban area can become known.

Table 2: Studies investigating the use of SR as a means of mitigating the effects of UHI within Canada

Location	Strategy & Simulation Tool	Results	Highlights and Limitations
Montreal QB – The use of reflective pavement around Concordia University 2016 (Wang & Akbari, 2016b)	Cool Pavement ENVI-met **Base pavement model:** Albedo 0.2, Heat capacity 2.25 [J m^{-3} K^{-1}] x 10^6, Heat conductivity 0.90 [W m^{-1} K^{-1}] **Cool pavement model:** Albedo 0.4, Heat capacity 2.34 [J m^{-3} K^{-1}] x 10^6, Heat conductivity 4.61 [W m^{-1} K^{-1}]	Increasing pavement albedo resulted in 6.3°C reduction in surface temperature at 11:00 am compared to base pavement. Switching to cool pavement resulted in increase in ability of pavement to transfer & store thermal energy. As a result, night air temperature (T) was 0.4 – 0.7°C > than base pavement T. Between 8 am & 5 pm, compared to base pavement, the MRT above cool pavement was between 3 – 3.3°C & PET was ca. 3 – 4°C lower. By switching to cool pavement at night, MRT was ca. 0.1 – 0.2°C, PET was ca. 0.1 – 0.5°C higher than base pavement.	Highlights • Discusses how thermal capacity and conductivity of a material can contribute to overheating conditions, and how thermal comfort can be altered. Limitations • Does not discuss effects on environmental parameters on larger scale.
Toronto ON 2016 (Wang, Berardi, & Akbari, 2016c)	Cool Pavement ENVI-met **Base pavement model:** Albedo 0.2, Heat capacity 2.25 [J m^{-3} K^{-1}] x 10^6, **Cool pavement model:** Albedo 0.4, Heat capacity 2.08 [J m^{-3} K^{-1}] x 10^6,	Increasing pavement albedo in 3 urban environments resulted in: • 0.1°C air temperature reduction at 12 pm at a height of 1.8 m for the detached, middle- & high-rise areas, respectively. • median pavement surface temperature decreases of 0.1°C, 0.9°C and 0.5°C at 12:00 pm for the detached, middle-rise and high-rise areas respectively. • 1°C increase in MRT at 12:00 pm at a height of 1.8 m for detached, middle-rise & high-rise areas, respectively.	Highlights • Shows how different urban geometry are affected by IRS. Limitations • Does not discuss the thermal conductivity of the material.
Toronto, ON 2016 (Wang, Berardi, & Akbari, 2016c)	Cool Roof ENVI-met **Base roof model:** Albedo 0.3 **Cool roof model:** Albedo 0.7	Increasing roof albedo in three urban environments resulted in 0.15°C, 0.15° and 0.1°C, air temperature reduction at 12:00 pm at a height of 1.8 m for the detached, middle-rise and high-rise areas respectively. Increasing the roof albedo in the three urban environments resulted in a median roof surface temperature decrease of 11.3°C and 9.6°C at 12:00 pm for the detached and high-rise areas respectively. Increasing roof albedo in three urban environments resulted in a negligible change in MRT at 12:00 pm at a height of 1.8 m for the detached, middle- & high-rise areas respectively.	Highlights • Shows how frame of reference between roof and ground is important when discussing UHI mitigation strategy's ability to alter pedestrian thermal comfort.

Location	Strategy & Simulation Tool	Results	Highlights and Limitations
Toronto ON 2018 (Taleghani & Berardi, 2018)	Cool Pavers and Water Pond ENVI-met **Base pavement scenario:** albedo 0.1 **Cool pavement scenario 1:** albedo 0.3 **Cool pavement scenario 2:** albedo 0.5 **Water Pond**	Increasing the pavement albedo resulted in 0.5°C and 1.0°C air temperature reduction at a height of 0.6 m for the cool pavement scenario 1 and 2 respectively. 0.5°C air temperature reduction from water pond. Increasing the pavement albedo resulted in a 5.3°C and 10.3°C increase in the MRT at a height of 0.6 m for the cool pavement scenario 1 and 2 respectively. While the water pond reduced MRT by 6.2°C. In other words, although the higher albedo surfaces reduced near surface air temperatures, they decrease thermal comfort situation for pedestrians.	Highlights • Material properties in addition to albedo should be considered when designing an urban space for occupant thermal comfort • That pedestrian thermal comfort and safety depends on more than just temperature and humidity Limitations Does not discuss the possible seasonal effects of these strategies.
Montreal and Toronto ON 2018 – 2021 (Jandaghian & Akbari, 2018) (Jandaghian & Akbari, 2021)	ISR of roofs, walls, roads and pavements **Base scenario:** 0.2	The surface albedo of roofs, walls, and roads are increased from 0.2 to 0.65, 0.60, and 0.45, respectively. ISR affords a decrease in air temperature (~ 2ºC), a small decrease in dew point temperature, and a slight increase in near-surface wind speed. ISR shifts days into more benign conditions by nearly 60% and thus the HRM will lessen by 3 to 7%, pointing those seven to eighteen lives could be saved.	
Toronto ON 2020 (Jandaghian & Berardi, 2020)	ISR of roofs, walls, roads and pavements WRF **Base scenario**: 0.2	The surface albedo of roofs, walls, and roads are increased from 0.2 to 0.65, 0.60, and 0.45, respectively. Maximum decrease in air temperature of 2°C at noon. Daily averaged decrease of surface temperature and absolute humidity are 3.3 °C and 0.6 g/kg. Mechanical Cooling energy demand savings in Toronto with higher surface albedo ranged from 7% to 10%.	

3 Canadian Bylaws and Policies on NbS

A review of Canadian bylaws and policies was conducted to determine if any specific UHI reduction strategy is being targeted along with any architype buildings or any specific areas within cities. This summary could be used by future researchers to address knowledge gaps and or by policy makers to refine and develop new policy and bylaws going forward. In addition, the information gathered could allow estimates to be made of the percent coverage/adoption that UHI reduction strategies may theoretically achieve based on these policies for use in future simulations. Table 3 provides a summary of current Canadian bylaws and policies currently in place for which the use of ISG and or ISR to reduce urban temperatures is specified.

Table 3: Canadian bylaws/policies specifying the use of SG and or SR to reduce urban temperatures

Province/ Territory	Location	Strategy	Year	Description	Links
BC		**No current strategy**	2020	B.C. Building Code • The B.C. Building Code regulates the design and construction of roofs but does not include a specific requirement for green roofs. • Technical building requirements of any type (unless for unrestricted matters) enacted by local bylaw are of no legal force even if they are identical to the requirements of the B.C. Building Code.	(gov.bc.ca, 2020)
AB		**No current strategy**	2016	Alberta Infrastructure: Green Roof Design – Considerations for New and Existing Structures. Documentation outlining the benefits of, design considerations and types of vegetated roofs.	(Alberta Infrastructure, 2022)
SK		**No current strategy**			
MB		**No current strategy**			

ON	Toronto	Green Roof Bylaw – Every building or building addition constructed after Jan 30th 2010 with a gross floor area of 2,000 m^2 or greater.	2009	• New commercial, institutional and residential developments with a minimum gross floor area of 2,000 m^2.
				• New additions to commercial, institutional and residential development where the new gross floor area added is greater than 2,000 m^2.
				• New applications for industrial buildings or additions to industrial buildings where the gross floor area is 2,000 m^2 or greater.
				• See Table 4, for the required percentage coverage based on available roof space.
				  ○ Gross floor area considers all floor area across multiple floors. Therefore, a building with 2,000 m^2 may have a small roof area but achieve 2,000 m^2 floor area.
				• An exemption allows a smaller amount of green roof than is required under the bylaw, where a cash-in-lieu payment of $200/m² is made for the reduced green roof area.
				• Industrial building or a building addition to an industrial building, constructed after April 29, 2012, with a gross floor area of 2,000 square meters or greater may instead make use of cool roofing materials for 100% of the available roof space and complies with the storm water management performance measures required through the site plan approval process,
				  ○ Where cool roof materials are defined as having a Solar Reflectance Index ("SRI") of 78
					City of Toronto Green Roof Bylaw – City of Toronto

Province/ Territory	Location	Strategy	Year	Description	Links
QB	Saint-Laurent Montreal,	Reglement sur le zonage no RCA08-08-001 – Roof cladding materials for flat and low-pitched roofs (slope less than 2:12 or 16.7%)	2016	• A permit or certificate of authorization must be obtained prior to installing or replacing the cladding of flat and low-pitched roofs (slope less than 2:12 or 16.7%) • Authorized materials ○ Vegetated roof ○ Materials with Solar Reflective Index ≥78	(City of Montreal, 2022)
NB		**No current strategy**			
NS	Halifax	Soft Landscaping requirement	2021	• Soft landscaping shall be required on any main building with a flat roof or a flat-roofed addition within a DD, DH, CEN-2, CEN-1, COR, HR-2, or HR-1 zone, on no less than 40% of the combined portions of the roof that are flat (with exceptions) • Soft Landscaping means covered by water-permeable material or vegetation, planter boxes, or another vegetative groundcover. A water feature, excluding a swimming pool, hot tub, or a water fountain, is considered soft landscaping. • Flat Roof means a roof with a maximum pitch of 1/12 (rise to run)	(Council of the Halifax Regional Municipality , 2022)
NL		**No current strategy**			
PE		**No current strategy**			
YT		**No current strategy**			
NT		**No current strategy**			
NU		**No current strategy**			

Table 4: Required percent coverage of available roof space for Toronto green roof bylaw

Gross Floor Area or Size of Building (m^2)	Required Percent Coverage of Available Roof Space
2,000 – 4,999	20
5,000 – 9,999	30
10,000 – 14,999	40
15,000 – 19,999	50
≥20,000	60

Total available floor = number of floors x roof area

4 Discussion

The strengthened climate plan released by the federal government, emphasizes the use of NbS as opposed to mechanical air conditioning for their ability to reduce the potential of overheating while providing one or more desired eco-system services. In order to investigate which NbS strategies might be most effective at reducing the UHI effect and the risk of overheating, a definition of what constitutes as a NbS was required. Through a combination of sources, NbS was defined as solutions that mimic, enhance, conserve or support nature, which fall on the spectrum between purely natural (green) and conventional (grey/hard structural) that can address one or more societal challenges. One of the reasons that Canada is experiencing warmer temperatures is due to rapid land change resulting in an overall decrease in surface albedo along with an increase in the amount, of exposed materials with high thermal storage and low permeability (Bush, et al., 2019) (Frie, Gilmer, Buraga, & Franceschini, 2022). As such, a review of studies investigating the effect of increasing SG and SR was completed, the results of which were summarised in table format within this report.

The review shows that despite awareness of the risks associated with overheating and the UHI effect within urban environments growing, there have been limited studies quantifying the effects of NbS mitigation strategies within Canadian cities. In addition, several conclusions can be made from the review, the first of which is that the frame of reference of where environmental parameters are analysed and or reported from, makes a difference in terms of the magnitude of change achieved from the environmental parameter. For example, the change in air temperature calculated at ground level from the implementation of rooftop vegetation may be less than the change predicted at roof level. Going forward, studies should clearly define both where the measurements and or predictions are being analysed from, and over what scale they are looking to reduce the risk of overheating.

Another finding was that changes to surface and air temperatures were often the only environmental parameters quantified within these studies. These two parameters are a good starting point for describing the level of "cooling" that could be achieved from mitigation strategies, however overheating and thermal stress due to a loss of thermoregulation is dependent on four environmental factors (air temperature, humidity, air speed and radiant temperature) and two individual factors (metabolic rate and clothing) (Holmes, Phillips, & Wilson, 2016). Studies should consider analyzing and reporting all four environmental parameters in order to better describe how effective a NbS mitigation strategy may be at reducing the risks of overheating. In some cases, air temperature can be reduced but because of high humidity levels, high radiant temperatures, low wind speeds or a combination of these environmental parameters an individual may still be at risk of overheating and experience thermal stress.

A third conclusion from the review was that the simulated domain and period of modeling is not always quantified, and because of that, comparing the results from one study to another becomes difficult. Without a description of the coverage area, conclusions as to the magnitude of difference one strategy might make in a specific location versus another location cannot be made. Therefore, without the magnitude of simulated coverage being described, it becomes hard to tell how effective a strategy is on a micro versus macro scale within the same location as it would be interesting to quantify both the small- and large-scale difference resulting from the addition of a specific strategy. Going forward, the size or coverage of the mitigation strategy within the study area should be described in sufficient detail so that simulations can be repeated and results compared against other locations and on multiple scales.

Despite the challenges associated with comparing the results between the reviewed studies, an attempt was made to quantify the magnitude of air temperature reduction that might be expected from ISG. For vegetated roofs, an air temperature reduction between 0.2°C – 1.1°C referenced at a height of 1.8 m from ground level might be achieved. These results, are dependent on many factors, including the height of the building, the orientation of the measurement relative to the wind and the size of the vegetated area to name a few. For urban trees, an average air temperature reduction between 0.2°C – 0.8°C analyzed across a large urban area at a height of 1.8 m from ground level might be achieved. However, as discussed before, where the measurements are analyzed from and the domain resolution makes a difference in the magnitude of change that might be expected. In comparison, a report measuring the air temperature reductions under the shade of a dense coverage of street trees obtained air temperature reductions between 1.2°C and 3.3°C. Compared to the vegetated surfaces reviewed in this report, reflective surfaces appear to achieved less of a reduction in air temperature compared to their base case scenarios.

On the other hand, analysing the effectiveness of ISR in previous studies, shows that in addition to surface albedo, other material properties such as thermal conductivity and thermal capacity can influence the amount of incoming energy that is stored and released. These parameters can affect when the risk of overheating is experienced within an urban space and should be taken into consideration when selecting what reflective strategies to implement.

In addition, a review of current Canadian bylaws or policies in place which specify the use of ISG and or ISR to reduce urban temperatures was performed. It was found that only a few Canadian cities have requirements in place for UHI mitigation strategies. The bylaws are currently written for low sloped roofs for both new construction as well as additions to the roof of existing structures. Unlike the bylaws written for Montreal and Halifax, the Green Roof Bylaw for Toronto is currently written for new structures and additions to existing structures, but does not include wording for existing structures that only need to replace their current roofing membrane. This is of interest as it is anticipated that more than 80 percent of our existing building stock will still be in use by 2050, and not targeting these roofs may result in a lower uptake of these strategies throughout the city. This current wording may also result in a lack of adoption in areas of the city with older building stock that may require greater levels of UHI mitigation strategies. However, without verification or performing an analysis, it is not possible to determine the effectiveness of one policy or mitigation strategy versus another, highlighting the need for future work.

These findings highlight the fact that of the limited number of studies looking at surface greenery or surface reflectivity to reduce the UHI effect; only two analyzed both vegetated and reflective solutions. However, the method in which the results were reported were not consistent making it difficult to compare the UHI reduction strategies even within the same study, emphasizing the need for a consistent language in how to report findings from studies analyzing UHI reduction strategies.

5 Concluding Remarks and Next Steps

To determine the effectiveness of one policy or mitigation strategy versus another at reducing the UHI effect and risk of overheating for a given urban center, future analysis needs to be conducted. As part of future studies, and using simulations, changes in environmental parameters could be analysed that result from different levels of simulated ISG and or ISR across an urban agglomeration under future climate scenarios. The results from such an analysis would permit quantifying the ability of these strategies to reduce the UHI effect and reduce the risk of overheating, thus providing policy makers and planners a means of assessing the extent of coverage of their urban area as would be needed to meet their UHI reduction objectives, thereby allowing them to prepare more effective UHI policies.

In addition to understanding the extent of mitigation strategies that would be required to be implemented across an urban agglomeration to reduce the UHI effect and risk of overheating, city planners and policy makers will need to understand what specific technologies or strategies can be utilized to reach these levels of coverage or expected level of mitigation. As outlined within the report by Hayes et al., 2022, there are many ways to increase urban vegetation or increase the reflectivity of urban surfaces, however their impact on environmental parameters and pedestrian and urban energy balance can be different. To this point, the level to which these specific strategies effect all four environmental parameters pertaining to thermal safety may be the focus of future work. As well, any potential co-benefits of these unique strategies will need to be ranked to help policy makers select an optimum strategy to meet their requirements.

As the effectiveness of UHI mitigation strategies can depend on parameters such as local climate, solar exposure, orientation and the urban aspect ratio, an understanding of the intra-city micro-climate at the pedestrian level will also be required to tailor UHI mitigation strategies to a specific location. Studies such as those conducted by Pioppi et al. (2020) and Wiechers (2018) are employing weather stations mounted on mobile platforms to record variations in environmental conditions throughout different parts of a city. Where, Pioppi et al. (2020) mounted a weather monitoring station to the helmet of cyclists to study urban microclimates of different neighbourhoods within New York. The helmet mounted weather stations recorded air temperature, relative humidity, solar radiation, wind speed and CO_2 concentration along pre-determined routes within the neighborhoods. These routes were cycled at different times of the day and multiple times throughout the year to collect data under evolving conditions. The collected data was then compared to the data collected by the closest fixed weather station for the same period of time to determine the degree of offset between the measurements and to determine how local features, such as bodies of water, trees, urban canyons or large areas of pavement, had an impact on the local climate.

Future studies should also clearly define the objectives that are to be achieved (Laouadi, Bartko, Gaur, & Lacasse, 2021). For example, if reducing the risk of overheating events from occurring within free running buildings is the desire, studies will need to clearly define both personal parameters such as the age, health, and activity level for the target audience they are looking to keep safe, along with the building quality and time of day in which they wish to reduce overheating. These parameters are important to consider, as solutions that are effective during the day may not be effective during the evening, and solutions that may be effective for areas of low activity may not be sufficient for areas of highly intense activity.

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