CLIMATE CHANGE RESILIENCE FOR BUILDINGS

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BC HOUSING RESEARCH CENTRE

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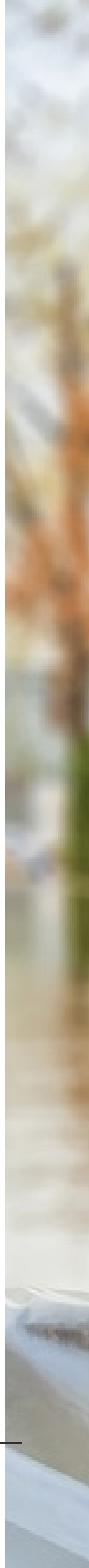


Contents

INTRODUCTION

WHY LOW CARBON RESILIENCE?

Climate change means that buildings need to change.

In recent years, unprecedented patterns of fire, drought, storms, and flooding have been observed around the world. The best available science tells us that this pattern will intensify and that its consequences depend greatly on human choices. According to the Council of Canadian Academies, the top six areas of climate change risk facing Canada are[1]:

- Physical infrastructure
- Coastal communities
- Northern communities
- Human health and wellness
- Ecosystems, and
- Fisheries

Decisions that we make about designing, constructing, and managing buildings can help minimize these risks. Within a built infrastructure context, our choices have a direct impact on two urgent needs:

1. *Climate change mitigation*, or the rapid reduction of greenhouse gas emissions to minimize the worsening of future climate loads, and

1. *Climate change adaptation*, or the process of adjustment of our built and natural environments to withstand future risks posed by climate change.

The confluence of mitigation and adaptation can be seen in the practice of *low carbon resilience (LCR)*, which is the deliberate design and use of techniques, methods, policies, and technologies to both reduce greenhouse gas emissions and adapt our infrastructure and society to future climate loads[2]. LCR is the most cost-effective way to prepare for the risks of a climate changed future.

In order to achieve our commitment to pursue the Paris Agreement target of a 1.5°C world by 2100 and avoid the worst effects of climate change, significant and timely action is needed. For example, a 2018 study found that building emissions will need to be reduced by 80-90% by 2050[3]. Both new

1 Council of Canadian Academies. 2019. *Canada's Top Climate Change Risks*. Ottawa, ON: Expert Panel on Climate Change Risks and Adaptation Potential, Council of Canadian Academies.

2 Harford, D. and C. Raftis. 2018. *Low Carbon Resilience: Best Practices for Professionals, Final Report*. Victoria, BC: Simon Fraser University Adaptation to Climate Change Team.

3 Kuramochi, T. et al. 2018. "Ten Key Short-Term Sectoral Benchmarks to Limit Warming to 1.5°C." *Climate Policy*, 18 (3). As cited in IPCC. 2018. *Global Warming of 1.5°C: An IPCC Special Report*. Masson-Delmotte et al. (eds.). Geneva, Switzerland: IPCC, p. 331.

construction and retrofits present important opportunities for change. There are myriad reasons to act, from environmental and humanitarian reasons, to the health and safety of building occupants, to the preservation of invested capital and assets, to reduction in operating and maintenance costs.

Regardless of your motivations, the time to act is now. The climate is already changing and significantly different than in the past. The opportunities to implement low carbon resilience in our buildings in a cost-effective manner are fleeting and only arise at certain points throughout a building's lifecycle. Both new buildings and existing building retrofits require careful climate resilience planning.

This primer will provide the information you need to get started.

WHAT THIS PRIMER COVERS

Climate change is an all-encompassing topic. To ensure local relevance and practical guidance, this primer focuses on the following:

- **Geography:** the area considered is limited to the main population centres of the Lower Mainland (the Greater Vancouver Area) and Vancouver Island (the Capital Regional District up to Nanaimo).
- **Building Types:** the focus is on residential buildings, both low and high-rise, from single family to multi-unit residential buildings.
- **Policy:** a primary purpose of adding climate resilience is to permit adoption of *shelter-in-place* policies, which are being adopted in various jurisdictions.
- **Climate Change Projections:** preparing for a global temperature range of 3.3ºC to 5.9ºC is the safest and most appropriate approach for long-lived (i.e., 100+ year) infrastructure. Representative concentration pathway (RCP) 8.5, representing a worst-case situation, does a good job of describing this temperature range and is assumed for all climate projections. See further discussion under "Risks and Hazards: Projected BC Climate", starting p. 11.
- **Timeline:** based on the typical building's design service life of 50+ years (often extending beyond 75-100 years), a range of time frames are considered, including the short-term future (2050) and long-term future (2080+).
- **LCR Measures:** low carbon resilience measures for built infrastructure are emphasised—that is, measures that provide both GHG mitigation benefits and increased adaptation resilience. Note that adaptation also involves non-material preparation (e.g. community planning, emergency policies, etc.), but this primer is focused primarily on material components of built infrastructure.

Seismic upgrades are omitted from the scope of this primer. However, the reader should be aware that there are appreciable cost-savings from addressing LCR measures as part of seismic upgrades, and vice versa.

WHAT IT WILL HELP YOU DO

- Understand the **causes of climate change** and **future projections** within the context of the built environment.
- Recognize **climate hazards** for buildings in specific locations and prioritize vulnerabilities.
- Understand **the LCR approach** and its application to buildings.
- Access **tools and processes** to start planning LCR for new and existing buildings

BACKGROUND

CLIMATE CHANGE

What is driving climate change?

People often confuse weather with climate. Weather represents the complex, instantaneous interaction of temperature, humidity, atmospheric pressure, wind, and precipitation at a specific location and at a specific time. Climate, on the other hand, defines the expected range of weather patterns that are likely to occur at a given location over a given period of time[4].

We can think of climate in terms of seasonal averages: we can't predict the weather on December 20, five years into the future, but intuitively know the odds are good we will need an umbrella if we're in Victoria and a winter jacket if we're in Fort Nelson.

The term *climate change* describes changes in the state of the climate that persist for extended periods (e.g., decades or more)[5]. Such changes can occur for a number of reasons. In this primer, we will typically use "climate change" to refer to the effects caused by *global warming*, i.e. human-driven increases in average global surface temperatures.

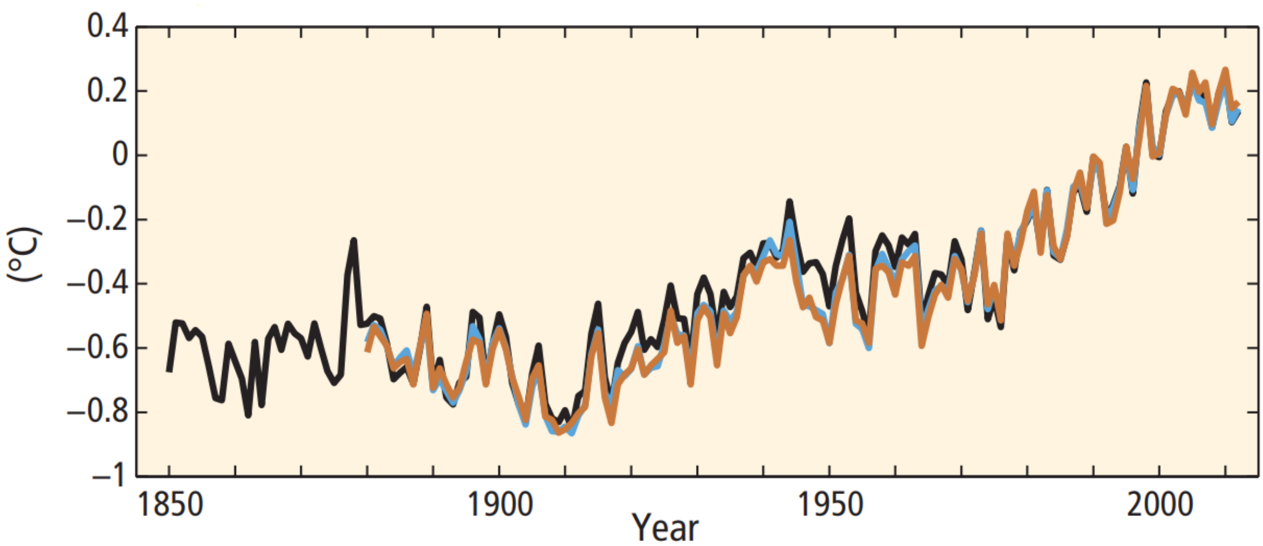


Image showing globally averaged combined land and ocean surface temperature anomaly, from IPCC (2014), p. 3. Global average temperatures vacillate over the short term from natural processes but have been steadily trending upwards over the last 130 years since the industrial revolution. Colors indicate different data sets.

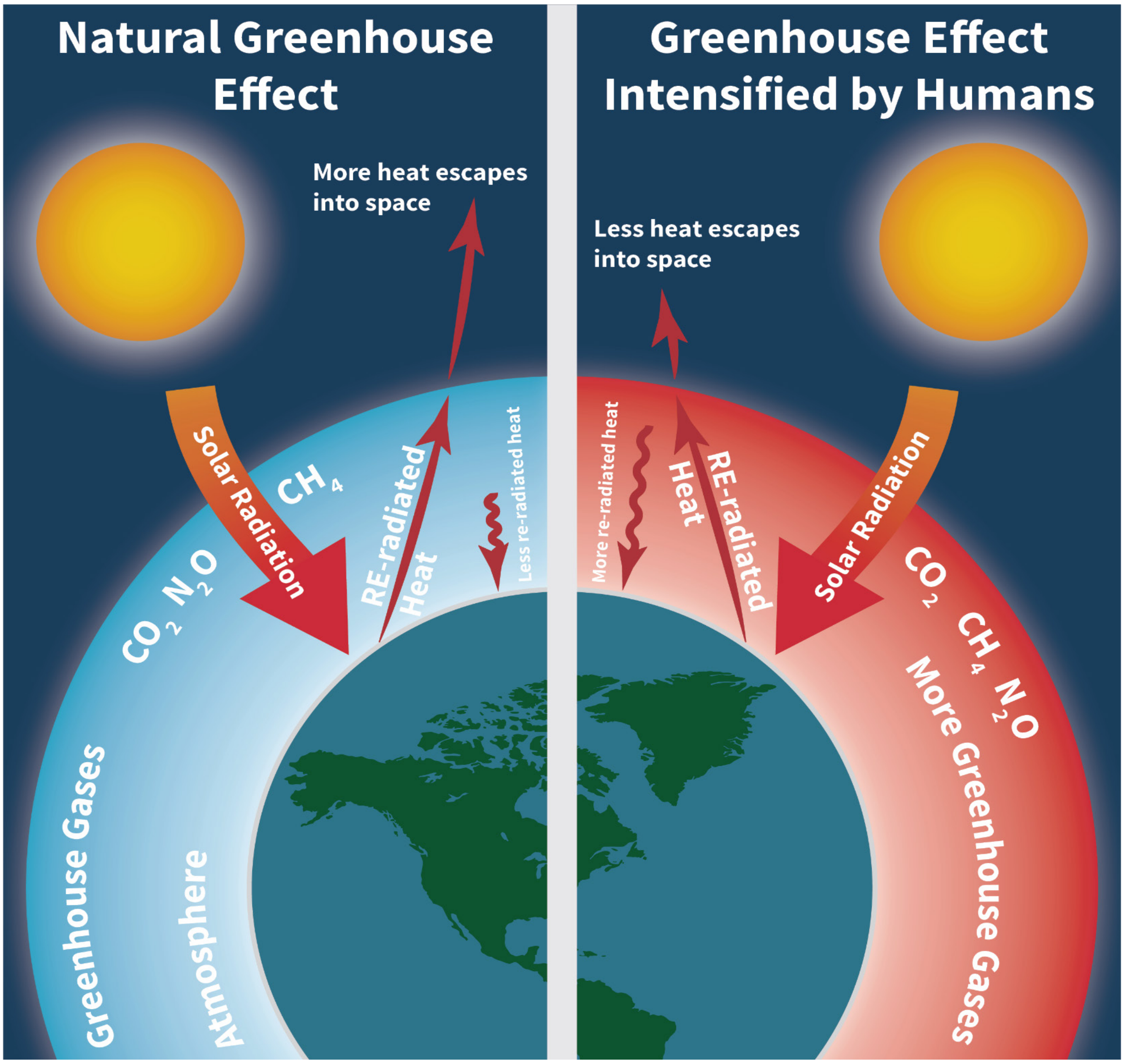
4 Research on climate often averages data over a standard period of 30 years. See IPCC. 2014. *Climate Change 2014: Synthesis Report*. Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.). Geneva, Switzerland: IPCC, p. 119.

5 IPCC. 2014. *Climate Change 2014: Synthesis Report*, p.120.

CLIMATE CHANGE CAUSES

Based on the best available science, *anthropogenic* (human-caused) activities are the dominant cause of the climate warming observed since the mid-20th century[6]. The primary anthropogenic contributor to global warming and climate change is increasing greenhouse gas (GHG) emissions.

The sun produces a wide spectrum of radiation, from very short wavelengths (ultraviolet) to very long wavelengths (infrared). GHGs permit short-wave radiation (visible light) to pass through, which warms up the surface of the Earth. GHGs, however, are opaque to long-wave infrared radiation, so it becomes trapped within



Greenhouse gases permit solar radiation to pass through, but trap heat that would otherwise radiate into space. Image based on Melillo, J., T. Richmond, and G. Yohe (2014), p. 748.

6 IPCC. 2014. *Climate Change 2014: Synthesis Report*, p. 4

the atmosphere. When this system is functioning normally, some heat escapes back into space and some is blocked by GHGs, keeping the earth at a livable temperature. When GHGs in the atmosphere are increased, more heat is trapped inside the atmosphere, causing an increase in average global temperatures.

The atmospheric lifetime of CO_2 can range from 50 to 200 years[7] . As a result, we are already locked into warming from GHG emissions released decades ago; our children and grandchildren will be faced with related climate risks and hazards and will need effective strategies to adapt. At the same time, the level of risks and hazards can potentially be reduced if current and future emissions are reduced.

Because climate change involves many different natural systems, its impacts are wide-ranging. In Canada, for example, more extreme hot temperatures will add to drought and wildfire risks, sea level rise will add to coastal flooding risk, and ocean warming, loss of oxygen, and acidification will create additional risk for marine ecosystems[8] . Understanding how impacts are predicted provides a framework for understanding why both adaptation and mitigation are critical.

CLIMATE PROJECTIONS

Projecting future climates requires the use of powerful computers to simulate the physical processes of the planet. The first climate models were published in 1967 and have been in constant development since. We can compare the projections of those early models with the measured outputs of the following 50+ years to verify their accuracy. These Global Climate Models (GCMs) can also be validated by simulating historical climates and comparing their output with measured data from those times (e.g. simulating from 1950 to 2000, then comparing the simulation results with the actual records). Climate change models have been in use for over 60 years and have been shown to be very accurate[9].

Climate models have gradually become more accurate and will continue to improve over time, as more data becomes available and as the processing power of modern computers increases. Numerical models of physics are also routinely used to design cars, airplanes, and skyscrapers.

The output from these climate models is a set of projected average values for climate variables, like barometric pressure, air temperature, humidity, wind speed, and precipitation, over a given area and time period. These variables are all connected to the weather we experience (for example, high humidity on a cool day might be foggy, whereas high humidity with warm temperatures and low wind speeds will be hot and muggy). However, they do not to predict *specific weather events*. Climate models project average climatic conditions and are not designed or intended to predict specific events.

7 US Environmental Protection Agency. 2005. *Inventory of US Greenhouse Gas Emissions and Sinks 1990-2003*. Washington, DC: US EPA, p. 3.

8 Bush, E. and D.S. Lemmen, eds. 2019. *Canada's Changing Climate Report.* Ottawa, ON: Government of Canada, pp. 5-6.

9 For example, see Hausfather, Z. et al. 2020. "Evaluating the Performance of Past Climate Model Projections." *Geophysical Research Letters,* 47. Note that early modellers often underestimated the level of CO_2 that humans would add to the atmosphere over time.

CONSIDERING MULTIPLE FUTURES

One of the biggest challenges faced by climate modellers is predicting human activity and associated future GHG emissions. To help with this uncertainty, the Intergovernmental Panel on Climate Change (IPCC) has characterized multiple possible scenarios. These scenarios, called *Shared Socioeconomic Pathways* (SSPs), represent how global society, demographics, and economics might change over the next century. Each SSP scenario has multiple associated *Representative Concentration Pathways* (RCPs), which quantify the global warming effect on the basis of *radiative forcing* (i.e., the amount of excess solar energy that is absorbed by the atmosphere) at the year 2100.

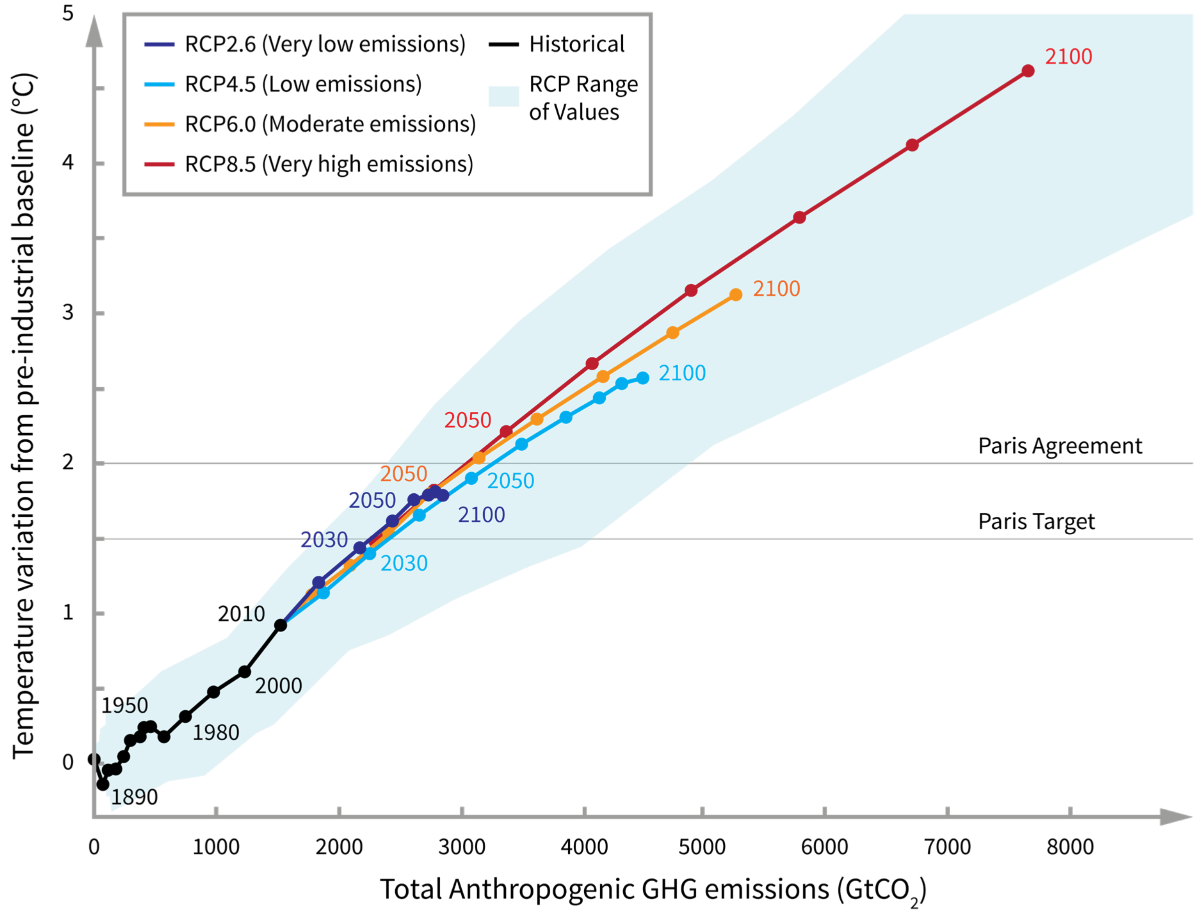
The SSP scenario represents how readily humanity can mitigate and adapt to climate change; the RCP value governs the modelled severity of the climate change impact. So, a best-case scenario would be SSP1 with RCP 2.6, whereas the worst case is SSP 3 to SSP 5 with RCP 8.5. There are five SSPs[10] and four main RCPs. Each SSP can have multiple RCP values. However, presently our primary concern is how the planet responds to our current situation, so the focus of this primer is on the different RCP scenarios.

The signatories of the Paris Agreement, the international accord within the United Nations Framework Convention on Climate Change, which includes Canada, have pledged to keep global average temperatures to well below 2°C above preindustrial levels, with an aspirational target to limit the temperature increase to 1.5 °C above preindustrial levels. Only RCP 2.6 is likely to meet the aspirational target, while the best-case scenarios in RCP 4.5 could meet the less strict pledge. These scenarios can only be achieved with a concerted effort to immediately reduce GHG emissions. Provincially, the CleanBC plan is aimed at reducing climate pollution while greening the economy; better buildings play a crucial role in this plan. The legislated climate targets aim to reduce GHG emissions by 40% by the year 2030.

10 Riahi, K., et al. 2017. "The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview." *Global Environmental Change*, 42, 153-168.

Table 1. IPCC Scenarios for Possible Change

Shared Socioeconomic Pathway	Representative Concentration Pathway
• **SSP1 – Sustainability** – Taking the Green Road • **SSP2 –Middle of the Road** • **SSP3 – Regional Rivalry** – A Rocky Road • **SSP4 – Inequality** – A Divided Road • **SSP5 – Fossil-Fueled Development** – Taking the Highway	• **RCP 8.5** – Very high emissions scenario • **RCP 6** – Moderate emissions scenario • **RCP 4.5** – Low emissions scenario • **RCP 2.6** – Very low emissions scenarios



The four Representative Concentration Pathways (RCPs) described in the IPCC's Fifth Assessment Report demonstrate how an increase in cumulative CO2 emissions are associated with global temperature increases. The main difference between the RCPs is how much global warming is expected by the year 2100. The only way to return to preindustrial levels (i.e., 0°C temperature increase) is by *actively removing the excess CO_2 in our atmosphere*. **Data points based on IPCC (2014), p. 55-74.**

KEY POINTS

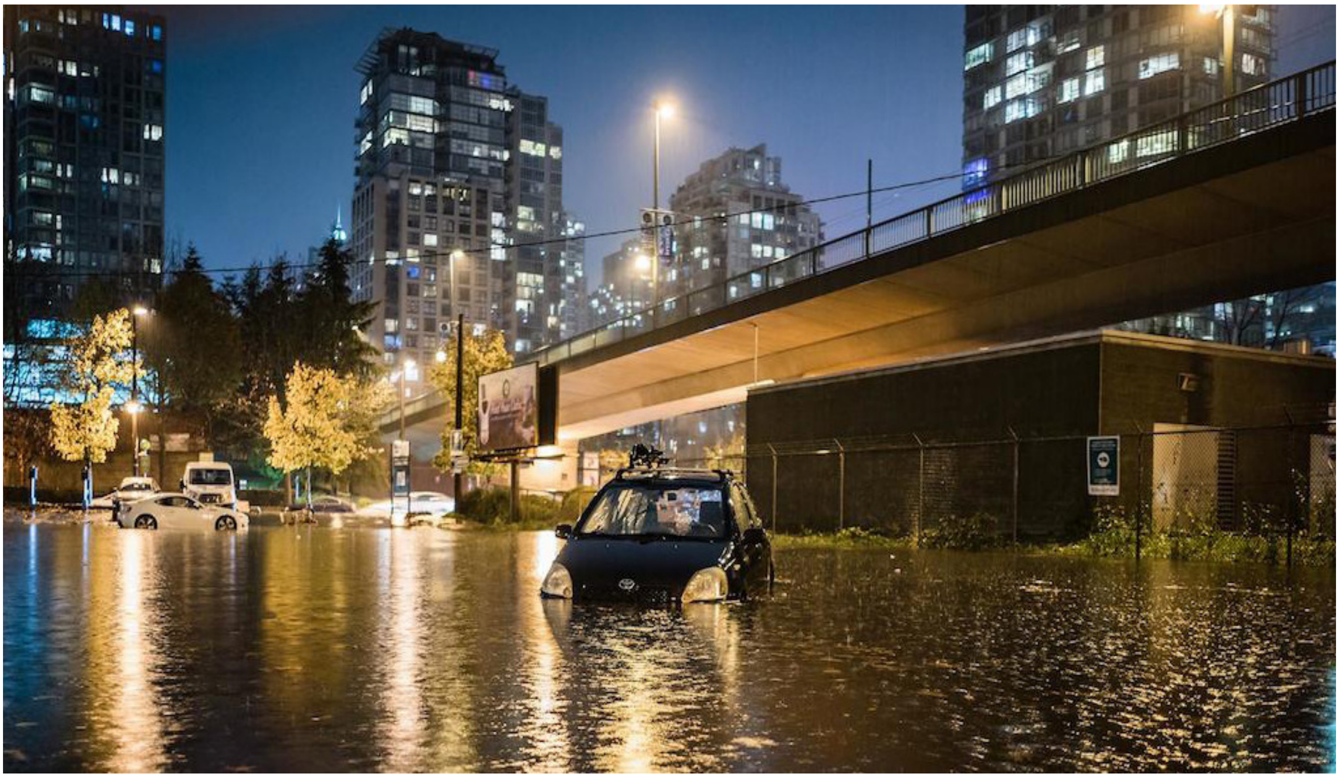
- Human-caused greenhouse gas emissions are the driving factor in current and projected climate change.
- Applying an LRC lens to the choices we make now for building design and construction can significantly mitigate, or limit, the severity of climate change.
- However, even stringent mitigation will not eliminate the impacts of past activity. Some level of adaptation to the changing climate is already needed and will continue to be required even if we take significant collective action to reduce greenhouse gas emissions at a global scale.

RISKS AND HAZARDS

PROJECTED BC CLIMATE

What do we know about the local context to support action on climate change mitigation and adaptation?

As a vast province with widely varying climates, from coastal rainforests to deserts, BC will experience a range of climate change effects. This primer focuses on the major metropolitan areas of British Columbia, the Greater Vancouver Area and the Capital Regional District, using climate projections developed by the Pacific Impact Climate Consortium at the University of Victoria. The worst-case climate scenario (RCP 8.5), which describes a temperature range between 3.3 to 5.9ºC[11], will be used as a benchmark for adaptive design; buildings designed to this standard can be expected to remain functional at year 2100 conditions and would have an extended functional service life beyond 2100 if a better-than-worst-case scenario occurs[12].



11 A global range of 3.3 to 5.9ºC is well-described by RCP 8.5 in the CMIP5 simulation ensemble produced by the Coupled Model Intercomparison Project, a collaborative framework for climate change projections based on coupled ocean-atmospheric global climate models that involved 33 modelling groups in 16 countries. CMIP5 operates on the RCP framework, whereas CMIP6, the latest iteration as of this publication, uses the Shared Socioeconomic Pathways (SSP) framework (see discussion of SSPs on page 9).

12 Much climate research focuses on the period up to 2080 or 2100, and for the building industry this is a relevant timeframe given the expected service life of many building components. However, it should be noted that global average temperatures will continue to rise after 2100 under all RCPs; rapid, significant mitigation efforts can reduce climate impacts but cannot at this point eliminate them. See IPCC (2014) Chapter 12.

HAZARDS: SHOCKS AND STRESSES

The effects of climate change are experienced in two ways: long-term stresses and acute shocks. *Stresses* are slowly changing baseline values that are difficult to notice on a daily, or even yearly, basis. For example, a stress is the gradual increase in cooling degree days, resulting in greater cooling costs year over year. *Shocks,* on the other hand, are experienced directly, as intense weather events. A shock might be a summer heat wave with a week of daytime high temperatures exceeding 32ºC. Both climate stresses and intensified weather shocks create potential hazards.

PROJECTED HAZARDS FOR BC

A range of stresses and intensified weather effects are anticipated for the BC metropolitan regions. The Preliminary Strategic Climate Risk Assessment for British Columbia[13] has identified 15 risk events and evaluated their likelihood of occurring and their potential consequences. The likelihood of each hazard's occurrence was derived from the best guesses of a committee of experts informed by future projections. That analysis suggests that the hazards in Table 2 are likely to occur within the two metropolitan areas of British Columbia. The *exposure* to each of these hazards is context dependent and requires assessment of a building's micro-climate, location, design, and intended use throughout its life cycle.

These hazards are intended to be a starting point for further analysis of the climate vulnerability of your building. The next section looks in more detail at the connections between buildings and climate change.

KEY POINTS

- A hazard is an event, process, or phenomenon that could cause harm, whereas risk is the chance of the event causing harm.
- A range of hazards with different degrees of risk are anticipated across BC.
- Key hazards related to buildings in both the Greater Vancouver Area and the Capital Regional District are wildfire, heat waves, water shortage (drought), extreme storms, and flooding.

13 Ministry of Environment and Climate Change. 2019. *Preliminary Strategic Climate Risk Assessment for British Columbia*. Victoria, BC: Government of British Columbia.

Table 2. Summary of Projected Hazards for Two Regions in BC

Wildfire

An unplanned or unwanted natural or human-caused fire in live or dead combustible vegetation.

Wildfire smoke is a very likely hazard in the Capital Regional District and the Greater Vancouver Area. Interface fires are unlikely except for those regions in Wildland Urban Interface zones.

By 2050, there will likely be a 2-4 times increase in the number of wildfires relative to 1970’s baseline.

Direct Effects	Indirect Effects
• Interface fire • Respiratory distress from air pollution • Disrupted local transportation systems	• Water quality impacts • Power outages (transmission line damage)

Heat Wave

A period of time with extreme daytime high temperatures exceeding typical design temperatures (e.g. 3 days with daytimes highs exceeding 32ºC).

Heatwaves are very likely to occur in the Capital Regional District and the Greater Vancouver Area, particularly in areas affected by urban heat island effects.

By 2050, a building will likely experience heatwaves 8-26 times over its lifespan.

Direct Effects	Indirect Effects
• Overheating, leading to comfort and health impacts to occupants • Increased stress on electrical and mechanical systems	• Power outage from grid capacity

Drought

High summer temperatures and low precipitation creating seasonal water shortages affecting human and ecosystem needs (e.g. Level 4 Drought rating).

Seasonal droughts are very likely to occur in the Capital Regional District and are likely in the Greater Vancouver Area.

By 2050, a building could experience seasonal droughts over 40 times over its lifespan.

Direct Effects	Indirect Effects
• Water shortages	• Increased fire hazards

Table 2. Summary of Projected Hazards for Two Regions in BC (CONT'D)

Extreme Storms

The combination of extreme strong winds and/or precipitation.

Extreme storms are projected to be very likely in the Capital Regional District and the Greater Vancouver Area.

By 2050, the intensity of storms will likely increase by about 15% and the frequency by about 50% from baseline.

Direct Effects	Indirect Effects
• Extreme winds and wind damage • Heavy rain, hail, or snow • Freezing rain	• Power outages from downed power lines • Water quality impacts • Pluvial flooding

Flooding

The excessive accumulation of rainwater and/or snowmelt in and around ground-related structures.

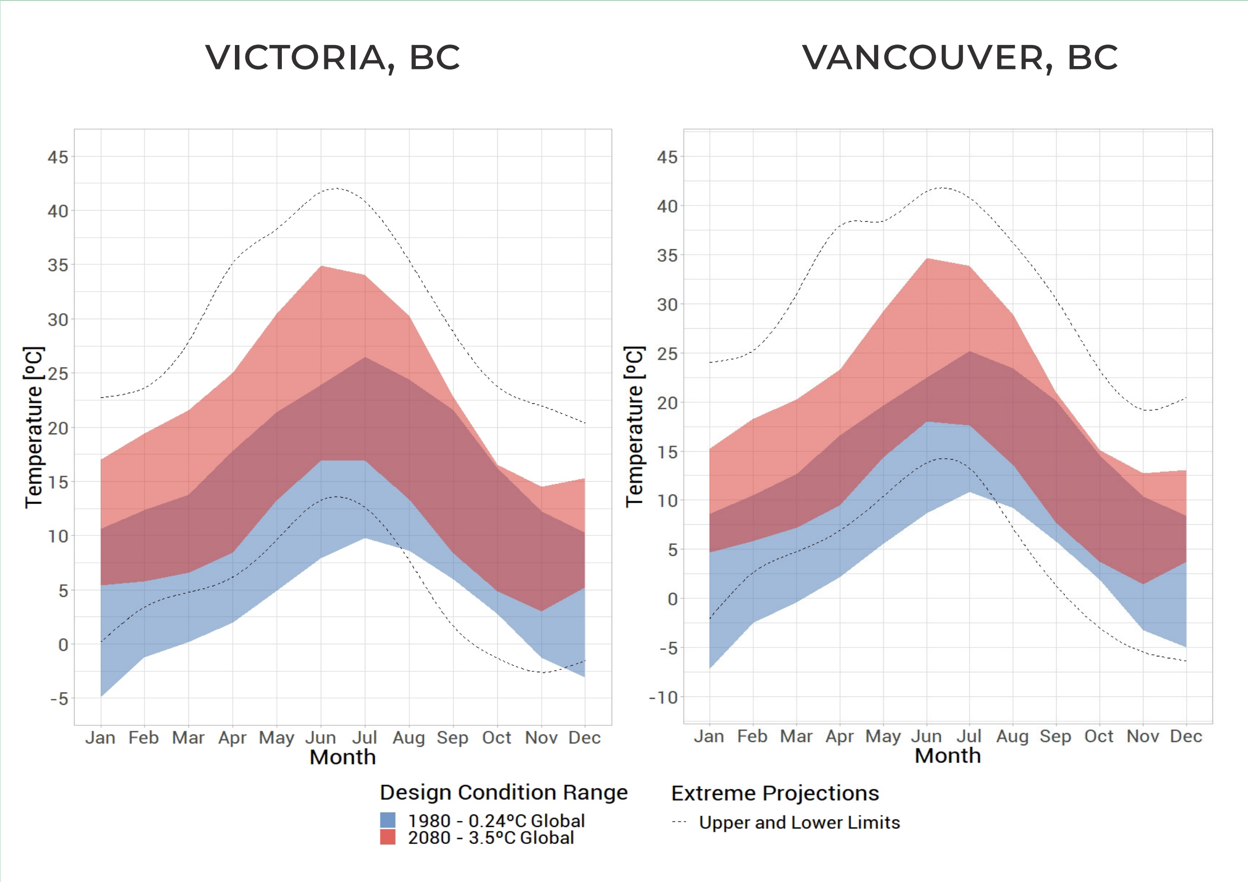
Flooding is highly dependent on local topography, but in the Capital Regional District and Greater Vancouver Area, pluvial flooding is likely to occur. Riverine and Coastal flooding are also likely but are dependent on building location.

By 2050, a building could experience pluvial floods 1-7 times over its lifespan.

Direct Effects	Indirect Effects
• Direct life-safety risk to persons • Flooded building, leading to potential damage to structural, mechanical, and electrical systems • Loss of property	• Compromised transportation systems • Water quality impacts

Table 2 shows key hazards related to buildings in both the Greater Vancouver Area and the Capital Regional District, namely wildfire, heat waves, water shortage (drought), extreme storms, and flooding. Based on information from the BC Ministry of Environment and Climate Change Strategy's *Preliminary Strategic Climate Risk Assessment* (2019), the *Nanaimo Regional General Hospital Climate Vulnerablity Assessment Report* (RDH Buliding Science, 2018), Metro Vancouver's 2016 *Climate Projections for Metro Vancouver Report*, and the Capital Region District's 2017 *Climate Projections for the Capital Regional District*.

PROJECTED DAILY TEMPERATURE RANGES



Projected local design temperatures at a global temperature of ~3.5°C. (red) compared to the 1980 global temperature of ~0.24°C (blue). Data from the Pacific Climate Impacts Consortium.

According to the Prairie Climate Centre[14], in the context of a ~3.5°C planet, the Capital Regional District is expected to experience **much wetter falls and winters, drier summers, and much warmer summers**. Over a year, the total amount of precipitation is expected to be slightly higher than the 1976-2005 average, but with reduced summertime precipitation; this pattern means heavier and stronger storms, with increased frequency and intensity of extreme wind, with greater chances of pluvial (i.e., rain-related) floods. Drier summers and higher summer temperatures also raise the risk of water shortages. Similarly, the Greater Vancouver Area can expect much **wetter falls and winters, far fewer cold days, and much warmer summers**. Parts of North Vancouver may experience even greater rainfalls, whereas lower-lying areas such as Surrey, Richmond, and False Creek will have to contend with larger and more frequent storm surges and sea level rise, including salt intrusion in the lower-lying farmlands.

14 Prairie Climate Centre. 2019. Climate Change and Canada's Cities Series.

IMPACTS OF ACTION

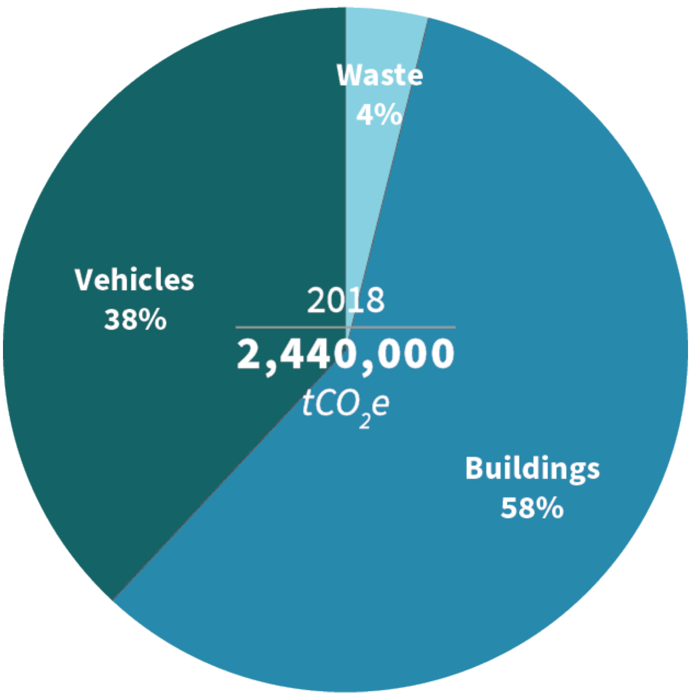
CLIMATE CHANGE AND BUILDINGS

Buildings affect and are affected by the climate.

Buildings interact closely with local and global climates. It is essential to understand both sides of the interaction: first, how buildings affect climate, and second, how climate (particularly in an era of climate change) affects building performance.

HOW BUILDINGS AFFECT CLIMATE

Buildings are designed to provide a comfortable and safe interior environment for people. This is achieved by separating the indoor and the outdoor environments with *passive* measures (e.g. the building enclosure, also known as an *environmental separator*) and modifying the interior environment using *active* measures (e.g. heating, lighting, etc.). However, these measures come at a cost: they require energy. And not all energy is made the same, as sources of energy that are derived from fossil fuels produce significant amounts of greenhouse gas emissions. The main goal for climate change mitigation is to *reduce* greenhouse gas emissions, which can be done by substitution of the energy source with cleaner alternatives,by reducing the demand for energy via demand reduction strategies, or by increasing the energy efficiency of the building.



Buildings represent a significant component of Vancouver's greenhouse gas emissions. High efficiency retrofits can readily achieve a 50-85% reduction in building emissions, with significant financial gains when completed in conjunction with planned renewals. This highlights the importance of depreciation reports and asset management guides. Adapted from Adapted from Vancouver City Council, Climate Emergency Action Plan Report (2020).

VANCOUVER GHG EMISSIONS

Buildings are responsible for 19% of all global greenhouse gas emissions[15], and at the municipal level may account for as much as 60% of all greenhouse gas emissions in typical North American cities[16].

The main source of a building's greenhouse gas emissions is direct and indirect combustion of fossil fuels. The total emitted carbon for a building is made up of those emissions associated with the operation of the building, known as *operating carbon*, and the carbon emitted as part of the manufacture and construction of the building, known as *embodied carbon*, both of which are discussed below in greater detail.

Operating Carbon

Buildings require energy and material input for their maintenance and operation. Building systems, particularly mechanical systems, require energy, whereas maintenance for renewals, repairs, and rehabilitation requires material. The carbon associated with both of these inputs is known as operating carbon.

The Greenhouse Gas Protocol (GHGP), developed by the World Resources Institute and the World Business Council for Sustainable Development, identifies three types of operating emissions (Scope 1, Scope 2, and Scope 3 below).

***Scope 1: Direct GHG emissions** include emissions created on site, for instance emissions from gas-fired appliances and refrigerant leaks of high global warming potential gases.*

***Scope 2: Electricity indirect GHG emissions** include all GHG emissions from the generation of electricity consumed by the building but purchased from an external supplier.*

***Scope 3: Other indirect GHG emissions** include everything else not captured by Scope 2, including land-use changes, transportation-related emissions, and the embodied carbon of any material brought on to site.*

Mitigation measures can reduce GHG emissions by substituting fossil fuels for cleaner sources of energy, using passive systems to reduce energy demand, or improving the performance of active systems via energy efficiency. However, as all sources of energy emit greenhouse gases, with some, like renewables, emitting significantly less than fossil fuel systems, the only way to have 'zero' emissions is by avoiding the need for energy through demand reduction. All three of these approaches are needed to tackle climate mitigation in buildings.

The most effective way to reduce a building's operating carbon is to eliminate all combustion of fossil fuels on site. This means no fossil fuel boilers, furnaces, stoves, or fireplaces. Electrification of a building allows it to experience the benefits of the rapidly decarbonizing energy grid. There are also many other benefits to a fully electric building: these buildings are frequently healthier, readily permit integration with on-site renewables, and build in cost resilience to any increases in carbon pricing.

15 Lucon, O. et al. 2014. "Buildings". In *Climate Change 2014: Mitigation of Climate Change*. New York: Cambridge UP, p. 675

16 Lucon, O. et al., p. 679 (based on OECD data). Note that this range is also consistent with Vancouver-specific data (see Vancouver City Council, Climate Emergency Action Plan Report, 2020).

Embodied Carbon

Embodied carbon refers to the greenhouse gases emitted in the process of extracting, manufacturing, and transporting building components, as well as in the construction of the building itself. Another term for embodied carbon is 'upfront carbon': this is the carbon that was already emitted to make this product.

Generally, the less processing involved in a material, the lower its embodied carbon. However, using the right material for the right application is equally important. It is of no use to replace one product with another, low embodied carbon product, if you end up having to replace the latter several times because of premature deterioration.

Some materials have very high embodied carbon, such as cement, metals, and plastics, due to the energy requirements needed for their production (e.g. natural gas-fired cement firing kilns or blast furnaces). Other materials can be made of elements with high global warming potential, such as the refrigerants that are used in mechanical systems or as part of the blowing agents in foam insulation. Many of these refrigerants have a global warming potential (GWP) thousands of times greater than an equivalent amount of CO2. However, this is a rapidly evolving landscape with many manufacturers innovating with new, low embodied carbon products, from low GWP blowing agents to low carbon cements. On the other hand, there are also many materials that can sequester, or store, carbon. Buildings made of natural materials, like wood or bamboo, may store the carbon absorbed in the plant matter and keep it out of the atmosphere for decades or centuries. Frequently, these natural materials also have lower embodied carbon as they require less processing.

Embodied carbon is calculated using Life Cycle Analysis, which accounts for the embodied carbon that occurs throughout a building's service life. There are several different ways LCAs are conducted and some are more useful than others, ranging from "cradle-to-gate" all the way to "cradle-to-cradle", and using either top-down or bottom-up approaches in their calculations. These are all stages of the building's lifecycle, and each one contributes to the building's embodied carbon.

Greenhouse gases are emitted through every part of the building's lifecycle. These are considered 'upfront' or 'embodied' carbon and must be included as part of climate mitigation measures.

HOW CLIMATE AFFECTS BUILDINGS

North Americans spend around 90% of their day inside, whether at home or at work. Clearly, having functional buildings is critical to our daily lives. The most basic function of a building is to separate the outdoors from the indoors.

This basic function can be further broken down[17]:

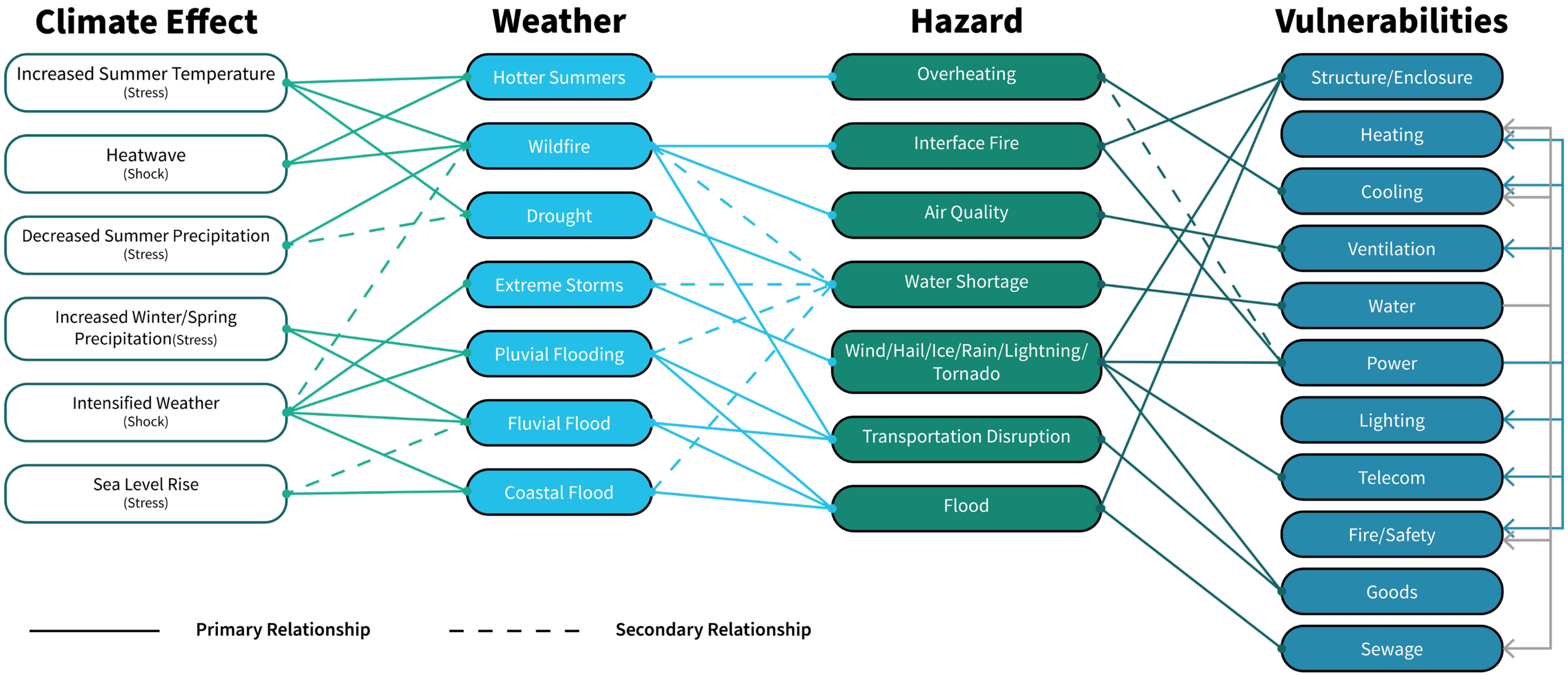
1. **Support function:** **to hold the building up (in technical terms, to support, resist, transfer, and otherwise accommodate structural loads such as wind pressure and weight).**
2. **Control function:** **to create safe, comfortable spaces by controlling how much heat, sound, moisture, air, etc. goes in and out of the building.**
3. **Distribution function:** **to distribute services and amenities within the building, for example heat and fresh air via HVAC systems, electricity, telecommunications signals).**
4. **Finish function:** **to provide durable, aesthetically pleasing surface finishes (e.g., on walls).**

All of these functions are interrelated and interdependent. If buildings don't function properly, the occupants will be uncomfortable (e.g. too warm or cold), inconvenienced (e.g. if power goes out) or potentially unsafe (lengthy power outages or extreme temperatures). Generally, the distribution function involves active systems, which require continued input energy and therefore higher operating carbon emissions. Control functions are usually passive in nature, and their GHG emissions are mainly as embodied carbon.

A changing climate impacts all of the functions of a building, from support to finish. However, the impacts vary. For example, disruption to power systems can cascade down the chain and disrupt most distribution functions unless back-up or on-site generation systems are in place. In contrast, many of the control functions are passive in nature, and therefore provide their functionality despite disruptions in utilities.

The relationship diagram opposite shows how the main climate hazards can cause cascading effects that impact the building in complex ways. When considering the effects of climate change, we need to consider how it could impact each of the functions provided by the building.

17 Many of these functions are specifically functions of the building enclosure, as described in Straube, J. and E. Burnett. 2005. *Building Science for Building Enclosures*. Westford, MA: Building Science Press.



This figure demonstrates how climate change effects impact building systems. The changing climate leads to different expressions of the weather, which can create hazards. These hazards, when considering exposure and vulnerability, can then create risks that affect building services. For instance, warmer summertime temperatures can lead to an overheating hazard in buildings. The downstream effect of overheating impacts the cooling system. A secondary effect is that high electrical demand on the grid could cause brown-outs or power failure. If a power outage occurs, then further downstream effects can affect everything from the HVAC system to lighting, telecom, and security systems.

MANAGING RISK AND VULNERABILITY

Risk, as it relates to climate resilience, is the combined consideration of the likelihood of an event occurring, the exposure to that event, and the consequence of that event's occurrence[18]. Risk awareness leads to understanding the underlying causes of uncertainty, finding strategies to minimize any negative outcomes, and maximizing potential benefits. However, the main concern is not really risk, but rather, *vulnerability*. Before we can discuss how to respond to climate change hazards, we first need to clarify what we mean by these terms.

What is Risk?

Risk management is a well-established discipline that provides guidance on decision-making in an uncertain future. Two key related terms are *hazard* and *risk*. A hazard is an event, process, or phenomenon that could cause harm, whereas risk is the chance of the event causing harm. Vulnerability is the degree to which a building system is susceptible to the adverse effects of that hazard.

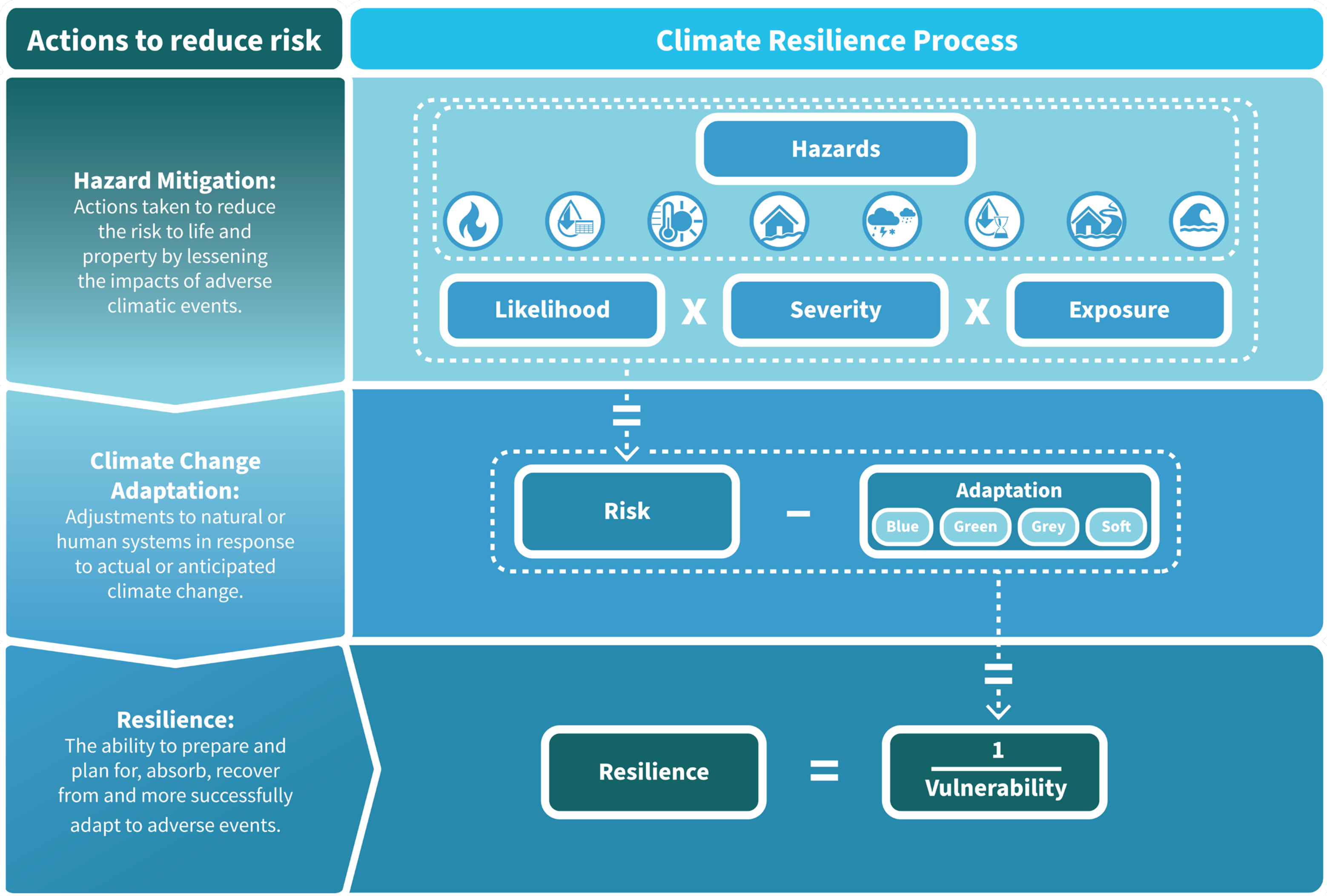
At the basic level, risk is a product of three separate factors: likelihood, consequence, and exposure. If any of these three separate factors can be minimized, then so is the risk. For example, a hazard could be slipping on outdoor ice. For this hazard:

- The risk is low in the summertime in BC, because the *likelihood* of the hazard occurring is vanishingly small.
- The risk is low if the distance of the fall is short, for instance, if you were crouched low to the ground, leading to a lowered *severity*.
- The risk is low if you're indoors in any season, because the *exposure* to outdoor ice (and the hazard of slipping on it) is zero.

Vulnerability is a result of the risk less your capacity to adapt to its adverse effects. In risk management, the primary objective is to minimize vulnerability. Continuing with the outdoor ice hazard, and assuming no actions were taken to reduce the risk of slipping on ice:

- Vulnerability would be low if you had some *capacity to adapt*, such as from wearing hockey equipment.

18 Engineers Canada. 2015. *PIEVC Engineering Protocol for Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate*. Version GP10.1. Ottawa, ON: Engineers Canada.



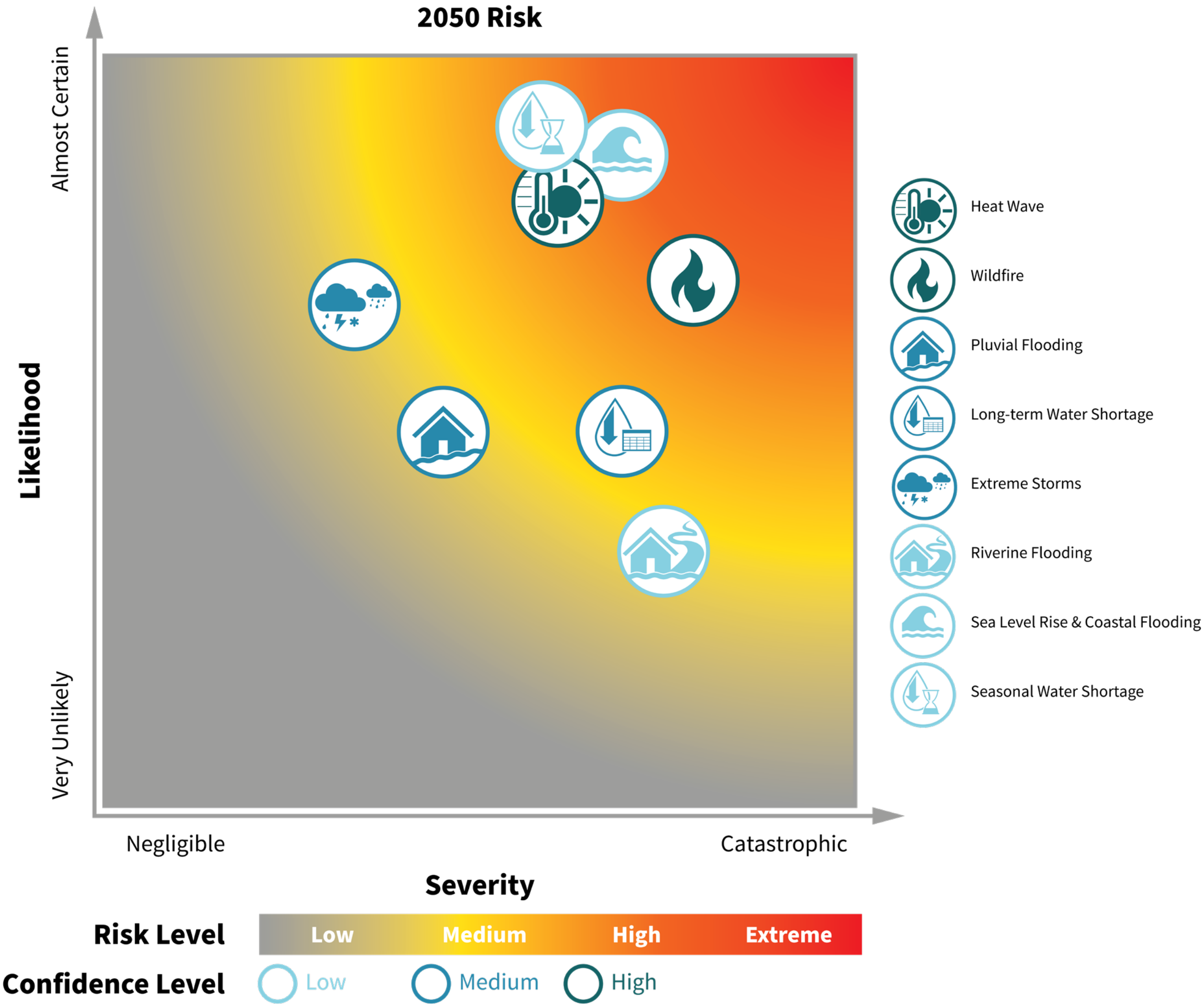
Climate adaptation is a process of reducing our vulnerability. This is done by lessening climate change hazards by mitigating our emissions. Reducing the likelihood, severity, or exposure to a hazard reduces our risk. Climate change adaptation is used to adjust our systems to the risks posed by climate hazards by increasing resilience through measures that serve to build or enhance adaptive capacity. Blue, green, and grey adaptation measures, so named based on the ‘colour’ of the measure, whether nature-based solutions or built infrastructures, combined with soft adaptation, for managerial and social measures, are all vital approaches to adapt to climate change (adapted from IPCC, 2014).

Risk forms an intrinsic part of climate adaptation. The challenge with climate change adaptation is in characterizing the *incremental increase in risk* over time for disasters that 1) normally occur in today's climate, and 2) are already challenging to predict and manage. A risk matrix helps define risk levels to prioritize resource allocation.

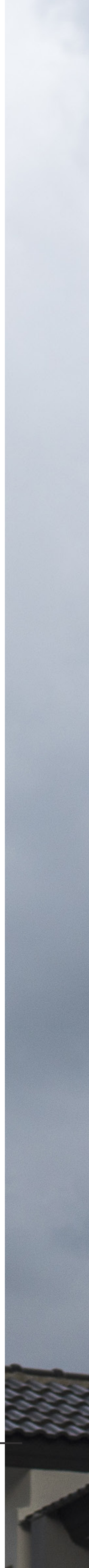
The challenge posed by climate change is that it is affecting the likelihood and severity of many of these hazards. Increasing the likelihood or severity leads to higher risk, and depending on the level of adaptive capacity, creates greater vulnerabilities.

For example, in the matrix shown, a hazard is wildfire. The risk is considered high because the 2050 likelihood of wildfires has increased from climate change effects, and the consequences of a wildfire are also very high. Note that exposure is not considered in this matrix since not all buildings have some exposure to this hazard.

In short, we can reduce our vulnerability to climate change in two ways: reduce the risks of climate change and find ways to adapt to anticipated changes. These two approaches are termed *climate change mitigation* and *adaptation* and both are essential.



A risk matrix plots the likelihood and severity of a climate hazard into low to extreme risk levels. This figure is adapted from the BC Preliminary Strategic Risk Matrix with a building centred context. See See BC Ministry of Environment and Climate Change Strategy, Preliminary Strategic Climate Risk Assessment (2019).



KEY POINTS

- Buildings affect climate change by generating GHG emissions.
- Both embodied carbon (GHGs emitted to create buildings) and operating carbon (GHGs emitted to operate buildings) must be addressed to mitigate climate change.
- Buildings are made up of interdependent systems which are differently affected by different climate hazards. Climate change effects can temporarily or permanently disrupt these systems.
- Buildings are positioned in areas that are more or less susceptible to the impacts of climate change based on zoning (e.g. floodplains, slopes, foreshores/creeks, etc.).

THE NEXT STEP

BUILDING LOW CARBON RESILIENCE

Low carbon resilience (LCR) measures address both mitigation and adaptation.

A climate change resilient building is one that can withstand the direct and indirect impacts of climate change and rapidly recover from any associated system failures without significantly affecting the occupants. Achieving climate change resilience is an iterative process of systematic planning and risk assessment, with contingency plans and identification of opportunities to "build back better." Not all adaptation measures can necessarily be implemented, so synchronizing capital asset planning with climate resilient adaptation is essential.

Risk assessment is a vital tool toward improving climate change resilience. Here we provide a high-level approach to conducting your own risk assessment. Additional tools are listed in the resources section (p. 33).

This section begins with the key hazards identified in the previous section for buildings in the Greater Vancouver Area and the Capital Regional District. It then introduces risk evaluation principles.

WHAT IS RESILIENCE?

Resilience is the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. Resilience takes two forms when it comes to climate change: minimizing worsening climate loads by mitigating emissions and adapting to a changing future climate. Mitigation reduces the impact of the hazards; adaptation reduces our vulnerabilities. These two aspects of resilience (mitigation and adaptation) are the basis for the Low Carbon Resilience approach.

OBJECTIVE: MITIGATION + ADAPTATION

The objective of climate mitigation is to minimize the worsening of future climate loads, while climate change adaptation minimizes negative effects or leverages new opportunities. Achieving both mitigation and adaptation is known as Low Carbon Resilience, and many building improvement measures can serve both functions. It is important that we not neglect one over the other. Without mitigation, the magnitude and rate of future climate change would render adaptation impossible for some systems[19], and without adaptation, many systems will not function in future climate conditions, rendering some efforts to reduce emissions futile.

Climate change mitigation decreases the likelihood of associated hazards, while adaptation either reduces the exposure, reduces the consequence, or increases the adaptive capacity to minimize vulnerability.

Climate Resilience Measures

A Low Carbon Resilience Measure is a project, technology, or process that increases adaptation (Climate Change Adaptation Measure, CCAM) and mitigation (Climate Change Mitigation Measure, or CCMM). The measures possible are unique to each building and limited only by your creativity. This section highlights some of the more common measures that apply to common building types. The key objective of these measures is to combine both climate change mitigation and adaptation. This leads to a large range of significant synergies and co-benefit opportunities[20] . For existing infrastructure, this is best streamlined with already planned renewals, as this is the most cost-effective approach toward. Co-benefits may include the following:

- Reduced air pollution.
- Reduced energy use and associated operating costs. A changing climate is anticipated to increase energy use by requiring a greater focus on cooling energy.
- Increased durability and economic life of the building.
- Reduced disruption to society from coastal hazards and extreme weather events, and consequently, reduced amount of future adaptation required.
- Improved physical and mental well-being.
- Increased biodiversity sustenance[21] .

Many of the associated measures are win-win-win or “no regret” options, meaning that even in the absence of climate change, they have highly desirable outcomes, from healthier buildings and more comfortable occupants to increased property values and advantageous life cycle costing.

The critical point to all adaptation measures though, is that **the future climate must be considered**.

19 Klein, R.J.T., S. Huq, F. Denton, T.E. Downing, R.G. Richels, J.B. Robinson, and F.L. Toth. 2007. “Inter-relationships Between Adaptation and Mitigation.” In *Climate Change 2007: Impacts, Adaptation and Vulnerability*. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds. Cambridge, UK: Cambridge University Press, p. 745-777.

20 Adaptation to Climate Change Team. 2019. *Low Carbon Resilience Interventions: Case Studies at the Building, Neighborhood and Community Levels*. Victoria, BC: Simon Fraser University.

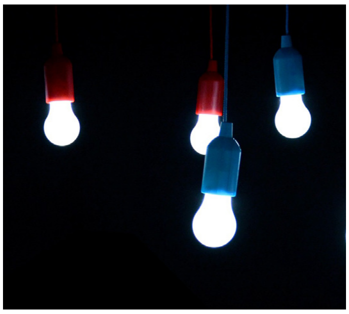
21 Engineers Canada. 2018. *Public Guideline: Principles of Climate Adaptation and Mitigation for Engineers*. Ottawa, ON: Engineers Canada.

Key Low Carbon Resilience Measures

Low carbon resilience measures, or building measures that can provide both adaptation and mitigation functions, fall roughly into three categories:

1. **Demand Reduction:** passive measures that reduce the energy and water loads applied to the building's active systems.

   Examples: optimized window-to-wall ratios, building airtightness, solar control (shading, low solar heat gain coefficients), high performance enclosure, drought-tolerant shade trees, low-flow appliances, etc.



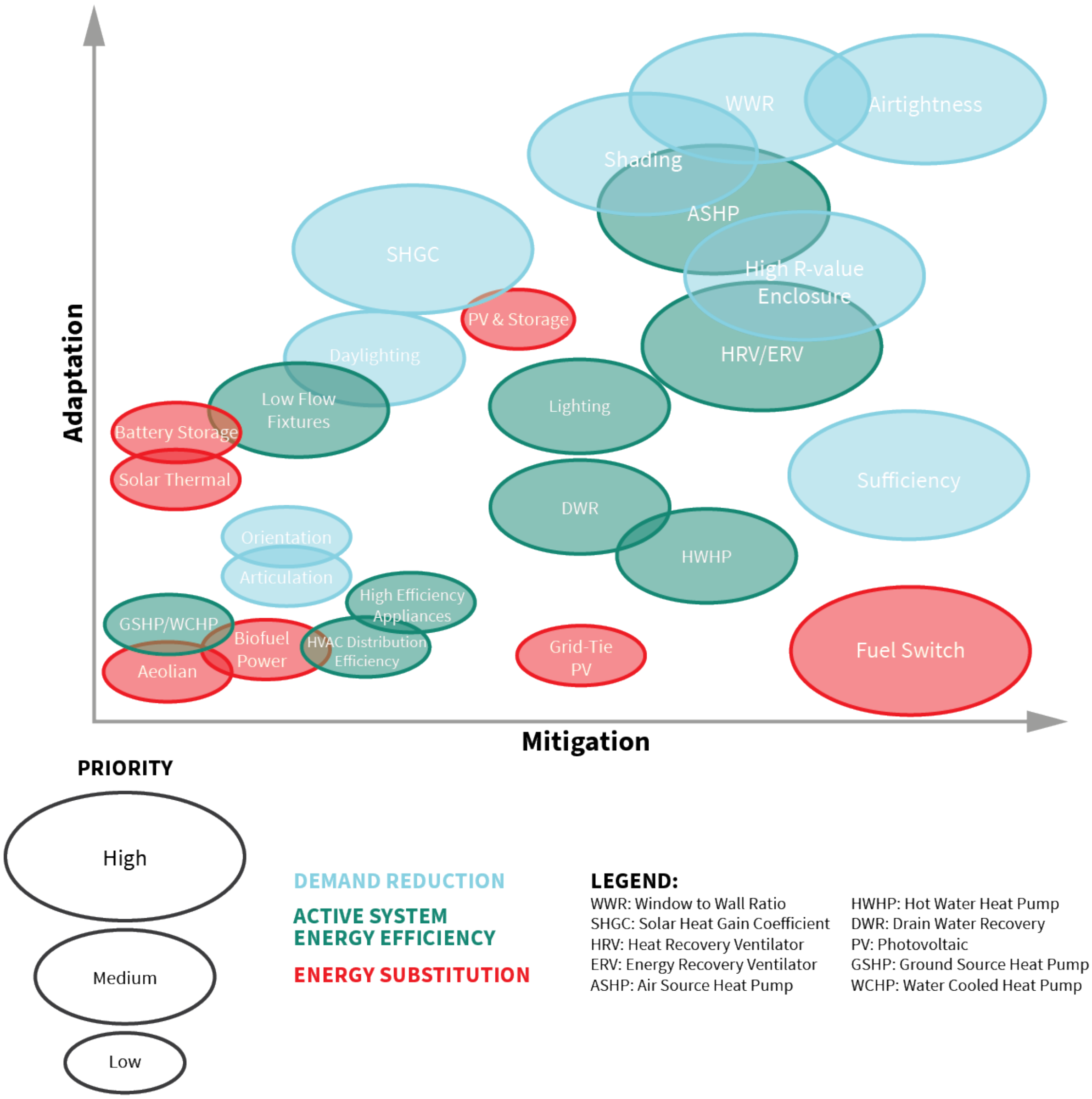
2. **Active System Energy Efficiency:** measures that better utilize the energy required to operate an active system by having greater efficiency.

   Examples: heat pump technology (air- and ground-source heat pumps, heat pump hot water heaters), energy recovery systems (heat recovery ventilator, drain water recovery), LED lighting, high efficiency appliances.

3. **Energy Substitution:** measures that supplement, or entirely replace, the building's grid energy demand. The energy generation systems must be renewable in nature, and there is generally a degree of grid independence and energy security during broader system disruption.

   Examples: photovoltaics (grid-tie or storage), energy storage (battery back-up or substitution, thermal storage, kinetic storage), wind-power, or micro-hydro installations.

Many of these measures can address a range of climate hazards while also increasing climate mitigation. However, there are some strategies that are unable to provide concurrent adaptation and mitigation benefits. Some mitigation-only measures have a nominal, or even negative, impact on adaptation, and vice versa. Nonetheless, both these classes of measures may still provide secondary benefits, such as improvement to occupant health and comfort, beautification of the building or site, or cost effectiveness.



This Prioritization Map ranks the relative priority of multiple building-specific measures, shown by their size, and approximately places them on a low carbon resilience graph, with the mitigation potential on the x-axis and adaptation potential on the y-axis. Three types of measures are identified: those that reduce energy demand, those that increase system efficiency, and those that substitute (supplement or replace) grid energy with on-site systems. The positions are approximate and unique building features may change priorities and climate resilience potential and this figure is only intended as a general guide.

Mitigation Measures

The low carbon resilience measures above focus on concurrent mitigation and adaptation features. Mitigation measures are focused on reducing the GHG emissions of the building by addressing energy and emissions profiles.

- **Sufficiency:** this is an approach to planning and use of space and energy to just meet the current and future needs of the owner. This means careful planning and consideration of the size of the building needed, the services provided, and the real needs of the occupants.

  Examples: judiciously sizing the building's footprint for the occupants (e.g. maintaining a floor area in the 250-750 sq.ft./person range), or avoiding excessive appliances that don't find frequent use, such as saunas and hot tubs, ornamental lighting, and aesthetic fireplaces not intended as sources of heat.

- **Emissions Intensity:** measures that reduce the greenhouse gas emissions associated with the operation of the building's active systems.

  Examples: fuel switching to all electric, renewable natural gas or biofuels.

- **Carbon Offsets:** carbon offsets provide financial support for others to adopt more cost-effective mitigation measures, and in turn allow you to claim the benefit of the associated reduction in emissions. However, carbon offsets are not sustainable; they don't truly remove any GHG from the atmosphere, but only displace what could have been emitted, and they rely on a third party's carbon quota. There is also the concern of permanence, since the carbon offsetting measures could be undone or removed at a later time. There are only two truly viable carbon offsets: Direct Air Capture (DAC) or Bio-Energy with Carbon Capture and Storage (BECCS), which both actively remove GHGs from the atmosphere and therefore directly compensate for your emissions.

KEY POINTS

- Climate change vulnerability is a product of risk of climate hazards (the likelihood, consequence, and exposure to climate-enhanced weather) less your ability to adapt to the hazards.
- Climate resilience involves an iterative process that understands risk and vulnerabilities, taking opportunities to adapt to future hazards (adaptation) while also minimizing or avoiding GHG emissions (mitigation). This approach is also known as Low Carbon Resilience.
- The best climate resilience measures are "no-regret" options that have tangible secondary co-benefits, such as improved occupant health and comfort, lower operating costs, or enhanced property values.

Adaptation Measures

Adaptation measures generally address specific climate change risks, for example, responding to sea level rise or overheating. The measures below provide strict adaptation benefits, with little, no, or negative mitigation benefits. This list provides a brief survey of climate hazards and a few associated measures, with references to resources that provide greater detail.

Table 3. Hazards and Related Adaptation Measures

Hazard	Adaptation Measures
Wildfire The two primary risks caused by wildfire include direct fire contact (called an interface fire) and air pollution.	• FireSmart design for contact wildfires; see e.g. FireSmart Canada's 2019 Home Development Guide. • Air filtration (MERV 13+ filters) for mechanical ventilation systems or portable filtration systems
Overheating The primary risk is overheating of occupants.	• Mechanical cooling (increases energy consumption of the building). • Shelter-in-place refuge rooms that have cooling.
Drought The primary risk is water shortages. See Ministry of Environment and Climate Change Strategy (2018).	• Low-flow fixtures. • Rainwater harvesting and storage for non-potable applications. • Xeriscaping and drought-tolerant plantings. • Wastewater reuse and reclamation. • Potable water storage systems.
Flooding The primary risk is pluvial, fluvial, or coastal flooding. See Lyle, Long, and Beaudrie (2015).	• Appropriate siting out of flood zones (100, 200, 500+ years, as applicable). • Carefully considering the design flood construction level (FCL) for new construction. • Backwater prevention valves. • Backflow prevention valves. • Storm water retention ponds. • Waterproof foundations (note structure must be designed to handle hydrostatic loads). • Sacrificial first/below grade floors.
Extreme Storms The primary risk is extreme winds, heavy precipitation, and power outages.	• Structural design for higher wind loads. • Structural consideration for short-term, higher-snow lowers (as applicable). • Back-up power systems (note: fossil fuel generators increase GHG emissions). • Rainwater management design for higher flows. • Landscape consideration for tree fall.

THE BOTTOM LINE

TAKEAWAYS FOR THE INDUSTRY

This primer on climate change and buildings provides a high-level overview of the complex fields of climate science, building science, and risk management.

There are many well-researched and well-written articles, guidelines, and standards that go into great detail and are more comprehensive than this primer.

The purpose of this primer is to help readers become acquainted with key principles and help direct them to sources where they can find further information.

Climate Change

We know that climate change is real. There is widespread scientific consensus on the causes, and on human activity being the main cause. The impacts are serious and are already affecting us. But most importantly, there's hope, as we have the technology and know-how to avoid the worst climate impacts. The informed choices we make now and in the near future can significantly mitigate, or limit, the severity of climate change. However, even stringent mitigation will not eliminate the impacts of past human activity.

Adaptation to the changing climate is already needed, but many of these adaptation measures have significant benefits and are "no-regret" options—things we would likely do anyway in the absence of climate change. Most climate resilience measures make our buildings healthier and more comfortable, valuable, and enjoyable to live in.

Projected Climate Hazards

A hazard is an event, process, or phenomenon that could cause harm, whereas risk is the chance of the event

Adapting to change can be difficult, but there is much to be gained by looking at the positives of building climate resilience and acting together.

causing harm. A range of hazards with different degrees of risk are anticipated across BC. The key hazards related to buildings in both the Greater Vancouver Area and the Capital Regional District are wildfire, overheating, water shortage, flooding, and extreme storms.

However, exposure to many of these hazards depends on the micro-climate of each specific building, and so careful analysis is required to evaluate the actual vulnerabilities.

Climate Change and Buildings

Buildings are a significant source of greenhouse gas emissions in our cities, due to both embodied emissions (GHGs emitted to create buildings) and operating carbon emissions (GHGs emitted to operate buildings). We must tackle both. While buildings are a major cause of climate change, they are also significantly affected by climate change.

Knowing how a building will respond to a climate event is challenging, as buildings are made up of interdependent systems which are differently affected by different climate hazards. Climate change effects can temporarily or permanently disrupt these systems. The long-term objective is to ensure that our building assets are preserved and continue to provide shelter and support the function of systems critical to our health and well-being, as well as minimizing impacts to the economy.

The way to prepare our buildings for the future effects of climate change is by building in low carbon resilience. We do this by identifying any vulnerabilities in our buildings (risk related to climate hazards less our ability to adapt). We can then implement low carbon resilience measures to minimize GHG emissions (mitigation) and adapt to future climate hazards (adaptation).

Building Low Carbon Resilience

Practical tools are available to assist with resilience efforts. This primer is one such tool, but it is very much a starting point. Additional resources and contacts are suggested below (p. 33).

There are also tremendous efforts being made at the governmental level to help achieve climate resilience in our buildings and communities. Reach out to local, provincial, or national climate experts and government officials who may be able to guide you to retrofit programs or suggest local consultants to assist with new developments and building projects.

RESOURCES

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Additional Resources

GENERAL RESOURCES

Climate Atlas of Canada. An accessible yet rich information portal that includes interactive maps, videos, articles, and topical collections on climate change in Canada. Available at https://climateatlas.ca/topics.

Climate Chance How-To Guide for Industry and Professional Associations: Practical Steps to Help Your Members Prepare for Climate Change. A resource for professional, industry, and business associations to support coordinated climate action. Available at https://www.bccic.ca/wp-content/uploads/2020/08/Climate-Change-Guide-Full-Version.pdf.

Online Library of the Intergovernmental Panel on Climate Change (IPCC). A comprehensive collection of reports and related resources produced by the IPCC, in multiple languages and formats. Available at https://www.ipcc.ch/library/.

Pacific Climate Impacts Consortium (PCIC) Website. Provides a data portal, analysis tools, and general resources and training. Available at https://pacificclimate.org/.

BUILDING OWNER RESOURCES

BOMA BEST Sustainable Buildings 3.0 Office Questionnaire. This questionnaire is designed to provide building owners and managers with a way to score the current operations of their buildings to better understand where improvements need to be made. Available at http://bomacanada.ca/wp-content/uploads/2016/09/BOMA-BEST-3.0-Office.pdf.

BOMA Canada 2019 Resilience Brief. This resilience brief provides building owners and managers of commercial buildings with an overview of resilience and extreme weather risks to the building industry. It also outlines details of resilience at the building level and discusses adaptation strategies. Available at http://bomacanada.ca/wp-content/uploads/2019/11/BOMA_Resilience_Brief_Eng_v5.pdf.

Ready to Respond: Strategies for Multifamily Building Resilience. Developed by Enterprise Community Partners, Inc., this document contains strategies to make properties more resilient and guidance on determining which strategies to apply. Available at https://www.enterprisecommunity.org/resources/ready-respond-strategies-multifamily-building-resilience-13356.

CASE STUDIES

Nanaimo Regional General Hospital Climate Change Vulnerability Assessment. This assessment was conducted using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol. The overall objective was to assess infrastructure components of the hospital that are at risk of failure or impaired function due to extreme climate events or a change in climate norms. Full report at https://www.egbc.ca/getmedia/c8863c8e-69cc-4957-932f-51034f5fd65f/NRGH-PIEVC-Climate-Change-Vulnerability-Assessment-Report.pdf.

CLIMATE STANDARDS AND DESIGN GUIDELINES

BC Energy Step Code Design Guide and Supplement. Published by BC Housing, the Design Guide provides information on the key strategies and approaches to meeting the Energy Step Code in mid- and high-rise wood-frame residential buildings. The Design Guide Supplement provides information on the key strategies and approaches necessary to reduce overheating and improve indoor air quality in these building types. Avaiable at https://www.bchousing.org/research-centre/library/residential-design-construction/bc-energy-step-code-design-guide.

BC Housing Design Guide Supplement on Overheating and Air Quality. This supplement identifies strategies that achieve both energy and emissions reductions while preparing for the impacts of a future climate. Available at https://www.bchousing.org/research-centre/library/residential-design-construction/bc-energy-step-code-design-guide.

City of Boston Climate Resilient Design Guideline. This guideline covers design temperatures, passive strategies, accounting for future conditions, and flooding. All major development projects in the City of Boston are now required to submit a completed Climate Resiliency Report. Available at https://www.boston.gov/environment-and-energy/climate-resilient-design-guidelines.

Climate Resilience Guidelines for BC Health Facility Planning & Design. This document provides a comprehensive guideline for planning, design, procurement (both at the project and consultant levels), and a high-level climate risk assessments methodology. The addendum includes a list of resilient design strategies. Available at https://bcgreencare.ca/system/files/resource-files/Climate-Resilience-Guidelines-for-BC-Health-Facility-Planning-and-Design_v1.0_0.pdf.

CSA S478 Durability in Buildings. This standard provides a guiding framework on ensuring durable building elements, with context for consideration of climate change impacts as part of the assessment. Available at https://www.csagroup.org/store/product/CSA%20S478%3A19/.

Thermal Resilience Design Guide. This is a comprehensive guide that covers governing mechanisms that lead to overheating, how overheating risks are exacerbated by climate change, and a series of measures to prevent or control the hazards. Available at https://pbs.daniels.utoronto.ca/faculty/kesik_t/PBS/Kesik-Resources/Thermal-Resilience-Guide-v1.0-May2019.pdf.

CLIMATE RISK ASSESSMENT STANDARDS AND RELATED TOOLS

BC's Hazard, Risk, and Vulnerability Analysis (HRVA) Tool. HRVA is a process used to identify hazards that are likely to cause an emergency or disaster within a community, and to assess the consequences if the emergency or disaster occurs. The HRVA tool allows Local Authorities and First Nations to conduct HRVAs for free online. Available at https://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/local-emergency-programs/hazard-risk-and-vulnerability-analysis.

Integrated Building Adaptation and Mitigation Assessment (IBAMA) Framework. Developed through a partnership between UBC and BC Housing, the IBAMA framework supports project teams to assess hazards, assets, and risks, clarify goals, and select strategies that consider both adaptation and mitigation. A primer, reference guide, and Excel-based tool are available at https://pics.uvic.ca/projects/adaptive-mitigation-framework-assessing-climate-change-solutions-urban-multifamily.

ISO 14090:2019, Adaptation to Climate Change. This standard covers risk assessment approaches for systems—not exclusively built infrastructure—based on ISO 31000 risk assessment concepts. Available at https://www.iso.org/standard/68507.html.

LEED v4.1 Assessment and Planning for Resilience Pilot Credit. This LEED credit is intended to encourage proactive planning for natural disasters and impacts on long-term building performance. The credit requires a Hazard Assessment prerequisite and one of two options: 1) Climate Related Risk Management Planning or 2) Emergency Preparedness Planning. Available at https://www.usgbc.org/credits/assessmentresilience.

PIEVC Protocol. A comprehensive engineering process that identifies how each component of a building interacts with a set of climate hazards. The process is a threshold-based risk assessment (defined level of performance) and the output is a risk matrix (likelihood vs severity). Available at https://pievc.ca/protocol/.

Sendai Framework for Disaster Risk Reduction 2015-2030. This framework outlines seven targets and four priorities for preventing or reducing disasters. Available at https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030.

KEY TERMS

Air Pollution: Degradation of air quality with negative effects on human health or the natural or built environment due to the introduction, by natural processes or human activity, of substances which have a direct or indirect harmful effect.

Anthropogenic Greenhouse Gas Emissions: *Greenhouse gas* emissions caused by human activity.

Climate: A statistical property of weather, i.e., climate describes the long-term pattern of *weather* in a particular area.

Climate Change: The statistically significant variation in either the mean state of the *climate* or in its variability, persisting for an extended period. Climate change may be due to natural internal or external forces; however, in this guide the use of "climate change" refers to the effects caused by increases in *anthropogenic greenhouse gas emissions*.

Climate Change Adaptation: The process of preparing physical infrastructure to withstand the current and/or future risk and hazards posed by *climate change*.

Climate Change Hazard: An event, process, or phenomenon related to *climate change* that could cause harm.

Climate Change Mitigation: Actions taken to reduce the *anthropogenic greenhouse gas emissions* causing *climate change*, either by reducing greenhouse gas emissions or enhancing removal of *greenhouse gases* from the atmosphere.

Climate Change Resilience: The ability for a system to withstand, adapt to, and recover from *climate change hazards*. Climate change resilience is achieved by both reducing *greenhouse gas emissions* (*climate change mitigation*) and adapting to future climate hazards (*climate change adaptation*).

Climate Change Mitigation Measure (CCMM): A measure (such as a project, technology, or process) that reduces *greenhouse gas* emissions or enhances removal of *greenhouse gases* from the atmosphere.

Climate Change Adaptation Measure (CCAM): A measure (such as a project, technology, or process) that improves adaptation. Climate adaptation measures are generally devised to address specific *climate change hazards.*

Climate Change Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change.

Embodied Carbon (EC): The carbon footprint, or cumulative carbon emitted, of a material or product measured throughout its lifecycle, including the extraction of materials, transport, refining, processing, assembly, in-use and end of life profile. Embodied carbon can also be referred to as *upfront carbon*.

Emission Scenario: AA plausible representation of the future development of emissions of substances that are radiatively active (e.g., *greenhouse gases*, aerosols). The development is based on a coherent and internally consistent set of assumptions about driving forces, such as demographic and socioeconomic development, technological change, energy and land use and their relationships. Concentration scenarios, derived from emission scenarios, are often used as input to a *climate model* to compute *climate projections*.

Greenhouse Gas (GHG): Greenhouse gases are the gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary GHGs in the earth's atmosphere.

Global Climate Models (GCMs): Models that simulate the interactions of important drivers of climate. Global climate models are used to understand the dynamics of the earth's climate system and to forecast climate change. GCMs discretize the atmosphere and oceans to elements in the range of hundreds of square kilometres.

Low Carbon Resilience (LCR): The deliberate design and use of techniques, methods, policies, and technologies to both reduce *greenhouse gas* emissions and adapt our infrastructure and society to future climate loads, with consideration of co-benefits for other planning priorities such as equity, health, and biodiversity.

Low Carbon Resilience (LCR) Measure: A measure (such as a project, technology, or process) that provides both *climate change mitigation* benefits and increased *climate change adaptation.*

Operating Carbon: *Greenhouse gas emissions* associated with the operation of a building, including lighting, process loads, powering of mechanical systems to maintain desired indoor climate, etc.

Paris Agreement: The Paris Agreement is a binding agreement between the countries that are part of the United Nations Framework Convention on Climate Change, of which Canada is a participating member, agreeing to combat climate change and adapt to its effects. The central aim is to keep global temperature rise this century to well below 2°C (66% of meeting it) with efforts to pursue the a 1.5°C target.

Radiative Forcing: The balance of incoming solar radiation to outgoing thermal radiation. A positive radiative forcing is excess energy that is absorbed by the earth system. Radiative forcing is measured in watts per square metre.

Regional Climate Models (RCMs): Models that break down each *Global Climate Model* element into smaller units, in the range of tens of square kilometres.

Representative Concentration Pathways (RCPs): Scenarios that include time series of emissions and concentrations of greenhouse gases, aerosols, and chemically active gases, as well as land use/land cover. The word "representative" signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. Each pathway is identified by a number indicating a specific level of radioactive forcing in the year 2100, above preindustrial levels:

- RCP 2.6: Very low emissions scenario.
- RCP 4.5: Low emissions scenario.
- RCP 6.0: Moderate emissions scenario.
- RCP 8.5: High emissions scenario.

Risk: The chance of an event, process, or phenomenon causing harm. Risk is the combined consideration of the likelihood of an event occurring, the exposure to that event, and the consequence of that event's occurrence.

Risk Assessment: The qualitative and/or quantitative scientific estimation of risks. Risk assessment is a vital tool in developing *climate change resilience*.

Risk Management: A discipline that attempts to provide guidance on decision making in an uncertain future. Risk management includes plans, actions, strategies, or policies to reduce likelihood and/or exposure or to respond to consequences.

Total Carbon (TC): The sum of *embodied carbon* and *operating carbon* over a defined time period.

Upfront Carbon: See *Embodied Carbon*.

Weather: Weather represents the complex, instantaneous interaction of meteorological variables at a specific location. These meteorological variables commonly include temperature, humidity, atmospheric pressure, wind, and precipitation.

CLIMATE CHANGE RESILIENCE

FOR BUILDINGS