Adaptation to Urban Heat Island Effect in Vancouver, BC:
A case study in analyzing vulnerability and adaptation opportunities

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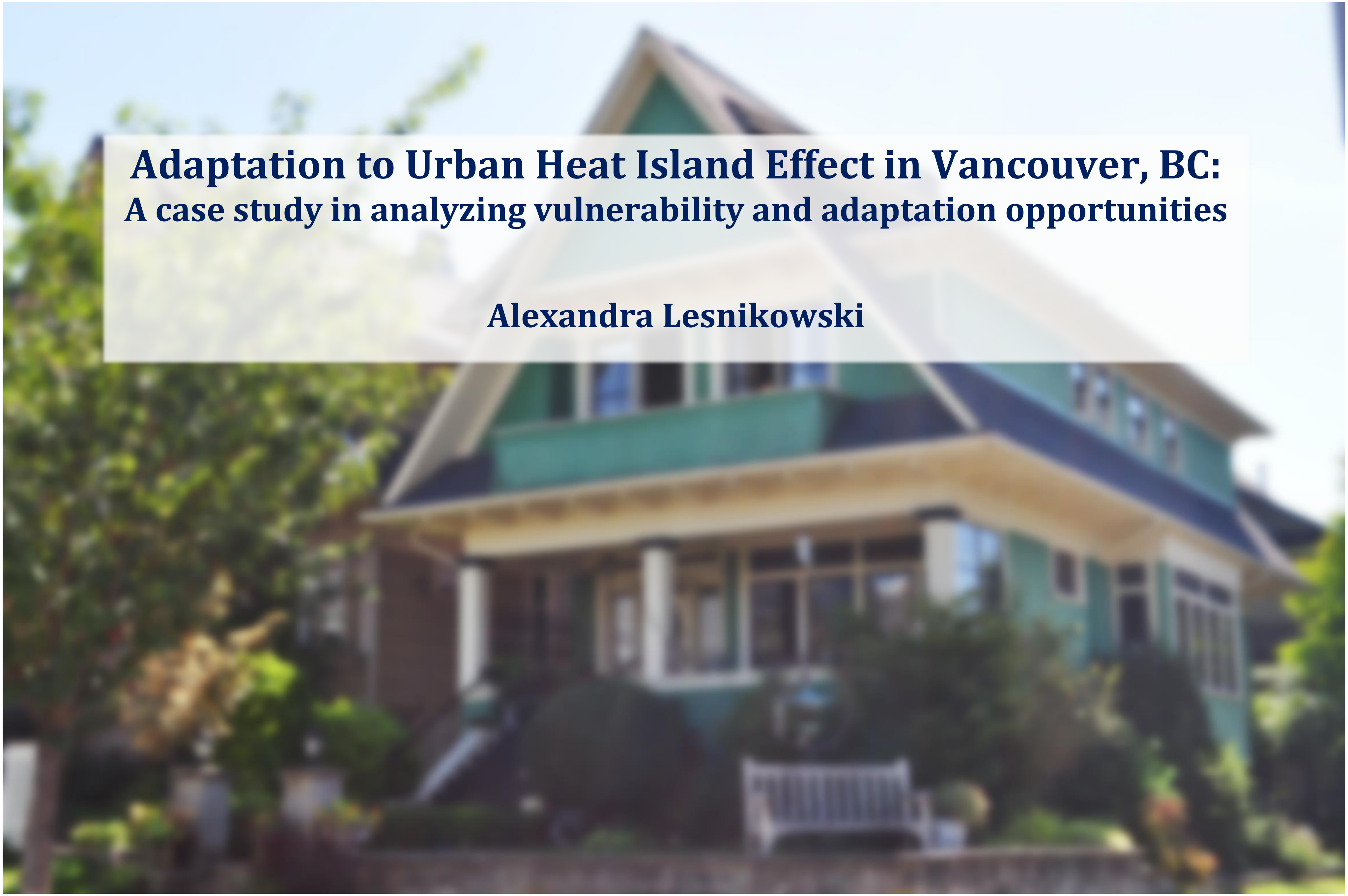

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Adaptation to Urban Heat Island Effect in Vancouver, BC: A case study in analyzing vulnerability and adaptation opportunities

by

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B.A. (Hons), McGill University, 2010

A PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS (PLANNING)

in

THE FACULTY OF GRADUATE STUDIES

School of Community and Regional Planning

We accept this project as conforming
to the required standard

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THE UNIVERSITY OF BRITISH COLUMBIA
September 2014

Acknowledgements

First I would like to acknowledge my supervisor, Maged Senbel, for his guidance and support over the last two years, and for giving me opportunities to explore new challenges and ideas. Special thanks also go to Tamsin Mills, who sparked the idea for this project and provided key information and insights that are the foundation of this study. Mark Stevens offered invaluable advice on spatial statistics and GIS during the early stages of my analysis. Last but certainly not least I would like to thank Sawngjai Manityakul, whose insightful comments greatly enriched this report at every stage.

I would not be where I am today without the tireless support and love of my family, who encourage and inspire me every day. Thank you for keeping me sane and moving forward. Finally, special appreciation goes to Brian Vermeire, Jim Beaudreau, and Megan Ahearn, who are always there for a laugh or a grumble.

Executive Summary

Climate projections for the City of Vancouver indicate that by mid-century extreme heat events that now occur about once every 25 years will triple in frequency, with summer temperatures beyond 24°C expected to occur twice as often as today. The July 2009 heat wave brought attention to the health risks of extreme heat for Vancouver's socially vulnerable populations, further reinforcing the seriousness of anticipated climate changes for community health and comfort in Vancouver.

This report has two goals: i) to conduct a preliminary assessment of heat vulnerability in the City of Vancouver and examine opportunities for mainstreaming adaptation to urban heat island effect into existing policies; and ii) to propose an analytical framework for further engaging in discussion about urban heat island risk under the Vancouver Adaptation Strategy. This framework is rooted in social vulnerability analysis and uses neighbourhood-level population characteristics to identify areas of the city with the highest health vulnerability to extreme heat.

To pilot this approach, one study area in Grandview-Woodland is selected that exhibits above average urban temperatures and a concentration of social vulnerability. This framework can be applied to other neighbourhoods in the future.

An analysis of existing regulations, policies, and guidelines indicates that Vancouver's building design and public space guidelines were crafted with underlying assumptions about a consistently temperate and rainy climate, and so emphasize access to sunlight and weather protection primarily from rain. With climate change projections indicating a future of hotter and drier summers, these policies need to be re-examined and the assumptions underpinning them adjusted to accommodate a greater number of annual hot days. Nineteen recommendations are made for further study of urban heat island conditions in Vancouver and for mainstreaming heat adaptation into existing policies and regulations.

Glossary

Albedo: The ability of a surface to reflect sunlight. Measured on a scale of 0-1.

Atmospheric boundary layer: Lowest layer of the Earth's atmosphere that is influenced by surface conditions, including radiative cooling.

Atmospheric heat island effect: Urban heat islands that consist of both canyon layer heat island effects and boundary layer heat island effects. Canyon layer heat island effects can be detected between the ground and upper levels of the urban tree canopy and rooftops. Boundary layer heat island effect can be detected between the canyon layer and point at which urban pollution no longer influences atmospheric conditions, generally one and a half kilometres above the ground.

Evaporative cooling: Evaporation of water that exercises a cooling effect on urban temperatures by removing latent heat from surfaces.

Heat wave: A prolonged period of hot weather lasting at least three consecutive days.

Radiative cooling: Emission of long-wave radiation that cools the earth's surface. Occurs mostly at night.

Solar absorption: A measure of solar energy absorption by materials on a scale of 0-1.

Solar Radiation: Energy transmitted as short-wave and infrared radiation (including ultraviolet) from the sun.

Solar Reflectance: Reflectance of short-wave solar radiation and infrared radiation from surfaces in a process that reduces heat transfer.

Surface Heat Island: Temperature of building and pavement surfaces measured through thermal infrared analysis.

Thermal Emittance: Ability of surfaces to radiate non-reflected solar energy. Measured on a scale of 0-1.

Thermal Mass: A measure of a material's resistance to temperature change.

Urban Canyon: Urban morphology determined by street width and length, and building height.

Urban Heat Island Effect: Phenomenon in which temperatures of urban areas are warmer than those in surrounding rural areas due to capture and release of solar energy into the built environment.

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1. BACKGROUND

1.1 Risk of extreme heat events in Vancouver, BC

In the summer of 2009 Metro Vancouver experienced a heat wave that saw temperature recordings at Vancouver International Airport peak at 34.4°C (Kosatsky, Henderson, and Pollock 2012). In a city with average summer temperatures in the range of 17°C to 22°C, this represented a 12.5°C increase over the 10-year average maximum temperature for summer months (Kosatsky, Henderson, and Pollock 2012). Up to this moment there was little to no concern about extreme heat in Vancouver, and Vancouver Coastal Health did not have a heat wave definition specific to the region (Proctor 2011).

The heat event prompted concern among public health agencies and local government about future health risks of heat in the Lower Mainland. Vancouver Coastal Health and Fraser Health created an "Extreme Hot Weather Preparedness and Response Plan" in 2010, which now issues alerts when temperatures reach 29°C at Vancouver International Airport and 36°C in Abbotsford over consecutive days (Vancouver 2010). The Plan also emphasizes engaging the public to educate them on the health risks of heat and coordinating emergency response services in case of a heat wave.

Climate projections for the Vancouver region further support these concerns about heat risk. These projections indicate that by the 2050s summer temperatures above 24°C can be expected to occur twice as often as they do now. Furthermore, by mid-century extreme heat events that until now occurred only once every 25 years may triple in frequency (Vancouver 2012a). Given this projected increase in hot days, the City anticipates heightened health risks for vulnerable populations. Extreme heat preparedness is thus an area of concern in the City of Vancouver's Climate Change Adaptation Strategy, which was adopted in 2012 and is based on the adaptation planning framework created by the Local Governments for Sustainability (ICLEI). The actions to address vulnerability to heat recommended in the Adaptation Strategy provide the foundation for this study, including urban heat island effect mapping, vulnerable population mapping, and analysis of adaptation opportunities for buildings and public spaces to reduce urban heat island effect.

Vancouver's building design and public space guidelines were crafted for a temperate and rainy climate, and emphasize access to sunlight and weather protection primarily from rain (Vancouver 1992a; Vancouver 2009; Vancouver 1992b). As the region's climate changes these policies will need to be re-examined and the assumptions underpinning them adjusted to accommodate a greater number of annual hot days. Previous research has

Heat waves are generally defined as prolonged periods of hot weather lasting at least a few days. They occur most commonly during summer months as a result of slow moving high pressure systems that settle over an area for an extended period of time. Low levels of soil moisture and above average sea surface temperatures have also been shown to impact heat wave intensity (Garcia-Herrera et al. 2010). Environment Canada defines a heat wave as "three or more consecutive days in which the maximum temperature is 32°C or more." In the context of public health, however, it is impossible to determine a fixed definition. In places with generally cooler climates, heat waves can occur at lower temperatures. Consequently it is recommended that thresholds for issuing an extreme heat alert be derived from percentiles of a place-specific temperature series (Carlos Montero et al. 2013). Vancouver's heat alert system, for example, sets a threshold of 29°C during one or two consecutive days.

Heat-related illness occurs when the body's temperature rises beyond its ability to cool (a condition called hyperthermia), and can lead to death or disability. Symptoms commonly include dizziness, fainting, heat cramps, exhaustion, and heat stroke (WHO 1990).

examined trade-offs between extreme heat infrastructure and the City of Vancouver's greenhouse gas emissions reduction policies, particularly in providing air conditioned cool refuges during extreme heat events (Procter 2011).

The first goal of this report is to conduct a preliminary assessment of heat vulnerability in the City of Vancouver and examine opportunities for mainstreaming adaptation to urban heat island effect into existing policies. The study conducted here analyzes the physical qualities of a sample neighbourhood that exhibits a strong urban heat island effect and above average levels of social vulnerability. It then assesses adaptation options in current urban design and building policy. Neighbourhood-level urban design (including qualities of buildings, streets, and open space) impacts community health and well-being and functions as a mediator for extreme heat exposure. Conducting analysis at this scale is therefore key to identifying adaptation opportunities in cities.

It is important to note that there is a large body of literature concerned with thermal performance and energy conservation in individual buildings. While this is an important component of building local resilience to heat waves, the goal of this analysis is to examine opportunities to reduce average neighbourhood temperatures and so lessen the severity of heat waves. As such there is less emphasis on building adaptations that lower interior temperatures and instead a focus on how individual building qualities have an aggregate effect on neighbourhood temperature.

This report also sets a secondary goal: to propose an analytical framework for further engaging in discussion about urban heat island effect under the Vancouver Adaptation Strategy. This framework is rooted in an analysis of social vulnerability and proposes using neighbourhood-level population characteristics to focus policy efforts in areas of the city that have the highest health vulnerability to extreme heat. This approach will help the City of Vancouver focus resources on neighbourhoods that will benefit most from adaptation interventions, thus lowering mortality and morbidity outcomes during future heat waves. To pilot such an approach this report examines a single neighbourhood in Vancouver, with the potential for this framework to be applied to other areas of the city.

1.2 Public health risks of extreme heat events

Eric Klinenberg's seminal book *Heat Wave* documents the July 1995 heat wave that swept through the City of Chicago and is one of the earliest analyses of the relationship between social vulnerability and extreme heat events. Researchers estimated the number of excess deaths due to heat to be upwards of 700 between July 14 and 17, with the highest impacts being among individuals with pre-existing illnesses and those living alone (Semenza et al. 1996; Whitman et al. 1997; Kaiser et al. 2007). The 1995 heat wave was a landmark moment in drawing attention to the health risks of extreme heat, which continues to be the mostly deadly natural hazard event year after year in the United States (Borden and Cutter 2008; Klinenberg 2002, p 17). This can largely be attributed to the relative frequency of heat waves when compared to other natural hazards.

Klinenberg's study is significant for this report because it included a spatial analysis of the social conditions underlying the high mortality rates recorded amongst Chicago's elderly, poor, and socially isolated. His analysis demonstrated that exposure to extreme temperatures and neighbourhood-level social and physical sensitivity to stress created high levels of vulnerability amongst certain population groups. Examination of

Urban heat island effect is broadly defined as the difference in temperature between built-up urban areas and surrounding rural areas. This temperature difference is attributable to four primary drivers: 1) the extensive use of impermeable surface coverage in urban areas that absorbs solar radiation and re-emits it as long-wave radiation, or heat; 2) reduced natural run-off needed for evaporative cooling; 3) buildings that absorb and reflect long-wave radiation at street-level; and 4) waste heat generated by human activity like mechanized heating and cooling systems and motorized vehicles.

mortality data revealed concentrations of deaths in neighbourhoods to the south and west of Chicago. These are predominantly low-income African American neighbourhoods that experienced massive industrial decline beginning in the 1950s, eroding the local economy and quality of public life and leaving a legacy of poverty and crime.

The public health literature on social and physiological vulnerability to heat has expanded substantially since Klinenberg and Semenza et al's initial studies on mortality outcomes of the Chicago heat wave. The August 2003 heat wave in Europe was a critical reminder of the destructive power of extreme temperatures. In the first two weeks of August temperatures were recorded across Western and Northern Europe at 7.5°C to 12.5°C above average levels (García-Herrera et al. 2010). Excess mortality was recorded at 20 times that of the 1995 Chicago heat wave. Mortality estimates for the month of August were in the range of 35,000 heat-related deaths, with excess mortality totaling 70,000 for the entire summer (Garcia-Herrera et al. 2010; Robine et al. 2008).

Researchers examining the effects of the 2003 European heat waves across nine affected cities observed that the highest mortality impacts were among individuals with pre-existing respiratory diseases, and among women between the ages of 75 and 84 (D'Ippoliti et al. 2010). Additionally, elderly living in old buildings with poor insulation, with bedrooms directly below the roof, and in neighbourhoods with higher urban heat island effect had an elevated risk (Vandentorren et al. 2006). While elderly are generally the largest group of concern in public health discussions about heat waves, a number of other factors put individuals at risk. Socio-economic disadvantage, social isolation, pre-existing and chronic health conditions, immigrant status, language barriers, race/ethnicity, education, and occupational exposure (e.g. working in construction or landscaping) are all major factors understood to increase vulnerability to extreme heat events (Xu et al. 2012; Kravchenko et al. 2013; Hansen et al. 2013; Jesdale, Morello-Frosch, and Cushing 2013; Aubrecht and Ozceylan 2013).

Extreme heat and air quality are also closely linked, creating another layer of risk for vulnerable populations (Reid et al. 2012). High ozone levels were found to be a major contributing factor to overall mortality in France during the August 2003 heat wave. Researchers found that daily deaths were 54 percent higher on high ozone days than on low ozone days among people age 75 to 84, and particularly among individuals with cardio-vascular or asthmatic conditions (Dear et al. 2006; Analitis et al. 2014). This synergistic relationship between air quality and heat may be due to the increased generation of secondary atmospheric particles that occurs in intensified sunlight, or to behavioural changes as residents cope by relying more heavily on mechanized cooling systems and air conditioned vehicles (Analitis et al. 2014).

These analyses indicate that alongside physiological response, social and environmental attributes of risk are critical to understanding heat vulnerability. As heat wave risk intensifies in Vancouver, identifying the intersections and spatial distribution of these factors will be critical for assessing adaptation opportunities. Vancouver's summer 2009 heat wave highlighted the relevance of heat wave preparedness for the Lower Mainland, and the region's relative inexperience in coping with extreme heat events. In response to July's rise in temperatures the Vancouver Sun published articles asking residents to reach out to elderly or frail neighbours, and to drink water and stay out of the sun. There were particular concerns about homeless individuals ability to cope with the heat given their unreliable access to shelter and drinking water (TeBrake 2009). The high pressure system that ushered in the heat wave also exacerbated poor air quality conditions resulting from elevated smog levels across Metro Vancouver and into the Fraser Valley. As a result public health officials also issued an Air Quality Advisory directed to people with cardiovascular or pulmonary conditions (Frances Hill 2009).

Between July 28 and 30, 2009 British Columbia's rapid mortality surveillance system showed an increase in mortality rates among Metro Vancouver residents of 40 percent, with the highest mortality being among people ages 65 to 74.[1] 398 non-accidental deaths were recorded, which was a significant increase over the average weekly number of summer deaths between 2001 and 2009 of 290 (Kosatsky, Henderson, and Pollock 2012). In comparing heat-specific codes from the *International Classification of Diseases 10th Revision* during the heat wave with the comparison years (2001-2008), Kosatsky et al (2012) found that the number of heat-specific causes of death rose significantly.

[1] This finding is particularly interesting given that elderly individuals over 75 are generally considered to be at higher risk than those between the ages of 65 and 74. During the July 2010 heat wave in Quebec, for example, excess deaths for the 65-74 cohort were not statistically significant, while death rates increased 33 percent for the 75 and older cohort (189 excess deaths) (Bustinza et al. 2013).

1.3 Extreme heat events in a changing climate

Heat waves are already the deadliest extreme weather event in North America. As noted previously, the danger to public health in Vancouver will only continue to grow as our climate changes. Heat wave modeling conducted using the Parallel Climate Model predicts that atmospheric circulation over North American and Europe will alter under scenarios of increased greenhouse gas emissions, intensifying the severity of heat waves in future and making them more frequent and longer lasting (Meehl and Tebaldi

2004).[2] Alongside increases in heat wave frequency and intensity, mortality attributable to heat can be expected to increase (Greene et al. 2011; Jackson et al. 2010; Huang et al. 2011; Peng et al. 2011). Researchers have projected that by mid-century, for example, Chicago could experience a heat wave on the same level as the August 2003 European heat wave, with over ten times the number of excess deaths as in 1995 (Hayhoe et al. 2010). Even with anticipated future greenhouse gas emissions reductions we are unlikely to halt climate change, making adaptation to extreme heat in our urban spaces a critical health and comfort issue for planners and urban designers.

Urban heat island effect and heat waves also have tremendous implications for greenhouse gas emissions reduction efforts. Increased use of air conditioning has a notable impact on urban energy consumption, and for cities like Vancouver that have greenhouse gas emissions reduction targets this can work against sustainability goals (Gutiérrez et al. 2013; Lundgren and Kjellstrom 2013). High temperatures in summer months generally increases demand for cooling, with an estimated 5-10 percent of this electricity demand attributable to urban heat island effect (Killingsworth, Lemay, and Peng 2011). This additional demand jeopardizes energy resilience and is a serious concern for regions with aging electricity grids. The August 2003 Northeastern blackout, for example, resulted from a spike in electricity demand that overloaded aging transmission corridors during a heat event (Stone 2012 p 68-70). Blackouts stress transportation systems, health care, and emergency response capacities of local and regional government, thus posing a major challenge to public health and safety.

Very little of Vancouver's housing stock currently uses air conditioning. Province-wide only one-fifth of residential buildings are equipped with air conditioning, with the largest concentration being in the interior of British Columbia where summer temperatures are routinely higher than those in the Lower Mainland (Procter 2011). Given the City's greenhouse gas mitigation goals, this is in fact an asset in efforts to reduce Vancouver's energy consumption. Responding to future increases in hot weather days by requiring mechanized cooling systems in new developments would undermine emissions reduction efforts and could pose a risk to the resilience of the region's electricity grid during a heat wave. As such this report explores alternative opportunities for adapting to extreme heat risks by addressing factors in the urban environment that artificially increase neighbourhood temperatures.

[2] The Parallel Climate Model is managed at the National Center for Atmospheric Research in Boulder, CO. It is a coupled atmospheric-ocean model that that comprehensively models the Earth's climate system.

1.4 The relationship of extreme heat events to urban heat island effect

Public health agencies prepare and respond to heat events through heat health warning systems (HHWS), which use meteorological forecasts and locally-specific temperature thresholds to issue heat advisories. Vancouver's "Extreme Hot Weather Preparedness and Response Plan" is an example of a HHWS (Vancouver 2010). Measures taken to alert and prepare the public vary from general advice on how to avoid heat stress, to the opening of cooling centres and home outreach visits to vulnerable individuals (Kovats and Ebi 2006). These emergency response efforts are critical when extreme heat events occur and so it is laudable that Vancouver has devoted resources to the creation of a heat health warning system and the supporting Extreme Heat Committee. This study, however, is concerned with understanding qualities of urban space that encourage the likelihood of extreme heat events to occur at all, with the goal of reducing the frequency and intensity of heat waves.

The key to understanding the relationship between urban form and extreme heat is a phenomenon called urban heat island effect (UHI). At its most basic, urban heat island effect is the tendency for urban areas to be several degrees warmer than surrounding rural areas. Urban heat island effect and heat waves interact synergistically as UHI tends to be greater during periods of high heat (Li and Bou-Zeid 2013). This synergy plays an important role in elevating the health impacts of heat in cities. During extreme heat events UHI is particularly pronounced at night, when heat stored in urban surfaces during the day is released. This was identified as an important risk factor for mortality in Paris during the 2003 heat wave (Laaidi et al. 2012).

Knowledge of urban heat island effect can be traced back to the early 19th century. One of the earliest urban climatology studies to compare temperatures in urban areas to those in rural areas was conducted by Luke Howard in and around London in 1818 (Stone 2012, p 75). Howard's study found that central London was on average 4°C warmer than the surrounding countryside. This temperature differential has now been documented in a large number of cities. During two summer heat waves in New York City during 2011, for example, temperatures were recorded at 39°C in the city centre and remained such throughout the night, with an urban-rural temperature difference of 4 to 5°C (Meir et al. 2013).

While urban heat island effect is most commonly associated with large cities like New York, it is critical to understand that urban-rural temperature differentials are not strictly the result of higher *densities* in urban areas, but also changes in natural land cover. Indeed, one study observed that sampled sprawling urban areas experienced an increase in frequency of extreme heat events at over twice the rate of compact urban areas between 1956 and 2005 (Stone, Hess, and Frumkin 2010). The same study found that forest canopy coverage in the most sprawling metropolitan regions had disappeared at more than twice the rate of compact regions, suggesting that vegetated land cover acts as a mediator between urban development patterns and extreme heat events. Corresponding increases in mortality across urban development patterns have yet to be estimated.

Vancouver is experiencing high rates of population growth and is looking to accommodate new residents within its existing neighbourhoods. This indicates a need to examine opportunities for mainstreaming of UHI adaptation into development planning, and as well as retrofitting aging building stock when routine maintenance is carried out and renovations occur.

1.5 Defining urban heat island effect

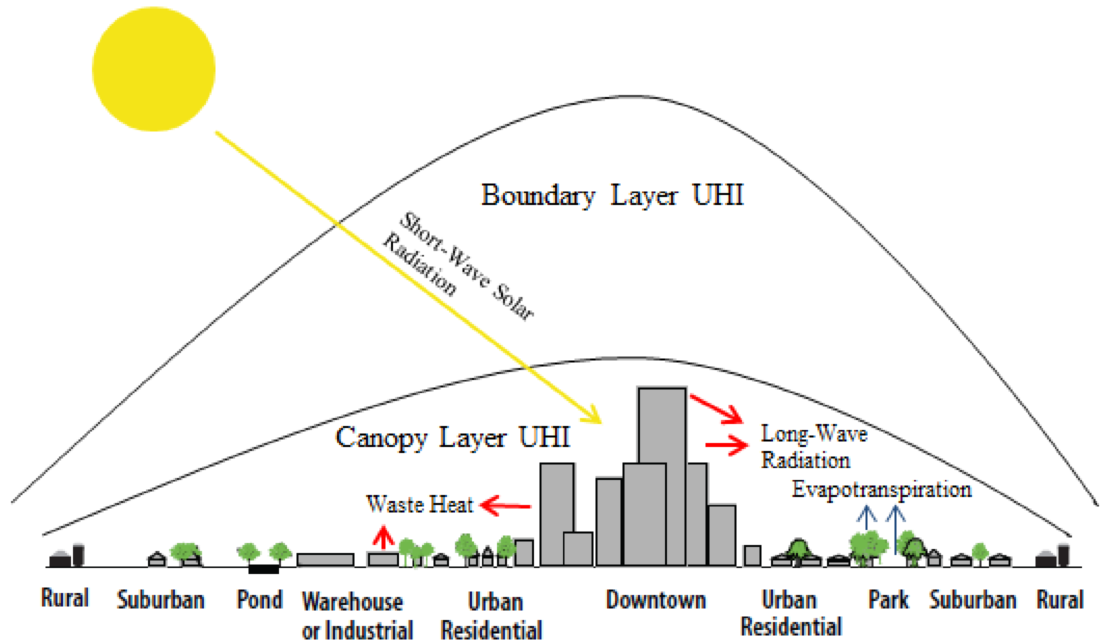
There are two basic types of urban heat islands that interact to impact air temperatures: surface heat islands and atmospheric heat islands (EPA 2008). Surface heat tends to be most intense during the day, and emanates from buildings and paving surfaces. Surface heat islands are measured remotely using thermal infrared data.

Atmospheric heat islands extend across urban areas and are generally what information materials are referring to when addressing urban heat island effect. They are typically divided into two further categories, canopy layer urban heat island and boundary layer urban heat island (Figure 1). Canopy layer UHI occurs between the ground and tree canopies and roof tops. It is heavily influenced by street geometry and surface materials (Oke 1976). Boundary layer UHI begins where canopy layer UHI ends and extends to the point where urban landscapes no longer influencing the atmosphere (about one and a half kilometres). This is typically at the point where urban pollution no longer exerts an influence on the planetary boundary layer (Oke 1976). Atmospheric urban heat islands are commonly strongest at night when heat stored in the built environment is released (EPA 2008). This is particularly dangerous for public health, as noted earlier.

The following section details four factors that influence the magnitude of atmospheric UHI (EPA 2008; Stone 2012).

Capacity for evaporative cooling: In areas with natural land cover, vegetation releases water that evaporates and helps reduce heat through evapotranspiration. Urban areas with greater amounts of impervious surface coverage and lower

Figure 1: Urban Heat Island Effect



Source: Adapted from EPA, 2008

levels of vegetation release less moisture and so raise surface and air temperatures. Vegetation (e.g. park space) has also been shown to reduce surface temperatures through shading.

Capacity for radiative cooling: Albedo is a measure of how much solar radiation is reflected from the Earth's surface, rather than being absorbed and then later released through radiative cooling. Albedo is influenced by a surface material's colour and its thermal capacity, i.e. the ability to retain or reflect heat. Dark surfaces like asphalt possess low albedo (i.e. absorb more heat), while other building materials like steel and stone have high albedo. High albedo materials are thus preferable for urban spaces to reduce UHI.

Urban canyon effect: Building height, spacing, and orientation influence wind patterns, energy absorption, and the emission of long-wave radiation. Urban canyons are a unit of urban surface consisting of the walls and ground between two adjacent buildings. The imaginary ceiling of this canyon is at roof-level, and generally corresponds with the lower boundary level of the urban boundary layer (Nunez and Oke 1977). When energy from the sun is reflected and absorbed by building walls with low albedo, the effect is an increase in temperatures. Street orientation exercises an influence on solar exposure and thus reflectance and absorption. This process becomes critical at night when long-wave radiation is released from buildings in the form of heat. Sky view factor is one measurement of urban canyon, and is defined as the amount of sky visible from the ground. As the sky view factor is reduced more solar radiation is absorbed by buildings and urban heat island effect increases. Another measurement is aspect ratio, which is the ratio of average building height to street width. A higher aspect ratio denotes a deeper canyon (Levermore and Cheung 2012).

Waste heat: Human activity produces large amounts of waste heat that contributes to UHI. Heating and cooling mechanical systems in buildings, combustion engines in transportation vehicles, and industrial machinery all generate heat that intensifies heat islands. Release of waste heat has also been shown to negatively influence ozone air quality, further endangering public health (Ryu, Baik, and Lee 2013).

1.6 Tools for reducing urban heat island effect

Spatial interventions to address urban heat island sit at a nexus between land use planning, urban design, engineering technology, and ecological enhancement. Observations about techniques for reducing urban temperatures can be traced back to antiquity. Roman planning systems recommended that streets be built narrowly and buildings tall to provide shading, and cities in the Persian Gulf used windcatchers to naturally ventilate buildings and courtyard styles of home design that reduced solar exposure by orienting windows towards the courtyard (Stone 2012; Palmer et al. 2012).

Today the dominant recommendations for UHI reduction include urban greening and expanding urban tree canopy, reducing impervious surface coverage, using of reflective (high albedo) materials, adjusting building orientation, and using heat-tolerant building materials (Gago et al. 2013). The following section summarizes adaptation options to reduce urban heat island effect through land use and transportation policy.

Increase Urban Vegetation: Vegetation provides a variety of benefits that are widely demonstrated in empirical literature, including seasonal shading, evapotranspiration, and minimization of ground surface temperatures (Gago et al. 2013). Urban greening can be achieved by the creation of parks, tree planting, expansion of ground vegetation, and green roofing. Tree canopies cool the atmosphere by blocking the pathway of solar radiation and creating cool surfaces and air below the canopy.

A meta-analysis of empirical evidence on the cooling effect of parks and green spaces found an average effect size of 0.94°C during the day, which rose to 1.15°C at night (Bowler et al. 2010). The size of the park and type of vegetative cover are factors in this cooling effect, with larger parks and parks that have more trees tending to have a greater effect (Bowler et al. 2010; Gago et al. 2013). This cooling effect of parks has been documented to be in the range of 500 m to 1 km (Bowler et al. 2010). Vegetation coverage can include rooftops, with green roofs demonstrated to reduce the energy consumption of buildings and also retain water necessary to generate an evaporative effect, thus contributing to lower urban temperatures (Gago et al. 2013).

Notwithstanding this evidence, additional data suggests that surfaces beneath trees interact with canopy coverage to influence urban cooling. A case study of Bloomington, Indiana found that during evening hours temperatures beneath street trees were about 0.5°C warmer than beneath other trees in the study sample, likely owing to the reflectance and re-emittance of solar energy from concrete into the underside of the canopy (Souch and Souch 1993). Similar results were found in a study of temperature differences beneath trees growing on turf and asphalt in southern Illinois (Kjelgren and Montague 1998). Modelling of thermal environments in Szeged, Hungary also demonstrates that cooling effects of trees can be mediated during daytime hours by street orientation and building height, largely as a result of altered direct exposure to solar radiation and wind patterns (Gulyás, Unger, and Matzarakis 2006).

These studies indicate that expanding tree canopy is a vital piece of urban heat island adaptation and should be not considered in isolation from surface materials and urban morphology when assessing adaptation options. Rather, the three should be studied together in the context of local climate conditions to understand what the full impact could be on urban heat island effect.

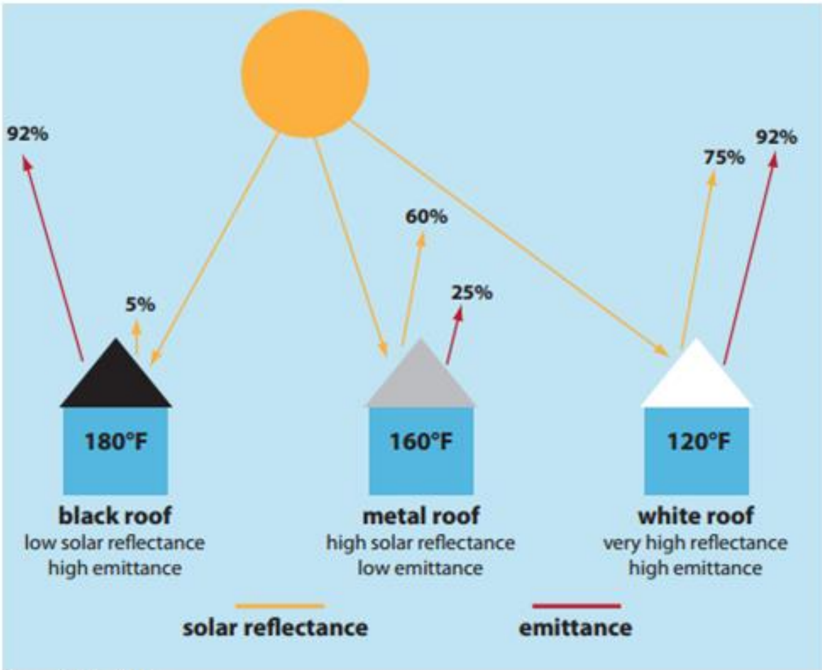
Improve Surface Reflectivity: Building and street surfaces absorb short-wave solar radiation during the day and release it as long-wave radiation (i.e. heat) at night in a process called radiative cooling. Using high-albedo materials on urban surfaces decreases solar heat retention and the output of long-wave radiation, thereby reducing urban heat island effect.

Cool roofs and pavements are measured by solar reflectance and thermal emittance, or in other words how well they reflect solar radiation and radiate absorbed solar energy.

Solar reflectance is a measure between 0-1 of the fraction of sun light reflected from a surface. Higher solar reflectance means a cooler roof. Similarly, thermal emittance is measured from 0-1, with higher values indicating more radiative cooling and consequently lower surface temperatures. Solar absorption is measured on a 0-1 scale, with higher values denoting more absorption and hotter surfaces (*A Practical Guide to Cool Roofs and Cool Pavements* 2012).

Given their direct exposure to solar radiation, rooftop surfaces are a particular concern in the literature. There is a considerable variation in reflectivity and emissivity across materials commonly used for building roofing (Figure 2). Current research and practice favours the use of white roofs for low-sloping buildings, which have been found to achieve 20 to 40 percent energy savings through reduced surface temperatures (Gago et al. 2013). White roofs are able to reflect 70-80 percent of sunlight away, and can be 28 to

Figure 2: Thermal Properties of Rooftop Materials



Source: EPA, 2008

36°C cooler than dark roofs during peak sunlight (*A Practical Guide to Cool Roofs and Cool Pavements* 2012). Sproul et al. (2014) also estimate that white roofs have an associated net savings of $26/m^2 when compared to black roofs over a 50-year life cycle.

It has been noted, however, that cool roofing options must be carefully considered within the climate context of cities. Where cool roofs can achieve energy savings during summer months, they also have the potential to significantly increase heating requirements during winter months (*A Practical Guide to Cool Roofs and Cool Pavements* 2012). Northern cities must therefore weigh potential trade-offs between energy savings on hot days and additional heating needs on cold days. In a city like Vancouver, which typically experiences mild winters, this trade-off is unlikely to be a significant impediment to implementing cool roof policies.

Recent technological advances for cool roofs are significant, and there are now material alternatives for basically every type of steep-slope roofing material. Options for these roofing materials include asphalt, metal, clay, and concrete. These materials can have a solar reflectance level of up to 0.55, which is a significant gain over conventional dark sloping roofs that have reflectance levels of about 0.10 (*A Practical Guide to Cool Roofs and Cool Pavements* 2012). Building codes are the primary tool for promoting reflective surfaces on roofs.

Pavement construction standards generally do not include reflectivity in pavement design considerations, but the Leadership in Energy and Environmental Design (LEED) Green Building Rating System does award one point for use of cool paving materials based on a Solar Reflectance Index (Akbari and Matthews 2012). Selection of appropriate paving materials is highly context-specific, depending on heaviness of use and load.

Enhance Surface Permeability and Evapotranspiration: Urbanization is closely associated with the replacement of natural ground cover with impermeable materials like asphalt and concrete. This interferes with natural soil infiltration by encouraging runoff. This interference undermines natural rates of evapotranspiration that are instrumental in dissipating urban heat island effect. Natural ground cover allows about 40 percent evapotranspiration to occur, while 35-50 percent impervious surface coverages reduces this to 35 percent and 75-100 percent impervious surface coverage reduces evapotranspiration to about 30 percent (Arnold and Gibbons 1996).

Improving surface permeability is a key way of supporting natural cycles of evaporative cooling by allowing water to filter to the soil through pores in the material and then to slowly evaporate as the temperatures rise. Testing indicates that using permeable surface paving is more effective in rainy climates where there is water for the ground to hold (Santamouris 2013). Permeable surfaces may therefore be particularly useful in Vancouver, although perhaps less so if climate change brings about extended periods of hot and dry weather. Heat waves would likely coincide with drought thereby reducing the capacity of permeable surfaces in combating extreme heat.

A frequently discussed co-benefit of permeable paving materials is in improving stormwater management, which is a key concern in the Vancouver Adaptation Strategy. Climate projections for Vancouver predict an increase of extreme rain events that will heighten risks of sewer overflows and surface water flooding. The City's stormwater management program already emphasizes street design that allows for natural runoff, and landscaping that incorporates bioswales and rain gardens. Linking urban heat island concerns with stormwater management planning is a leading example of integrative climate change adaptation planning.

Re-Shape Urban Morphology: The urban canopy layer of urban heat island is located below roof level, and is heavily influenced by what is referred to as urban canyons, or streets that run between dense buildings. Urban canyons have unique microclimates that affect the urban canopy layer, and are influenced by street orientation, building height, canyon length, and street width. These factors shape solar exposure and wind patterns, and by extension heat exposure of buildings and public spaces. High-rise buildings on a north-south orientation, for example, can allow for shading of building facades throughout the day (Gago et al. 2013). Assessing urban canyon effects is particularly critical in downtown cores that have numerous high-rise buildings.

Urban morphology analyses consider building dimensions (density, height, surface-to-volume ratio), building alignment, street layout or pattern, street width, size and shape of blocks, and site coverage (open space ratio) (Rode et al. 2014). Different building typologies create unique morphologies, for example single detached housing has a high surface-to-volume ratio and low site coverage while high-rise apartments have a wider possible range of surface-to-volume ratios and potential for lower site coverage.

A comparative study of London, Berlin, Istanbul, and Paris found that building height and density correlate negatively with heat-energy efficiency, while surface-to-volume ratio correlates positively with heat-energy demand. Overall compact urban blocks performed best in terms of heat-energy demand (Rode et al. 2014). Increasing building density was observed to have the largest positive impact on neighbourhoods transitioning from the lowest levels of density.

Comprehensive assessments of available tools to reduce urban heat island effect have been compiled by the Environmental Protection Agency, the Institute national de sante publique, and Health Canada (EPA 2008; Giguere 2012; Richardson and Otero 2012). The following is a summary of key adaptation interventions identified by these assessments.

Increase urban vegetation:

- Selective tree planting that takes into account soil quality, water availability, and sufficiency of root space. Use of technologies like cell structures can aid tree growth under asphalt surfaces.
- Parking lot greening to shade paved surfaces using vegetated strips

surrounding the lot and vegetated medians within the lot.

- Construction of living walls or green facades that absorb solar radiation and improve energy performance of buildings.
- Construction of green roofs to improve thermal insulation, provide opportunities for urban agriculture, and extend rooftop lifespans.
- Investment in greenways that simultaneously promote urban greening and active transportation, thus reducing anthropogenic heat generated by vehicle traffic.

Improve surface reflectivity:

- Use of materials on flat roofs with high reflectivity like light coloured tile, gravel, heat-reflective elastomeric membranes (including white paints), and polished aluminum or copper.
- Use of roof materials on sloped roofs with colour pigments that reflect higher rates of infrared radiation.
- Use of building materials that have high thermal mass, like stone, concrete, or brick.
- Installation of low emissivity windows that adapt to the angle of incident radiation or double and triple glazed windows that minimize heat exchange. Alternately, application of plastic films that block solar radiation.
- Use of high-albedo pavement materials on roads, parking lots, and paved yards. Options include coloured asphalt, whitetopping (with a concrete layer), and reversed layering that lays down bitumen first followed by a high-albedo aggregate material.

Expand surface permeability and support evapotranspiration:

- Construction of water features in parks that encourage evapotranspiration and create microclimates facilitated.
- Planting of rain gardens on private properties to reduce runoff and improve soil moisture, thus promoting evaporative cooling.
- Use of pavers that promote high soil moisture levels necessary for an evaporative cooling effect. Options include interlocking pavers, modular pavers, porous concrete or asphalt, plastic grid systems, and porous turf.

Re-shape the urban morphology:

- Reduce heat-energy demands with building typologies that feature lower surface-to-volume ratios, higher density, and compact urban blocks.
- Balance the exterior glazing ratio (window to surface ratios) to lower solar gain.
- Orient new buildings and blocks to allow air flow to reach street level.

- Expansion of cycle paths and bicycle parking infrastructure to encourage alternatives to driving and reduce anthropogenic heat generated by vehicle traffic.

Local governments have a number of policy tools available to them to implement these strategies. Official plans and other strategic planning documents are key opportunities to mainstream adaptation to urban heat island into existing policies and propose new policies and programmes to address climate change impacts. To the extent that these policies are implemented, zoning bylaws, design guidelines, tree ordinances, and parking bylaws have been used in various capacities in Canadian and American cities to set promote the use of reflective and permeable materials, and to protect and expand tree coverage. Building codes and green building standards like the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) programme can be used to mandate minimum solar reflectance, improve insulation, and raise performance standards for window performance.

Table 1 highlights examples from Canada and the United States of policies or pilot programmes aimed at reducing urban heat island effect. Urban greening and cool roofing are the most common strategies implemented at the municipal level, and are applied through a number of mechanisms, including zoning bylaws, energy codes, and parking ordinances.

Table 1: Municipal Policies Addressing Urban Heat Island Effect

<table>
<tr><th>Vancouver, BC</th><th>Protection of Trees Bylaw (2014)</th></tr>
<tr><td colspan="2">The City of Vancouver's tree preservation bylaw was recently amended to remove the right of property owners to remove one tree per year without requiring a permit. Permits for tree removal may only be granted now if: the tree is within the building envelope, the tree prevents location of accessory buildings, the tree is dying or a danger, the tree is interfering with public utilities such that it cannot be reasonably maintained, or a tree is interfering with sewer or drainage systems.</td></tr>
<tr><th>Edmonton, AB</th><th>Urban Forest Management Strategy (2012)</th></tr>
<tr><td colspan="2">Edmonton's urban canopy is highly vulnerable to drought and pests, issues that will be exacerbated under changing climatic conditions. The Urban Forest Management Strategy supports efforts to monitor and sustain the city's canopy coverage, and enhance public awareness about the value of urban canopies.</td></tr>
<tr><th>Vancouver, BC</th><th>LEED Gold Building Standards (2011)</th></tr>
<tr><td colspan="2">The Green Rezoning Policy requires that all rezonings in the City of Vancouver meet LEED Gold status. The LEED rating system for building design and construction includes points for addressing heat islands, including shading, reflective paving materials (at least 0.28), open-grid paving, high reflectivity roofs, or green roofs. Other points for water management and reduced energy use also carry benefits for reducing heat island effect.</td></tr>
<tr><th>Rosement-La Petite-Patrie, QC</th><th>Zoning Bylaw Revision (2011)</th></tr>
<tr><td colspan="2">Four requirements were integrated into the Borough of Rosemont-La Petite-Patrie's zoning bylaw to reduce urban heat island effect, including reflective or green roof requirements for all new or replaced roofs, a minimal requirement for 15 percent landscaping coverage in parking lots of 10 or more spaces, reflectivity standards for new paving materials, and a 20 percent landscaped open space requirement for new development sites.</td></tr>
<tr><th>Chicago, IL</th><th>Chicago Energy Conservation Code (2009)</th></tr>
<tr><td colspan="2">The Chicago Energy Conservation Code goes beyond the Illinois Building Energy Code in the areas of solar reflectivity and insulation. Under Chicago's code low-sloping new roofs on residential and commercial buildings are required to have a minimum solar reflectance of 0.72 and medium-sloping new roofs are required to have a minimum reflectance of 0.15.</td></tr>
<tr><th>Toronto, ON</th><th>Green Roof Bylaw (2009)</th></tr>
<tr><td colspan="2">The first City in North America to require and set standards for green roof construction on new building permit applications over 2000m^2. The Bylaw is applicable to new residential, commercial, institutional, and industrial development. Coverage requirements are linked to roof size and range from 20 percent to 60 percent. Cash in-lieu payments of $200 per m^2 can be made at the discretion of the Chief Planner.</td></tr>
<tr><th>Seattle, WA</th><th>Green Factor (2007)</th></tr>
<tr><td colspan="2">The first city in North America to integrate a landscaping requirement into its municipal zoning bylaw. The Green Factor is designed as a scoring system with minimum scores determined for each zone Landscaping options are provided and include green roofs, rain gardens, vegetated walls, trees, and shrubbery.</td></tr>
<tr><th>Chicago, IL</th><th>Green Alleys Initiative (2006)</th></tr>
<tr><td colspan="2">Began as a pilot program to improve stormwater filtration and surface reflectivity. Approaches incorporated into the program include permeable surface paving, rainwater capture, use of light coloured surface materials, and industrial materials recycling. Green alleys provide benefits for stormwater management as well as urban heat island control.</td></tr>
<tr><th>Portland, OR</th><th>Green Roof Density Bonusing (2001)</th></tr>
<tr><td colspan="2">Portland's zoning bylaw includes a Floor Area Ration bonus for projects in the city centre that include green roofs. The amount of additional density is determined by the coverage of the green roof. Building owners sign an agreement to ensure that the roof will be maintained at code.</td></tr>
</table>

2. METHODOLOGY

2.1 Neighbourhood selection

This report seeks to establish a framework for analyzing extreme heat adaptation opportunities based on an understanding of the spatial distribution of population vulnerability to heat in Vancouver. To pilot this analytical framework a study area was identified that exhibits an above average degree of social vulnerability and also provides a rich variety of buildings and public spaces for neighbourhood analysis. A map of urban heat island measurements in Vancouver was obtained through the Simon Fraser University Remote Sensing and Spatial Predictive Modeling Lab, which completed the heat map of Metro Vancouver used in this study (Ho et al. 2014). Social vulnerability data was provided by Natural Resource Canada in the form of a Social Vulnerability Index (SoVI) for Metro Vancouver. Overlaying these data sets pointed to hotspots at the Dissemination Area (DA) level across the City with high health risk to extreme heat. The following sections describe the approach taken to integrate the data sets and identify the study area.

2.1.1 Social Vulnerability Index

The goal of the Metro Vancouver SoVI is to quantify the relative influence of different social characteristics that make communities more or less vulnerable to natural hazards. This is intended to capture the sensitivity of a population to hazards and its capacity to respond and recover (Cutter and Finch 2008). The SoVI follows the principal components analysis (PCA) methodology advanced by Cutter, Boruff, and Shirley (2003) with Dissemination Area level data from the 2006 Canadian census.[3] The analytical power of the index lies in enabling spatial comparisons of vulnerability, rather than returning an absolute value of vulnerability (Cutter and Finch 2008).

A total of 12 factors influencing social vulnerability were specified in the PCA and used to generate the index. Appendix A provides a list of these factors, the census variables that comprise them, and their relative influence on overall vulnerability. In all, these 12 factors were estimated to explain a reasonable 62 percent of Metro Vancouver's vulnerability. Generally the factors identified as having the strongest influence on vulnerability (e.g. income, age, isolation, minority status, education, and language) are consistent with the literature on vulnerability to extreme heat (Aubrecht and Özceylan 2013).

Positive SoVI scores indicate higher levels of social vulnerability. The literature differs on what threshold constitutes high vulnerability; Cutter, Boruff, and Shirley (2003) for example specify >1 standard deviations as defining high vulnerability,

[3] A principal components analysis is a statistical method for measuring the structure (direction and magnitude) of data.

while Cutter and Finch (2008) specify >2 standard deviations. In this study I used the average of these two values and assumed that dissemination areas with SoVI scores >1.5 standard deviations from the mean to be highly vulnerable.

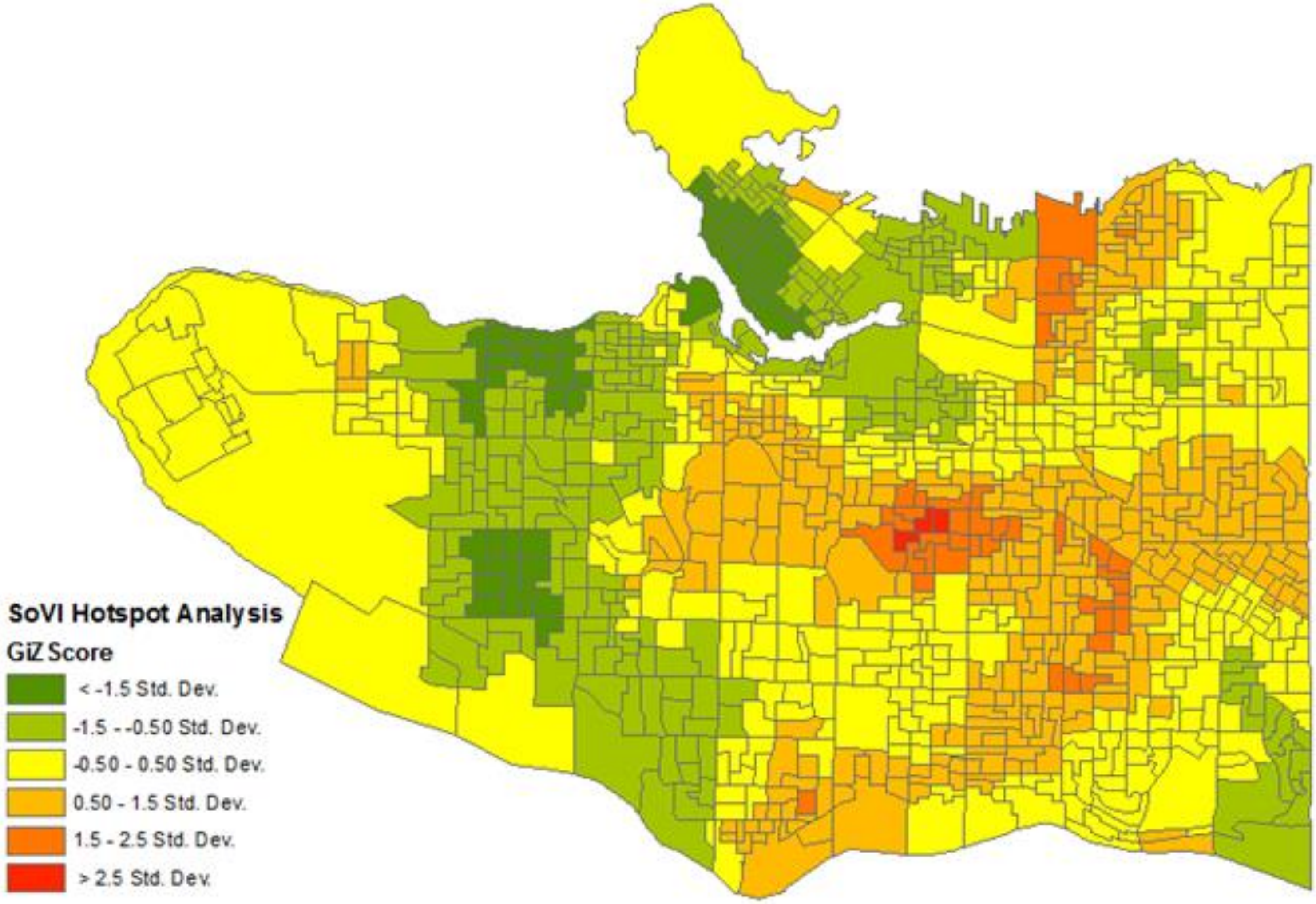
I conducted a hot spot analysis with ArcGIS 10.2 using the Getis-Ord Gi* statistic to identify spatial clusters of higher social vulnerability (Figure 3). The Gi* analyzed each Dissemination Area in relation to its surrounding Dissemination Areas. Statistically significant hot spots are Dissemination Areas with high SoVI values that are surrounded by other Dissemination Areas with high values. The results of the Gi* statistic were graphed by standard deviation, with hot spots >1.5 standard deviations considered highly vulnerable. Areas of high vulnerability were concentrated to the east and south of Vancouver. In particular, hot spots were identified in east Strathcona and west Grandview-Woodland, as well as the Riley Park, Kensington Cedar Cottage, Collingwood, Sunset, and Marpole areas of east and south Vancouver.

2.1.2 Urban heat island map

The Metro Vancouver Urban Heat Island Map shows maximum air temperature on a typical hot summer day relative to the temperature reading at Vancouver International Airport (Figure 4). Regression modeling conducted with elevation data and Landsat images estimated temperatures across Metro Vancouver for six hot summer days between 2001 and 2010 when temperatures above 25°C were recorded at Vancouver International Airport. These data layers included land surface temperatures, Normalized Difference Water Index (a predictor of evaporative cooling), elevation, sky view factor, and solar radiation. Maximum temperature readings from 59 weather stations through Metro Vancouver were used to calibrate and validate the models (see Appendix C for weather station locations in the City of Vancouver). The six regression models were averaged to estimate maximum temperatures on a typical hot summer day (Ho et al. 2014).

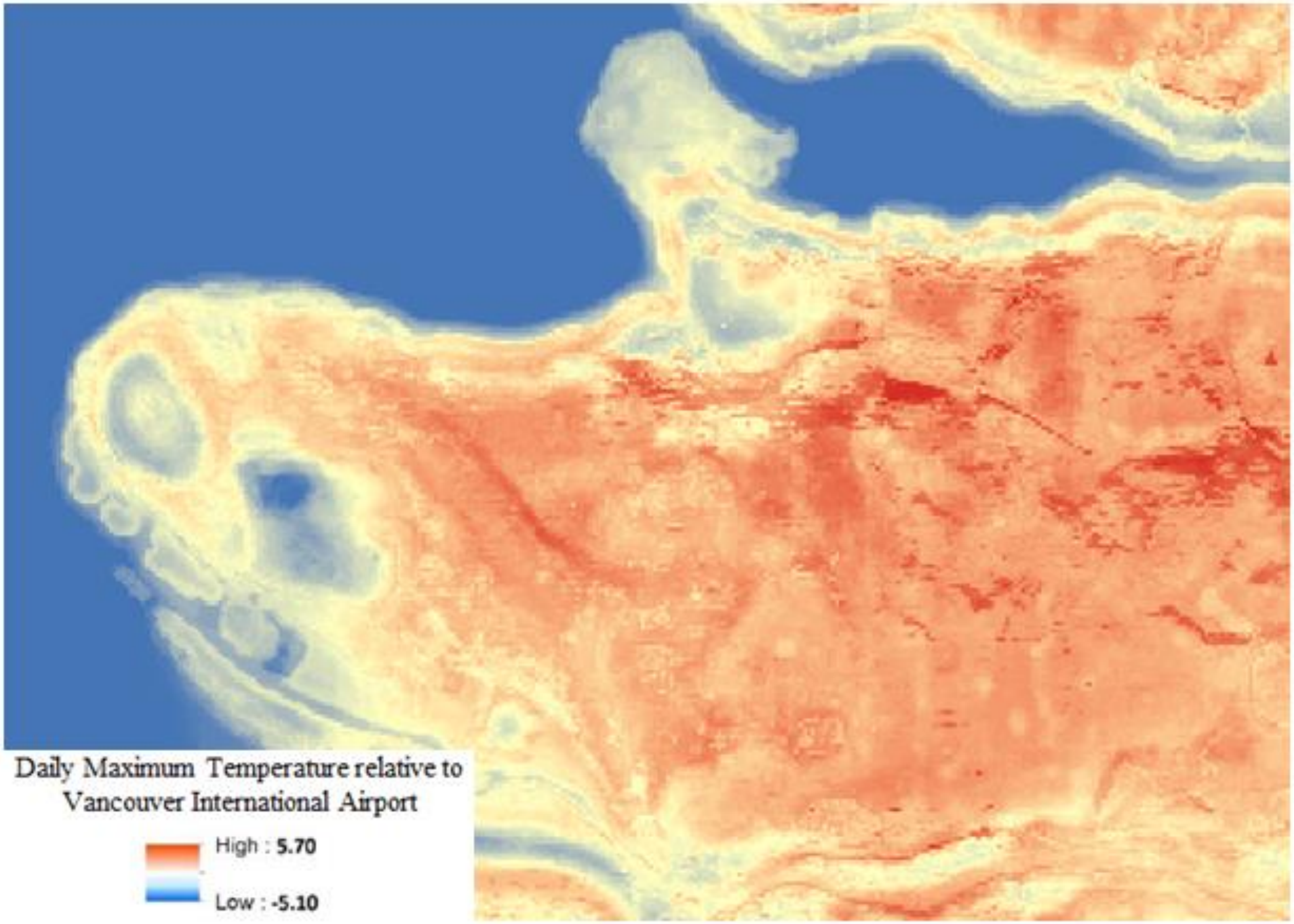
Vancouver has a complex microclimate due to its unique geography, with mountains to the north, the Pacific Ocean to the west, and the semi-arid Fraser Valley to the east. The heat map shows predictably cool areas in heavily wooded areas like Pacific Spirit Regional Park and Stanley Park, and in areas exposed to ocean breezes. The map is unusual in that downtown Vancouver is actually considerably cooler than the southern areas of the city, unlike many other cities that have elevated UHI effects in the downtown core. This is likely due to the proximity of the downtown to ocean breezes (English Bay and the Burrard Inlet). The highest positive temperature

Figure 3: Social Vulnerability Index Hot Spot Analysis



Source: Natural Resources Canada, 2008

Figure 4: Vancouver Urban Heat Island Map



Source: Ho et al, 2014

differential relative to recordings at Vancouver International Airport was just over 5°C, concentrated to the south of the False Creek Flats industrial area and in pockets to the east of this area. Southeast Vancouver also had large concentrations of urban heat island effect.

I converted the original Metro Vancouver Urban Heat Island layer from a raster map to a vector map, intersected this map with Dissemination Area boundaries for the City of Vancouver, and calculated average heat values for each DA (Appendix D). I then visually overlaid the final UHI map with the SoVI hot spot map to identify the area that has the highest level of social vulnerability and elevated urban heat island profile.

The final study area identified is the Commercial Drive area of Grandview-Woodland. The area is bounded to the south by E 1st Ave, to the east by Clark Drive, to the west by Commercial Drive, and to the north by Venables Street (see Figure 5). The study area measures about 0.44 kilometres in size.

2.1.3 Methodological limitations

There are several limitations to both the vulnerability hot spot analysis and urban heat island map that are worth noting. First, the Social Vulnerability Index was completed using 2006 census data and so is potentially outdated. An updated index is currently being produced using 2011 census data, but given the methodological changes to the 2011 census it is unclear how comparable these indices will be. Given concerns about data reliability in the 2011 census the 2006 data was deemed preferable for a spatial analysis of vulnerability.

Second, the SoVI follows an unweighted factor analysis methodology that asserts no theoretical justification for assigning a particular factor more importance than another. In the index overall social vulnerability is a product of intersecting attributes, and so this is generally a robust approach to spatial analysis of vulnerability. In the case of heat vulnerability, however, there are particular factors that are understood to elevate health risks (e.g. age, health status, income) and so the SoVI can only be understood as a general proxy for heat vulnerability. To my knowledge, this SoVI is the only existing vulnerability index for Vancouver and so is applied to this study; however, a more fine-grained vulnerability analysis could be achieved by building a specific heat vulnerability index.

Third, some Dissemination Areas in Vancouver's downtown are missing values that are substituted with the mean values for the entire data set (Metro Vancouver) for the purposes of running the principal components analysis. These values may be missing due to privacy concerns with data in DA's with small populations. This could impact on the hot spot analysis by skewing the area data for the downtown.

Figure 5: Study Area

Finally, the urban heat island map does not account for nighttime temperatures, which have been demonstrated to have a powerful influence on mortality. As further efforts are made to map the heat landscape of Metro Vancouver this will be an important gap to address.

2.2 Neighbourhood analysis

The neighbourhood analysis of the study area is informed by the science basis underlying urban heat island effects. I collected information about area demographics, building typology, building age, current zoning, current land use, city-owned property, non-market housing locations, laneway access, tree canopy coverage, drinking fountain location, parks, and surface materials (roofing and paving).

I obtained data on Grandview-Woodland demographics from the background information materials prepared by the City of Vancouver for the current local area planning process. This information validated the results of the SoVI analysis, indicating a higher than average presence of disadvantaged households. The City of Vancouver's online platform VanMap provided information on current land use, parks, location of heritage properties, location of city-owned lots, non-market housing, and drinking fountains. The City's Urban Forest Strategy provided information on tree canopy coverage for Grandview-Woodland. I observed laneway access, building typology (single detached, townhouse, apartment up to 3 stories, apartment over 3 stories), roofing colour, and impermeable surface coverage through Google Maps satellite images and verified my observations through a site visit.

Finally, I retrieved digital copes of policies and bylaws relevant to urban heat island adaptation and covering a range of tools leveraged by planners to implement sustainability policies. These documents include zoning districts, design guidelines, parking bylaws, tree bylaws, and strategic plans. The full list of policies and bylaws considered is provided in Appendix B.

It is worth noting that while Metro Vancouver produces regional strategic plans relating to land use and transportation, they are not included in this analysis. This is owing to the fact that these strategies only indirectly effect neighbourhood-level planning processes and so have less impact on localized adaptation interventions. Additionally, this project does not delve into the current local area planning process that Grandview-Woodland is going through. With ongoing setbacks to the planning process and recent addition of a Citizens Assembly to make recommendations for a new Local Area Plan, there is no draft plan at an advanced enough stage for inclusion in this analysis.

3. NEIGHBOURHOOD ANALYSIS

Grandview-Woodland is one of Vancouver's most distinct and diverse neighbourhoods. Its historic roots reach back to the early days of Vancouver when Commercial Drive functioned as a logging corridor between New Westminster and False Creek. Today it is a thriving, pedestrian-oriented retail centre and a hub for political activism and cultural expression in Vancouver.

The 2011 Canadian census recorded a neighbourhood population of 27,297 with above average segments of certain socially vulnerable groups, as compared to the City of Vancouver overall. Grandview-Woodland has a disproportionately high concentration of both single-parent households (26 percent, compared to City share at 16 percent) and low-income households (35 percent, compared to City share at 27 percent). It also has a higher than average percentage of individuals who identify as Aboriginal, North American Indian, or Métis (9 percent, compared to City share of 2 percent). This is likely in part due to the large number of non-market housing complexes serving First Nations and Métis individuals. Grandview-Woodland is rich in linguistic diversity, with just over half of residents identifying English as their dominant language, and Chinese (25 percent) being the next most frequently spoken language. Despite this diversity of language, only one-third of residents were born outside Canada, while city-wide this group jumps to 45 percent (Vancouver 2012b).

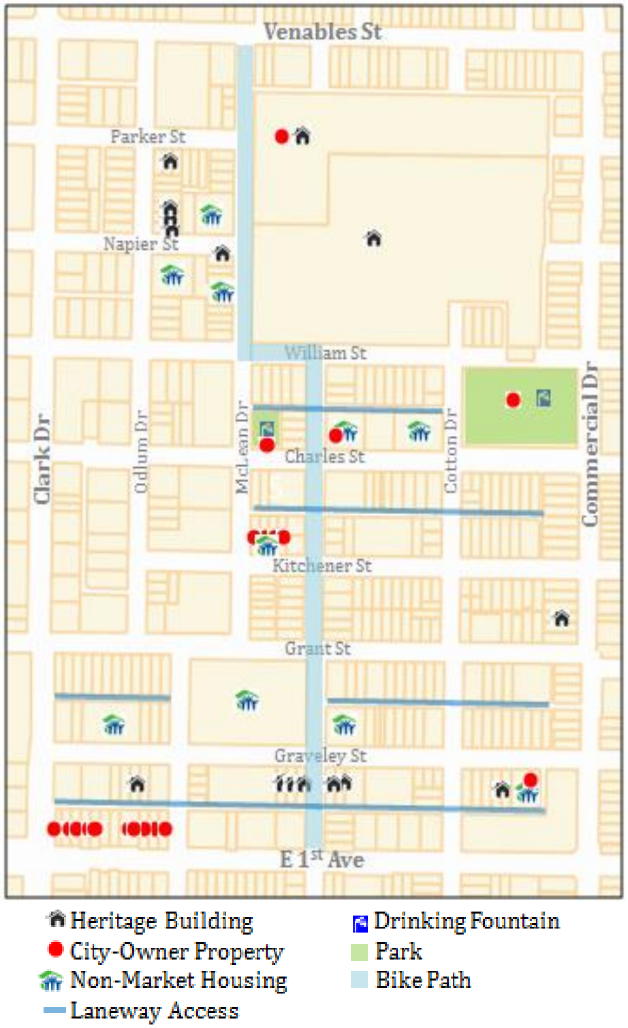
Grandview-Woodland benefits from a variety of land uses due to its location to the east of the False Creek Flats industrial lands, retail corridor on Commercial Drive, and wide spectrum of residential housing types. The study area analyzed in this report sits between industrial rail yards on the west side and the retail corridor to the east, with residential and institutional uses in between. The following sections describe the physical qualities of the study area as informed by the literature about neighbourhood design and urban heat island effect. This chapter discusses local assets, tree canopy coverage, current zoning and land uses, building typologies, and surface materials. Photos of the study site that visually demonstrate what is described here can be found in Appendix E.

3.1 Asset mapping

An analysis of Vancouver's geographic data on this neighbourhood indicated that the study area has a number of registered heritage buildings, city-owned properties, non-market housing units, and parks with drinking water facilities (Figure 6).

Heritage Buildings: There are 15 sites with designated heritage buildings. Eleven of these sites are single detached homes in the traditional Britannia architectural style

Figure 6: Neighbourhood Asset Map



of the Grandview-Woodland neighbourhood. This style features wood-frame construction, wooden roof shingles, and accents like bay windows, turrets, dormers, and porches (Vancouver 2013). One heritage site consists of six 4-storey wood-frame row homes in the Britannia style with wood siding, asphalt shingles, and dormers. The remaining sites are a commercial building located on Commercial Drive, and the Britannia Secondary School and Britannia Community Services Complex.

City-Owned Properties: The City of Vancouver owns 19 parcels in the study area, though some parcels tied together in a single development. Existing buildings on these properties include the Britannia Community Services Complex, three non-market housing developments (two operated by the Lu'Ma Native Housing Society and one operated by the Mennonite Social Housing Society), one three-storey strata apartment development, and five lots with ageing single-family homes. These single-family homes and the 3-storey apartment building are on the 1st Ave and Clark Drive block, where there are also four empty lots owned by the City. The remaining two properties are used as parks, Grandview Park and Mosaic Creek Park.

Non-Market Housing: There are ten non-market housing sites in the study area, including the three owned by the City and operated by non-profit associations. Five further sites are co-ops, and the remaining two are a Vancouver Native Housing Society property and BC Housing property.

These sites include the Charles Square Co-op, Charleswood Court (Operator: Mennonite Social Housing Society; City-owned property), Grandview Co-op, Watershed Co-op, Tidal Flats Co-op, Lu'Ma Housing (Operator: Lu'Ma Native Housing Society; City-owned property), The Marjorie White Building (Operator: Lu'Ma Native Housing Society; City-owned property), Sitka Co-op, Grandview Terrace (BC Housing), and 1339 Graveley Street (Vancouver Native Housing Society).

Parks and Drinking Fountains: There are two parks within the study area: 1) Grandview Woodland Park, located at Commercial Drive and Charles St, and 2) Mosaic Creek Park, located at Charles St and McLean Dr. Each park has one drinking fountain, and Grandview Park also has a playground featuring a fountain for children to play in. There is additional recreational space in the area, including the Britannia Secondary School yard and gymnasium, track, field, pool, ice rink, and tennis courts attached to the Britannia Community Services Complex. Currently the school yard space at Britannia Secondary School is an open area with no trees and gravel surface coverage.

Active Transportation Corridors: There is an existing bike route running through the study area on Woodland Drive, which forms a piece of a larger route stretching 7.5 km from Adanac St in the north to E 59th Ave in the south. The route is designated a "Local Street Bikeway," indicating that the path is on a low-traffic neighbourhood street that is shared with motor vehicles.

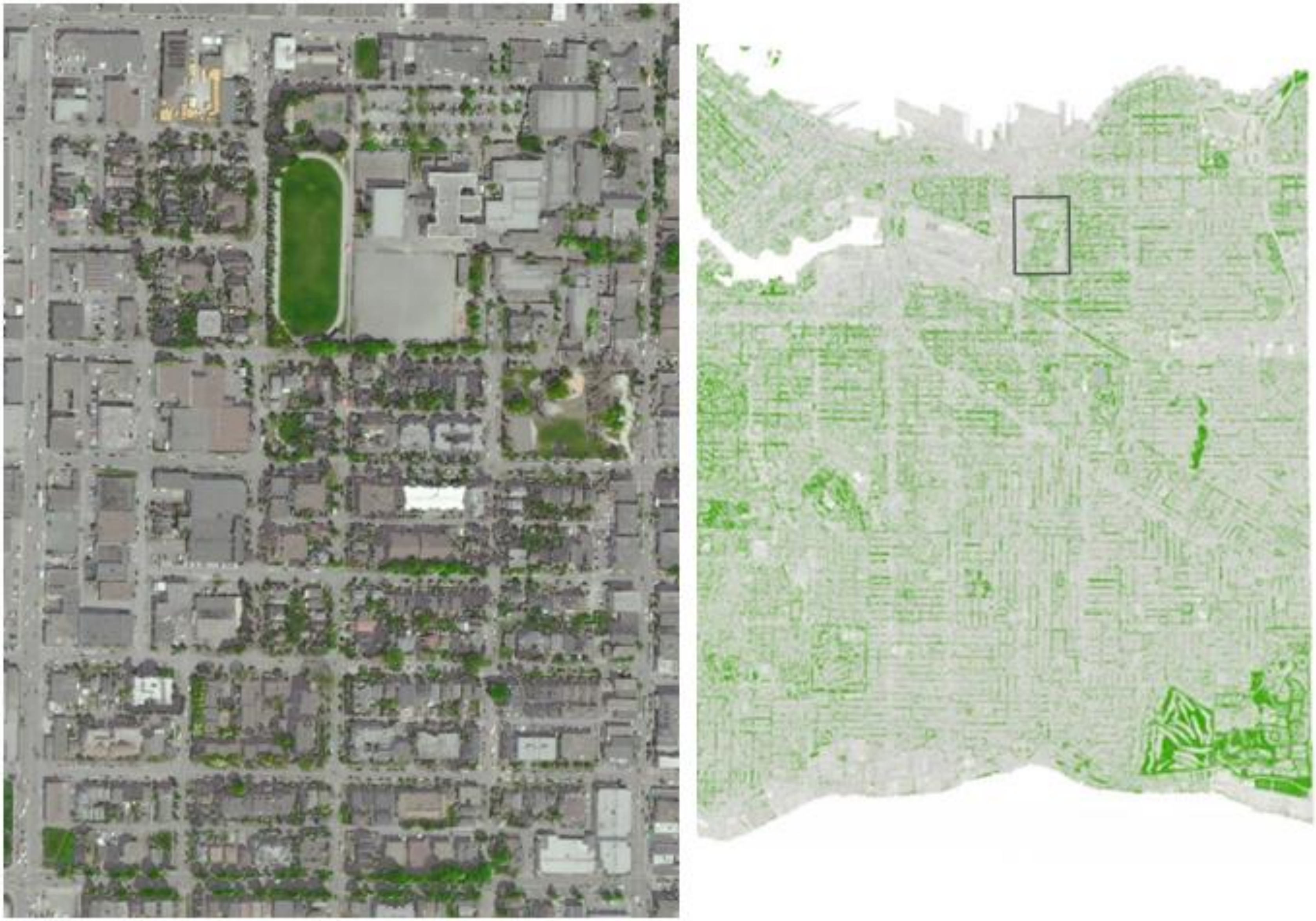
Laneway Access: There are 12 blocks with laneway access, all located south of William St and north of E 1st Ave. The laneways are paved with asphalt and gravel, and vary in current condition. They provide parking access for both single and multifamily homes.

3.2 Tree canopy

As part of the background research for the Urban Forest Strategy, the City of Vancouver commissioned a LIDAR tree canopy map of the city. Using this map the City was able to calculate canopy cover for each neighbourhood. City-wide tree canopy coverage is 18 percent, which is comparable to Victoria but falls below Seattle (23 percent) (Vancouver 2014). Over time canopy coverage has declined from 22.5 percent in 1995 to its current 18 percent, in part due to gaps in the Protection of Trees Bylaw that allowed property owners to remove one tree per year without a permit.

Grandview-Woodland falls below the city average with canopy coverage of 13.6 percent. Tree canopy coverage in the study area is concentrated to the south and east in residential areas. Areas with limited tree coverage include industrial sites along Clark Drive and extending to McLean Drive, and facilities surrounding the Britannia Secondary School and Community Services Complex (Figure 7). The study area lies directly to the east of the False Creek Flats rail yards, which also has extremely limited tree canopy coverage. Gaps in tree coverage are mostly around industrial and commercial buildings where there is a predominance of surface parking for cars and trucks, and larger building footprints.

Figure 7: Tree Canopy Map



Source: City of Vancouver Urban Forest Strategy, 2014

Canopy coverage provided by street trees varies considerably across the study area, with some streets benefitting from larger mature trees and other streets with newer buildings having smaller and younger trees. There are no street trees located around industrial buildings.

3.3 Building age

Grandview-Woodland has a disproportionately older building stock relative to the city as a whole (Figure 8). Within the study area over half of existing buildings were constructed between 1900 and 1959 (see Table 2). The largest share of buildings was constructed in the 1910s (125, 32 percent).

This age profile presents older neighbourhoods like Grandview-Woodland distinct challenges in adapting residential buildings to increased heat stress. Older homes are more likely to have poor insulation, increasing heat gains during hot days. In addition, the traditional style of this neighbourhood features steeply pitched roofs with wood or asphalt shingles that have low albedo. Replacing aging shingles with alternative high-albedo roofing materials is one adaptation option for older homes that can contribute at a neighbourhood scale to reducing urban heat island effect. On a household health and comfort level, however, retrofitting homes for long-term improved thermal performance in hot weather can require deeper (and more costly) renovations to the building envelope, and in particular walls and windows. Improving insulation and air sealing around windows helps to eliminate thermal bridges, which are points of poor insulators that allow heat transfer.

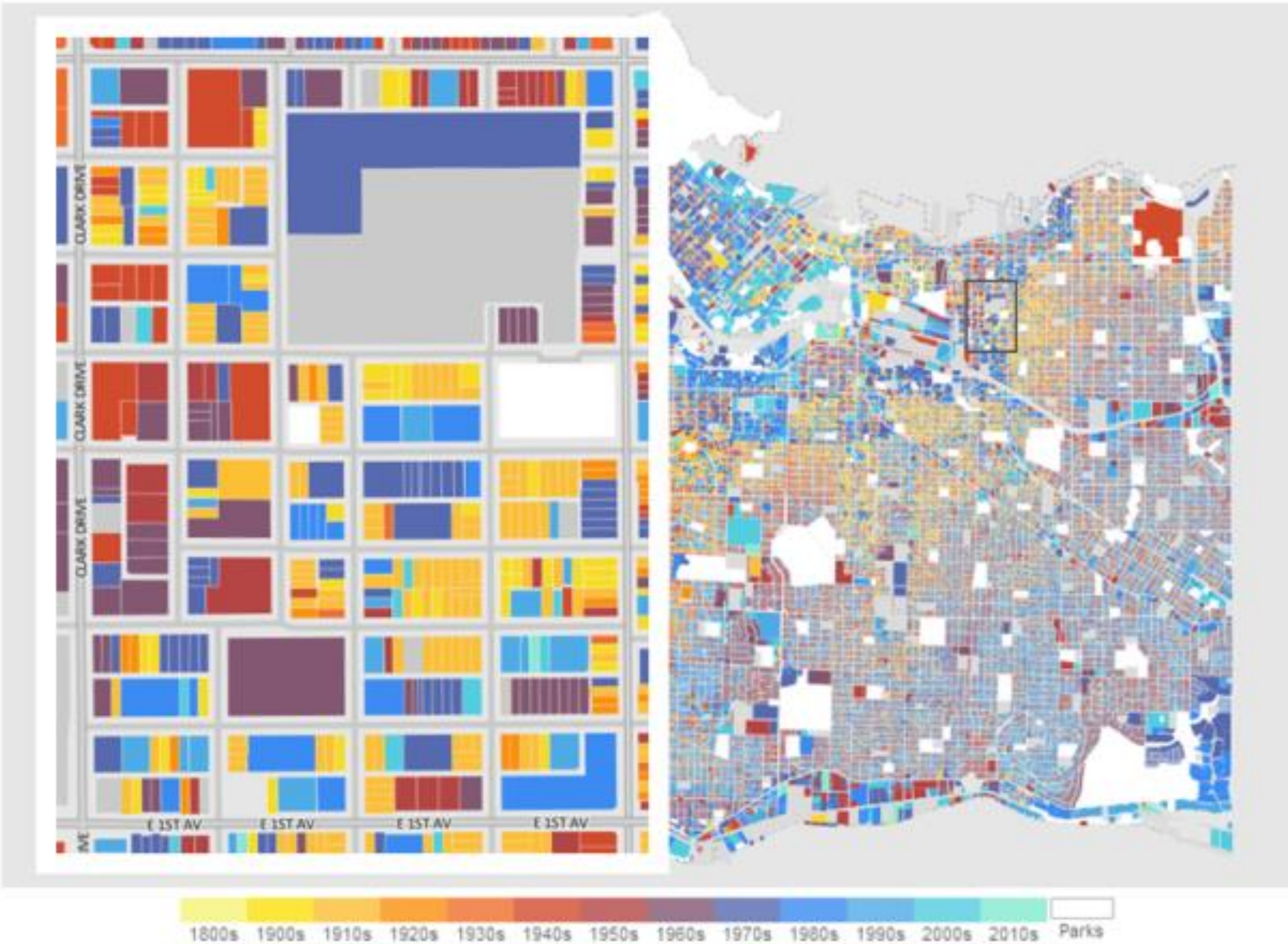
Table 2: Building Age Summary

Year	Site Count	Proportion
1900s	49	13%
1910s	125	32%
1920s	18	5%
1930s	5	1%
1940s	20	5%
1950s	25	6%
1960s	45	12%
1970s	58	15%
1980s	21	5%
1990s	17	4%
2000s	9	2%
2010s	1	<1%
Total	393	

Source: Ekaterina Aristova, 2014

The multifamily dwellings in the study area were built primarily in the 1960s-1980s and largely follow the Britannia style, though there are some exceptions (e.g. the BC Housing non-market housing development). These buildings are also wood-frame but differ in a few notable ways. Rooftops, for example, tend to be flat and a number of buildings feature balconies on each unit.

Figure 8: Building Age



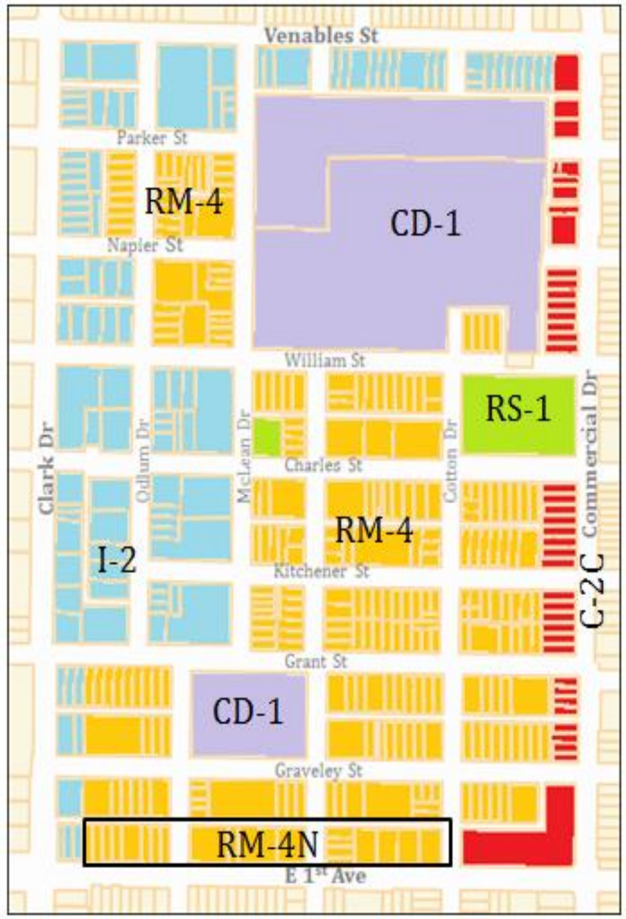
Source: Ekaterina Aristova, 2014

3.4 Existing zoning and current land use

The existing zoning for the study area is predominantly RM-4 and RM-4N, which applies to 255 parcels in the study area (Figure 9). This is a zoning district for medium density multi-family residential uses. RM-4N differs in that it requires additional noise mitigation considerations for residences that are located on E 1st Ave, an arterial street.

The western and northern-most blocks of the study are zoned for light industrial activity (I-2), which includes cultural activities like artist studios or publishing services, services like vehicle repair stores, wholesaling, and light manufacturing, including food and beverage manufacturing, clothing and textiles manufacturing, and vehicle equipment manufacturing. In total 104 parcels are zoned I-2. These uses tend to generate greater levels of waste heat, which

Figure 9: Existing Zoning



contributes to rising neighbourhood temperatures. C-2C zoning runs along Commercial Drive, providing for pedestrian-oriented retail space with some residential space above. A total of 40 parcels are zoned C-2C.

There are two lots designated RS-1 but both are currently utilized as park space. Existing single family homes are primarily located in the multi-family RM-4 and RM-4N zones. Comprehensive Development zoning is in place for three parcels, including the Britannia Secondary School and Britannia Community Services Complex, as well as the non-market housing development on the block of Graveley St and Woodland Drive.

The current use map indicates that the study area has a large stock of multi-family housing, primarily wood-frame apartment buildings up to 3-storeys in height (43 in total) (Figure 10). There are an additional 12 apartment buildings of 4-storeys and over. Ten of these sites are non-market housing complexes. The remaining

Figure 10: Current Land Use

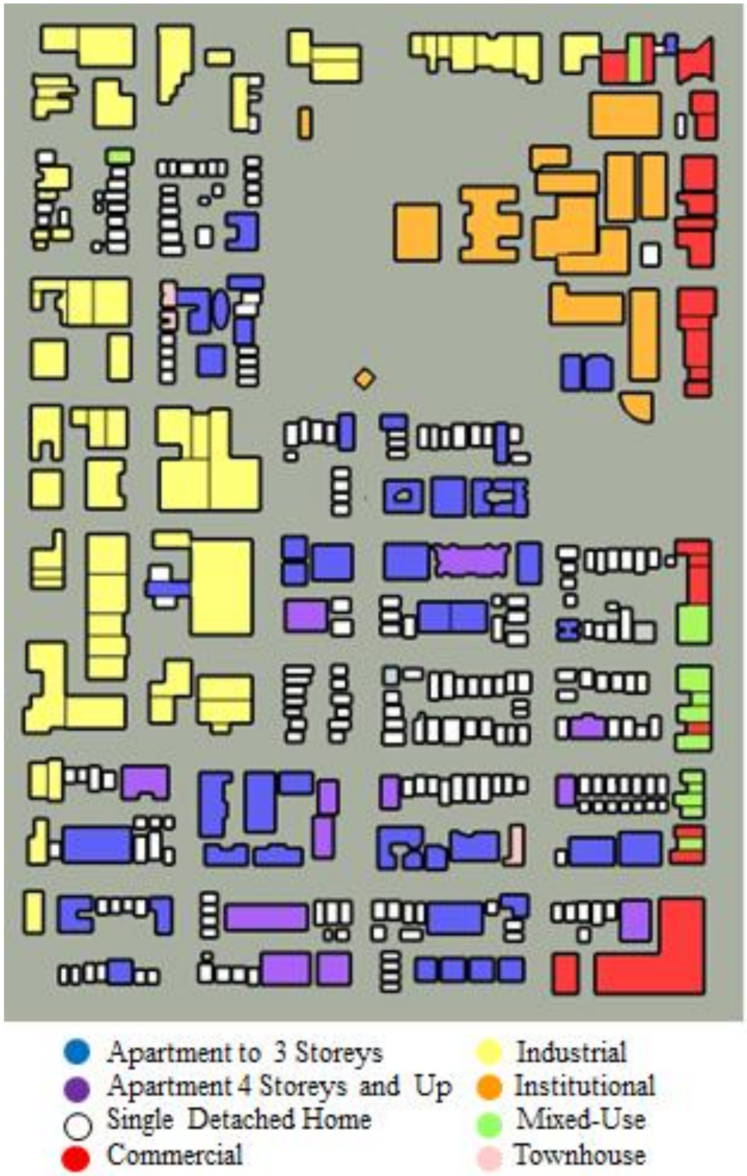


Figure 11: Rooftop Colour Estimate

residential housing stock is primarily single family detached homes, with only three sets of row-homes in the boundaries of the study area. The industrial building stock is one to two storeys in height with low-grade roofs and large areas of surface parking. There are only a handful of mixed use buildings that have ground-level retail with residential units above, and nearly all are located along Commercial Drive.

The maximum permitted floor space ratio (FSR) in RM-4(N) areas is 0.75, which is well below the average densities for compact urban blocks (1.5-2.5) that were found by Rode et al (2014) to perform the best with regards to heat-energy demand. These compact blocks also had average heights of six storeys, which is higher than what is currently found in this area of Grandview-Woodland. While the I-2 and C-2C zones permit density up to 3 FSR (depending on mix of uses in the case of C-2C sites), most buildings are well below this maximum and also have a number of features (low tree canopy coverage, surface reflectivity, and permeability) that are known to exacerbate UHI.

3.5 Surface materials: Reflectivity and permeability

Figure 11 roughly captures roofing colours within the study area. Materials used on single family homes are predominantly grey, dark grey, or black ashpalt shingles while roofs on commercial and industrial buildings are grey, black, or brownish in colour. These materials tend to have high thermal emissivity and low albedo, meaning they absorb high levels of solar radiation and gradually heat the buildings that they cover. As discussed previously, heat retention like this tends to increase energy demands for cooling and reduces indoor comfort. It also increases requirements for roof maintenance. There are a few notable examples in the study area of multi-family buildings with white or light grey roofing materials, which demonstrates that using lightly coloured materials with higher solar reflectance is feasible for the Grandview-Woodland area.

Particularly concerning is the overwhelming use of dark roofing materials on the low-grade roofs of light industrial buildings to the west and north of the study area, and high concentration of surface parking throughout the industrial areas. In combination with roadways and laneways throughout the neighbourhood, there is extensive impermeable surface coverage throughout the study area that reduces evapotranspiration and increases absorption of solar radiation. The low level of canopy coverage in this area, high proportion of impermeable surface coverage, and use of low-albedo materials on low-grade roofs is likely a major contributing factor to elevated heat island effects in Grandview Woodland and neighbouring Strathcona.

Figure 12: Study Area Highlights

Historic Britannia Style of Detached Home

Large Industrial Buildings, Impermeable Surfaces, Flat Roofs

Impermeable Surface Coverage Throughout Laneways

Steeply-Sloped Roofs With Low-Albedo Shingles

3.6 Summary

This area of Grandview-Woodland contains a rich diversity of building typologies and land uses, in addition to 12 neighbourhood blocks containing laneways and two public parks. A number of markers for urban heat island vulnerability were identified however. Low building heights and densities, uneven and limited tree canopy coverage, extensive impermeable surface coverage, and certain design features are likely factors driving the elevated neighbourhood temperatures captured in the Metro Vancouver urban heat island map. The presence of 10 non-market housing buildings (including three serving First Nations residents and one BC Housing development for low-income households) also suggests a concentration of residents with demographic characteristics that are commonly associated with increased mortality risk during extreme heat events, including low socio-economic status and minority status. It is likely that these non-profit developments also house a number of seniors, though this is not verifiable without consulting tenant data for each development.

This concentration of multifamily buildings is located in a neighbourhood with below-average tree canopy coverage, and exhibits building characteristics (e.g. flat, dark rooftops and wood construction) that are known to exacerbate UHI. Close proximity of these buildings to industrial uses on the western edge of the study area is also likely influencing local microclimates. These industrial buildings have large footprints, flat rooftops covered in dark materials (likely asphalt or bitumen composites), and extensive impermeable surface areas that are poorly shaded. Together these elements promote heat absorption and raise neighbourhood temperatures. That the non-profit housing developments are built on City-owned land indicates that there may be opportunities in Grandview-Woodland to partner with non-profit housing operators in piloting UHI adaptation strategies within buildings and blocks that have high levels of social vulnerability.

The other dominant building typology in this study area is single detached homes that are largely built in the traditional Britannia style found throughout Vancouver's older neighbourhoods. This housing stock presents interesting opportunities for thinking creatively about how to work within unique urban fabrics to adapt to extreme heat risk. The abundance of heritage homes will require the City of Vancouver to consider how new technologies can be sensitively integrated into existing neighbourhoods while improving thermal performance of buildings by increasing reflectivity and reducing solar radiation absorption.

In summary, there were four major elements of the built environment in this neighbourhood that are likely contributing to elevated levels of urban heat island effect:

- Wide use of low-albedo roofing materials on steeply-sloped roofs of single detached homes, multifamily buildings, and industrial/commercial buildings;
- Gaps in urban canopy coverage, particularly around industrial areas;
- Extensive impermeable surface coverage, especially in laneways and surface parking for industrial and commercial areas; and
- A predominance of older single detached homes likely requiring significant retrofitting to reduce heat gain.

4. POLICY ANALYSIS

An analysis of bylaws and guidelines applicable to this study area indicated that current land use, landscaping, and building practices in Vancouver are inadequate to fully address underlying drivers of urban heat island effect. Critical areas of intervention relevant to this neighbourhood include surface material selection, tree canopy coverage and landscaping, as well as retrofitting aging single detached homes and multifamily buildings. The following section summarizes current policy gaps.

4.1 Tree planting and landscaping

The City of Vancouver's Urban Forest Strategy seeks to halt the decline of urban canopy coverage by reducing the annual number of healthy trees removed on private property and encouraging more retention of trees on redevelopment sites (Vancouver 2014). The City also seeks to expand canopy coverage on both city-owned land and private property to regain a canopy coverage level of 22.5 percent by 2055. The plan calls for strategic planting of new trees in areas with low canopy coverage.

With these goals in mind the City has already taken the positive step of requiring permits for all tree removals on private property, and only in the event that the tree presents a safety hazard, is diseased or dying, is located within a building envelope, or is causing damage to structures or sidewalks. Notwithstanding this, Section 6.2 of the Tree Removal Bylaw permits the removal of a tree without requiring a replacement as long as the site has the minimum number of trees described in Schedule C of the bylaw (Vancouver 2014b). In effect this provision allows for a shrinking in the tree canopy, which could undermine efforts to return the canopy to 1995 levels.

Tree planting and landscaping requirements are also specified in guidelines accompanying specific zoning districts, which outline standards for vegetation density, surface materials, and weather protections in public spaces. The Britannia/Woodland RM-4 and RM-4N Guidelines complement the district schedules in the Zoning and Development Bylaw and are provided as additional information for projects seeking approval within permitted uses as well as those seeking approval for conditional use or relaxation of regulation (Vancouver 1992b). Landscaping requirements contained in the guidelines are generic, emphasizing preservation of existing features, grassy lawns, screening of unattractive industrial areas, and use of decorative elements. There is no clear and enforceable standard for vegetation or tree canopy coverage.

In contrast, the Commercial Drive "East Lane" CD-1 Guidelines provides a standard for vegetation, stating that there should be a continuous "landscape character" from the ground to a height of 10.5 metres (Vancouver 1989). This is more rigorous that landscaping guidelines found in other district guidelines, though it leaves room for creativity in how the standard will be achieved. Given that the site is a Comprehensive Development Area, there is more flexibility to make landscaping standards appropriate to the site. Nonetheless, these guidelines fall far short of cities like Seattle that have used their zoning bylaws to integrate very specific landscaping targets as a percentage of site area, increasing the effectiveness of zoning tools in urban greening.

The industrial uses (I-2) zoning district and accompanying Non-Industrial Uses (I-2 and M-2) Policies and Guidelines do not address building design or landscaping in light industrial areas, which is concerning given the proximity of these districts to residential areas (Vancouver 2006; Vancouver 2014c). Furthermore, given that these uses require extensive surface space for large vehicles and other equipment it is unlikely that tree planting and landscaping will be prioritized in these districts. Some municipalities like London, ON have worked to increase voluntary tree planting on private industrial lands but efforts in Vancouver to date have focused on enhancing tree canopy in parks and private residential land. Specifications on roofing and paving materials in industrial areas are thus likely to be more important in enhancing the environment performance of industrial sites given the low level of canopy coverage throughout these areas and high levels of waste heat generated from light manufacturing activities.

The C-2C district schedule contains several relevant sections to landscaping and public space, including provisions requiring "special paving, weather protection, landscaping, and benches" (Vancouver 2014c). The schedule also encourages the use of awnings, which enhance the quality of pedestrian experiences and also provide shading from rain and the sun. Weather protection in Vancouver is generally interpreted as shelter from rain, but this passage demonstrates that weather protection should also be considered for hot days. Explicitly linking the need for weather protection to heat would clarify the purpose of these sections in zoning districts with landscaping requirements, and make them a more effective tool for implementing urban heat island adaptations.

4.2 Energy retrofit guides

The City provides passive building design guidelines for new developments that are intended to improve building energy performance, but many of these recommendations (for example around building orientation, building shape, façade design, window-wall ratio, and buffer space) are not applicable to older, established neighbourhoods like Grandview-Woodland that have a large existing supply of single detached and multifamily homes (Vancouver 2009b). As noted previously, the neighbourhood features a traditional architectural style with steeply pitched roofs and shingles of asphalt or wood. The key challenge for older neighbourhoods like Grandview-Woodland will therefore be in adapting existing residential building stock to warming temperatures while maintaining the character of Vancouver's heritage neighbourhoods.

Many of these retrofits will be aimed at managing indoor comfort and reducing cooling loads, but there are also retrofits than can contribute to reducing average neighbourhood temperatures. The City's green home renovation guides provide some guidance on improvements that have benefits for reducing urban heat island effect (Vancouver 2012c). In particular, the guidelines on roof replacement summarize material options and their associated challenges and benefits for Vancouver's climate context. There are several references to summer heat gain of particular materials (like dark asphalt shingles) but no discussion of how rooftop materials and colour impact urban temperature. The landscaping guidelines make no reference at all to the relationship between landscaping and urban temperature.

These guidelines aim to educate homeowners about what retrofitting means for lighting, water usage, household appliances, landscaping, materials reuse, and roofing. Better connecting these information materials with strategic objectives in the Greenest City Action Plan and Adaptation Strategy would give the public a better sense of where opportunities lie for autonomous adaptation to climate change, which will be critical in preparing for future extreme weather events like heat waves. Linking home retrofits to climate change impacts can better educate the public about the role their can play as private citizens in improving the environmental performance of their homes and neighbourhoods.

4.3 Green building standards

The City's Green Buildings Policy for Rezonings was implemented in 2011 and requires new developments that undergo a rezoning to meet the Leadership in Energy and Environment Design (LEED) Gold standard, with at least 63 points across different categories of energy consumption (Vancouver 2010b). The policy requires at least 6 energy performance points, 1 water efficiency point, and 1 stormwater point. The LEED for New Construction standards include points for heat island reduction, notably for the use of high-reflectance roofs (defined as having a three-year Solar Reflectance Index score of 32 for steeply sloped roofs and 64 for low sloped roofs, or construction of a green roof and use of covered parking) and paving materials with a 3 year Solar Reflectance Index of at least 28.[4] At the moment the City does not require that points be met to address urban heat island effect.

Development capacity modeling conducted for the Grandview-Woodland Local Area Plan estimates that there will be relatively substantial redevelopment towards mixed-use buildings from 663 dwelling units as of 2011 to 1,290 in 2041 (Vancouver 2012c). These rezonings will present important opportunities to incorporate architectural and landscape features into new developments through the LEED rating system that address some of the drivers underlying urban heat island effect. Expanding the minimum distribution of LEED points to include steps to mitigate urban heat island effect is one low-cost option the City can consider to mainstream UHI adaptation into new developments.[5]

4.4 Landscaping requirements for surface parking

A number of municipalities in Canada and the United States have strengthened landscaping requirements for surface parking, including vegetation and canopy coverage, and permeable or reflective surfaces. While Vancouver has less surface parking than many other municipalities of its size, there is still extensive parking in industrial areas like the I-2 zones that are in close proximity to residential areas.

Vancouver's Parking Bylaw is vague regarding landscaping, generally referring to landscaping standards that are "to the satisfaction of the Director of Planning" (Vancouver 2014d).Section 4.9.2 of the Parking Bylaw design standards specifies use of asphalt or impermeable surface, or at least 10 cm of crushed asphalt to allow some degree of permeability. Off-street parking considerations are focused almost exclusively on regulating laneway access and only specify design standards in terms of architectural compatibility between parking structures and associated buildings. Nowhere are requirements for reflective surface materials specified.

In contrast, Toronto's Design Guidelines for Greening Surface Parking Lots provides an extensive description (with images) of landscaping measures for thermal comfort and stormwater management that go well beyond the landscaping components of Vancouver's Parking Bylaw (City of Toronto 2013). The guidelines include specifications both to limit impermeable surface coverage and improve surface reflectivity. It recommends using porous pavement, open-jointed pavers, and turf grids on parking lot surfaces to increase water

[4] A Solar Reflectance Index measures the ability of a root to reflect solar radiation and re-emit heat gain on a scale of 0-100. The least reflective black roof, for example, would have an index score of 0 while the highest reflective white roof would have a score of 100.

[5] The LEED for Neighbourhood Design standard also awards points for heat island mitigation, but at present this standard is not required in Vancouver.

filtration, and using light materials like concrete, white asphalt, and white pavers to reduce surface temperatures. The Vancouver guidelines, on the other hand, fail to specify materials that should be used on surface parking and driveway areas, and have less rigorous vegetation standards. Requirements for surface parking peripheries require trees every 6.1-12.2 metres, while Toronto requires trees every 5-6 metres.

In summary, drawing stronger connections between landscaping requirements for surface parking and goals for mitigating urban heat island effect and stormwater runoff could provide an opportunity for more robust implementation of both the Urban Forest Strategy and the Adaptation Strategy. As noted in the previous discussion about the evidence base for urban greening and UHI reduction, there are a number of factors that influence the cooling effect of street trees, including local microclimates, surface materials, and tree species. A complete assessment of the effectiveness of parking greening for UHI reduction in Vancouver will need to model these influences on temperature outcomes.

4.5 Roofing requirements for solar reflectivity

The City's design and zoning guidelines demonstrate that existing land use policies were drafted under assumptions of a cool and rainy local climate. As such architectural details and landscaping requirements found in these policies are not necessarily suited to drier and hotter weather. With Vancouver's summer climate beginning to change it is critical to look for opportunities to mainstream more heat resilient materials into current building practices.

The Britannia/Woodland RM-4 and RM-4N Guidelines specify that these neighbourhoods should seek to preserve the existing traditional character of the area, which was influenced primarily by northern European architectural traditions featuring sharply pitched roofs and dark wood or asphalt shingles. The RM-4 and RM-4N guidelines thus recommend steeply pitched roof angles with street-facing gables and secondary roofs over entrances and exterior spaces like porches (Vancouver 1992b). Recommended roofing materials include asphalt and wood shingles, which are demonstrated to exacerbate thermal gain in buildings unless specially treated with high reflectivity coatings.

Guidelines for I-2 and C-2C areas likewise do not specify minimum required levels of roof solar reflectivity, which is a significant issue given the prevalence of low-sloping (almost flat) roofs in these districts (Vancouver 2014c). Other jurisdictions like Rosemont-Petit Patrie in Montreal, Chicago, and the State of California have integrated minimum reflectivity requirements into their zoning bylaws or energy codes, and are examples that

Vancouver should look into how to reduce surface temperatures in industrial and commercial areas.

While white roofs are generally demonstrated to be the coolest roofing option, a considerable range of technology exists that improves solar reflectivity in traditional roofing materials and so could be integrated into older neighbourhoods without disrupting traditional architectural styles. Reflective coatings, for example, can be applied to standard shingles to improve reflectance for grey, green, and red tiles. The Cool Roof Rating Council maintains a Rating Program database, which provides an exhaustive list of current products with their manufacturing information, and data on solar reflectance, thermal emittance, and Solar Reflectivity Index score. This database is easily accessible to both building professionals and the public.[6]

[6] The Cool Roof Rating Council was formed in 1998 to evaluate the reflectivity and emittance of roofing materials. It is based in California.

Linking to resources like this could support regulatory efforts to increase reflectivity across Vancouver.

The City of Vancouver is unique in British Columbia for its power to adopt regulations on design and construction of buildings. The Vancouver Building Bylaw is able to go beyond the British Columbia Building Code in setting building standards, and so gives the city greater flexibility in implementing policy priorities related to energy conservation, health, and safety. Recent revisions to the Vancouver Building Code allow for green roofs, but does not set standards for minimum roof reflectivity (Vancouver 2014e). Industrial areas of the City have a large number of buildings with sizeable footprints and low sloping roofs, and also experience a pronounced urban heat island effect. In these areas cool roofing may be the most cost effective approach to reducing heat gain, and as such the City should also explore potential benefits of setting minimum reflectivity standards on low-slope roofs.

4.6 Impermeable surface policies

The study area has significant swaths of impermeable surface coverage, largely owing to surface parking in industrial areas but also due to roadways, laneways, and the Britannia Community Services Complex parking lot. The City's parking bylaw has only limited reference to the use of permeable surface materials (Section 4.9.2 provides an option to use a 10 cm layer of crushed asphalt), which is not a requirement for surface parking lots (Vancouver 2014d). Discussions about the importance of expanding permeable surface are almost entirely restricted to landscaping guidelines, and are primarily framed in regards to stormwater management goals.

As discussed previously, permeable surface area is important not only for supporting evaporative cooling effects, but also for increasing the cooling effect of street trees. Empirical evidence suggests that temperatures beneath street trees are higher than temperatures beneath trees in green areas because of solar radiation reflected up under the tree canopy and then back to the street surface. Mainstreaming UHI adaptation into the City's guidance materials about landscaping and tree planting should thus take into account the impact of impermeable surfaces, and consider opportunities for using alternative surface materials on sidewalks and laneways. Any future updates to parking lot design standards should especially consider this interaction.

4.7 Design guidelines for the public realm

An analysis of several urban design guidelines from the City of Vancouver demonstrated that the City has already integrated urban heat island adaptation into some of its public space recommendations. Vancouver's Water Wise Landscape Guidelines complement the City's Green Building Strategy, and have a stated aim to support urban ecology and sustainability, including the reduction urban heat island effect (Vancouver 2009). The guidelines accompany the Zoning and Development Bylaw and are intended to inform landscaping components of development permit applications. They provide extensive information on strategies to reduce impermeable surface coverage and extend the life of urban infrastructure. Information from these guidelines could be integrated into other bylaws and policies (e.g. the City's Parking Bylaw) to enhance landscaping requirements in regulatory tools.

The City's Urban Agriculture Guidelines for the Public Realm and High-Density Housing for Families with Children Guidelines do not explicitly address urban heat island effect, but do provide opportunities for mainstreaming a heat perspective into residential landscaping guidelines (Vancouver 2009b; Vancouver 1992c). For example, integrating information about permeable surfaces from the Water Wise Landscape Guidelines into the design of outdoor play areas for children could improve reflectivity and evapotranspiration around multifamily buildings. Similarly, partnering with schools to integrate urban agriculture into school yards like the Britannia Secondary School would provide educational opportunities for children and teens while improving access to healthy food and reducing impermeable surface coverage in neighbourhood school yards.

Like the Water Wise Landscape Guidelines, the City's Plaza Design Guidelines include recommendations that are applicable to UHI adaptation (Vancouver 1992a). The guidelines outline strategies for enhancing pedestrian comfort in public spaces, and recommend weather refugia (awnings or canopies) that are flexible enough to provide respite on both rainy and hot days.

They also emphasize the use of permeable paving, particularly decorative pavers, and reflective surfaces. Landscaping recommendations provided in the guidelines are broad, suggesting grassy lawns near sidewalks and maintenance of existing features like trees.

Despite some recommendations being applicable to urban heat island adaptation, there is a persistent assumption underlying these guidelines that Vancouver's climate is principally rainy and cool. As a result, the guidelines all emphasize maximization of sunlight without discussing trade-offs for thermal comfort or mitigation measures for hot days. Climate change will challenge these assumptions and require a rethinking of how we design our public spaces.

4.8 Active transportation considerations

As noted in the previous section detailing local area assets, there is currently a designated bike back running through the study area. Bike paths are significant on two levels for urban heat island reduction: first, in reducing waste heat from vehicles, and second, in providing an urban greening opportunity through the development of greenways.

Investing in active transportation infrastructure is an opportunity to connect efforts to reduce anthropogenic sources of heat in our neighbourhoods with strategic objectives in the City's strategic transportation plan (Transportation 2040) and the Healthy City Strategy to reduce vehicle miles traveled, increase active transportation, and improve local air quality (Vancouver 2012e). As the city continues to expand its network of greenways and bike paths, considering how these goals intersect will open new avenues for addressing some of the underlying drivers of urban heat island effect.

4.9 Summary

This policy analysis indicated that while there are pieces of some existing guidelines that are relevant to urban heat island adaptation, there are also significant gaps in the City's regulatory mechanisms for encouraging heat sensitive building design and landscaping. The following is a summary of the most critical gaps identified:

- There is currently no mechanism for requiring reflective roofing materials on new or renovated buildings;
- Tree planting policies do not specify urban heat island considerations in location selection;
- Zoning districts and accompanying guidelines provide only vague standards for vegetation and tree canopy coverage;
- The updated Tree Protection Bylaw leaves open a loophole in the tree replacement ordinances by not

requiring replacement of removed trees on properties that meet the required minimum number of trees by size of lot;

- Energy retrofit guides do not emphasize opportunities for autonomous UHI adaptation and linkages between individual properties and neighbourhood temperature;
- Recommendations on impermeable surface coverage are limited to public space design guidelines and are not adequately promoted in the City's Parking Bylaw;
- Current green building standards do not require development permit applications to address UHI in the LEED scoring system;
- Landscaping guidelines assume that the dominant experience of inclement weather in Vancouver is rain, and do not adequately consider how to enhance comfort and lower temperatures in public spaces during hot weather days.

5. POLICY RECOMMENDATIONS

This report has focused on gaps in land use policies that should be addressed if the City of Vancouver is to work toward reducing urban heat island effect. The results of this study highlighted a number of opportunities for further analysis and information collection about the spatial distribution of heat vulnerability in Vancouver, as well as mainstreaming of urban heat island adaptation into existing regulations, policies, and guidelines. The following recommendations address the need for better information on the physical qualities of neighbourhoods and modelling of different adaptation options, opportunities for mainstreaming UHI adaptation into regulatory and policy mechanisms, and potential pilot projects that could test adaptation options in neighbourhoods. The recommendations specify whether an action should be regarded as a short, medium, or long-term priority.

Short-term recommendations include further research and analysis necessary to improve our understanding of heat vulnerability and the physical environment across Vancouver, thus enabling comprehensive adaptation planning for urban heat island effect. Other short-term recommendations address "low-hanging fruit," including specific amendments that can be mainstreamed into existing regulations or plans to make them more effective in reducing UHI. Medium-term recommendations discuss opportunities for assessing regulations and guidelines to identify trade-offs between UHI adaptation and other policy priorities, and to pilot adaptation interventions in vulnerable neighbourhoods. Long-term recommendations address ongoing adaptation of Vancouver's urban form to UHI and extreme heat events.

1. **Develop a Heat Vulnerability Index to better capture the social dimensions and spatial distribution of extreme heat health risks in Vancouver (SHORT-TERM).**

One of the goals of this study was to develop a framework for moving forward on adaptation that is rooted in an understanding of the spatial distribution of heat vulnerability in Vancouver. The Social Vulnerability Index developed by Natural Resources Canada was applied as a proxy for heat vulnerability in this study, but the index only roughly captures the characteristics of vulnerability that are understood in the litearture to increase risk for heat-related illness and death. Creating a vulnerability index specific to heat would permit a more robust spatial analysis of neighbourhoods with higher health risks, and more targeted focusing of adaptation efforts. The City should explore options for partnerships to produce such an index.

2. **Expand regional analyses of urban heat island effect to account for nighttime temperatures (SHORT-TERM).**

The current heat map for Metro Vancouver does not account for nighttime urban heat island effect, which is a critical risk factor for heat-related illness and death. The next stages of mapping efforts should examine both daytime and nighttime temperature differences across the region. This, in combination with a Heat Vulnerability Index, would substantially improve the quality of neighbourhood-level vulnerability analysis.

3. **Map impermeable surface coverage and rooftop characteristics across Vancouver (SHORT-TERM).**

The City now has an urban canopy map providing detailed information about tree coverage across the city. Completing similar maps that systematically document impermeable surface coverage and the reflectivity characteristics of rooftops would provide additional information critical to identifying opportunities for engaging in UHI adaptation. The approach taken in this study that relies on visual interpretation of satellite images should only be considered a stopgap until more rigorous analysis can be completed.

4. **Model the relative impacts of different roofing and paving materials on surface temperatures (SHORT-TERM).**

Using data on rooftop area and existing impermeable surfaces, modelling should be done to estimate the relative impact of different interventions on average neighbourhood temperatures. The benefits of different types of roofing materials and pavements can vary significantly depending on climate zone, humidity, wind patterns, and a host of other factors. Identifying materials that are most effective for the Vancouver context therefore requires closer study.

5. **Integrate a public health perspective into decision-making processes for tree planting under the Urban Forest Strategy (SHORT-TERM).**

The Urban Forest Strategy calls for strategic planting of new trees to increase the urban canopy in areas that will experience the greatest improvements. An integral piece of this assessment should be identifying areas with low existing canopy cover, high urban heat island effect, and above average concentrations of populations vulnerable to extreme heat.

6. **Explicitly integrate urban heat island effect into public education materials about green renovation and passive building design (SHORT-TERM).**

Urban heat island effect has significant consequences for personal comfort and energy performance of homes. Many of the technological interventions to lower urban temperatures can be implemented at the household level during regular maintenance procedures or green renovations. Making information materials available through the City more explicit about benefits of home renovations for both household and neighbourhood comfort may help encourage uptake among residents.

7. **Amend the Green Rezoning Policy to require 1 heat island point (SHORT-TERM).**

The Green Building Policy currently requires a minimum achievement of 63 points on the LEED scale for all rezonings, corresponding to the level of LEED Gold. This must include 1 water efficiency point, 1 stormwater point, and a 22 percent reduction in energy costs. The City should consider expanding the minimum points system to include a point in the LEED Heat Island category, which covers high reflectance roofs and pavement materials.

8. **Revise Section 6.2 of the Tree Removal Bylaw to require replacement trees even in cases where sites have more the minimum number of trees required (SHORT-TERM).**

As the Tree Removal Bylaw currently reads, replacement of removed trees is not required if a property already has the minimum required number of trees for its size. Over time this loophole is likely to work against efforts to grow the canopy back to mid-1990s levels and should be revisisted and amended to require a complete 1:1 replacement rate.

9. **Model average neighbourhood temperature at different levels of density in neighbourhoods undergoing Local Area Planning processes to inform discussions about density increases (MEDIUM-TERM).**

As noted at the end of the discussion on study methods, Grandview-Woodland is currently going through a local area planning process. Discussions about densificiation have stirred controversy among some neighbourhood groups and resulted in strong opposition to the initially proposed Local Area Plan. Studying the benefits of different density levels for thermal comfort and environmental performance of buildings may help bring stronger awareness to the benefits of different density levels for the quality of life of existing residents, and help move the planning process in Grandview-Woodland forward.

10. Integrate elements of the Water Wise Guidelines into zoning district guidelines and other guidelines like the High-Density Living for Families with Children Guidelines (MEDIUM-TERM).

Many elements of the Water Wise Guidelines cover recommendations in the empirical literature around shading, evapotranspiration, and permeable surfaces. Integrating these considerations into other guidelines and bylaws that address landscaping is a relatively straight-forward way to update landscaping standards and ensure greater synergry between policies and regulations governing public and private outdoor space.

11. Assess guidelines for landscaping parking areas and consider integrating a minimum threshold for tree canopy coverage in parking lots (MEDIUM-TERM).

Cities like Toronto are leading Vancouver in considering how roadways and parking lots can be redesigned to reduce surface temperatures and improve stormwater management. Vancouver should look to these examples for ideas on how existing policies and regulations can be updated to reflect projected impacts of climate change on urban temperatures. Industrial areas of the city have low canopy coverage and extensive surface parking, indicating that the City should consider options for encouraging tree planting in these zones, particularly where they border residential areas.

12. Examine trade-offs between access to sunshine requirements in design guidelines and heat risks during hot summer months (MEDIUM-TERM).

Vancouver's urban design regulations and public space guidelines aim to maximize sunlight exposure in response to the city's generally cool and rainy climate. Going forward the City may need to re-evaluate this assumption in its policy documents as average temperatures warm and heat waves become more frequent. Guidelines should take into account the multiple benefits of urban heat island reduction strategies like permeable surfaces for other policy priorities and encourage symbiotic weather protection strategies that offer dual protection from rain and direct sunshine.

13. Integrate minimum reflectivity requirements into the Vancouver Building Bylaw, particularly for low-slope industrial and commercial buildings (MEDIUM-TERM).

A number of municipalities have taken steps to establish minimum reflectivity standards for new developments and replacement roofs, especially on low-sloping commercial and industrial buildings. The City of Vancouver should carefully examine how this approach can be applied to industrial and commercial areas with concentrations of flat roof buildings, as well as to residential buildings with steep sloping roofs.

14. Pilot laneway greening in Grandview-Woodland to reduce neighbourhood heat island effect and enhance natural stormwater management (MEDIUM-TERM).

Vancouver has a fairly extensive network of laneways not unlike Chicago, which implemented an ambitious pilot program to replace impermeable surfaces in laneways with permeable materials that enhance stormwater drainage and reduce heat absorption. Vancouver should consider implementing a similar pilot program in partnership with community groups under the Adaptation Strategy. Such a program could link urban heat island mitigation with stormwater management, urban agriculture programs, and community building for social resilience.

15. Pilot building retrofits on City-owned non-market housing sites in Grandview-Woodland (MEDIUM-TERM).

The City-owned residential buildings in Grandview-Woodland provide a key opportunity to explore retrofitting options that improve thermal comfort in wood-frame multifamily buildings. This could include installation of awnings, application of alternative roofing materials, and landscaping that integrates City goals on shade enhancement, urban agriculture, and stormwater management.

16. Identify potential funding sources or incentives programs for building retrofits (MEDIUM-TERM).

Over the long-term energy retrofits like those encouraged to reduce heat gain of detached homes and multifamily buildings tend to pay off in reduced heating and cooling costs, but it can be challenging to encourage owners to make these changes without additional support to manage up-front costs. The City should examine the impact of existing grant programs and incentives offered by the City and other government agencies to identify effective programs that could be expanded to cover additional retrofits for UHI or replicated in new programs.

17. Work with industry partners to identify cost-effective opportunities to integrate use of reflective and permeable surface materials into new developments (MEDIUM-TERM).

Changes to the building code, zoning byaw, and design standards should be explored in partnership with industry experts and developers to identify possible implementation challenges and opportunities. This can help smooth implementation and enhance compliance with updated guidelines.

18. Reconsider zoning district design guidelines with particular focus on landscaping, roofing, and parking area design (LONG-TERM).

District guidelines provide information on how new buildings can be integrated into the fabric of existing neighbourhoods with regards to architectural details, landscaping, orientation, and parking. Adaptation planning efforts should consider opportunities to revisit these guidelines and identify opportunities to integrate more specific requirements for vegetation coverage, alternative roofing materials, and permeable surfaces that maintain neighbourhood character but deliver improved thermal performance.

19. Continue with efforts to promote active transportation and expand network of bike paths and greenways into neighbourhoods with elevated heat profiles (LONG-TERM).

Shifting transportation modes from motorized vehicles to walking and cycling offers a number of benefits for community energy conservation, health, air quality, and also waste heat reduction. Greenway networks can increase shading and improve the quality of outdoor spaces. Linking adaptation priorities with active transportation goals is an excellent example of finding co-benefits in seemingly disparate policy areas that can aid the city in more effective policy implementation.

6. CONCLUSION

This study set out to create a framework for assessing adaptation options to extreme heat risk in Vancouver that is informed by the spatial distribution of social vulnerability in the city. The analysis of a sample neighbourhood in Grandview-Woodland pointed to the presence of a number of architectural and public space qualities that are known to increase urban heat island effect. With ongoing neighourhood planning efforts in Grandview-Woodland it is important that this discussion about the relationship between climate resilience and urban form have a place in debates about densification and preservation of neighbourhood character.

This analysis also highighted critical information gaps that need to be addressed in order to form a more complete picture of neighbourhood-level heat vulnerability. As noted in the final recommendations, the City should look to partnerships with researchers and industry professionals to more systematically analyze vulnerability and adaptatation opportunities across neighbourhoods.

While this study focuses on just one neighbourhood, it is likely that similar challenges exist across the city as many of Vancouver's neighbourhoods developed with a similar style. Strathcona in particular is likely to face similar challenges for reducing urban heat island effect, and also has a large concentration of population groups that are considered to be at high risk for adverse health outcomes during extreme heat events. As such this kind of study should be expanded to examine other neighbourhoods in Vancouver.

Climate change presents unique challenges to land use planning and the urban design tradition in Vancouver, and requires that we engage in a nuanced analysis of existing policies and regulations to identify where maladaptation to urban heat island effect is being encouraged. Rising global average temperatures and more frequent and intense extreme weather events will challenge the assumptions underlying Vancouver's zoning bylaw and design guidelines about what constitutes normal weather conditions. As such we must look for opportunities to engage creatively in climate change adaptation and reach those most vulnerable to harm.

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Appendix A: Metro Vancouver Social Vulnerability Index Factors

Table 2: Metro Vancouver Social Vulnerability Index Factors

ID	Factor	Description	Variability	Cumulative	Rank
D1	Family Structure	% lone female parent households % lone parent households	6.824%	6.824%	3
D2	Elderly Living Alone (Age)	% population 65 years and older % population not participating in labour force % female population % population living alone % population with no post-secondary degree	6.905%	13.729%	2
D3	Education	% employees working in industrial sector % population with no high school diploma % population with registered apprenticeship or trade certificate	6.407%	20.125%	4
D4	Low Income Families	% households earning <$80,000 % low-income families Average household income % owner-occupied households spending >30% on shelter % population without access to a vehicle % visible minority % recent immigrants (within last 5 years)	8.887%	29.022%	1
D5	Mobility	% population that has moved within the last year % population that has moved within the last 5 years % population that has migrated from within BC % population that has migrated from elsewhere in Canada	5.802%	34.825%	5
D6	Language	% population without knowledge of official language % population English as a second language	4.234%	39.059%	6
D7	Reliance on Service Industry	% employed in service industries	4.027%	43.086%	8
D8	Employment	% low-income families % population not in health care occupations % civil labor force unemployed	3.595%	46..681%	10
D9	Cost of Home Ownership	Average payments for owner-occupied housing units % owner-occupied households spending >30% on shelter	3.809%	50.490%	9
D10	First Nation	% low-income individuals	3.791%	54.282%	11

		% aboriginal community			
D11	Reliance on Resource Extraction Industry	% employed in primary resource extraction industries % civil labor force unemployed	3.513%	57.794%	12
D12	Children	% population under 5 years of age % housing units in need of major repairs % families spending > 30 hours of unpaid childcare	4.591%	62.386%	7

Appendix B: Policies and Bylaws

Table 1: Municipal Policies Addressing Urban Heat Island Effect

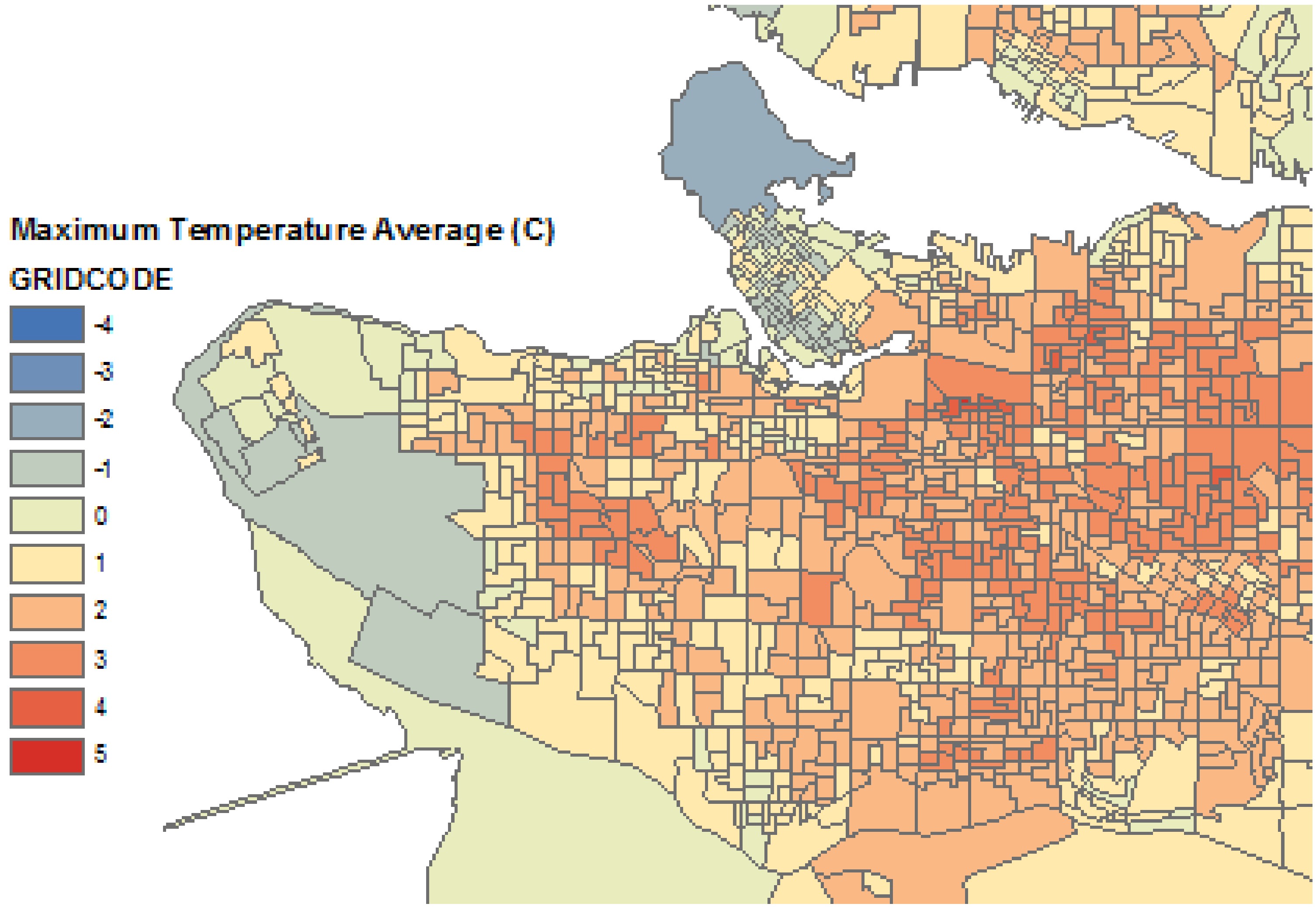
I-2 District Schedule	**Last Updated 2014**
District in Vancouver's Zoning and Development Bylaw governing light industrial uses.	
C-2C District Schedule	**Last Updated 2014**
District in Vancouver's Zoning and Development Bylaw governing commercial uses in neighbourhood centres.	
City of Vancouver Parking Bylaw	**Last Updated 2014**
Bylaw governing off-street car and bicycle parking space.	
Protection of Trees Bylaw	**Last Updated 2014**
Bylaw government removal of trees on private property.	
2015 Building Bylaw update for Vancouver	**2014**
Most recent updates to the City of Vancouver's Building Bylaw, which is enabled under the Vancouver Charter's powers of building design and construction.	
Urban Forest Strategy	**2014**
Strategic plan that assess the current state of Vancouver's tree canopy and its health over time, and outlines priorities for maintaining and growing current tree coverage.	
RM4 and RM-4N District Schedule	**Last Updated 2013**
District in Vancouver's Zoning and Development Bylaw governing medium density residential development.	
Rezoning Policy for Sustainable Large Developments	**Last Updated 2013**
Council policy that applies to new developments over 45,000 m^2 and requiring particularly consideration of energy conservation, sustainable transportation, rainwater and solid waste management, and housing affordability.	
Green home renovation guides	**2012**
Remodeling information for property owners addressing salvage and reuse, energy audits, roofing, landscaping, lighting, painting, bathrooms, and home appliances.	
Transportation 2040	**2012**
Strategic transportation plan for the City of Vancouver establishing goals for mode shift away from private cars to public transit, cycling, and walking.	
Green Buildings Policy for Rezonings	**Last Updated 2010**
Council policy requiring a minimum level of LEED Gold on rezoning applications.	
C-2B, C-2C and C-2C1 Guidelines	**Last Updated 2009**
Accompanying guidelines to zoning districts C-2B, C-2C, and C-2C1 for development permit applications.	
Urban Agriculture Guidelines for the Private Realm	**2009**
Voluntary guidance document for urban agriculture projects for residential developments and rezoning applications.	
Water Wise Landscape Guidelines	**2009**

Voluntary guidance document on water conservation and landscaping for residential developments and rezoning applications.	
City of Vancouver Passive Design Toolkit	**2009**
Information materials for the development industry and planning community about low-energy building design.	
Zoning Bylaw Schedule C – Streets Requiring Landscaped Setbacks	**Last Updated 2006**
Schedule to Vancouver's Zoning and Development Bylaw specifying setbacks for particular streets across districts.	
Non-Industrial Uses (I-2 and M-2) Policies and Guidelines	**Last Updated 2006**
Specifications on non-industrial conditional uses for I-2 and M-2 districts in the Zoning and Development Bylaw.	
Britannia/Woodland RM-4 and RM-4N Guidelines	**Last Updated 1992**
General design and landscaping guidelines for RM-4 and RM-4N districts in the Zoning and Development Bylaw.	
Street Tree Bylaw	**Updated 1992**
Bylaw regulating maintenance and management of trees on City-owned streets.	
Commercial Drive "East Lane" CD-1 Guidelines	**Last Updated 1989**
Landscaping and parking guidelines for Bylaw No 6479's CD-1 district.	
High-Density Housing for Families with Children Guidelines	**1992**
Guidelines accompanying the Zoning and Development Bylaw summarizing site, building, and unit design standards for multifamily buildings with over 75 units.	
Plaza Design Guidelines	**1992**
Guidelines accompanying districts DD, DWD, BCPED, FCCDD, FC-1, DEOD, C-2 AN DC-3A in the Zoning and Development Bylaw on landscaping and amenities in public spaces.	

Appendix C: City of Vancouver Weather Stations

Source: Ho et al, 2014

Appendix D: City of Vancouver Urban Heat Island Map at the Dissemination Area Level



Source: Ho et al, 2014

Appendix E: Study Area Photos

Non-Market Housing

BC Housing

Charles Square Co-Op

BC Housing

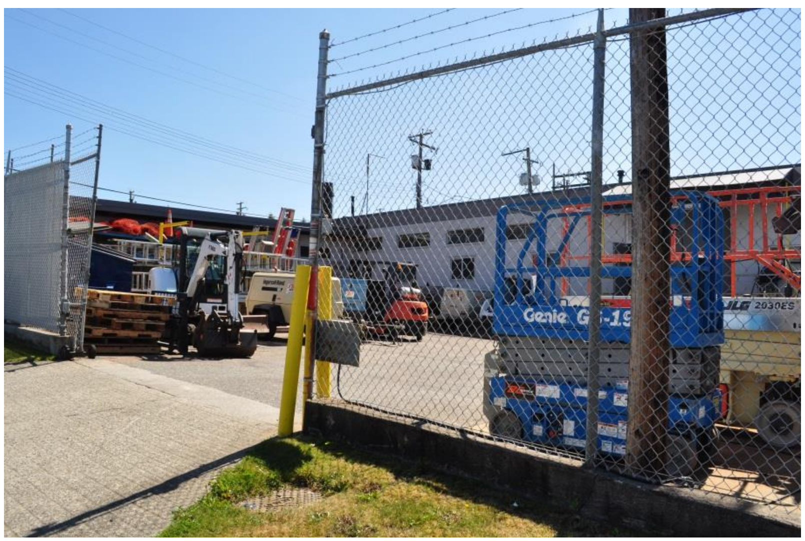
Vancouver Native Housing Society

Heritage Homes: Britannia Style

Multifamily Homes: Britannia Style

Multifamily Homes: Flat Roof Style

Industrial Uses



Institutional Uses

Britannia Community Complex Greenway

Britannia Secondary School Yard

Britannia Pre-Teen Centre

Britannia Community Complex Sports Field

Steeply-sloping Rooftops

Laneways

Street Trees

Park Space

Grandview Park

Mosaic Creek Park

Woodland Drive Bike Path

Water Features in Private Gardens